GEOLOGY OF THE INTERMOUNTAIN WEST
an open-access journal of the Utah Geological Association
Volume 1 **2014**

The Major Pre-Mississippian Unconformity in Rock Canyon, Central Wasatch Range, Utah

David L. Clark[1], Drew Derenthal[2], Bart J. Kowallis[2], and Scott M. Ritter[2]
[1]Department of Geosciences, University of Wisconsin, Madison, WI; dlclark15@gmail.com
[2]Department of Geological Sciences, Brigham Young University, Provo, UT

GEOLOGY OF THE INTERMOUNTAIN WEST

an open-access journal of the Utah Geological Association

Volume 1 **2014**

Cover Photograph
Cambrian and Devonian section and possible location of the pre-Mississippian unconformity in Rock Canyon, Utah; figure 2 from article. Photograph by Bart J. Kowallis.

Become a member of the UGA to help support the work of the Association and receive notices for monthly meetings, annual field conferences, and new publications. Annual membership is $20 and annual student membership is only $5. Visit the UGA website at www.utahgeology.org for information and membership application.

The UGA board is elected annually by a voting process through UGA Members. However, the UGA is a volunteer driven organization, and we welcome your voluntary service. If you would like to participate please contact the current president or committee member corresponding with the area in which you would like to volunteer.

Utah Geological Association formed in 1970 from a merger of the Utah Geological Society, founded in 1946, and the Intermountain Association of Geologists, founded in 1949. Affiliated with the American Association of Petroleum Geologists

GEOLOGY OF THE INTERMOUNTAIN WEST
an open-access journal of the Utah Geological Association
Volume 1 **2014**

The Major Pre-Mississippian Unconformity in Rock Canyon, Central Wasatch Range, Utah

David L. Clark[1], Drew Derenthal[2], Bart J. Kowallis[2], and Scott M. Ritter[2]
[1]*Department of Geosciences, University of Wisconsin, Madison, WI; dlclark15@gmail.com*
[2]*Department of Geological Sciences, Brigham Young University, Provo, UT*

ABSTRACT

In central Utah, the major pre-Mississippian unconformity is fairly well understood at most of the localities where it is recognized. However, the unconformity is more enigmatic in Rock Canyon of the central Wasatch Range. At this locality, dolomitization of most pre-Mississippian rocks obscures stratigraphic identification of Devonian and older units. The absence of any identifiable angular relationship further complicates resolution. Because of this, both identification of the stratigraphic level of the unconformity and, consequently, its magnitude remain controversial. Large-size dolomite samples taken in Rock Canyon at closely spaced intervals for the 3.6-m directly below definite Upper Devonian rocks yield microfossils, including conodonts, in the uppermost 1.6-m of that interval that indicate no unconformity exists between the Cambrian Maxfield Limestone and the Upper Devonian-Lower Mississippian Fitchville Dolomite at the horizon previously identified as unconformable. Rather, an unknown thickness of dolomitized Upper Devonian Pinyon Peak Formation and probable older rock (possibly Bluebell Dolomite and Victoria Formation) occurs between the top of definite Maxfield and base of the Fitchville. The identification of the unconformity horizon remains unknown. Our preliminary work outlines a promising procedure for future understanding of the magnitude and stratigraphic level of the unconformity.

THE PROBLEM

Earliest documentation of the widespread Upper Devonian unconformity in central and eastern Utah included the conclusion that in Rock Canyon (figure 1), upper Middle Cambrian dolomite beds are overlain by Lower Mississippian carbonates (Baker, 1947; Rigby, 1959). However, additional work on the Mississippian section in this part of Utah demonstrated that the lower part of the carbonates assigned to the Mississippian contained Late Devonian conodonts (Beach, 1961), and the rocks earlier interpreted to be Lower Mississippian were differentiated into the Fitchville Formation of Late Devonian-Early Mississippian age and the overlying Gardison Formation of younger Mississippian age (Morris and Lovering, 1961). Since this early work, the major pre-Mississippian unconformity in Rock Canyon has been interpreted to occur between the base of the

Clark, D.L., Derenthal, D., Kowallis, B.J. and Ritter, S.M., 2014, The major pre-Mississippian unconformity in Rock Canyon, central Wasatch Range, Utah: Geology of the Intermountain West, v. 1, p. 1-5.

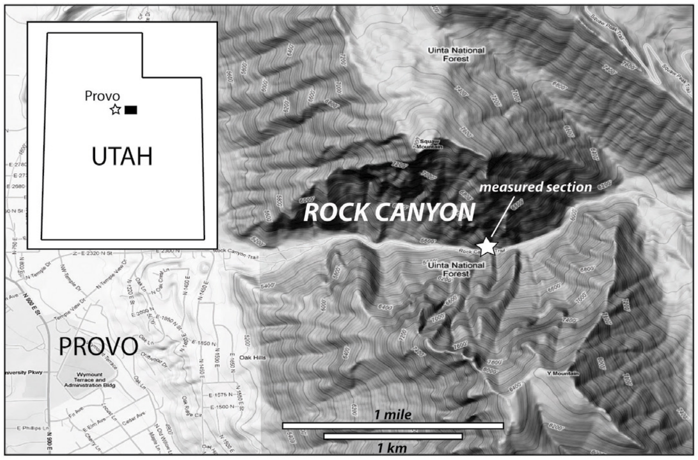

Figure 1. *Location of section studied in Rock Canyon, adjacent to Provo.*

Devonian-Mississippian Fitchville Formation, marked by a sandstone unit, and what was assumed to be the underlying late Middle Cambrian Maxfield Limestone (Sandberg and Gutschick, 1979; Derenthal and others, 2008; Hintze and Kowallis, 2009), an unconformity perhaps representing almost 150 my. A similar unconformable relationship exists at other localities in central and eastern Utah, but the Fitchville rests on Paleozoic strata of different ages in some of these areas (Rigby, 1959).

In several areas of central Utah, the Fitchville Formation consists of several hundred meters of carbonate with the base of the formation marked by a 30- to 50-cm-thick bed of sandstone and sandy dolomite. In the Fitchville type area of the East Tintic Mountains, the basal sandstone is referred to as the "sand grain marker bed" (Morris and Lovering, 1961, p. 82). A similar stratigraphy is recognized in Rock Canyon.

In Rock Canyon, all of the dolomites below the sand grain marker bed of the Fitchville Formation have previously been assigned to the Cambrian Maxfield Limestone. The Maxfield is widespread in central Utah, but it is not as easily understood in the Wasatch Range where exact stratigraphic interpretations are difficult because the limestone beds of the Maxfield and overlying formations have been dolomitized. In addition, there are few diagnostic fossils in any part of the Maxfield, especially in the Wasatch Range.

As a consequence of these observations, we have questioned whether the stratigraphic level of the major pre-Mississippian unconformity in Rock Canyon has been accurately determined. We have considered the possibility that the dolomite beds traditionally assigned to the upper part of the Maxfield Limestone and below the Fitchville might be older Devonian, Silurian, or even Ordovician in age because strata of all of these ages underlie the Upper Devonian unconformity at different localities elsewhere in central Utah (Rigby, 1959). This appears reasonable because rocks of these Early Paleozoic ages are much thicker only a few kilometers west of the Wasatch due to a general eastward thinning onto the shelf and because this locality was on the south flank of a west-trending crustal arch that affected Paleozoic deposition (Morris and Lovering, 1961). During the early Paleozoic, the area of the present Wasatch Range was the eastern margin of the same depositional basin. At least some of the dolomite beds assigned to the upper part of the Cambrian Maxfield Limestone in Rock Canyon could be older Devonian and possibly as old as Ordovician (figure 2).

In order to address this problem, we decided to use the same method that was successfully used in resolving a similar problem involving the Cambrian-Ordovician unconformity in southern Wisconsin. There, the dolomites and dolomitic sandstones of the Cambrian-Ordovician interval are conformable and contain few megafossils, but large size samples treated with formic acid yielded definitive conodonts and other microfossils that were adequate for a high level of stratigraphic resolution (Parsons and Clark, 1999). Therefore, in order to

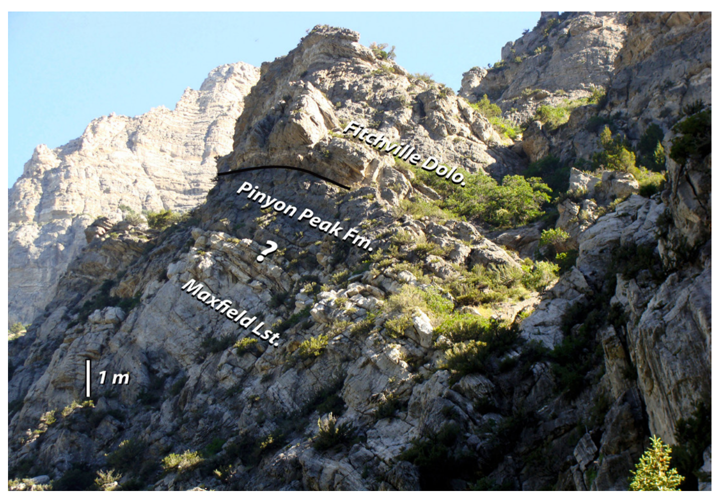

Figure 2. *Photograph of Rock Canyon section showing contact of Fitchville and Pinyon Peak, formerly considered to be the pre-Mississippian unconformity. Precise age of lower strata unknown.*

better understand the nature of the unconformity in Rock Canyon, we sampled the dolomites immediately below the base of the Fitchville clastic unit at 10- to 40-cm increments over an interval of 3.6 meters. A total of 96, two to four kg samples were processed for conodonts and other phosphatic or siliceous fossils.

RESULTS OF LAB WORK

The conodont terminology used here is the same as that documented in the conodont Treatise on Invertebrate Paleontology (Clark and others, 1981). For purposes of description, the 3.6-m section has been divided into six units as shown on figure 3.

Unit 1 – The 30-cm interval of dolomite immediately beneath the Upper Devonian clastic unit of the Fitchville Formation yielded 23 conodonts, all fragmentary, in 12 samples, including: *Polylophodonta* ?, P*olygnathus sp. aff. costatus, Polygnathus* fragments, various probable conodont fragments including *P. semicostatus, Icriodus Pa*, two fragments of basal part of coniform elements of *Icriodus*, one partial and one complete Pa element (*spathognathodid*) of *Ozarkodina sp.*, one unidentified ramiform, and unidentified fragments. A single shark dermal denticle and a broken sponge spicule were also recovered.

Unit 2 – The next lower 75-cm interval (16 samples) yielded fragments of probable ramiform specimens and a fragmentary piece of an *Icriodus* Pa element plus a broken sponge spicule.

Unit 3 – The next 30-cm interval below (14 samples) yielded a single fragment of the Pa element of *Icriodus* and several unidentifiable fragments.

Unit 4 – The next lower 30-cm interval (16 samples) yielded possible conodont fragments plus the partial internal mold of a gastropod.

Unit 5 – The next lower 60-cm interval (9 samples) yielded no conodonts or fragments, but at the base of the interval several specimens of *Tasmanites*, a phosphatic green algae with an extremely long stratigraphic range in the Paleozoic.

Unit 6 – The lower 135-cm interval of the sampled interval (29 samples) yielded part of an internal mold of a gastropod, plus a single possible fragment of a coniform conodont.

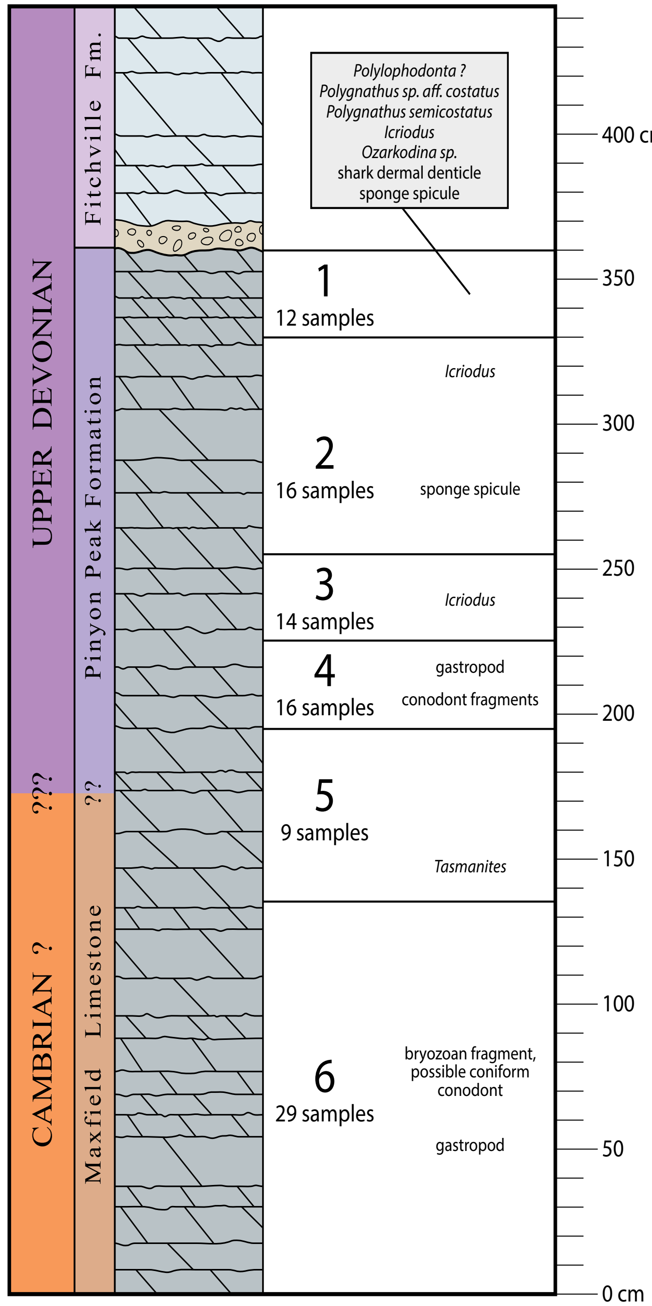

Figure 3. *Details of stratigraphic section with fossils and numbered sequences of samples referred to in text.*

INTERPRETATIONS

The uppermost 1.3-m of what has been assigned to the Cambrian Maxfield Limestone yielded 25 poorly preserved Devonian conodont fragments (CAI 5+), a single sponge spicule, and one shark dermal denticle (figure 3). In addition, a number of unidentifiable fragments, possible pieces of conodonts, occur in this uppermost interval as well as in the next 30-cm lower unit (4) in the section that also yielded a single gastropod mold. Together, the conodont fragments suggest that at least the uppermost 1.6-m interval of the rocks (units 1 to 4) assigned to the Cambrian Maxfield Limestone in Rock Canyon are Late Devonian in age and are more realistically considered to be part of a dolomitized Pinyon Peak Formation. The conodonts of the upper part of the Pinyon Peak are the same age and are representative of the same fauna as that described from the overlying basal Fitchville Formation (Sandberg and Gutschick, 1979), a condition that has been noted in other parts of north-central Utah (Gosney, 1982). While the conodont faunas are separated by a clastic layer that marks the base of the Fitchville Formation, both faunas (i.e., that from the upper part of the dolomite beds previously assigned to the Cambrian Maxfield and that from the dolomites and limestone beds of the overlying Fitchville), represent a Late Devonian (probably *Expansa*) interval, slightly older than the youngest Late Devonian conodont zone recognized. Whether there exist additional beds of the Pinyon Peak Limestone or other rocks younger than the Cambrian Maxfield (i.e., the Bluebell Dolomite and Victoria Formation) below our lowest sampled interval was not determined. However, approximately 60-cm lower, the phosphatic green algae *Tasmanites* occurs along with another partial internal mold of a gastropod. *Tasmanites* has been reported from strata ranging through rocks of the entire Phanerozoic Era. A possible bryozoan fragment occurs just above the 3-m base of our sampled section. Although this tiny fragment is not definitive, most likely it is not Cambrian.

