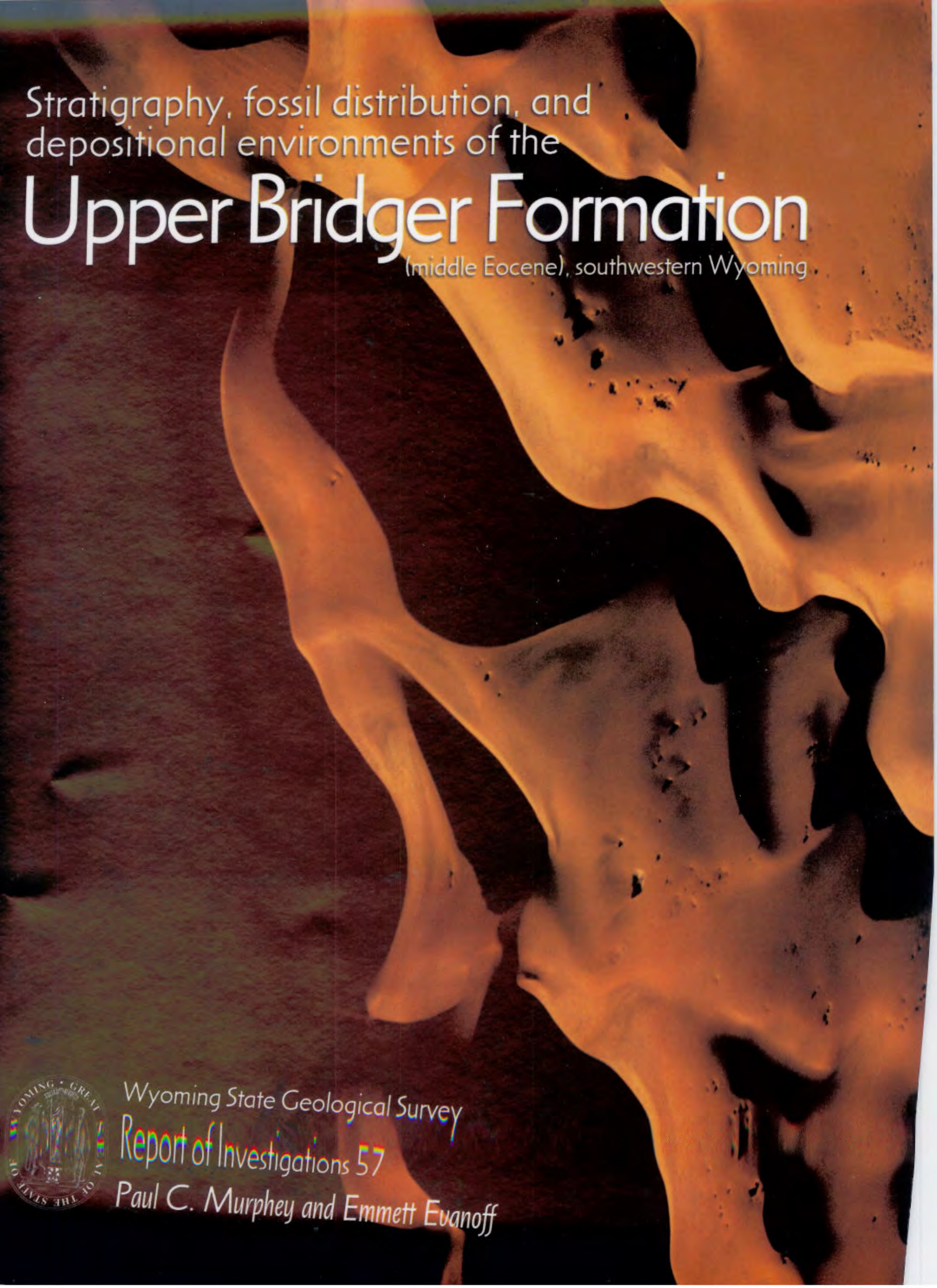

Stratigraphy, fossil distribution, and depositional environments of the Upper Bridger Formation (middle Eocene), southwestern Wyoming

Wyoming State Geological Survey

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Wyoming State Geological Survey

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Well-exposed rocks of the upper Bridger Formation near Lonetree Divide, Uinta County

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Stratigraphy, fossil distribution, and depositional environments of the upper Bridger Formation (middle Eocene), southwestern Wyoming

by Paul C. Murphey[1] and Emmett Evanoff[2]

Dedicated to the memory of
STEPHEN L. WALSH,
a great friend and colleague

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Table of Contents

List of Figures

List of Tables

List of Plates

ABSTRACT

This study documents the stratigraphy, areal distribution, origin, tempo and mode of deposition, fossil distribution, and depositional environments of the Twin Buttes and Turtle Bluff members of the Bridger Formation. Green, brown, and red mudstone and claystone dominate the highly fossiliferous Twin Buttes Member, which also includes scattered ribbon and sheet sandstones, widespread beds of micritic and sparry limestone, and thin but widespread ash-fall tuffs. The sparsely fossiliferous Turtle Bluff Member consists primarily of variegated red, green, and gray claystone and mudstone, with lesser amounts of grayish-white tuffaceous sandstone, gray and brown limestone, and light gray gypsiferous mudstone. We described fifteen marker units consisting of limestone, tuff, and tuffaceous sandstone, and used seven of these to subdivide two of the informal Bridger submembers (C and D) into lower, middle, and upper subdivisions. We mapped seven marker units over approximately 885 km^2 (329 square miles) of the basin.

Rock accumulation rates, isotopic ages of ash-fall tuffs, and fossils indicate that the Bridger Formation was deposited over approximately 3.5 million years (My), from approximately 49.09 to 45.57 million years ago (Ma), and that the faunal transition from the Bridgerian to the Uintan North American Land Mammal Age was underway by approximately 46 Ma as indicated by fossils collected from the base of the Turtle Bluff Member.

Depositional environments of the Bridger Formation include fluvial, lacustrine, paludal, marginal mudflat, basin margin, volcanic, and playa lacustrine. An influx of fluvially transported volcaniclastic sediment 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 that persisted for up to 85% of upper Bridger time. Occasional lapses in the flow of sediment to the basin permitted the development of shallow, mostly groundwater-fed lakes and ponds in which sediments accumulated up to four times more slowly than did floodplain deposits. These lapses decreased in frequency throughout deposition of the upper Bridger. As indicated by fossil distribution and diversity, lakes and their margins provided favorable habitats for both aquatic and terrestrial organisms.

INTRODUCTION

With its abundant and diverse vertebrate fossils and extensive exposures, the Bridger Formation provides an excellent opportunity to study middle Eocene continental environments of North America. Located in the southern Green River Basin in southwestern Wyoming, the dramatic and picturesque Bridger badlands are a thick sequence of volcaniclastic mudstone and claystone beds, scattered sandstone beds, and thin but widespread beds of limestone and ash-fall tuff (**Figure 1**). Although the formation is the stratotype for the Bridgerian Land Mammal Age, and Bridger fossils have been collected and studied for more than 130 years, few detailed studies of the formation's geology have been published since W.D. Matthew (1909) proposed the first stratigraphic subdivision.

This report builds on the stratigraphic framework proposed by Matthew in his classic 1909 monograph and provides a significant refinement over the stratigraphic subdivisions that have been used for the last 98 years. It also provides a framework for accurately positioning fossil localities in the upper Bridger (Twin Buttes and Turtle Bluff members). We map and describe in detail both previously known and new marker units, and correlate upper Bridger rocks across the southern Green River Basin from Hickey Mountain (Uinta County) to Twin Buttes (Sweetwater County). As a result, stratigraphic subdivisions once thought to be useful only in the classic area around Lonetree and Sage Creek Mountain are extended well to the east, cover-

Figure 1. Looking east at exposures of Bridger C and D from the northeast side of Sage Creek Mountain, Uinta County, Wyoming. The north side of Cedar Mountain occupies the horizon from the left center to the right edge of the photograph.

ing an area larger than 885 km^2 (329 square miles). Areal distribution, lithologies, isotopic ages, rock accumulation rates, and fossil distribution patterns provide a basis for interpreting the origin, environments, and tempo and mode of deposition of the Twin Buttes and Turtle Bluff members.

Study area

The Greater Green River Basin (GGRB) occupies approximately 32,187 km^2 (12,380 square miles) of southwest Wyoming and northwest Colorado (Roehler, 1992a). It contains four structural basins, the Green River, Great Divide, Washakie, and Sand Wash. Encompassing 16,898 km^2 (6,500 square miles), the Green River Basin is the largest (**Figure 2**). This structural basin is bounded by the Wind River Range to the north, the Rock Springs uplift to the east, the Uinta Mountains to the south, and the Wyoming Overthrust Belt to the west. Topographically, the basin is dissected by ephemeral drainages with a few perennial streams, and vegetation consists mostly of sagebrush and grasses. Elevations in the Green River Basin range from 1,829 m to 2,896 m (6,000 to 9,500 feet), and groves of juniper, pine, and aspen are common above 2,134 m (7,000 feet).

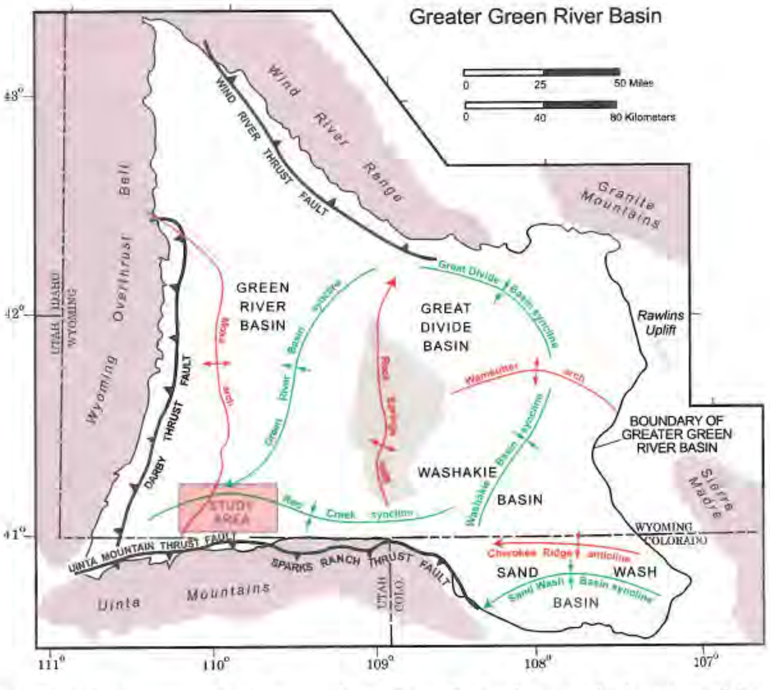


Figure 2. Index map of the Greater Green River Basin showing the location of the upper Bridger Formation study area, major structural features (anticlines in red, basin synclinal axis in green, and major faults in black), and surrounding uplifts. Modified from Murphey, 2001, and Roehler, 1992a.

The Bridger Formation occupies a large area in the Green River Basin, and rocks of equivalent age and similar lithology mapped as Bridger Formation occur in the Great Divide and Sand Wash basins. The Washakie Formation of the Washakie Basin is equivalent in part to the Bridger Formation, but Roehler (1973) presented evidence for mapping the Washakie Formation separately and distinguishing it from the Bridger Formation. The upper part of the Bridger Formation (the focus of this study) is mostly restricted to topographically and stratigraphically higher areas in the south part of the Green River Basin, near the southern margin of the formation's distribution. The upper Bridger is defined as including the Bridger C, D, and E of Matthew (1909), or the Twin Buttes and Turtle Bluff members of Wood (1934) and Evanoff and others (1998), respectively. The study area is approximately 885 km^2 (329 square miles) in size, and contains all of the well-exposed upper Bridger rocks in the southern Green River Basin. This area, located north of the Uinta Mountains and south of the Blacks Fork of the Green River in Uinta and Sweetwater counties, Wyoming, has been traditionally referred to as the Bridger basin (Hayden, 1871) and is a physiographic, not a structural, basin.

The major geographic features in the area include Hickey Mountain, Sage Creek Mountain, Cedar Mountain, Twin Buttes, Black Mountain, the Henrys Fork of the Green River, and the Green River at Flaming Gorge National Recreation Area (**Figure 3**). The study area includes Townships 13 and 14 North, Ranges 109 to 113 West, and the eastern part of R. 114 W., 6th Principal Meridian. The west part of the study area, which contains extensive badlands, includes Hickey Mountain, Sage Creek Mountain, and the west end of Cedar Mountain. It was popular with early fossil collectors because it was relatively close to Fort Bridger. It also includes the type locality of the Sage Creek White Layer (Matthew, 1909; Sinclair, 1906), type localities for the other marker units described in this report, the reference section for the Twin Buttes Member of the Bridger, and the type section for the Turtle Bluff Member of the Bridger. The central part of the study area includes most of Cedar Mountain, and widespread exposures of lower Bridger C between Cedar Mountain and Twin Buttes. The area between Cedar Mountain and Twin Buttes was formerly known as Spanish John's Meadow (**Figure 3**). The east part of the study area includes Black Mountain and Twin Buttes, and contains the type section for the Twin Buttes Member of the Bridger.

Since publication of Matthew's 1909 monograph on the Bridger Formation and its fossils, the names "Turtle Bluff" and "Henrys Fork Table" have been replaced with "Cedar Mountain", and Twin Buttes has been divided into a north part called Black Mountain and a south part which retains the name Twin Buttes (**Figure 3**). This may have resulted partly from the fact that there are two small buttes present on the summit of what is now called Twin Buttes. The name "Big Bone Buttes" in refer-

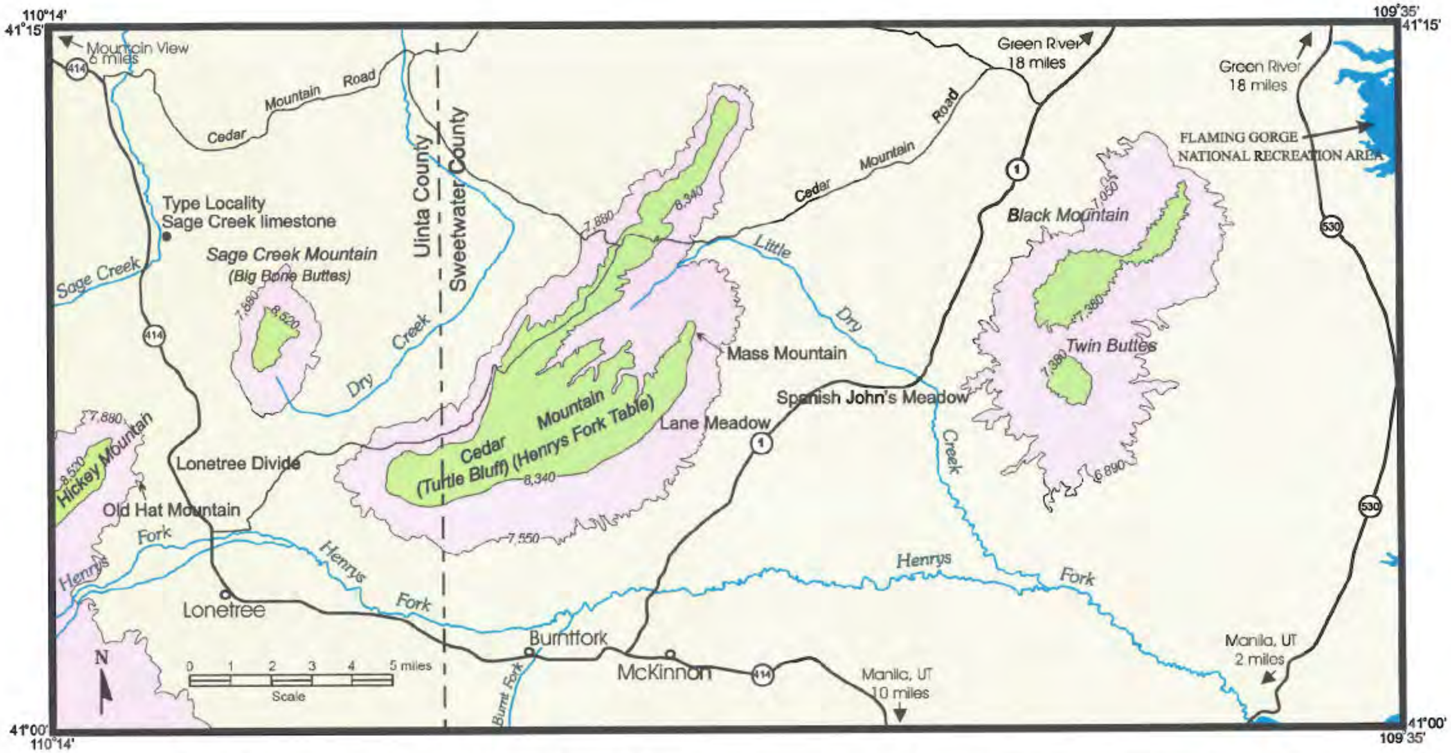


Figure 3. Map of the study area showing both modern and historical geographic terminology. The lavender color represents areas on the lower slopes of the principal mountain landforms (approximate elevations in feet are shown) and the green color represents areas above the base of the uppermost slopes (approximate elevations in feet are shown) for each landform.

ence to Sage Creek Mountain has disappeared from the local vocabulary. "Lonetree divide" refers to the area surrounding the ridge crossed by Wyoming State Highway 414 approximately 4.8 km (3 miles) west-northwest of Lonetree. The prominent butte just west of Lonetree divide in the SE¼NW¼ sec. 19, T. 13 N., R. 113 W. was informally called Old Hat Mountain by the early collectors, and is attached to Hickey Mountain. Mass Mountain, actually a part of Cedar Mountain, is located in the NE¼ sec. 33, T. 14 N., R. 111 W.. Lane Meadow, another area frequented by early fossil collectors, is located several miles south of Mass Mountain in secs. 14 and 15, T. 13 N., R. 111 W..

Geologic setting

The GGRB is a large asymmetrical syncline with gently dipping flanks (3° to 5°) and an approximately north-south axis (Koenig, 1960; Roehler, 1992a). Three intra-basin arches divide the area into four smaller sub-basins. The largest of these arches, the north-south-trending Rock Springs uplift, divides the basin into approximately equal halves with the Green River Basin to the west and the Great Divide, Sand Wash, and Washakie basins to the east (**Figure 2**).The east-west trending Wamsutter arch separates the Great Divide and the Washakie basins, while the Cherokee Ridge anticline separates the Washakie and Sand Wash basins. The GGRB began forming during the Laramide Orogeny, a period of tectonism in western North America that began during the Late Cretaceous Period and continued episodically in southwest Wyoming for approximately 30 My until the late Eocene Epoch. The last major Laramide-associated event in the GGRB was a final late Eocene rise of the Rock Springs uplift (Roehler, 1992a). In addition to the uplift of surrounding mountain ranges, Laramide tectonism resulted in rapid subsidence in basin depositional centers. The Red Creek syncline (**Figure 2**) approximates the axis of the depositional basin for the upper Green River and Bridger formations.

The GGRB 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 Tertiary rocks in the Green River Basin, the Paleocene Fort Union Formation and the early Eocene Wasatch Formation, are exposed mostly along its east and west flanks. The early Eocene Green River Formation is perhaps the most well known of the formations present in the basin because of its economic potential and well-preserved fossils. Occupying the center of the basin in the shape of a large, irregular lens (Bradley, 1964; Roehler, 1993), this formation resulted from at least 5 My of lacustrine deposition lasting from approximately 53.5 to 48.5 Ma (Smith and others, 2001). Brand (2002) reported that deposition of the Green River Formation continued until deposition of the Sage Creek limestone (base of the upper Bridger) began, estimated to have occurred approximately 47.0 Ma (Murphey, 2001; this study). Lithologically, the Green River Formation is a complex sequence of limestone, shale, and sandstone beds with a maximum thickness of approximately 840 m (2,755 feet) (Roehler, 1993). It was deposited lateral to and above the predominantly fluvial Wasatch Formation, and lateral to and below the fluvial and lacustrine Bridger Formation. Many of the widespread limestone beds in the lower Bridger Formation are actually intertongues of the Green River Formation. In most places, the base of the Bridger is uncertain because it grades vertically and laterally with the Laney Member of the Green River Formation (Bradley, 1964). The Laney is the uppermost member of the Green River Formation in Wyoming, and represents the final phase of Eocene Lake Gosiute. The Oligocene Bishop Conglomerate unconformably overlies the Bridger Formation.

Since the Eocene, erosion, regional uplift, and normal faulting have modified the GGRB, but the basic structure of the basin remains the same as it was during deposition of the Wasatch, Green River, Washakie, and Bridger formations. Deposition of the Oligocene Bishop Conglomerate followed a cycle of erosion that truncated and removed an unknown quantity of the upper Bridger. Pliocene to Recent erosion dissected the basin, forming the present topography.

Previous Investigations

Trapper and long-time local resident Jack Robinson (also called Robertson), who found what he described as a "petrified grizzly bear" in the late 1860s, is reputed to be the first collector of a mammalian fossil from the Bridger Formation (West, 1990). 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 to 15 miles) southeast of Fort Bridger where fossils were particularly common (**Figure 4**). The name Grizzly Buttes has since disappeared from the local geographic vocabulary.

F.V. Hayden named the Bridger Formation the "Bridger Group" in 1869 (**Figure 5**). In 1870, Hayden and his party collected along the Henrys Fork valley and farther north in the vicinity of Church Buttes as part of the 1867-1878 U.S. Geological and Geographical Survey of the Territories (Hayden, 1873). Fossils collected by Hayden's group were sent to Joseph Leidy in Philadelphia for study, and were described in his 1873 monograph on fossil vertebrates. 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 in 1869, and in a corridor 16 to 32 km (10 to 20 miles) 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 O.C. Marsh for description.

Many of the early scientific expeditions to the Bridger basin area staged out of Fort Bridger, an army post since the 1857 Mormon War. The fort was originally estab-

Figure 4. Looking southwest at extensive badlands of middle Bridger B in the area historically known as Grizzly Buttes. The snow-capped peaks of the Uinta Mountains are on the skyline.

lished as a trading post in 1843 by trapper and guide Jim Bridger and his partner Louis Vasquez. Judge Carter and Dr. J. Van A. Carter, brothers and later residents of Fort Bridger, maintained an active correspondence with Joseph Leidy in Philadelphia during the late 1860s and early 1870s. This correspondence included mailing fossils to Leidy, which he described in subsequent publications (Leidy, 1869, 1871, 1872a, 1872b, 1873). Regarded as the dean of American vertebrate paleontology (Lanham, 1973), Leidy named the first Bridger fossil to be formally described - the omomyoid primate *Omomys carteri* - after Dr. Carter (Leidy, 1869). *Omomys carteri* was also the first fossil primate described from North America.

The reports of fossils from the Bridger did not go unnoticed by paleontologists O.C. Marsh and E.D. Cope. The incidents that set the stage for the long and bitter conflict between these two men began in the Bridger in 1872. Sometimes referred to as the "bone wars," the dispute between Marsh and Cope lasted for more than 30 years and included concerted efforts by each man to destroy the scientific reputation and integrity of the other. This rivalry soured Leidy's interest in paleontology and led to his eventual abandonment of the discipline.

Marsh was the first paleontologist to collect in the Bridger Formation and brought crews with him from Yale College for four consecutive summers (1870-1873). Leidy's

Hayden, 1869	Matthew, 1909			Osborn, 1929	[1]Wood, 1934 [2]West, 1976; West & Hutchinson,1981	Evanoff, Brand, and Murphey, 1998				This Study			
Bridger group	Bridger formation	E		Bridger E	[1]Equals Uinta A [2]Cedar Mtn. Member	Bridger Formation	Turtle Bluff Member (E)			Bridger Formation	Turtle Bluff Member (E) (Behunin Reservoir Gypsum Bed; Basal E limestone)		
		D	D5; D4 Upper White Layer	Bridger D	Twin Buttes Member		Twin Buttes Member	D	upper (Promontory limestone)		Twin Buttes Member Upper Bridger	D	upper (Upper White limestone)
			D3						middle (Blue Sheet sandstones)				middle (Basal Blue sheet sandstone)
			D2; D1 Lonetree White Layer	Lonetree White Layer					lower (Lonetree limestone)				lower (Lonetree limestone)
		C	C5; C4	Bridger C				C	upper (Henrys Fork tuff)			C	upper (Henrys Fork tuff)
			C3 Burnt Fork White Layer						middle (Soap Holes limestone)				middle (Soap Holes limestone)
			C2; C1 Sage Creek White Layer	Cottonwood Creek White Layer					lower (Sage Creek limestone)				lower (Sage Creek limestone)
		B	B5; B4	Bridger B	Blacks Fork Member		Blacks Fork Member	B	upper (Black Mountain Turtle Layer)		Blacks Fork Member Lower Bridger	B	upper (Black Mountain Turtle Layer)
			B3 Cottonwood White Layer						middle (Church Butte tuff)				middle (Church Butte tuff)
			B2; B1						lower (Lyman limestone)				lower (Lyman limestone)
		A		Bridger A				A				A	

Figure 5. History of stratigraphic nomenclature for the Bridger Formation from 1869 until the present. The correlation between Matthew's (1909) subdivisions (B1 through B5, etc.) and the lower, middle, and upper subdivisions of the most recent studies are uncertain.

only excursion to the west occurred in 1872 when he visited the Bridger badlands, guided by the Carter brothers of Fort Bridger. Cope's only visit to the Bridger occurred in 1872 while he was attached to the Hayden survey as a paleontologist. This visit infuriated Marsh, who, at the time, considered the Bridger his exclusive fossil-collecting territory. By the late 1870s, Cope and Marsh had left the Bridger for good, although both independently and at different times retained the services of paid fossil collector Sam Smith until 1882 (West, 1990), when he met a grisly end. Smith was bushwhacked on his way from Lonetree to Evanston, and his body was not found until several years later.

Other early fossil collectors in the Bridger included H.F. Osborn, W.B. Scott, and F. Speir for Princeton University (1877, 1878). Scott returned to the area with Speir in 1886. Jacob Wortman and J.W. Gidley collected for the American Museum of Natural History (AMNH) in 1893. The early expeditions resulted in large collections of Bridger fossils at Philadelphia's Academy of Natural Sciences (Leidy), Yale University (Marsh), the AMNH (they 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 positions of the fossils they collected; nevertheless, their collections do contain the holotypes of most presently recognized Bridger fossil taxa.

In 1902, United States Geological Survey (USGS) paleontologist Henry Fairfield Osborn initiated the first program of stratigraphic collection and documentation in the Bridger. He charged Walter Granger and William Diller Matthew of the AMNH to carry out the study, and directed Matthew to find a uintathere for display at the museum. The AMNH party, led by Granger, worked in the Bridger basin from 1903 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 scouring the basin for fossils. The efforts of the AMNH parties over these four years resulted in an excellent fossil collection that, for its time, was very well documented stratigraphically. In late summer of 1905, Granger wrote to Osborn that the entire basin had been thoroughly canvassed and that it was "pretty well exhausted" (West, 1990).

William J. Sinclair, who joined the AMNH field party for the summer of 1905, wrote the first paper published on the geology of the Bridger Formation in 1906. Sinclair was the first to recognize the volcanic component of Bridger rocks, and he made other important and astute geological observations and interpretations regarding the formation's origin, fossil distribution, and depositional environments.

Matthew (1909) briefly described the geology of the Bridger Formation and introduced a system of stratigraphic subdivisions for the formation in his monograph titled *The Carnivora and Insectivora of the Bridger Basin, Middle Eocene* (**Figure 5**). These subdivisions, Bridger A through E, were based on areally extensive limestones he dubbed "white layers." Matthew also included a map and correlation diagram. Although some problems with his map and correlations exist, his efforts for the time were not only remarkable but also useful. This is further evidenced by the fact that his stratigraphic units are still in use today. Matthew's units have only recently been subdivided as the result of more detailed stratigraphic studies (Evanoff and others, 1998; Murphey, 1995; this study).

H.F. Osborn (1929) devoted a considerable amount of discussion to the Bridger Formation and its fossils in his monograph titled *The Titanotheres of Ancient Wyoming, Dakota, and Nebraska*. While giving full credit to Matthew for his paleontologic and stratigraphic work, Osborn strangely left out any mention of the Sage Creek White Layer, which forms the boundary between Matthew's Bridger B and C (**Figure 5**). Instead, he renamed it the Cottonwood White Layer without any justification in his text (Osborn, 1929, p. 80, 83, 86). Matthew's Cottonwood White Layer was defined as occurring within the Bridger B (Matthew, 1909, p. 296). Most of the later workers retained Matthew's original terminology.

Noting problems with the correlation of Matthew's white layers away from the Bridger badlands near Sage Creek Mountain, Uinta County, H. E. Wood (1934) divided the 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 the boundary between them (**Figure 5**). Contrary to rules of stratigraphic nomenclature, these members were defined by perceived faunal differences rather than lithologic differences. The informal usage of the terms "Blacksforkian" and "Twinbuttean" as land mammal subages is derived from the names of the two Bridger members. Wood (1934) regarded Horizon E of Matthew (1909) as faunally equivalent to the "Uinta A" of paleontologists.

