The Lower Cretaceous Cedar Mountain Formation of Eastern Utah: A Comparison with the Coeval Burro Canyon Formation, Including New Measured Sections on the Uncompahgre Uplift

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THE LOWER CRETACEOUS CEDAR MOUNTAIN FORMATION OF EASTERN UTAH: A COMPARISON WITH THE COEVAL BURRO CANYON FORMATION, INCLUDING NEW MEASURED SECTIONS ON THE UNCOMPAHGRE UPLIFT

by

Roger D. Miller

A report as a partial requirement for the degree

of

MASTER OF SCIENCE

in

Applied Environmental Geosciences, Plan B

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ABSTRACT

The Lower Cretaceous Cedar Mountain Formation of Eastern Utah: a Comparison with the Coeval Burro Canyon Formation, Including New Measured Sections on the Uncompahgre Uplift

by

Roger D. Miller, Master of Science
Utah State University, 2016

Department: Geology
Program: Applied Environmental Geosciences

The Early Cretaceous (Barremian-Albian) Burro Canyon Formation in Eastern Utah and Western Colorado is a dominantly fluvial system that resembles the Cedar Mountain Formation, a correlative unit that lies across the Colorado River and is famous for recent dinosaur discoveries. The Burro Canyon Formation is arbitrarily split from the Cedar Mountain Formation using the Colorado River as a dividing line. This non-stratigraphic means of splitting one unit from the other is largely due to convention and it has become entrenched in the literature.
Sections measured on Hotel Mesa and Buckhorn Mesa, both in eastern Grand County, Utah, were made in order to better delineate the contact between the two formations in this remote area on the Uncompahgre Plateau. The section on Hotel Mesa is in the Poison Strip Sandstone Member of the Cedar Mountain Formation, as demonstrated by correlation to nearby established measured sections.

Multiple paleocurrents were taken on Buckhorn Mesa, along with three new measured sections. These measured sections and paleoflows were then used to determine whether these rocks are likely to be in the Burro Canyon Formation or the Cedar Mountain Formation. Facies were established for the outcrops, with preliminary facies associations then being developed and outlined on photographs.

Analyses show that these fluvial sandstones on this edge of the Uncompahgre Plateau are all in the Poison Strip Sandstone Member of the Cedar Mountain Formation. Also, no other Early Cretaceous sediments are found on this entire portion of the Plateau, as illustrated using panoramic photographs.
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Roger D. Miller
INTRODUCTION

The Early Cretaceous (Barremian-Albian) Burro Canyon Formation in Eastern Utah and Western Colorado represents a dominantly fluvial, braided stream system (Owen, et al., 1978; Craig, 1981; Aubrey, 1992; Fillmore, 2011). There are few studies that have either reconstructed the depositional environment of the Burro Canyon Formation in Western Colorado, or adequately traced its stratigraphic relationship to the Cedar Mountain Formation to the west. This study will examine the Burro Canyon Formation in a remote area on the east side of the Colorado River, near Dewey Bridge, Utah. A possible correlation between the two formations in this area will then be developed.

In 1952, William Lee Stokes separated the two formations arbitrarily by using the Colorado River as a dividing line, a practice that has become entrenched in the literature for lack of better mapping (Young, 1960; Carpenter, 2014) (Figure 1). The inaccessibility of the study area (requiring either a 50-mile drive on rugged roads, or a fording of the Dolores River, possible only at low water) has made accurate mapping of the contact between the two formations difficult. I measured sections in this remote area, coming to the conclusion that the Cedar Mountain Formation (in particular the Poison Strip Sandstone member) extends to the east beyond the Colorado River, requiring a re-drawing of the contact between the two formations. The river is not a stratigraphically valid contact, and further mapping is needed to accurately determine the formations' true extents.
After briefly outlining the history of the two formations, contrast and comparison will be made by literature review, in order to give adequate grounds to my interpretation of field observations.

Figure 1. Google map of the Four Corners region with Cedar Mountain Formation outcrops in purple and Burro Canyon Formation outcrops in maroon. The Colorado River (blue line) is used as an arbitrary dividing line between the two formations across southeastern Utah (formations overlay courtesy Dr. Kenneth Carpenter, Utah State University; basemap ©2016 Google).

In order to be sure that the Cedar Mountain Formation extended into the study area, field work initially focused on the lithology and stratigraphy of a small stratigraphic
section measured on Hotel Mesa, near the last verified Cedar Mountain Formation section across the Colorado River north of Dewey Bridge, Utah (Stikes, 2007). The section on Hotel Mesa can be shown to be in the Poison Strip Sandstone Member of the Cedar Mountain Formation, by comparing stratigraphy and lithology with Matthew Stikes’ measurements near Dewey Bridge (Stikes, 2007).

Several lines of inquiry were pursued during and after the gathering of field data, including: To what degree do the Burro Canyon Formation's lithological and stratigraphic characteristics differ from those of the Cedar Mountain Formation? How did the environment of deposition differ between the two correlative formations? Is there any way to determine paleotopography for the Burro Canyon Formation? What are the differences in structural constraints on sediment transport between the two formations? Do the formations differ significantly in thickness in the study area?

Although all these questions are addressed to some degree, the primary thrust of this study is to further elucidate the stratigraphy just east of the Colorado River on the Uncompahgre Plateau in order to ascertain the existence of the Burro Canyon Formation at this location.
BACKGROUND

William Lee Stokes first named the Cedar Mountain Formation from an outcrop along the northern San Rafael Swell in Emery County, Utah in 1944 (Stokes, 1944). In 1948, Stokes and Phoenix named the Burro Canyon Formation in San Miguel County, Colorado (Figure 2). They describe the Burro Canyon type section (Section 29, T44N, R18W) as being "a relatively thin sequence of rocks," presumably Lower Cretaceous by "analogy with the surrounding regions," sandwiched between the Morrison Formation and the Dakota Sandstone (the Naturita Formation senso Young, 1960; see also Carpenter, 2014) (Stokes and Phoenix, 1948).

Figure 2. Google Earth screenshot, showing Eastern Utah and the locations of type sections for the Cedar Mountain Formation and the Burro Canyon Formation, as well as
(Figure 2 continued) the general study area. Dewey Bridge crosses the Colorado River, which is the arbitrary line dividing the two formations.

The Burro Canyon Formation type section is further described by Stokes and Phoenix as consisting of "alternating conglomerate, sandstone, shale, limestone and chert ranging from 150 to 260 feet in thickness. The sandstones and conglomerates are gray, yellow, and brown, and the shales are faintly varicolored, mainly purple and green" (Stokes and Phoenix, 1948).

The authors then describe the contact of the lower Burro Canyon Formation with the underlying Morrison Formation, Brushy Basin Member, placing it "at the base of the lowest, resistant, light-colored, conglomeratic sandstone." The contact of the upper Burro Canyon with the Dakota (Naturita) Formation is described as "above the highest varicolored beds, so as to exclude any carbonaceous shales or sandstones in which plant fragments are abundant" (Stokes and Phoenix, 1948).

Stokes indicates that the Burro Canyon Formation and the Cedar Mountain Formation are lithologically and stratigraphically distinct. For example, the Cedar Mountain Formation has more abundant limestone nodules than the Burro Canyon Formation (Stokes, 1952, Craig, 1981). But in 1952 the line separating the two formations had not yet been mapped, so Stokes suggested that the Colorado River be used as an arbitrary dividing line (Stokes, 1952). This convention was subsequently adopted for general use (Young, 1960).

There are further lithological and sedimentological differences between the Cedar Mountain Formation and the Burro Canyon Formation that have been described since
Stokes’ work. These include: 1. sequential stacking and lithological differences—the Cedar Mountain sandstone intervals are not as often interbedded with mudstones as are the Burro Canyon's, and the Burro Canyon has a higher ratio of sandstone to mudstone than does the Cedar Mountain (Craig, 1981); 2. the Cedar Mountain Formation's upper mudstone section includes swelling (montmorillonite) clays in the Mussentuchit Member west of the San Rafael Swell, whereas the Burro Canyon Formation's mudstones are generally sandier and non-swelling (illite/chlorite) clays (Craig, 1981; Kirkland et al. 1997); and 3. paleocurrents indicate different source areas for the two formations—the Cedar Mountain's are directly to the west from the Sevier orogeny, and the Burro Canyon's are to the south and southwest, from the Cretaceous Mogollon Highlands in central and southern Arizona and southwestern New Mexico (Craig, 1981; Tschudy, et al., 1984; Owen, et al., 2005).

These scalar and vector differences suggest that the Burro Canyon Formation is more proximal to its source than is the Cedar Mountain Formation. Larger grain sizes overall indicate a more energetic environment of deposition than that found in the Cedar Mountain Formation. Pulses of tectonism in source areas likely led to deposition of high-energy sandstones, alternating with low-energy mudstones during tectonically quiescent periods in both formations (Craig, 1981).
Pangaea began breaking up in the Late Jurassic, as lithospheric heat collected under the supercontinent enough to cause crustal rifting. The once buoyant crust released its thermal load and the continents sank slowly back into the lithosphere, gradually allowing the formation of relatively shallow epicontinental seas worldwide by the Late Cretaceous (Blakey and Ranney, 2008; Fillmore, 2011).

As the Farallon Plate subducted along North America's western edge, it carried island arcs that were accreted to what is now the Western United States. During this time the Gulf of Mexico and the Proto-Atlantic were opening up, as South America and Africa drifted gradually away. The shallow subduction of the Farallon Plate along with the accretion of island arcs to the west combined to produce massive overthrusting eastward, with thin-skinned tectonics pushing enormous blocks of rock over the North American basement. These blocks affected 1,000km (600mi) of western North America, with up to 120km (72mi) of crustal shortening (Baldridge, 2004; Blakey and Ranney, 2008; Fillmore, 2011).