SUMMARY

The poorly preserved conodont fauna of the 1.6-m interval underlying the basal Fitchville Formation clastic unit in Rock Canyon firmly identifies the interval as Late Devonian (figure 3). Clearly, the clastic unit of the basal Fitchville does not mark the unconformity as previously assumed. The Devonian dolomite beds of what have previously been assigned to the Cambrian Maxfield Limestone are not distinctive from the beds of definite Maxfield found lower in the Rock Canyon section. Thus, position of the major pre-Mississippian unconformity is somewhere below the 1.6-m interval of conodont-bearing dolomite beds (below the basal clastic unit of the Fitchville). The dolomite lithologies as well as the absence of an angular relationship in the underlying strata are problems that will continue to trouble those attempting to identify the location and age of the unconformity.

Clearly, the major pre-Mississippian unconformity in Utah is not well understood. Additional field work is needed in Rock Canyon and elsewhere in central and eastern Utah in order to retrieve large size samples taken at closely spaced stratigraphic intervals below the established Devonian strata. Microfuana from such samples will be the most helpful tool for understanding the location and magnitude of Utah's major pre-Mississippian unconformity.

ACKNOWLEDGMENTS

Charlie Sandberg, U.S. Geological Survey, provided details of his earlier work in Rock Canyon as well as suggestions that were important for our interpretations. Ray Ethington, University of Missouri, reviewed conodont identifications. Funding for the field and lab work was provided from the Weeks Bequest of the University of Wisconsin Geoscience Department and from the Department of Geological Sciences, Brigham Young University.

REFERENCES

Baker, A.A., 1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geological Survey Oil and Gas Investigations Preliminary Chart 30, 1 plate.

Beach, G.A., 1961, Late Devonian and Early Mississippian biostratigraphy of central Utah: Brigham Young University Geology Studies, v. 8, pt. 2, p. 37-54.

Clark, D.L., Sweet, W.C., Bergström, S.M., Klapper, G., Austin, R.L., Rhodes, F.H.T., Müller, K.J., Ziegler, W., Lindström, M., Miller, J.F., and Harris, A.G., 1981, Miscellanea, Supplement 2, Conodonta, *in* Robison, R.A., Ashlock, V., Keim, J., and Williams, R.B., editors, Treatise on invertebrate paleontology, Part W: Geological Society of America and University of Kansas, 202 p.

Derenthal, D., Pahnke, P., and Ritter, S.M., 2008, Stratigraphy and geochemistry of the Cambro-Devonian unconformity, Rock Canyon, Utah: Power Point Presentation, Department of Geological Sciences, Brigham Young University, Spring Research Conference.

Gosney, T.C., 1982, Conodont biostratigraphy of the Pinyon Peak Limestone and the Fitchville Formation, Late Devonian-Early Mississippian, north Salt Lake City, Utah: Brigham Young University Geology Studies, v. 29, pt. 2, p. 27-39.

Hintze, L.F., and Kowallis, B.J., 2009, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 9, 225 p.

Morris, H.T., and Lovering, T.S., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geologic Survey Professional Paper 361, 145 p., 5 plates, various scales.

Parsons, B.P., and Clark, D.L., 1999, Conodonts and the Cambrian-Ordovician boundary in Wisconsin: Geoscience Wisconsin, v. 17, p. 1-10.

Rigby, J.K., 1959, Upper Devonian unconformity in central Utah: Geological Society of America Bulletin, v. 70, p. 207-218.

Sandberg, C.A., and Gutschick, R.C., 1979, Guide to conodont biostratigraphy of Upper Devonian and Mississippian rocks along the Wasatch Front and Cordilleran Hingeline, Utah, *in* Sandberg, C.A., and Clark, D.L., editors, Conodont biostratigraphy of the Great Basin and Rocky Mountains: Brigham Young University Geology Studies, v. 26, pt. 3, p. 107-133.

GEOLOGY OF THE INTERMOUNTAIN WEST
an open-access journal of the Utah Geological Association
Volume 1 *2014*

A Guide to the Bedrock Geology of Range Creek Canyon, Book Cliffs, Utah

Nora M. Nieminski[1] and Cari L. Johnson[2]
[1]*Department of Geological and Environmental Sciences, Stanford University, Stanford, California; norski87@gmail.com (formerly Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah)*
[2]*Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah*

GEOLOGY OF THE INTERMOUNTAIN WEST

an open-access journal of the Utah Geological Association

Volume 1 **2014**

Production

Cover Design and Desktop Publishing
Douglas A. Sprinkel

Cover Photograph
Range Creek Canyon.
Photograph by Nora Nieminski.

Become a member of the UGA to help support the work of the Association and receive notices for monthly meetings, annual field conferences, and new publications. Annual membership is $20 and annual student membership is only $5. Visit the UGA website at www.utahgeology.org for information and membership application.

The UGA board is elected annually by a voting process through UGA Members. However, the UGA is a volunteer driven organization, and we welcome your voluntary service. If you would like to participate please contact the current president or committee member corresponding with the area in which you would like to volunteer.

Utah Geological Association formed in 1970 from a merger of the Utah Geological Society, founded in 1946, and the Intermountain Association of Geologists, founded in 1949. Affiliated with the American Association of Petroleum Geologists

GEOLOGY OF THE INTERMOUNTAIN WEST
an open-access journal of the Utah Geological Association
Volume 1 **2014**

A Guide to the Bedrock Geology of Range Creek Canyon, Book Cliffs, Utah

Nora M. Nieminski[1] and Cari L. Johnson[2]
[1]*Department of Geological and Environmental Sciences, Stanford University, Stanford, California; norski87@gmail.com*
(formerly Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah)
[2]*Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah*

ABSTRACT

Range Creek Canyon, located within the Book Cliffs of eastern Utah, contains some of the most abundant and well-preserved archaeological sites in North America. Its cliffs and landscapes provide a canvas for rock art panels and a foundation for granaries, ruins, and artifacts of the prehistoric Fremont Indians. In order to place these Range Creek sites within a geologic context, an illustrated geologic field guide was created for the general public. The guide focuses on the major bedrock formations that crop out in the canyon, as well as many indicators that facilitate geologic interpretation of these rocks. Outcrops of the Paleogene Flagstaff and Colton Formations (~58 to 48 million years old) in Range Creek Canyon were investigated in order to interpret their depositional environments. The lacustrine Flagstaff Limestone contains limestone beds and fossils of freshwater gastropods, oysters, and turtles indicative of lake environments. The unit coarsens upward with an increase of interbedded sandstone, which was deposited in and near ancient river channels. This trend suggests dynamic levels of the ancient lake, with overall encroachment of river systems near the contact with the Colton Formation. The fluvial Colton Formation is characterized by discontinuous, stacked beds of sandstone, representing a succession of migrating river channels and floodplain deposits. The Colton Formation exhibits a general upward trend of increased grain size and increased channel belt (continuous sandstone beds) frequency and lateral extent, implying a transition to higher energy river systems through time. These dynamic, ancient rivers may have been flowing generally northward into Eocene Lake Uinta, recorded in deposits of the Green River Formation north of Range Creek Canyon.

INTRODUCTION

Range Creek Canyon is an isolated canyon located southeast of Price, Utah, within the Book Cliffs (west of Desolation Canyon between the Book and Roan Cliffs) in Emery County (figure 1). The entire canyon is cut by the serenely flowing Range Creek, which is guarded on either side by walls of beautifully exposed rock; a physical record of the canyon's geologic past and a gallery of hundreds of Fremont Indian sites that recount its archaeological history.

Range Creek Canyon was discovered by white settlers in 1884 and was used primarily for cattle ranching until recently. After the Wilcox family purchased the property in 1951, two generations of Wilcoxes succeeded in making a living in this remote area. The Wilcox family held the ranch until 2001, when it was sold to the U.S. Bureau of Land Management. Ownership was

Nieminski, N.M., and Johnson, C.L., 2014, A guide to the bedrock geology of Range Creek Canyon, Book Cliffs, Utah: Geology of the Intermountain West, v. 1, p. 6-31.

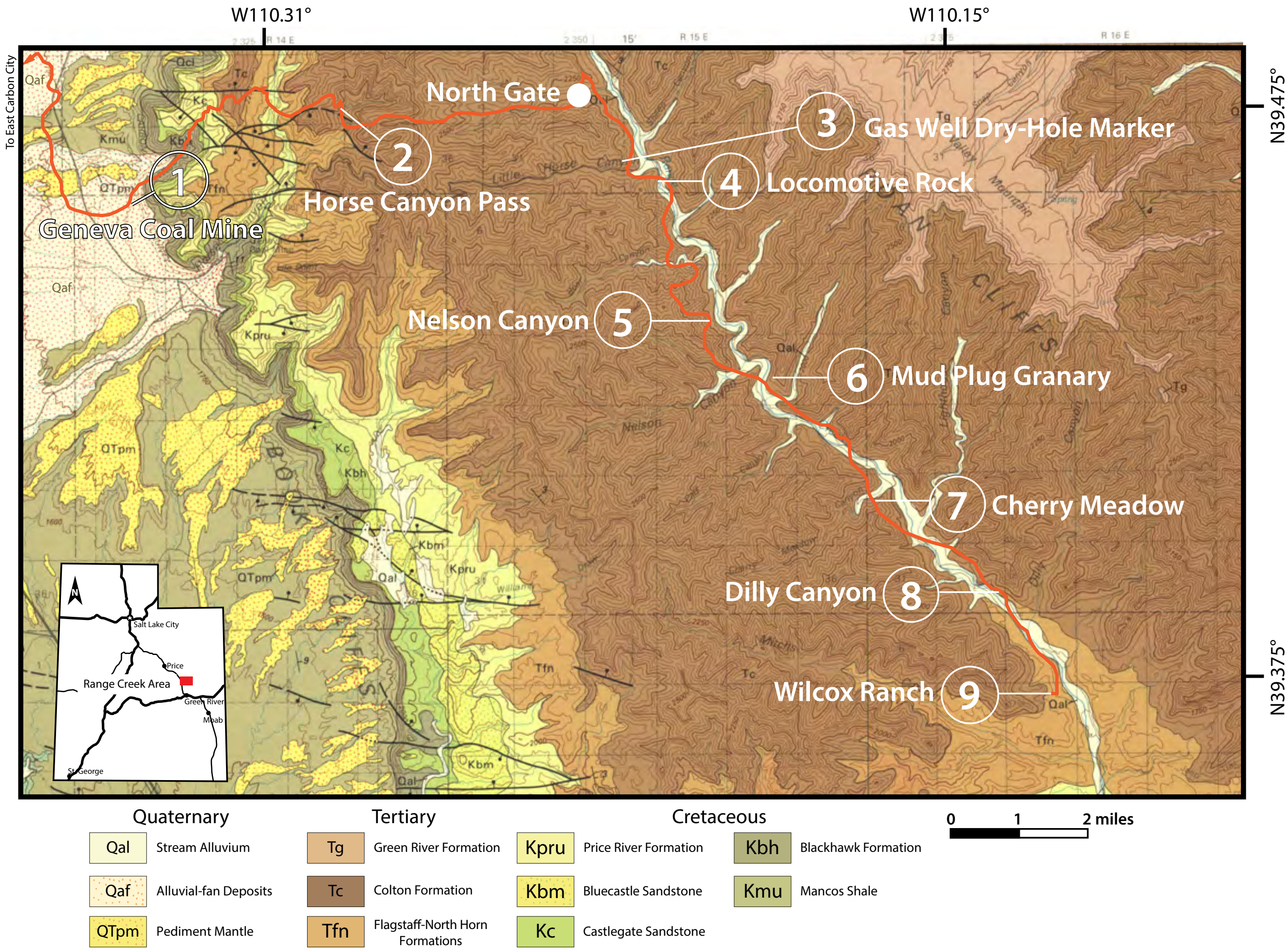

Figure 1. *Geologic map of the Range Creek area showing the route and stops described in this article (geologic map after Witkind, 2004).*

later transferred to the State of Utah (Gerber and Aton, 2011). In 2009, the former ranch came under the management of the Natural History Museum of the University of Utah as a field station to train students and serve as a catalyst for the study of the natural history of the area.

There are numerous markers throughout the canyon that recount the relatively recent history of Range Creek. Near the top of the switchbacks of the Horse Canyon Road, leading into Range Creek from the north, historic graffiti strictly warn visitors that there is "No pickin' flowers" and "no beer drinkin' " within the canyon. Coal cars used as dams in the creek are still visible. A few stone houses and remains of homesteads can be found near the creek, and abandoned exploratory gas wells document exploration drilling that was abandoned in the 1970s. Just as the canyon offers reminiscent remains of "early" settlers of the nineteenth and twentieth centuries, Range Creek is also filled with evidence of the much more ancient inhabitance by the Fremont Indians, who occupied the canyon a thousand years ago, before mysteriously disappearing (Kloor, 2006). As of 2013 archaeologists have found and recorded 465 archaeological sites, with only about 10 percent of the canyon explored (Duncan Metcalfe, University of Utah, written communication, November 27, 2013). Archaeologist Kevin Jones explains that what makes Range Creek such a "national treasure" is that "there are few places left in the continental U.S. where the sites haven't been picked over and vandalized to a great extent" (Potterfield, 2004; Kloor, 2006, p. 70). The relatively pristine condition of many of the sites in Range Creek offers more dependable insight into their original purpose and use. The Fremont Indians were foragers and farmers who lived in most of what is now the state of Utah between A.D. 200 and A.D. 1300. Evidence of their occupation of Range Creek includes dwellings, granaries, petroglyphs, and pictographs.

The specific locations of sites are of particular interest to archaeologists. Dwellings are usually found along the lower slopes of the canyon, above the valley bottom and farm plots, where the flat terrain is easily accessible and proximal to the creek. Many of the granaries for storage of food, however, are located on heart-stoppingly steep cliff faces hundreds of feet high. Clearly, the Fremont had something to fear, something from which to keep their food protected (Metcalfe, 2008; Barlow and Phillips, 2010). Some archaeologists speculate this threat led to their subsequent, sudden disappearance (Madsen and Simms, 1998).

The dangerous location of granaries is one direct connection that has inspired archaeologists' interest in the geologic history of Range Creek—a fascinating story millions of years older than the prehistoric Fremont sites. The rocks within Range Creek offer an excellent opportunity to learn about the region's geologic history. In particular, the canyon provides abundant clues as to the processes by which the rocks were deposited, millions of years before the Fremont came to inhabit them.

