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MAJOR BONEBEDS IN MUDROCKS OF THE MORRISON FORMATION (UPPER JURASSIC), NORTHERN COLORADO PLATEAU OF UTAH AND COLORADO

John R. Foster, Julia B. McHugh, Joseph E. Peterson, and Michael F. Leschin

A Field Guide Prepared For
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Cover

A Morrison Formation scene from 152 million years ago. Sauropods, theropods, stegosaurs, ankylosaurs, and crocodyliforms feed, rest, or stroll near a small river while pterosaurs fly low. Artwork by Brian Engh, dontmesswithdinosaurs.com.

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Major Bonebeds in Mudrocks of the Morrison Formation (Upper Jurassic), Northern Colorado Plateau of Utah and Colorado

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ABSTRACT

The Morrison Formation contains a number of large quarries that have yielded dinosaurs and other vertebrates, and many of these occur in sandstone beds representing ancient river channels. However, a number of very productive sites occur in mudstone beds representing other environments such as ephemeral ponds, and some of these yield both large dinosaurs and microvertebrates; these localities in mudstone beds represent different taphonomic modes of preservation and often preserve vertebrate taxa in different relative abundances from the channel sandstone sites. Among these important and very productive mudstone localities are the Cleveland-Lloyd Quarry, the Mygatt-Moore Quarry, and the microvertebrate sites of the Fruita Paleontological Area, and each of these preserves distinct vertebrate paleofaunas, different from sandstone sites and from each other, suggesting that mudstone localities had a very different mode of sampling the local biotas than did sites in sandstone.

INTRODUCTION

The Morrison Formation is a mostly freshwater-terrestrial unit of Late Jurassic age exposed in eight states in the Rocky Mountain region of western North America (Dodson and others, 1980). The formation is famous for dinosaur discoveries but contains a diverse fossil biota, including more than 90 species of fossil vertebrates from fish to mammals (Foster, 2003; Chure and others, 2006). In a formation with numerous large bonebeds in channel sandstone deposits (e.g., Carnegie Quarry at Dinosaur National Monument, Hanksville-Burpee Quarry, Bone Cabin Quarry, and Dry Mesa Quarry), the northern part of the Colorado Plateau stands out for being home to several large quarries and some important, highly productive microvertebrate sites, all in fine-grained mudstones. Whereas the large sites in sandstones appear to be longer term attritional deposits sampling a broad range of dinosaurian taxa from surrounding areas, the major mudstone quarries of the Morrison Formation demonstrate taphonomic and preservational characteristics suggesting individually unique sampling of aspects local populations not typically seen at sites in coarser-grained sediments representing higher-energy environments.

Here, we profile four important sites in the Morrison Formation: the Cleveland-Lloyd Dinosaur Quarry near Price, Utah; the Fruita Paleontological Area, near

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Fruita, Colorado; the Riggs Quarry 13 locality in Grand Junction, Colorado; and the Mygatt-Moore Quarry near the Utah-Colorado border.

CLEVELAND-LLOYD QUARRY

History of Site and Research

The Cleveland-Lloyd Dinosaur Quarry (CLDQ) of central Utah is located in the Brushy Basin Member of the Upper Jurassic Morrison Formation at the northern end of the San Rafael Swell (figure 1). The quarry is world-famous for its unusually high concentration of dinosaur bones, including at least 70 individuals representing a minimum of nine genera (Madsen, 1976a; Gates, 2005). Of these, 66% (MNI: 46, based on a count of left femora) are attributable to a single taxon—*Allosaurus fragilis.* Six more dinosaurs from four different species yield a predator-prey ratio of 3:1 (Madsen, 1976a; Gates, 2005) (figure 2).

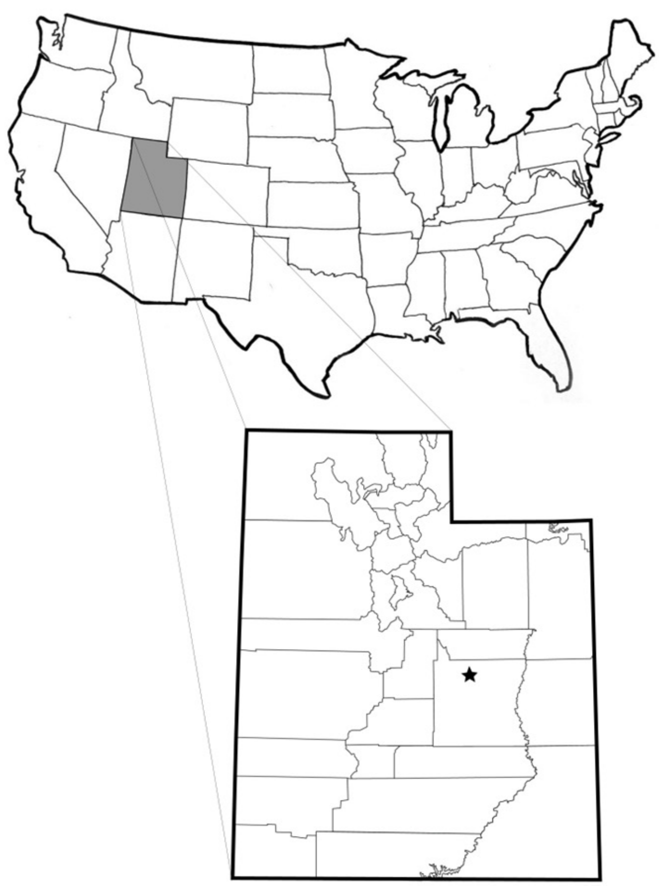

Figure 1. Location of the Cleveland-Lloyd Dinosaur Quarry in Emery County, Utah.

Since the initial discovery of the site in 1927, more than 10,000 bones have been collected by at least seven institutions. In 1929, the first formal excavations were carried out by the University of Utah, collecting nearly 1000 bones from 1929 to 1931 (Miller and others, 1996). Excavations resumed again in 1939 through 1941 by W.L. Stokes and Princeton University, which excavated and collected approximately 450 bones during the three-year period. During the early 1960s, the University of Utah resumed excavations and collected nearly 7000 bones from 1960–1964 (Miller and others, 1996) (figure 3). Excavations resumed again in the late 1970s by the Utah Division of State History, and continued intermittently through the 1980s by Brigham Young University, collecting nearly 1100 bones (Miller and others, 1996). The quarry was once again worked from 2001–2002 through the Natural History Museum of Utah (UMNH), yielding 400 bones (Gates, 2005). In 2008, the University of Utah briefly worked the quarry and collected approximately 20 bones. In 2012, the University of Wisconsin-Oshkosh began surveying the quarry and started excavations in the south Butler Building, collecting nearly 50 bones and focusing efforts on researching the 3D distribution of bones, microfossils, and geochemistry of the quarry.

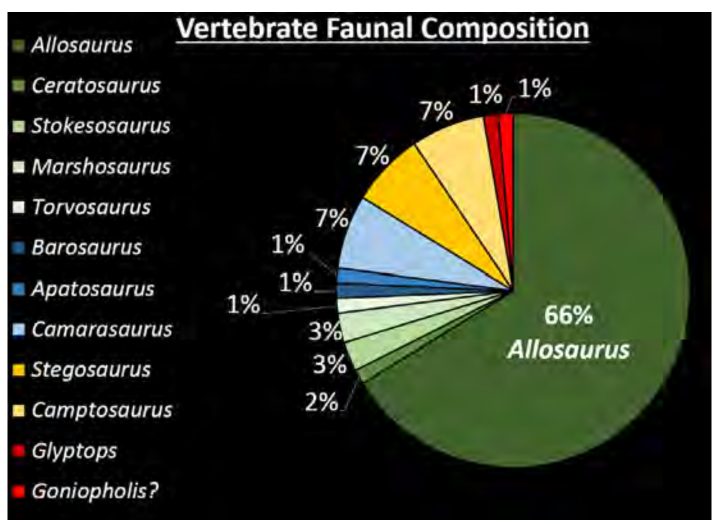

Figure 2. Vertebrate faunal composition of the CLDQ. Modified from Gates, 2005.