This episode of overthrusting all along the western margin of North America—the Sevier orogeny—deformed and emplaced rocks from Arizona to Alberta and British Columbia, Canada. By the Late Cretaceous, the Sevier had compressionally deformed rocks from what is now California and Nevada all the way to Colorado and New Mexico.

The Sevier caused a series of imbricated low-angle detachment faults to develop, where sediments piled up and eroded into basins formed by crustal loading (Baldridge, 2004; Fillmore, 2011). Isostatic flexural subsidence of the North American craton on its
western edge formed a vast foreland basin where sediments loaded up the lithosphere, piling up in imbricated layers (Davis and Reynolds, 1996). As thrusting proceeded to increase inland—due to the Farallon Plate's shallow subduction angle—the north/south trending basin axis also migrated inland to the east, along with volcanic activity associated with the Farallon subduction zone (Fillmore, 2011). Sediments were thrust up and then eroded down into the foredeep, only to be recycled up into the next thrust coming from the west (Baldridge, 2004). These imbricated sediments eventually became the source for the Cedar Mountain Formation (Cole, 1987).

During this episode of enormous overthrusting to the west, the Bisbee Basin was rifting in the south (Figure 3). The thermotectonic rift shoulder along the edge of the Bisbee Basin was tipped up to the northeast as volcanics rose up in the widening rift to the south in what is now Mexico. These sediments on the rift shoulder became the source for the Burro Canyon Formation, as the Mogollon Rim was uplifted on the Bisbee Basin's edge, along with the entire southern edge of the Colorado Plateau (Bilodeau, 1986; Blakey and Ranney, 2008).

The lack of Lower Cretaceous rocks on the southern edge of the Colorado Plateau indicates that this edge was uplifted. The uplift along the west from the Cordilleran Sevier thrust belt along with that in the south along the Mogollon Rim led to the subsidence of the eastern and northern edges of the Colorado Plateau, creating vast basins for Cretaceous sediments from the highlands to erode into (Blakey and Ranney, 2008).
Figure 3. Paleotectonic map showing the Sevier orogeny along the western edge of the North American Plate. A thermotectonic rift shoulder lies along the northern edge of the Bisbee Basin, lower center. These are the sources of fluvial sediments seen in the study area (Cedar Mountain Formation, CMF, red arrows and Burro Canyon Formation, BCF, yellow arrows). North America was in the tropics at this time, with higher rates of precipitation (Suarez, et al., 2014). Generalized paleoflow arrows and formation labels mine (modified from Blakey, 2011).
Another image of the situation in the Early Cretaceous of Western North America is seen in Figure 4. The gigantic overthrust belts in the Sevier to the west are shown, along with an accreting island arc on the oceanic Farallon Plate. The Mogollon highlands in Central Arizona are also seen along the thermotectonic Bisbee rift shoulder to the south. Superimposed general paleoflow directions indicate deposition of the Cedar Mountain and the Burro Canyon formations.

Figure 4. Colorado Plateau Geosystems map of the situation in the Western United States during the Early Cretaceous. Although trunk rivers are shown flowing north, paleoflow patterns in the Cedar Mountain Formation (CMF) indicate that these trunk streams likely
(Fig. 4 continued) flowed farther east before turning north (Craig, 1981: see also Figure 31 below). (BCF-Burro Canyon Formation.) (Modified from Blakey, 2011.)

One more paleogeographic reconstruction is seen in Figure 5, showing the study area flooded by the Western Interior Seaway (also called the Mowry Seaway at this time, due to its deposition of the Mowry Shale—Kirkland, et al., 1997). Rivers can be seen draining the Sevier highlands to the west, as well as the Mogollon rift shoulder to the south (Blakey, 2011).

Figure 5. Cretaceous paleogeographic reconstruction, showing the transgression of the Western Interior Seaway from the north. Rivers can be seen draining the highlands to the west and south. This "snapshot" shows the study area inundated, which occurred after Burro Canyon and Cedar Mountain deposition. Fluvial-style deposition with ephemeral lakes occurred here during the Late Barremian through Albian ages (modified from Blakey, 2011).
As North America drifted gradually north it slowly exited the arid sub-tropics, becoming more temperate, with westerly winds bringing moisture from the Panthalassa Ocean (the modern Pacific), as well as monsoonal rains from the incipient Gulf of Mexico (Kirkland and Madsen, 2007; Suarez, et al. 2014; Arens and Harris, 2015). High rates of precipitation led to increases in plant growth and organic material. Increased organic material caused many of the rocks deposited on the Colorado Plateau in the Cretaceous (e.g. the marine Mancos Shale) to often be more gray and black than those previously deposited in the Triassic and Jurassic, which tend to be various shades of red, orange, white and yellow (Blakey and Ranney, 2008).

Dysoxic oceans and higher CO₂ levels indicate a global super-greenhouse during the Cretaceous, with the possibility that there were no polar ice caps (Benton, 2005; Kirkland and Madsen, 2007; Fillmore, 2011). δ¹⁸O levels in fossil shells show that the entire globe was as much as 15°C (59°F) warmer than now (Fillmore, 2011). Mid-Cretaceous ¹⁸O levels were depleted due to rain-out in the atmosphere. Also, the proximity of the encroaching Western Interior Seaway controlled local ¹⁸O rain-out on the Colorado Plateau, as seen using calcite/siderite proxies for δ¹⁸O levels, as well as phosphates in crocodile, turtle, and herbivorous dinosaur teeth (Suarez, et al., 2009; Suarez, et al., 2011; Suarez, et al., 2014). Heavy rains prevailed.

The increased rainfall in the Cretaceous caused enormous streams to flow from the highlands along the edges of the Colorado Plateau, resulting in braided and meandering rivers depositing thick sediments which became the Cedar Mountain and the Burro Canyon Formations.
In the Cedar Mountain Formation, the Yellow Cat Member was deposited in streams and lakes. Northeast-flowing meandering streams in the foreland basin became the Poison Strip Sandstone Member. Later, the Ruby Ranch Member was deposited as fluvial and floodplain deposits in a monsoonal climate (Kirkland, et al., 1997; Kirkland and Madsen, 2007).

Braided streams that deposited rocks in the Burro Canyon Formation flowed north and east across a vast coastal plain, with a small sub-component of northwesterly flows (Craig, 1981; Owen and Head, 2005). The Burro Canyon was deposited between the region-wide K1 unconformity at the top of the Jurassic and the K2 unconformity at the base of the Dakota Formation (Owen and Head, 2005).

A comparison of the thicknesses of the two formations is shown in Figure 6. Note the lobate nature of the Burro Canyon Formation, as well as the Sevier foredeep in the upper left, where Cedar Mountain sediments thicken dramatically.

Figure 6. Isopach map north of the Four Corners area, with thicknesses of the Cedar Mountain and Burro Canyon Formations. Contour intervals 20m. Red star indicates study area. Heavy dotted line is the arbitrary dividing line of Stokes and Phoenix, 1948. Note Sevier foredeep, upper left corner (modified from Craig, 1981).
THE BURRO CANYON FORMATION

The Burro Canyon Formation consists of lenticular conglomeratic sandstone beds alternating with generally non-swelling green-gray mudstones (Craig, 1981; Owen, et al., 2005). The Burro Canyon is informally divided into a lower section dominated by conglomeratic sandstones and an upper section dominated by green-gray mudstones (Craig, 1981; Tschudy et al., 1984). Although the lower sandy section in the Burro Canyon is highly conglomeratic in places—as is the lower Cedar Mountain Buckhorn Conglomerate—this is more likely to be from local incised valley fills (Craig, 1981; Owen and Head, 2005), rather than indicating a region-wide characteristic.

The Buckhorn Conglomerate Member of the Lower Cedar Mountain Formation (which incidentally is also not found east of the San Rafael Swell) is therefore not correlatable to the conglomerates in the Burro Canyon Formation to the east. However, the conglomeratic sandstones are a good way of differentiating the Burro Canyon conglomeratic sediments from those of the underlying Morrison Formation paleosols in these areas (Stokes and Phoenix, 1948; Craig, 1981).

Conglomeratic sandstones in the basal Burro Canyon Formation are siliceously cemented with a low component of calcitic cementation—as low as 6% (Miskell-Gerhardt, 2013; Craig, 1982). (The Cedar Mountain Formation's Buckhorn Conglomerate is calcitic—Young, 1960.) Angular quartzite clasts at the bases of conglomeratic blocks in the Burro Canyon indicate relatively rapid cementation rates (Miskell-Gerhardt, 2013), as well as deposition proximal to source terranes. In places, as much as 83% of Burro Canyon Formation sandstones are made up of these angular quartzite clasts (Craig, 1982).
This conglomeratic interval is known as the Karla Kay Conglomerate (Ekren and Houser, 1959).

The Burro Canyon Formation is mapped from the Colorado River in southeastern Utah to the San Juan Basin in New Mexico, to the north in the Paradox and Piceance Basins in southwestern Colorado, and as far east as the Gunnison Uplift (Fig. 1) (Stokes, 1952; USGS Geolex 'Burro Canyon Formation'; Ekren and Houser, 1959; Craig, 1981). Some Burro Canyon outcrops are also found farther east in the Eagle Basin in Colorado. The Burro Canyon's farthest southern extent is near the Four Corners area, where it has been shown to pinch out (Fig. 6) (USGS Geolex; Ekren and Houser, 1959; Craig, 1981).