REGIONAL GEOLOGY

The geologic origin of the rocks within Range Creek Canyon is associated with the ancient Uinta Basin, which encompasses most of northeast Utah (Johnson, 1985; Morgan and others, 2003). The Uinta Basin is a sedimentary basin, which is a relatively low topographic area that was filled with different layers of sediments deposited during successive time periods (figure 2). At periods when there is high accommodation (space for sediment to be deposited and preserved) relative to sediment supply, lake environments are most common. However, when available accommodation becomes much smaller relative to sediment supply, rivers commonly occupy and migrate over one another across the floodplain. These successive changes of environments are recorded in the stratigraphy of the ancient Uinta Basin. The Uinta Basin and co-existing Piceance Basin (separated by the Douglas Creek arch in Colorado) are generally bound by the Uinta Mountains to the north, the San Rafael Swell to the south, the White River uplift and Elk Mountain (in Colorado) to the east, and the Wasatch Range and Wasatch Plateau to the west (figure 3; Johnson, 1985; Morris and others, 1991; Dubiel, 2003).

The Uinta Basin formed as a result of active thickening and loading of the Earth's crust due to a regional mountain-building event known as the Laramide orogeny, 75 to 35 million years ago, during Late Cretaceous to late Eocene time (Johnson, 1985; Carroll and others, 2006; Lawton, 2008). This tectonic event helped form the Uinta Basin by loading the crust, which resulted in a depression adjacent to the loading in the same way that a diving board will bend behind the person (load) applying stress to it. Structurally, the uplifted surrounding highland produced a basin with internal drainage, which was filled by ancestral Lake Uinta and Lake Flagstaff, and was fed by several rivers. This ancestral lake deposited both fluvial (river) and lacustrine (lake) sediments (Johnson, 1985; Morgan and others, 2003; Dubiel, 2003; Keighley and others, 2003).

ROCKS AND DEPOSITIONAL ENVIRONMENTS OF RANGE CREEK CANYON

Exposed rocks within Range Creek Canyon are roughly late Paleocene to early Eocene in age, and thus range from approximately 58 to 48 million years old (Ryder and others, 1976; Franczyk and Pitman, 1991). The age ranges for rock units is variable depending on location (figure 2). The major rock units exposed in Range Creek include the Flagstaff and Colton Formations, both lying below the Green River Formation (figure 1). Each of these rock units is described at various stops in the field guide.

Flagstaff Limestone

The Flagstaff Limestone, partially equivalent to the North Horn Formation, is late Paleocene to early

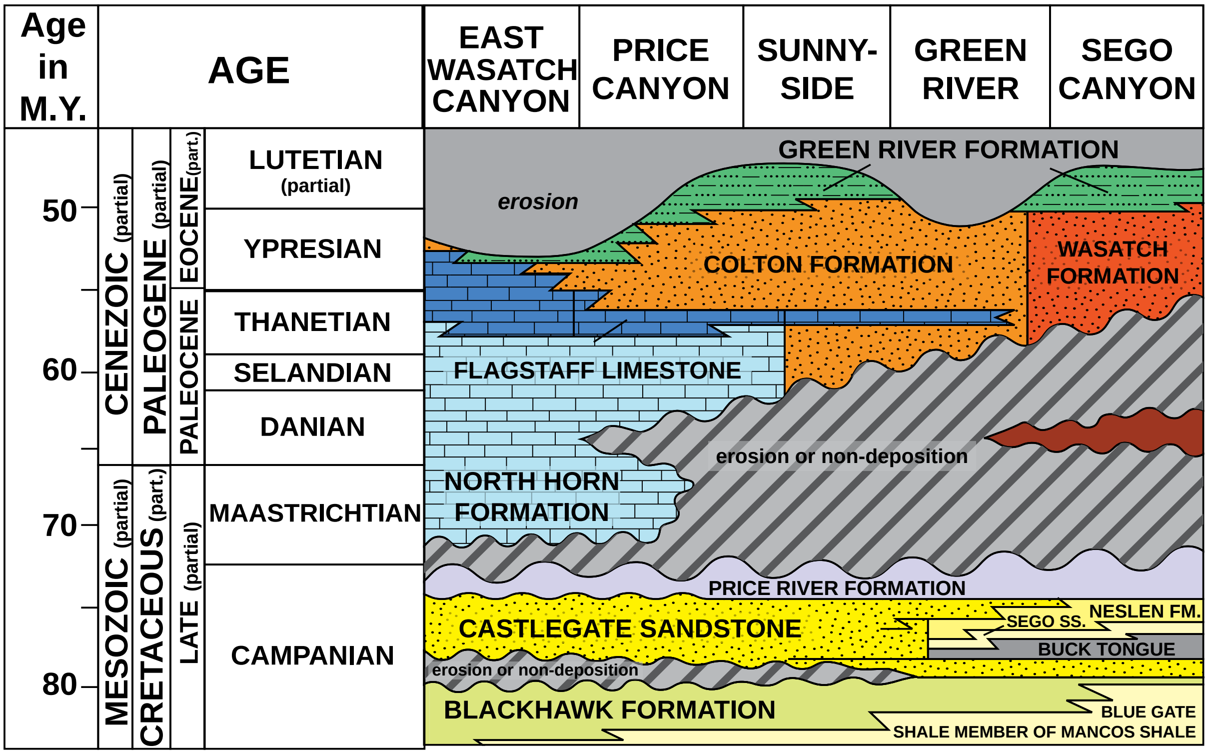

Figure 2. *Simplified stratigraphic cross section of Late Cretaceous and early Paleogene sedimentary units deposited in the Uinta Basin near Range Creek Canyon (scaled to time axis). Approximate location of Range Creek Canyon is near Sunnyside. General stratigraphy exposed near Range Creek Canyon (from oldest to youngest) is: Blackhawk, Castlegate, Price River, North Horn, Flagstaff, Colton, and Green River Formations. Gray, diagonally marked units represent missing time in section (unconformities) from non-deposition or erosion. Vertical lines that break up units mark changes in nomenclature, depending on region (modified from Franczyk and Pitman, 1991).*

Eocene in age (beginning ~58 million years ago) and is exposed north of Range Creek, along the drive up Horse Canyon and at the southern end of Range Creek Canyon (figure 2; Stanley and Collinson, 1979; Wells, 1983; Franczyk and Pitman, 1991). In the road guide that follows, the Flagstaff Limestone is distinguished from the North Horn Formation, and is first described 11.2 miles from the North Gate. In Range Creek, the Flagstaff Limestone is comprised primarily of limestone beds. Limestone is a sedimentary rock largely composed of calcium carbonate ($CaCO_3$), which has chemical properties that make it highly soluble in water and weak hydrochloric acid solution (HCl). Limestone is formed by organic and inorganic processes that precipitate the mineral calcite in marine, lacustrine, or evaporite environments. Within the limestone beds of the Flagstaff Limestone, there is a relatively high concentration of fossils including gastropods, oyster shells, and even turtle shell fragments, all of which have been documented to inhabit freshwater lakes during the late Paleocene and early Eocene geological epochs. There are also burrows in the rocks, which can be created by a variety of water-living organisms as they scrounge for food or escape predators in an environment of relatively low energy, such as a lake (Stop #8 and corresponding figures). Thus, the Flagstaff Limestone reflects lake and lake-margin depositional environments.

The Flagstaff Limestone, though mostly limestone, coarsens upward and has increased interbedded sandstone layers up-section. Sandstone is usually deposited in higher energy environments, such as fluvial depositional environments. The interbedded sandstone within the limestone suggests dynamic levels and hydrology of the ancient Lake Flagstaff with an overall increase in proximity to fluvial sediment input at the contact of the Flagstaff with the Colton Formation. These dynamic

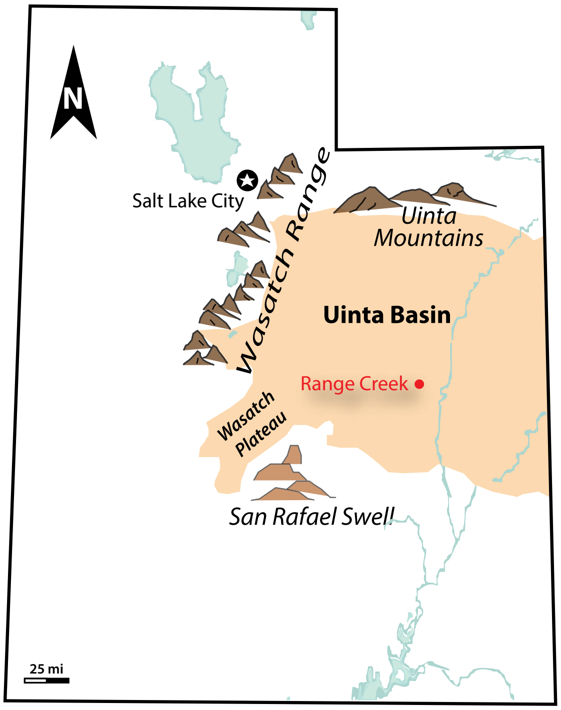

Figure 3. *Location of Range Creek Canyon with respect to bounding structural features that contributed to the formation of the Uinta Basin. The co-existing Piceance Basin in Colorado (not shown) was separated by the Douglas Creek arch, also in Colorado. The Paleogene extent of the Uinta-Piceance Basins is bounded by the Uinta Mountains to the north, by the San Rafael Swell to the south, by the White River uplift and Elk Mountains on its eastern edge in Colorado (not shown), and by the Wasatch Range and Wasatch Plateau on its western edge (modified after Stanley and Collinson, 1979; Dubiel, 2003).*

lake levels were most probably a response to tectonic and climactic changes at the time, similar to contemporary lakes that vary in size and depth due to the same causes (Stanley and Collinson, 1979).

Colton Formation

Exposed in the northern part of Range Creek Canyon, and stratigraphically above the Flagstaff Limestone, lies the younger Colton Formation, partially equivalent to the Wasatch Formation (figure 2; Franczyk and Pitman, 1991; Morgan and others, 2003). The Colton Formation is early Eocene in age, or roughly 55 to 48 million years old (Ryder and others, 1976; Pitman and others, 1986; Franczyk and Pitman, 1991). It is composed of sandstone and mudstone and is the rock unit where most of the Fremont granaries are located. Because sandstone is deposited under higher energy and has a larger grain size, it tends to resist erosion and form large cliff faces, whereas mudstone and shale wear away and appear receded within the walls of rock (Stop #4 and corresponding figures), depending on degrees of cementation. Fremont granaries were meant to be protected from weather and foe, and that is most likely the reason the Fremont Indians in Range Creek chose to build their granaries in more resistive, cliff-forming sandstone rock layers of the Colton Formation.

Sandstone beds of the Colton Formation were deposited by rivers that flowed throughout the area that is now Range Creek Canyon. These rivers flowed northward and fed into ancient Lake Uinta (Dickinson and others, 1986; Morris and others, 1991; Dickinson and others, 2012). This can most easily be tested with more research within the canyon, specifically by taking measurements of structures within the sandstone bedding to statistically determine the direction of water flow (paleocurrents) as sediments were deposited. It is clear that rivers occupied what is now Range Creek Canyon for millions of years, as indicated by the discontinuous, stacked beds of sandstone and interbedded mudstone layers, representing a succession of migrating river channels and inter-channel (floodplain) deposits.

Outcrops of discontinuous sandstone beds are indicative of fluvial systems because of the river system's dynamic energy levels (as opposed to a constant, more stagnant, lower energy lake environment that can be recognized by continuous limestone beds). Relatively continuous sandstone cliffs such as those visible throughout Range Creek indicate migrating river channels. As rivers migrate across a floodplain, they continually stack layers of sand that are deposited out of the water column as high-energy events (like floods) wane to lower-energy flow (figure 4). Finer-grained sediments, like mud and silt, in contrast, are more easily transported by low-energy systems. Thus, mudstone is usually deposited during lower-energy events, or during sudden (and often complete) waning of high-energy systems. If a river suddenly abandons its channel and moves to another position on the floodplain or if its water level decreases rapidly, the energy dramatically drops from

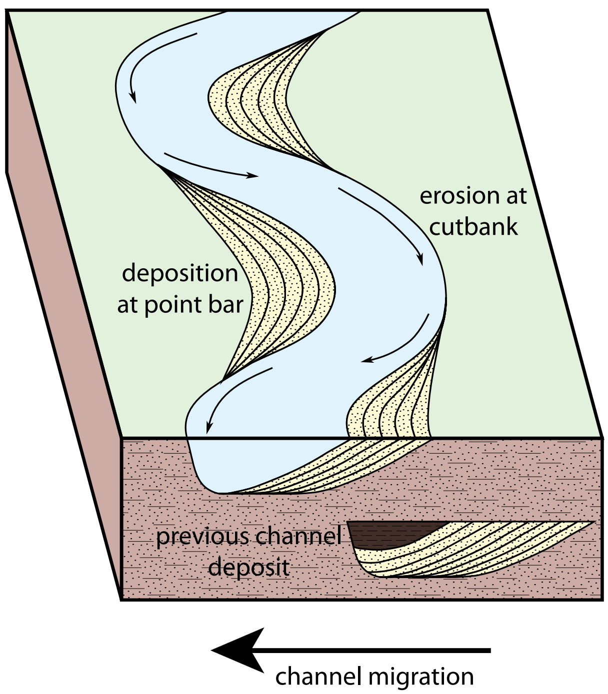

Figure 4. *A meandering river channel migrates laterally by cutting away at its cutbank and by depositing sediment at its point bar. The process of erosion and deposition is related to the vortex water flow of the water around each bend of the channel. The arrows in the figure represent the flow path that hits the cutbank with the highest energy, after which a secondary, lower-energy flow carries the eroded material from the cutbank across the floor of the channel where it is deposited at the point bar, at the other side of the channel, and only a small distance downstream. As the channel migrates, the point bar deposits end up stacked on top of one another and can then be preserved in the rock record if ever buried below the surface. The previous channel deposits of a migrating channel represent what comprises the sandstone cliffs in Range Creek.*

the high energy of a flowing river to much lower energy. The mud that the river was carrying at higher energy is deposited during such a low-energy event, and eventually becomes mudstone that can often be seen deposited in the shape of its ancient channel (Stop #6 and corresponding figure). When a mudstone layer appears to be deposited in the shape of a smile (which, with some imagination, reflects the shape of the cross section of a river channel), it is indicative of an abandoned channel that was filled in by lower-energy mud after the river avulsed from its previous location on the floodplain.

Smaller-scale features within the Colton Formation that characterize the fluvial depositional system include cross-bedding within the sandstone, which indicates direction of water flow; channel scours, which are indicative of erosion at the base of river channels; and other sedimentary features such as channel lags, which contain larger-grained pebbles, indicating higher energy of a river channel (Stop #5 and corresponding figures). All of these features, both large and small scale, in Range Creek describe the ancient river regime.