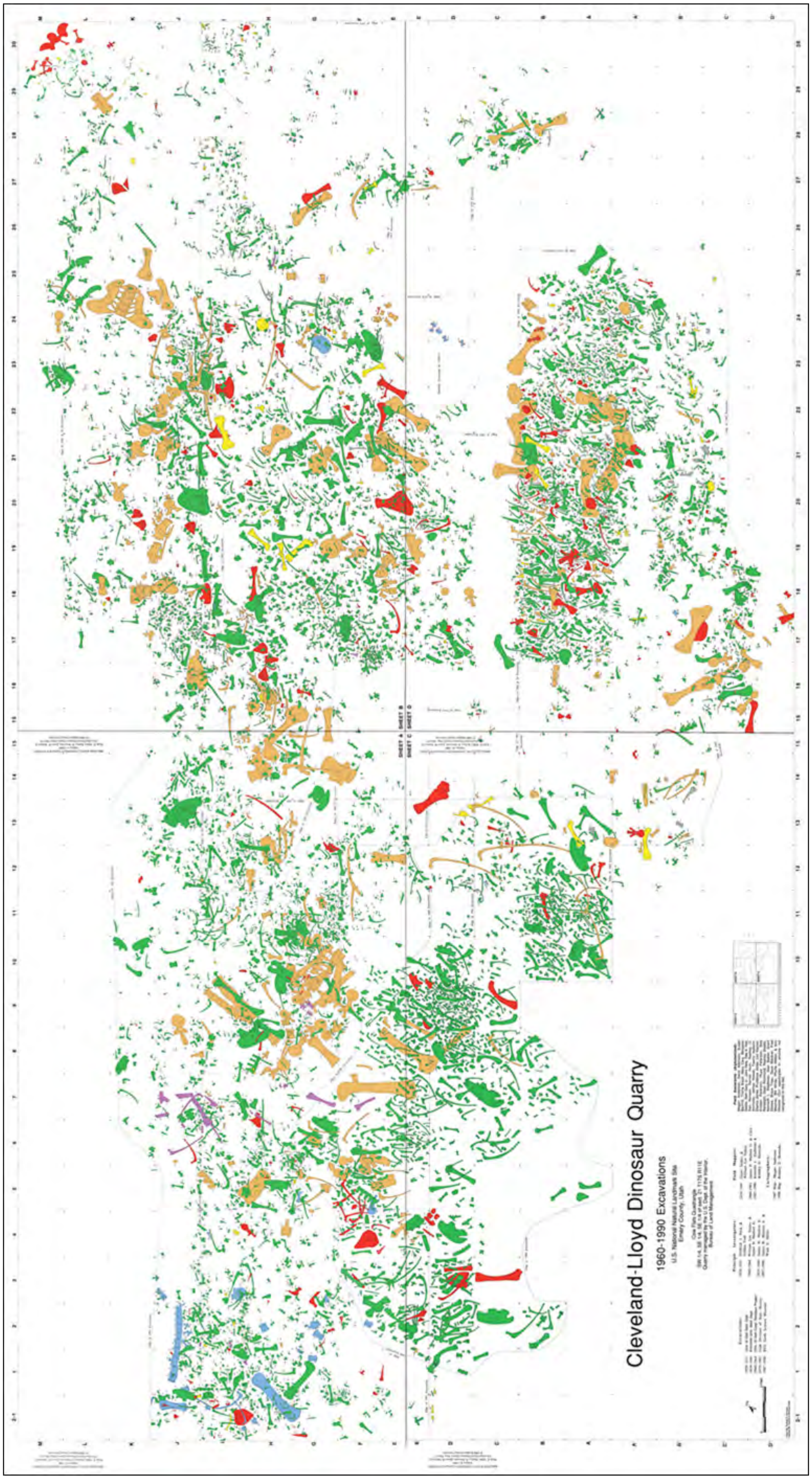

Figure 3. Composite map of the CLDQ excavations from 1960-1990, color-coded based on genera. *Allosaurus fragilis* remains are represented in green. Modified illustration courtesy of Mark Loewen (Natural History Museum of Utah).

Stratigraphy and Paleoenvironmental Interpretations

The Brushy Basin Member is composed of floodplain-deposited mudstone and limestone, with some channel sandstone, and is the youngest of three laterally extensive members of the Morrison Formation (Gates, 2005). In the immediate vicinity of the CLDQ, other extensive members are present, including the basal evaporites and playa/sabkha limestones of the Tidwell Member and the distal alluvial fan complex of the Salt Wash Member, which underlies the Brushy Basin Member (Peterson and Turner-Peterson, 1987; Gates, 2005). Previous reconstructions of Late Jurassic climate patterns in Utah indicate strong seasonality, subject to variably arid to monsoonal conditions (e.g., Dodson and others, 1980; Hallam, 1993; Rees and others, 2000; Parrish and others, 2004; Sellwood and Valdes, 2008; Tanner and others, 2014). Furthermore, scarce plant material and coal deposits (Dodson and others, 1980) and the distribution of authigenic minerals associated with periodic aridity throughout the Morrison Formation strongly support this climatic interpretation (Turner and Fishman, 1991).

The CLDQ is located approximately 38 m above the basal contact of the Brushy Basin Member (Bilbey, 1992). The bone-bearing unit is composed of a calcareous mudstone that varies in thickness from a few cm to 1 m, and also includes abundant diagenetic limestone nodules and clay clasts. The mudstone underlies a micritic limestone unit that varies in thickness from 0.3 to 1.0 m, and overlies a massive silty mudstone approximately 20 m in thickness (Bilbey, 1992; Suarez, 2003; Gates, 2005) (figure 4). Based on limited exposures, the bone-bearing mudstone unit is laterally continuous for 50 to 75 m before pinching out to the south (Gates, 2005). Whereas various depositional models have been proposed for the CLDQ, the lithologies, abundant vertebrate macrofossils, and rare microvertebrate and invertebrate remains suggest an ephemeral pond or similar overbank deposit with a fluctuating water table (calcareous mudstone facies) that became a more permanent basin in the form of a shallow lacustrine setting (limestone facies) (Bilbey, 1999; Gates, 2005).

Taxonomy/Biota/Major Discoveries

Invertebrate and Micropaleontology

The CLDQ has produced few identifiable microvertebrate remains other than shed dinosaur teeth, two shed neosuchian crocodyliform teeth, a crocodyliform osteoderm, and partial vertebra possibly attributable to the choristodere *Cteniogenys*. However, the quarry also contains microfossils such as charophytes and ostracodes (Madsen, 1976b) and three taxa of gastropods (Stokes, 1985), which contribute to the freshwater depositional model (table 1).

Vertebrate Paleontology

The vertebrate fauna of the CLDQ has received

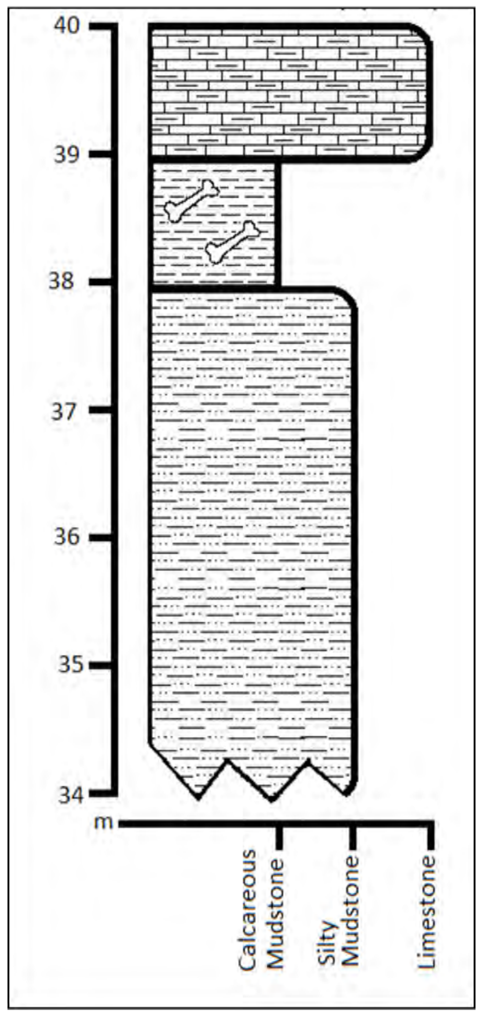

Figure 4. Stratigraphic column of the Brushy Basin Member of Morrison Formation, Cleveland-Lloyd Dinosaur Quarry.

Table 1. List of fossil genera from the Cleveland-Lloyd Dinosaur Quarry. Numerals indicate estimated number of individuals (modified from Bilbey, 1999).