This study focuses on the western limb of the Uncompahgre Plateau above the Colorado River in east central Utah, on Hotel Mesa and Buckhorn Mesa, both in Grand County (Figure 7).
The Early Cretaceous Burro Canyon Formation is Early Barremian to Early Albian in age—approximately 100-129Ma, by palynological analysis (Tschudy, et al., 1984). This is supported by fission-track analysis of detrital zircons in the same pollen-bearing shales, giving an age of $125 \pm 10$ Ma (Craig, 1982). These ages correlate well with dates for the Cedar Mountain Formation to the west, which are Early Barremian (Buckhorn Conglomerate and Yellow Cat Members, as old as 139Ma) to Early Cenomanian (Mussentuchit Member, as young as 98Ma) (Kirkland and Madsen, 2007; Ludvigson, 2015). For reasons outlined below, the Buckhorn Conglomerate and Mussentuchit Members are rejected as a potential lithological candidates for correlation in the study area.

The youngest Cedar Mountain Formation in the study area is therefore the Ruby Ranch Member, which is dated by U/Pb detrital zircon analysis as being 109-116Ma in age (Kirkland and Madsen, 2007; Ludvigson, 2015). The Burro Canyon Formation age overlaps this, being as old as 129Ma via pollen, or as old as 135Ma via fission-track analysis (Tschudy, 1984; Craig, 1982). This makes the Burro Canyon Formation as much as 26Ma older than the Ruby Ranch Member (Tschudy, et al., 1984).

The Burro Canyon was first described by Coffin in 1921, who referred to it only as "post-McElmo" (Coffin, 1921), i.e. post-Morrison. The 'McElmo' designation was later scrapped in favor of the more popular Morrison, due mainly to disuse (USGS Geolex, 'McElmo Formation').

The Burro Canyon Formation was included by Stokes and Phoenix in their 1948 geologic map of the region. They designated the group of rocks that lay between the Jurassic Morrison Formation and the Cretaceous Dakota (Naturita) Formation as the
Burro Canyon Formation (Figure 8). The type section is in Burro Canyon, Section 29, T44N, R18W in San Miguel County, Colorado, approximately 3/4 mile north of Slickrock (Fig. 2).

Figure 8. General stratigraphic column for the Grand Valley in Western Colorado. The Burro Canyon Formation (red arrow) is beneath the Lower Cretaceous Naturita (Dakota) Formation and above the Upper Jurassic Morrison Formation, Brushy Basin Member. (Stratigraphic column courtesy Dr. Julia McHugh, Museum of Western Colorado. Red arrow mine.)

The Burro Canyon Formation was subsequently dated as being Lower Cretaceous, primarily based on fossil plant evidence (*Frenelopsis varians*) from the Slick Rock Mining District in Colorado, which also included ganoid fish scales and ostracods.
(Stokes, 1952). This age was later confirmed by palynological analysis, as well as the presence of tree fern *Tempskya* sp. (Tschudy et al., 1984; Tidwell and Hebbert, 1992).

Similar fossil plants—as well as invertebrate fossils—are found in the Cedar Mountain Formation across the Colorado River in Utah, along with ganoid fish scales of the same general type as those found in the Burro Canyon Formation in Colorado (Stokes, 1952; Ekren and Houser, 1959). The invertebrates—gastropods, pelecypods, and ostracods—also correspond to Lower Cretaceous invertebrate assemblages in Wyoming (the Cloverly Formation and the Gannet Group) and in Montana (the Kootenai Formation). These fossil discoveries in the Cedar Mountain and the Burro Canyon Formations indicate that they are coeval (Stokes, 1952; Young, 1960; Craig, 1981; Tschudy, et al., 1984).

Stratigraphically, the Burro Canyon Formation lies between the Jurassic Brushy Basin Member of the Morrison Formation and the Upper Cretaceous Dakota Formation (Naturita Formation *sensu* Young, 1960; Carpenter, 2014) (Fig. 8). The Burro Canyon has the K1 unconformity at its base (Owen and Head, 2005), where it is differentiated from the Brushy Basin Member below by a distinctive light-colored, lenticular, sandy/cherty pebble matrix-supported lag conglomerate, the Karla Kay Conglomerate (Ekren and Houser, 1959). This conglomerate is in sharp contrast to the variegated smectitic Brushy Basin Member paleosols beneath. Although the Karla Kay Conglomerate might be coeval with the Buckhorn Conglomerate Member of the Cedar Mountain Formation, it would be difficult to correlate the two, as they likely represent only local incised valley fills rather than region-wide units.
Though certain authors have made the seemingly well-substantiated claim that the Brushy Basin is conformable with the Burro Canyon in the Four Corners area (Ekren and Houser, 1959), there is later cross-sectional evidence that the Burro Canyon Formation truncates the Brushy Basin Member of the Morrison Formation in the San Juan Basin to the southeast in New Mexico, demonstrating its unconformable nature (Owen and Head, 2010).

The source of clastics for the Burro Canyon Formation is claimed to be in the Mogollon Highlands in Central Arizona and Southwestern New Mexico (Craig, 1981; Bilodeau, 1986). A general decrease in conglomerates and sandstone lenses as one moves southward toward the Four Corners area indicates that this is the southern edge of coarse clastics in the Burro Canyon Formation (Ekren and Houser, 1959).

Overall, the Burro Canyon represents a proximal—coarser/sandier, and thinner—association of facies than does the Cedar Mountain Formation (Craig, 1981; Cole, 1987). Also, the Burro Canyon has much less accommodation space than the Cedar Mountain Formation, which thickens significantly to the west in south central Utah where the Cretaceous Sevier foredeep lies (Craig, 1981; Stikes, 2007; Fillmore, 2011).

This difference in accommodation space is due to different source area orogenic processes occurring during the Early Cretaceous. The Cedar Mountain's source is in the Sevier Highlands, where compressive and load forces dominated. The Burro Canyon's source is in the Mogollon Highlands, where extensional volcanic forces dominated, although sediments in the Burro Canyon are primarily from uplifted areas with few volcanic clasts included in them (Craig, 1981; Bilodeau, 1986; Blakey and Ranney, 2008).
THE CEDAR MOUNTAIN FORMATION

The Cedar Mountain Formation is also a fluvially-dominated unit, which was once believed to be stratigraphically indistinct from the Burro Canyon Formation to the southeast of the Colorado River (Young, 1960). It comprises primarily overbank fines and fluvial sandstones, as well as a minor component of interfluvial paleosols, lacustrine cherts, and limestones. The Cedar Mountain Formation reaches a thickness of 1160m (3806ft) at Chicken Creek in the San Pitch Mountains (Kirkland, et al., 1997). William Lee Stokes first named the Lower Cretaceous Cedar Mountain Formation in 1944 while mapping exposures near Cedar Mountain on the northern end of the San Rafael Swell (Fig. 2) (Stokes, 1952).

Stokes later amended his preliminary definition of the Cedar Mountain to include the basal Buckhorn Conglomerate. The Buckhorn Conglomerate is considered to be part of the Late Jurassic Morrison Formation by some scientists (discussed in Stokes, 1952; Aubrey, 1998; Roca-Argemi and Nadon, 2003; and Kirkland and Madsen, 2007); however most geologists and paleontologists place the Buckhorn Conglomerate at the base of the Cedar Mountain Formation (Kirkland, et al., 1997; Kirkland, et al., 1999; Taylor, et al., 2011 ). Paleontologists largely ignored the Cedar Mountain Formation until fresh discoveries came to light in the early 1990s. Subsequent stratigraphic plotting allowed scientists to further divide the Cedar Mountain Formation into several distinct lithologic members: the Yellow Cat Member, the Poison Strip Sandstone Member, the Ruby Ranch Member, and the Mussentuchit Member (Kirkland and Madsen, 2007).

Towards the west, the Cedar Mountain Formation outcrops extend from Western Colorado across east-central Utah, passing south of Green River, Utah. The outcrops then
parallel the flanks of the San Rafael Swell, turning north up the Price River valley, then south down Castle Valley. Cedar Mountain outcrops are also seen near Vernal, Utah and along the flanks of the Henry Mountains (Fig. 1) (Stokes, 1951; Craig, 1981; Kirkland and Madsen, 2007).

The Cedar Mountain Formation is formed from the remnants of a series of alluvial coastal plains and valley fills from large braided rivers that drained into the Western Interior Seaway, arising from overthrust belts that created highlands in Central Utah (Figs. 3-5). As mentioned, these highlands were products of the Late Jurassic/Early Cretaceous Sevier orogeny (Craig, 1981; Cole, 1987; Owen and Head, 2005). The conglomeratic valley fills that were deposited from the highlands create heterogeneities, adding to the complexity of the Cedar Mountain Formation (Kirkland and Madsen, 2007).

The compressive overthrust folds of the Sevier orogeny formed the Rocky Mountain geosyncline, a vast foreland basin into which the huge quantities of sediments were deposited via Cedar Mountain river systems associated with the onset of Sevier tectonism, beginning in the Late Jurassic. Strata were deposited to the east of the thrust zone (which is presently west of the Wasatch Plateau) into the axis of the foreland basin, formed by thrusts of the Sevier orogeny that burdened the lithosphere, creating the geosynclinal foredeep (Cole, 1987; Kirkland, et al., 1997; Currie, 1998). Some call these most proximal sediments west of the Wasatch Plateau the Pigeon Creek Formation. It is considered to be a lateral equivalent to the Cedar Mountain Formation farther east (Fillmore, 2011).
The Upper Jurassic Morrison Formation, Brushy Basin Member, was originally dated at 148.1 ± 0.5 million years old, a radiometric age determined by $^{40}\text{Ar}/^{39}\text{Ar}$ isotopic analysis of sanidine from bentonitic clays (montmorillonite) at the K1 unconformity in various locations in east-central Utah and Western Colorado (Kowallis, et al., 1998). This has since been recalibrated to 150.0 ± 0.52Ma (Trujillo and Kowallis, 2015). Recent data from the Cedar Mountain Formation show an age of about 103.7 ± 2.6 Ma, from U/Pb and U/Th/He zircon analysis (Ludvigson, 2015). This indicates that the Brushy Basin Member of the Morrison Formation is as much as 47Ma older than the Cedar Mountain Formation.