The Colton Formation as a whole exhibits a general upward trend of increased grain size, channel belt (sandstone bed) frequency, and lateral extent. The lower part of the Colton Formation is distinguished by a darker red lithology (rock composition) that is much finer grained and has more abundant interbedded mudstone compared to the upper, lighter-colored, coarser-grained, sandstone-dominated unit of the Colton (figure 5). This coarsening-upward sequence of the Colton Formation implies a transition from lower energy river environments, deposited just after the deposition of lacustrine sediments of the Flagstaff Limestone, to higher energy river systems that evolved with time.

GREEN RIVER FORMATION

Even though the Green River Formation is not exposed in the bottom of Range Creek Canyon, it can be seen in the distance on top of many of the peaks bordering the canyon, capping both the Flagstaff and Colton Formations. The Green River Formation ties together the depositional history of the Flagstaff and Colton Formations, as the rivers of the Colton Formation are interpreted to have flowed into Lake Uinta, which is recorded in the deposits of the middle Eocene Green River Formation (Marcantel and Weiss, 1968; Blakey and Ranney, 2008; Smith and others, 2008). The Green River Formation has been extensively described north of Range Creek Canyon, in Nine Mile Canyon. The rock unit is characterized by finer-grained sandstone that has fewer fossils than the Flagstaff and Colton Formations and is interbedded with abundant green shale (Marcantel and Weiss, 1968; Remy, 1992; Keighley and others, 2003). The shale beds of the Green River Formation have proven to be a reliable source for oil and gas in the Uinta Basin, having been buried to sufficient depths and temperatures to convert ancient biomass to valuable hydrocarbons (Cashion, 1967; Pitman and others, 1986).

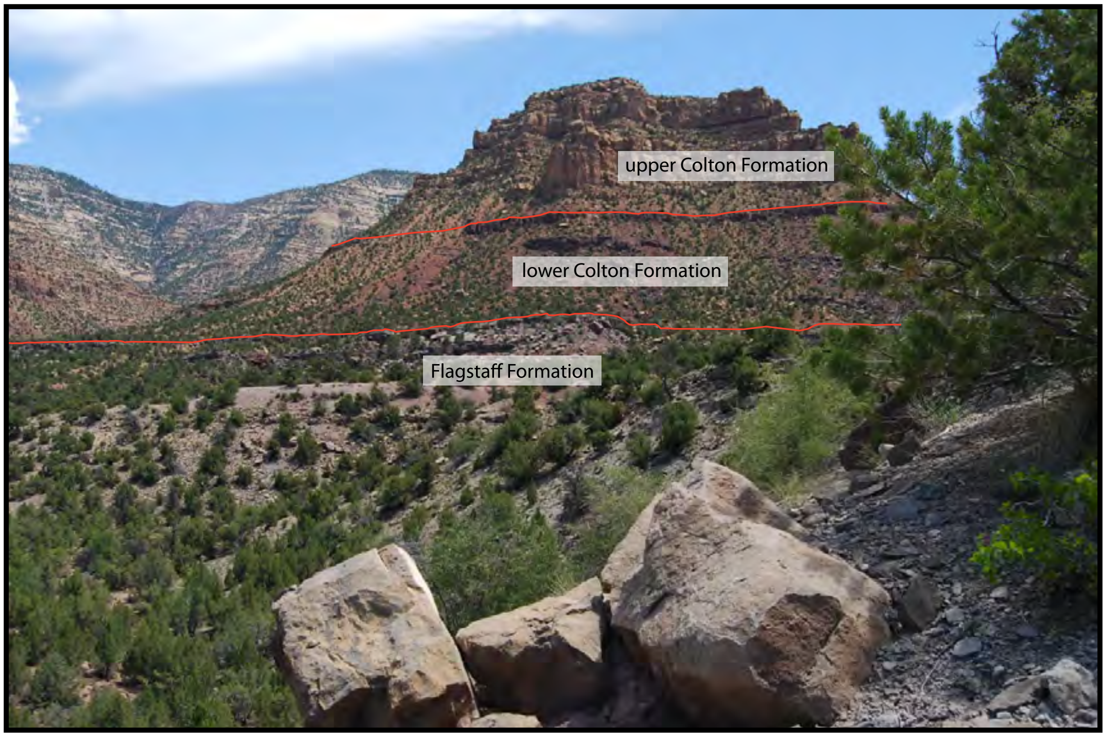

Figure 5. *View facing southeast from the mouth of Dilly Canyon, showing exposed rock formations in Range Creek. The Flagstaff Limestone is easily distinguishable by its gray color and laterally continuous thin limestone beds. Recall that the Flagstaff Limestone is exposed along the drive up Horse Canyon, but is not exposed within Range Creek Canyon until 11.2 miles from the north gate. Above the Flagstaff Limestone in Range Creek Canyon is the lower unit of the Colton Formation, which is distinguished from the upper unit by its redder color and more abundant interbedded mudstone within the sandstone. The upper Colton Formation exhibits a higher channel belt frequency (has more abundant laterally continuous cliffs of sandstone).*

GEOLOGIC EVOLUTION OF PALEOGENE STRATA OF RANGE CREEK

Just as the Fremont history reveals conditions of prehistoric human life in Range Creek Canyon, the geologic layers indicate changing environmental conditions of the area before the canyon cut by Range Creek ever existed. A working hypothesis is that the Paleogene rocks exposed in Range Creek record a major climatic shift, in addition to changing tectonic conditions (Bowen and others, 2008).

More detailed study of these rocks, particularly of the contact between the Flagstaff and Colton Formations, might offer information concerning environmental conditions roughly 56 million years ago. The limestone of the Flagstaff preserves significant organic content. Not only is the limestone abundant in fossils, but it also contains wood fragments and coal seams, both indicative of high organic matter preservation favored particularly in wet, oxygen-reducing conditions (figure 6). The lower unit of the Colton Formation immediately above the Flagstaff, however, is much poorer in organic content and is distinctly red, indicating more oxidized and high-energy environments. Organic content does increase near the top of the Colton Formation and into the Green River Formation at the top of the plateau. Thus, moving upward in the section, or moving up into younger layers, organic content decreases for a certain interval in time before increasing again much higher in the section (later in time). This dramatic change could signify a warming and drying within the periods of deposition of these two layers.

On the geologic time scale, the Flagstaff and Colton Formations encompass the Paleocene-Eocene boundary, which is well known for the Paleocene-Eocene

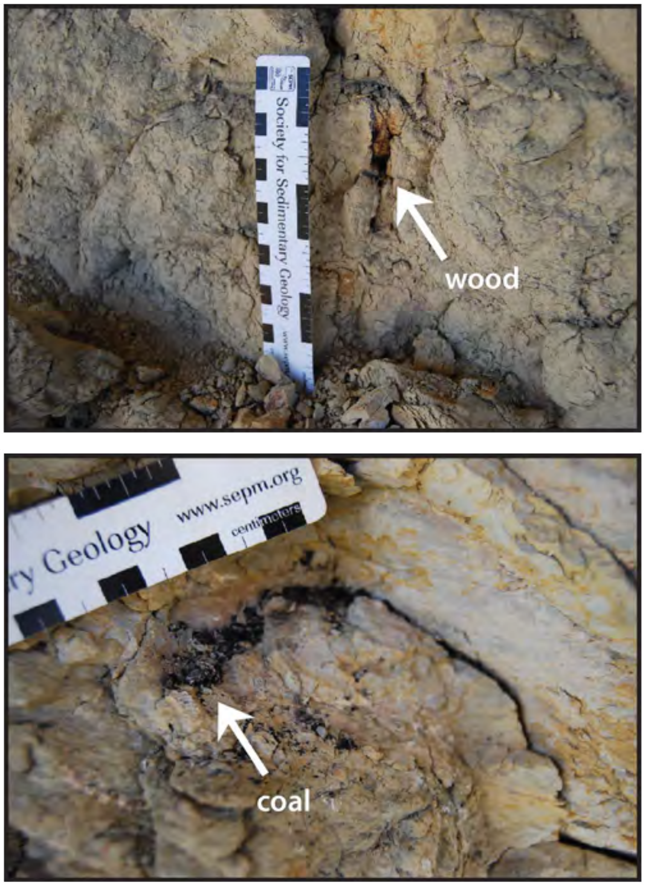

***Figure 6.** Two indicators of organic content in rocks are wood fragments and coal seams. Wood fragments that are preserved in rocks are usually red in color from being oxidized over time. Coal is usually thinly bedded and can be poorly consolidated. Both wood and coal are often associated with very low-energy, organic-rich depositional environments such as lagoons or backswamps on the other side of river channel levees.*

Thermal Maximum (PETM). This major climatic shift is documented worldwide as a time when the global mean temperatures increased by 6 to 8°C (11-14°F) within 10,000 to 30,000 years (Higgins and Schrag, 2006; Roehl and others, 2007). Regionally, temperatures may have increased by 4 to 5°C (7-9°F) or even by as much as 12°C (22°F) over the subsequent 6 million years following the early deposition of the Flagstaff Limestone (Wilf, 2000; Zachos and others, 2001). Although the causes of this drastic event are still debated, the warming was clearly triggered by an incredible and sudden influx of carbon into the atmosphere (Torfstein and others, 2010). Pending further research, it is postulated here that the rocks of Range Creek Canyon could record this remarkable event.

ROAD GUIDE TO GEOLOGIC POINTS OF INTEREST

Range Creek Canyon, although most well known for its beautifully preserved Fremont Indian sites, is also filled with interesting geologic sites that display features in the rocks that are indicative of ancient depositional processes and geologic history of the area. Several select sites are described in this road guide starting at the mouth of Horse Canyon, 9.5 miles southeast from East Carbon City, entering Range Creek Canyon on the east side of Horse Canyon Pass, and ending at the Wilcox Ranch, roughly 7 miles west of where Range Creek feeds into the Green River.

Visitor permits (obtained from the National History Museum of Utah) are required to enter Range Creek Canyon. Permitted access to the canyon is available from approximately mid-May to late November. Visitors should consult the Natural History Museum of Utah website (www.nhmu.utah.edu) for updated specifications concerning permits. Disruption and/or collection of any rocks, fossils, or artifacts from the canyon are strictly prohibited.

Once within Range Creek Canyon (starting at the second gate, described in the guide), this road guide follows the same 13-mile route through Range Creek Canyon that is covered by guided tours that are available through various tour providers. The guided tours stop at several locations to view rock art and granaries within the canyon. This road guide is best used to supplement a guided tour by adding information about geologic features at many of the stops highlighting fantastic Fremont Indian sites. Figure 1 shows the locations of the nine sites covered in the 23-mile guided route road guide. Each of these numbered sites corresponds to the following numbered stops along the route.

1. Geneva Coal Mine at Horse Canyon

To reach the Geneva Coal Mine (Stop #1) at the mouth of Horse Canyon, turn right on UT-124 S and continue 9.4 miles from East Carbon City. Stay left where UT-124 S becomes Horse Canyon Road. Just after the paved Horse Canyon Road that leads to the mouth of Horse Canyon becomes a dirt road, it passes alongside the remains of the abandoned Geneva Coal Mine (figure 7). The mine, originally run by Geneva Coal and Steel, was developed in 1942 to support the World War II war effort (Butler, 1961; also see Utah Coal Program website). The Geneva Steel Mill was built in Orem, Utah, during the same year to process the mine's metallurgical grade coal from the Book Cliffs reserves. After the war, the United States Steel Corporation purchased both the mine and the mill and continued operation

Figure 7. *View of Geneva Coal Mine, at the mouth of Horse Canyon, on the right side of the road looking up the canyon.*

under the name of Horse Canyon coal mine until the facilities were closed in 1982.

The rock layers directly above the mine consist of the Upper Cretaceous Blackhawk Formation, Castlegate Sandstone, and Price River Formation, ranging from roughly 80 to 70 million years in age (figures 1 and 2). These rock formations, though nicely exposed along the drive up Horse Canyon Road, are not exposed in Range Creek Canyon.

The Blackhawk Formation is characterized as a fine- to medium-grained sandstone with siltstone and interbedded coal and has been interpreted as the westernmost edge of the Western Interior Seaway: an ancient sea that divided North America during the Late Cretaceous (~100 to 66 million years ago). The ancient seaway's shoreline gradually migrated eastward during the Late Cretaceous time period, as shown in figure 8 (Johnson and others, 2005). This eastward regression of the Western Interior Seaway deposited sediment that resulted from the marine and shoreline depositional environments, and that are represented in the Blackhawk Formation throughout the Book Cliffs. By comparison, the Flagstaff (North Horn), Colton (Wasatch), and Green River Formations were deposited beginning ~20 million years later, after this seaway had receded and was replaced by large river and lake systems.

The coal that was mined in Horse Canyon (and the seam of coal that can be seen capping a white layer of shoreface sandstone here at the bottom of Horse Canyon) was most likely deposited in the coastal mires near the shoreline of the Western Interior Seaway. Here organic plant material was deposited as peat and eventually converted to coal during burial.

The uppermost part of the drive up Horse Canyon offers an ample introduction to the rock units that are exposed in Range Creek Canyon; the Flagstaff and the Colton Formations, composed of rocks that were deposited from the lakes and rivers that existed in the area roughly 58 to 48 million years ago (figure 1; Franczyk

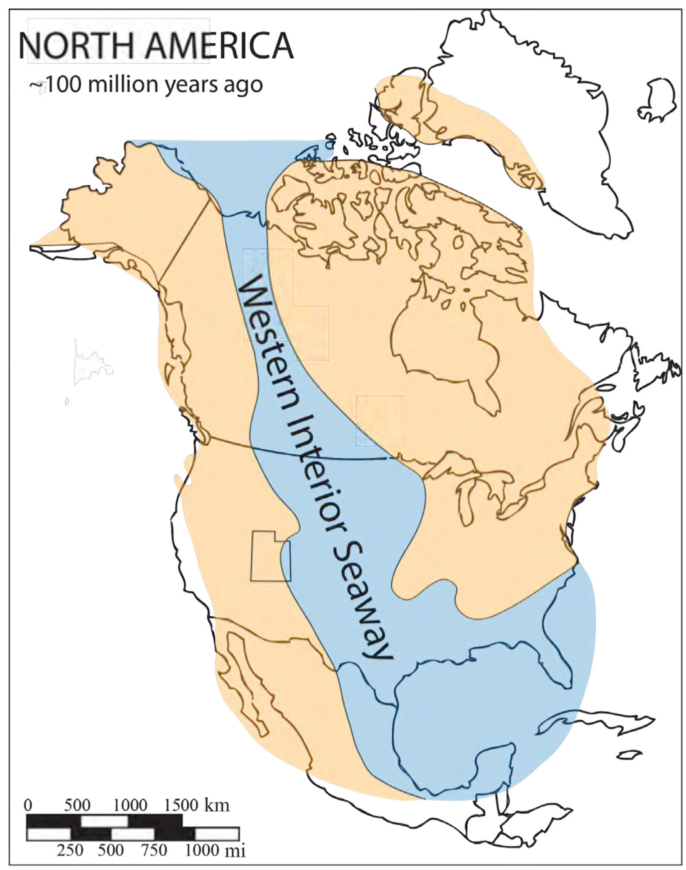

Figure 8. *North America split in two by the Western Interior Seaway, roughly 100 million years ago. Highlight of Utah shows the approximate paleoshore during the deposition of the Blackhawk Formation (modified after Johnson, 1985).*

and Pitman, 1991; Witkind, 2004). Above the Blackhawk, Castlegate, and Price River Formations there is a transition into the gray limestone of the Flagstaff Limestone, which is exposed again in the southern end of Range Creek Canyon. Along the climb up Horse Canyon, watch for yet another transition and contact between this gray limestone of the Flagstaff Limestone and a reddish sandstone that makes up the Colton Formation (figure 9).