Under the direction of J.W. Gidley, and later C.L. Gazin, the Smithsonian Institution began an active collecting program in the Bridger beginning in 1930. Gazin was active in the Bridger from 1941 to 1968. This period of activity resulted in a relatively large and well-documented collection that Gazin used to write many publications on the systematic paleontology and diversity of Bridger fossil mammals (e.g., Gazin, 1949, 1957, 1958, 1965, 1968, 1976).

K. J. Koenig studied the geology of the Bridger for his Ph.D. dissertation (Koenig, 1949) and later published a summary paper about the formation (Koenig, 1960). Koenig followed Osborn (1929) in renaming Matthew's Sage Creek White Layer the Cottonwood White Layer, and like Osborn, offered no explanation. Citing problems with Matthew's (1909) white layers as persistent markers, Koenig (1960) noted that the Cottonwood and Upper White layers were the only two that could be traced across the basin, and recommended a tripartite subdivision of the formation into lower, middle, and upper members. The Cottonwood White Layer was used as the boundary between the lower and middle members, and the Upper White Layer was used as the boundary between the middle and upper members. To our knowledge, this recommendation has not been adopted by any subsequent workers.

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. R.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 screen washing techniques to collect microvertebrates, a portion of the Bridger fauna that had not previously been adequately 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 (**Figure 5**). West and Hutchison (1981) named the Bridger E the Cedar Mountain Member, adding a third member to the Bridger Formation.

Many USGS geologists have described or mapped the Bridger units. Bradley (1964) included descriptions of the Bridger Formation in his description of the geology of the Green River Formation and associated Eocene rocks in Colorado, Wyoming, and Utah. Although its primary focus is the Green River Formation, Bradley's professional paper includes a useful discussion of Bridger geology and stratigraphy as well as a number of measured sections and a map showing the distribution of two of Matthew's white layers in a part of the basin. More recently, H.W. Roehler published a series of papers on the Green River Formation and other Eocene rocks in the GGRB, which included further stratigraphic work in the Bridger Formation although no new terminology was introduced (Roehler, 1992a, 1992b, 1992c, 1993). Dover and M'Gonigle (1993) compiled the geologic map of the Evanston 30' x 60' Quadrangle, which includes the west part of the area encompassed by this study. On this map, the authors attempted to identify and include some of Matthew's (1909) white layers, as well as other unnamed Bridger limestones.

McKenna and others (1973) estimated that the Bridger Formation was deposited over 2.0 My between 49.5 and 47.5 Ma. More recently, Murphey and others (1999) obtained a series of three isotopic ages from Bridger B, Bridger C, and just below the base of the Turtle Bluff Member (Bridger E) using $^{40}Ar/^{39}Ar$ techniques. These dates, which we will discuss in more detail in this report, suggest that the Bridger Formation was deposited over a period of approximately 3.2 My ending approximately 45.6 Ma.

The University of Colorado Museum (UCM) began an active research program in the Bridger Formation in 1991. This effort, initiated by Emmett Evanoff and joined later by Paul Murphey and Peter Robinson, has resulted in a large collection of fossils from the Twin Buttes and Turtle Bluff members with more than 350 fossil localities, most associated with measured sections at meter-level resolution. A detailed stratigraphic study and geologic mapping of the major markers in the Twin Buttes Member has been completed (Murphey, 2001; this report; and ten 1:24,000 scale open file geologic maps available from the Wyoming State Geological Survey). Evanoff and others (1998) published a preliminary report on these stratigraphic projects in which they propose a refinement of Matthew's stratigraphic subdivisions, and divide each original subdivision (Bridger B through D) into lower, middle, and upper informal subunits (**Figure 5**). In addition, they renamed the Cedar Mountain Member of West and Hutchison (1981) the "Turtle Bluff Member" because the stratigraphic name "Cedar Mountain" already referred to a sequence of Lower Cretaceous rocks in Utah.

Because of their close proximity to Interstate 80, the Bridger badlands have been visited by many other universities and museums over the years, resulting in a large number of relatively small reference collections in many institutions. In addition, a large number of graduate theses have focused on, or at least included, Bridger fossils. Theses focusing specifically on geological aspects of the Bridger include those of Koenig (1949), Kistner (1973), Gustav (1974), Socci (1978), Jerskey (1981), and Murphey (1995, 2001). The only papers focusing specifically on Bridger Formation geology published after Matthew's 1909 monograph are those of Koenig (1960), McGrew and Sullivan (1970), and Evanoff and others (1998).

STRATIGRAPHY

Matthew (1909) based his stratigraphic subdivisions of the Bridger Formation primarily on five areally-extensive limestones. He named these the Cottonwood, Sage Creek, Burnt Fork, Lonetree, and Upper White layers, and used some of them to subdivide the formation into five units: from lowest to highest, Bridger A; Bridger B; Bridger C; Bridger D; and Bridger E (**Figure 5**). By doing this, Matthew intended to make it possible to locate the numerous known fossil localities in the formation stratigraphically. 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, and B5). Because Matthew 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) and this study are uncertain.

In his monograph, Matthew (1909, p. 296) briefly described the five members and the white layers. "Horizon A" was 200 feet (61 m) thick, and was composed primarily of calcareous shales alternating with tuffs and rare fossils. "Horizon B" was 450 feet (137 m) thick, consisted of two benches separated by the Cottonwood White Layer, and contained abundant and varied fossils. Matthew noted that the largest number of complete skeletons found in the entire formation was recovered from the lower part of horizon B, namely B2. "Horizon C" was 300 feet (91 m) thick and "defined inferiorly" by the Sage Creek White Layer, with the Burnt Fork White Layer occurring at its approximate middle, and with abundant and varied fossils. He also observed that the Sage Creek White Layer was the "heavy and persistent calcareous stratum" at Sage Creek Spring, thereby designating a type locality where this unit had been previously described and illustrated, but not named, by Sinclair (1906). "Horizon D" was 350 feet (107 m) thick, composed of harder gray and greenish gray sandy and clayey tuffs, and "defined inferiorly" by the Lonetree White Layer, with the Upper White Layer approximately 75 feet (23 m) from the top, and with abundant and varied fossils. "Horizon E" was 500 feet (152 m) thick, composed of soft, banded tuffs with heavy volcanic ash layers, nearly barren of fossils, and rich in gypsum. Matthew reported a total thickness for the Bridger of 1,800 feet (549 m).

Despite Matthew's lithologic descriptions of the five horizons made (1909), subsequent workers have not been able to subdivide the Bridger Formation based on lithologic differences (Bradley, 1964; Roehler, 1992a). 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; Evanoff and others, 1994).

The Sage Creek White Layer was the only marker unit for which Matthew (1909) designated a type locality. In addition, Matthew did not map his markers in detail, so it is difficult to be certain of the correspondence between the actual rocks in the field and some of his markers and subdivisions. Nevertheless, the redefinition of Matthew's markers remains extremely useful, and, along with other more recently recognized markers (Evanoff and others, 1998; Murphey, 1995, 2001), makes it possible to significantly refine the stratigraphy of the Bridger Formation.

The stratigraphic subdivisions of this study are based on widespread limestones, tuffs, and tuffaceous sheet sandstones that are used as markers. This study describes fifteen such units, seven of which are major markers used to subdivide the Bridger C and D (Twin Buttes Member) into lower, middle, and upper informal subdivisions. Another two markers are used to re-define the base and define the top of the Bridger E (Turtle Bluff Member). Four of Matthew's original "white layers" are included in the stratigraphy of the Bridger C and D, and these are mapped and re-described in detail. Because many markers units are not continuously exposed or traceable across the entire study area, accurate correlation is possible using the mineralogically diagnostic Henrys Fork tuff (Evanoff and others, 1998; Murphey, 1995; Murphey and others, 1999) as a datum, and recognizing facies-related lithology changes in marker limestones.

Materials and methods

The fieldwork for this study was conducted between 1995 and 2001, and was preceded by initial fieldwork accomplished between 1991 and 1994. We mapped stratigraphic marker units directly on the following USGS 7.5-minute topographic maps: Reed Reservoir (1964, PR 1980); Lonetree (1964, PR 1980); Soap Holes Reservoir (1964, PR 1980); Burntfork (1964, 1980); Horse Ranch (1964, PR 1980); McKinnon (1964, 1980); Black Spring Reservoir (1964); Antelope Wash (1964, PR 1980); Devils Playground (1987); and Linwood Canyon (1987). We compared the field mapping to U.S. Bureau of Land Management stereographic aerial photos of the same area. We digitized the compiled mapping using ESRI ArcInfo® software.

We measured fourteen stratigraphic sections through the upper Bridger, including six detailed sections with all of the rock units described, and eight in which the entire section was measured but only the marker units were described in detail. We measured all stratigraphic sections with a Jacob's staff and Abney level and documented rock color with a Munsell rock color chart (Geological Society of America, 1991). Dips and strikes were measured using a Brunton Pocket Transit. The locations of measured sections are listed in **Table 1** and plotted on **Plate 1**. The stratigraphic data from each measured section are tabulated in **Appendix 1** through **Appendix 6** (appendices can be found on the CD in the inside back cover pocket).

As a result of this study and the efforts of other UCM crews working from 1991-2000, more than 3,500 catalogued fossil vertebrate specimens from more than 500

Table 1. Locations and references for measured sections in the upper Bridger Formation, Uinta and Sweetwater counties, Wyoming.

Section	Location		References	D or T	Map Ref.
	Base	Top			
Twin Buttes Member Type Section	NW¼SW¼NW¼NE¼ sec.8, T. 13 N, R. 109 W	SE¼NE¼SW¼NW¼ sec. 7, T. 13 N, R. 109 W	Table 17, Appendix 1	D	f
Twin Buttes Member Reference Section	SE¼NE¼NE¼SE¼ sec. 19, T. 14 N, R. 113 W	SW¼NE¼SE¼NW¼ sec. 19, T. 13 N., R. 113 W	Table 18, Appendix 2	D	a
Turtle Bluff Member Type Section	NE¼NW¼SE¼SE¼ sec. 24, T. 13 N, R. 113 W	NW¼SW¼SW¼SW¼ sec. 20, T. 13 N, R. 112 W	Table 19, Appendix 4	D	d
SW Sage Creek Mountain	NE¼NW¼NW¼SE¼ sec. 9, T. 13 N, R. 113 W	SE¼NW¼NE¼NW¼ sec. 10, T. 13 N., R. 113 W	Table 20, Appendix 5	D	b
SW Cedar Mountain	Center SE¼NE¼ sec. 26, T. 13 N, R. 113 W	SE¼SW¼NW¼SE¼ sec. 24, T. 13 N, R. 113 W	Table 19, Appendix 3	D	c
SE Cedar Mountain	NE¼NW¼SE¼SE¼ sec. 32, T. 13 N, R. 113 W	SW¼NW¼NW¼SW¼ sec. 30, T. 13 N, R. 111 W	Table 21, Appendix 6	D	e
NE Hickey Mountain	NE¼NW¼SE¼SE¼ sec. 1, T. 13 N, R. 114 W	NW¼SW¼SE¼SE¼ sec. 12, T. 13 N, R. 114 W	Table 22	T	g
NE Sage Creek Mountain	Center NE¼SW¼NW¼ sec. 30, T. 14 N, R. 112 W	NW¼SE¼SE¼NW¼ sec. 36, T. 14 N, R. 113 W	Table 23	T	h
N Cedar Mountain	SE¼SE¼NW¼NW¼ sec. 33, T. 15 N, R. 112 W.	SW¼NW¼NE¼NE¼ sec. 13, T. 14 N, R. 112 W	Table 24	T	j
S Cedar Mountain	SE¼NE¼NE¼NW¼ sec. 11, T. 12 N, R. 112 W	SW¼SE¼NW¼NE¼ sec. 32, T. 13 N, R. 112 W	Table 25	T	i
NE Mass Mountain	SW¼SW¼NW¼SW¼ sec. 16, T. 14 N, R. 110 W.	NW¼SE¼SE¼NW¼ sec. 27, T. 14 N, R. 111 W	Table 26	T	l
NE Cedar Mountain	NE¼NW¼NE¼NW¼ sec. 1, T. 14 N, R. 111 W.	SE¼SW¼NW¼SW¼ sec. 35, T. 15 N, R. 111 W	Table 27	T	k
NW Twin Buttes	SW¼NW¼NW¼NW¼ sec. 10, T. 13 N, R. 110 W	NW¼SE¼NE¼SE¼ sec. 1, T. 13 N, R. 110 W	Table 28	T	n
NW Black Mountain	C SE¼NE¼ sec. 12, T. 14 N, R. 110 W	NE¼NE¼NE¼NE¼ sec. 20, T. 14 N, R. 109 W	Table 29	T	m

D = detailed stratigraphic section described; T = only marker beds described and thickness between marker beds recorded; Map Ref. = measured section designation used on **Plate 1**.

fossil localities have been collected. The stratigraphic positions of these localities relative to the closest marker units were measured to the nearest meter, and then referenced to stratigraphic sections using the base of the Sage Creek limestone as a datum. UCM accessioned all fossils collected during the fieldwork for this study.

Upper Bridger Formation lithologies

The upper Bridger Formation is composed primarily of green and brown mudstone and claystone, ribbon and sheet sandstones, micritic or sparry limestone, and rare ash-fall tuff. With the exception of the limestone beds, most Bridger rocks are volcaniclastic (Bradley, 1964; Sinclair, 1906). Many of the limestone beds are locally cherty, and some grade laterally into, interbed with, or are underlain or overlain by thin dark brown to black beds of carbonaceous shale. Sandstones are mostly gray, bluish gray, green, and brown, and are predominantly very fine- to medium-grained and well sorted. Rare pebble conglomerates occur locally. Secondary gypsum occurs throughout the upper Bridger, mostly in the form of selenite crystals. These are especially abundant in the Turtle Bluff Member, which also contains thick beds of gyspum on Cedar Mountain. Fossils are present in most upper Bridger rock types, but are most abundant and diverse in micritic limestone beds, marlstone, and underlying and overlying calcareous mudstone beds.

Mudstone and claystone are the dominant lithologies of the upper Bridger, accounting for 53% of the type section at Twin Buttes, which is 320 m (1,050 feet) thick (**Appendix 1**). Sandstone accounts for 43% and limestone makes up 4% of the total thickness of the type section. The Henrys Fork tuff, at 1.1 m (3.6 feet) thick, represents less than 1% of the total thickness. Like many of the limestone beds, which are also individually less than 1 m (3.3 feet) thick, this tuff is extremely widespread, occurring over a distance of more than 50 km (31 miles) from the northeast flank of Black Mountain in Sweetwater County to the northwest flank of Hickey Mountain in Uinta County.

In the west part of the study area, approximately 42 km (26 miles) west of the type section, mudstone and claystone account for 77% of the combined total thickness of the 441 m (1,446 foot)-thick upper Bridger, which includes the Twin Buttes Member reference section and the Turtle Bluff Member type section (**Appendix 2** and **Appendix 4**). Sandstone accounts for 18% and limestone makes up 5% of the total combined thickness. At 0.7 m (2.3 feet) thick, the Henrys Fork tuff at the reference section represents less than 1% of the total thickness.

Stratigraphic subdivisions and marker units

The type section for the Twin Buttes Member was measured on Twin Buttes, Sweetwater County (**Appendix 1**). This section also includes rocks of the overlying Turtle Bluff Member (Bridger E) which occur on Twin Buttes. The reference section for the Twin Buttes Member was measured at Sage Creek Mountain and Hickey Mountain, Uinta County (**Appendix 2**). This section was originally designated as the type section by Murphey (2001), but is used as the reference section in this report. This re-designation will help avert confusion that could arise from the type section for the Twin Buttes Member not being physically located at Twin Buttes. Despite this change, the reference section remains a better section because of its location in the "classic" Bridger badlands which were so popular with the early collectors, and where the upper Bridger is exposed over a larger geographic area. The reference section is also thicker and includes all of the stratigraphic markers we use to subdivide the upper Bridger. Most type localities for marker units are located in the west part of the study area because they are best exposed there. The type section of the Turtle Bluff

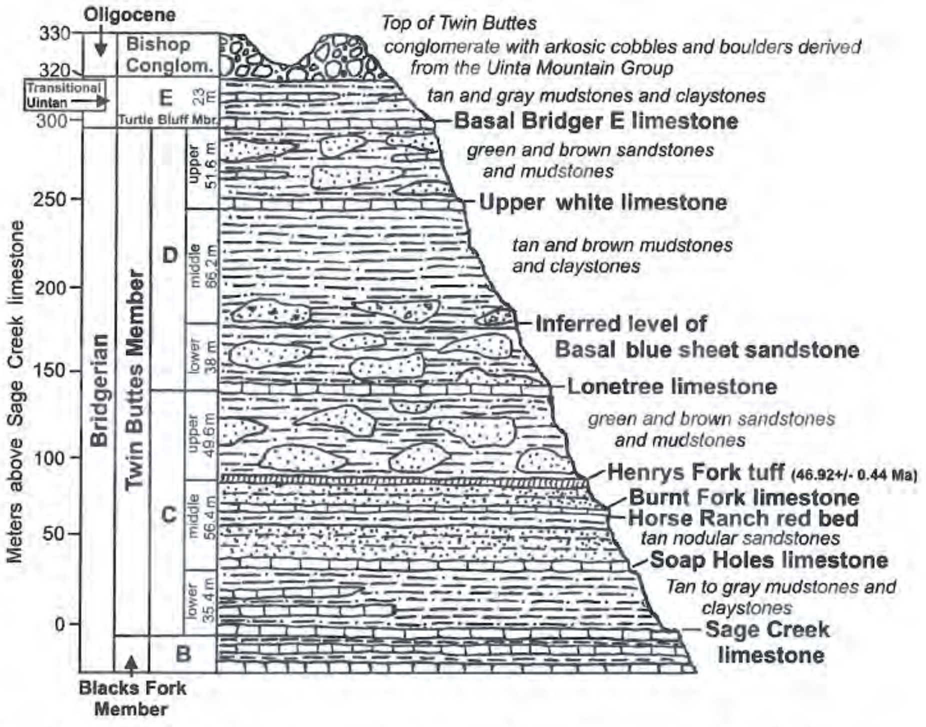


Figure 6. Generalized stratigraphic section of the upper Bridger Formation in the Twin Buttes area, Sweetwater County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from type section for the Twin Buttes Member, which includes the Turtle Bluff Member on Twin Buttes (Appendix 1).

Member was measured on the southwest flank of Cedar Mountain, Uinta County, where it is thickest and best exposed (**Appendix 4**).

Figure 6 and **Figure 7** illustrate stratigraphic subdivisions, marker units, and general stratigraphic features of the upper Bridger Formation. **Plate 1** shows the geographic distributions of the stratigraphic subdivisions and marker units. Positions of marker units in the type sections and reference sections are also summarized with respect to the base of the Sage Creek limestone in **Appendix 7** and **Appendix 8**. The following marker units form the bases of the lower, middle, and upper Bridger C and D (Twin Buttes Member): the Sage Creek limestone; Soap Holes limestone; Henrys Fork tuff; Lonetree limestone; Basal blue sheet sandstone; and Upper white limestone. The Basal Bridger E limestone and Behunin Reservoir gypsum bed form the base and top, respectively, of the Turtle Bluff Member. Note that for Matthew's (1909) Sage Creek, Burnt Fork, Lonetree, and Upper White layers, the term "white layer" has been replaced with a lithologic description that, for all of these units, is "limestone."

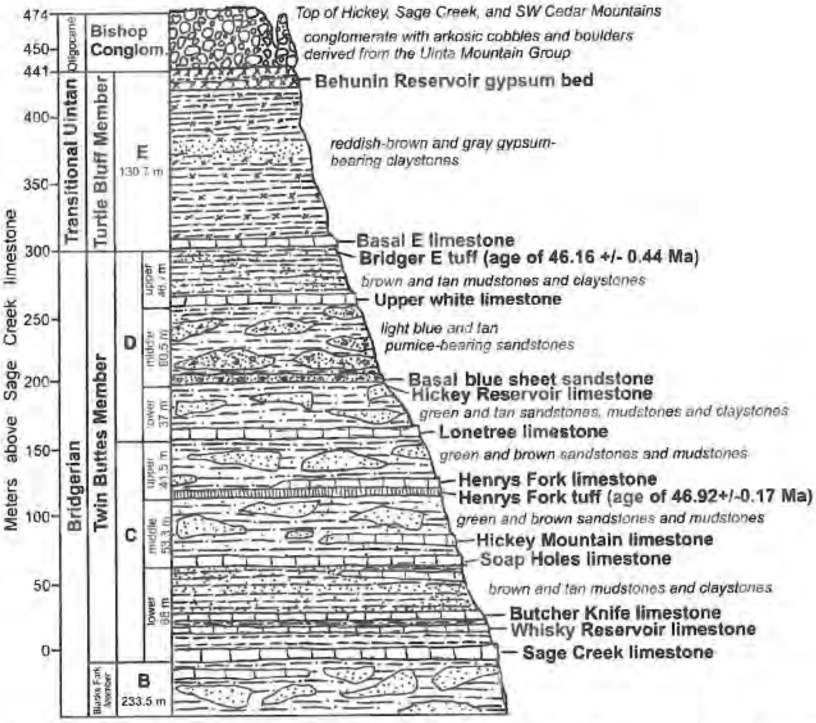


Figure 7. Generalized stratigraphic section of the upper Bridger Formation in the Sage Creek Mountain area, Uinta County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from the reference section (Appendix 2) for the upper Bridger Formation and type section of the Turtle Bluff Member (Appendix 4).

The most notable difference between the upper Bridger in the Twin Buttes area (**Figure 6**) and the Sage Creek Mountain/southwest Cedar Mountain area (**Figure 7**) is thickness. At Twin Buttes, the upper Bridger is 320 m (1,050 feet) thick, compared to 441 m (1,446 feet) thick in the Sage Creek Mountain/southwest Cedar Mountain area. This difference, discussed later, results from the occurrence of thicker sequences of lower Bridger C and Turtle Bluff Member in the west part of the study area.

Another important difference between the areas is that the Basal blue sheet sandstone, which forms the base of the middle Bridger D in the west and central parts of the study area, is absent on Twin Buttes and Black Mountain. Because its stratigraphic distance above the Lonetree limestone throughout most of the study area is so consistent, its position on Twin Buttes and Black Mountain is inferred based on an average distance above the Lonetree limestone elsewhere.

Twin Buttes Member

The Twin Buttes Member includes Matthew's (1909) Bridger C and D (**Figure 6** and **Figure 7**). The Bridger C and D are each divided into lower, middle, and upper subdivisions (Evanoff and others, 1998; Murphey, 2001). The Sage Creek limestone defines the base of the Twin Buttes Member and the base of the lower Bridger C. The member's upper contact is defined by the base of the Basal Bridger E limestone, which also forms the top of the upper Bridger D and the base of the Turtle Bluff Member. In the type section on Twin Buttes, the Twin Buttes Member is 297 m (974 feet) thick, while in the reference section in the west part of the study area, it is 307 m (1,007 feet) thick.

Lower Bridger C

The lower Bridger C in the west part of the study area consists primarily of tan and brown mudstone and claystone beds and includes three marker units (**Figure** 7). The basal marker is the Sage Creek limestone. The other markers are the Whisky Reservoir and Butcher Knife limestones. One other unnamed limestone, limited in distribution to the northwest part of the study area, occurs 5 m (16 feet) below the lithologically similar Soap Holes limestone (which forms the base of the middle Bridger C). On the southeast side of Cedar Mountain, five additional unnamed limestones are present within the lower Bridger C between the Sage Creek and Soap Holes limestones. At Twin Buttes and on Black Mountain, the lower Bridger C consists mostly of tan and gray mudstone and claystone beds (**Figure 6**), but locally includes a distinctive dark gray or greenish mudstone interval just above the Sage Creek limestone.

The most widely preserved of the upper Bridger subdivisions, the lower Bridger C is the only one exposed outside of the study area. It extends approximately 29 km (18 miles) north of the study area, almost to Interstate 80. It also occurs west of the study area south of the town of Robertson, where it was mapped by Dover and M'Gonigle (1993). Compared to the rest of the upper Bridger, the lower Bridger C is relatively unfossiliferous. Vertebrate fossils are especially rare, except for near the top.

The Sage Creek limestone is 4.1 m (13.5 feet) thick at its type locality, making it the thickest of Bridger Formation limestone units (**Figure 8**). Composed primarily of blocky and shaly micritic limestone beds interbedded with green and brown mudstone and carbonaceous shale beds, the Sage Creek limestone contains abundant gastropods and plant fragments, but only rare vertebrate fossils. The best exposure of this unit in the east part of the study area occurs in a road-cut 3.2 km (2 miles) north of McKinnon in Sweetwater County (**Figure 9**). Here, it is underlain by a sequence of limestone and shale beds at least as thick as the 30 m (98 foot)-thick exposure in the road-cut, and lithologically resembles the Laney Member of the Green River Formation more than the Bridger Formation (Brand, 2002). Mapping of the Sage Creek limestone across the study area has confirmed that the uppermost blocky limestone at the McKinnon road cut (**Figure 9**) is stratigraphically equivalent to the

Figure 8. Type locality of the Sage Creek limestone (SCLS) to the northwest of Sage Creek Mountain. Arrow points to base of unit.

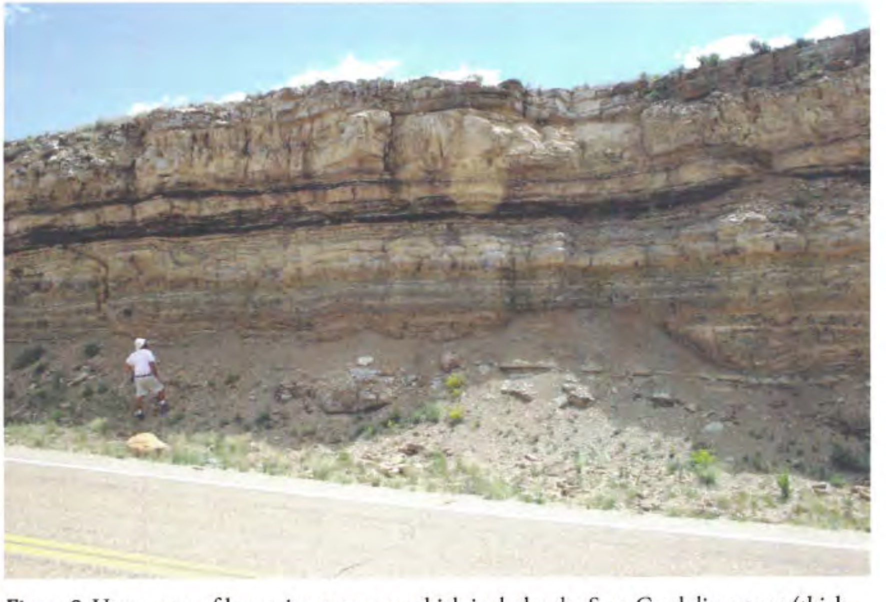


Figure 9. Upper part of lacustrine sequence which includes the Sage Creek limestone (thick white unit near the top of this exposure). Exposure is located in Sweetwater County approximately 3 km (2 miles) north of McKinnon, Wyoming, in a Highway 1 roadcut.

Sage Creek limestone at the type locality (**Figure 8**). **Table 2** summarizes geologic data for the Sage Creek limestone.

The Whisky Reservoir limestone is a 1-2 m (3.3-6.6 foot)-thick tan blocky limestone bed with locally interbedded tan shaly limestone beds that supports a widespread bench, and contains only rare fossilized plant fragments. In the Twin Buttes Member reference section in the west part of the study area, this limestone occurs 22 m (72 feet) above the base of the Sage Creek limestone. **Table 3** summarizes geologic data for the Whisky Reservoir limestone.

The Butcher Knife limestone is a thin (generally <0.5 m, or 1.6 feet), tan to gray blocky limestone bed that occurs 8 m (26 feet) above the base of the Whisky Reservoir limestone in the Twin Buttes Member reference section in the western part of the study area. It contains rare vertebrate bone fragments and snail shells. **Table 4** summarizes geologic data for the Butcher Knife limestone.

Table 2. Data summary for the Sage Creek limestone.

Unit name	Sage Creek limestone
Abbreviation	SCLS
Previous work	Described and photographed by Sinclair (1906, Plate 38). Mapped and named "Sage Creek White Layer" by Matthew (1909). Discussed, described, and/or mapped by Osborn (1929), Bradley (1964), Gustav (1974), West (1976), Roehler (1992b), Dover and M'Gonigle (1993), Murphey (1995), and Evanoff et al. (1998).
Type locality	SE¼NE¼NE¼SE¼ sec. 19, T. 14 N, R. 113 W. (6th Principal Meridian); map UTM 568552E, 4558525N (Zone 12); elevation 2,152 m (7,059 ft); also UCM fossil locality 91350.
Map name	Type locality on Reed Reservoir USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality, consists of lower massive tan micritic limestone, middle shaly limestone with dark gray to black chert bands, and upper platy to shaly limestone (**Figure 8**). Elsewhere, includes massive to blocky marly and micritic limestone, ledgy marlstone, and platy calcareous shale, locally interbedded with green to brown mudstone and claystone and thin carbonaceous shales (**Figure 9**). Supports a very widespread bench. Underlain and overlain by grayish-green, tan, and brown mudstone and claystone west of Sage Creek Mountain. Commonly overlain by dark gray to blackish or green mudstone and claystone in Twin Buttes area, and underlain by dark gray to blackish mudstone with a purplish tint locally.
Stratigraphic position	Base of SCLS divides upper Bridger (Twin Buttes Member) from lower Bridger (Blacks Fork Member), and forms base of lower Bridger C. Unit 1 of Twin Buttes Member type section (**Appendix 1**), units 9-13 of Twin Buttes Member reference section (**Appendix 2**).
Distribution	Well-exposed across much of the southern Green River Basin, especially north and west of Sage Creek Mountain; north and southeast of Cedar Mountain; north, east, and west of Black Mountain; and southwest, south, and east of Twin Buttes (Uinta and Sweetwater counties).
Thicknesses	Thickest lacustrine unit in upper Bridger Formation; maximum thickness 4.1 m (13.5 ft) at type locality; minimum known thickness 0.5 m (1.6 ft) northwest of Black Mountain. Underlain by at least 30 m (98 ft) of lacustrine shale, mudstone, marlstone, and limestone at Sweetwater County Highway 1 road-cut 3.2 km (2 miles) north of McKinnon.
Fossils	Scattered gastropods, bone fragments (mostly fish), and turtle shell fragments in blocky limestone, locally stromatolitic in ledgy limestone, with scattered plant fragments in platy limestone and carbonaceous shale.