However, more recent studies using U/Pb detrital zircon analysis show that the Lower Yellow Cat Member of the Cedar Mountain Formation may be as old as 139.7 ± 2.2 Ma, leaving a significantly shorter erosional gap of only 10 Ma between the basal Cedar Mountain Formation and the underlying Morrison Formation (Hendrix, et al., 2015). However, these detrital zircons may be reworked from lower horizons, making them older than the actual deposition of the Yellow Cat Member. Either way, there is a significant erosional gap between Jurassic rocks and Cedar Mountain rocks.

Just west of the study area, along the eastern edge of the Poison Strip south of Cisco, Utah, charophytes were found, particularly *Nodosclavator bradleyi* (Harris), giving a biochronologic age control for the Yellow Cat Member at no younger than Barremian in this area (Kirkland, et al., 1997). The Yellow Cat Member is therefore older than 125Ma just west of the study area.

To reiterate, the Cedar Mountain Formation has been subdivided into five members: the Buckhorn Conglomerate, the Yellow Cat Member, the Poison Strip...
Sandstone, the Ruby Ranch Member, and the Mussentuchit Member (Figure 9). As a mainly valley-fill conglomeratic unit, the Buckhorn Conglomerate is not correlatable across the San Rafael Swell into the study area, as mentioned. The Mussentuchit Member is limited to the western side of the San Rafael Swell (Kirkland and Madsen, 2007). This leaves the Yellow Cat Member, the Ruby Ranch Member, and the Poison Strip Sandstone as potential lithological candidates for correlation of the Cedar Mountain Formation across the study area (Stikes, 2007).

With the Cedar Mountain Formation and the Burro Canyon Formation both being primarily fluvial and lacustrine in nature, it requires some study to distinguish them. However, the two formations do have significant differences.

Figure 9. Stratigraphic chart showing the various members of the Cedar Mountain Formation. Note the Jurassic Morrison at the base and the scattered Naturita/Dakota Formation at the top (courtesy Dr. Kenneth Carpenter, Utah State University).
Characteristics that differentiate the Burro Canyon Formation from the Cedar Mountain Formation include: more mudstone interbeds, overall more sandstone, and a notable difference in paleoflow trends (Table 1). The Burro Canyon Formation is informally divided into a lower sandy conglomeratic section and an upper mudstone-dominated section (Craig, 1981; Tschudy, et al., 1984; Owen, et al., 2005).

Table 1. Differences between the Cedar Mountain Formation and the Burro Canyon Formation, with references cited.

<table>
<thead>
<tr>
<th>Cedar Mountain</th>
<th>Burro Canyon</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>More mudstones/siltstones in lower section</td>
<td>More conglomeratic sandstones in lower section</td>
<td>Craig, 1981; Owen and Head, 2005; Kirkland and Madsen, 2007</td>
</tr>
<tr>
<td>Distal</td>
<td>Proximal</td>
<td>Craig, 1981</td>
</tr>
<tr>
<td>Lower energy EOD</td>
<td>Higher energy EOD</td>
<td>Craig, 1981</td>
</tr>
<tr>
<td>Paleoflows from due west (Sevier Highlands)</td>
<td>Paleoflows from the south and southwest (Mogollon Highlands)</td>
<td>Craig, 1981</td>
</tr>
</tbody>
</table>

Because the Cedar Mountain Formation is now formally divided into members, any lithological extension of these members across the arbitrary dividing line—the
Colorado River—will indicate the existence of the Cedar Mountain Formation rather than the Burro Canyon Formation to the east and southeast of the river. Such appears to be the curious situation at the Hotel Mesa Dinosaur Quarry just east of the Colorado River, where the Poison Strip Sandstone and the Ruby Ranch Members of the Cedar Mountain Formation are alleged to be present in what up until now has been called the Burro Canyon Formation (Figure 10) (Kirkland, et al., 1997; Taylor, et al., 2011).

Figure 10. Outcrop map of the Cedar Mountain Formation (purple) showing a projection across the Colorado River to the east (yellow arrow, mine), contradicting the arbitrary line of Stokes, 1952. This is presumably to account for Taylor, et al. 2011’s description of the Poison Strip and Ruby Ranch Members at the Hotel Mesa dinosaur quarry (from Ludvigson, et al., 2010).
METHODS/ANALYSIS

The goal of this project was to document local lithological and stratigraphic characteristics of appropriate outcrops east of the Colorado River and then to compare those findings with the known Cedar Mountain Formation to the west. Initially, a review of pertinent scientific literature was undertaken in order to develop methods of comparison and contrast between the Cedar Mountain Formation and the Burro Canyon Formation (Table 1). Following this, lithologies and measured sections were taken at appropriate sites on the Uncompahgre Plateau near known sections across the Colorado River. The presence of the Poison Strip Sandstone Member of the Cedar Mountain Formation on Hotel Mesa was initially documented on the east side of the Colorado River. Measurements were taken to demonstrate that the Poison Strip Sandstone does extend beyond the river to the east, using stratigraphic and lithological analyses to make the point. This more firmly underscores the necessity of redrawing the contact between the Cedar Mountain Formation and the Burro Canyon Formation, using a stratigraphic basis rather than an arbitrary dividing line.

Next, measured sections were taken 4 1/2 miles (7 1/4 km) to the northeast at a readily accessible place on Buckhorn Mesa where outcrops are at higher elevations. The intent was to extend the stratigraphic and lithological analyses farther east in an attempt to delineate the true contact between the two formations on Buckhorn Mesa.

Multiple paleocurrents were then taken in association with the measured sections on Buckhorn Mesa, as described below. Preliminary paleocurrent analysis and fluvial facies were then developed, the latter requiring facies definitions and facies association development. The latter analyses are termed 'preliminary,' as there was only strike data
gathered on the paleocurrents—for reasons outlined below—and facies associations were developed using only photographic data, rather than further outcrop investigation on the ground, due in part to the remoteness of the study area. The study area was visited twice in the fall of 2015, with a total of 11 days spent collecting data.

**Lithological Analysis**

Scalar properties of sediments were noted by examining variation in sediment grain size, sorting, roundness, color, and field mineralogy. At 10% solution, hydrochloric acid was also employed to determine differences in sandstone cementation and mudstone nodule composition. As sections were measured, grain sizes were examined using a Wentworth grain scale and 30X hand lens. 27 samples were gathered, then examined for these same characteristics.

These scalar characteristics were then compared and contrasted to known lithologies in the literature in an attempt to correlate the new data to information found there.

**Stratigraphic Analysis**

Sections at non-precipitous locations were measured using a Jacob's staff. GPS waypoints were taken at the tops and bottoms of each section, as well as at significant stratigraphic contacts with other formations, such as the overlying Dakota/Naturita Formation and the underlying Morrison Formation, Brushy Basin Member.

Stratigraphic data collection began on Hotel Mesa near Dewey Bridge, Utah, a location initially determined from Stokes, 1952. Then, using Matthew Stikes’ 2007 study
of the Poison Strip Sandstone Member of the Cedar Mountain Formation as a guide, I
determined the location of the last, eastern-most traced outcrop of Cedar Mountain
sediments northeast of Arches National Park, just north of Dewey Bridge—Stikes’
"Section 5-Dewey Bridge" (Stikes, 2007; p.67).

    Stratigraphic correlation of my Hotel Mesa section with similar patterns in Stikes’
section was then made, showing that the Poison Strip Sandstone Member of the Cedar
Mountain Formation does indeed crop out on the east side of the Colorado River, as is
also claimed for the Hotel Mesa Dinosaur Quarry (Kirkland, et al., 1997; Taylor, et al.,
2011).

    Following this preliminary investigation, several stratigraphic sections along with
multiple paleocurrents (Appendix) were measured on Buckhorn Mesa, on the western
side of the Uncompahgre Plateau, 4 1/2 miles northeast of the Hotel Mesa site, as
mentioned (Figure 11). Stratigraphy was accomplished by noting thicknesses of distinct
units, the nature of their contacts, sedimentary structures (both primary and secondary),
and lithologies.
Figure 11. Google Earth screenshot showing the location of measured sections on Buckhorn Mesa in relation to the Hotel Mesa measured section northeast of Dewey, Utah, as well as the Colorado River and Utah State Highway 128. Bureau of Land Management Road 107 is the access into the area from Colorado. Stikes Dewey Bridge section is also indicated (arrow).

Stratigraphic measurements were taken at a point near the road that resembled an interfluve contact between the Poison Strip Sandstone and the Burro Canyon Formation on Buckhorn Mesa. This assumed contact was based on visual differences between the two outcrops, including: 1. more incalced sandstone and mudstone beds in the upper portion of what looked like the Burro Canyon outcrop, with the assumed Poison Strip having one main sandstone section and only a few subsidiary stringers in the mudstones below and above it; 2. subtle weathering differences—the presumed Poison Strip
Sandstone weathered blockier than the Burro Canyon outcrop, which was more rounded; 3. coloration of the rocks, with the Poison Strip having a more reddish color than the grayer Burro Canyon rocks, presumably due to the presence of more hematite; and, 4. the Burro Canyon has more conglomeratic sandstone in its lower portion, while the Cedar Mountain has more mudstone in its lower portion.

**Paleocurrent Analysis**

Upon researching the necessary corrections to paleoflow data, I found that it was unnecessary to correct my data for tilt, as any structural tilt on the Uncompahgre Plateau is post-Laramide (Fillmore, 2011) and so has no relevance to Early Cretaceous environments of deposition. Also, structural dips that are less than 30° can generally be ignored (Miall, 2000). I took several remote dips on distant strata in scattered places near my measured sections in order to determine regional dip angles. They all ranged from 4° to 6°, far short of Miall's 30° limit. Dips were therefore not recorded while measuring paleocurrents. Although dip data are important to fluvial architectural reconstruction, the lack of dips does not preclude good estimates of regional and local paleocurrent trends (Miall, 2013).