DINOSAURS
Theropods
Allosaurus - 46
Ceratosaurus - 1
Marshosaurus - 2
Stokesosaurus - 2
Torvosaurus - 1
Sauropods
Apatosaurus - 1
Barosaurus - 1
Camarasaurus - 5
Haplocanthosaurus - 1
Ornithischians
Camptosaurus - 5
Stegosaurus - 5
OTHER PLANTS AND ANIMALS
Reptiles
Glyptops - 2
Goniopholis - 1
Gastropoda (fresh water)
Amplovalvata
Valvata
Viviparus
Charophyta (fresh water)
Aclistochara bransoni
Latochara latitruncata
Stellatochara obovata

considerably more attention than the invertebrate or microfossil faunas and floras due to the sheer abundance of dinosaur taxa present at the quarry (table 1). Stokes (1945) first reported on remains of *Stegosaurus, Camptosaurus, Ceratosaurus,* and *Allosaurus* at the quarry, followed by two new theropod taxa, including the holotypes of *Stokesosaurus clevelandi* (Madsen, 1974) and *Marshosaurus bicentesimus* (Madsen, 1976b). Later excavations produced skeletal material attributable to the sauropods *Barosaurus*, *Camarasaurus*, and possibly *Haplocanthosaurus* (Stokes, 1985), and remains assigned to the large megalosaurid *Torvosaurus tanneri* (Richmond and Morris, 1996). Recently, a large cervical vertebra attributable to *Apatosaurus* was described, and still remains in the quarry (Foster and Peterson, 2016).

Other notable discoveries include a single dinosaur egg, which is relatively uncommon in the Morrison Formation (Hirsch and others, 1989), and shell fragments from the turtle *Glyptops* and the aforementioned shed teeth and scute attributable to a goniopholidid (Stokes, 1985). However, the most striking aspect of the quarry assemblage is the unusual predator to prey ratio, which is dominated by theropods (75%, Gates, 2005); of the 52 theropods present at the quarry, 46 are attributable to *Allosaurus fragilis*, representing 66% of the total dinosaur assemblage (Gates, 2005).

Taphonomy and Models of Skeletal Accumulation

Typically the sedimentology of the bonebed would provide data which would help to highlight a most likely hypothesis to explain the strange assemblage represented within the CLDQ. However, the unique sedimentology of the quarry, (a hard mudstone containing abundant calcite nodules, often associated with bone, and capped with ~1 m of limestone) makes further environmental and taphonomic interpretations difficult (Suarez, 2003; Gates, 2005). Additionally, the taphonomy of the vertebrate remains is unusual. Unlike the majority of the bones found within the Morrison Formation, 30% of the bones in the CLDQ possess some form of syndepositional fracturing, and less than 1% are crushed (Gates, 2005). Furthermore, very few bones in the CLDQ show signs of surface traces such as tooth marks and insect borings (Gates, 2005). This implies a very rapid deposition and/or an environment largely devoid of scavengers.

Whereas this specific quarry has received wide research attention focusing on the taphonomic signatures of dinosaur bones, there is little agreement among the numerous interpretations and hypotheses for the development of the accumulation (table 2); as Madsen once

Table 2. Selected Interpretations for the Cleveland-Lloyd Dinosaur Quarry (modified from Hunt and others, 2006).

Interpretation	Author(s)
Dinosaurs died on a bed of a seasonal evaporating pond.	Stokes (1945)
Predator trap – dinosaurs mired in a bog formed from an oxbow lake.	Dodson and others (1980)
Dinosaurs were mired in a spring-fed pond or seep.	Bilbey (1999)
Drought-induced death around a watering hole; abundant *Allosaurus* caused by carnivores intimidating herbivores from coming near the water.	Gates (2005)

stated, "theories on the demise of the Cleveland-Lloyd dinosaurs are but slightly fewer in numbers than visitors to the quarry" (Madsen, 1976a).

The first technical record of the quarry interpreted the assemblage as an evaporating pond on which dinosaurs died and skeletons became disarticulated by scavenging and trampling (Stokes, 1945). Whereas this conclusion was based on very preliminary stratigraphic and petrologic data, it failed to take the distribution of skeletal elements into consideration. Furthermore, this hypothesis would also require a high frequency of crushed and trampled bones (Weigelt, 1989); a condition that is relatively rare in the remains at the CLDQ.

A broader analysis of lithofacies and taphonomic properties of the CLDQ elements later interpreted the quarry as a predator trap, in which *Allosaurus* became mired in a bog formed by an oxbow lake as they approached previously mired herbivore carcasses (Dodson and others, 1980). This hypothesis has been prevalent in the literature in one form or another for the last 30 years; Stokes (1985) interpreted the site as a bog in which dinosaurs sank over a long period of time. Hunt and others (2006) concluded that the site had evidence of both attritional miring and catastrophic scenarios based on sedimentologic data. Using x-ray defraction and sedimentary petrology, Bilbey (1999) proposed that dinosaurs were mired in a spring-fed pond or seep.

Despite the popularity of the general miring hypothesis, animals mired in a viscous medium, such as mud or a bog, are commonly found articulated and (in some cases) still standing (Weigelt, 1989). The lack of articulation at the CLDQ makes this general hypothesis—and the many versions of it—problematic. While some hypotheses have attempted to explain the disarticulation of elements, such as struggling animals churning previously deposited bones or groundwater disarticulating skeletons, these types of movements are unlikely to be sufficient in disarticulating remains to the degree observed in the quarry (Weigelt, 1989).

Gates (2005) proposed that the quarry represents a drought-induced death assemblage, based on a review of diverse sedimentologic and taphonomic data. While this hypothesis addresses the problems normally overlooked by the "miring" or "predator trap" hypotheses, it does not specifically address the large number of predator fossils in the quarry. Furthermore, this hypothesis predicts that individual skeletons should be found articulated or associated, which is uncommon in the CLDQ.

Current Research

Whereas sedimentological and microfossil analyses suggest that the CLDQ represents a small ephemeral pond, new information is required to form a robust taphonomic framework supported by all available data. Current research efforts by the University of Wisconsin at Oshkosh and Indiana University of Pennsylvania are being coordinated to produce a comprehensive taphonomic framework for the CLDQ.

First, small bone fragments (< 5 mm) recovered from quarry sediment were analyzed for relative degree of abrasion and hydraulic equivalency. The fragments have a hydraulic equivalence equal to grains larger than the encasing matrix, suggesting an autochthonous or parautochthonous origin. Furthermore, fragments possess a wide range of relative abrasion stages, suggesting multiple depositional events (Peterson and others, 2016a) (figure 5).

Second, 3D photogrammetric mapping of the deposit within the north quarry building reveals distinct orientations of bones in at least three layers, providing further evidence of multiple depositional events in addition to bone fragment data (Clawson and others, 2015) (figure 6).

Finally, X-ray diffraction (XRD) and X-ray fluorescence (XRF) comparisons of the sediments of the CLDQ and sedimentary beds above and below the quarry indicate enrichment in heavy metals relative to other sediments from the Morrison Formation (Peterson and others, 2016b). Whereas some metals, such as uranium, may be diagenetic in origin, other metals present in elevated concentrations, such as As, Pb, Sr, and Cr may have bioaccumulated in the shallow depression from the decay of a large quantity of predator carcasses, promoting reducing conditions that further explain the lack of expected freshwater fauna, the rarity of feeding traces on remains recovered from the quarry, and the presence of sulfide minerals in the quarry cement (figure 7).

Figure 5. Relative abrasion stages of bone fragments collected from the matrix of the CLDQ. Stage 0 represents angular fragments and Stage 3 represents rounded fragments. Scale bar equals 5 mm.

In order to further understand the taphonomy of CLDQ, and thereby use it to gain insights into Jurassic paleoecology, future research will include 3D mapping of bones as they are exposed in the deposit, geochemical comparisons to other Morrison bonebeds, and geochemical and isotopic analysis of the bones preserved at the quarry.