2. Horse Canyon Pass

Horse Canyon Pass (elevation 8577 feet) is 5.5 miles farther along the main dirt, Horse Canyon Road, from the Horse Canyon Mine. Stop #2 offers an ideal opportunity to step outside the car, take in the beauty of the surrounding Book Cliffs, and peer down (looking east) into the mystifying Range Creek Canyon. Roughly 50 feet from the pullout at the pass, in the direction of Horse Canyon, there is a road cut that illustrates the transition from lacustrine to fluvial deposits (figure 10). The distinct tabular bedding of sand is indicative of lacustrine deposits, which often include tabular, continuous beds of limestone or other sediments such as siltstone and/or mudstone (figure 10A). Alternating layers of red and green siltstone indicate changing conditions of lake levels from more oxidizing to more reducing conditions, respectively, as the lake expanded and contracted over time (figure 10B). Overall, these sediments may have been deposited in an interdistributary floodplain (a boggy, low energy environment).

North Gate is a gate located 4.1 miles past the Horse Canyon Pass along Little Horse Canyon Road, which is a continuation of the Horse Canyon Road from the pass. After passing through this first gate, make a right turn (on Range Creek Road) after the creek crossing to reach the second gate (0.3 miles south of first gate) and begin the journey to Range Creek Field Station, or Wilcox Ranch (the road that veers left after crossing the creek leads to private property).

3. Gas Well Dry-Hole Marker

One of the most important applications of geoscience involves the interpretation and mapping of geology in the subsurface for oil and gas exploration. Stop #3 is a dry-hole marker on the west side of the road that marks an abandoned exploratory gas well drilled by Chevron Oil Company 1.4 miles past the second gate and at the mouth of Dry Canyon (figure 11). This well, Nelson Unit #1 (API# 43-015-30022), is located at an elevation of 6633 feet above sea level and reached

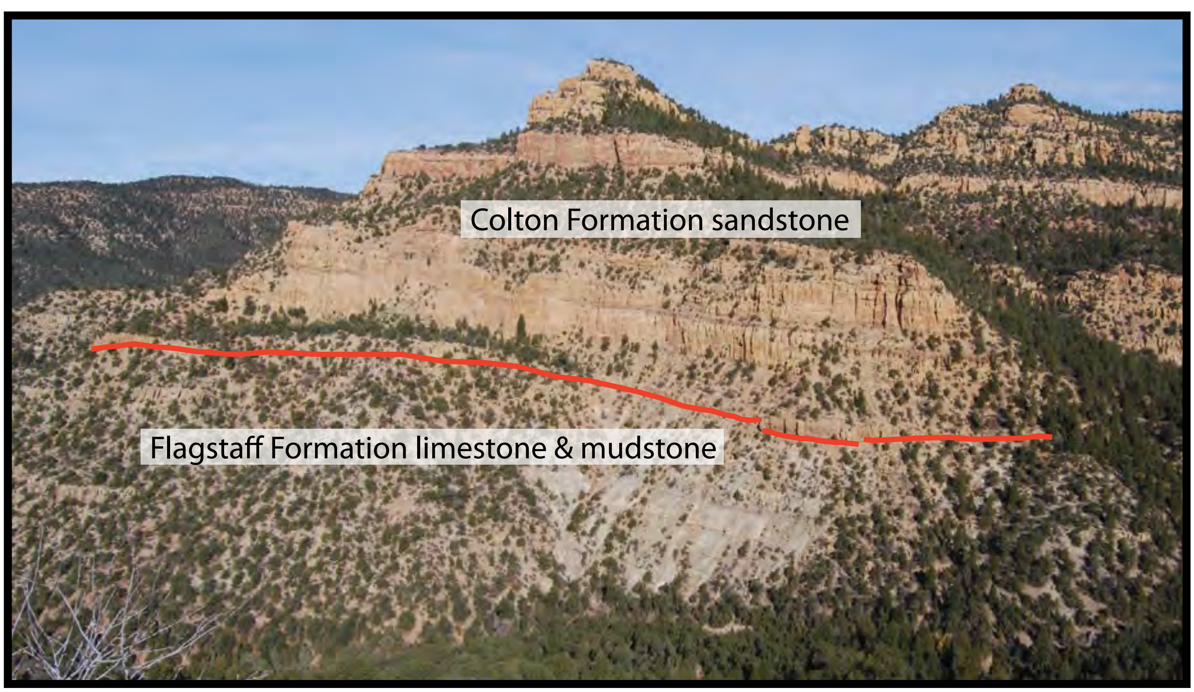

Figure 9. *View of Flagstaff and Colton Formations (the two predominant rock units that are exposed within Range Creek Canyon) along the drive up Horse Canyon. Photo taken in Horse Canyon, facing northwest, approximately 3 miles east of the Geneva Coal Mine.*

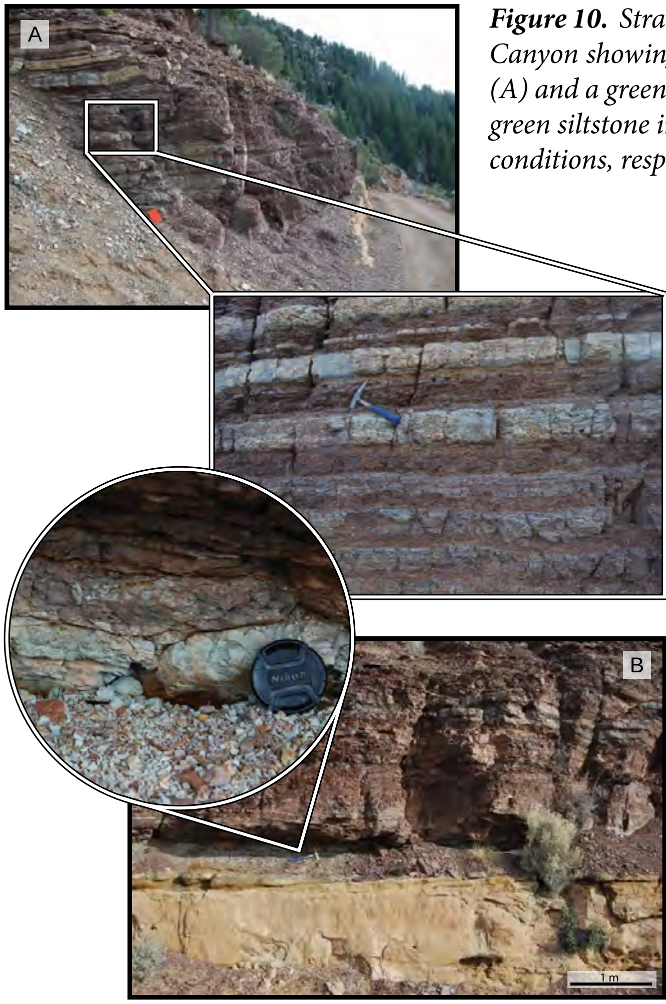

Figure 10. *Stratigraphy exposed on the south side of the road at the summit of Horse Canyon showing red, oxidized siltstone interbedded with tabular beds of sandstone (A) and a green, reduced horizon of siltstone (B). These alternating layers of red and green siltstone indicate fluctuating lake levels from more oxidizing to more reducing conditions, respectively, as the lake expanded and contracted over time.*

a total measured depth of 8773 feet (all inscribed on the marker itself). The drilling of the well commenced in 1974, and the well was plugged and abandoned just over a year later in 1975 (see Utah Oil and Gas Program website for well information). Schlumberger, an oilfield service company, was hired to run gamma-ray, resistivity, neutron density, and sonic wireline logs (measurements with depth) in the well; no core was taken. These measurements are used by geologists and petroleum engineers to interpret rock types and determine the rock properties of the penetrated subsurface formations. Chevron drilled two additional wells within Range Creek Canyon (Dilly Unit #1 [API# 43-015-30023] and Lighthouse Unit #1 [API# 43-015-30024]) with the purpose of exploring or testing the Lower Cretaceous Cedar Mountain and Upper Cretaceous Dakota Formations (roughly ranging from 125 to 94 million years in age) at depths of approximately 7000 feet for potential gas reservoirs. All wells proved non-commercial with respect to gas, producing a significant amount of water but very little gas. Perhaps because of successful oil and gas wells north of Range Creek in the highly productive areas of Nine Mile Canyon, other companies (including Bow Valley Petroleum Inc.) also drilled exploration gas wells throughout Range Creek. However, all wells failed to produce a significant amount of gas and have been plugged and abandoned.

Figure 11. *Dry well marker at the mouth of Dry Canyon, capping an abandoned exploratory gas well drilled by Chevron Oil Company in 1974.*

4. Locomotive Rock

Stop #4 is a pullout on the east side of the road, 0.4 miles past the gas well dry-hole marker. Locomotive Rock, composed of Colton Formation, is a stunning geological feature because of the interesting manner in which it eroded into the shape of a steam engine (figure 12). This phenomenon is a result of the contrasting lithologies (rock types) and the role that grain size plays on the erosion of the rocks. Grain size is a fundamental property of sedimentary rocks, as it relates to porosity and permeability of a unit (important for petroleum geologists and hydrologists) and is indicative of depositional conditions of sedimentary rocks. Course-grained sediment (sandstone) is usually deposited in relatively high-energy environments such as rivers or beach shorelines, whereas finer-grained deposits (mudstone, siltstone, shale) are deposited in calmer environments such as lakes or river floodplains. Just as coarser-grained sediments are deposited by higher-energy events, they also require more energy to erode because they are more resistant to weathering and erosion than are finer-grained sedimentary rocks. Cementation may also play a role in differential weathering in some cases. Thus, the cliff-forming, rounded rocks that create the shape of the "locomotive" are composed of sandstone, and we can assume that the more receded (eroded), darker red lithologies of the locomotive are mudstone or siltstone.

Another attraction at Locomotive Rock is its archaeological sites. To the northeast of Locomotive Rock, on the opposite (east) side of the canyon, there is a pictograph commonly referred to as "The TV" because of its shape (figure 13A); there are colored pictographs inside the cave in the rock face (figure 13B), and there is a small granary slightly farther to the south on the same rock face (figure 13C).

5. Nelson Canyon

Drive 3.2 miles farther along Range Creek Road from the Locomotive Rock site to the west of the pull-off just past Nelson Canyon. At Stop #5, there is a wall of

Figure 12. *Locomotive Rock illustrates the role that grain size and cementation exert on the differential erosion of rocks. The "steam engine" is shaped by a combination of cliff-forming sandstone and more erosive and receded mudstone or shale.*

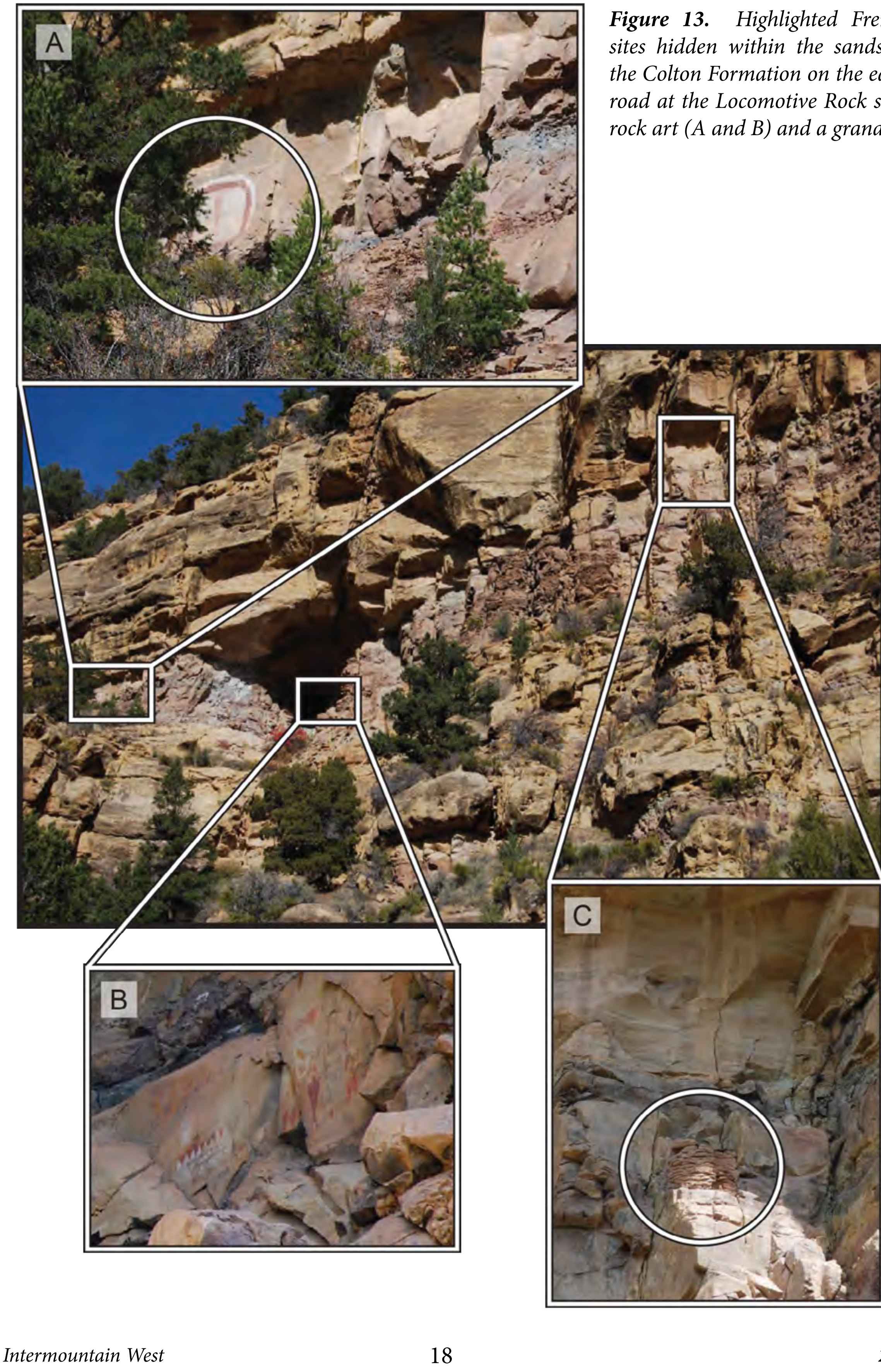

Figure 13. *Highlighted Fremont Indian sites hidden within the sandstone cliffs of the Colton Formation on the east side of the road at the Locomotive Rock stop including rock art (A and B) and a granary (C).*

Colton sandstone (figure 14) that is almost entirely covered with petroglyphs (figure 14E). This rock wall not only offers the opportunity to see an incredible number of Fremont rock inscriptions, but also to view many geologic sedimentary structures indicative of past depositional environments (figures 14A to 14D). In addition, note that roughly 200 feet north from the pullout, there is a triple-chambered granary nestled in the sandstone cliff face (figure 15A). From this point, there is also a view of Budge's Arch, named after the nickname of Waldo Wilcox's father, high on the eastern ridgeline of the canyon (figure 15B).