In addition, even though the Colorado Plateau has undergone an average 5° clockwise rotation relative to the North American craton since Late Cretaceous times (Hamilton, 1981; Bryan and Gordon, 1990), the whole compass of the present study is on the Uncompahgre Plateau and entirely within the Colorado Plateau province. The Uncompahgre Plateau rotated along with the entire province, so this rotation must be taken into account only when comparing Uncompahgre/Colorado Plateau rotation to the
North American craton—something beyond the scope of this study. Therefore, my paleocurrents are raw data as gathered in the field without correction, including strikes only (Appendix).

Azimuthal readings were taken from a Brunton compass. All paleocurrents were taken on 3-D ripple and dune cosets, most of which were found on sandstone outcrop tops, rather than on cliff faces or edges, due to safety considerations. Outcrop tops were ample though, and three sets of paleocurrents were gathered, each in association with each of my measured sections. The three sets totaled 132 paleocurrents: 62 at Section #1, 20 at Section #2, and 50 at Section #3. 3-D ripples were the primary structure from which paleocurrents were taken, as other structures (e.g. tool marks and flute casts) were unfortunately not observed in the field.

Many troughs on outcrop tops were three-dimensional in plan view and were therefore easily measured. Others were on edge, and only two-dimensional measurements were taken. Nonetheless, these are likely to be within 25° of the true paleoflow azimuth (DeCelles, et al., 1983).

After collection of paleocurrent data, the azimuths were organized into 10° bins on rose diagrams in order to determine paleocurrent trends, which were subsequently compared to those found in the literature (Craig, 1981).

**Facies Development**

Facies and facies association development were undertaken in an attempt to determine overall fluvial style in the study area. Facies were based on Matthew Stikes’ study of the Poison Strip Sandstone (Stikes, 2007), as well as from other sources (James
and Dalrymple, eds., 2010; Miall, 1977). Using close-up photographs to illustrate the facies found in my study area, I then develop facies associations in larger-scale outcrop photos.

Data Synthesis

With lithologies, stratigraphy, paleoflows, and facies in place a better picture of the nature of the strata in this remote location emerges. After completion of these data analyses, it will be seen that the Poison Strip Sandstone is found east of the Colorado River on Hotel Mesa, based on lithological and stratigraphic evidence.

Although at first it was assumed that two of my measured sections on Buckhorn Mesa were likely in the Burro Canyon Formation, it became evident that the stratigraphy of the two sections was similar to that of the third, leading to the conclusion that all of the sections are in the Poison Strip Sandstone Member of the Cedar Mountain Formation.

RESULTS

1) Lithology

Initially, I located what I thought to be the Poison Strip Sandstone Member of the Cedar Mountain Formation on Hotel Mesa by comparing elevations of known sections to the west of the Colorado River with major sandstone bodies on the east side of the river. Hiking to the bottom of the section on Hotel Mesa, I discovered that the tell-tale calcrete that marks the base of the Yellow Cat Member at other sites—including the type section (Kirkland et al., 1997; Stikes, 2007)—was missing here (these calcretes aren't present
everywhere in the Yellow Cat). However, I surmised that the base of the Poison Strip Sandstone was at the top of a series of variegated popcorn-textured mudstones that include paleosols and some sandstone lenses in the Upper Morrison Formation (Kirkland and Madsen, 2007).

Because the Poison Strip Sandstone Member of the Cedar Mountain Formation is found on the west side of the Colorado River near Dewey Bridge, its lithologic characteristics are now enumerated as a baseline of comparison to the measured section I took at Hotel Mesa: 1. the Poison Strip is a well-cemented, mature quartz arenite; 2. it is primarily calcitic, with intergranular carbonate cementation, micritic spar, and secondary carbonate cementation; 3. its grains range from very fine-grained to very coarse-grained, but are primarily medium- to coarse-grained, and sub- to well-rounded; 4. it includes chert-pebble lenses in its lower part, with mudstone partings in its upper section; 5. it includes trough-tangential cross-stratification, low-angle planar laminations, and climbing ripple laminations, with recumbent folds locally; 6. bedding thicknesses in general run from about 0.2 to 1.0m (0.67-3.3ft); 7. unweathered, it is white to light tan, with occasional black lithics; and it weathers tan to brown, with black streaks of desert varnish (Kirkland and Madsen, 2007; Stikes, 2007; Ludvigson, 2015).

The top of the Poison Strip Sandstone is marked by mudstone partings, as mentioned, but also by a drab maroon mudstone that includes numerous CaCO₃ nodules. This is the Ruby Ranch Member of the Cedar Mountain Formation (Kirkland, et al., 1997; Kirkland and Madsen, 2007; Stikes, 2007).

As an aside, it is interesting to note here that the Ruby Ranch Member includes ephemeral ponds, indicated by limestone lenses (Kirkland, et al., 1997). I found extensive
chert beds in what I assume to be the Ruby Ranch Member on Buckhorn Mesa. Although outside the scope of the present study, I think these chert beds will be found to be diagenetically altered limestone lake beds.

The lithologies found in my section on Hotel Mesa compare favorably with those of the Cedar Mountain Formation in the literature, specifically the Poison Strip Sandstone Member and the Ruby Ranch Member (Table 2).

**Table 2. Comparison of known Cedar Mountain Formation lithologies (Kirkland and Madsen, 2007; Stikes, 2007) with those found at my Hotel Mesa measured section.**

<table>
<thead>
<tr>
<th>Known Cedar Mountain Formation lithologies</th>
<th>Lithologies found at my Hotel Mesa measured section</th>
</tr>
</thead>
<tbody>
<tr>
<td>well-cemented (micritic/spar), Qtz arenite</td>
<td>well-cemented (CaCO₃ cement), Qtz arenite</td>
</tr>
<tr>
<td>vfg-vcg; primarily mg-cg</td>
<td>fine upper to medium lower (170-400 µ); within range</td>
</tr>
<tr>
<td>sub- to well-rounded</td>
<td>rounded to well-rounded; within range</td>
</tr>
<tr>
<td>chert-pebble lenses in lower part</td>
<td>none observed</td>
</tr>
<tr>
<td>MS partings in upper section</td>
<td>MS partings in upper section</td>
</tr>
<tr>
<td>trough-tangential cross-stratification</td>
<td>trough-tangential cross-stratification</td>
</tr>
<tr>
<td>low-angle planar laminations</td>
<td>low-angle planar laminations</td>
</tr>
<tr>
<td>climbing ripple laminations</td>
<td>climbing ripple laminations</td>
</tr>
</tbody>
</table>
(Table 2 cont.)

<table>
<thead>
<tr>
<th>local recumbent folds</th>
<th>local recumbent folds</th>
</tr>
</thead>
<tbody>
<tr>
<td>bedding thicknesses generally from 0.2-1.0m (8in-3.3ft)</td>
<td>cm-scale bedding; bounding surfaces observed: 6in (20cm) to 2ft (0.67m)</td>
</tr>
<tr>
<td>sandstone white to light tan, with black lithics</td>
<td>sandstone white to light tan, with black lithics</td>
</tr>
<tr>
<td>weathers tan to brown with streaks of desert varnish</td>
<td>weathers tan to brown with streaks of desert varnish</td>
</tr>
<tr>
<td>Top of Section: drab maroon MS, with abundant CaCO₃ nodules</td>
<td>Top of Section: drab maroon MS, with abundant CaCO₃ nodules</td>
</tr>
</tbody>
</table>

No chert-pebble lenses were observed in the lower part of my Hotel Mesa section. All other Poison Strip Sandstone lithological characteristics were observed at my section, giving lithological basis for correlation (Kirkland, et al., 1997; Kirkland and Madsen, 2007; Stikes, 2007).

The three sections measured at Buckhorn Mesa (Buckhorn #1, #2, and #3) have lithologies very similar to those found on Hotel Mesa. Buckhorn Sections #1 and #2 comprise a composite section, with Buckhorn Section #3 standing alone. Upon close inspection and comparison of the various lithologies, it was found that these three sections likely represent the same types of rocks, contrary to my initial assumption that they represent two different formations.

All three of my measured sections on Buckhorn Mesa include non-swelling (hackly textured) mudstones that vary in color from gray, to drab maroon and brown, to
bright olive green. The sandstones in my three sections are similar to those found elsewhere in the Cedar Mountain Formation, with the exception of those found in the upper part of my Section #2—the top of my composite section—which I believe are in the Dakota/Naturita Formation due to the presence of bioturbation and organic mudstones, along with twig and leaf impressions (Craig, 1981; Tschudy et al, 1984).

Sandstones in my Section #1 and Section #3 are generally white to tan, to light gray, with brown, black and rare red lithics. They are without exception quartz arenites, as the quartz fraction is high, the grains are mature, and there is very little argillaceous matrix (Bates and Jackson, eds., 1984). They are very fine-grained to coarse-grained, but mostly medium- to fine-grained. The grains vary from sub- to very well-rounded, but are primarily well-rounded. They are well- to very well-sorted. The sandstones all have moderate CaCO$_3$ cementation, and are friable to well-indurated, with the more indurated portions being those that are found mid-section. Near the tops and bottoms of sections the sandstone is more friable.

Sandstone bedding ranges from laminations to very thin beds (1cm, 0.4in). The sandstone laminations are horizontal, to low-angle planar, to trough-tangential, and beds are rarely massive. The beds come in cosets that range from 3-13in (8-33cm). Climbing ripple laminations and extremely long-axis recumbent folds (up to 17ft or 5m) were also found, and one small section of festoon cross-stratifications was observed.