Table 3. Data summary for the Whisky Reservoir limestone.

Unit name	Whisky Reservoir limestone
Abbreviation	WRLS
Name derivation	Named for Whisky Reservoir, a small cattle reservoir 3.2 km (2 miles) east-northeast of the type locality.
Previous work	None published.
Type locality	SE¼SW¼NE¼NW¼ sec. 20, T. 14 N, R. 113 W. (6th Principal Meridian); map UTM 569100E, 4559100N (Zone 12); elevation 2,170 m (7,118 ft).
Map name	Type locality on Reed Reservoir USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality, consists of lower light gray to white shaly limestone, middle blocky tan limestone, and upper light brownish-gray shaly limestone. Elsewhere, typically consists of tan blocky limestone with variable amounts of overlying and/or underlying tan shaly limestone. Locally supports bench.
Stratigraphic position	22 m (72 ft) above base of Sage Creek limestone in reference section (**Appendix 2**), within lower Bridger C.
Distribution	Well-exposed north of Sage Creek Mountain, Cedar Mountain, and Black Mountain, possibly equivalent to unit 5 (**Appendix 6**) southeast of Cedar Mountain, Uinta and Sweetwater counties.
Thicknesses	Thickest at type locality, 3.3 m (10.8 ft). Thins to east, varying from 0.6 to 1.4 m (2.0 to 4.6 ft).
Fossils	None observed, but rare plant fragments occur in underlying finely laminated shale at type locality.

Table 4. Data summary for the Butcher Knife limestone.

Unit name	Butcher Knife limestone
Abbreviation	BKLS
Name derivation	Named for Butcher Knife Draw, where this unit is well-exposed (Butcher Knife Draw USGS 7.5' Quadrangle Map, secs. 3,4,9, and 10, T. 15N, R. 112 W.).
Previous work	None published.
Type locality	SE¼SW¼NE¼NW¼ sec. 20, T. 14 N, R. 113 W. (6th Principal Meridian); map UTM 569140E, 4559100N (Zone 12); elevation 2,176 m (7,137 ft).
Map name	Type locality on Reed Reservoir USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	Typically consists of blocky, locally cherty, grayish-brown micritic limestone which weathers to tan, rusty brown, or light gray.
Stratigraphic position	30 m (98 ft) above base of Sage Creek limestone in reference section (**Appendix 2**), within lower Bridger C.
Distribution	Locally exposed north of Sage Creek Mountain, Cedar Mountain, and Black Mountain, possibly equivalent to unit 13 (**Appendix 6**), southeast of Cedar Mountain (Uinta and Sweetwater counties).
Thicknesses	0.4 m (1.3 ft) at type locality. Varies from 0.2 m to 0.5 m (0.7 ft to 1.6 ft) elsewhere.
Fossils	Uncommon, but includes scattered turtle shell fragments, crocodile bones, fish bones, Lepisosteus scales, and gastropods (mostly on top of unit).

Middle Bridger C

The middle Bridger C in the west part of the study area consists mainly of green and brown sandstone and mudstone beds, and includes two marker units. The Soap Holes limestone forms the base of the middle Bridger C, and the Hickey Mountain limestone occurs 10.5 m (34 feet) above it in the west part of the study area. The middle Bridger C is more fossiliferous than the lower Bridger C, and most fossils occur within limestone and marlstone beds or immediately above or below the limestone beds in thin calcareous mudstone beds. In the Twin Buttes/Black Mountain area, two additional marker units occur: the Burnt Fork limestone and the Horse Ranch red bed. The middle Bridger C at Twin Buttes and Black Mountain is composed largely of tan nodular sandstone and mudstone.

Like the Sage Creek, Whisky Reservoir, and Butcher Knife limestones, the Soap Holes limestone is extremely widespread, and can be traced westward from its type locality to the northwest of Hickey Mountain, and eastward all the way to the northeast side of Black Mountain. It is very well exposed in the low badlands north of Cedar Mountain and north and northeast of Sage Creek Mountain. Lithologically, it is a sparry, locally cherty limestone bed that weathers to a distinctive rusty reddish-brown and contains only rare vertebrate fossils (**Figure 10**). It is overlain locally by carbonaceous deposits containing silicified wood and other woody plant debris. Several large logs are preserved in sec. 19, T. 14 N., R. 112 W. northeast of Sage Creek Mountain. Matthew (1909) suggested that the Soap Holes limestone was equivalent

Figure 10. Looking east at the Soap Holes limestone (SHLS) and Hickey Mountain limestone (HMLS) from State Highway 414 in Uinta County, Wyoming.

to his Burnt Fork White Layer. The two are lithologically similar and the Burnt Fork White Layer also weathers to rusty red. However, the Burnt Fork limestone is not present north of Cedar Mountain, and it occupies a different stratigraphic position than the Soap Holes limestone. **Table 5** summarizes geologic data for the Soap Holes limestone.

The Hickey Mountain limestone is a thin unit restricted to the areas north and northeast of Hickey Mountain and west of Sage Creek Mountain (**Figure 10**). Intermittently exposed over a distance of 9 km (5.6 miles), it varies in lithology from dominant tan marlstone to well-indurated rusty brown sparite (**Table 6**), and occurs 10.5 m (34.4 feet) above the base of the Soap Holes limestone at the Hickey Mountain limestone type locality. The Hickey Mountain limestone and thin overlying calcareous mudstone are locally highly fossiliferous and contain locally abundant terrestrial and aquatic invertebrates and vertebrates, and occasional wood fragments (see Murphey and others, 2001). **Table 6** summarizes geologic data for the Hickey Mountain limestone.

Table 5. Data summary for the Soap Holes limestone.

Unit name	Soap Holes limestone
Abbreviation	SHLS
Name derivation	Named for area west of Soap Holes reservoir, where extensive exposures of this limestone occur (Soap Holes Reservoir USGS 7.5' Quadrangle Map).
Previous work	Described by Murphey (1995), partially mapped and described by Evanoff et al. (1998).
Type locality	NW¼SE¼SE¼SE¼ sec. 17, T. 14 N, R. 112 W. (6th Principal Meridian); map UTM 578900E, 4559940N (Zone 12); elevation 2,140 m (7,019 ft).
Map name	Type locality on Soap Holes Reservoir USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality and in west part of study area, consists of blocky, ledge-forming, well-indurated, tan to gray silicified limestone which weathers to rusty brown (**Figure 10**). Locally cherty. Northwest of Black Mountain, consists of blocky brown to gray sparry limestones which weather to rusty brown, and locally interbed with or are replaced by finely laminated tan and light bluish-gray shaly limestone beds underlain by thin carbonaceous shale beds containing plany fragments. Locally supports benches throughout its distribution.
Stratigraphic position	35 m (115 ft) above Sage Creek limestone in type section (**Appendix 1**), and 68 m (223 ft) above Sage Creek limestone in reference section (**Appendix 2**), forms base of middle Bridger C.
Distribution	Extremely widespread. Well-exposed north of Hickey Mountain; west and north of Sage Creek Mountain; north of Cedar Mountain; on the southeast side of Cedar Mountain; and north, south, east, and west of Black Mountain and Twin Buttes (Uinta and Sweetwater counties).
Thicknesses	1.2 m (3.9 ft) at type locality, 1.0 m (3.3 ft) in type section, and 1.3 m (4.3 ft) northwest of Black Mountain. Thins to the south, where it is 0.4 m (1.3 ft) thick on the east side of Cedar Mountain and 0.3 m (1.0 ft) thick on the southeast side of Twin Buttes.
Fossils	Rare, but include gastropod shell fragments and fish bone fragments, with scattered mammal and reptile bone fragments within and on top of unit. Locally underlain by thin carbonaceous shales which contain occasional plant fragments in the Black Mountain area. An approximately 4 meter-long silicified log and smaller chunks of silicified wood underlie the SHLS in sec. 19, T. 14 N, R. 112 W.

Table 6. Data summary for the Hickey Mountain limestone.

Unit name	Hickey Mountain limestone
Abbreviation	HMLS
Name derivation	Named for Hickey Mountain, which lies approximately 2.4 km (1.5 miles) southwest of the type locality.
Previous work	Mapped and described by Murphey (1995) and Murphey et al. (2001).
Type locality	SE¼SE¼NW¼SE¼ sec. 6, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 568160E, 4553460N (Zone 12); elevation 2,237 m (7,337 ft).
Map name	Type locality on Reed Reservoir USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality, consists of poorly-indurated pinkish-tan marlstone with occasional light olive green and brown clay balls near base. Elsewhere, varies from dominant blocky tan marlstone and micrite to well-indurated cherty limestone, to pale green calcareous sandy mudstone, to well-indurated tan sparry limestone that weathers to rusty brown where the unit is thickest (**Figure 10**). Commonly underlain by pale olive green non-calcareous claystone.
Stratigraphic position	10.5 m (34 ft) above the base of the Soap Holes limestone on the northeast side of Hickey Mountain, 78.6 m (258 ft) above the base of the Sage Creek limestone as extrapolated from reference section (**Appendix 2**), within middle Bridger C.
Distribution	Relatively limited in distribution. Occurs over a distance of approximately 9 km (5.6 miles), north of Hickey Mountain and west of Sage Creek Mountain, Uinta County.
Thicknesses	8-10 cm (3-3.9 in) thick at type locality; minimum thickness 4 cm (1.6 in); maximum thickness 45 cm (18 in).
Fossils	Locally abundant, including charophytes, wood and petiole fragments, molluscs, amphibians, reptiles, birds, and mammals. Terrestrial vertebrates are most abundant in overlying calcareous mudstone 2-3 cm (0.8-1.2 in) thick. Vertebrate fossils are typically fragmentary.

Red beds are rare in the Bridger C and D. The Horse Ranch red bed is a distinctive brick red interval approximately 4 m (13 feet) thick that is well exposed at the base of the west sides of Twin Buttes and Black Mountain. The Horse Ranch red bed consists predominantly of brick red and greenish gray mudstone and fine sandstone beds, and occurs 15 m (49 feet) above the base of the Soap Holes limestone at the type locality. It can be traced west from Twin Buttes to the east side of Cedar Mountain (**Figure 11**), where it is exposed east of Mass Mountain in sec. 24, T. 14 N., R. 111 W. near its type locality. The most extensive exposures occur at the base of the northwest and southwest sides of Black Mountain. Mentioned but not named in Matthew and Granger's field notes (1903, Frick Archives, AMNH), the Horse Ranch red bed contains locally abundant bone fragments (typically turtle shell). **Table 7** summarizes geologic data for this unit.

The Burnt Fork limestone is best exposed on the south and east sides of Cedar Mountain, and on Twin Buttes. It is well exposed near the confluence of the Burnt Fork and Henrys Fork rivers on the south side of Cedar Mountain, near the small hamlet of Burntfork (UTM 579140 E, 4544660 N; Zone 12). It is similar in lithology and appearance to the Soap Holes limestone and consists of a widespread sparry limestone that weathers to rusty brown, but is stratigraphically higher by 24 m (79 feet). **Table 8** summarizes geologic data for the Burnt Fork limestone.

Figure 11. Looking east at the type locality of the Horse Ranch red bed in Sweetwater County, Wyoming. The base of the unit is level with the bottom of the Jacob's staff.

Table 7. Data summary for the Horse Ranch red bed.

Unit name	Horse Ranch red bed
Abbreviation	HRRB
Name derivation	Named for Horse Ranch, located approximately 0.8 km (0.5 miles) west-southwest of the type locality and 3.2 km (2 miles) northeast of the north summit of Mass Mountain.
Previous work	Referenced in Matthew and Granger's field notes (1903-1906), and by Roehler (1992b).
Type locality	C W½ sec. 24, T. 14 N, R. 111 W. (6th Principal Meridian); map UTM 593898E, 4559099N (Zone 12); elevation 2,143 m (7,029 ft).
Map name	Type locality on Horse Ranch USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	Consists of non-calcareous brick red, greenish-gray, and light brown claystone, blocky mudstone, and blocky fine muddy sandstone (VFS-FS). At type locality, underlain by a fine, pale olive sandstone, and consists of a lower 1 m (3.3 ft)-thick brick-red mudstone, a middle 0.1 m (0.3 ft)-thick greenish gray sandstone, and an upper 3.3 m (10.8 ft)-thick sequence of brick-red claystone, mudstone, and muddy sandstone (VFS-FS) (**Figure 11**).
Stratigraphic position	15 m (49 ft) above the base of the Soap Holes limestone in the vicinity of Horse Ranch, northeast of Mass Mountain (**Table 26**), within the middle Bridger C.
Distribution	Restricted to the east side of Cedar Mountain (vicinity of Mass Mountain), east to Twin Buttes and Black Mountain (especially the west sides, where it is exposed near the bases), Sweetwater County.
Thicknesses	Ranges from 4.4 m (14.4 ft) at the type locality to 3.0 m (9.8 ft) on the northwest end of Black Mountain (**Table 26** and **Table 29**).
Fossils	Locally abundant bone fragments (turtle, crocodile, mammal).

Table 8. Data summary for the Burnt Fork limestone.

Unit name	Burnt Fork limestone
Abbreviation	BFLS
Name derivation	Named for the Burnt Fork of the Green River, which flows into the Henrys Fork approximately 4.8 km (3 miles) east-southeast of the type locality on the south side of Cedar Mountain.
Previous work	Briefly described and named the "Burnt Fork White Layer" by Matthew (1909). Discussed, described, and/or partially mapped by Osborn (1929), Bradley (1964), Dover and M'Gonigle (1993), and Murphey (1995). Considered by Roehler (1992b) to correspond to the Sage Creek White Layer mapped by Bradley (1964, A51, Plate 1).
Type locality	NE¼SE¼SE¼NE¼ sec. 5, T. 12 N, R. 112 W. (6th Principal Meridian); map UTM 579140E, 4544660N (Zone 12); elevation 2,212 m (7,255 ft).
Map name	Type locality on Burntfork USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality, consists of blocky, ledge-forming dark brown to gray thrombolitic sparry limestone that weathers to rusty brown (**Figure 12**). Grades into and is locally underlain by carbonaceous shale and coal on the south side of Twin Buttes. Similar in lithology and appearance to Soap Holes limestone.
Stratigraphic position	24 m (79 ft) above the base of the Soap Holes limestone on the south side of Cedar Mountain (**Table 25**), within middle Bridger C.
Distribution	Occurs only on south and southeast sides of Cedar Mountain and on Twin Buttes, Sweetwater County.
Thicknesses	Varies from 0.3 m (1.0 ft) at type locality to 0.5 m (1.6 ft) on south side of Twin Buttes.
Fossils	Thrombolitic, with scattered gastropods and fragmentary fish bones. Locally overlain by carbonized logs, stem fragments, and poorly-preserved leaves in thin layer of carbonaceous shale and coal on south side of Twin Buttes (UCM L. 99019).

The most useful diagnostic features of the Burnt Fork limestone are thrombolites, which occur throughout much of its distribution. Ranging in size from 10 cm (4 inches) to more than 1 m (3.3 feet) in diameter, they are mostly hemispheroidal in shape with no discernible internal structure (**Figure 12**). The unit is also locally associated with lenses of carbonaceous shale and lignite in which roots, branches, and mostly woody plant tissues are preserved. The highest concentrations of these fossils occur on the southeast side of Twin Buttes where the limestone grades completely into lignite.

Although no specific type locality was designated for this unit by Matthew (1909), we believe that his Burnt Fork White Layer and the Burnt Fork limestone of this study are the same unit because: 1) we compared a photograph of Matthew's Burnt Fork white layer (housed in the Frick Archives at the AMNH) to our field observations of the Burnt Fork limestone, and found them to be the same; and 2) the Burnt Fork limestone matches Matthew's (1909) description as "another persistent stratum of flinty lime, occurring at approximately the middle of the (C) horizon." Though lithologically similar to the Soap Holes limestone, the Burnt Fork limestone occurs almost exactly at the middle of the Bridger C, and is the only "flinty" limestone that occurs within that stratigraphic interval near the confluence of the Burnt Fork and Henrys Fork rivers, and the town of Burntfork.

Figure 12. Thrombolites in the Burnt Fork limestone on the southeast side of Cedar Mountain in Sweetwater County, Wyoming.

Upper Bridger C

Throughout the study area, the upper Bridger C consists mostly of green and brown sandstone and mudstone. It contains two marker units in the west part of the study area. The Henrys Fork tuff defines the base of the upper C. In the west part of the study area, the tuff is immediately overlain by the Henrys Fork limestone. In the Twin Buttes area, the Henrys Fork limestone is not present. On the south side of Cedar Mountain, three additional limestones occur within the upper C above the Henrys Fork limestone, but these are not widespread and were not named. Fossil vertebrates and mollusks are locally abundant in the upper C, occurring primarily within the Henrys Fork limestone and a thin overlying calcareous mudstone, and secondarily within channel sandstone deposits.

The Henrys Fork tuff is a blocky gray biotitic claystone that contains no fossils. It is widespread and well exposed, appearing as a dark purplish-gray bed (especially when badlands surfaces are wet) low on the slopes of Hickey Mountain, Sage Creek Mountain, Cedar Mountain, Black Mountain, and Twin Buttes (**Figure 13** and **Figure 14**). **Table 9** summarizes geologic data for this unit. Using this tuff's stratigraphic position throughout the region, characteristic mineralogy (Murphey, 1995), and macroscopic features including weathered color and the presence of large euhedral biotite crystals, we have correlated it from mountain to mountain with certainty. In fact, the Henrys Fork tuff proved the most distinct upper Bridger marker unit dur-

Figure 13. Looking north from State Highway 414 five miles west of Burntfork in Uinta County at the southwest side of Cedar Mountain with the type localities (yellow star) of the Henrys Fork tuff and Henrys Fork limestone (prominent grayish-white beds).

Figure 14. Well-exposed Henrys Fork tuff (prominent gray bed, HFT) and Henrys Fork limestone (thin overlying white bed, HFLS) on the south side of Cedar Mountain in Uinta County, Wyoming.

Table 9. Data summary for the Henrys Fork tuff.

Unit name	Henrys Fork tuff
Abbreviation	HFT
Name derivation	Named for the Henrys Fork tuff of the Green River, located approximately 0.25 miles south of the type locality.
Previous work	Mapped and described by Murphey (1995), Evanoff et al. (1998). Dated by Murphey et al. (1999).
Type locality	SE¼NW¼SE¼SE¼ sec. 36, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 576581E, 4545289N (Zone 12); elevation 2,243 m (7,357 ft).
Map name	Type locality on Burntfork USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality and elsewhere, consists of blocky, non-calcareous, gray to white biotitic claystone. Contains biotite, zircon, allanite, and apatite crystals. Plagioclase is the most abundant feldspar. Typically consists of structureless lower unweathered portion with coarse euhedral biotite [up to 1.3 mm (0.005 in) in diameter], which grades upward into a reworked portion with less coarse and less abundant biotite. Bottom contact distinct, top contact diffuse. Overlain by the Henrys Fork limestone at Hickey Mountain, Sage Creek Mountain, and Cedar Mountain. Weathers to an approximately 1 m (3.3 ft)-thick dark gray band which is clearly visible when wet (**Figure 13** and **Figure 14**). $^{40}Ar/^{39}Ar$ age of 46.92 ± 0.17 Ma.
Stratigraphic position	92 m (302 ft) above base of Sage Creek limestone in type section (**Appendix 1**), 121 m (397 ft) above base of Sage Creek limestone in reference section (**Appendix 2**), forms base of upper Bridger C.
Distribution	Exposed north and east of Hickey Mountain; in the divide between Hickey Mountain and Sage Creek Mountain; on the west, north, and northeast of Sage Creek Mountain; on the south, east, and northeast sides of Cedar Mountain; and around Twin Buttes and Black Mountain, Uinta and Sweetwater counties.
Thicknesses	Un-reworked tuff has maximum thickness of 0.95 m (3.1 ft) at type locality, minimum thickness of 0.2 m (0.6 ft), and is approximately 0.5 m (1.6 ft) thick over most of its distribution. Reworked portion is typically 0.5 m (1.6 ft) thick.
Fossils	None observed.

ing field work for this study. The Henrys Fork tuff typically consists of a basal ash-fall deposit and a fluvially reworked upper portion, with a typical maximum total thickness of 1 m (3.3 feet). However, thickness can reach 3 m (10 feet) on the south side of Cedar Mountain. Because ash-fall tuffs are deposited in time spans of a few days to a few years (Schminke and van den Bogaard, 1991), the base of this tuff represents an essentially isochronous horizon, and is therefore an excellent stratigraphic datum. As it is the only widespread ash-fall tuff identified in the upper Bridger, it probably represents the best isochron. The Henrys Fork tuff has a single crystal laser fusion $^{40}Ar/^{39}Ar$ age of 46.92 ± 0.17 Ma (Murphey and others, 1999).

Directly overlying the Henrys Fork tuff, the Henrys Fork limestone consists of tan to light gray blocky micritic limestone and marlstone beds. **Table 10** summarizes geologic data for this unit. A thin, highly fossiliferous calcareous mudstone overlies the Henrys Fork limestone throughout much of the limestone's distribution (Murphey, 1995). Like other upper Bridger micritic limestone units, the Henrys Fork limestone contains mostly the remains of aquatic vertebrates and mollusks, while the overlying calcareous mudstone contains mixed terrestrial and aquatic fossil remains. These are typically found in localized concentrations along and just above the limestone beds.

Table 10. Data summary for the Henrys Fork limestone.

Unit name	Henrys Fork limestone
Abbreviation	HFLS
Name derivation	Named for the Henrys Fork tuff of the Green River, located approximately 0.4 km (0.25 miles) south of the type locality.
Previous work	Mapped and named "marlstone zone" (Burnt Fork White Layer?) by Dover and M'Gonigle (1993). Mapped and described by Murphey (1995).
Type locality	NE¼SW¼SE¼SE¼ sec. 36, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 576581E, 4545289N (Zone 12); elevation 2,245 m (7,364 ft).
Map name	Type locality on Burntfork USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality, consists of blocky, grayish-white to light gray micritic limestone and light gray shale. Elsewhere, varies from tan to white blocky micritic limestone, to tan and grayish-brown marlstone and calcareous mudstone, to dark brown carbonaceous shale. Blocky light gray micrite is the dominant lithology. Overlies Henrys Fork tuff; overlain by thin, highly fossiliferous, calcareous mudstone (**Figure 13** and **Figure 14**).
Stratigraphic position	122 m (400 ft) above the base of the Sage Creek limestone in reference section (**Appendix 1**), within upper Bridger C.
Distribution	Exposed in the divide between Hickey Mountain and Sage Creek Mountain; west, north, and northeast of Sage Creek Mountain; and along the south side of Cedar Mountain, Uinta and Sweetwater counties. Easternmost occurrence is on the southeast side of Cedar Mountain in the SW¼ sec. 22, T. 13 N, R. 111 W.
Thicknesses	1.5 m (4.9 ft) at type locality; maximum 1.65 m (5.4 ft)on south side of Cedar Mountain; minimum measured thickness 3 cm (1.2 in) on northwest side of Sage Creek Mountain.
Fossils	Gastropods, *Lepisosteus* scales, fish bones, turtle shell fragments, and crocodilian bones/osteoderms are most abundant, with rare unionid clams. Terrestrial vertebrates are comparatively rare within the limestone, but are locally abundant in overlying calcareous mudstone. Fossils in the calcareous mudstone include mostly small mammal and reptile bone fragments and teeth, although amphibian and bird fossils also occur.

Rare wood fragments have also been found in the overlying calcareous mudstone. The Henrys Fork limestone is limited to the west part of the study area, including Hickey, Sage Creek, and Cedar mountains. Like the Henrys Fork tuff, it attains its maximum thickness of 1.65 m (5.4 feet) and is most prominent on the south side of Cedar Mountain. Together, the tuff and limestone in this area form a thick gray bed overlain by a thinner white bed (**Figure 14**) that is easily seen from Wyoming State Highway 414, especially in sec. 5, T. 12 N., R. 112 W. Here, the Henrys Fork limestone consists of up to three limestone beds interbedded with muddy sandstone beds. The lowest of these limestone beds includes the reworked portion of the Henrys Fork tuff. Because it thins significantly to the north and west, it can be difficult to locate elsewhere in the study area. The Henrys Fork limestone was studied in detail by Murphey (1995), and was mapped by Dover and M'Gonigle (1993) as possibly the Burnt Fork White Layer of Matthew (1909), but does not match the features Matthew listed for his Burnt Fork White Layer.

Lower Bridger D

Across the study area, the lower Bridger D consists mostly of greenish-gray and tan sandstone, mudstone, and claystone. Two marker units are located in the west part of the study area: the Lonetree limestone, which is the base of the lower D; and the Hickey Reservoir limestone, which lies just below the top of the lower D.

The Lonetree limestone is exposed low on the slopes of Hickey, Sage Creek, and Cedar mountains, and in the Lonetree divide area where it crosses Wyoming State Highway 414 (**Figure 15**). It is also well exposed just above the level of the saddle between Twin Buttes and Black Mountain. Typically, it is 2-3 m (6.6-10 feet) thick and consists of two to three distinct gray to white micritic limestone beds interbedded with calcareous mudstone, fine sandstone, and occasional carbonaceous shale beds. **Table 11** summarizes geologic data for the Lonetree limestone. On the north side of Sage Creek Mountain and the north and east sides of Cedar Mountain, the limestone beds that make up the Lonetree limestone grade laterally into thinner pale green marlstone and calcareous mudstone beds. Both vertebrate and mollusk fossils occur within the Lonetree limestone, but terrestrial vertebrates are most abundant in calcareous mudstone beds surrounding or interbedded with the limestones. Previous workers did not recognize the Lonetree limestone at Twin Buttes because limestone beds on Twin Buttes change in their petrology and relative stratigraphic position compared to those in the west part of the study area (Wood, 1934; Koenig, 1960;

Figure 15. Looking northeast from Wyoming State Highway 414 at exposures of the Lonetree limestone (LTLS) and the approximate position of the Basal blue sheet sandstone (BBS) in Uinta County, Wyoming.

Table 11. Data summary for the Lonetree limestone.

Unit name	Lonetree limestone
Abbreviation	LTLS
Name derivation	Named for the town of Lonetree, located approximately 4.8 km (3 miles) south-southeast of the type locality.
Previous work	Briefly described and named "Lonetree White Layer" by Matthew (1909). Discussed, described, and/or partially mapped by Osborn (1929), Bradley (1964), West (1976), Roehler (1992b), Dover and M'Gonigle (1993), Murphey (1995), and Evanoff et al. (1998).
Type locality	SE¼NE¼NE¼NE¼ sec. 19, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 568680E, 4549640N (Zone 12); elevation 2,310 m (7,577 ft).
Map name	Type locality on Lonetree USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	Near type locality, consists of two blocky gray to white micritic limestone beds containing light gray chert nodules separated by gray and green mudstone. Across much of its distribution, composed of two or three distinct ledge-forming, light gray, blocky micritic limestone beds or muddy limestone beds separated by a thin muddy or carbonaceous interval. Lateral variations include shaly limestone interbedded with very fine sandstone, mudstone, claystone, and occasional thin carbonaceous beds, which can overlie or underlie the unit. Tends to weather to rusty brown or grayish-white along the east side of Hickey Mountain and the west and south sides of Cedar Mountain, and to light green and rusty brown on the north side of Sage Creek Mountain, the northeast end of Cedar Mountain, and Mass Mountain (**Figure 15** and **Figure 19**).
Stratigraphic position	141 m (463 ft) above the base of the Bridger C in type section (**Appendix 1**); 163 m (535 ft) above the base of the Bridger C in reference section (**Appendix 2**); forms base of Bridger D.
Distribution	Exposed north and east of Hickey Mountain; west, north, northeast of Sage Creek Mountain; south, west, east, and northeast of Cedar Mountain; around Twin Buttes and Black Mountain, Uinta and Sweetwater counties.
Thicknesses	2.0 m (6.6 ft) at type locality; typically 0.5-2.0 m (1.6-6.6 ft). Minimum thickness of 0.2 m (0.7 ft) on the northwest side of Black Mountain and 0.3 m (1.0 ft) on the south side of Cedar Mountain. Maximum thickness of 2.3 m (7.5 ft) on the saddle between Twin Buttes and Black Mountain.
Fossils	Locally abundant, including gastropods, rare unionid clams, and scattered aquatic vertebrate bone fragments and *Lepisosteus* scales. Terrestrial vertebrate fossils include mostly fragmentary reptiles and mammals, and are most common in interbedded and overlying calcareous mudstones.