Channel Scour/Incision

The clearly-cut edge of the sandstone on the bottom left of the petroglyph wall is a channel scour, which is indicative of erosion at the base of a river channel (figure 14A). The erosive nature of fluvial channels can often be recognized by the truncation of sedimentary strata (layers) below the scour surface.

Trough Cross-Bedding

Cross-beds are sedimentary structures that are characterized by inclined layering within a bed of rock. Cross-bedding, also known as cross-stratification, is usually indicative of a depositional environment that had a significant flowing force or energy, such as flowing water or wind. Trough cross-bedding consists of trough-shaped sets that merge tangentially with their lower surface (figure 14B). These scoop-shaped lineations, or laminae, often originate from the migration of current ripples, commonly at the base of a river channel (Boggs, 2006). Trough cross-beds are often helpful not only as an indicator of depositional environment, but also as an indicator of direction of current flow at the time of deposition.

Silty Mudstone

The mudstone and siltstone that is interbedded within the sandstone is often red in color (figure 14C). The red siltstone beds found near Nelson Canyon are

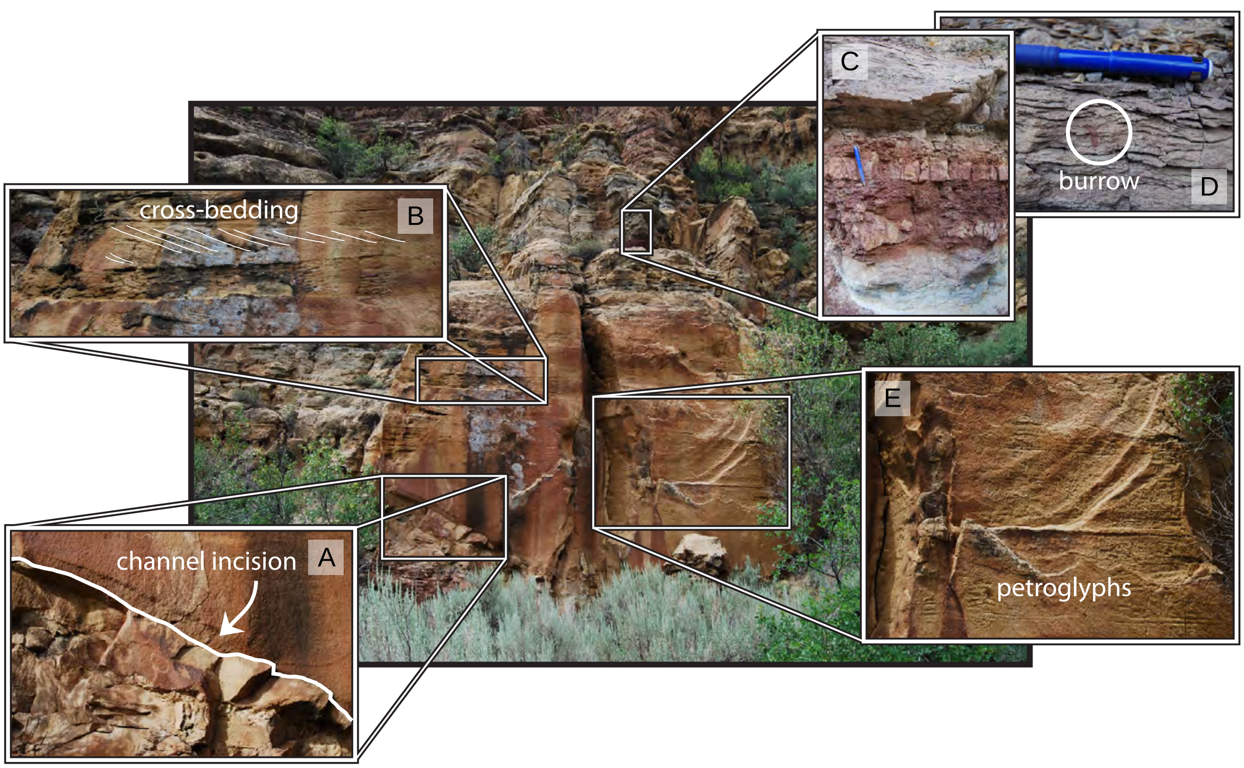

Figure 14. *Rock wall south of Nelson Canyon (view west of road) displaying many Fremont rock inscriptions (E) in addition to several geologic sedimentary structures that are indicative of past depositional environments. Sedimentary features include a channel scour (A), trough cross-bedding (B), and interbedded mudstone/siltstone with a fossilized burrow (C and D).*

Figure 15. *The stop at Nelson Canyon also offers this view of a spectacular three-chambered granary (A) and of Budge's Arch (B), named in honor of Budge Wilcox.*

similar to those seen at Horse Canyon Pass (Stop #2) before entering Range Creek, and are similarly indicative of an oxidation process. The red color results from iron oxide from a heavily oxidized environment or period of time. The mudstone/siltstone shows some evidence of animal life as well, with a few burrows within the sediment (figure 14D). A burrow is a trace fossil that is the remaining evidence of the movement, or path, of a small worm or snail.

Stratigraphic Column

Geologists use stratigraphic columns as a representation of the vertical arrangement of different rock units and their relationship to one another. The bottom of a stratigraphic column includes a scale of grain size of sedimentary rocks ranging from very fine grained sediments such as coal and clay to very coarse sand. This small-scale stratigraphic column of the petroglyph wall near Nelson Canyon (figure 16) shows how the sediments that were deposited as part of the Colton Formation vary in grain size. Recall that finer-grained sediments are deposited by lower-energy events, in which these lighter grains settle out from the water column, and coarser-grained sediments result from waning of higher-energy flows. Given this distinction in depositional energy, fluvial deposits are generally characterized by a fining upward succession. This occurs because the high-energy (coarse-grained) deposits are initial-

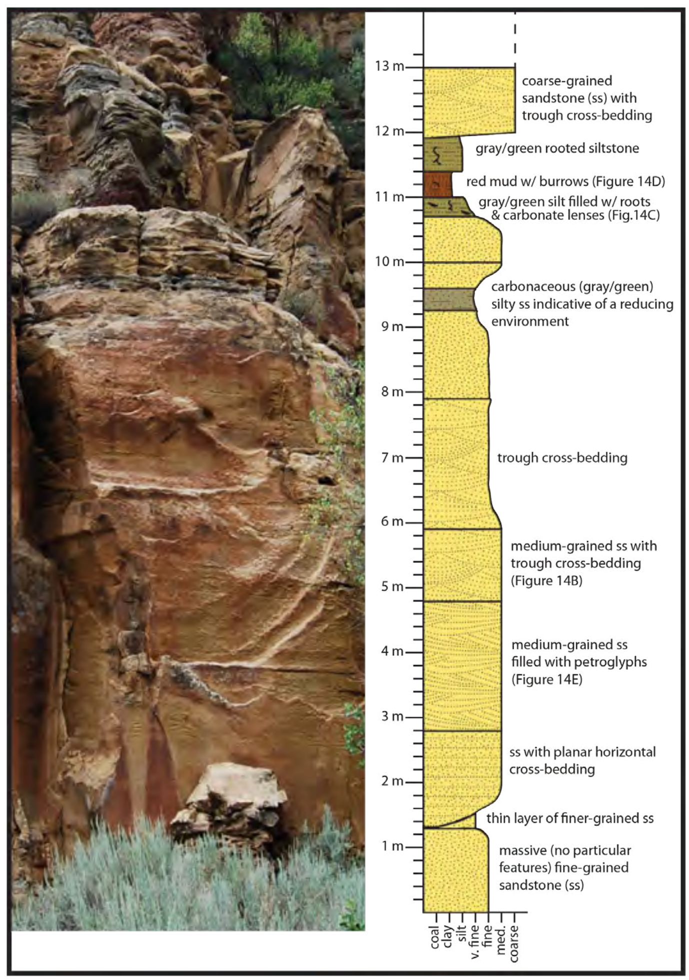

Figure 16. *Stratigraphic column showing the section that was measured at the Nelson Canyon rock art panel and representing the vertical arrangement of rock units and their relationship to one another. The column records the vertical variance in grain size and bed thickness, subsequently marking a whole range of depths or energies at which sediments were deposited within a fluvial channel.*

ly deposited in the deeper portion of a river, and are successively overlain by finer-grained sediments as the point bar of the river migrates laterally and water depth decreases (decreasing velocity of flow further). Thus, this stratigraphic column records the vertical variance in grain size and bed thickness, subsequently marking a whole range of depths or energies at which sediments were deposited within a fluvial channel system. Also note that red coloring of rocks (such as the red mud layer at roughly 11 meters [36 feet]) is associated with oxidizing conditions, whereas green in rocks is associated with reducing conditions. The green color of the rock layer at 9.5 meters (31.2 feet) implies that it was deposited in a reducing environment where oxygen was not available. Thus, it could have been deposited in a wet boggy area, possibly on the backside (back-swamp) of a channel levee.

Mud Rip-ups

A large boulder (figure 17) that fell from up above now lies just to the left (east) of the foot trail that leads from the road to the petroglyph wall. This boulder is filled with mud rip-up clasts, which are finer-grained, tan-colored clasts in a coarser-grained matrix of sandstone. The partially consolidated mud was most likely torn up in some high-energy water flow, such as the initiation of an erosive river channel. The sharp distinction between the medium-grained sandstone on the bottom part of the boulder and the coarser-grained sandstone that is dominated by pebbles, limestone clasts, and mud rip-up clasts could be interpreted to indicate a river channel's dramatic change from lower to higher energy. The contact between different grain sizes could be the bottom of a channel that came tearing through muddy sediment with current velocities strong enough to erode and pick up bits of mud along the way. Another interesting feature in this boulder is the clasts of limestone that are intermingled in the lag deposit. When hydrochloric acid is applied to the limestone, the calcium carbonate reacts with the acid and causes it to fizz. Geologists often carry bottles of dilute hydrochloric acid to perform this test in the field to confirm the presence of limestone in a rock.

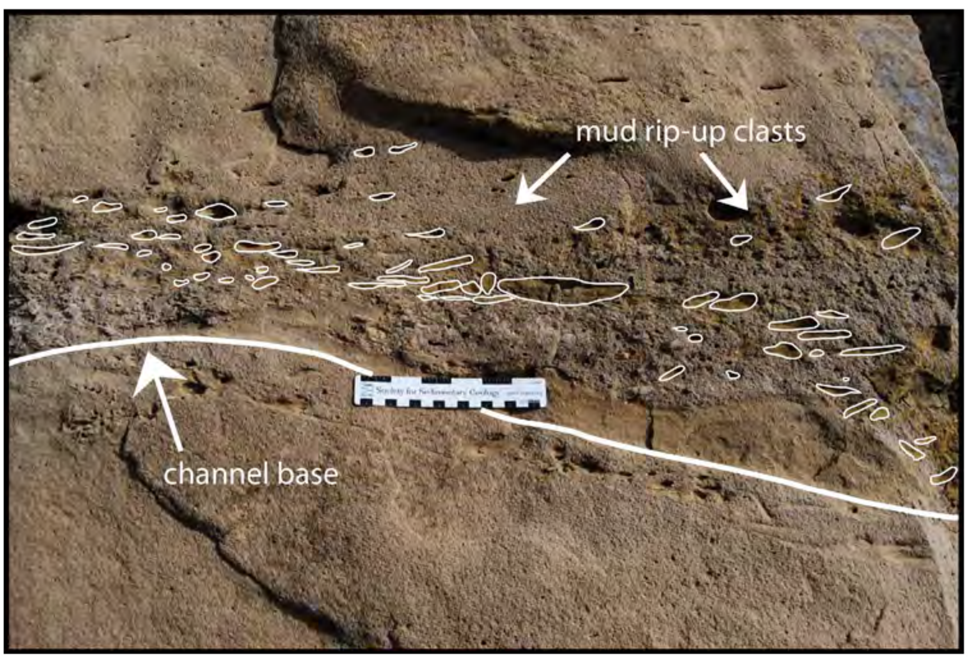

Figure 17. *Boulder (along the path leading to the Nelson Canyon rock art panel) with preserved mud rip-up clasts, which are finer-grained, tan-colored clasts in a coarser-grained matrix of sandstone. This partially consolidated mud was most likely torn up in some high-energy water flow, such as the initiation of an erosive river channel that must have had current velocities strong enough to erode and pick up pieces of mud along its path.*

6. Mud Plug Granary

Another 1.5 miles from the Nelson Canyon (Stop 5), on the east canyon wall 0.5 miles south of Calf Canyon, a Fremont granary is perched at the edge of an outstanding example of a "mud plug" formed by the abandonment of an ancient river channel (figure 18). River channels are very dynamic systems because they constantly migrate within their respective floodplains. When a channel migrates, it deposits continuous beds of sediment, such as the many continuous and stacked beds of sandstone within Range Creek Canyon. A channel is also capable of abandoning (or avulsing from) its path more suddenly. Avulsion occurs when a river or stream abandons its channel entirely and moves to another position on the floodplain. This event can result in an oxbow lake. A "mud plug" is geologic evidence of a channel that avulsed, or abandoned its route as it moved across its floodplain, often by cutting off its own path and leaving behind an oxbow lake. Note that the highlighted "mud plug" resembles the shape of a smile, or that of the cross section of a river channel (figure 18).