Sandstones include conglomeratic stringers of white, gray and black cherty pebbles in scour-and-fill troughs. In Section #3, there is a portion that includes a 4-8in (10-20cm) bed of matrix-supported conglomerate. Section #2 has a significant portion of elast-supported conglomeratic sandstone over 5ft (1.5m) thick at the base of its upper
sandstone body. Scattered conglomeratic stringers embedded in laminate troughs likely represent flooding events (Stikes, 2007; James and Dalrymple, eds., 2010; Boggs, 2012).

2) Stratigraphy

A. Hotel Mesa

From bottom to top, a typical Poison Strip stratigraphic sequence is: 1. an erosional scour at the basal contact with up to 5m (16.5 ft) of relief; 2. trough cross-stratified sandstone; 3. horizontal, planar-stratified sandstone; 4. ripple-bedded or low-angle heterolithic sandstone, with slabby, conformable mudstone partings toward the top; and 5. drab purple to green non-smectitic mudstone with abundant CaCO₃ nodules at the top of the sandstone sequence (Kirkland, et al., 1997; Stikes, 2007).

These drab mudstones on top of the Poison Strip Sandstone represent the pedogenically altered overbank fines of the Ruby Ranch Member of the Cedar Mountain Formation (Kirkland, et al., 1997; Kirkland and Madsen, 2007; Stikes, 2007). I determined that Stikes’ total measured Section #5 at Dewey Bridge (Stikes, 2007, p.67) was 26m (86ft) with approximately 9m (30ft) of sandstone interbedded with mudstone in its upper section, measured from the top of the carbonate mudstone interval at the bottom, to the lowermost sandstone stringer in the Ruby Ranch section at the top.

My Hotel Mesa Section (Figure 12) observed sequence is as follows: 1. basal erosional scour with up to 3m (10ft) of local relief; 2. horizontal planar cross-stratified sandstone; 3. trough cross-stratified sandstone; 4. rippled-bedded sandstone; 5. low-angle horizontal laminations/planar stratification, with mudstone partings near the top; and, 6. drab purple/maroon to green non-smectitic (hackly textured) mudstone with abundant
CaCO$_3$ nodules, this last likely being the Ruby Ranch Member equivalent at the top of the section.

My total measured thickness was 30 ft (9m), correlating closely to the sandstone thickness in Stikes’ Dewey Bridge Section 5.

Figure 12.
Stratigraphic section on Hotel Mesa between the dinosaur quarry (Taylor et al., 2011) and Matthew Stikes’ easternmost section (Stikes, 2007). Facies codes from Stikes, 2007, outlined in Figures 23 and 24 below.
B. Buckhorn Mesa

After a hard rain the night before, it was interesting to note that the presumed Jurassic Morrison Brushy Basin mudstones at the bottom of Buckhorn Mesa Section #1 readily stuck to my shoes. These basal mudstones also had a popcorn texture to them, and were therefore bentonitic and indicative of the Brushy Basin Member of the Morrison Formation. (These sticky muds were also at the appropriate stratigraphic level.) Mudstones just above this interval were much sandier, and didn't stick to my shoes. This difference is likely due to grain sizes, with the stickier muds containing more clays and the less sticky muds more silt and sand. This is the level at which Section #1 begins.

The stickiness of the mud was only one criterion for judging where the contact between the Jurassic Morrison Formation and the Lower Cretaceous strata lies on Buckhorn Mesa. The brighter-colored bentonitic Morrison gives way up-section to drabber mudstones that are hackly-textured—an indication they are less bentonitic (Craig, 1981; Kirkland, et al. 1997; Owen and Head, 2005; Kirkland and Madsen, 2007; Stikes, 2007). When the mudstones at Buckhorn were inspected closely, it was found that this was the case.

Another criterion for identifying the base of the Cretaceous is the existence of a thick, region-wide series of paleosols in the upper Morrison. Bureau of Land Management Road 107 crosses a thick paleosol on Buckhorn Mesa, close to the lower level of the Cretaceous strata (Figure 13).

Calcretes ("nodular palustrine carbonates"—Ludvigson, et al., 2010) are cited as yet one more region-wide criterion for finding the base of the Lower Cretaceous strata (Kirkland, et al., 1997; Stikes, 2007; Ludvigson, et al., 2010); however, none were
observed on Buckhorn Mesa, at least not at the appropriate levels along sections
(calcretes higher up were noted, but these were very local in nature, perhaps representing
only small ephemeral ponds).

Figure 13. Well-developed paleosol near Buckhorn Mesa Section #1. Jacob's staff at
center right is 5ft (1.5m) long. Smaller sections of paleosols were also observed higher
up-section, near the base of the Lower Cretaceous strata. Drabber-colored, non-smectitic
Cretaceous strata crop out above these.

Subsequent to finding a suitable line for climbing the section, the lower contact
with the Morrison Formation was determined using the foregoing criteria: appropriate
level; sandy, non-adhering mud; drabber coloration; lack of bentonitic popcorn texture;
and the existence of well-developed paleosols just down-section.
A 1.5ft (0.5m) thick chert bed was found at the top of the first section. This correlated with another chert bed about 0.5mi (0.8km) away. Both chert beds were at the same level stratigraphically, both were the same thickness, both had similar remote dip angles, and both had similar mudstones beneath them (Figure 14). A composite section (Buckhorn Mesa Sections #1 and #2) was made using these chert beds for a more complete stratigraphic picture (Figure 15).

Figure 14. Chert bed at the top of Section #1, foreground, with a chert bed at the bottom of Section #2 seen in distance. The prominent green-yellow plant is matchweed, which grows profusely on the chert, making the beds easy to spot from afar.
Figure 15. Composite Sections #1 and #2 on Buckhorn Mesa. The chert bed was used for compositing.
Measured Section #3 was taken at the prominent green mudstone, seen at right center in Figure 16 at the contact with the main sandstone body, about 1/3 up the Line of Section (LOS #3). This was chosen as a good example of the mudstone/sandstone contact, with a significant erosional basal scour (at the 85ft/25m mark in Figure 17 below).

(Note: Due to safety considerations in the field, the LOS on the photo includes a 29ft (29.5m) vertical section that was estimated using a Jacob's staff, as seen in Figure 37 following. All lithologies are from a safer equivalent lateral extension, slightly to the west of LOS #3, along bottom of bracket indicating the Poison Strip Sandstone in Fig. 16.)

The bottom of the section was chosen using the same criteria for differentiating Morrison Formation mudstones from Lower Cretaceous mudstones used at Section #1 (see text above). The top of the section includes another chert bed with characteristics similar to those found elsewhere (Fig. 17).

Figure 16. Photo showing Buckhorn Mesa Section #3 (black Line of Section). Three candidate members of the Cedar Mountain Formation are illustrated (photo by author).
3) Paleocurrents

Paleocurrents were taken in conjunction with all three measured sections on Buckhorn Mesa in an attempt to illustrate the nature of the local depositional flow pattern, with comparison to known regional patterns in the literature following. Rose diagrams were then drawn using the raw data gathered in the field. Each rose diagram has 10° bins, with two currents radially per circular bin, so that each 10° bin can represent up
to 16 currents. Roses were drawn for measured Sections #1, #2, and #3 separately (Figures 18, 19 and 21). Sections #1 and #2 were then drawn together on a separate rose to illustrate the composite section's total paleocurrent trends (Figure 20). For a complete picture of paleocurrent trends on Buckhorn Mesa, a fifth rose diagram was drawn including all three sets of data (Figure 22).

All five rose diagrams show a bimodal, bipolar distribution with a largely NW/SE trend. Sections #1 and #2 indicate a more northwesterly trend overall. Section #3 appears to be more uniformly bimodal overall (Fig. 21).

Figure 18. Rose diagram from paleocurrents associated with Buckhorn Mesa measured Section #1, showing a bimodal, bipolar distribution.
Figure 19. Lesser numbers of paleocurrents nonetheless show a bimodal, bipolar distribution associated with Buckhorn Mesa Section #2.

Figure 20. Combined rose diagram showing a bimodal, bipolar distribution for the composite of Sections #1 and #2 on Buckhorn Mesa.
Figure 21. Rose diagram of paleocurrents associated with Buckhorn Mesa measured Section #3. Stronger bimodality is seen here, with a lesser northeastern component.

Figure 22. Rose diagram with all Buckhorn Mesa paleocurrents combined.
4) Facies

Facies development is after Stikes, 2007, and James and Dalrymple, eds., 2010. Both of these works draw heavily from Miall, 1977 and Miall, 1978. My section at Hotel Mesa uses facies codes and interpretations directly from Stikes, 2007, Table 1, page 12. These descriptions also apply to facies found at Buckhorn Mesa. Descriptions of these facies follow Figure 23.

Figure 23. Facies found at Hotel Mesa and Buckhorn Mesa. Jacob's staff 5ft (1.5m) long. Knife 4in (10cm) long (facies and interpretations from Stikes, 2007.) A. **Fm**-mudstone:
(Fig. 23 continued) silt and clay, massive-fissile, tabular units, floodplain and lacustrine deposits; B. Fe-mudstone with carbonate nodules: silt and clay, carbonate nodules typically cobble-sized, massive-nodular, pedogenic alteration, tabular units, floodplain and lacustrine deposits; C. Sh/Sl-sandstone: plane bed or slightly inclined plane bed sand, vfg to mg, plane-bed or low-angle lamination, parting lineation, upper flow regime or lower flow regime, bar tops, crevasse splays, shallow flow; D. Sp-sandstone: planar cross-stratified, mg to vcg, tangential base common, tabular sheets, 2-D dunes, transverse bars, lower flow regime; E. Sr-sandstone: ripple cross-laminated, vfg to mg, climbing and solitary sets, thin lenses or tabular sheets, falling stage, lower flow regime, crevasse splays; F. St-sandstone: trough cross-stratified, mg to vcg, 3-D dunes, upper portion of flow regime.