West, 1976). Until recently (Murphey, 2001), the Henrys Fork tuff was not used as a marker unit to correlate Twin Buttes and Black Mountain with stratigraphically equivalent rocks farther west on Cedar, Sage Creek, and Hickey mountains. Using the Henrys Fork tuff as a datum, and recognizing that facies-related lithology and petrology changes occur within most Bridger markers, the Lonetree limestone may be identified on Twin Buttes and Black Mountain at approximately the same relative stratigraphic position observed in the west part of the study area.

The Hickey Reservoir limestone is a thin unit relatively limited in distribution. The unit has a high fossil content. Geologic data for this unit are summarized in **Table 12**. It is best exposed in badlands of low topographic relief southeast of Hickey Mountain, especially near Old Hat Mountain (secs. 19 and 30, T. 13 N., R. 113 W.). It also occurs on the southwest side of Cedar Mountain in secs. 25 and 26, T. 13 N., R. 113 W. Positioned just below the base of a prominent sequence of light-blue and brown sandstone sheets that mark the base of the middle Bridger D, the

Table 12. Data summary for the Hickey Reservoir limestone.

Unit name	Hickey reservoir limestone
Abbreviation	HRLS
Name derivation	Named for the Hickey Mountain Reservoir, a small cattle pond located approximately 0.4 km (0.25 miles) southeast of the type locality.
Previous work	None published.
Type locality	SE¼NW¼NW¼SE¼ sec. 19, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 568075E, 4548833N (Zone 12); elevation 2,359 m (7,737 ft).
Map name	Type locality on Lonetree USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality and elsewhere, consists of platy light gray to pinkish-gray marlstone which is locally sandy (FS-VFS) (**Figure 17**).
Stratigraphic position	200 m (656 ft) above the base of the Sage Creek limestone in reference section (**Appendix 2**), within lower Bridger D.
Distribution	Relatively limited in distribution, cropping out southeast of Hickey Mountain, and south of a butte the early collectors called "Old Hat Mountain" (SW¼NW¼ sec. 19, T. 13 N., R. 113 W.). Possibly occurs east of Old Hat Mountain, and may be lateral equivalent to thicker limestone exposed as a prominent white bed approximately three quarters of the way up the north-facing cliffs in sec. 36, T. 14 N., R. 114 W., and secs. 30 and 31, T. 14 N., R. 113 W. (Soap Holes Reservoir 7.5' Quadrangle Map), Uinta County.
Thicknesses	Thin, varying in thickness over short distances. In the vicinity of the type locality, varies from 1-3 cm to 10 cm (0.4-1.2 in to 3.9 in).
Fossils	Abundant gastropods, locally abundant aquatic and terrestrial vertebrate remains consisting primarily of small mammal and reptile bone fragments and teeth.

Hickey Reservoir limestone is a pinkish gray marlstone bed that contains abundant gastropods and bone fragments. It varies in thickness from 1 to 10 cm (0.4 to 4 inches) over short distances, possibly because overlying sandstones have cut into it. The Hickey Reservoir limestone is not present at Twin Buttes, although based on its position, it may be equivalent to the prominent unnamed limestone bed exposed in the steep badland slopes east of Sage Creek Mountain and north of Cedar Mountain in the S½ sec. 30, T. 14 N., R. 112 W. (visible in **Figure 1**). This limestone was not measured into a section because steep terrain rendered it inaccessible. It is not present in the type section or reference section, or on the south or southeast side of Cedar Mountain, and consequently is not shown in **Figure 6**. For reference, the approximate position of the Hickey Reservoir limestone is shown on **Figure 7**. The lower Bridger D and all stratigraphically higher rocks in the upper Bridger Formation in the southern Green River Basin are restricted to the slopes of Hickey Mountain, the Lonetree divide, Sage Creek Mountain, Cedar Mountain, Black Mountain, and Twin Buttes.

Middle Bridger D

The middle Bridger D in the west part of the study area is a sequence of light blue and tan pumice-bearing sandstone beds and muddy sandstone beds interbedded with mudstone beds. In general, the blue sandstones lie stratigraphically below the tan sandstones. No limestone beds occur within the middle D in the type section at

Twin Buttes, but several are present within the top 6 m (20 feet) of the middle D in the west part of the study area. The blue sandstone sequence is especially conspicuous near Lonetree divide, south and southeast of Hickey Mountain, south of Sage Creek Mountain, and south and southwest of Cedar Mountain. In the Twin Buttes area, the middle D consists of tan and brown mudstone and claystone beds with lesser tan and green sandstone beds. No blue sheet sandstones are present.

The Basal blue sheet sandstone marker defines the base of the middle Bridger D. In the west part of the study area, it consists of a blocky light grayish blue pumiceous sandstone sheet locally interbedded with thin tan to light bluish gray mudstone beds and muddy sandstone beds. Because the Blue sheet sandstone is not present on the east side of Cedar Mountain, however, the base of the middle D there is marked by the base of the lowest blue sandstone, which lies at the same stratigraphic position. The position of the base of the light-blue and tan sandstone sequence on Old Hat Mountain and on the south side of Cedar Mountain is shown in **Figure 16** and **Figure 17**.

As defined by the base of a sheet sandstone sequence, the base of the middle Bridger D is the most difficult of the upper Bridger markers to correlate. It is also the only marker that cannot be correlated between Twin Buttes and Black Mountain. From

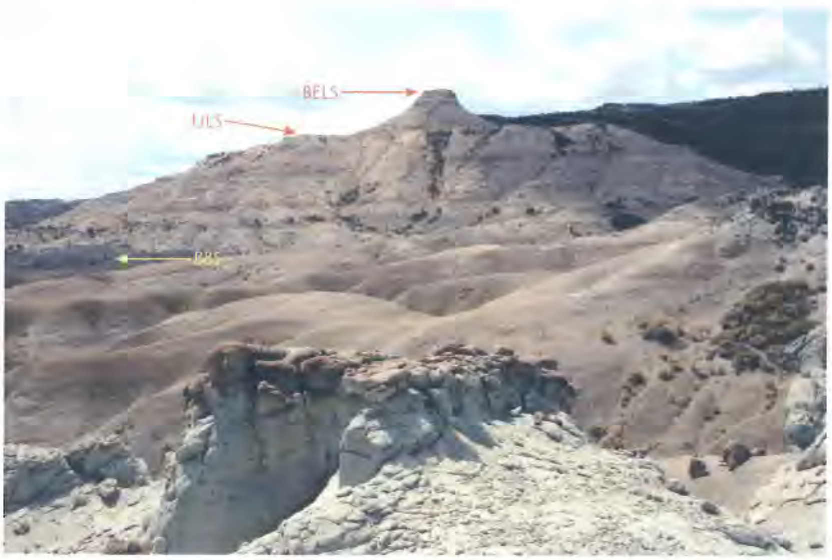


Figure 16. Blue sandstones exposed in the foreground and near the base of Old Hat Mountain, a butte on the east side of Hickey Mountain in Uinta County. Arrow shows approximate level of the base of the Basal blue sheet sandstone (BBS), located at the base of the pale blue-gray beds in this photo. The Upper white limestone (ULS) and Basal Bridger E limestone (BELS), which marks the base of the Turtle Bluff Member (TbE on Plate 1), are visible on Old Hat Mountain.

Figure 17. Type locality of the Hickey Reservoir limestone and view of the Basal blue sheet sandstone on the south side of Old Hat Mountain. Dashed line shows approximate position of Hickey Reservoir limestone (HRL) and arrow shows approximate base of the Basal blue sheet sandstone (BBS). The middle Bridger D lies between the Hickey Reservoir Limestone and the base of the Upper white limestone (ULS) at top of photo.

the Henrys Fork divide east, the blue sandstones becomes less prominent and the blue sandstone sheet which occurs at the base of the blue sandstone sequence in the Henrys Fork divide/Old Hat Mountain area is not present. Nevertheless, thin light blue pumiceous sandstone beds do persist at the same stratigraphic position. Because no blue sandstones occur in the middle D on Twin Buttes or Black Mountain, we interpolate the base of the middle D there at 38 m (125 feet) above the base of the Lonetree limestone, because that is the average level it occupies throughout most of the study area. In the west part of the study area to the east side of Cedar Mountain, this position ranges from 35 to 39 m (115 to 128 feet) above the base of the Lonetree limestone, although in most locations it is 37 to 38 m (121 to 125 feet) above the base.

At its type locality east of Hickey Mountain (UTM 568000 E; 4549380 N; Zone 12), the Basal blue sheet sandstone consists of three light bluish gray fine pumiceous sandstone sheets interbedded with two light bluish gray mudstone beds, with a combined thickness of 2.4 m (7.9 feet). With the addition of fine-grained blocky tan sandstone beds, this is lithologically similar to much of the middle Bridger D in the west part of the study area. Fossils are locally common within these blue sandstone beds, and early records indicate that many specimens of *Uintatherium* (Mammalia, Dinocerata) were collected from this interval in the area surrounding the Henrys

Fork divide (1903 field notes of W.D. Matthew, Frick Archives, AMNH). **Table 13** summarizes geologic data for the Basal blue sheet sandstone.

Upper Bridger D

In the west part of the study area, the upper Bridger D is a sequence of brown and tan mudstone and claystone beds. At Twin Buttes, it consists of brown mudstone beds with some green sandstone beds. Throughout the study area, the base of the upper D is marked by the Upper white limestone, the only marker unit within this interval. Elsewhere in the study area, a variable number of additional unnamed thin limestone beds, some fossiliferous, are present within the upper D. None of these are widespread enough to be considered markers, but one, which occurs only on Twin Buttes and Black Mountain, is particularly noteworthy. Ten meters (33 feet) above the Upper white limestone, the top of this dark bluish-gray, brown, and black cherty limestone contains bone fragments and locally abundant plant fragments including

Table 13. Data summary for the Basal blue sheet sandstone.

Unit name	Basal blue sheet sandstone
Abbreviation	BBS
Name derivation	Named for the base of a prominent interval of thick blue sheet sandstones best exposed east of Hickey Mountain and west of Cedar Mountain, near the type locality.
Previous work	Blue sands in general described in Matthew (1909) as "harder gray and greenish-gray sandy and clayey tuffs with one or more ash beds."
Type locality	NE¼NW¼SW¼NE¼ sec. 19, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 568000E, 4549380N (Zone 12); elevation 2,359 m (7,737 ft).
Map name	Type locality on Lonetree USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	At type locality and in west part of study area, consists of blocky, non-calcareous, light grayish-blue sheet sandstone (ms-vfs) locally interbedded with thin tan to light bluish-gray mudstone and muddy sandstone. Locally contains coarse pumice near top, and locally underlain in western area by Hickey Reservoir limestone and a thin brick-red claystone. Top contact distinct. On east side of Cedar Mountain, light bluish-gray locally pumiceous sandstones crop out at approximately the same stratigraphic position in a more limited geographic area, but are not sheet sandstones. Because of their similar stratigraphic position, however, we infer the bases of these outcrops to be equivalent to the bases of the blue sandstones in the west part of the study area (**Figure 16** and **Figure 17**).
Stratigraphic position	200 m (656 ft) above the base of the Sage Creek limestone in reference section (**Appendix 2**), forms base of middle Bridger D.
Distribution	Well-exposed on north and east sides of Hickey Mountain, the divide between Hickey Mountain and Sage Creek Mountain, the north side of Sage Creek Mountain, in the badlands northeast of Sage Creek Mountain, and on the south and southwest sides of Cedar Mountain in Uinta County. Less prominent blue sandstones are exposed at the same stratigraphic position on the northeast end of Cedar Mountain and on Mass Mountain in Sweetwater County. We infer that these are stratigraphically equivalent to the blue sandstones in the west part of the study area. The blue sandstones are not present on Twin Buttes or Black Mountain, so we infer the base of the middle Bridger D in these areas to be 38 m (125 ft) above the base of the LTLS.
Thicknesses	Thickness can be difficult to measure as bottom contact is undulatory and top contact is diffuse. 2.4 m (7.9 ft) at type locality; maximum of 3.2 m (10.5 ft) on northeast side of Sage Creek Mountain and 3.4 m (11.2 ft) on southwest side of Cedar Mountain; minimum of 1.3 m (4.3 ft) on southwest side of Sage Creek Mountain.
Fossils	Rare, but include occasional vertebrate bones and teeth.

stems and poorly preserved leaves, which are uncommon in the Bridger. It is poorly exposed and therefore was not named (**Appendix 1**, unit 132).

The Upper white limestone occurs high on the slopes of Hickey, Sage Creek, Cedar, and Black mountains, and Twin Buttes, where it forms a prominent ledge (**Figure 16**, **Figure 18**, **Figure 19**, and **Figure 20**). **Table 14** summarizes geologic data for this unit. In the west part of the study area, it is a blocky gray to white micritic limestone bed that locally contains chert nodules. It reaches its maximum thickness of 3.2 m (10.5 feet) on Twin Buttes, forms three distinct limestone ledges, and weathers to reddish brown. Fossils include mostly mollusks and aquatic vertebrates, with locally abundant terrestrial vertebrate remains in a thin, dark brown, overlying calcareous mudstone bed. Matthew (1909) originally named the Upper white limestone the Upper White Layer. However, because stratigraphically higher white limestones exist, the name "Upper White" is potentially misleading, and Evanoff and others (1998) replaced it with "Promontory limestone." Matthew's (1909) terminology is both well known and referenced in many Bridger fossil collections. Therefore, and for the sake of continuity, we retain the name "Upper White" in this report while noting that it is not the stratigraphically highest limestone.

Figure 18. View looking east to exposures of the Upper white limestone (ULS) at the top of the middle Bridger D (TbDm), the upper Bridger D (TbDu), and the Turtle Bluff Member (TbE = Bridger E) on the southwest side of Cedar Mountain. The base of the Turtle Bluff Member is the Basal Bridger E limestone (BELS). The Behunin Reservoir gypsum bed (BRGB) at the top of the Bridger E and the overlying Bishop Conglomerate (Tbi) are also shown.

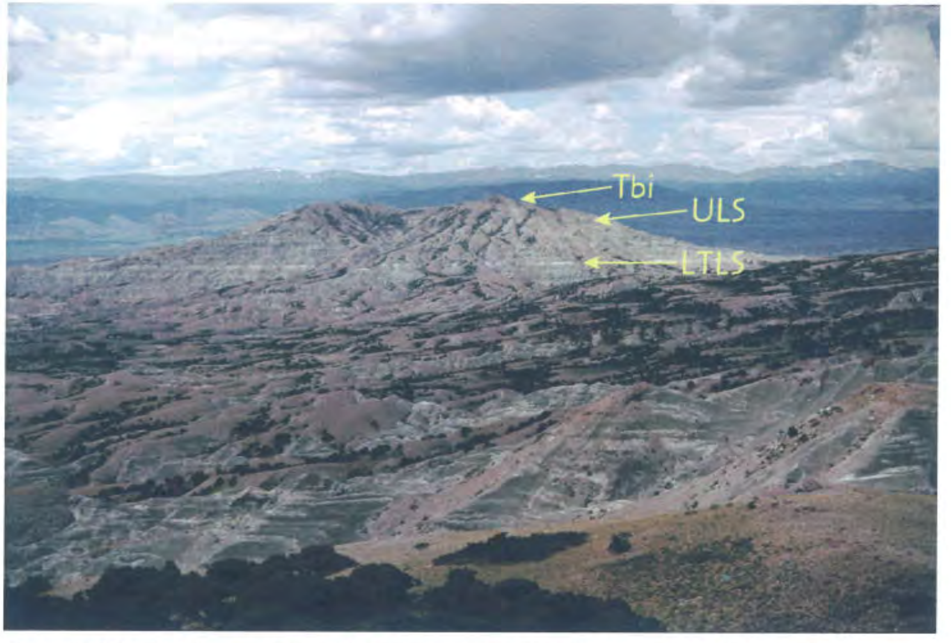


Figure 19. View looking south from Black Mountain to Twin Buttes with the Lonetree limestone (LTLS) and Upper white limestone (ULS) visible. Tops of both summits of Twin Buttes are capped by Oligocene Bishop Conglomerate (Tbi). Uinta mountains are on the horizon.

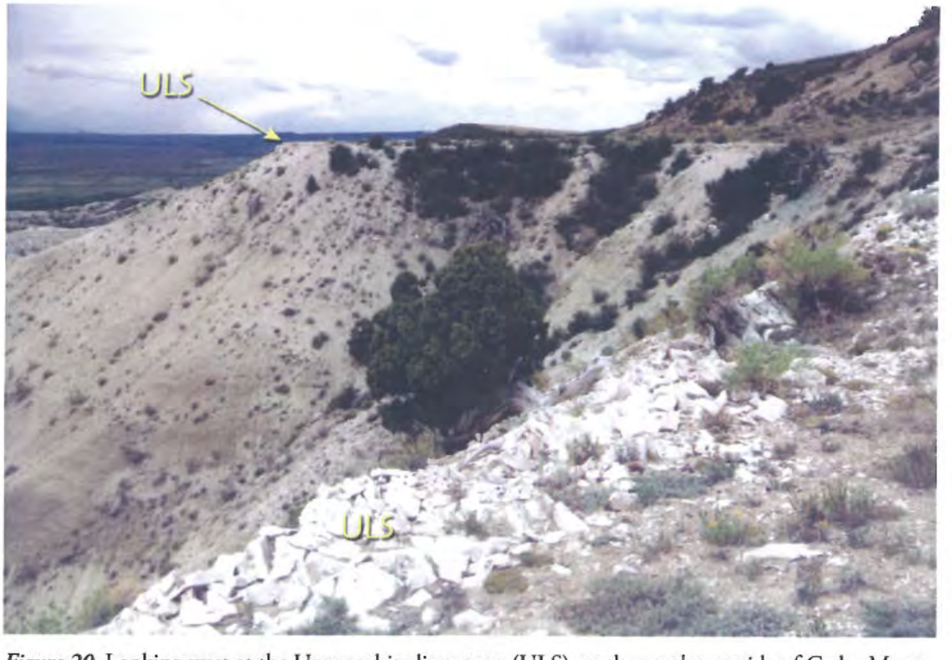


Figure 20. Looking west at the Upper white limestone (ULS) on the southwest side of Cedar Mountain, Uinta County, Wyoming.

Table 14. Data summary for the Upper white limestone.

Unit name	Upper white limestone
Abbreviation	ULS
Name derivation	Originally named "Upper White Layer" because it is a prominent ledge-forming limestone high in the Bridger sequence. It is not, however, the uppermost limestone in the Bridger Formation.
Previous work	Briefly described and named "Upper White Layer" by Matthew (1909). Discussed, described, and/or partially mapped by Osborn (1929), Bradley (1964), West (1976), Roehler (1992b), Dover and M'Gonigle (1993), Murphey (1995), and Evanoff et al. (1998). Renamed "Promontory limestone" by Evanoff et al. (1998). "Upper white limestone" is used in this report.
Type locality	On northeast corner of prominent ledge beneath summit of a butte called "Old Hat Mountain" by locals. NE¼NE¼SE¼NW¼ sec. 19, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 567820E, 4549380N (Zone 12); elevation 2,420 m (7,938 ft). Also, UCM fossil localities 94116 and 94117.
Map name	Type locality on Lonetree USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	Forms prominent ledge. At type locality and in west part of study area, consists of light tan to light grayish-brown and pinkish-white flaggy to blocky micritic limestone with occasional light gray to black chert nodules. Weathers to light brown or white ledge. On Twin Buttes and Black Mountain, the blocky limestone forms three distinct ledges interbedded with calcareous shales, and entire sequence weathers to a reddish-brown ledge (**Figure 16**, **Figure 18**, **Figure 19**, **Figure 20**).
Stratigraphic position	246 m (807 ft) above the base of the Sage Creek limestone in type section (**Appendix 1**); 260 m (853 ft) above the base of the Sage Creek limestone in reference section (**Appendix 2**); forms base of upper Bridger D.
Distribution	Exposed on the north, east, and southeast slopes of Hickey Mountain; the north and west slopes of Sage Creek Mountain; the south, east, and northeast slopes of Cedar Mountain; and around Black Mountain and Twin Buttes, Uinta and Sweetwater counties.
Thicknesses	0.4 m (1.3 ft) at type locality, which is the minimum known thickness; tends to vary between 0.4 and 1.1 m (1.3 and 3.6 ft) in the Hickey Mountain, Sage Creek Mountain, and Cedar Mountain area. Thickest on Black Mountain and Twin Buttes, where it measures 3.2 m (10.5 ft) thick.
Fossils	Local domed lenses of algal chert, abundant gastropods and occasional fragmentary aquatic vertebrate remains including fish and turtles, with scattered fragmentary terrestrial vertebrate remains near top. Terrestrial vertebrates are locally abundant in overlying dark brown calcareous mudstones.

Turtle Bluff Member

Matthew's uppermost informal subdivision of the Bridger Formation, the Bridger E, was renamed the Cedar Mountain Member by West and Hutchison (1981). Because the name Cedar Mountain had been previously used for the Lower Cretaceous Cedar Mountain Formation in Utah, however, the Cedar Mountain Member of the Bridger was renamed the Turtle Bluff Member by Evanoff and others (1998). They chose the name because: 1) the King Survey named Cedar Mountain Turtle Bluff; 2) a "Turtle Bluff" triangulation station is located in the SE¼NE¼NW¼NE¼ sec. 29, T. 13 N., R. 112 W.; and 3) the Turtle Bluff Member is thickest and best exposed at Cedar Mountain.

The base of the Bridger E was originally defined at the level of the lowest "banded tuff" (red bed). This definition was almost certainly established on Cedar Mountain, where the lowest red beds were reported at approximately 23 m (approximately 75 feet) above the Upper White Layer (Matthew, 1909). However, the Basal Bridger E limestone on Cedar Mountain, which occurs approximately at the level of the lowest red bed, actually lies 46 m (approximately 151 feet) above the base of the Upper white limestone. This 46-meter interval is significantly thicker than the 23 meters reported by Matthew (1909). Because the position of the lowest red beds in relation to the Upper white limestone is variable on Hickey, Sage Creek, and Cedar mountains, the use of a laterally extensive marker is preferable. In this report, we use a limestone that occurs at the approximate level of the lowest red beds on Hickey Mountain, Sage Creek Mountain, Cedar Mountain, and Twin Buttes to define the base of the Turtle Bluff Member (Bridger E).

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. By far the most extensive and thickest exposures of the Turtle Bluff Member occur on the southwest side of Cedar Mountain (**Figure 18**), but because of its high stratigraphic position and the topography of the study area, the member is restricted to the upper slopes below the Bishop Conglomerate on Hickey Mountain, Sage Creek Mountain, Black Mountain, and Twin Buttes. The type section for the Turtle Bluff Member on Cedar Mountain is a 131.5 m (431 foot)-thick sequence of reddish-brown and gray claystone beds with a high gypsum content (**Appendix 4**). This gypsum is both primary and secondary. Primary gypsum occurs in thin beds, but the Turtle Bluff Member on Cedar Mountain is capped by a thick and laterally extensive gypsum bed. Secondary gypsum consists of selenite and satin spar crystals, which are abundant on the upper slopes of Cedar Mountain. Based on their color, the mostly fine-grained reddish Turtle Bluff sediments were probably derived from the adjacent Uinta Mountains, unlike those sediments of the Bridger A through D, which, as will be discussed below, were largely derived from more distal volcanic sources. A distinctive lenticular pumiceous conglomerate bed containing charcoal, biotite, plagioclase, and sanidine, from a 2.3 m (7.5 foot)-thick sandstone bed 8 m (26 feet) below the base of the Turtle Bluff Member on Sage Creek Mountain, was dated at 46.16 ± 0.44 Ma (Murphey and others, 1999) (**Appendix 5**, unit 192). Similar tuffaceous rocks containing charcoal fragments and biotite crystals occur within fluvial sandstones in the upper Bridger D on Twin Buttes (**Appendix 1**, unit 148). Only 21 m (69 feet) of the Turtle Bluff Member remains on Twin Buttes; these rocks differ from the same interval to the west because they consist of tan and gray mudstone and claystone beds with low gypsum content.

The Turtle Bluff Member contains two markers: the Basal Bridger E limestone, which marks the base of the member (base of Matthew's Bridger E); and the Behunin Reservoir gypsum bed, which is the youngest and stratigraphically highest well-exposed rock unit in the Bridger Formation. On southwest Cedar Mountain, the Turtle Bluff Member contains four additional unnamed limestone beds (**Appendix 4**), and on Twin Buttes there are three (**Appendix 1**). A 2.3 m (7.5 foot)-thick laterally extensive quartz arenite bed that lies 75 m (246 feet) above the base of the member on Cedar Mountain is the only sandstone. Similar sandstones in the Turtle Bluff Member also occur on the northwest flanks of Hickey Mountain and Sage Creek Mountain.

The base of the Turtle Bluff Member is best defined by a pair of limestone beds (units 297 and 300, **Appendix 2**). The lower bed is called the Basal Bridger E limestone. **Table 15** summarizes geologic data for this unit. In the reference section on Old Hat Mountain, the Basal Bridger E limestone is a blocky 0.4 m (1.3 foot)-thick white limestone bed that is stratigraphically separated from the upper of the two limestone beds in the pair by 1.8 m (5.9 feet) of mudstone and claystone. This limestone couplet occurs at approximately the same stratigraphic position on Sage

Table 15. Data summary for the Basal Bridger E limestone.

Unit name	Basal Bridger E limestone
Abbreviation	BELS
Name derivation	Named for the fact that it occurs directly below the lowest red bed at the base of the Turtle Bluff Member (Bridger E) on Cedar Mountain, where the member is thickest and best exposed.
Previous work	Described and mapped by Dover and M'Gonigle (1993), who referred to is as "7 limestone."
Type locality	NW¼SW¼NW¼SE¼ sec. 24, T. 13 N, R. 113 W. (6th Principal Meridian); map UTM 576020E, 4548860N (Zone 12); elevation 2,401 m (7,875 ft).
Map name	Type locality on Burntfork USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	On Cedar Mountain, Sage Creek Mountain, and Twin Buttes, consists of blocky gray, yellowish-gray, or tan limestone which weathers to light gray or white, locally nodular and cherty (black).
Stratigraphic position	Defined as lower limestone in limestone couplet which occurs at approximately similar stratigraphic positions on Hickey, Sage Creek, and Cedar mountains, and on Twin Buttes. The upper and lower limestones are typically separated by 1 to 2 m (3.3 to 6.6 feet) of mudstone and/or claystone. Basal Bridger E limestone is 307 m (1,007 feet) above base of Sage Creek limestone in reference section (**Appendix 2**); 312 m (1,023 feet) above base of Sage Creek limestone (**Appendix 5**) on southwest flank of Sage Creek Mountain; and 310 m (1,017 feet) above base of Sage Creek limestone on southwest side of Cedar Mountain (**Appendices 3** and **4**), as extrapolated from the position of the Lonetree limestone in the reference section. On Twin Buttes, Basal Bridger E limestone is 297.5 m (976 feet) above the base of the Sage Creek limestone (**Appendix 1**). Matthew (1909) originally defined the base of the Bridger E as occurring approximately 75 feet (246 m) above the Upper White Layer; this study redefines the base as the lower limestone in the limestone couplet which is at about the level of the lowest red beds on the southwest side of Cedar Mountain (actually 46 m [151 feet] above the Upper white limestone).
Distribution	Intermittently exposed on the southwest side of Cedar Mountain near the type locality, and on Hickey Mountain, Sage Creek Mountain, Twin Buttes. Because the unit cannot be correlated directly from the west part of the study area east to Twin Buttes, and there are no red beds on Twin Buttes, we define the base of the Turtle Bluff Member (Bridger E) on Twin Buttes with caution.
Thicknesses	0.9 m (3.0 ft) at type locality; 0.4 m (1.3 ft) in reference section (**Appendix 2**); 0.4 m (1.3 ft) on the southwest side of Sage Creek Mountain; 0.3 m (1.0 ft) on the south end of Twin Buttes (**Appendix 1**).
Fossils	Scattered bone fragments, gastropods, and ostracods.

Creek Mountain, on the southwest side of Cedar Mountain, and on Twin Buttes. It is useful for defining the top of the upper Bridger D in the reference section and base of the Turtle Bluff Member (Bridger E) in the Turtle Bluff Member type section (**Appendix 4**), but caution should be exercised on Twin Buttes because its pair of limestone beds (units 142 and 144, **Appendix 1**) cannot be correlated directly with the Basal Bridger E limestone on Cedar, Sage Creek, and Hickey mountains. Furthermore, the Turtle Bluff Member in the west part of the study area is characterized by red beds that begin at approximately the same level as the Basal Bridger E limestone. With the exception of the relatively thin Horse Ranch red bed that occurs at its base within the Bridger C, there are no red beds on Twin Buttes, or on Black Mountain.

The Behunin (pronounced "buhannan" by locals) 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 just below the Bishop Conglomerate, the Behunin Reservoir gypsum bed consists of a 7 m (23 foot)-thick sequence of gray and tan unfossiliferous beds of gypsum interbedded with gypsiferous mudstones and marlstones, all visible as a prominent white bed high on Cedar Mountain (**Figure 18** and **Figure 21**). This unit was described by Dover and M'Gonigle (1993) as "light gray limestone (tuffa?) and marlstone." The top of the Behunin Reservoir gypsum bed is the highest marker unit in the Bridger Formation. **Table 16** summarizes geologic data for the Behunin Reservoir gypsum bed.