FRUITA PALEONTOLOGICAL AREA

History of the Site

Vertebrate fossils from the badlands southwest of Fruita, Colorado (figure 8), have been known since their first reports in 1891 (Armstrong and Perry, 1985). These early reports drew paleontologist Elmer Riggs from the Columbian Field Museum in Chicago, Illinois (now the Field Museum of Natural History), to the Grand Valley in 1900 and 1901. Though he apparently did not visit what is now known as the Fruita Paleontological Area (FPA), Riggs' discoveries in nearby Grand Junction and the Redlands north of Colorado National Monument included the discovery of *Brachiosaurus*, as well as the recovery of remains of *Camarasaurus*, *Apatosaurus*, and others. Amateur geologist, Al Look, was instrumental in the early promotion of the geological and paleontological resources in the area, but it was not until the 1970s that the gray badlands southwest of Fruita (now

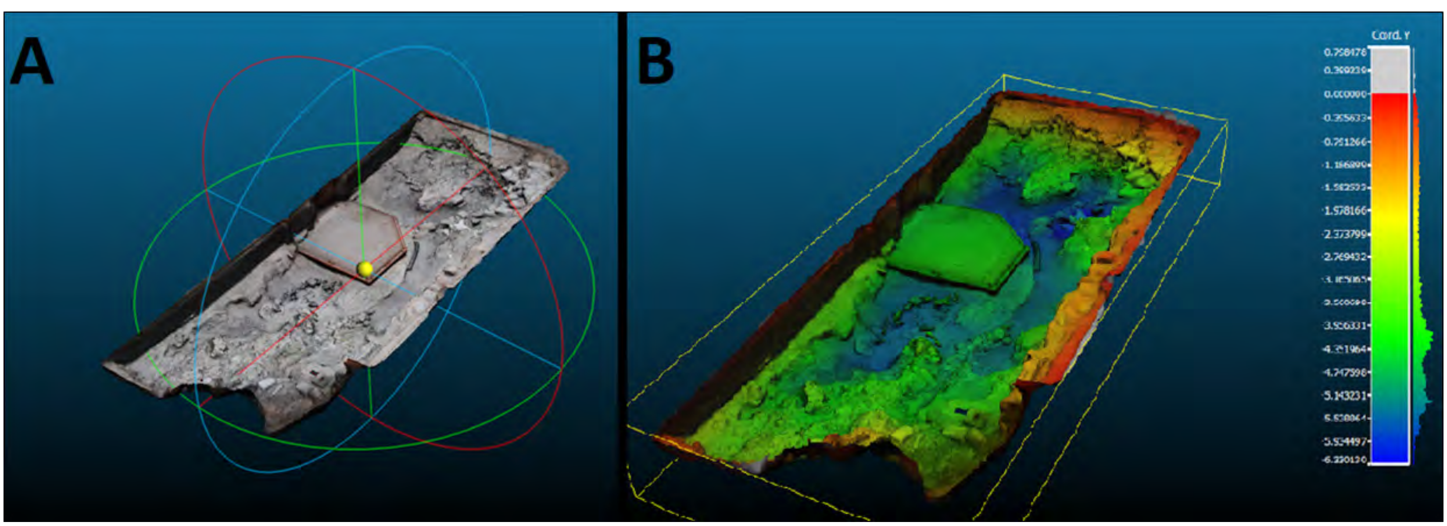

Figure 6. (A) Photogrammetric model of the north CLDQ building; (B) model with false-coloration based on depth.

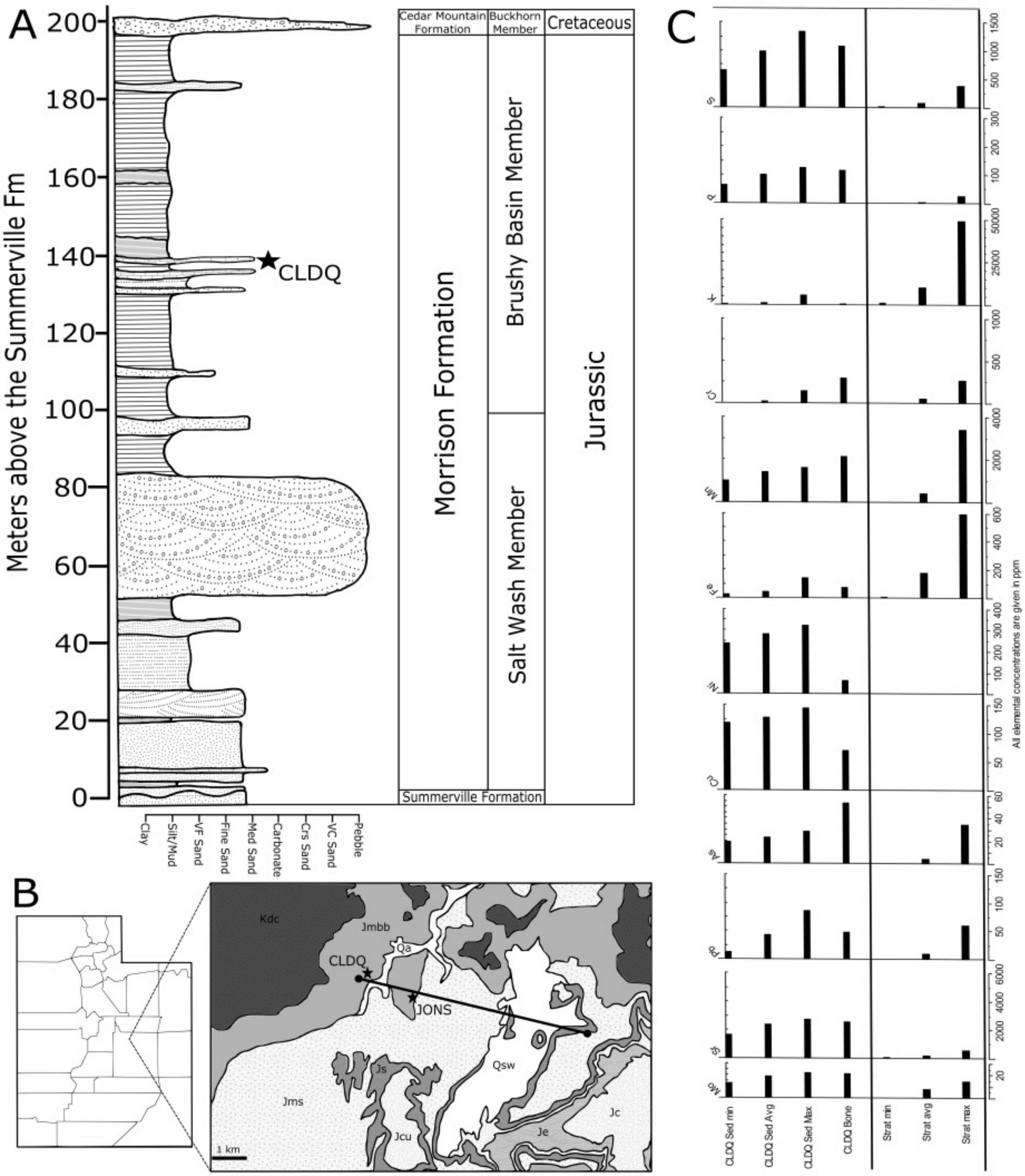

Figure 7. Regional stratigraphy and geochemistry of the Cleveland-Lloyd Dinosaur Quarry (CLDQ) vicinity (modified from Peterson and others, 2016b). (A) Stratigraphic column of the Morrison Formation in the area around the CLDQ shown in meters above the basal contact of the Salt Wash Member of the Morrison Formation with the upper Summerville Formation. Standard USGS symbols of rock units are used in the diagram. (B) Map showing the stratigraphic section line and regional stratrigraphy in the context of the San Rafael Swell (from Witkind, 1988). Abbreviations are as follows: Qsw – Quaternary slope wash; Kdc – Dakota-Cedar Mtn Fms; Morrison Formation – Jmbb (Brushy Basin Mbr), Jms (Salt Wash Mbr), Jmt (Tidwell Mbr); Js – Summerville Fm; Jcu – Curtis Fm; Je – Entrada Ss. (C) X-ray fluorescence results of concentrations of selected metals dectected in sediment and bone samples collected from the CLDQ and compared with sediments from the stratigraphic column through the Morrison Formation (labeled "Strat"). All values are given in ppm, and abbreviations are as follows: min – minimum; ave – average; max – maximum.