Because no panoramic photo of the outcrop was taken, facies associations will not be developed for Hotel Mesa; however, facies are given as a means of comparison with Stikes’ Dewey Bridge Section 5 (Stikes, 2007)—see discussion below. Other facies found on Buckhorn Mesa are described following Figure 24.
Figure 24. Photos showing more facies found on Buckhorn Mesa. Knife 4in (10cm) long. (Facies descriptions and interpretations are from Stikes, 2007, Table 1, p. 12; and James and Dalrymple, eds., 2010, Table 2, p. 113). A. **Gm**-massive gravel, primarily pebble/conglomerate, typically in sand matrix, structureless or crude horizontal bedding, channel lag deposits, diffuse gravel sheets, overbank incorporation; B. **Gcm**-clast-supported massive gravel, pseudoplastic debris flow (inertial bedload, turbulent flow); C. **Fl**-heterolithic sandstone/mudstone, very fine to med. sand, silt and clay, horizontal laminations, fine laminations, ripples, and contorted bedding with occasional ball-and-pillow structures, proximal overbank, waning flood flow, crevasse splay; D. **Ch**-green chert beds, 1.5ft (0.5m) thick, structureless, diagenetically altered lake beds.
DISCUSSION

1. Lithology

At Hotel Mesa the lithology of the sandstones compared favorably with Stikes' Dewey Bridge Section 5 in the Poison Strip Sandstone Member of the Cedar Mountain Formation (see Table 2). Correlation is suggested based on rock types and sedimentary structures alone.

Comparison of observed lithological characteristics at Buckhorn Mesa with known Cedar Mountain and Burro Canyon lithologies is difficult, but my observed lithologies fall within the range of characteristics found in the Cedar Mountain Formation, specifically the Poison Strip Sandstone Member, as described in the literature (Stokes, 1944; Stokes and Phoenix, 1948; Ekren, et al., 1959; Craig, 1981; Tschudy et al., 1984; Kirkland et al., 1997; Owen and Head, 2005; Kirkland and Madsen, 2007; Ludvigson et al., 2010; Suarez et al., 2014).

Other described Cedar Mountain lithologies, specifically mudstones in the Yellow Cat and Ruby Ranch Members, were also noted in the measured sections on Buckhorn Mesa. This further supports a correlation of Cedar Mountain lithology with that found on Buckhorn Mesa.

The differences between my measured lithologies and those found in the Burro Canyon Formation literature are not enough to warrant complete rejection of the Burro Canyon Formation. However, certain stratigraphic characteristics, including similar stacking patterns, point towards the inclusion of all of my measured sections in the Cedar Mountain Formation, as will now be shown, beginning with the section on Hotel Mesa.
2. Stratigraphy

When the section taken at Hotel Mesa is compared stratigraphically with Stikes' Dewey Bridge Section 1.1 miles (1.8km) to the northwest, there is some reason to consider correlation, although the pattern isn't exact.

Starting at the bottom of Figure 25 there is a similar basal scouring in both sections, the sandstones filling in the erosional relief that cuts into underlying mudstones. Carbonate nodules in mudstones are likely relics of limestone lake beds, worked down into underlying mudstones by erosion (Kirkland, et al. 1997; James and Dalrymple, eds., 2010). Carbonate nodules were found both above and below the sandstone bodies in the mudstone units.

Figure 25. Comparison of my Hotel Mesa section, left (modified from Figure 12, this paper), with Stikes’ 2007 Dewey Bridge Section 5 (modified from Stikes, 2007, p. 67). By matching scales a similar stacking pattern can be seen, with fining upwards sequences at similar levels. Note also the basal scour at the bottom of each section. Facies codes described in Figs. 23 and 24.

The resolution of measurements at my section is higher than at Stikes’, so features are more closely drawn, leading to differing facies being outlined. However, the stacking
patterns are similar enough to be correlated, with basal scours at the same stratigraphic levels and fining upward sequences occurring at similar levels.

The bottom fining upward sequence in my section includes horizontal laminations at the same interval as Stikes’ (Sh/Sl facies code). At the top of the section, Stikes has climbing ripples and I have wavy laminations, structures that occur in similar environments of deposition: waning flow in a high-sedimentation environment (Boggs, 2012; James and Dalrymple, eds., 2010). The sandstone found on Hotel Mesa seems to correlate well with the Poison Strip Sandstone Member of the Cedar Mountain Formation across the Colorado River at Stikes' Dewey Bridge section.

Although I had first assumed that I'd found a contact between the Poison Strip Sandstone and the Burro Canyon Formation at Buckhorn Mesa, upon closer inspection of the stratigraphy this is not the case. The lower portion of the Burro Canyon rocks in Unaweep Canyon, Colorado, have a significant sandstone bed or series of beds topped by an upper mudstone section (Figure 26). These distinctive lower sandstones are up to 300ft (90m) thick in places (Craig, 1981; Owen and Head, 2005).

Sandstones make up over 50% of the total Burro Canyon Formation, whereas the Cedar Mountain Formation is composed of less than 30% sandstones (Craig, 1981). I found a 28% sandstone component at Buckhorn Mesa Section #1, a 31.5% component at Section #2, and a 44% component at Section #3. The greater thickness at Section #3 is likely a local variance, rather than evidence that the strata are in the Burro Canyon Formation.
In contrast to the Burro Canyon Formation, my sections at Buckhorn Mesa include a thick lower mudstone topped by fluvial sandstones of considerably less thickness than those found in Unaweep Canyon (Figure 27).

Figure 26. A thick fluvial sandstone in Unaweep Canyon, Colorado, makes up the lower section of the Burro Canyon Formation. The upper mudstone section is also here, capped by thin Dakota Sandstones.

Figure 27. A thinner set of fluvial sandstones overlies mudstones on Buckhorn Mesa. Mudstones of the Jurassic Morrison Formation(?) make up the valley floor (photos by the author).
The composite section on Buckhorn Mesa (Sections #1 and #2) compares with Section #3, in that the stacking patterns are correlatable, even though thicknesses of the various mudstone and sandstone bodies are not the same (Figure 28).

Interpreting the environments of deposition starting at the bottom of the sections, mudstones in the presumed Yellow Cat Member of the Cedar Mountain Formation are of
lacustrine and fluvial origin (Kirkland and Madsen, 2007). Without further studies, it is surmised that the mudstones found in the study area are mainly of overbank origin, because no carbonate nodules were observed. CaCO₃ was observed in the lower mudstone, but not specifically in nodules. This calcium carbonate might simply be from groundwater effects in the modern semi-arid environment.

At the point of contact between the lowermost mudstones and the beginning of the sandstone sequences there is recumbent folding, contorted bedding, and comformable laminations in Section #1. These features are interpreted as evidence of unconsolidated river beds crossing a coastal plain (Owen and Head, 2005) which experienced major earthquake activity, as seen in contorted beds and extremely long-axis recumbent folding.

The stratigraphic sections measured at Buckhorn Mesa correlate with the section on Hotel Mesa, which in turn correlates with Stikes' Dewey Bridge Section 5 farther west (Stikes, 2007). Therefore the strata in the study area correlate well with the Poison Strip Sandstone Member of the Cedar Mountain Formation west of the Colorado River (Figure 29).

Similarities between the sections closer to the Colorado River and those on Buckhorn Mesa include: 1. erosional scours at the bases of sandstone sequences in Stikes' Dewey Bridge Section 5, my Hotel Mesa section, and my Buckhorn Mesa Section #3; 2. contorted and recumbent bedding in the lowest strata in my Hotel Mesa section and Buckhorn Section #1; 3. sedimentary structures, including climbing ripple laminations at similar stratigraphic levels in my Hotel Mesa section and Buckhorn Mesa Section #1, along with planar and trough tangential laminations in all sections; and, 4. all sections fine upward at the same stratigraphic levels.
Figure 29. Figures 28 and 25 combined. Although the measured section on Hotel Mesa is 4.5 miles (7.25 km) away, it can still be seen that there are several similarities with the measured sections on Buckhorn Mesa: 1. erosional scours at the bases; 2. contorted/recumbent bedding at the bases; 3. similarities in sedimentary structures; and, 4. similar fining upward sequences (Dewey Bridge section modified from Stikes, 2007, p. 67).
3. Paleocurrents

Raw paleocurrent roses at Buckhorn Mesa (see Appendix for azimuths) seem to show a bimodal NW/SE trend, with a stronger NW trend overall (Fig. 22). However, when the average paleoflow trends are taken, a pronounced SW/NE trend can be seen (Figure 30). The apparent northwestern trend seen in the raw paleocurrents represents lateral accretion deposits that are orthogonal to the true overall flow of the ancient rivers and streams, which were likely meandering (Kirkland and Madsen, 2007; Stikes, 2007). The overall flow of meandering streams is generally perpendicular to their lateral accretion deposits, and rose diagrams reflect this (Miall, 2013).

Figure 30. Rose diagrams from Figs. 18-22, showing average trends (black arrows). The overall bipolar trend for all three Buckhorn Mesa sections (lower right) is $229^\circ/49^\circ$. 
Based on work done by Craig, it becomes feasible to compare paleoflows collected on Buckhorn Mesa with those found elsewhere (Figure 31) (Craig, 1981).

Figure 31. Lawrence Craig's paleoflow map of the eastern Cedar Mountain Formation and the Burro Canyon Formation, with paleoflows shown (black arrows). From Craig, 1981.