Bishop Conglomerate

The Bishop Conglomerate unconformably overlies the Bridger Formation. This unit, formerly known as the Wyoming Conglomerate (U.S. Geological and Geographic Survey of the Fortieth Parallel, 1867-1872), was first thought to be Pleistocene in age (Sinclair, 1906). It 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) (**Figure 22** and **Figure 23**). It is as much as 40 m (131 feet) thick (Dover and M'Gonigle, 1993). Though unfossiliferous, the Bishop Conglomerate is currently believed to be Oligocene in age (with a K/Ar date of 29.50 ± 1.08 Ma, biotite) based on isotopic ages obtained from a tuff that occurs within it on the south side of the Uinta Mountains (Hansen, 1986).

Correlations and thickness variations within the upper Bridger

We measured all stratigraphic sections from the base of the Sage Creek limestone or the base of the lowest exposed marker, and measured most to the top of the highest exposed marker or the top of the Bridger Formation (if present in the area). Steep terrain prevented measurements in some areas. **Table 17** through **Table 29** sum-

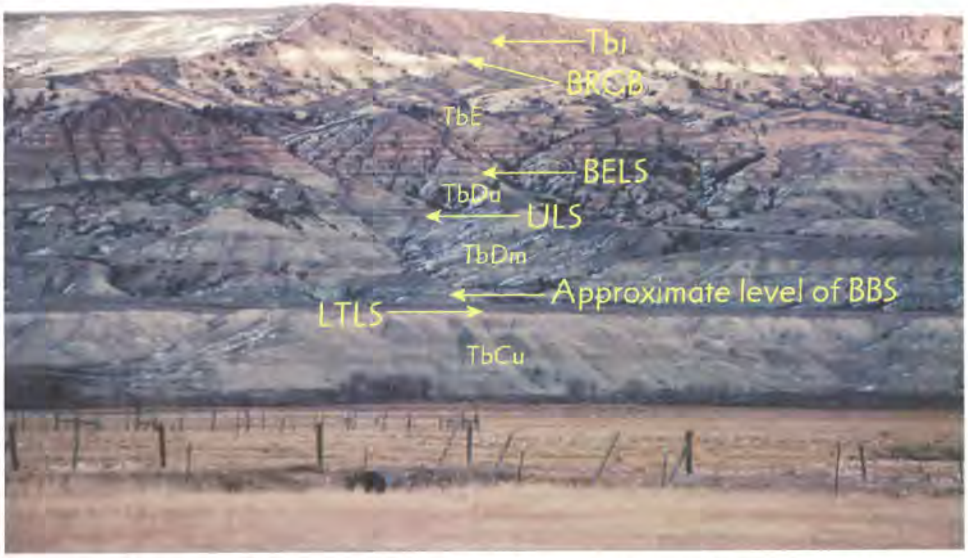


Figure 21. Behunin Reservoir gypsum bed (BRGB), which marks the top of the exposed Bridger Formation below the south rim of Cedar Mountain, Uinta County, Wyoming. The Bishop Conglomerate (Tbi) caps the top of Cedar Mountain. The base of the Basal Bridger E limestone (BELS) marks the base of the Bridger E, while the Lonetree limestone (LTLS) is the base of the Bridger D. The approximate positions of the Basal blue sheet sandstone (BBS) and the Upper white limestone (ULS) are also shown.

Table 16. Data summary for the Behunin Reservoir gypsum bed.

Unit name	Behunin Reservoir gypsum bed
Abbreviation	BRGB
Name derivation	Named for Behunin Reservoir, a small reservoir located approximately 3.6 km (2.24 miles) west-northwest of the type locality. Behunin is pronounced "buhanan" by locals.
Previous work	Described and mapped by Dover and M'Gonigle (1993), who referred to is as "8 Zone, limestone (tuffa?)."
Type locality	NW¼SW¼SW¼SW¼ sec. 20, T. 13 N, R. 112 W. (6th Principal Meridian); map UTM 577600E, 4548660N (Zone 12); elevation 2,554 m (8,377 ft).
Map name	Type locality on Burntfork USGS 7.5' Quadrangle Map, photorevised 1980.
Lithologies	Sequence of gray and tan gypsum beds interbedded with gypsiferous mudstone, claystone, and marlstone. Weathers to two prominent white bands near the summit of Cedar Mountain visible from the Henrys Fork valley to the south (**Figure 21**).
Stratigraphic position	418 m (1,371 feet) above the base of the Sage Creek limestone as extrapolated from the position of the Lonetree limestone in the reference section (**Appendix 2**) for the interval up to the Lonetree limestone, and using the section on the southwest side of Cedar Mountain (**Appendix 3**) and the Turtle Bluff Member type section (**Appendix 4**) for the interval above the Lonetree limestone.
Distribution	Intermittently exposed only on the southwest and south sides of Cedar Mountain, Uinta County.
Thicknesses	7 m (23 feet) at type locality; varies from 6 to 9 m (20 to 30 feet).
Fossils	None observed.

Figure 22. Outcrop of Bishop Conglomerate on the north side of Sage Creek Mountain. Lens cap left of center shows scale.

Figure 23. Massive pillars of Bishop Conglomerate on the southwest rim of Cedar Mountain. View looking northeast from State Highway 414.

Table 17. Positions of marker beds and stratigraphic intervals in the type section of the Twin Buttes Member and overlying Turtle Bluff Member on Twin Buttes (**Appendix 1**; measured section *f* on **Plate 1**). All stratigraphic positions are measured in meters to the base of the Sage Creek limestone. Major marker beds in bold; stratigraphic intervals and thicknesses in meters.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
TbE	**Base of Tbi** (15 m below top of Twin Buttes)	0		23.0
	unspecified lithologies	22.7		
	Basal Bridger E limestone	0.3	297.2	
upper D (TbDu)	unspecified lithologies	48.4		51.6
	Upper white limestone	3.2	245.6	
middle D (TbDm)	unspecified lithologies	66.2		66.2
	inferred level of Basal blue sheet sandstone	not present	179.4	
lower D (TbDl)	unspecified lithologies	37.3		38.0
	Lonetree limestone	0.7	141.4	
upper C (TbCu)	unspecified lithologies	48.5		49.6
	Henrys Fork tuff	1.1	91.8	
middle C (TbCm)	unspecified lithologies	23.2		56.4
	Burntfork limestone	0.3	68.3	
	unspecified lithologies	29.6		
	Soap Holes Limestone	3.3	35.4	
lower C (TbCl)	unspecified lithologies	34.5		35.4
	Sage Creek limestone*	0.9		
			TOTAL MEASURED THICKNESS	**320.2**

*Only top limestone ledge of Sage Creek limestone is exposed. Total thickness is unknown.

Table 18. Positions of marker beds and stratigraphic intervals in the reference section of the Twin Buttes Member of the Bridger Formation (**Appendix 2**; measured section *a* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds relative to the top of the Sage Creek limestone. Major marker beds in bold; stratigraphic intervals in meters.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
TbE	top of "Old Hat Mountain"	5.3		5.7
	Basal Bridger E limestone	0.4	302.85	
upper D (TbDu)	unspecified lithologies	44.2		46.7
	Upper white limestone	2.5	256.15	
middle D (TbDm)	unspecified lithologies	58.1		60.5
	Basal blue sheet sandstone	2.4	195.65	
lower D (TbDl)	level of Hickey Reservoir limestone	0.1	195.7	37.0
	unspecified lithologies	34.9		
	Lonetree limestone	2.0	158.75	
upper C (TbCu)	unspecified lithologies	40.3		41.5
	Henrys Fork limestone	0.15	118.3	
	unspecified lithologies	0.3		
	Henrys Fork tuff	0.7	117.3	
middle C (TbCm)	unspecified lithologies	42.5		53.3
	level of Hickey Mountain limestone	0.1	74.7	
	unspecified lithologies	9.7		
	Soap Holes Limestone	1.0	64.0	
lower C (TbCl)	unspecified lithologies	37.9		68.1
	Butcher Knife limestone	0.4	25.7	
	unspecified lithologies	3.9		
	Whisky Reservoir limestone	3.4	18.4	
	unspecified lithologies	18.4		
	Sage Creek limestone*	4.1		
			TOTAL MEASURED THICKNESS	**312.8**

Table 19. Positions of marker beds and stratigraphic intervals on the southwest side of Cedar Mountain (**Appendix 3**; measured section *d* on **Plate 1**), including the type section for the Turtle Bluff Member (**Appendix 4**; measured section *c* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds. Major marker beds in bold; stratigraphic intervals in meters.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
TbE	top of Bridger E on SW Cedar Mountain	3.4	(top 280.6)	130.7
	Behunin Reservoir gypsum bed	6.9	270.3	
	unspecified lithologies	118.4		
	Basal Bridger E limestone	2.0	149.9	
upper D (TbDu)	unspecified lithologies	42.9		44.0
	Upper white limestone	1.1	105.9	
middle D (TbDm)	unspecified lithologies	65.2		68.6
	Basal blue sheet sandstone	3.4	37.3	
lower D (TbDl)	unspecified lithologies	0.4		37.3
	Hickey Reservoir limestone	1.7	35.2	
	unspecified lithologies	34.2		
	Lonetree limestone*	1.0		
			TOTAL MEASURED THICKNESS	**280.6**

*Not exposed at location of section; projected from exposures to southwest.

Table 20. Positions of marker beds and stratigraphic intervals on the southwest side of Sage Creek Mountain (**Appendix 5**; measured section *b* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds. Major marker beds in bold; stratigraphic intervals in meters.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
TbE	top of SW flank Sage Creek Mountain	0.5		0.9
	Basal Bridger E limestone	0.4	195.15	
upper D (TbDu)	unspecified lithologies	52.7		53.3
	Upper white limestone	0.6	141.85	
middle D (TbDm)	unspecified lithologies	63.3		64.6
	Basal blue sheet sandstone	1.3	77.25	
lower D (TbDl)	unspecified lithologies	36.4		37.7
	Lonetree limestone	1.3	39.55	
upper C (TbCu)	unspecified lithologies	38.25		39.7
	Henrys Fork limestone*	0.15	1.3	
	unspecified lithologies	0.5		
	Henrys Fork tuff*	0.8		
			TOTAL MEASURED THICKNESS	**196.2**

*Because of poor exposures at base of section, thicknesses of Henrys Fork tuff and Henrys Fork limestone are inferred from good exposures 0.25 miles to the northwest (UCM L. 92180).

Table 21. Positions of marker beds and stratigraphic intervals on the southeast side of Cedar Mountain (**Appendix 6**; measured section *e* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds relative to the uppermost 4 m of the Sage Creek limestone. Major marker beds in bold; stratigraphic intervals in meters.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
middle D (TbDm)	**Basal blue sheet sandstone**	2.1	185.8	2.1
lower D (TbDl)	unspecified lithologies	37.4		38.0
	Lonetree limestone	0.6	147.8	
upper C (TbCu)	unspecified lithologies	43.8		49.1
	Henrys Fork limestone	0.7	103.3	
	unspecified lithologies	4.0		
	Henrys Fork tuff	0.6	98.7	
middle C (TbCm)	unspecified lithologies	25.9		51.4
	Burntfork limestone	1.5	71.3	
	unspecified lithologies	23.6		
	Soap Holes limestone	0.4	47.3	
lower C (TbCl)	unspecified lithologies	43.3		47.3
	Sage Creek limestone*	4.0		
			TOTAL MEASURED THICKNESS	**187.9**

*Base of Sage Creek limestone is covered, total thickness is unknown, but is at least 30 m. Measured section includes only uppermost 4 m of the unit.

Table 22. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the northeast side of Hickey Mountain (measured section *g* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
upper D (TbDu)	unspecified lithologies	–		–
	Upper white limestone	0.5	196.5	
middle D (TbDm)	unspecified lithologies	59.7		62.6
	Basal blue sheet sandstone	2.9	133.9	
lower D (TbDl)	unspecified lithologies	38.3		38.7
	Lonetree limestone	0.4	95.2	
upper C (TbCu)	unspecified lithologies	43.4		45.0
	Henrys Fork limestone	0.1	51.7	
	unspecified lithologies	0.8		
	Henrys Fork tuff	0.7	50.2	
middle C (TbCm)	unspecified lithologies	39.7		50.2
	Hickey Mountain limestone	0.1	10.4	
	unspecified lithologies	10.0		
	Soap Holes limestone	0.4		
			TOTAL MEASURED THICKNESS	**197.0**

Table 23. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the northeast side of Sage Creek Mountain (measured section *h* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
middle D (TbDm)	unspecified lithologies	–		–
	Basal blue sheet sandstone	3.2	138.7	
lower D (TbDl)	unspecified lithologies	38.8		39.3
	Lonetree limestone	0.5	99.4	
upper C (TbCu)	unspecified lithologies	46.9		48.4
	Henrys Fork limestone	0.1	52.5	
	unspecified lithologies	0.4		
	Henrys Fork tuff	1.0	51.1	
middle C (TbCm)	unspecified lithologies	50.7		51.1
	Soap Holes limestone	0.4		
			TOTAL MEASURED THICKNESS	**142.0**

Table 24. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the north side of Cedar Mountain (measured section *j* on **Plate 1**). All stratigraphic positions are measured in meters relative to the bases of marker beds relative to the top ledge of the Sage Creek limestone, because the base of the unit is covered. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
lower D (TbDl)	unspecified lithologies	–		–
	Lonetree limestone	0.4	157.9	
upper C (TbCu)	unspecified lithologies	44.1		44.9
	Henrys Fork tuff	0.8	113.0	
middle C (TbCm)	unspecified lithologies	47.6		48.2
	Soap Holes limestone	0.6	64.8	
lower C (TbCl)	unspecified lithologies	42.5		67.1
	Butcher Knife limestone	0.2	22.1	
	unspecified lithologies	3.0		
	Whisky Reservoir limestone	1.1	18.0	
	unspecified lithologies	18.0		
	Sage Creek limestone	2.3		
			TOTAL MEASURED THICKNESS	**160.6**

Table 25. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the south side of Cedar Mountain (measured section *i* on **Plate 1**). All stratigraphic positions are measured in meters relative to the bases of marker beds. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
middle D (TbDm)	unspecified lithologies	–		–
	Basal blue sheet sandstone	2.4	141.9	
lower D (TbDl)	unspecified lithologies	38.8		39.1
	Lonetree limestone	0.3	102.8	
upper C (TbCu)	unspecified lithologies	46.4		50.8
	Henrys Fork limestone	0.7	55.7	
	unspecified lithologies	1.5		
	Henrys Fork tuff	2.2	52.0	
middle C (TbCm)	unspecified lithologies	27.8		52.0
	Burntfork limestone	0.3	23.9	
	unspecified lithologies	23.6		
	Soap Holes limestone	0.3		
			TOTAL MEASURED THICKNESS	**144.3**

Table 26. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the northeast side of Mass Mountain (measured section *l* on **Plate 1**). All stratigraphic positions are measured in meters relative to the bases of marker beds relative to the uppermost ledge of the Sage Creek limestone. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
upper D (TbDu)	unspecified lithologies	–		–
	Upper white limestone	0.9	246.6	
middle D (TbDm)	unspecified lithologies	67.6		69.4
	Basal blue sheet sandstone	1.8	177.2	
lower D (TbDl)	unspecified lithologies	34.0		35.0
	Lonetree limestone	1.0	142.2	
upper C (TbCu)	unspecified lithologies	45.3		46.1
	Henrys Fork tuff	0.8	96.1	
middle C (TbCm)	unspecified lithologies	30.6		50.0
	Horse Ranch red ned	4.4	61.1	
	unspecified lithologies	14.7		
	Soap Holes limestone	0.3	46.1	
lower C (TbCl)	unspecified lithologies	45.1		46.1
	Sage Creek limestone*	1.0		
			TOTAL MEASURED THICKNESS	**247.5**

*Only top limestone ledge of Sage Creek limestone is exposed. Total thickness is unknown.

Table 27. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the northeast end of Cedar Mountain (measured section *k* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds relative to the uppermost limestone ledge of the Sage Creek limestone. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
middle D (TbDm)	unspecified lithologies	–		–
	Basal blue sheet sandstone	2.0	178.6	
lower D (TbDl)	unspecified lithologies	35.8		37.0
	Lonetree limestone	1.2	141.6	
upper C (TbCu)	unspecified lithologies	44.5		45.3
	Henrys Fork tuff	0.8	96.3	
middle C (TbCm)	unspecified lithologies	48.5		48.8
	Soap Holes limestone	0.3	47.5	
lower C (TbCl)	unspecified lithologies	46.5		47.5
	Sage Creek limestone*	1.0		
			TOTAL MEASURED THICKNESS	**180.6**

*Only top limestone ledge of Sage Creek limestone is exposed. Total thickness is unknown.

Table 28. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the northwest side of Twin Buttes (measured section *n* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds relative to the uppermost limestone ledge of the Sage Creek limestone. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
upper D (TbDu)	unspecified lithologies	–		–
	Upper white limestone	1.4	243.4	
middle D (TbDm)	unspecified lithologies	67.6		67.6
	inferred level of the Basal blue sheet sandstone	not present	175.8	
lower D (TbDl)	unspecified lithologies	35.1		37.0
	Lonetree limestone	1.9	138.8	
upper C (TbCu)	unspecified lithologies	47.6		48.4
	Henrys Fork tuff	0.8	90.4	
middle C (TbCm)	unspecified lithologies	25.1		44.9
	Horse Ranch red bed	3.3	62.0	
	unspecified lithologies	16.2		
	Soap Holes limestone	0.3	45.5	
lower C (TbCl)	unspecified lithologies	44.5		45.5
	Sage Creek limestone*	1.0		
			TOTAL MEASURED THICKNESS	**244.8**

*Only top limestone ledge of Sage Creek limestone is exposed. Total thickness is unknown.

Table 29. Positions of marker beds and stratigraphic intervals in the upper Bridger Formation on the northwest side of Black Mountain (measured section *m* on **Plate 1**). All stratigraphic positions are measured in meters to the bases of marker beds relative to the uppermost limestone ledge of the Sage Creek limestone. Major marker beds in bold; stratigraphic intervals in meters; dash indicates not measured or calculated.

Map unit	Marker bed or stratigraphic interval	Interval thickness	Stratigraphic position	Map unit thickness
upper D (TbDu)	unspecified lithologies	–		–
	Upper white limestone	1.1	242.0	
middle D (TbDm)	unspecified lithologies	66.5		66.5
	inferred level of the Basal blue sheet sandstone	not present	175.5	
lower D (TbDl)	unspecified lithologies	36.8		37.0
	Lonetree limestone	0.2	138.5	
upper C (TbCu)	unspecified lithologies	42.5		43.2
	Henrys Fork tuff	0.7	95.3	
middle C (TbCm)	unspecified lithologies	27.2		48.3
	Horse Ranch red bed	3.0	65.1	
	unspecified lithologies	16.8		
	Soap Holes limestone	1.3	47.0	
lower C (TbCl)	unspecified lithologies	45.6		47.0
	Sage Creek limestone*	1.4		
			TOTAL MEASURED THICKNESS	**243.1**

*Only top limestone ledge of Sage Creek limestone is exposed. Total thickness is unknown.

marize thickness data from each of the 14 stratigraphic sections. Thicknesses of each marker unit and the intervening rocks, as well as thicknesses of the upper Bridger stratigraphic subdivisions at each measured section, are listed on these tables. The bottom contacts of the major markers, shown in bold on the tables, form the bases of each subdivision. The tables show the positions of upper Bridger marker units relative to the base of the Sage Creek limestone, or the base of the lowest marker unit exposed at each location. In some areas, only a thin upper ledge of Sage Creek limestone is exposed, and the total thickness of the unit is unknown. For these sections, we used the base of the highest exposed ledge. **Table 1** gives the locations of measured sections.

Upper Bridger marker units display a wide degree of variation in lateral continuity. Averaging 0.8 m (2.6 feet) thick but ranging from 0.15 m to 2.2 m (0.5 to 7.2 feet) thick, the Henrys Fork tuff has the most consistent thickness of the major markers, and was the most distinct marker used for this study as discussed above. The Basal blue sheet sandstone is the most problematic marker because it does not occur on Twin Buttes or Black Mountain, and its upper and lower contacts elsewhere in the study area are difficult to identify precisely. As defined in this report, this unit ranges from 1.3 m to 3.4 m (4.3 to 11.2 feet) thick and averages 2.3 m (7.5 feet) thick (average of nine localities measured). With the exception of the much thicker Sage Creek limestone, the limestone markers vary from 0.3 to 3.2 m (1.0 to 10.5 feet) thick and average 0.8 m (2.6 feet) thick. The most prominent and widespread of these are the Henrys Fork, Lonetree, and Upper white limestones.

The Sage Creek limestone exhibits the greatest thickness variation of all upper Bridger limestones, but at many locations within the study area, only an isolated ledge or partial sequence of the strata that make up the unit is exposed. This results primarily from erosion or colluvial cover, and makes accurate thickness measurements difficult. At the type locality for this unit, the entire 4.1 m (13.5 feet) thickness is exposed because underlying fluvial rocks at and to the north of the type locality along the east bank of Sage Creek are visible. Although there are areas north of Sage Creek, Cedar, and Black mountains where only the top ledge of the unit is exposed, there are also locations in the northern part of the study area where the full thickness of the Sage Creek limestone depositional package appears to be exposed. At these locations, complete thicknesses vary from 1 to 3 m (3.3 to 10 feet) and suggest that the Sage Creek limestone thins to the north from the thickest known outcrops in the Henrys Fork valley. At the McKinnon road-cut and along the Henrys Fork valley, the full thickness of the Sage Creek limestone and underlying lacustrine sequence is not known because the base of the lacustrine depositional sequence is not exposed, but it is at least 30 m (98 feet) thick. The upper blocky limestone at the McKinnon road-cut correlates with the blocky limestone at the type locality (see **Figure 8** and **Figure 9**) because it supports a widespread bench that can be traced to the north of Cedar Mountain, around the east and south sides of Black Mountain and Twin Buttes, and then west into the Henrys Fork valley.

Lithologically, the limestone and shale sequence exposed at the McKinnon road cut more closely resembles rocks of the lacustrine Green River Formation rather than those of the dominantly fluvial Bridger Formation. This resemblance and its stratigraphic significance was first noted by Matthew (1909, p. 297), who described the Bridger C along the Henrys Fork valley near McKinnon as "resting upon thin bedded lignitic shales which might be regarded as equivalent in age to the Green River or to Green River and Lower Bridger, but have no correspondence to the typical development of the lower (Bridger) horizons." Bradley (1964) and Roehler (1992a through c, 1993) also studied the stratigraphic relations between the Green River and Bridger Formations. Bradley reported, "nearly everywhere the base of the Bridger is uncertain because it grades downward into the Laney Shale Member of the Green River Formation." He went on to state that the lithologic gradation between the two formations takes place as extensive interfingering, and that the thickest part of the Green River Formation in the center of the basin grades laterally outward into successively lower units of the Bridger Formation. Roehler (1993) agreed with these observations. Brand (2002) observed that many Bridger limestone beds are actually temporal extensions of Lake Gosiute (Green River Formation). The Sage Creek limestone and underlying lacustrine sequence along the Henrys Fork valley appear to represent a relatively late and widespread tongue of the Laney Member of the Green River Formation based on lithological similarities and the much greater thickness of the lacustrine sequence along the Henrys Fork valley compared to the typically thin Bridger lacustrine intervals.

The thicknesses of most upper Bridger stratigraphic subdivisions are extremely consistent across the entire study area (**Table 30**). Thicknesses of the upper, middle,

Table 30. Summary of thicknesses in meters (footage equivalents in parentheses) of stratigraphic subdivisions of the upper Bridger Formation, Uinta and Sweetwater counties.

Stratigraphic Subdivision	**Measured Section**												
	NE Hickey Mountain	*Twin Buttes Member Reference Section*	*SW Sage Creek Mountain*	*SW Cedar Mountain and Turtle Bluff Member Type Section*	*NE Sage Creek Mountain*	*N Cedar Mountain*	*S Cedar Mountain*	*SE Cedar Mountain*	*NE Mass Mountain*	*NE Cedar Mountain*	*NW Twin Buttes*	*NW Black Mountain*	*Twin Buttes Member Type Section*
Bridger E (BELS-top of Fm.)	-	5.7 (19)	0.9 (3)	130.7 (429)	-	-	-	-	-	-	-	-	23.0 (75)
Upper D (ULS-BELS)	-	46.7 (153)	53.3 (175)	44.0 (144)	-	-	-	-	-	-	-	-	51.6 (169)
Middle D (BBS-ULS)	62.6 (205)	60.5 (198)	64.6 (212)	68.6 (225)	-	-	-	-	69.4 (228)	-	67.6 (222)	66.5 (218)	66.2 (217)
Lower D (LTLS-BBS)	38.7 (127)	37.0 (121)	37.7 (124)	37.3 (122)	39.3 (129)	-	39.1 (128)	38.0 (125)	35.0 (115)	37.0 (121)	[1]37.0 (121)	[1]37.0 (121)	[1]38.0 (121)
Total Bridger D	-	144.2 (472)	155.6 (511)	149.9 (491)	-	-	-	-	-	-	-	-	155.8 (511)
Upper C (HFT-LTLS)	45.0 (148)	41.5 (136)	39.7 (130)	-	48.4 (159)	44.9 (147)	50.8 (167)	49.1 (161)	46.1 (151)	45.3 (149)	48.4 (159)	43.2 (142)	49.6 (163)
Middle C (SHLS-HFT)	50.2 (165)	53.3 (175)	-	-	51.1 (168)	48.2 (158)	52.0 (171)	51.4 (169)	50.0 (164)	48.8 (160)	44.9 (147)	48.3 (158)	56.4 (185)
Lower C (top SCLS-SHLS)	-	[2]64.0 (210)	-	-	-	[2]64.0 (210)	-	[2]43.3 (142)	[2]45.1 (148)	[2]46.5 (153)	[2]44.5 (146)	[2]45.6 (150)	[2]35.4 (113)
Total Bridger C	-	158.8 (521)	-	-	-	157.1 (515)	-	143.8 (472)	141.2 (463)	140.6 (462)	137.8 (452)	137.1 (450)	140.5 (461)
Total Bridger C + D	-	303 (993)	-	-	-	-	-	-	-	-	-	-	296.3 (972)
Total Bridger C + D + E	-	308.7 (1,012)	-	-	-	-	-	-	-	-	-	-	319.3 (1,047)

Sections are arranged approximately west (left) to east (right). Abbreviations for marker units are as follows: BELS, Basal Bridger E limestone; ULS, Upper white limestone; BBS, Basal blue sheet sandstone; LTLS, Lonetree limestone; HFT, Henrys Fork tuff; SHLS, Soap Holes limestone; and SCLS, Sage Creek limestone.

[1]Position of BBS on Black Mountain and Twin Buttes is inferred as the unit is not present there.

[2]Thickness of SCLS is not added to thicknesses listed for Lower C because its base is covered in some of the measured sections.

and lower D, and the upper and middle C typically vary by less than 3 m (10 feet). Thickness of the Turtle Bluff Member (Bridger E), however, does vary. The apparent dramatic thickness differences of this member between the Twin Buttes Member type section, the Turtle Bluff Member type section, and the Twin Buttes Member reference section reflect erosion prior to the deposition of the Bishop Conglomerate. By far, the thickest sequence occurs on the southwest side of Cedar Mountain.

With the exception of the Turtle Bluff Member, the most significant depositional thickness change within the upper Bridger occurs within the lower Bridger C, which thins from 64 m (210 feet) along Sage Creek in the west part of the study area to 43 m (141 feet) on Twin Buttes in the east part (**Table 30**), a difference of 21 m (69 feet). Most of this thinning occurs on the east half of Cedar Mountain (**Figure 24**). Historically, the correlation of the upper Bridger in the west and central parts of the study area to Twin Buttes in the east has been problematic because limestones at Twin Buttes do not occur at predicted stratigraphic positions relative to the Sage Creek limestone (Koenig, 1960; West, 1976; Wood, 1934). This is further complicated because the Sage Creek limestone is the only upper Bridger marker continuously exposed from Cedar Mountain to Twin Buttes, and because the other Bridger limestones exhibit lateral facies-related lithology changes across the basin.

Because of its distinctive lithology and mineralogy, the Henrys Fork tuff was identified on the southwest side of Black Mountain, enabling the first reliable stratigraphic correlation between Twin Buttes and Cedar Mountain. Its base also represents the most isochronous event horizon in the upper Bridger, making it particularly important and valuable as a stratigraphic datum. Using the base of the Henrys Fork tuff as a datum, the reason for the difficulties in correlating across the basin reported by previous workers becomes clear. The lower Bridger C (bounded by the Soap Holes and Sage Creek limestones) thins significantly towards the east. The Soap Holes limestone can be recognized on Twin Buttes because of its position relative to the Henrys Fork tuff and the Burnt Fork limestone, and because of its lithology. If the Sage Creek limestone is used as the datum, as it has been by previous workers (Koenig, 1960; West, 1976; Wood, 1934), the positions between the marker units on Twin Buttes and Black Mountain are approximately 20 m (66 feet) lower than in the west part of the study area. When the Henrys Fork tuff is used as a datum, the positions of the markers are closely aligned (**Figure 24**).