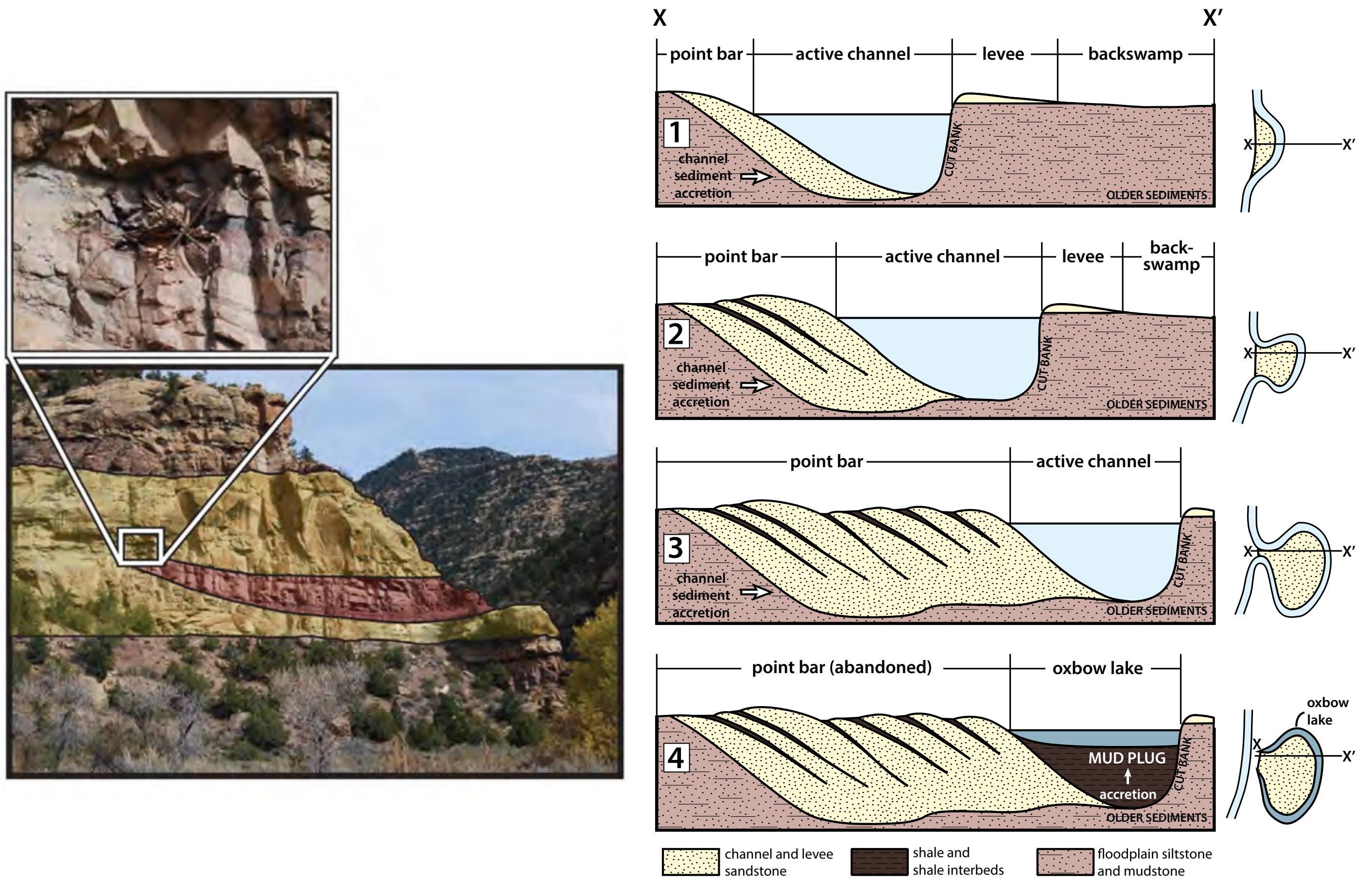

Figure 18. *Photo showing the east wall of Range Creek Canyon about 0.5 miles south of Calf Canyon. Left: mud plug highlighted (red/brown) within sandstone (yellow) with a Fremont platform granary at the edge of the "smile" of the mud plug. Right: an explanation of sequential channel deposits and the formation of mud plugs that are commonly deposited in oxbow lakes (modified after Davies and others, 1991). 1: Initial point bar deposition during migration of the active channel (migrating left in figure). 2: Lateral accretion, or buildup, of point bar deposits and cutbank erosion results in a larger channel meander. 3: Continued channel migration leads to an unstable degree of sinuosity (tighter meanders). 4: The main river channel bypasses the meander by cutting it off and begins the process over. The abandoned channel is immediately filled with sediment held in the water column and then filled with future floodplain deposits. Water left in this abandoned channel forms an oxbow lake. The sediment that is suddenly deposited in the oxbow lake is left in the sedimentary rock record as a mud plug.*

7. Cherry Meadow

Stop #7 is roughly 2.3 miles farther along the road from Stop #6. As the name suggests, Cherry Meadow is the first true opening, or meadow, in Range Creek Canyon. This widening in the canyon relates directly to a change in lithology, or rock composition, in the sedimentary layers in Range Creek. Just as Locomotive Rock is shaped as it is because of harder, more resilient sediments resisting erosion and softer, finer-grained sediment being weathered away, Cherry Meadow is evidence of the presence of a finer-grained, softer rock layer that has eroded more easily, leading to a significant opening in an otherwise tight, narrow canyon. This softer sediment layer was not encountered stratigraphically higher in the northern part of the canyon, but is still classified as part of the Colton Formation. This different rock layer is a lower member of the Colton Formation and can be distinguished by its redder, mahogany-colored, and finer-grained fluvial sandstone beds, which are less frequent and much less laterally extensive (figure 19). This darker red, finer-grained unit is absent in the exposed section along the drive up Horse Canyon. Recall that in Horse Canyon, the upper unit of the Colton lies directly on top of the gray limestone. This lower Colton unit that contains more mudstone interbedded within the sandstone pinches out between here, in Cherry Meadow, and Horse Canyon.

Mud Plug

Recall that a "mud plug" is geologic evidence of a channel that avulsed, or abandoned its route as it moved across its floodplain. The "smile" shape of the mud plug in Cherry Meadow is filled with a darker, finer-grained layer that was deposited by a channel as its energy decreased when it abandoned its path (figure 19A). Thus, the shape of the half smile here outlines the shape of the ancient abandoned channel that was eventually filled by fine sediment.

Boulder Recording Migration of a River Channel

One particular boulder of sandstone nicely illustrates several features that represent directional water flow (figure 19B). In the cross section of a river channel the cutbank is where the erosive process of a channel occurs, while the channel deposits sediment at the point bar (figure 4). Thus, a river channel (shown in figure 4 as a meandering river) migrates or expands in the direction of its cutbank. The features outlined near the bottom of this boulder are representative of point bars in a channel migrating to the left (in this orientation). The thick white, drawn-in boundary, topping these migrating bar forms, represents the deposition of much coarser-grained sediment (figure 19B). This coarser-grained sediment even includes small pebbles, and can thus be interpreted as a higher-energy event that occurred after the point bar migration or as the base of a separate channel that formed during a flood stage of the river.

Mud Cracks

Both contemporary and ancient mud cracks are an indicator of desiccation, or drying up, of sediment. Mud cracks usually occur in environments that are alternately wet and dry, where muddy sediment is subjected to intermittent drying. Mud cracks are often representative of lagoonal or fluvial floodplain depositional environments (Boggs, 2006). They often form in a hexagonal shape and can be preserved either as v-shaped cracks on the top of a muddy sediment bed (appearing just like contemporary mud cracks), or as casts on the base of an overlying bed (figure 19C). The boulder in Cherry Meadow contains ancient mud cracks preserved as casts, or positive-relief fillings, on the bottom of a younger, overlying sedimentary bed. These casts are the result of ancient mud cracks that formed, then completely dried, were covered with younger wet sediment, and were then buried and preserved. Looking at this boulder, we see the underside of a layer of mud cracks that were filled in with overlying sediment.

8. Dilly Canyon

A great location to pull over and explore limestone rock at Dilly Canyon is 2.4 miles from the Cher-

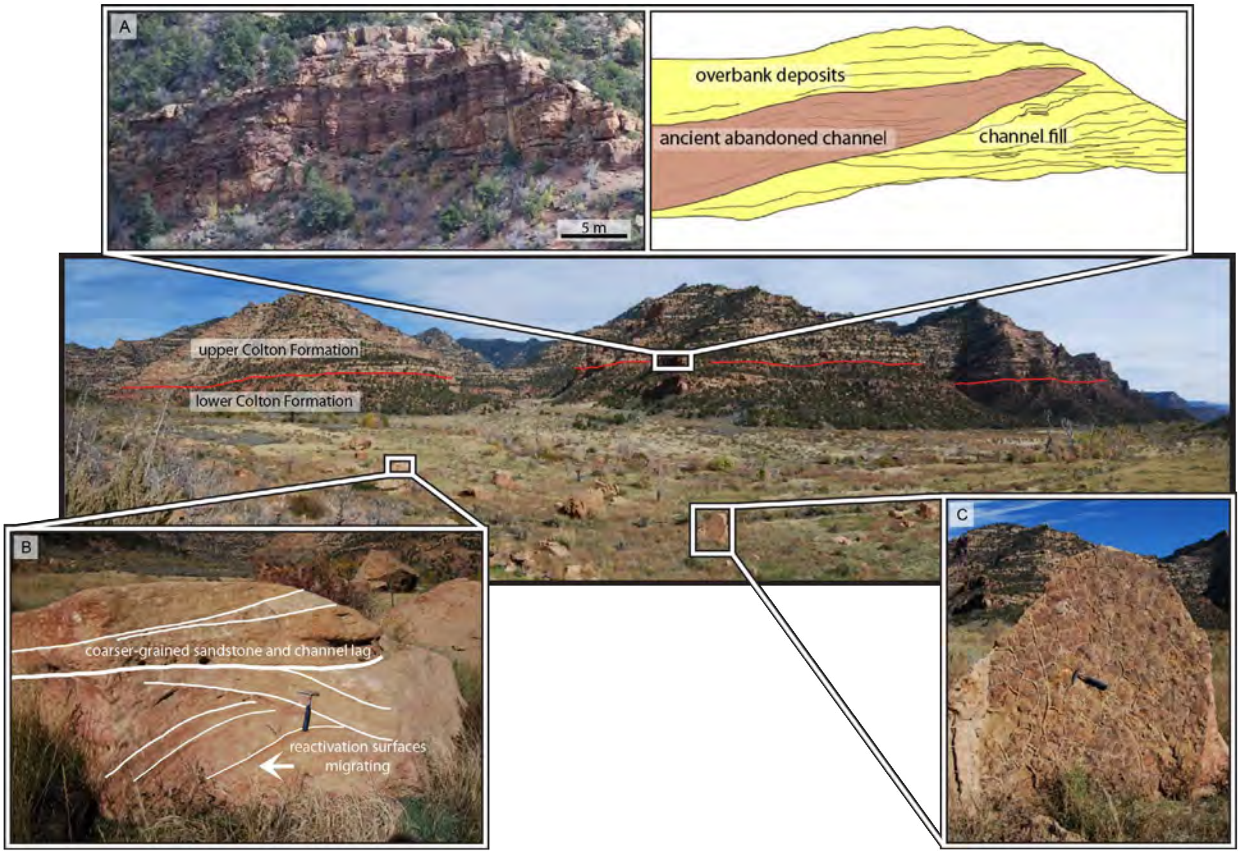

Figure 19. *The view (main panorama) looking east from the road into Cherry Meadow and opposite Lighthouse Canyon, offers a view of two units (upper and lower) of the Colton Formation marking a general upward trend of increased grain size, channel belt (sandstone bed) frequency, and channel belt lateral extent. The coarsening-upward succession of the Colton Formation (from the darker red, lower unit with numerous interbedded mudstone and little lateral extent, to the lighter-colored, sandstone-dominated upper unit) implies a transition from lower-energy river environments to higher-energy river systems with time. Highlighted within the Colton is a mud plug (A), which is geologic evidence of a fluvial channel that avulsed, or abandoned its route as it moved across its floodplain. The "smile" shape of the mud plug is filled with a darker, finer-grained layer that was deposited by a channel as its energy decreased when it abandoned its path. Thus, the shape of the half smile outlines the cross section of the ancient channel where fine sediment settled out. Also highlighted in the foreground is a boulder that has beautifully preserved evidence of channel/stream flow (B) and another boulder with preserved world-class mud cracks (C).*

ry Meadow stop (Stop #7). Recall that the limestone of the Flagstaff Limestone was exposed along the drive up Horse Canyon (figure 5). Yet in Range Creek Canyon, the drive from the north gate southward through the canyon has been stratigraphically too high for the Flagstaff Limestone outcrops. Stop #8 is one of the first locations within Range Creek Canyon where the creek cuts low enough in the section to reach limestone beds of the Flagstaff Limestone, below the Colton Formation. This stop not only offers an opportunity to walk up to the rocks to see the differences between the Flagstaff Limestone limestone and the Colton Formation sandstone, but also to find various fossils within the Flagstaff. Along the gentle slope of the hill on the east side of the road are loose blocks, or "float," of limestone that are filled with both body and trace fossils (figures 20 and 21). Roughly 500 feet farther down the road and on the east side of the canyon, there is a petroglyph carved into a layer of sandstone interbedded within the Flagstaff Limestone (figure 22).

Body Fossils

Body fossils are skeletal and shelly remains of ancient plants or other organisms. Although there are many ways that organisms can become fossils, many require the presence of muddy sediment and water, making fossilized marine organisms more common. The Flagstaff Limestone, as previously mentioned, is representative of an ancient lacustrine, or lake, environment, and preserves evidence of many freshwater organisms that inhabited the region and are now left behind as fossils. Some of the abundant fossils that can be found within the Flagstaff Limestone are gastropods, oysters, and freshwater turtles (figures 20A to 20F).

Figure 20. *Body fossils found in the lacustrine limestone of the Flagstaff Limestone include fossils of gastropods, oysters, and freshwater turtles (A-F). Fossils can be found in bedrock exposures, on the talus slope just south of Dilly Canyon, or wherever there is limestone exposed.*

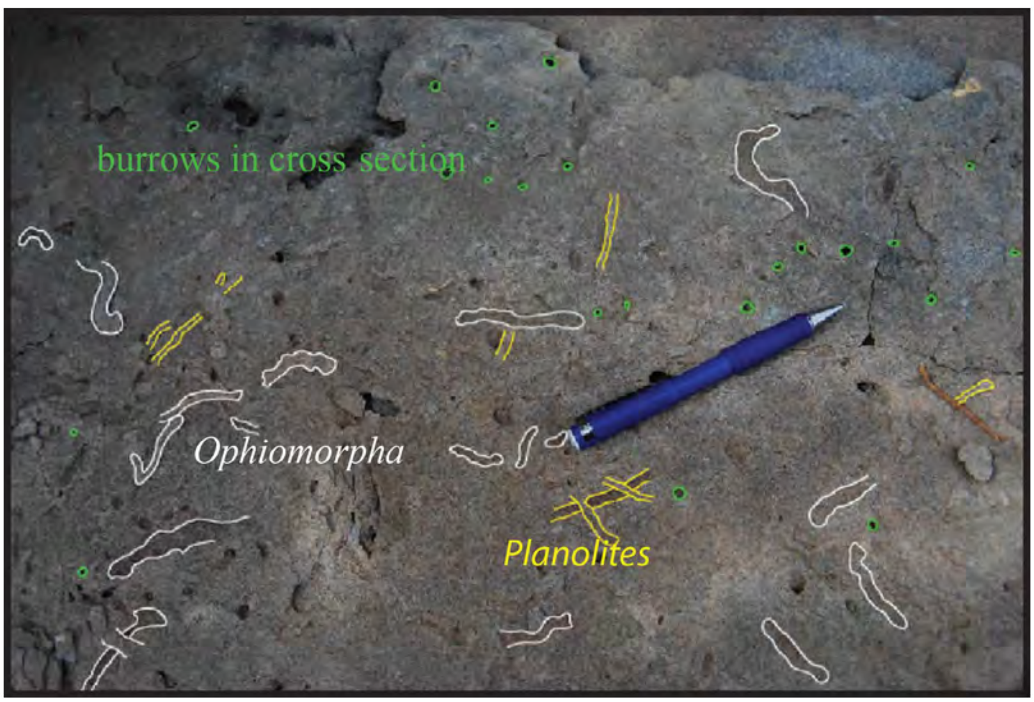

Figure 21. *Trace fossils are also abundant and easy to find along the road in the fossiliferous limestone of the Flagstaff Limestone. These fossils do not consist of animal remains as do body fossils, but rather of animal tracks and burrows, indicating evidence of animal behavior. Though trace fossils are named after their appearance, they are often qualified by the behaviors that they are interpreted to record as well. <u>Planolites</u> is described as cylindrical to subcylindrical infilled burrows that are straight, gently curved, and nonbranching. <u>Planolites</u> is considered a grazing trace of a wandering deposit feeder (Uchman, 1995). <u>Ophiomorpha</u> is a 3D burrow system of cylindrical tunnels that are larger and often dichotomously branch at acute angles. The tunnels can be vertically (shafts) or horizontally oriented and have local swelling at the branching. The walls are internally smooth, but lined with pellets (Uchman and Gazdzicki, 2006).*

Figure 22. *View looking east from the road, roughly 300 feet south of Dilly Canyon, showing a petroglyph of an anthropomorphic figure. Sometimes referred to as a shield figure, the petroglyph is pecked into a layer of sandstone that is interbedded in the tabular limestone beds of the Flagstaff Limestone (top) with a close up (bottom).*

Trace Fossils

Trace fossils are preserved trails, depressions, borings, or any kind of trace left by an organism (figure 21). These fossils do not consist of animal remains as do body fossils, but rather of animal tracks and burrows, indicating evidence of animal behavior (Seilacher, 1967; Prothero, 2004). The image in figure 21 exemplifies, as do many rocks within the Flagstaff Limestone, the burrowing action of organisms, called bioturbation.