Averaging all of Craig's paleoflows gives an overall trend of 77° (Figure 32, rose diagram, inset).
However, according to Dr. Craig:

"In the area surrounding Grand Junction, Colorado and extending from Green River, Utah to Delta, Colorado, the direction of transport fans through an arc of about 100 degrees, from north-northwest to due east. This fanning of transport directions is thought to result, primarily, from a radiating stream pattern in the Burro Canyon, and secondarily, from the merging of sediments from two major source areas, one to the west (Cedar Mountain) and one to the south (Burro Canyon)." (Craig 1981, p. 198.)

The radiating stream pattern Craig mentions is local to the northeastern side of the Uncompahgre Plateau (red oval, Figure 33). If sediments from the two formations are merging here, then these paleoflow vectors are not purely Burro Canyon source sediments. The directions of transport for source sediments are questionable in this area,
so this group of paleoflows from Green River, Utah to Delta, Colorado can be discounted (red circle also). If these anomalous paleoflows are ignored, a better picture of the directional trend of Burro Canyon source sediments emerges, giving a bipolar transport trend of 342°/162° (Fig. 33, inset).

Figure 33. Map showing Burro Canyon paleoflows discounted due to the likelihood they are merged with Cedar Mountain Formation sediments (red oval and circle). Remaining paleoflows are shown averaged (inset) indicating a bipolar trend of 342°/162°. Modified from Craig, 1981.

This bipolar trend that results from discounting the merged paleoflows is now compared with the average trend from this study's combined rose diagram (Figure 34).
Figure 34. Left: bipolar trend (black arrow) from Fig. 33. Right: rose diagram from Fig. 30 with bipolar trend indicated (black arrow).

The pattern from Buckhorn Mesa indicates that the sediments were deposited in a SW/NE direction, in accord with paleoflows seen in the Cedar Mountain Formation, as opposed to those in the Burro Canyon Formation (Figure 35).

Figure 35. Craig's 1981 map with the overall bipolar trend from Buckhorn Mesa superimposed (red arrow). This is more in alignment with Cedar Mountain paleoflows (upper left quadrant) than Burro Canyon Paleoflows (lower half) (modified from Craig, 1981).
4. Facies Associations

Because scant data was recorded regarding facies and their associations on Buckhorn Mesa, only a preliminary analysis is undertaken here (see also facies codes in Hotel Mesa stratigraphic columns, Fig. 25 above). As mentioned, all facies definitions and interpretations are taken from Stikes, 2007, and James and Dalrymple, eds., 2010 (see Figs. 23 and 24).

Facies associations near Buckhorn Mesa measured Section #1 can be seen in Figure 36. Those found at Section #3 are seen in Figure 37. Facies at the top of Section #2 were in the Dakota/Naturita Formation and outside the scope of this study. Facies associations were made using photographs taken in the field, so they are approximate. Further study is needed in order to more accurately portray true facies in the outcrops.

Figure 36. Facies associations near Buckhorn Mesa measured Section #1, which is out of the picture to the right. Mudstones in the Jurassic Morrison Formation, Brushy Basin Member(?) are seen at the base, with drab, non-smectitic Yellow Cat Member(?) mudstones above them. Fine-grained laminated heterolithic sandstones and mudstones
(Fig. 36 continued) make up the conformable contact with the sandstones (Fl).

Sandstones (Ss) include St, Sh/Sl, Sp, and Sr in this area, but these various facies aren't resolvable at this scale. Another series of fine-laminated heterolithic sandstones is seen above the first main sandstone body, overlain by a final Ss body at the top. See Figs. 23 and 24 for facies codes descriptions. (Photo by the author).

Figure 37. Buckhorn Mesa measured Section #3, with facies associations illustrated. Fm at base is the Yellow Cat Member(?) of the Cedar Mountain Formation. Above this, mudstones with carbonate nodules are found interbedded with sandstone laminations just below the erosional contact with the main sandstone body (Fl/Fc). The main Poison Strip Sandstone Member(?) is made up of horizontal laminations (Sh/Sl), then planar laminations (Sp), then trough-cross bedded sandstone (St), more horizontal laminations (Sh/Sl) and finally more trough cross-stratified sandstones (St). Fine-grained mudstones
(Fig. 37 continued) make up much of the top of the section, with several trough-cross
stratified (St) stringers interbedded. This is the Ruby Ranch Member(?). The chert bed at
TOS is seen upper left. Note geologist on LOS, center left for scale: Jacob's staff 5ft
(1.5m) long. For facies definitions see Figs. 23 and 24. This photo was used to estimate
thickness of vertical sandstone body along LOS. Equivalent lithology determined along
lateral along top of colluvium, lower left (photo by Marjie Miller).
CONCLUSIONS

There is ample lithological and stratigraphic evidence to conclude that the Hotel Mesa measured section correlates to Stikes’ 2007 Dewey Bridge section across the Colorado River. Lithologies at both sections closely correlate, and stratigraphic stacking patterns and primary sandstone structures indicate that the Poison Strip Sandstone Member of the Cedar Mountain Formation is found on Hotel Mesa.

On Buckhorn Mesa, the pronounced visual differences between the strata at Sections #1 and #3 first led me to think that I'd found the contact between the Poison Strip Sandstone and the Burro Canyon Formation. Subsequent to data collection and comparison of the sections and their lithologies, I came to the contrary conclusion that I'd simply discovered variations in the same sandstone rather than the contact between two formations, with the possibility that I'd found two different stream beds with subtle variations in interbedding, stacking patterns, and rock color. I have now come to the conclusion that all of my measured sections on Buckhorn Mesa are in the Cedar Mountain Formation, including a fluvial component of Poison Strip Sandstone (Figs. 25, 28 and 29).

Comparing the sections on Buckhorn Mesa (Fig. 28), it can be seen that the composite section has thinner sandstone geometries overall than Section #3. Also, Section #1 at the bottom of the composite has a conformable base; Section #3 does not.

Paleocurrent data show a pronounced bimodal SW/NE trend (Fig. 30). In general, the paleocurrent measurements on the ground (LADs) appear to be orthogonal to this
overall flow pattern. The paleoflows found on Buckhorn Mesa match those seen elsewhere in the Cedar Mountain Formation (Fig. 35).

Facies are similar in all respects to those found elsewhere in the Cedar Mountain Formation, giving further support to the conclusion that the outcrops on Hotel Mesa and on Buckhorn Mesa are in the Poison Strip Sandstone, sandwiched by Yellow Cat and Ruby Ranch mudstones. Multiple fining up sequences at the top of the sections indicate a decrease in sediment supply, a regional characteristic of the Poison Strip Sandstone (Stikes, 2007).

It is now apparent that the Colorado River is not a stratigraphically valid means of separating the Cedar Mountain Formation from the Burro Canyon Formation. Although no Burro Canyon rocks were found in the study area, a reasonable correlation to the Poison Strip Sandstone Member of the Cedar Mountain Formation has been demonstrated. These sandstone sequences are in the Poison Strip Sandstone and the line demarcating the Cedar Mountain Formation can now be more closely drawn (Figure 38).

Although no Burro Canyon Formation rocks were seen in the study area, I believe they will be found farther to the southeast, based on close study of that region on Google Earth. Visual inspection of the outcrops while standing on Buckhorn Mesa also led to the conclusion that the Burro Canyon and Cedar Mountain Formations don't outcrop on this entire northwest portion of the Uncompahgre Plateau (Figure 39). When searching for Cedar Mountain and Burro Canyon outcrops, geologists and paleontologists can concentrate their efforts elsewhere, as neither of these formations are found here.
Figure 38. Screenshot (from Fig. 6) with the current arbitrary line dividing the Cedar Mountain Formation (CMF) from the Burro Canyon Formation (BCF) along the Colorado River (black dashed line). White dashed line is my proposed new contact, based on the work outlined in this paper, as well as tracing the outcrops on Buckhorn and Hotel Mesas using Google Earth.
Figure 39. Photos showing the lack of Burro Canyon and Cedar Mountain outcrops on the entire northwestern side of the Uncompahgre Plateau. **Top:** photo from Buckhorn Mesa TOS #3, looking north. The Colorado River flows between here and the Bookcliffs. The northernmost flank of the Uncompahgre Plateau is seen to the right. **Center:** photostitch showing the interfluve between Sections #1 and #3. The entire northwestern limb of the Uncompahgre Plateau is seen on the skyline. **Bottom:** photo looking ESE, with the Uncompahgre Plateau, also known as Piñon Mesa, in the far distance. Jurassic Morrison Formation seen in middle distance (blue arrow). Uppermost rocks on Piñon Mesa are of Jurassic age—likely Wingate, Kayenta, and Entrada Formations—as observed by the author using binoculars (photos by the author.)
The Cedar Mountain Formation and the Burro Canyon Formation, although correlative, have significant distinguishing characteristics. Even though environments of deposition for the two formations were quite similar, differences in provenance and source terranes are enough to warrant separation of the two formations into distinct bodies. By adding differences in stratigraphic stacking patterns and differences in paleotopographic constraints, the division of the Burro Canyon Formation from the Cedar Mountain Formation becomes even more pronounced.

My initial hypothesis that I would find the contact between the Burro Canyon Formation and the Cedar Mountain Formation in the study area has not been borne out; however, two perhaps more important discoveries have been outlined: 1. the Cedar Mountain Formation is found across the Colorado River in the Dolores Triangle, requiring that the geologic map be re-drawn in this area; and 2. there is no Burro Canyon Formation to be found on this entire portion of the Uncompahgre Plateau.
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USGS Geolex, 'McElmo Formation':

APPENDIX
Paleocurrent Azimuths: paleocurrents taken on 3-D ripple and dune sets, as well as a few (<10%) 2-D ripple sets.

1. Buckhorn Mesa Section #1.

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Average Section #1: 250°

2. Buckhorn Mesa Section #2.

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Average Section #2: 285°

3. Buckhorn Mesa Section #3.

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Average of all paleocurrents for Buckhorn Mesa: 229°.