The existence of all of the markers, except for the Basal blue sheet sandstone on Twin Buttes and Black Mountain, permits correlation with the west part of the study area (Cedar Mountain, Sage Creek Mountain, and Hickey Mountain) (**Figure 24**). The Basal blue sheet sandstone forms the base of the middle Bridger D in the west part of the study area. The position of the base of this unit relative to the base of the underlying Lonetree limestone is consistent throughout most of the study area, rang-

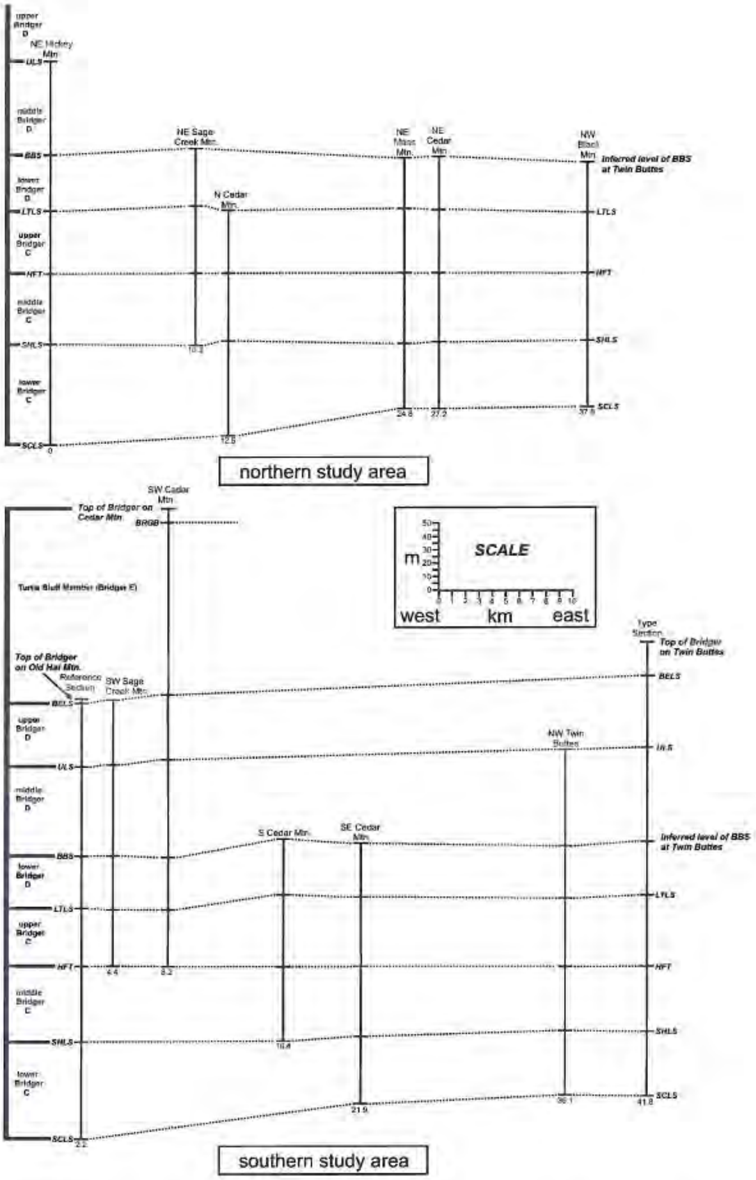


Figure 24. Stratigraphic correlation of the upper Bridger Formation across the study area using the base of the Henrys Fork tuff as a datum. Numbers below each measured section represent distance to the east from the westernmost measured section on the northeast flank of Hickey Mountain. Vertical exaggeration is 100x. Abbreviations for marker units are: SCLS, Sage Creek limestone; SHLS, Soap Holes limestone; HFT, Henrys Fork tuff; LTLS, Lonetree limestone; BBS, Basal blue sheet sandstone; ULS, Upper white limestone; BELS, Basal Bridger E limestone (base of Turtle Bluff Member); and BRGB, Behunin Reservoir gypsum bed.

ing between 35.0 and 39.3 m (115 to 129 feet) (**Table 30**). Furthermore, because the thickness of the interval between the Lonetree limestone and the Upper white limestone is approximately the same as it is farther west, there is no reason to suspect that sedimentation rates on Twin Buttes were significantly different from rates in the west part of the study area during the time of deposition. The average thickness between the Lonetree limestone and the base of the blue sandstone is 37.7 m (123.7 feet), which is rounded up to 38 m (125 feet) to approximate the temporal base of the middle D on Twin Buttes and Black Mountain.

Previously published thicknesses of the Bridger Formation differ from those obtained during this study. Matthew (1909, p. 296) reported that the upper Bridger was 351 m (1,151 feet) thick. His total for the entire formation, presumably calculated in the west part of the study area based on its proximity to most of his fossil localities, was 549 m (1,801 feet). Bradley (1964, p. A53) reported a thickness of 475 m (1,558 feet) at Twin Buttes and 696 m (2,283 feet) in the west part of the study area, a difference of approximately 221 m (725 feet). He added, "the 725 feet of westward thickening replaces an equal part of the Laney Shale Member of the Green River Formation in the vicinity of Twin Buttes." Roehler (1993, p. F65) reported a total thickness of 642 m (2,106 feet), with the lower Bridger measured to the northeast of Black Mountain and the upper Bridger on its southwest side (just north of Twin Buttes). This is 167 m (548 feet) thicker than Bradley's measurement for the same area.

The results of this study indicate that the thickest upper Bridger sequence occurs in the west part of the study area, where it measures 441 m (1,446 feet) from the base of the Sage Creek Limestone (reference section, **Appendix 2**) to the top of the Turtle Bluff Member on the southwest side of Cedar Mountain (**Appendix 4**). At Twin Buttes, because the lower Bridger C and Turtle Bluff Member are so much thinner than they are in the west, the upper Bridger is only 320 m (1,050 feet) thick (type section, **Appendix 1**). Because we did not measure the thickness of the lower Bridger during this study, we added a measurement of the Bridger B (233.5 m = 766 feet) reported by Evanoff and others (1998) and a measurement of the Bridger A (168 m = 551 feet) reported by McGrew and Sullivan (1970) to the thickness of the Twin Buttes and Turtle Bluff Members reported here to obtain a total. The total thickness for the upper Bridger in the west part of the study area, combined with the Bridger B from near the town of Lyman and the Bridger A from near the town of Opal, is 842.5 m (2,763 feet). This is 146.5 m (481 feet) thicker than Bradley's (1964) figure of 696 m (2,283 feet).

The final consideration of the thickness of the upper Bridger concerns the Oligocene Bishop Conglomerate, which unconformably overlies the upper Bridger Formation. In the study area, the Bishop Conglomerate caps Hickey Mountain, Sage Creek

Mountain, Cedar Mountain, Black Mountain, and Twin Buttes. It also caps pediments, isolated benches, and portions of the Rock Springs uplift along the north flank of the Uinta Mountains throughout the southern Green River Basin. The top of the Bridger Formation is truncated by the Bishop Conglomerate, so the original thickness of the Bridger is unknown. The base of the Bishop is an erosional surface, topographically highest closest to the Uinta Mountains. Both the contact between the Bishop Conglomerate and Bridger Formation and the surface formed by the top of the Bishop dip north toward the basin center, cutting into the Turtle Bluff Member and lower into the upper Bridger D on the northeast end of Cedar Mountain and the north half of Black Mountain. Thicknesses of the Bishop Conglomerate in the south part of the Green River Basin commonly measure more than 40 m (131 feet) (Dover and M'Gonigle, 1993), and the unit thins to the north until it is eroded away approximately 56 km (35 miles) north of the Uinta Mountain front. We measured a maximum thickness of 50 m (164 feet) on the south side of Cedar Mountain during this study.

Structural Geology

The Bridger Formation consists of essentially horizontal strata with gentle, mostly northeast dips of 1°-3° (**Table 31** and **Plate 1**). Since deposition, Bridger rocks have been only minimally modified by differential basin subsidence, local slumping, and rare faulting. We observed three such faults, all of which are high-angle normal faults showing dip slip, during this study. The Soap Holes limestone is faulted with a displacement of 2 m (7 feet) in the SW¼ sec. 32, T. 14 N., R. 113 W. This fault extends from just east of Wyoming State Highway 414 to the west flank of Sage Creek Mountain. The same unit is faulted with a displacement of 5 m (16 feet) in the SE¼NE¼ sec. 16, T. 14 N., R. 112 W., north of Cedar Mountain. Also north of Cedar Mountain, the Whisky Reservoir limestone is faulted with a displacement of 3.2 m (10.5 feet) in the SW¼SW¼ sec. 28, T. 15 N., R. 112 W. Because these faults are poorly exposed, have relatively minor displacements, and have little effect on the structure, they were not shown on **Plate 1**.

The Moxa arch (**Figure 2**) is a subtle anticline visible as a slight dome on the horizon looking north from Sage Creek Mountain. This structure trends through the upper Bridger with a north-northeast axis that runs between Hickey Mountain and Sage Creek Mountain. According to Royse (1993), the last major movement on the arch occurred during the Maestrichtian (latest Cretaceous), with later episodes of minor movement during the Paleocene and early Eocene. Based on distributions of at least two limestone markers, it is possible that movement along this arch occurred as late as the time of deposition of the upper Bridger. Evidence for these later movements includes both limestone distributions and lateral thickness variations observed in the Bridger C and D. For example, the east margin of the lake in which the Hickey Mountain limestone was deposited occurs at the approximate location of the axis of the Moxa arch. The Henrys Fork limestone thins over the arch, and its west margin occurs at the axis of the arch (Murphey, 1995). Lateral thickness variations of subunits in the Bridger C and D across the arch suggest subtle contemporaneous movements as late as the deposition of the Bridger D (**Figure 24**, SW Cedar Mountain section to SE Cedar Mountain section).

Distributions and thicknesses of upper Bridger limestones are also useful for interpreting basin architecture. The most numerous and thickest limestone beds occur on the south and southwest sides of Cedar Mountain in the southernmost part of the basin. The Sage Creek and Henrys Fork limestones are two examples. At the McKinnon road-cut (**Figure 9**), the Sage Creek limestone is underlain by a sequence of interbedded limestone beds, calcareous shale beds, carbonaceous shale beds, and mudstone beds which measures at least 30 m (98 feet) thick. The persistence of Green River Formation-type lithologies below the Sage Creek limestone may reflect the continued center of basin subsidence in the McKinnon area. The Henrys Fork limestone is thickest 3 km (1.8 miles) west of this area (Murphey, 1995). Its pattern of lateral thickness variation and distribution, as well as those of other named and unnamed limestones, indicates that the center of the depositional basin during upper Bridger time was an elongate trough located along the Uinta

Table 31. Strikes and dips of marker beds in the upper Bridger Formation.

Marker unit	Location	Strike and dip
Basal Bridger E limestone (SW Cedar Mountain)	NE¼NW¼SE¼SE¼ sec. 24, T. 13 N., R. 113 W.	N74°E, dip to NW at 1°
Upper white limestone (S Black Mountain)	SW¼SE¼SW¼NE¼ sec. 36, T. 14 N., R. 110 W.	N62°W, dip to NE at 1.5°
Upper white limestone (SW Cedar Mountain)	Center SE¼NE¼SW¼ sec. 24, T. 13 N., R. 113 W.	N24°W, dip to NE at 3°
Lonetree limestone (NW Black Mountain)	NE¼NW¼NE¼NE¼ sec. 20, T. 14 N., R. 109 W.	N35°W, dip to NE at 1°
Lonetree limestone (SW Sage Creek Mountain)	SE¼SE¼SW¼NE¼ sec. 20, T. 13 N., R. 113 W.	N30°W, dip to NE at 1°
Lonetree limestone (SW Cedar Mountain)	Center SE¼NE¼ sec. 26, T. 13 N., R. 113 W.	N40°W, dip to NE at 1°
Henrys Fork limestone (S Cedar Mountain)	NE¼NE¼SW¼SW¼ sec. 5, T. 13 N., R. 112 W.	N42°W, dip to NE at 1°
Henrys Fork tuff (S Cedar Mountain)	SE¼NW¼SE¼SE¼ sec. 36, T. 13 N., R. 113 W.	N15°W, dip to NE at 1.5°
Henrys Fork tuff (SW Sage Creek Mountain)	NE¼NW¼NW¼SE¼ sec. 9, T. 13 N., R. 113 W.	N84°E, dip to NW at 1°
Burntfork limestone (SE Twin Buttes)	NW¼SW¼SE¼SE¼ sec. 7, T. 13 N., R. 109 W.	N60°W, dip to NE at 1°
Hickey Mountain limestone (N Hickey Mountain)	NW¼NW¼NE¼NE¼ sec. 12, T. 13 N., R. 114 W.	N10°W, dip to NE at 1°
Soap Holes limestone (SW Twin Buttes)	NE¼NW¼NW¼NE¼ sec. 14, T. 13 N., R. 110 W.	S55°E, dip to SW at 1.5°
Soap Holes limestone (N Cedar Mountain)	Center SW¼SW¼NE¼ sec. 16, T. 14 N., R. 112 W.	N55°W, dip to NE at 2°
Soap Holes limestone (NW Sage Creek Mountain)	NW¼NW¼NE¼NW¼ sec. 28, T. 14 N., R. 113 W.	N80°E, dip to SE at 1.5°
Sage Creek limestone (E Twin Buttes)	NW¼NW¼SE¼NE¼ sec. 9, T. 13 N., R. 109 W.	N33°W, dip to NE at 1°
Sage Creek limestone (SE Twin Buttes)	SE¼SE¼NE¼NW¼ sec. 17, T. 13 N., R. 109 W.	N60°W, dip to NE at 1°
Sage Creek limestone (SE Cedar Mountain)	NE¼NW¼SE¼SE¼ sec. 32, T. 13 N., R. 111 W.	N28°E, dip to NW at 1°
Sage Creek limestone (NW Sage Creek Mountain)	NW¼NE¼SW¼SW¼ sec. 32, T. 15 N., R. 113 W.	N9°E, dip to SE at 1°
Sage Creek limestone (NW Sage Creek Mountain)	Center NW sec. 20, T. 14 N., R. 113 W.	N65°E, dip to SE at 1.5°
Sage Creek limestone (NW Sage Creek Mountain)	SE¼NE¼NE¼SE¼ sec. 19, T. 14 N., R. 113 W.	N74°E, dip to NW at 1°

Mountain front, a pattern that also dominated during the deposition of the lateral and underlying Green River Formation (Roehler, 1993). This trough is an east-west trending structural downwarp (in approximately the position of the Red Creek syncline) which was formed during the uplift of the adjacent Uinta Mountains (Murphey, 1995; Roehler, 1993). This is further suggested by ribbon sandstones in the upper Bridger C and lower Bridger D, which trend toward the south and southeast north of the Lonetree divide, and then swing to the east in the Lonetree divide area, presumably along the basin axis.

Sediment Sources

Bridger sediments have six sources: 1) primarily, they were derived from volcanoes in the Absaroka Range of northwestern Wyoming; 2) relatively minor amounts originated in the neighboring Uinta Mountains; 3) smaller amounts originated in the Wyoming Overthrust Belt; 4) smaller amounts also originated in the Wind River Range; 5) the source of some of the volcanic ash-fall deposits was the Challis volcanic field of central Idaho; and 6) the lacustrine carbonates were developed in situ. Bridger sedimentation was apparently continuous, with fluvial deposition probably corresponding with times of higher sedimentation and lacustrine deposition corresponding with times of lower sediment input.

The connection between the Absaroka volcanic field and rocks of the Bridger Formation is solidly established (Bradley, 1964; Love, 1939), and is based on the intermediate to mafic volcanics of the Absarokas. Massive amounts of these sediments were transported into the Green River Basin from the north in broad, shallow rivers, and were deposited and reworked on wide muddy floodplains of low topographic relief. Bradley (1964) and Gustav (1974) discuss the sedimentology of Bridger non-lacustrine rocks – many of which are vividly colored, irregularly bedded sandstone, mudstone, and claystone beds containing a large quantity of altered volcanic material – in greater detail. Sinclair (1906) was the first to recognize the volcaniclastic component of Bridger rocks. Bradley (1964) suggested that the presence of a variety of glauconite called celadonite causes the bright green and bluish green colors of many of these rocks. Later mineralogic analysis confirmed this (D. Rossetti, personal communication, 1992). Sand- and gravel-sized clasts of andesite and other volcanic rocks, which occur locally within Bridger sandstone bodies and also in somewhat more rare conglomerates, are further evidence of sediment transport into the basin from the Absarokas. According to Bradley (1964) and Roehler (1993), a significant portion of non-lacustrine Bridger sediment also derives from ash-fall tuff that was deposited and then extensively reworked in the Green River Basin.

Un-reworked tuff beds occur, but are far less common than fluvially deposited volcaniclastic sediments. As we will discuss in greater detail later in this report, six thin ash-fall deposits, some more localized and some very widespread, have been sampled so far. Three tuffs – the Church Butte tuff in the Bridger B, the Henrys Fork tuff in the Bridger C, and the Basal E tuff in the upper Bridger D – have been isotopically dated (Murphey and others, 1999; see **Table 32**). Three tuffs have been studied mineralogically so far: the Henrys Fork, Church Buttes, and Leavitt Creek tuffs. They are all more silicic than tuffs in the Absarokas, suggesting that their source was the contemporaneous Challis volcanic field in central Idaho (Edwin Larson, written communication, 1995; Evanoff and Rossetti, 1992; Evanoff and others, 1996). The mineralogies of the Leavitt Creek tuff (Bridger B), "C-7" tuff (upper Bridger C),

Table 32. $^{40}Ar/^{39}Ar$ analyses of three Bridger ash-fall tuffs (from Murphey and others, 1999)*.

Sample	Mineral	Mean and SD	Weighted mean and SD
Church Buttes tuff[1]	Plagioclase	48.07 ± 0.71	47.91 ± 0.21
	Biotite	48.01 ± 0.20	47.99 ± 0.17
	Hornblende	48.38 ± 0.51	48.35 ± 0.20
	Combined weighted mean and SD		**47.96 ± 0.20 Ma**
Henrys fork tuff[2]	Sanidine	47.05 ± 0.46	46.99 ± 0.21
	Plagioclase	46.80 ± 0.37	46.79 ± 0.28
	Biotite	47.78 ± 0.18	47.75 ± 0.14
	Combined weighted mean and SD		**46.92 ± 0.17 Ma**
Basal Bridger E tuff[3]	Sanidine	46.20 ± 0.54	46.35 ± 0.37
	Plagioclase	45.84 ± 2.28	45.11 ± 0.88
	Biotite	47.73 ± 1.58	48.36 ± 0.58
	Combined weighted mean and SD		**46.16 ± 0.44 Ma**

*The flux monitor mineral for the analysis was 85G003 sanidine, which has an age of 27.92 ± 0.13 Ma.

[1]Church Buttes tuff (base of middle Bridger B, 128 m [420 feet] below the base of the Sage Creek Limestone)

[2]Henrys Fork tuff (base of upper Bridger C, 121 m [397 feet] above the base of the Sage Creek Limestone–see **Appendix 2**, unit 105)

[3]Basal Bridger E tuff (8 m [26 feet] below the base of Turtle Bluff Member or Bridger E, 303 m (994 feet) above the base of the Sage Creek Limestone–see **Appendix 5**, unit 192)

and an unnamed tuff from the Bridger D (**Appendix 1**, unit 82) have not yet been studied with respect to their origin.

Surprisingly, the contribution of sediment from the Absaroka Range was far greater than the contribution from the neighboring Uinta Mountains. Sinclair (1906) first recognized this, and stated confidently, "although pebbles and boulders of all the rocks of the Uinta range occur in the Wyoming (Bishop) conglomerate, not a fragment derived from such sources has been found in place in the Bridger. The conclusion appears to be well established that the drainage from the Uinta Range during this stage of the Eocene did not reach the Bridger area." Sinclair's conclusion was correct but perhaps overstated. Prior to deposition of the Turtle Bluff Member, sediment input from the Uintas into the Green River Basin was relatively minimal, and is represented by laterally and stratigraphically restricted red beds containing what appear to be sediments derived from the Precambrian Uinta Mountain Group. It is important to note that we obtained no petrographic evidence for the origin of Bridger red beds during this investigation. Their relation to rocks of the Uinta Mountain Group is inferred only from the group's general lithologic similarities to the red mudstone and sandstone beds that are interbedded with alluvial fan deposits (in the Bridger) along the Uinta Mountain front. The best examples of red beds in the upper Bridger include the Horse Ranch red bed near the base of Twin Buttes and Black Mountain, and the prominent sequence of red beds in the Turtle Bluff Member on Cedar Mountain. Quartz arenite beds within the Turtle Bluff Member represent the best available evidence for sediments derived from the Uinta Mountains.

The lithologic relations between the upper Bridger and the Uinta Mountains have not been studied in detail, but some observations have been made. Bradley (1964) reported that along the Uinta Mountains, the Bridger and the underlying Green River and Wasatch formations become so conglomeratic that they lose their identity. Readily located today, these conglomerate beds contain clasts of pebbles and cobbles derived primarily from Paleozoic limestones in the Uinta Mountains, and represent alluvial fans that developed at the foot of the Uintas during the Eocene. Some of the more fine-grained rocks along the Uinta Mountains strongly resemble typical Wasatch Formation lithologies. The stratigraphic and temporal equivalence of these rocks with the upper Bridger Formation is demonstrated at several locations south of Wyoming State Highway 414 between Lonetree and Manila, Utah, despite the fact that much of the area was mapped as "slumped masses of Bridger Formation" by Dover and M'Gonigle (1993). Bradley (1964, p. A54-A55) listed several locations specifically. Minor amounts of chert derived from the Wyoming Overthrust Belt and microcline feldspar from the Wind River Range were also deposited in the Bridger Formation (D. Rossetti, personal communication, 1992).

Upper Bridger carbonate beds were deposited in broad shallow lakes and ponds with typically muddy and/or swampy margins. These environments existed for much shorter durations than did the huge lakes of the Green River Formation. Gustav (1974), Murphey (1995), and Murphey and others (2001) have studied the sedimentology of several upper Bridger lacustrine intervals in detail. The carbonate within upper Bridger limestone beds consists mainly of micrite, which precipitated primarily as a byproduct of photosynthesis by algae and aquatic plants. The limestone also contains significant amounts of clay, but lacks coarser clastics other than the occasional grain of detrital quartz or feldspar. Bridger limestone units can also be locally cherty, and most contain locally abundant gastropods and scattered, fragmentary bones of aquatic vertebrates. Some limestone beds have been silicified or recrystallized to sparite, and contain much less common and more poorly preserved fossils. Most marlstone beds also contain a high percentage of calcite and clay, with more common grains of detrital quartz, feldspar, and glass, than occur in the limestones. Terrestrial vertebrates are most commonly preserved in thin calcareous mudstone beds overlying or interbedded within micritic limestone and marlstone (Murphey, 1995, 2001; Murphey and others, 2001). Lateral facies are present in most limestone beds, and reflect greater amounts of detrital clastic material toward lake margins, and swampy environments represented by carbonaceous deposits. The consistent fine particle sizes of the sediments that make up Bridger lacustrine deposits and the general absence of terrestrial vertebrate fossils in Bridger limestone beds indicate a low-energy depositional environment with little potential for sediment transport. No sandy beach or deltaic deposits have been found in association with an upper Bridger lacustrine deposit, and some of the lakes may have been hydrologically sustained by groundwater and small localized streams (Murphey, 1995; Murphey 2001).

Age of the Bridger

Based on mammalian fossil assemblages and limited radiometrically dated ash-fall tuffs, the Bridger Formation is of late early and middle Eocene age. Its mammalian fossils represent most of the Bridgerian North American Land Mammal Age (NALMA), of which the Bridger Formation is the type locality. The NALMA system is a widely accepted and robust paleontologically-based time scale that uses Cenozoic terrestrial fossil mammals to establish biochrons. Wood and others (1941) first formalized the system as a series of "provincial land-mammal ages" based on long-accepted faunal correlations. The NALMA system is revised as new faunal data are collected, and has inspired the development of similar provincial land mammal age systems on other continents.

Published estimates of the duration of the Bridgerian Land Mammal Age are far more numerous than estimates of the time represented by the Bridger Formation. However, due to improvements in isotopic dating methods and advances in magnetostratigraphy and biostratigraphy, age estimates for the Bridger Formation and the late early to middle Eocene Bridgerian Land Mammal Age have been refined significantly over the last decade.

The Bridgerian was first defined as the "time of deposition of the Bridger A-D inclusive" (Wood and others, 1941). Flynn (1986) placed the Bridgerian-Uintan boundary at approximately 49 Ma. Krishtalka and others (1987) estimated that the Bridgerian lasted for approximately 3 My, between approximately 51 and 48 Ma, and noted that, despite the fact that the oldest Bridgerian (Gardnerbuttean) rocks occur in the Huerfano, Wind River, northeastern Green River, and Bighorn basins, the Bridger Formation represents most of Bridgerian time. Woodburne and Swisher (1995) estimated the Bridgerian to have lasted approximately 5 My, from approximately 50.7 to 46 Ma. Based on $^{40}Ar/^{39}Ar$ dates and magnetostratigraphy, Prothero (1995) placed the Wasatchian-Bridgerian boundary at approximately 50.4 Ma, and the Bridgerian-Uintan boundary at approximately 46 Ma. Walsh (1996) and Walsh and others (1996) suggested that the Bridgerian-Uintan transition occurred at approximately 47 Ma based on mammal-bearing continental rocks that intertongue with magnetostratigraphically analyzed marine rocks in San Diego, California. Clyde and others (1997) placed the Wasatchian-Bridgerian boundary at either 52 Ma or 50.5 Ma based on the magnetostratigraphy of rocks on the western margin of the Green River Basin, but preferred 52 Ma in a later publication (Clyde and others, 2001). Based on $^{40}Ar/^{39}Ar$ ages and magnetostratigraphic evidence, Smith and others (2001) estimated the Wasatchian-Bridgerian boundary at between 52.5 Ma and 50.5 Ma, and later reported an estimate of 50.6 Ma (Smith and others, 2003). The age of the Wasatchian-Bridgerian boundary remains the focus of active study and ongoing debate, although it is known to predate the oldest rocks of the Bridger Formation.

Evernden and others (1964) were the first to estimate the numeric age of the Bridger Formation based on K-Ar dating of an ash collected from the Beaver Divide area in central Wyoming. They reported ages of 49.0 to 45.4 Ma. McKenna and others (1973) later estimated that the Bridger Formation was deposited between 49.5 and 47.5 Ma.

Six ash-fall tuffs from the southern Green River Basin have been sampled by UCM workers. These include, from lowest to highest, the Church Buttes and Leavitt Creek tuffs from the Bridger B (Evanoff and others, 1998), the Henrys Fork tuff and "C-7 tuff" (**Appendix 6**, unit 120) from the Bridger C, an unnamed tuff from the lower Bridger D on Twin Buttes (**Appendix 1**, unit 82), and the Basal Bridger E tuff, which occurs 8 m (26 feet) below the base of the Turtle Bluff Member on Sage Creek Mountain (**Appendix 5**, unit 192). Isotopic ages ($^{40}Ar/^{39}Ar$) for the Church Buttes, Henrys Fork, and basal Bridger E tuffs were reported by Murphey and others (1999) (**Table 32**). These dates span approximately 1.8 My and place the base of the middle Bridger B at 48.0 Ma, the base of the upper Bridger C at 46.9 Ma, and the base of the Bridger E at approximately 46.2 Ma. Extrapolating the average Bridger rock accumulation rate of 0.24 m/ky (0.79 feet per 1,000 years) for the intervals between the isotopically dated tuffs (see discussion below) to the undated portions of the formation [Bridger A; lower Bridger B; uppermost 8 m (26 feet) of upper Bridger D; Bridger E] provides an estimate of total Bridger Formation deposition time of 3.52 My, from 49.09 to 45.57 Ma.

Because of its rare fossils and steep, limited exposures, the biochronologic affinity of the Turtle Bluff Member (Matthew's Bridger E) has been difficult to establish with confidence. 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 conclusion 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. These researchers also used turtle fossils representing two species, both known only from Bridgerian-aged rocks, to assign a Bridgerian Land Mammal Age.

Workers from the UCM have since collected a much more diverse mammalian fauna (14 genera) from a dark green to dark gray calcareous mudstone at the base of the Turtle Bluff Member (Evanoff and others, 1994). Donnas Locality (UCM L. 92189) produced at least three Uintan-age taxa: the eomyid rodent *Namatomys* (= *Metanoiamys*); an artiodactyl comparable to *Merycobunodon*; and the basal Uintan index rhinoceros *Triplopus*. A derived species of the omomyid primate *Hemiacodon* is also present. The basal Turtle Bluff Member fauna suggest that the most appropriate biostratigraphic assignment for the base of the Turtle Bluff Member of the Bridger Formation is transitional Uintan, perhaps even older than the "Shoshonian" of Flynn (1986). The author and colleagues have since discovered additional mammal fossils from other levels of the Turtle Bluff Member, and a new tuff (currently being analyzed) 70 m above the base of the member. We expect the results of this work to clarify the biochronologic and geochronologic age of this important unit.