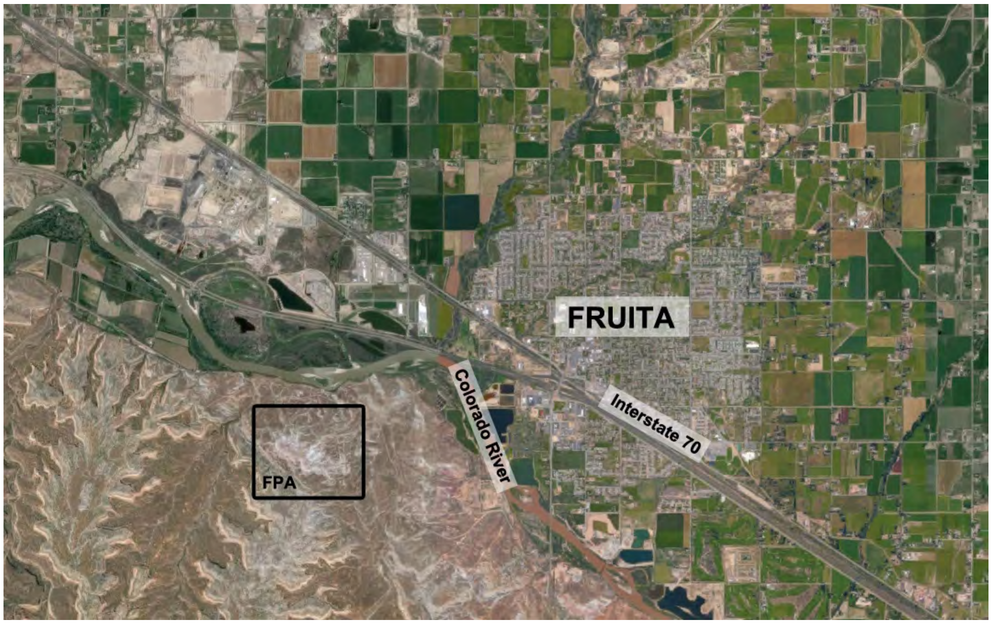

Figure 8. Map of the Fruita, Colorado (approximately 19 km west of Grand Junction, CO) area showing the location of the FPA.

the Fruita Paleontological Area [FPA]) became the subject of detailed scientific research (Armstrong and Perry, 1985).

Prior to the protection of the paleontological resources in the FPA, vandalism and theft of fossils was increasing. In 1975, in direct response to this illegal collection and vandalism, presumably by commercial fossil collectors, curator of paleontology, Lance Eriksen, of the Historical Museum Institute of Western Colorado (changed to Museum of Western Colorado but in 2015 became the Museums of Western Colorado) applied for a permit to excavate vertebrate fossils from the FPA. He recovered the skull and partial skeleton of *Ceratosaurus* in 1976, as well as *Stegosaurus* and *Allosaurus* material from a separate quarry (Eriksen, 1976; BLM, unpublished transcript, 1977; Madsen and Welles, 2000). These became the first catalogued vertebrate paleontological specimens at the museum.

In the summer of 1975, George Callison first brought his students from California State University at Long Beach to Fruita, Colorado. During a tour of the Colorado National Monument, the group spied the gray, low hills of the FPA from the "Historic Trail Overlook" and decided to prospect in that area (Armstrong and Perry, 1985). Callison's expeditions, with the help of volunteers from Earthwatch, continued for the next decade, recovering the small vertebrate fossils from multiple sites in the FPA (figure 9) (Callison, 1987). They had prospected other sites in the Grand Valley, but only the FPA produced good quarries for small vertebrate remains (Armstrong and Perry, 1985; BLM, unpublished transcript, 1977). Due to the abundance of swelling clays in the horizon, fossils were excavated through hand quarrying and not through the more traditional method of screen washing, which tends to disassociate remains. Through this practice, not only were numer-

Figure 9. Field work under the Callison Expeditions c. 1979. Crew clockwise from the left are Jim Clark, Steve May, and Mark Norell. Photo courtesy of George Callison, California State University.

ous small vertebrates recovered, including several new taxa (see discussion below), but whole and partial skeletons were recovered, offering a more complete picture of Mesozoic small vertebrate biology.

Due to the conservation and scientific efforts of George Callison, Lance Eriksen, and their colleagues, a workshop was held with the U.S. Bureau of Land Management (BLM) to discuss the paleontological resources of the FPA and how to ensure their protection and availability for scientific research (BLM, unpublished transcript, 1977). From this workshop protection measures were moved forward and the FPA was established as a protected research area by the BLM in 1977. In 1998, the FPA was incorporated into the interpretive sites of the Dinosaur Diamond National Scenic Byway. By 2000, the FPA and surrounding areas were designated as a National Conservation Area by the U.S. Department of Interior's BLM, creating the Colorado Canyons National Conservation Area and Black Ridge Canyons Wilderness (Public Law 106-535), but in 2004 the area was renamed to its current designation: the McInnis Canyons National Conservation Area and Black Ridge Wilderness. This designation has allowed for the long-term preservation of the cultural and natural, including paleontological, resources of the area.

Stratigraphy

The fossil sites of the FPA are located within the Upper Jurassic Morrison Formation. Two members of the formation are exposed within the FPA, the older Salt Wash Member and the younger Brushy Basin Member (figure 10). All vertebrate fossil localities in the FPA are found within the lower part of the Brushy Basin (Kirkland, 2006). The lower Brushy Basin in the FPA contains a localized change in clay lithology that has been proposed to be laterally extensive across the Morrison Formation (Owen and others, 1989; Turner and Peterson, 1999, 2004); however, Trujillo (2006, 2014) has shown this regional clay change to be questionable. This change, from predominately illitic, non-swelling clays to smectitic, swelling clays, is likely the result of an increase in the amount of volcanic ash that was deposited in the area from sources to the south and west of the Morrison basin. After ash was incorporated into the mud, it may have been altered by specific chemical conditions after burial to smectitic clay that swells when exposed to water. If no other alterations occur, this swelling clay can often be observed in outcrop as mudstone with a distinctive "popcorn" texture (Moore and Reynolds, 1997). In the FPA region, a change in clay mineralogy low in the Brushy Basin Member has been documented in XRD studies, and it is often visible in outcrop (Kirkland 2006; Trujillo, 2006). In other areas, however, several changes in clay mineralogy at varying stratigraphic levels occur throughout the Brushy Basin Member as a result of a variety of chemical conditions.

The contact between the underlying Salt Wash Member and the Brushy Basin Member is defined as the top of the uppermost thick and laterally extensive sandstone unit (Turner and Peterson, 1999; Kirkland, 2006). Previously, the contact between these units was placed higher in the section, near the local "clay change," but its placement has been restored lower in the section, atop the highest occurring sandstone unit (Rasmussen and Callison, 1981a, 1981b; Callison, 1987; Kirkland 1994, 2006).

Deposition and Taphonomy

More than 20 quarries have been excavated for vertebrate remains in the FPA since 1975. An exhaustive summary of each of these quarries' depositional and taphonomic origins is beyond the scope of this paper; therefore, we chose to focus the following selected quarries which exemplify three disparate depositional and taphonomic regimes: Kirkland Egg site, Eriksen *Ceratosaurus*, and Tom's Place.

The Kirkland Egg site is the lowest in the FPA section of the three exemplar quarries discussed here. This site lies 3.6 m below the local "clay change" in the lower Brushy Basin Member, in the illitic clays of overbank deposits. This low-energy depositional environment is characterized in the FPA by interbedded sandstone and mudstone, with occasional intervals of sandstone and siltstone interbeds. Vertebrate fossil sites are less common below the local "clay change," making the preservation of this nesting site, preserving egg shell fragments along with vertebrate remains of *Fruitachampsa* and young *Dryosaurus*, even more remarkable (Kirkland, 1994, 2006).

The Eriksen *Ceratosaurus* occurs above the local "clay change" at the intersection of a sandstone unit, representing a channel facies, and a levee facies within the FPA at the edge of a crevasse splay (Kirkland, 2006). Vertebrate fossils are generally rare in the levee facies, with the exception of the *Ceratosaurus*, though trace fossils (burrows, tracks, etc.) can be more common (Hasiotis and others, 1998a, 1998b). Dinosaurian remains are most abundant within the sandstone facies, particularly in high sinuosity channels (e.g., the Eriksen Ceratosaurus channel) compared to the other ten channels in the Brushy Basin Member of the FPA; the sandstone facies and high sinuosity channels may have created more optimal conditions for trapping large carcasses than other facies (Kirkland, 2006). The channel is a well-cemented, coarse-grained to conglomeratic lithic arenite, with most of the lithics representing volcanics sourced from the southwest of the Morrison basin (Turner and Peterson, 2004; Kirkland, 2006). Other sites located in channel facies include the Eriksen Stegosaur and the Traildust Theropod Quarry. Vertebrate taxa recovered from the sandstone facies in the FPA include *Allosaurus*, *Apatosaurus*, *Camarasaurus*, *Ceratosaurus*,