9. Wilcox Ranch

The ranch, which is the final stop of this geologic tour (2.1 miles from Dilly Canyon, and 23 cumulative miles from Stop #1 at Geneva Coal Mine at the mouth of Horse Canyon), originally served as a line station for cattle operations within Range Creek Canyon. Nearly a century later, the original, single-room cabin is still standing. What eventually became known as the Wilcox Ranch, was a working ranch until the end of the twentieth century. It is currently managed by the Natural History Museum of Utah at the University of Utah as a field station (Metcalfe, 2008). The mission of the field station is to protect, preserve, and study the remarkable archaeological record within Range Creek Canyon, while providing professional training to students in all aspects of natural history (figure 23).

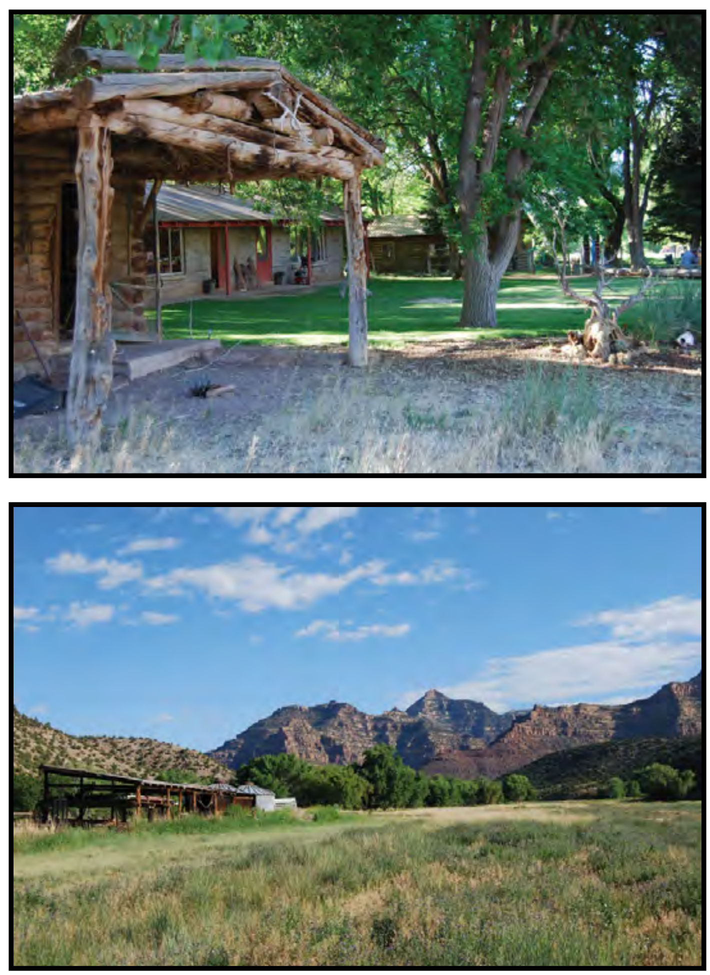

Figure 23. *Wilcox Ranch (top) and its view looking north up Range Creek Canyon (bottom).*

Old work shed at Wilcox Ranch. Photograph by Nora Nieminski.

ACKNOWLEDGMENTS

This work was part of an undergraduate thesis sponsored by the University of Utah Undergraduate Research Opportunities Program. Special thanks are extended to Corinne Springer for her selfless hospitality at the project site and her wealth of knowledge of the field area. Thanks are also due Duncan Metcalfe for permitting entry into Range Creek Canyon, and special thanks to David Dinter, Jared Gooley, and Ian Semple for indispensible help and knowledgeable input with fieldwork. Thanks to Sharon Hamre for her help with formatting and editing of a previous version of this guide. The authors thank Steven Schamel for his management of the peer review process and Marc Eckels, Thomas Morris, and Grant Willis for their comments and assistance with manuscript review. This publication is provided free to the public. Please consider donations to support Range Creek Research at the Natural History Museum of Utah: www.nhmu.utah.edu.

REFERENCES

Barlow, R., and Phillips, K.L., 2010, Simple financial economic models of Fremont maize storage and an assessment of external threat: University Library of Munich, Germany, Munich Personal RePEc Archive, Paper 23502, 18 p.

Blakey, R.C., and Ranney, W., 2008, Ancient landscapes of the Colorado Plateau: Grand Canyon Association, 156 p.

Boggs, S., Jr., 2006, Principles of sedimentology and stratigraphy, 3rd Edition, Upper Saddle River, New Jersey: Pearson Education, Inc., p. 112-462.

Bowen, G.J., Daniels, A.L., and Bowen, B.B., 2008, Paleoenvironmental isotope geochemistry and paragenesis of lacustrine and palustrine carbonates, Flagstaff Formation, central Utah, U.S.A.: Journal of Sedimentary Research, v. 78, p. 162-174.

Butler, D.P., 1961, The Geneva Coal Mine at Horse Canyon, Utah: UTGenWeb Project, Carbon County <http://www.carbon-utgenweb.com/geneva.html>, accessed April 14, 2011.

Carroll, A.R, Chetel, L.M, and Smith, M.E., 2006, Feast to famine—sediment supply control on Laramide basin fill: Geology, v. 34, no. 3, p. 197-200.

Cashion, W.B., 1967, Geology and fuel resources of the Green River Formation, southeastern Uinta Basin, Utah and Colorado: U.S. Geological Survey Professional Paper 548, 48 p.

One of many Fremont petrolyphs in Range Creek Canyon. Photograph by Nora Nieminski.

Davies, D.K., Williams, B.P.J., and Vessell, R.K., 1991, Reservoir models for meandering and straight fluvial channels; examples from the Travis Peak Formation, east Texas: Gulf Coast Association of Geological Societies, v. 41, p. 152-174.

Dickinson, W.R., Lawton, T.F., and Inman, K.F., 1986, Sandstone detrital modes, central Utah foreland region—stratigraphic record of Cretaceous-Paleogene tectonic evolution: Journal of Sedimentary Research, v. 56, no. 2, p. 276-293.

Dickinson, W.R., Lawton, T.F., Pecha, M., Davis, S.J., Gehrels, G.E., and Young, R.A., 2012, Provenance of the Paleogene Colton Formation (Uinta Basin) and Cretaceous–Paleogene provenance evolution in the Utah foreland—evidence from U-Pb ages of detrital zircons, paleocurrent trends, and sandstone petrofacies: Geosphere, v. 8, no. 4, p. 854-880.

Dubiel, R.F., 2003, Geology, depositional models, and oil and gas assessment of the Green River total petroleum system, Uinta-Piceance Province, eastern Utah and western Colorado, *in* Petroleum systems and geologic assessment of oil and gas in the Uinta-Piceance Province, Utah and Colorado: U.S. Geological Survey Digital Data Series DDS-69-B, Chapter 5, 41 p.

Franczyk, K.J., and Pitman, J.K., 1991, Latest Cretaceous nonmarine depositional systems in the Wasatch Plateau area—reflections of foreland to intermontane basin transition, *in* Chidsey, T.C., Jr., editor, Geology of east-central Utah: Utah Geological Association Publication 19, p. 77-93.

Gerber, S.L., and Aton, J.M., 2011, Empires and homesteads—making a living in Range Creek: Utah Historical Quarterly, v. 79, no. 1, p. 20-41.

Higgins, J.A., and Schrag, D.P., 2006, Beyond methane—towards a theory for the Paleocene-Eocene Thermal Maximum: Earth and Planetary Science Letters, v. 245, p. 523-537.

Johnson, K.A., Culver, S.J., and Kamola, D.L., 2005, Marginal marine foraminifera of the Blackhawk Formation (Late Cretaceous, Utah): Journal of Foraminiferal Research, v. 35, no. 1, p. 50-64.

Johnson, R.C., 1985, Early Cenozoic history of the Uinta and Piceance Creek Basins, Utah and Colorado, with special reference to the development of Eocene Lake Uinta, *in* Flores, R.M., and Kaplan, S., editors, Cenozoic paleogeography of the west-central United States: Special Publication of the Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Symposium 3, p. 247-277.

Keighley, D., Flint, S., Howell, J., and Moscariello, A., 2003, Sequence stratigraphy in lacustrine basins—a model for part of the Green River Formation (Eocene), southwest Uinta Basin, Utah, USA: Journal of Sedimentary Research, v. 73, no. 6, p. 987-1006.

Kloor, K., 2006, Secrets of the Range Creek Ranch: Smithsonian Magazine, March 2006 <http://www.smithsonianmag.com/history-archaeology/range_creek_ranch.html>, accessed on December 1, 2010.

Lawton, T.F., 2008, Laramide sedimentary basins: Sedimentary Basins of the World, v. 5, p. 429-450.

Madsen, D.B., and Simms, S.R., 1998, The Fremont complex—a behavioral perspective: Journal of World Prehistory, v. 12, p. 255-336.

Marcantel, E.L., and Weiss, M.P., 1968, Colton Formation (Eocene: fluviatile) and associated lacustrine beds, Gunnison Plateau, central Utah: The Ohio Journal of Science, v. 68, no. 1, p. 40-49.

Metcalfe, D., 2008, Range Creek Canyon, *in* Fowler, C.S., and Fowler, D.D., editors, The Great Basin—people and place in ancient times: Santa Fe, New Mexico, School for Advanced Research Press, p. 117-123.

Morgan, C.D., Chidsey, T.C., Jr., McClure, K.P., Bereskin, S.R., and Deo, M.D., 2003, Reservoir characterization of the lower Green River Formation, Uinta Basin, Utah: Utah Geological Survey Open-File Report 411, 140 p.

Morris, T.H., Richmond, D.R., and Marino, J.E., 1991, The Paleocene/Eocene Colton Formation—a fluvial-dominated lacustrine deltaic system, Roan Cliffs, Utah, *in* Chidsey, T.C., Jr., editor, Geology of eastern-central Utah: Utah Geological Association Publication 19, p. 129-139.

Pitman, J.K., Anders, D.E., Fouch, T.D., and Nichols, D.J., 1986, Hydrocarbon potential of nonmarine Upper Cretaceous and Lower Tertiary rocks, eastern Uinta Basin, Utah, *in* Spencer, C.W., and Mast, R.F., editors, Geology of tight gas reservoirs: American Association of Petroleum Geologists Studies in Geology, v. 24, p. 235-251.

Potterfield, P., 2004, The Lost World of Range Creek: The Great Outdoors, July 16, 2004, <http://www.greatoutdoors.com/published/the-lost-world-of-range-creek>, accessed on April 13, 2011.

Prothero, D.R., 2004, Bringing fossils to life—an introduction to paleobiology, 2nd edition: New York, McGraw-Hill Companies, Inc., 472 p.

Remy, R.R., 1992, Stratigraphy of the Eocene part of the Green River Formation in the south-central part of the Uinta Basin, Utah: U.S. Geological Survey Bulletin 1787-BB, 79 p.

Roehl, U., Westerhold, T., Bralower, T.J., and Zachos, J.C., 2007, On the duration of the Paleocene-Eocene Thermal Maximum (PETM): Geochemistry, Geophysics, Geosystems, v. 8, no. 12, p. 1-13.

Ryder R.T., Fouch, T.D., and Elison, J.H., 1976, Early Tertiary sedimentation in the western Uinta Basin, Utah: Geological Society of America Bulletin, v. 87, no. 4, p. 496-512.

Seilacher, A., 1967, Fossil behavior: Scientific American, v. 217, p. 72-80.

Smith, M.E., Carroll, A.R., and Singer, B.S., 2008, Synoptic reconstruction of a major ancient lake system—Eocene Green River Formation, western United States: Geological Society of America Bulletin, v. 120, no. 1-2, p. 54-84.

Stanley, K.O., and Collinson, J.W., 1979, Depositional history of Paleocene—Lower Eocene Flagstaff Limestone and coeval rocks, central Utah: American Association of Petroleum Geologists Bulletin, v. 63, no. 3, p. 311-323.

Torfstein, A., Winckler, G., and Tripati, A., 2010, Productivity feedback did not terminate the Paleocene-Eocene Thermal Maximum (PETM): Climate of the Past, v. 6, no. 2, p. 265-272.

Uchman, A., 1995, Tiering patterns of trace fossils in the Paleogene flysch deposits of the Carpathians, Poland: Geobios, v. 18, p. 389-394.

Uchman, A., and Gazdzicki, A., 2006, New trace fossils from the La Mesata Formation (Eocene) of Seymour Island, Antarctica: Polish Polar Research, v. 27, no. 2, p. 153-170.

Utah Oil and Gas Program website, undated: Utah Division of Oil, Gas and Mining, <http://oilgas.ogm.utah.gov>.

Wells, N.A., 1983, Carbonate deposition, physical limnology and environmentally controlled chert formation in Paleocene-Eocene Lake Flagstaff, central Utah: Sedimentary Geology, v. 35, no. 4, p. 263-296.

Wilf, P., 2000, Late Paleocene-early Eocene climate changes in southwestern Wyoming: Paleobotanical analysis: Geological Society of America Bulletin, v. 112, p. 292-307.

Witkind, I.J., 2004, Geologic map of the Huntington 30' x 60' quadrangle, Carbon, Emery, Grand, and Uintah Counties, Utah: Utah Geological Survey Open-File Report 440DM, compact disc, 1 plate, scale 1:100,000, GIS data (originally published in 1988 as U.S. Geological Survey Miscellaneous Investigations Series Map I-1764., 1 plate, scale 1:100,000).

Zachos, J.C., Pagani, M., Sloan, L., Thomas, E., and Billups, K., 2001, Trends, rhythms, and aberrations in global climate 65 Ma to present: Science, v. 292, p. 686-693.