Murphey and others (1999) reported that the Bridgerian-Uintan transition was underway by approximately 46 Ma based on the basal Bridger E fauna and the age of the Basal Bridger E tuff. This agrees with the estimates of Woodburne and Swisher (1995) and Prothero (1995). If the Wasatchian-Bridgerian boundary occurred between 51 and 50 Ma, as Krishtalka and others (1987), Woodburne and Swisher (1995), Prothero (1995), Clyde and others (1997), Smith and others (2001), and Smith and others (2003) estimated, then the Bridgerian Land Mammal Age may have lasted 4-5 My. Clyde and others (2001) reported an estimate of 52 Ma for the Wasatchian-Bridgerian boundary, which would suggest a duration of approximately 6 My for the Bridgerian. These recent studies, along with this report, suggest that the Bridger Formation may only correspond to approximately 60-75% of Bridgerian time, although precise data on rock accumulation rates in Bridger A and lower Bridger B of the Blacks Fork Member are needed.

Rock Accumulation Rates

Because sedimentation was continuous during deposition of the Bridger Formation, average rock accumulation rates can be calculated using the three isotopic ages discussed above (Murphey and others, 1999) (**Table 32**). Positioned between the Church Buttes and Basal Bridger E tuffs, the Henrys Fork tuff permits the comparison of rock accumulation rates from the interval between the Church Buttes and Henrys Fork tuffs to the interval between the Henrys Fork and Basal Bridger E tuffs. The Basal Bridger E tuff [8 m (26 feet) below base of E] is 431 m (1,414 feet) higher and approximately 1.79 My younger than the Church Buttes tuff (base of middle Bridger B). The 249 m (817 foot)-thick interval between the Church Buttes tuff and Henrys Fork tuff represents approximately 1.04 My, an average of 0.24 m/ky (0.79 feet/ky). The 182 m (597 foot)-thick interval between the Henrys Fork and the Basal Bridger E tuffs represents approximately 0.76 My, also an average of 0.24 m/ky 0.79 feet/ky). The similarities indicate that sedimentation rates were remarkably consistent from the base of the middle Bridger B to the top of the upper Bridger D, and allow us to reasonably extrapolate those rates to the undated portions of the formation and estimate the total amount of time represented by the Bridger Formation as discussed above.

Fossil Distribution

The Bridger has long been considered one of the most fossiliferous continental formations in North America. Despite its contributions to our knowledge of middle Eocene vertebrate faunas and mammalian evolution, only general observations about the distribution of fossils within the formation have been made during the last 130 years. These observations, along with data reported here, are useful for evolutionary, paleoecologic, and paleoenvironmental studies of the Bridger Formation and its fossil record. The information presented in this report should promote the relocation of historical localities with poor geographic and little or no stratigraphic data, and assist with the prediction and management of scientifically significant paleontological resources in the formation.

Leidy (1873, p. 23) stated that nearly all fossils in the Bridger were "collected as loose specimens picked up on the surface of the buttes," and that excavations were made only to collect partially exposed bones. He went on to note that usually only a few fragments or bones of a skeleton were found in association, and that no complete skeletons were found during his one field season in the Bridger. One of the members of Marsh's 1871 party wrote that because of the small size of most of the Bridger fossils, locating them "was attended with much difficulty," and that it was often necessary to "literally crawl over the country on hands and knees." He continued, "often a quarter of a mile of the most inviting country would be gone over with no result, and then again someone would chance upon a butte which seemed almost made of fossils" (from Lanham, 1973). According to Sinclair (1906, p. 276), "remains of insectivores and other small mammals are found in great abundance in certain of the white layers, or at the contact with the white layer and the bed lying immediately underneath." Matthew (1909, p. 296) reported, "the main body of the formation (Bridger B-D) is fossiliferous throughout, although certain levels and localities have proved especially rich." Matthew's definitions of his five horizons (Bridger A through E) include references to the fossil content of each. More specifically, he reported (p. 297), "Horizons C and D … are fossiliferous at all levels, the various white levels being especially rich in small species." Bradley (1964, p. A53) concurred, noting that "for some reason, these white layers, particularly the Lonetree and Upper white layers, contain numerous remains of small animals," and that "teeth and jaws are especially common." Both Matthew (1909) and Koenig (1960) remarked on the high fossil content of the Bridger B in the Grizzly Buttes area (B2 and B3 of Matthew). The "Cosmic layer" in the Bridger B is particularly noteworthy because of its excellently preserved fossils, including complete skeletons (Alexander and Burger, 2001). Murphey (1995, 2001; Murphey and others, 2001) reported that while many of the "white layers" in the upper Bridger are highly fossiliferous, aquatic vertebrates dominate the limestone beds, while terrestrial vertebrates occur mostly in immediately overlying, underlying, and occasionally interbedded calcareous mudstone and sandy mudstone beds.

The various observations made by these workers are in general agreement, and may be summarized as follows: 1) most upper Bridger vertebrate fossils are small, consisting of isolated skeletal elements or fragments; 2) associated skeletal elements are uncommon, especially complete skeletons; and 3) numerically, vertebrate fossils are most abundant and diverse within limestone beds or stratigraphically adjacent calcareous mudstone beds, where they often occur in laterally restricted concentrations.

The typical fossil content of upper Bridger lithologies and corresponding inferred depositional environments are summarized in **Table 33**. Micritic limestone beds contain the remains of mostly aquatic organisms, and are often overlain and/or underlain by thin locally sandy calcareous mudstone beds containing both aquatic and terrestrial taxa. These contain the most diverse and abundant vertebrate and mollusk remains in the upper Bridger (see Murphey and others, 2001). Other accumulations occur locally in channel sandstone deposits, especially in point bar deposits, and many of these fossils show clear evidence of fluvial transport. The mudstone and claystone beds that make up most of the formation contain the lowest number of fossils in the upper Bridger. These consist mostly of isolated, relatively large bone fragments, especially turtle carapace.

Plant fossils occur locally, and are typically found in carbonaceous or calcareous mudstone and shale beds associated with limestone beds (**Table 33**). Most are poorly preserved fragments of silicified wood, including stems, branches, roots, and even logs. Reed mats and algal-covered wood occur locally, but leaves are rare. Fern petioles, Celtis seeds, and charophytes have also been identified (S. Manchester, personal communication, 1997). Mollusk fossils include locally abundant terrestrial and freshwater gastropods, and less common unionid bivalves. Upper Bridger trace fossils include uncommon coprolites, solitary bee cases, and rhizoliths.

Although the general pattern of fossil distribution is the same as it was 135 years ago when observations were first reported, years of collecting have undoubtedly influenced the relative representations of vertebrate fossils present on the surface, further biasing the pre-erosional taphonomic signature. This has implications for estimating relative abundances of taxa, which are often so important to taphonomic and paleoecologic studies. For example, early collectors were known to seek large, relatively complete specimens for exhibit purposes. Because these take considerably longer to erode, they are probably under-represented on the surface today compared to their relative representation in Eocene communities. The comparatively high number of medium and large vertebrates in historical museum collections suggests that medium- and large-sized fossils were more abundant on the surface in the late

Table 33. Typical fossil content of upper Bridger Formation lithologies. Inferred depositional environments are italicized.

Lithologies	Typical fossil content
Limestones, calcareous shales, and marlstones (*lacustrine*)	Abundant gastropods (mostly aquatic); occasional unionid bivalves; mostly small, scattered, and fragmentary vertebrate remains including turtle shell fragments, scales, bones, and teeth of fish, crocodilians, and rare amphibians. Locally heavily bioturbated and with abundant fish pellets. Remains of land vertebrates rare.
Calcareous mudstones (*marginal mudflat*)	Thin beds that typically overlie (mostly), underlie, or are interbedded with limestones, and which are the most fossiliferous deposits in the upper Bridger. Contain abundant gastropods (aquatic and terrestrial); isolated or locally concentrated, mostly fragmentary mixed aquatic and terrestrial vertebrate remains including fossil types typically found in limestones (above); and mammalian and reptilian teeth, jaws, and assorted postcrania. Rare avian remains. Larger fossils are much less common than microfossils. Rare silicified wood and stem fragments.
Carbonaceous shales/lignites (*paludal*)	Isolated or locally concentrated, generally very poorly preserved plant remains, including trunks, branches, stems, roots, and leaves. Most commonly carbonized stem fragments of reed-like plants and unidentifiable woody and leafy debris.
Sandstones (*fluvial-streams*)	Isolated or locally concentrated mixed aquatic and terrestrial vertebrates, including teeth, jaw, and assorted bone fragments of fish, reptiles, and mammals, often exhibiting evidence of transport. Larger fossils more common than in limestones or calcareous mudstones. Point bar deposits are especially rich. Invertebrates occur, but are relatively uncommon.
Mudstones and claystones (*fluvial-floodplain*)	Comparatively rare, scattered, and isolated vertebrate bones (terrestrial and aquatic), mostly fragmentary. Turtle shell fragments are the most common fossils. Larger fossils more common than in limestones or calcareous mudstones.

nineteenth and early twentieth centuries than they are today. Additionally, screen washing techniques to adequately sample the microfauna were not employed in the Bridger until the 1970s. Therefore, microvertebrates may be under-represented in collections made prior to that time.

In addition to pre-erosional taphonomic processes, the quantity of fossils present on the surface at any given time is influenced by rates of erosion and the potential for post-erosional preservation. Here, we report preliminary results based on observations of eroding fossils of various types, shapes, and sizes. We continue to make observations in order to establish more accurate estimates. We are currently studying 130 bones from different lithologies and varying slope gradients at six localities, and add more each field season. We have made annual observations since 1995. Although the exposure rates of individual specimens are highly variable, the average observed rate of matrix removal from bone, as estimated from bone exposure, is 6 mm (0.02 inch)/year. Based on this average, it would take approximately 50 years for a 30 cm (11.8 inch)-long bone to become completely exposed, and a large skeleton could take several hundred years or more to become completely exposed. A small tooth, on the other hand, could be fully exposed in less than one year. During and after exposure, the longevity of a surface fossil is limited by factors including fragmentation by swelling clays, secondary weathering and transport, and trampling by animals. No data on the post-erosional longevity of Bridger fossils have been published.

The stratigraphic framework reported here is associated with a large fossil collection. Since 1991, UCM crews have collected approximately 3,800 identifiable fossil vertebrate specimens from 650 localities in the Bridger B through E. Approximately 350 of these localities occur in the Twin Buttes and Turtle Bluff Members, and have been referenced to stratigraphic sections at meter-level resolution (**Appendix 1** through **Appendix 6, Appendix 9**). These localities consist of surface fossil concentrations, isolated surface occurrences, wash sites, and quarries. Geographically, they range in size from 1 m to approximately 20 m (3.3 to 65.6 feet) across, and most are less than 10 m^2 (108 square feet) in area. Stratigraphically, localities are restricted to individual beds, levels within thick beds, or lenticular rock bodies, and their stratigraphic positions were measured relative to the base of the closest marker unit (**Appendix 9**). The stratigraphic framework for the upper Bridger also permits the retrospective positioning of previously recorded and poorly documented fossil localities, many of which were first collected in the late nineteenth and early twentieth centuries.

Figure 25, **Figure 26**, and **Figure 27** illustrate the stratigraphic distribution of UCM mammalian fossils in the Twin Buttes Member. In each figure, lacustrine/marginal-lacustrine rocks, shown in blue, are distinguished from fluvial rocks, shown in orange. The fluvial rocks include both stream and basin-fill floodplain deposits. **Figure 25** shows the number of localities per meter level, **Figure 26** shows the num-

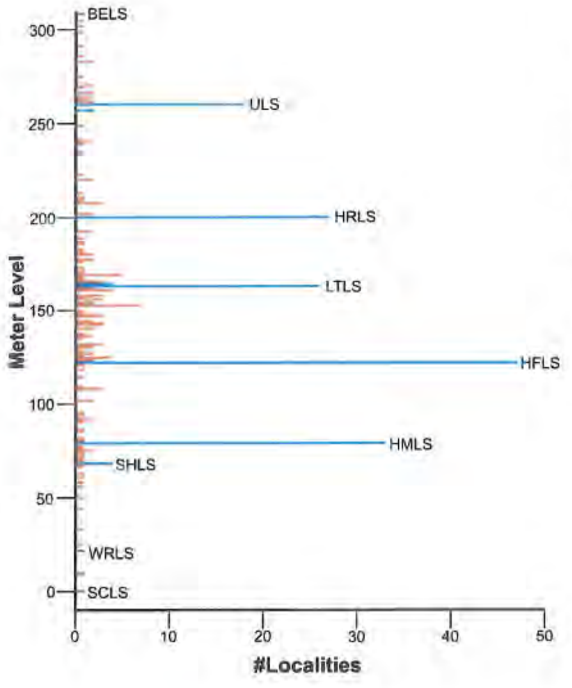


Figure 25. Stratigraphic distribution of UCM fossil localities in the Twin Buttes Member of the Bridger Formation. Blue lines indicate lacustrine and marginal lacustrine units. Orange lines indicate fluvial units. Abbreviations for marker units are SCLS, Sage Creek limestone; WRLS, Whisky Reservoir limestone; SHLS, Soap Holes limestone; HMLS, Hickey Mountain limestone; HFLS, Henrys Fork limestone; LTLS, Lonetree limestone; HRLS, Hickey Reservoir limestone; ULS, Upper white limestone; and BELS, Basal Bridger E limestone (base of Turtle Bluff Member).

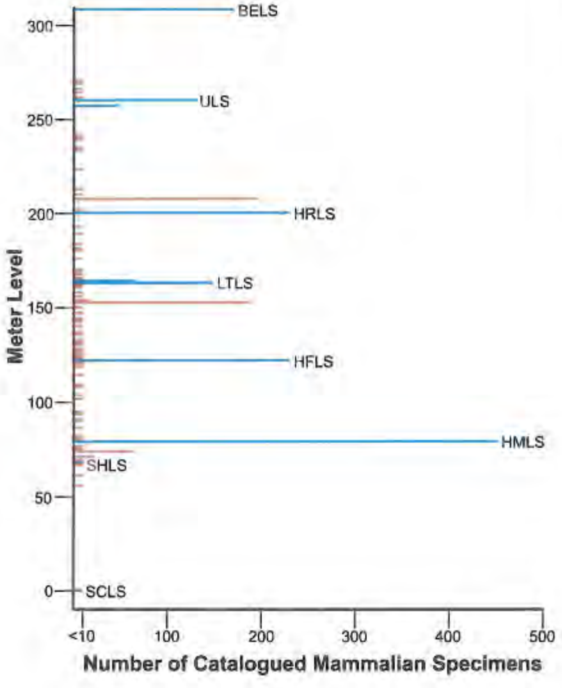
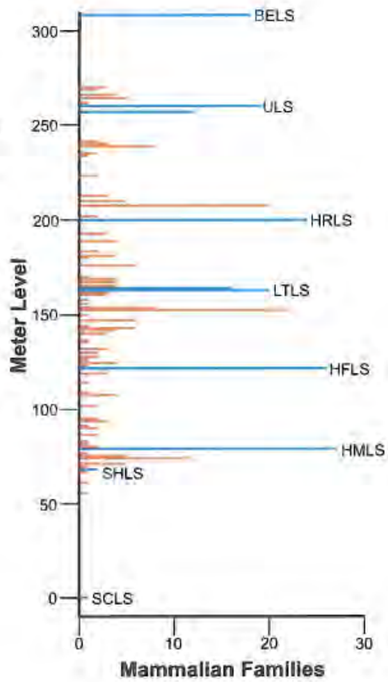


Figure 26. Stratigraphic distribution of catalogued UCM mammalian specimens from the Twin Buttes Member of the Bridger Formation. Blue lines indicate lacustrine and marginal lacustrine units. Orange lines indicate fluvial units. Abbreviations for limestone marker beds the same as those used in Figure 25.

Figure 27. Stratigraphic diversity of mammalian families in the UCM collections from the Twin Buttes Member of the Bridger Formation. Blue lines indicate lacustrine and marginal lacustrine units. Orange lines indicate fluvial units. Abbreviations for limestone marker beds the same as those used in Figure 25.



ber of catalogued (identifiable) mammalian specimens per meter level, and **Figure 27** shows the mammalian diversity at the family level per meter level. The pattern in each figure clearly demonstrates that lacustrine/marginal-lacustrine levels preserve the greatest abundance and diversity of mammalian fossils, as well as the most localities. As noted above (**Table 33**), most mammalian fossils are not actually preserved in the limestone beds (lacustrine deposits), but instead occur in stratigraphically adjacent calcareous mudstone beds (marginal mudflat deposits). These associated lithofacies are combined in the figures because of scale. Note that in **Figure 26** and **Figure 27**, two particularly fossiliferous fluvial localities occur at 153 m and 207 m. These include a sandstone (point bar deposit) (UCM L. 92183) and a sandy mudstone (overbank deposit) (UCM L. 95013), respectively. Overall, the pattern of fossil distribution indicates that, while they are most numerous and diverse in lacustrine/marginal-lacustrine rocks, fossils occur throughout much of the section in much lower diversity and abundance. The observed pattern of fossil distribution results from a combination of taphonomic, temporal (time averaging), and paleoenvironmental factors. A further evaluation of the pattern of fossil distribution is beyond the scope of this report, but is the subject of ongoing study.

Lithofacies and Depositional Environments

Sinclair (1906) was the first to offer detailed interpretations of Bridger sediment sources and depositional environments based on geologic evidence. He characterized the Bridger Formation as almost entirely volcanic in origin, but did not postulate a source. The overall absence of sediments derived from the Uinta Mountains led him to conclude that sediment input from them was minimal. It is unclear whether he based this conclusion on petrologic evidence. Because of their "fine grain, high angularity, and homogeneity," Sinclair believed that most Bridger sediments were transported to the Green River Basin by wind and deposited as ash-fall. He described even the limestone beds as tuffaceous, and believed they were deposited in "remarkably wide but rather shallow" lakes that were "subject to fluctuations in level as shown by the accumulations of lignite which alternate with beds containing fresh water shells" (Sinclair, 1906, p. 279). He cited the abundant fossils found in certain white layers as evidence that the lakes and ponds in which the marls accumulated were the "favorite haunts of the Eocene microfauna." He went on to name two other depositional environments. Sinclair interpreted the coarse sandstones with "basal conglomerates, cross-bedding, and bone pebbles," as stream or delta deposits, and fossiliferous fine-grained "greenish tuffs with both fish and mammal remains" as "in large part flood-plain deposits."

Osborn (1929) concluded that Bridger sediments were deposited almost entirely by fluvial processes in river channels and on floodplains, and that the volcanic ash was washed into the basin from the Uinta Mountains to the south. He offered no evidence for a volcanic source in the Uinta Mountains, and described the basin's depositional environment as "a nearly level country, which was probably covered with vegetation and well-forested" (Osborn, 1929, p. 80). He interpreted the distribution of fossils as indicating that the animals "lived near the places where they became buried, and that they were chiefly such as may inhabit well-wooded regions."

Like Sinclair (1906), Koenig (1960) proposed a volcanic origin for virtually all Bridger sediments except the limestone beds. He suggested a northwest Wyoming (Absaroka area) volcanic source, although direct evidence was lacking. Located more than 370 km (200 miles) south of the Absarokas, the southern Green River Basin did not receive continuous showers of ash. Instead, streams with headwaters far to the north washed volcaniclastic sediments into the basin. Air-transported ash only reached the basin during occasional periods of "extremely violent volcanic activity." Some of the ash was deposited in lakes and ponds, where it mixed with limy and marly sediments, while the remainder "fell upon the valley flat and was soon reworked by water action and redeposited in the stream channels or over the floodplains." Koenig considered the bulk of Bridger sediments to have been fluvially deposited.

Bradley (1964) interpreted the carbonate-rich, widespread Bridger limestone beds as having been deposited in extensive but shallow lakes, and the carbonaceous lenses within or adjacent to them as evidence that swampy areas sometimes bordered and at times replaced them. Of the lenticular, cross-bedded, and often bright green channel sandstones, Bradley (1964, p. A50) wrote, "ash-falls choked the drainage channels and caused the overloaded streams to wander widely in the newly fallen ash until their former gradients were reestablished." He named the Absaroka Range in northwest Wyoming as a likely volcanic source. Bradley concluded that most Bridger sediments are tuffaceous but also include a significant amount of epiclastic material. Furthermore, he considered virtually all Bridger sediments except the limestone beds to have been fluvially deposited in rivers and on floodplains, and then heavily reworked. He did not discuss the relative amount of ash-fall versus fluvially transported ash.

Roehler (1993) concluded that the primary depositional axis for Eocene sedimentation in the Green River Basin was the Uinta Mountain trough, a structural and topographic depression that formed along the north flank of the Uinta Mountains during the early Eocene. He provided evidence of climatically-mediated cyclic deposition in the Green River Formation, which reportedly conforms with 100,000-year orbital eccentricity, precessional, and other cycles. He attributed the infilling and extinction of Lake Gosiute during lower Bridger time to increased volcanism, although he believed this resulted from ash-fall rather than fluvially imported volcanic sediments. He believed the intensity and frequency of volcanic eruptions increased during the Bridgerian and into the Uintan, and recognized the source of the volcanic sediments as the Absaroka region, Idaho, and states farther west. Roehler concluded that Bridger sediments are dominantly volcaniclastic, and consist almost entirely of ash-fall tuffs that accumulated on flood plains and were reworked by wind and water. According to Roehler, Bridger floodplains occasionally contained ponds in which fossiliferous limestones were deposited, and also marshes where thin carbonaceous beds that contain poorly preserved wood and leaf fragments were deposited. In addition to lakes, ponds, swamps, and floodplains, he also recognized mountain front alluvial fan, mudflat, and volcanic depositional environments.

Depositional environments are defined by the conditions in which sediments are deposited, which result in the formation of distinct lithofacies. They typically differ from adjacent environments physically, chemically, and biologically. Deposits (lithofacies) from the seven depositional environments recognized in the upper Bridger Formation in this report are classified as: 1) fluvial; 2) lacustrine; 3) paludal; 4) marginal mudflat; 5) basin margin (alluvial fan); 6) volcanic; and 7) playa.

Fluvial deposits

Most of the earlier workers agreed that most upper Bridger sediments were deposited in fluvial depositional environments where sediments accumulated in stream channels and as fine-grained overbank basin fill. Fluvial depositional environments represent 96% of the total thickness of the upper Bridger in the Twin Buttes area (type section) and 95% in the west part of the study area (reference section). Lithologies representing these environments include interbedded tuffaceous sandstones, mudstones, and claystones.

Upper Bridger sandstone units consist dominantly of ribbons and sheets, with only rare channel splay deposits. The ribbon sandstones are typically brown or green, cross-bedded, lenticular in cross section, and have occasional gravel conglomerates at their bases. Vertebrate fossils, many of which show evidence of mechanical abrasion, are concentrated in point bar deposits. Sand body orientations and paleocurrent directions, which are primarily south and east, support the hypothesis that the volcaniclastic sediment was washed into the basin from the north.

Sheet sandstones differ from ribbon sandstones in that they are laterally extensive and less variable in thickness. Typically structureless or parallel-bedded, the sheet sandstones are sometimes interbedded with mudstones and only rarely contain fossils. The thickest sheet sandstone sequence in the upper Bridger is the approximately 40 m (131 foot)-thick light grayish-blue and tan pumiceous sandstone and mudstone interval that occurs in the middle Bridger D in the west part of the study area. This interval is widely exposed near the Lonetree divide on the east flank of Hickey Mountain, and the south flanks of Sage Creek and Cedar mountains.

Basin fill floodplain deposits typically include structureless gray, tan, brown, olive, and green mudstone and claystone. Vertebrate fossils are uncommon and typically consist of isolated fragments of bone from mid-sized and large animals, especially perissodactyls and turtles. Poorly preserved rhizoliths and burrows occur locally but are also uncommon. Plant macrofossils and invertebrates are rare. The high smectite content of these sediments confirms their volcanic origin. While ash-fall deposits certainly contributed to floodplain sedimentation, most floodplain sediments appear to have been transported into the basin fluvially from the north, with only minor input from the adjacent Uinta Mountains. Recognizing this, it is difficult to quantify the amount of ash-fall versus fluvially imported ash because floodplain sediments have been so extensively reworked. Two lines of evidence, however, suggest that the amount of fluvially imported volcanic sediment is far greater than believed by some prior workers. First, based on their more silicic composition, the only un-reworked ash-fall deposits that have been identified and studied in the Bridger so far indicate a source in the Challis volcanic field in central Idaho. Representing less than 1% of the total thickness of the upper Bridger in the western part of the study area (the reference section), these thin and usually widespread deposits could not have been washed into the Green River Basin in significant quantities from Idaho because of intervening mountain ranges. Second, stream channel directions are predominantly from the north, and based on lithology and mineralogy, these channels contain sands and gravels that were derived in the Absarokas. These sands and gravels are too coarse to have traveled 370 km (230 miles) in the atmosphere.

Lacustrine deposits

Fossiliferous limestone, marlstone, calcareous mudstone, and shale beds deposited in lakes and ponds represent lacustrine depositional environments. While the distribution of limestones indicates that some of these lakes were small, others were quite large, extending over much of the southern Green River Basin, and may represent late intertongues of Lake Gosiute. Representing only 4% of the upper Bridger total thickness at Twin Buttes (type section), and 5% of the total thickness in the west part of the study area (reference section), lacustrine rocks consist mainly of micritic, sparry, marly, and silicified limestone with significant amounts of clay, but with little other detrital material.

Fossil preservation in the sparry limestones is generally poor, but micritic limestone lithologies are typically heavily bioturbated with abundant fish pellets and snail shell fragments. They also contain abundant aquatic vertebrate fossils including isolated fish scales, bones, and teeth; turtle carapace fragments; and crocodilian bones, teeth, and scales or scutes. Modern populations of the gastropod *Biomphalaria* spp. (Basommatophora, Planorbidae) are most abundant in less than 1.8 m (5.9 feet) of water, and are not usually found below the level of rooted aquatic vegetation, which is typically 4.5 m (14.8 feet) (Hanley, 1974). The abundant shells of *Biomphalaria pseudoammonius* present within most Bridger limestones suggest that Bridger lakes were shallow, probably less than 4.5 m (14.8 feet) deep. This is supported by the presence of abundant fish pellets and disarticulated fish remains, which are more common in shallow water where decay, currents, and scavengers are more prevalent (Vallentyne, 1960; Wilson, 1987). The clam *Plesielliptio* spp. (Unionida, Unionidae) is locally present in some limestones, suggesting a relatively shallow, clean, well-oxygenated, lime-rich, perennial water environment (Hanley, 1974). The prevalence of pulmonate gastropods (lung breathers), on the other hand, suggests that water chemistry and/or turbidity may have been a limiting factor.

The fine-grained relatively pure Bridger limestones suggest a predominance of low hydraulic energy in Bridger lakes and ponds. This, in combination with the absence of deltaic deposits in association with lacustrine depositional environments, suggests that groundwater sustained the upper Bridger lakes.

Paludal deposits

Lithologies that represent paludal (swamp) depositional environments are thin carbonaceous shale and lignite beds and lenses, which are stratigraphically adjacent to, or interbedded with limestone, marlstone, and calcareous mudstone beds. Carbonaceous deposits do not occur within every upper Bridger lacustrine sequence, but do occur in association with the Burnt Fork, Soap Holes, Henrys Fork, and Lonetree limestones. In addition, the Sage Creek limestone sequence contains one or two thin carbonaceous beds at most localities. Plant fossils, including algal-covered logs, roots, branches, reed stems, and unidentifiable debris, are locally abundant in carbonaceous deposits but are highly compacted and poorly preserved. The presence of fossilized trees, roots, and wood fragments in paludal lithofacies suggests lake succession associated with infilling, and/or lake expansion resulting in drowned forests along lake margins. More widespread deposition of carbonaceous material, such as that contained within the Sage Creek limestone lacustrine sequence, may have occurred as swamps developed across lacustrine basins during times of low water levels associated with lake contraction.

Marginal mudflat deposits

Thin calcareous mudstone and calcareous sandy mudstone beds represent marginal mudflat depositional environments. These lithologies are always associated with lacustrine limestone beds, which they overlie, underlie, or occasionally interbed with. Composed of micrite, clay, mud, and fine sand, marginal mudflat deposits are the most fossiliferous in the upper Bridger Formation. They contain locally abundant aquatic and terrestrial vertebrate and invertebrate fossils, and localized accumulations of poorly preserved plant fossils. The presence of trees and arboreal mammals indicates that lake margins were forested, and other plant fossils including ferns and reeds suggest that these environments were well vegetated. Marginal mudflat deposits formed where lake waters intersected with muddy lake and pond shorelines, and include adjacent areas of land that were episodically or seasonally flooded. Aquatic and terrestrial animal remains were mixed in these sediments largely through attrition. Together with lacustrine and paludal deposits, as well as overlying and underlying fluvial deposits, marginal mudflats are part of a lithofacies succession that represents the development, expansion, and contraction of lakes and ponds on upper Bridger floodplains, including episodic fluctuations in shoreline position resulting from changes in water level. Based on fossil distribution, it can be argued that most fossils collected from the upper Bridger over the last 130 years represent a lake and lake-margin fauna.