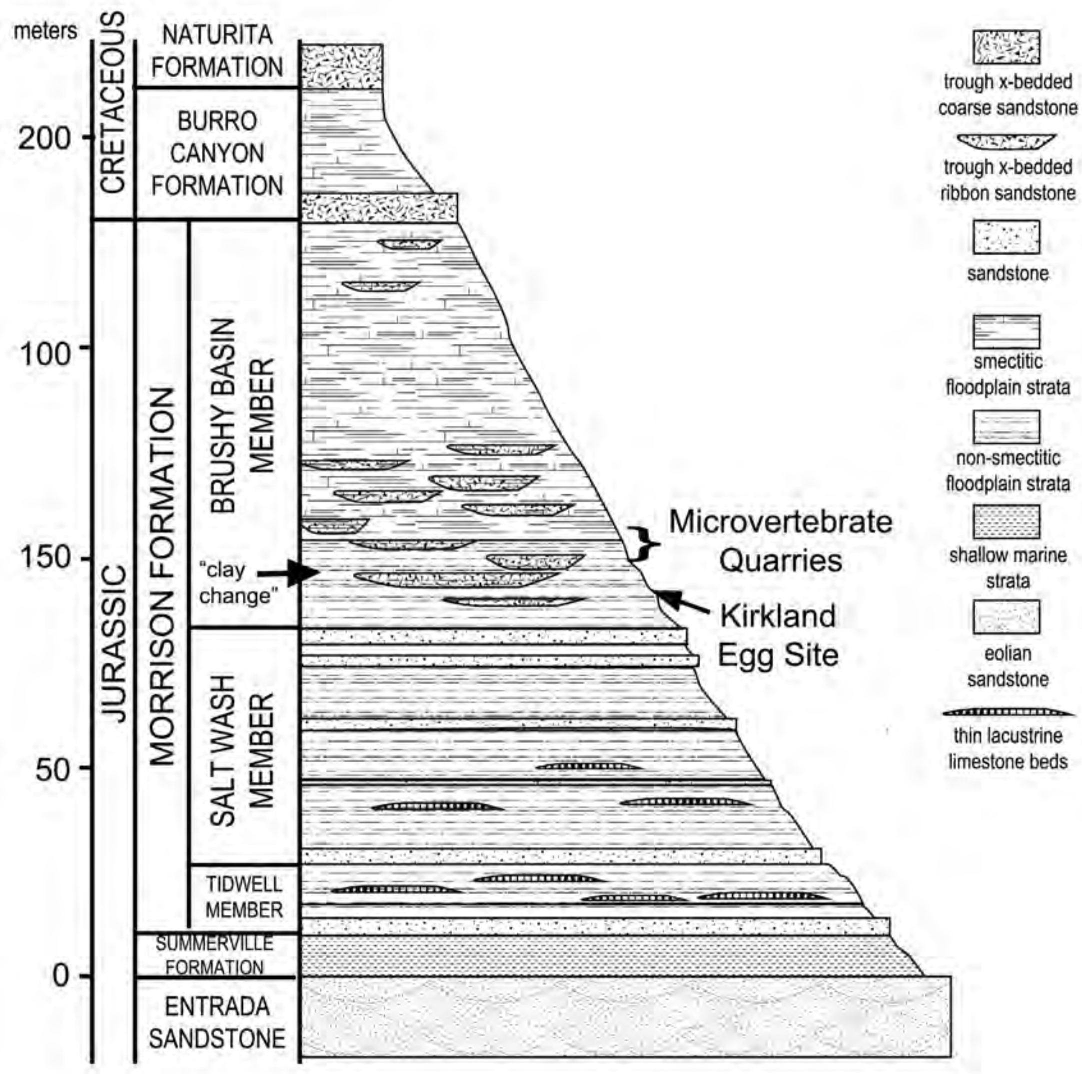

Figure 10. Stratigraphic column for the Fruita Paleontological Area (modified from Kirkland, 2006).

Dryosaurus, and *Stegosaurus* (Kirkland, 2006).

Tom's Place lies above the local "clay change" in the lower Brushy Basin Member (Turner and Peterson, 1999) in similar overbank/floodplain deposits to the Kirkland Egg site (figures 10 and 11). Deposition would have been similar to the Kirkland Egg site, with a low-energy environment allowing fine particle sedimentation and deposition of clays. However, unlike at levels at and below the Kirkland Egg site, above the local "clay change," vertebrate fossil sites are much more abundant, suggesting more rapid burial than floodplain facies below the "clay change" with little to no transport, protecting small vertebrates from scavenging and damage due to surface exposure, as well as promoting the preservation of articulated remains (Kirkland, 2006). Preserved vertebrate fossils include egg shell fragments, actinopterygian scales and teeth, mammals, lizards, turtles, sphenodontians, sphenosuchians, and small dinosaurs (Rasmussen and Callison 1981a, 1981b; Callison, 1987; Engelmann and Callison, 1998, 1999; Evans and Chure, 1999; Göhlich and others, 2005; Arcucci and others, 2013). The preservation of articulated and associated nearly complete skeletons of microvertebrates at Tom's Place is similar to other sites such as Rainbow Park at Dinosaur National Monument and the Wolf Creek Quarry in northwestern Colorado, and it differs significantly from the taphonomic preservation of microvertebrates at other productive localities such as Quarry 9 at Como Bluff, the Small Quarry at Garden Park, and the Little Houston Quarry in the Black Hills (Foster, 2001a, 2003).

Palynomorphs are also found in the Tom's Place sediments. Early cementation coupled with increasing alkalinity of sediments may have isolated the palynomorphs and favored their preservation (Litwin and others, 1998).

Figure 11. View of Tom's Place (TP). Black arrow indicates level of the "clay change."

Major Discoveries and Preserved Biota

Most recovered taxa represent small vertebrates (lepidosaurs, mammals, etc.), but larger crocodylomorphs and dinosaurs are also present in the assemblage (Foster, 2003). Small vertebrate faunas are rare in the Morrison Formation, making their abundance and diversity in the FPA of great scientific interest. The FPA may more closely represent original ecosystem diversity than most other sites in the Morrison Formation (Foster, 2003). Vertebrate fossils collected from the FPA have been reposited in collections at the Natural History Museum of Los Angeles County (LACM), Carnegie Museum of Natural History (CM), the American Museum of Natural History (AMNH), and the Museums of Western Colorado (MWC).

Seven specimens recovered from the FPA have been designated as holotype material. These type specimens include the mammals _Priacodon fruitaensis_ (Rasmussen and Callison, 1981a) and _Fruitafossor windscheffeli_ (Luo and Wible, 2005), the sphenodontian _Eilenodon robustus_ (Rasmussen and Callison, 1981b), the snake _Diablophis gilmorei_ (Caldwell and others, 2015), the crocodylomorph _Fruitachampsa callisoni_ (Clark, 1985, 2011), and the dinosaurs _Fruitadens haagarorum_ (Butler and others, 2010) and _Ceratosaurus magnicornis_ (Madsen and Welles, 2000). Paratype material of the multituberculate mammal _Glirodon grandis_ is from the FPA, the holotype being from Dinosaur National Monument (Engelmann and Callison, 1999). A full list of vertebrate taxa recovered from quarries in the FPA is given in table 3.

The FPA has produced at least three small, cursorial crocodylomorphs: the shartegosuchid _Fruitachampsa_ (Clark, 2011), the sphenosuchian _Macelognathus_ (Göhlich and others, 2005), and an unnamed new sphenosuchian (Arcucci and others, 2013). The diversity and abundance of small, terrestrial crocodylomorphs at the FPA are higher than in any other area of the Morrison Formation.

Among dinosaurian taxa, the discovery of _Ceratosaurus_ in 1975 by Lance Eriksen was the second known skeleton of the genus (Kirkland, 2006) and was thought to represent a new species, _C. magnicornis_ (Madsen and Welles, 2000). However, recent anal-

Table 3. Alpha taxonomy of sites within the Fruita Paleontological Area. * indicates that the type locality of that taxon occurs within the FPA.

Osteichthyes			
	Actinopterygii indet.		
Mammalia			
		Multituberculata	
			Glirodon grandis
			Multituberculata indet.
		Triconodonta	
			_Priacodon fruitaensis_*
			Triconodonta indet.
		Theriliformes	
			Dryolestidae indet.
			Paurodontidae indet.
			Symmetrodonta indet.
		Mammalia Indet.	
			_Fruitafossor windscheffeli_*
Testudines			
	Paracryptodira		
		Pleurosternidae	
			Glyptops sp.
Lepidosauria			
	Rhynchocephalia		
			_Eilenodon robustus_*
			Opisthias sp.
			Sphenodontia indet.
	Squamata		
		Dorsetisauridae	
			Dorsetisaurus sp.
		Paramacellodidae	
			Paramacellodus sp.
			Saurillodon sp.
		Serpentes	
			_Diablophis gilmorei_*
		Anguimorpha indet.	
		Lacertilia indet.	
Crocodylomorpha			
	Mesoeucrocodylia		
		Goniopholididae	
			Amphicotylus sp.
		Shartegosuchidae	
			_Fruitachampsa callisoni_*
			Macelognathus vagans
Pterosauria			
	Pterosauria indet.		
Dinosauria			
	Ornithischia		
		Heterodontosauridae	
			_Fruitadens haagarorum_*
		Ornithopoda	
			Dryosaurus sp.
		Thyreophora	
			Stegosaurus sp.
	Saurischia		
		Sauropoda	
			Apatosaurus sp.
			Barosaurus sp.
			Camarasaurus sp.
			Diplodocus sp.
			Sauropoda indet.
		Theropoda	
			Allosaurus fragilis
			_Ceratosaurus magnicornis_* (= _Ceratosaurus nasicornis_)
			Theropoda indet.
	Dinosauria indet.		
		Prismatoolithidae	
			Preprismatoolithus coloradensis

yses by Rauhut (2003), Carrano and Sampson (2008), and Carrano and others (2012) have cast doubt on the number of species of *Ceratosaurus* represented in the Morrison Formation, favoring only one: *C. nasicornis* (figure 12).

The discovery of *Fruitadens haagarorum* from the FPA (originally in 1976) marked the first occurrence of the ornithischian clade Heterodontosauridae in North America (figures 13 and 14) (Galton, 2007; Butler and others, 2010). The smallest known ornithischian, *F. haagarorum* was one of the last surviving members of this enigmatic clade, shedding light on a rare evolutionary trend in the group. Early members are interpreted to be rather specialized herbivores, but later members like *F. haagarorum* have a more generalized omnivorous dentition (Butler and others, 2010).

Multiple sites preserving egg shell fragments have been reported from the Morrison Formation (Hirsch, 1994; Kirkland, 1994; Foster, 2003). However, the Kirkland Egg site in the FPA is the only one of these sites that preserves both egg shell and hatchling bones, identifying the egg layer as *Dryosaurus* sp. (Kirkland, 1994). This site produces a bimodal assemblage of *Dryosaurus* material, including both hatchling size and juvenile size individuals—adults have not yet been recovered from the site. Also recovered from the site are egg shell, belonging to the oospecies *Preprismatoolithus coloradonesis* (Hirsch, 1994; Carpenter, 1999), and postcranial remains of the shartegosuchid crocodylomorph *Fruitachampsa callisoni*, hypothesized to have been

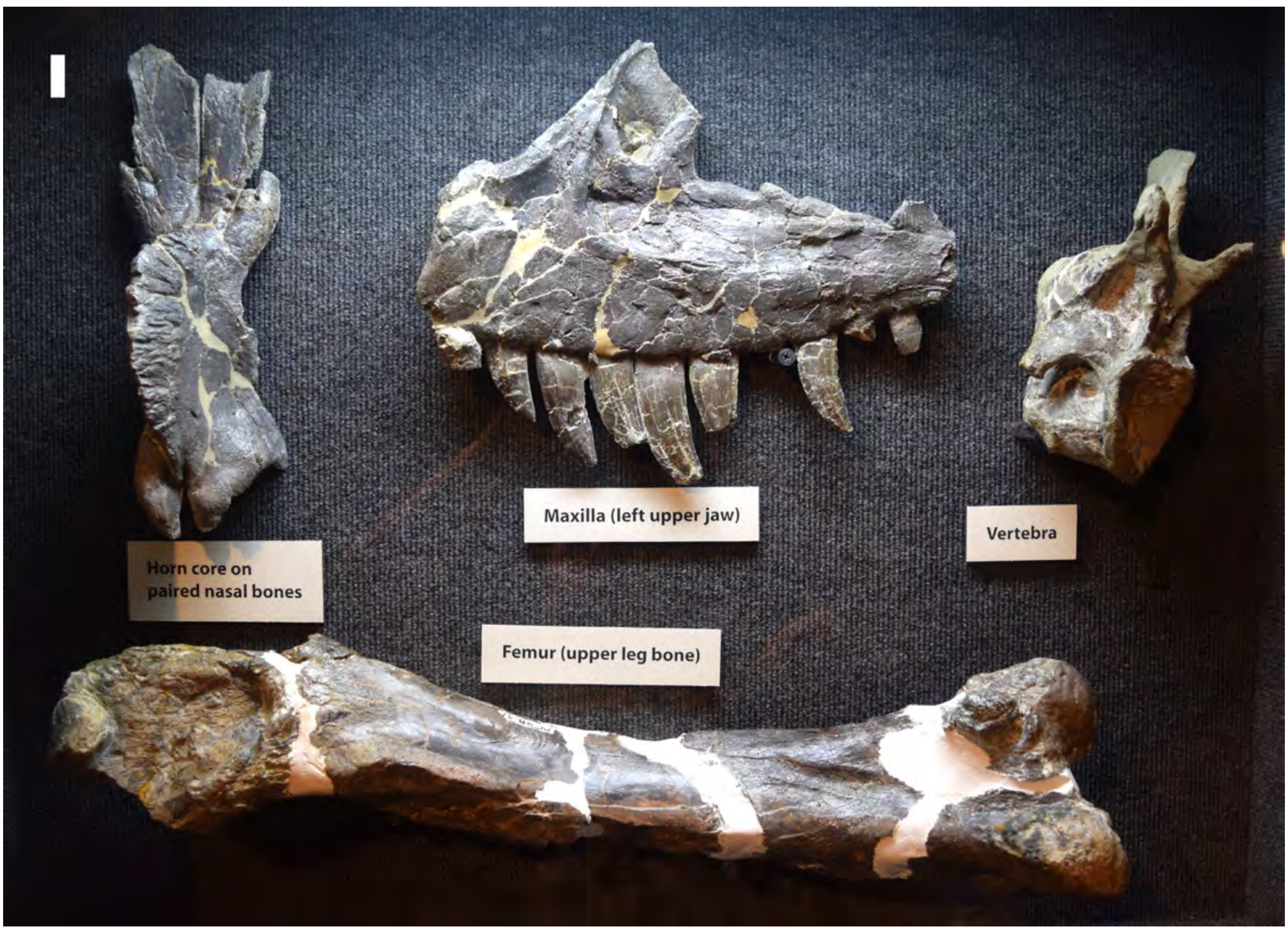

Figure 12. Cranial and postcranial elements of the holotype specimen of *Ceratosaurus magnicornis* (MWC 1) on exhibit. Scale bar equals 1 cm.

Figure 13. Cast of *Fruitadens* jaws, LACM 128258, in dorsal (left) and oblique (right) views. Scale bar equals 1 cm.

raiding the dinosaur nests (Kirkland, 1994).

Discoveries from the FPA have not only shed light on taxonomic and ecosystem-level questions (Foster, 2003; Kirkland, 2006), but have revealed early evolutionary pathways in several higher taxonomic groups. The discovery of *Fruitafossor windscheffeli* by Wally Windscheffel generated a rare Jurassic mammal known not just from isolated teeth and bones, but with rare articulated cranial and postcranial remains (figure 15) (Luo and Wible, 2005). Examination of the specimen revealed a basal mammal with a combination of many primitive characteristics and numerous derived skeletal adaptations for a fossorial lifestyle that are convergent with modern xenarthans, suggesting a more complicated early radiation of basal mammals than previously thought, driven by ecological selection (Luo and Wible, 2005).