Basin margin deposits

Deposits from basin margin depositional environments are preserved along the north flank of the Uinta Mountains, and are located south of the area that we mapped for this study (**Plate 1**). These are alluvial fan deposits consisting of conglomerate, sandstone, and mudstone. The conglomerates contain rounded pebbles, cobbles, and boulders primarily composed of Paleozoic limestones in a tan sandstone matrix. Only rare clasts derived from the Precambrian Uinta Mountain group are present, suggesting that the Precambrian core of the mountain range had not been breached until the Eocene (Roehler, 1993). Interbedded with these conglomerates are gray and red sandstone and mudstone beds that more strongly resemble similar lithologies in the lower Eocene Wasatch Formation than they do the Bridger Formation. However, these beds correlate with the Bridger Formation. The conglomerate, sandstone, and mudstone beds grade basinward into typical Bridger fluvial deposits as defined above. To date, no fossils have been reported from Bridger alluvial fan deposits.

Volcanic deposits

Deposits from this depositional environment as defined here include three ash-fall tuffs, which combined represent less than 1% of the total thickness of the upper Bridger. Ash-fall tuffs were deposited directly on floodplain sediments, and each was probably deposited over a period of a few hours to a few days. The bases of the Henrys Fork tuff and other Bridger tuffs are remarkably flat, attesting to the low topographic relief of the basin. No fossils or bioturbation were observed in these deposits.

Playa deposits

At the top of the Turtle Bluff Member (the top of the exposed Bridger Formation) the unfossiliferous Behunin Reservoir gypsum bed is unique in the upper Bridger in that it represents the only playa depositional environment. This unit is actually a 7 m (23 foot)-thick sequence of interbedded gypsum, gypsiferous mudstone, claystone, and marlstone. Like playa depositional environments in the Green River Formation, the gypsum in the Behunin Reservoir gypsum bed precipitated during contractions of a saline lake, and is important because it suggests a change to more arid climatic conditions. This unit is exposed only on the southwest rim of Cedar Mountain.

TIME ESTIMATES

Sinclair (1906) was the first to comment on what he perceived as possible differential sedimentation rates within the Bridger Formation. In reference to the tuffaceous middle D bluish-gray and tan sandstone interval ("gray pumiceous tuffs"), he wrote, "this material has apparently accumulated too rapidly to contain much in the way of vertebrate fossils" (Sinclair, 1906, p. 275). Osborn (1929) speculated that the white layers "mark periods during which the deposition of volcanic dust was less rapid, when the Bridger basin was temporarily base leveled, and the waters rose into wide, shallow playa lakes in which sedimentation was slow." He added that because the white layers mark boundaries between the faunal zones which he proposed, they represent "long periods of geologic time ... which indicate that extensive migration occurred before and after the deposition of each of these layers." Subsequent studies (see Mader, 1989) based on more recent collections have shown that Osborn's (1929) largely "titanothere"-based faunal zonations are not valid.

The importance of sedimentation rate to fossil accumulations in marine rocks is well established (Kidwell, 1985), and continental rocks have been shown to exhibit similar patterns (Bown and Kraus, 1981a, 1981b). These studies document the general concentration and time averaging of fossil remains during periods of relatively low sedimentation, and the comparative dilution of fossil remains during periods of more rapid sedimentation. While it is apparent from the fossil evidence that Bridger lakes teemed with life, and that lake margin environments were vegetated and inhabited by a wide variety of mammals, birds, reptiles, amphibians, and fish, the nature of fluvial environments is more difficult to establish. The higher concentrations of fossils in lacustrine and lacustrine-associated depositional environments can be interpreted as follows: 1) an indication that lacustrine sedimentation rates were lower than those of fluvial environments; 2) an indication that animals and plants were more abundant in lacustrine and associated environments than fluvial environments; 3) an indication that lacustrine and associated environments were more favorable for fossil preservation; or 4) some combination of these hypotheses. The evidence discussed below suggests that differential sedimentation rates were only partly responsible for the observed pattern of fossil distribution in the upper Bridger.

Isotopic ages of Bridger ash-fall tuffs permit the calculation of an average rock accumulation rate for portions of the Bridger that are bracketed by these dates (base of middle Bridger B to base of upper Bridger C; base of upper Bridger C to top of Bridger D) (Murphey and others, 1999). Although it seems reasonable to extrapolate this rate to undated Bridger rocks and estimate total Bridger time (see rock accumulation rates, above), this method does not allow for estimates of the amount of time represented by lacustrine versus fluvial rocks within the formation. This question is important to paleoenvironmental interpretations and understanding the evolution of the Bridger fauna. Differences in sedimentation rates between lacustrine and fluvial facies are suggested by modern environments, patterns of upper Bridger fossil distribution, and comparisons with varved lacustrine rocks from the intertonguing and underlying Green River Formation.

Based on the average rock accumulation rate of 0.24 m/ky (0.79 feet/ky), the 441 m (1,446 foot)-thick upper Bridger Formation in the west part of the study area (thickest section) represents approximately 1.83 My, and the entire Bridger Formation (842.5 m or 2,763 feet) was deposited in approximately 3.5 My. Varved rocks from near the base of the Laney Member of the Green River Formation provide a conservative proxy for estimating the amount of time represented by Bridger limestones based on their thicknesses. Roehler (1993, p. F10) reported a rate of 4,200 varves per foot of shale [13,780 varves (years) per meter = 0.07 m/ky (0.22 feet/ky)]. Based on this rate, the 20.3 m (67 feet) of lacustrine rocks in the upper Bridger reference section represents a total of approximately 290,000 years. The estimated total amount of time represented by the upper Bridger (1.83 My) minus the 290,000 years estimated for lakes using the accumulation rate of 0.07 m/ky (0.22 feet/ky) leaves 1.54 My for the accumulation of the remaining 421 m (1,381 feet) of fluvial-deposited sandstone, mudstone, and claystone. This results in an average rock accumulation rate of 0.27 m/ky (0.89 feet/ky) for the fluvial rocks. If the rate of 0.07 m/ky (0.22 feet/ky) is applied to the 4.1 m (13.5 foot)-thick Sage Creek limestone lacustrine sequence, for example, it represents 58,571 years. The same thickness of fluvial rocks using the rate of 0.27 m/ky (0.89 feet/ky) represents only approximately 15,185 years. Thus, because upper Bridger limestones represent such a small proportion of upper Bridger lithologies (5% in reference section), applying the 0.07 m/ky (0.22 feet/ky) rock accumulation rate from the Green River Formation to Bridger lacustrine rocks has only a minor influence on the average rock accumulation rate for floodplain deposits, increasing it from 0.24 to 0.27 m/ky (0.78 to 0.89 feet/ky). Based on available data, it is not possible to accurately determine sedimentation/rock accumulation rates for Bridger lacustrine versus fluvial environments, and comparable data are few. However, the rate of 0.07 m/ky (0.22 feet/ky) reported for the Green River Formation suggests that Bridger lacustrine sediments accumulated more slowly than fluvial sediments.

Besides comparisons with the Green River Formation, the composition of Bridger limestones is the most direct evidence that lacustrine depositional environments formed during conditions of relatively low sedimentation. Predominantly composed of micrite, marl, and clay, they indicate that the input of allochthonous sediment into even proximal shore facies was minimal, and that the hydraulic potential to transport sediment was low compared to floodplain depositional environments. The low terrestrial fossil content of the limestones supports the low hydraulic energy hypothesis because it indicates that remains of terrestrial organisms only rarely washed into lakes.

Depositional History

During deposition of the Green River Formation, continuous lacustrine deposition prevailed in the Green River Basin for at least 5 My. Volcanic ash-fall settled on lake waters and was preserved in lake bottom sediments along with remains of animals and plants that lived in and around Lake Gosiute. The pattern of continuous lacustrine deposition ended during the middle Eocene between approximately 49 and 48 Ma, when increased volcanism in the Absaroka Range significantly augmented the amount of volcanic ash and coarser clastic debris that entered river headwaters north of the Green River Basin and gradually overwhelmed Lake Gosiute from north to south.

In the north part of the depositional area for the Bridger Formation, closer to where the major drainages entered the basin, the transition from continuous lacustrine sedimentation to fluvially dominated sedimentation occurred during deposition of the Bridger A and B. This transition occurred later in the south part of the basin (southeast Cedar Mountain and south of Twin Buttes), at approximately the boundary between the Bridger B and C. In this area, lacustrine strata of the Laney Member of the Green River Formation directly underlie the Sage Creek limestone and replace an unknown thickness of the Bridger B, indicating that lacustrine sedimentation did not end abruptly, and persisted longer in the south part of the basin along the Uinta Mountain trough. As upper Bridger (Twin Buttes and Turtle Bluff members) deposition progressed, lakes persisted for shorter periods, decreased in size, and became less common. Some of the thicker and more widespread limestone beds in the upper Bridger may represent late expansions of Lake Gosiute from the east.

Active volcanism persisted throughout much of upper Bridger time and provided an almost continuous supply of sediment. Volcaniclastic clay, mud, and sand reworked from the Absaroka volcanics were deposited on wide floodplains of low topographic relief that persisted for up to 85% of upper Bridger time. Occasional decreases in the flow of sediment to the basin permitted the development of shallow, mostly groundwater-fed lakes and ponds. While these lacustrine sediments represent up to 15% of upper Bridger time, they account for only approximately 4% of the total thickness of upper Bridger rocks in the Sage Creek Mountain area (reference section). Unlike earlier periods of cooler and wetter conditions that caused Lake Gosiute to expand (Roehler, 1993), wetter conditions during upper Bridger time resulted in floodplain deposition, not lake expansion, because they increased sediment input to the basin. Episodes of lower sediment input decreased in frequency during the deposition of the upper Bridger as evidenced by fewer lacustrine deposits in successively higher stratigraphic levels. At least four ash-fall tuff deposits are present in the upper Bridger sequence. Unlike the fluvially deposited volcaniclastic sediments, these ash-fall tuffs may not have originated in the Absaroka Range. Based on its composition, the Henrys Fork tuff is believed to have originated in the contemporaneous Challis Volcanic Field in central Idaho.

Lacustrine sediments of the upper Bridger Formation were deposited during times of low allocthonous sediment input, and may have accumulated almost four times slower than fluvially deposited sediments. These lakes and their margins provided favorable habitats for aquatic and terrestrial organisms. Lake margins were well-vegetated and at least partially forested, based on associated tree fossils and the presence of arboreal mammal fossils in lake margin deposits. Unlike the Green River Formation, the upper Bridger contains no sedimentologic evidence of arid climatic conditions until deposition of the thick gypsum beds capping the formation on Cedar Mountain.

The upper Bridger Formation thins from west to east, indicating that sedimentation and basin subsidence rates were higher in the west (Sage Creek Mountain and Hickey Mountain) than in the east (Twin Buttes and Black Mountain). An unknown thickness of Eocene-age sediments may have been deposited after the deposition of the transitional Uintan-age (approximately 46 Ma) rocks of the Turtle Bluff Member, indicating that the original thickness of the upper Bridger Formation is unknown. However, the composition of the Turtle Bluff Member implies that sediments from the Uinta Mountains were prograding basinward, suggesting that basin subsidence along the northern Uinta trough was slowing near the end of upper Bridger deposition, and that there was little space left in the basin to accommodate more sediments. Prior to the Oligocene, an unknown thickness of Bridger Formation in the south part of the basin had eroded away, leaving what remains (stratigraphically) of the Turtle Bluff Member. This was followed by deposition of the unconformably overlying Bishop Conglomerate composed of clasts derived from the Uinta Mountains, and by formation of the northward-dipping Bishop surface during the Oligocene. Pliocene to Recent erosion dissected the basin, forming the present badland topography.

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WYOMING STATE GEOLOGICAL SURVEY
Ronald C. Surdam, State Geologist
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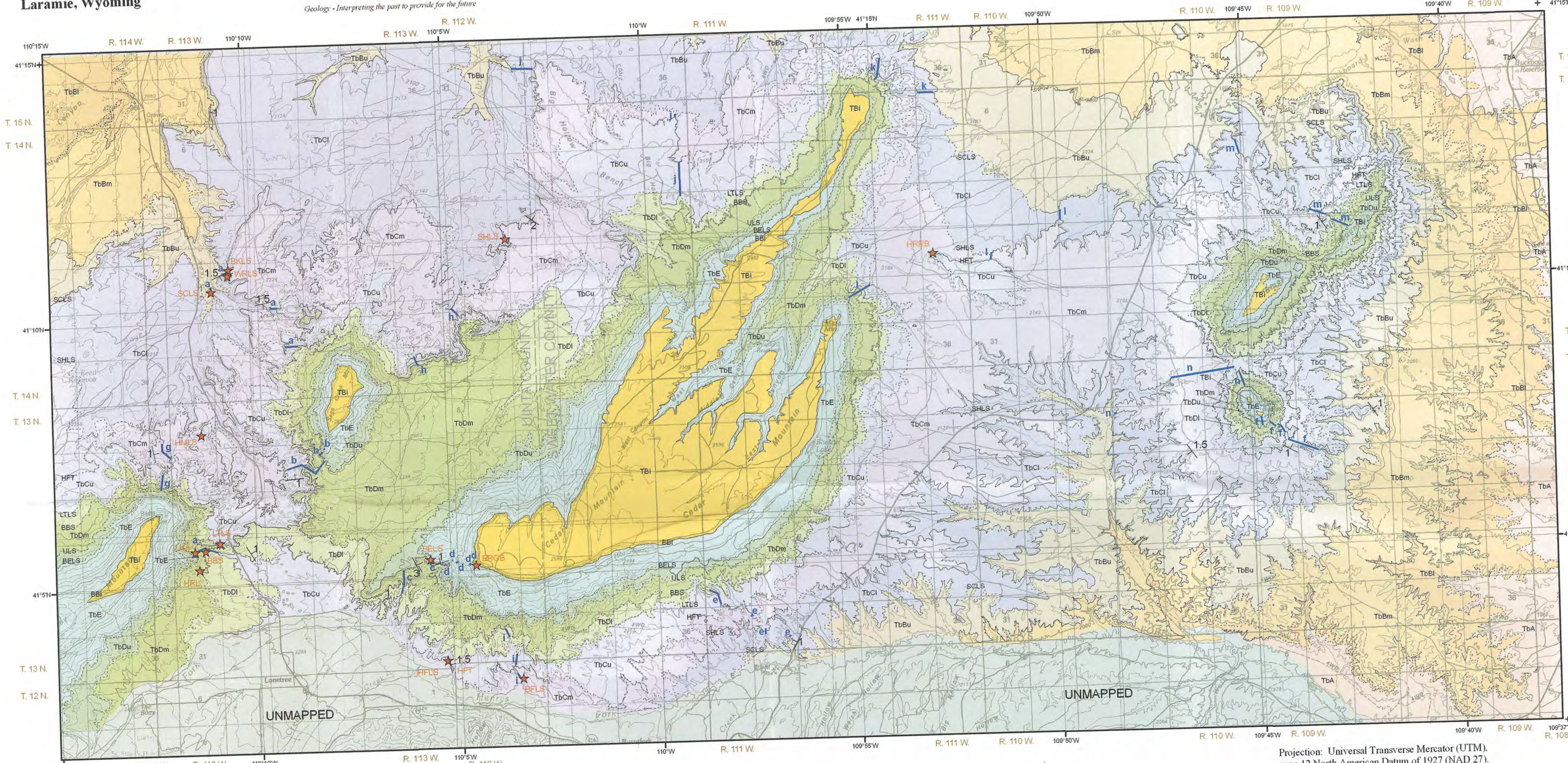
Geology - Interpreting the past to provide for the future

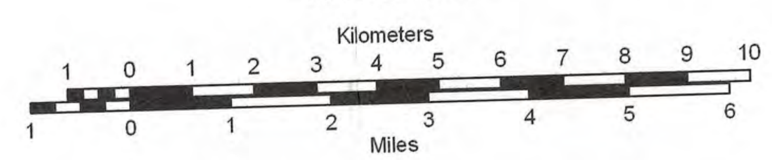
REPORT OF INVESTIGATIONS 57, PLATE 1

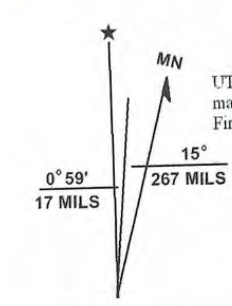
Bedrock geologic map of part of the southern Green River Basin, southwestern Wyoming



Cartography by David W. Lucke

Scale 1:100,000





UTM grid convergence (GN) and 1980 magnetic declination (MN) at center of Firehole Canyon Quadrangle.

Projection: Universal Transverse Mercator (UTM), zone 12 North American Datum of 1927 (NAD 27).
Base map from USGS Firehole Canyon and Evanston 30 x 60 minute quadrangles, 1980.

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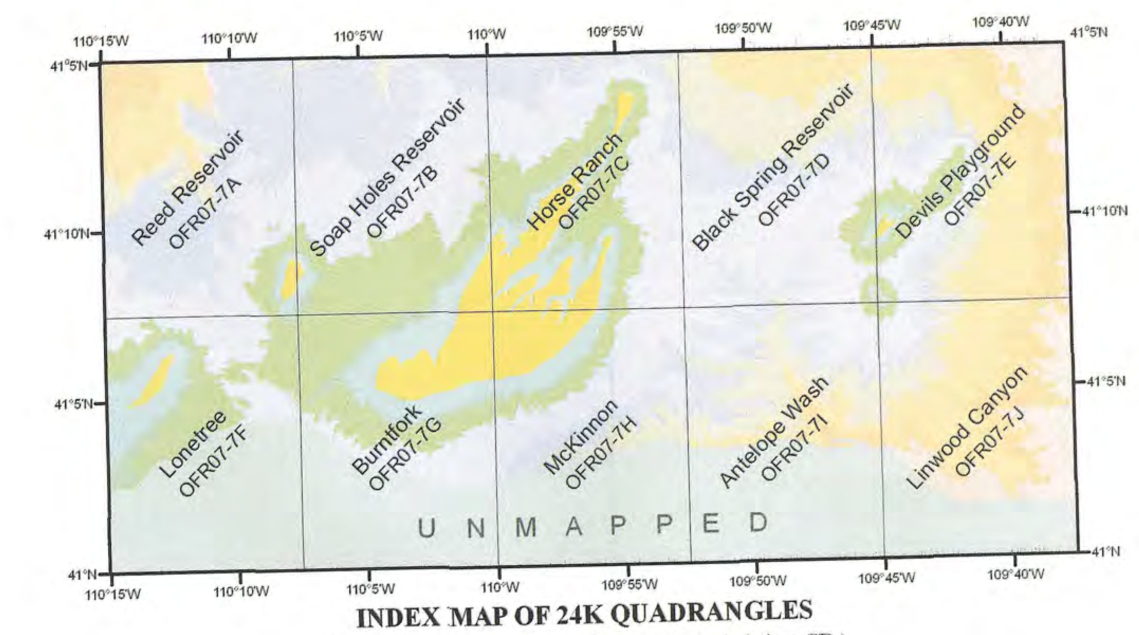
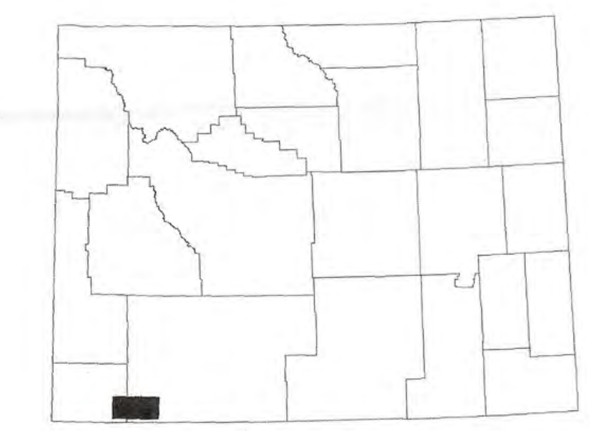


INDEX MAP OF 24K QUADRANGLES

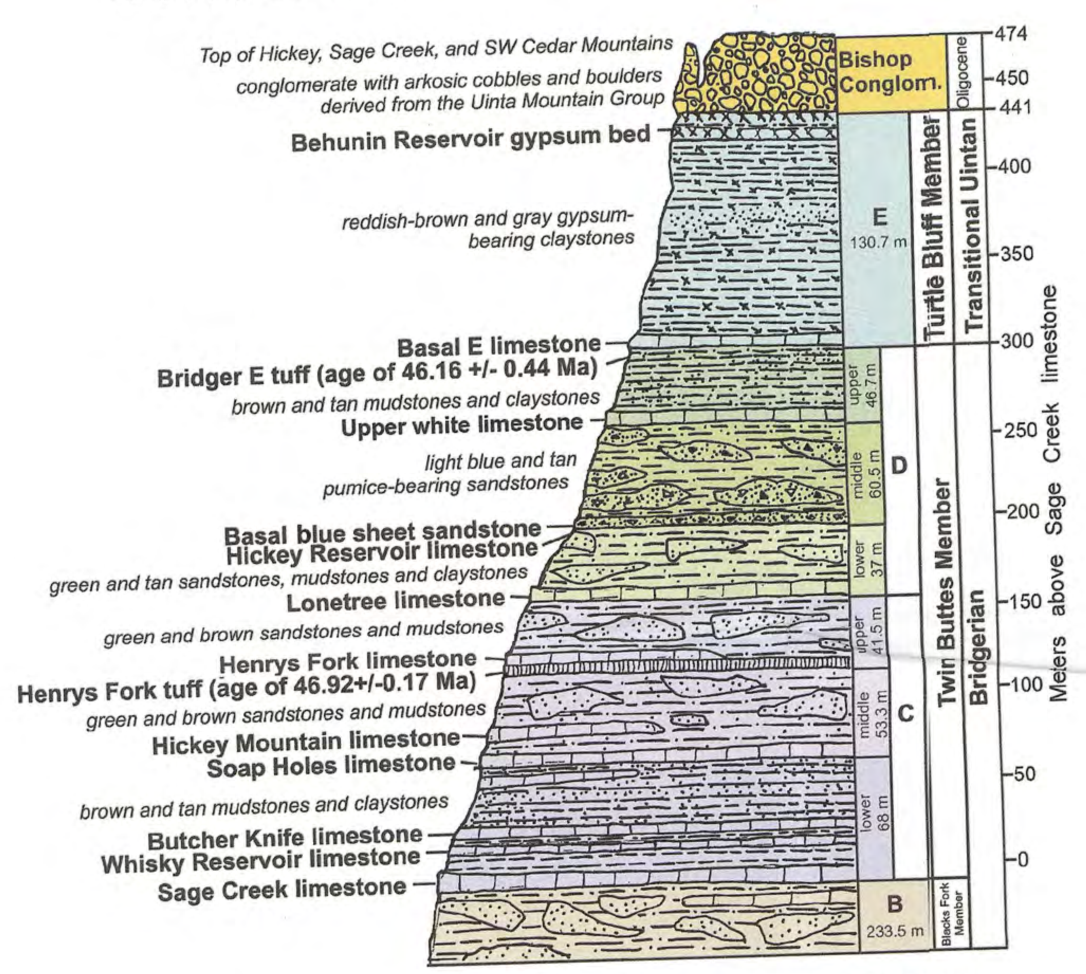
(1:24,000-scale digital geologic maps are included on CD.) These maps are also available as separate Open File Reports (OFRs) from the Wyoming State Geological Survey.

MAP SYMBOLS

- HFT — Marker unit, exposed; see ABBREVIATIONS FOR MARKER UNITS
- SHLS — Marker unit, inferred where poorly exposed; see ABBREVIATIONS FOR MARKER UNITS
- BKLS ★ — Type locality for marker unit; see ABBREVIATIONS FOR MARKER UNITS
- b — Measured section; see KEY TO MEASURED SECTIONS
- 1 — Strike and dip of beds



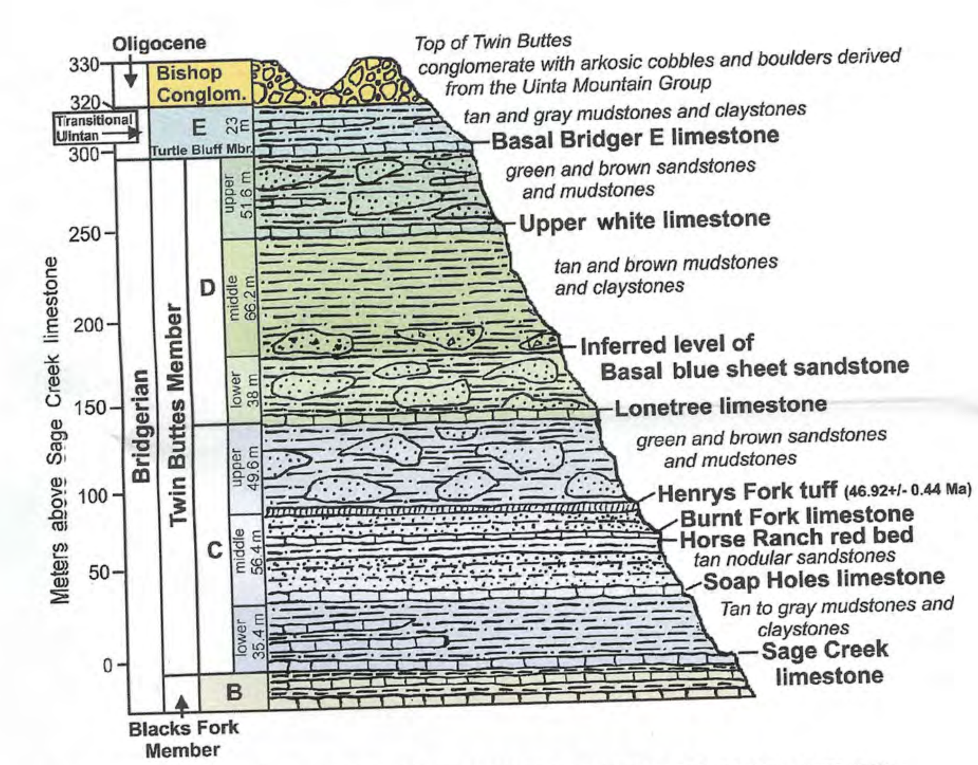
LOCATION MAP



GENERALIZED STRATIGRAPHIC SECTION IN THE HICKEY, SAGE CREEK, AND CEDAR MOUNTAINS AREA

GEOLOGIC MAP UNITS

- TBi — **BISHOP CONGLOMERATE** (Oligocene)
- **BRIDGER FORMATION** (early and middle Eocene)
  - TbE — *Turtle Bluff Member* (Bridger E) (middle Eocene)
  - *Twin Buttes Member* ("Upper Bridger" or Bridger C and D) (middle Eocene)
    - TbDu — upper Bridger D
    - TbDm — middle Bridger D
    - TbDl — lower Bridger D
    - TbCu — upper Bridger C
    - TbCm — middle Bridger C
    - TbCl — lower Bridger C
  - *Blacks Fork Member* ("Lower Bridger" or Bridger A and B) (early and middle Eocene)
    - TbBu — upper Bridger B
    - TbBm — middle Bridger B
    - TbBl — lower Bridger B
    - TbA — Bridger A



GENERALIZED STRATIGRAPHIC SECTION IN THE TWIN BUTTES AND BLACK MOUNTAIN AREA

KEY TO MEASURED SECTIONS

Map reference	Name of measured section	Reference sources
a	Reference Section, Twin Buttes Member (Northwest Sage Creek Mountain)	Appendix 2, Table 18
b	Southwest Sage Creek Mountain	Appendix 5, Table 20
c	Southwest Cedar Mountain	Appendix 3, Table 19
d	Type Section, Turtle Bluff Member (West Cedar Mountain)	Appendix 4, Table 19
e	Southeast Cedar Mountain	Appendix 6, Table 21
f	Type Section, Twin Buttes Member (Southeast Twin Buttes)	Appendix 1, Table 17
g	Northeast Hickey Mountain	Table 22
h	Northeast Sage Creek Mountain	Table 23
i	South Cedar Mountain	Table 25
j	North Cedar Mountain	Table 24
k	Northeast Cedar Mountain	Table 27
l	Northeast Mass Mountain	Table 26
m	Northwest Black Mountain	Table 29
n	Northwest Twin Buttes	Table 28

ABBREVIATIONS FOR MARKER UNITS

BBI	Base of Bishop Conglomerate
BRGB	Behunin Reservoir gypsum bed
BELS	Basal E limestone
ULS	Upper white limestone
BBS	Basal blue sheet sandstone
~BBS	Approximate level of basal blue sheet sandstone
HRL	Hickey Reservoir limestone
LTLS	Lonetree limestone
HFLS	Henrys Fork limestone
HFT	Henrys Fork tuff
BFLS	Burnt Fork limestone
HRRB	Horse Ranch red bed
HMLS	Hickey Mountain limestone
SHLS	Soap Holes limestone
BKLS	Butcher Knife limestone
WRLS	Whiskey Reservoir limestone
SCLS	Sage Creek limestone

DISCLAIMERS

Users of this map are cautioned against using the data at scales different from those at which the maps were compiled. Using this 1:100,000-scale map at a larger scale will not provide greater accuracy and is, in fact, a misuse of the data. More detailed maps at a scale of 1:24,000 are available as open file reports (see INDEX MAP OF 24K QUADRANGLES, above).

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BEDROCK GEOLOGIC MAP OF PART OF THE SOUTHERN GREEN RIVER BASIN, SWEETWATER AND UINTA COUNTIES, SOUTHWESTERN WYOMING

by

Paul C. Murphey and Emmett Evanoff

2006