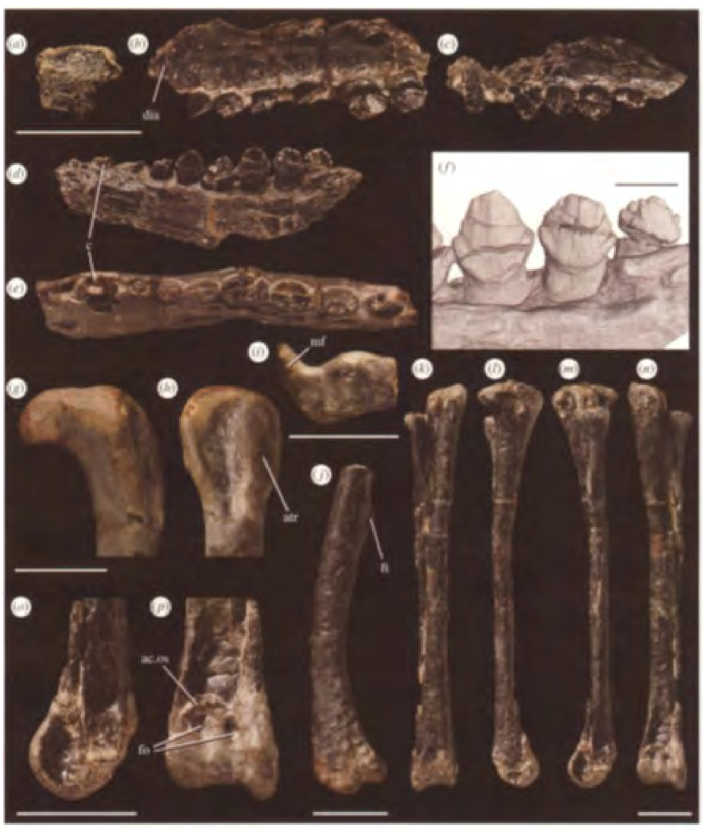

Figure 14. Holotype and referred jaw and limb specimens of *Fruitadens*, LACM 128258, LACM 115747, LACM 115727, and LACM 120478 (figure 2 from Butler and others, 2010).

The evolutionary origin of Serpentes, once hypothesized to have occurred during the Jurassic Period, lacked support of fossil evidence to solidify the clade's diversification and origin in that time period. Callison's crews collected the partial remains of a peculiar lepidosaur from the FPA, which were first described by Evans (1996) as an anguimorph lizard: *Parviraptor gilmorei*. However, Caldwell and others (2015) re-examined the material in the light of new fossil discoveries from Europe and reassigned the taxon to *Diablophis gilmorei*, an early snake, corroborating an early idea by Callison (1987) almost 30 years prior. Together with the new European discoveries, Caldwell and others (2015) pushed the origin of the clade back nearly 70 million years into the Middle Jurassic Period.

Current Research

Excavations continue today at several sites in the FPA. A team led by Gabe Bever from the New York Institute of Technology and the American Museum of

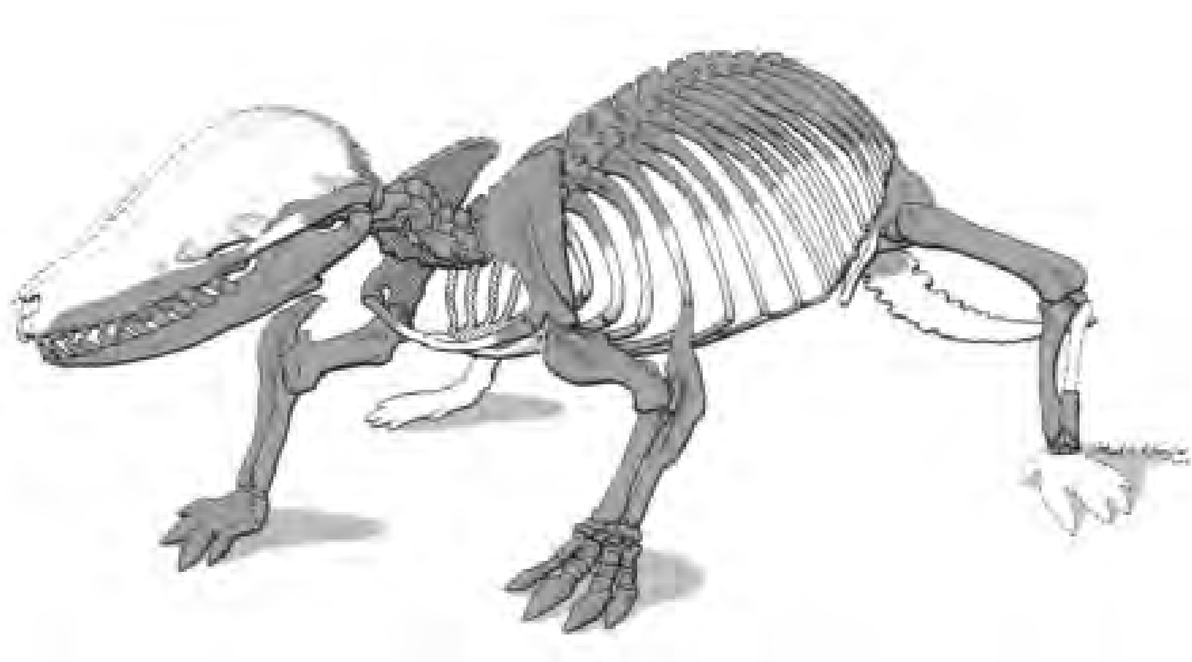

Figure 15. Reconstruction of *Fruitafossor* by Mark Klingler, Carnegie Museum of Natural History, (figure 2 from Luo and Wible, 2005).

Natural History in New York continues excavations for small vertebrates at Tom's Place, investigating the early evolution of mammals, as well as rhynchocephalians, snakes, and other lepidosaurs.

The MWC also continues to excavate sites in the FPA each summer. Currently, excavations are focused on the small vertebrates of the original Callison Quarry, the *Allosaurus* bonebed at the Traildust Theropod Quarry, the Kirkland Egg site, as well as surface collection throughout the FPA, which in 2015 yielded the first conifer cone from the FPA.

RIGGS HILL (QUARRY 13)

In the winter and spring of 1900, Elmer Riggs of the Field Columbian Museum (now named the Field Museum of Natural History) in Chicago was planning a paleontological field expedition to western Colorado. Riggs was a former student of S.W. Williston and classmate of Barnum Brown at the University of Kansas. Originally from Indiana, Riggs had been at the Field for several years working as its Assistant Curator of Geology. He had been working in Wyoming previously and had spent the season of 1899 in the Freezeout Hills working in the Morrison Formation. Riggs recognized the utility of working near rail lines and had written letters to the scientific societies of several small towns along rail routes in the western United States, in hope of learning the outcrops from which to collect dinosaurs for the museum. He had received a letter back from a dentist in charge of the scientific society in Grand Junction, Colorado (a town that was less than 20 years old at the time), saying that dinosaur bones had been being collected from area badlands since the town was first settled in the early 1880s (Armstrong and Perry, 1985).

Riggs initially planned to return to the Freezeout Hills and investigate the western Colorado lead on his 1900 expedition but eventually settled on just the Grand Junction area. In a series of letters to the department head, who was the advocate with the museum's director, Riggs argued in favor of the Grand Junction destination and justified a submitted budget, at one point explaining that the request for funds for a new field tent was justified because the Anthropology Department at the museum had borrowed the geology tent and never returned it! By May, Riggs's expedition was approved and a $700 budget was provided for the summer, mostly for field equipment, shipping, train tickets for the crew, and a team of horses and a wagon in Colorado. Riggs brought a young man named Harold Menke as his field assistant, and Menke was also the photographer for the expedition, much to the benefit of later paleontologists. Riggs also hired a relative named Victor Barnett as the camp cook.

The three arrived in Grand Junction early in the summer and began prospecting Morrison Formation outcrops south and west of the city. As Riggs noted, they had very little luck for about six weeks and only found one site worth excavating, Quarry 12, which was located near today's east entrance to Colorado National Monument. This site produced a number of bones of the sauropod *Camarasaurus*, but nothing of major significance. On July 4, the crew took a break from digging and went prospecting along the outcrops west of the quarry. Menke found the end of a limb element sticking out of the south slope of a hillside about 4 km north and west of the area of Quarry 12, in the Brushy Basin Member of the Morrison Formation (figure 16). Riggs was curious, but at the time the site did not look promising enough to move from the quarry on which they were already working. So, for several more weeks Riggs and the crew worked on Quarry 12.

On July 26, 1900, Riggs and the crew began digging in to Menke's find from the Fourth of July. They uncovered a humerus just over 2 m long, and Riggs recognized immediately that the material was significant and unusually large. This became Riggs's Quarry 13 (figure 17). In a letter written to the director from camp that night, Riggs told the director of the find and asked that it be kept quiet; Riggs knew that the Carnegie Museum and American Museum of Natural History were also working in the Morrison Formation at the time and that they would certainly pay the Grand Junction area a visit if they knew of Riggs's success there. Riggs told the director that time was needed to collect "the cream of it" from the area (not just the current sauropod) before

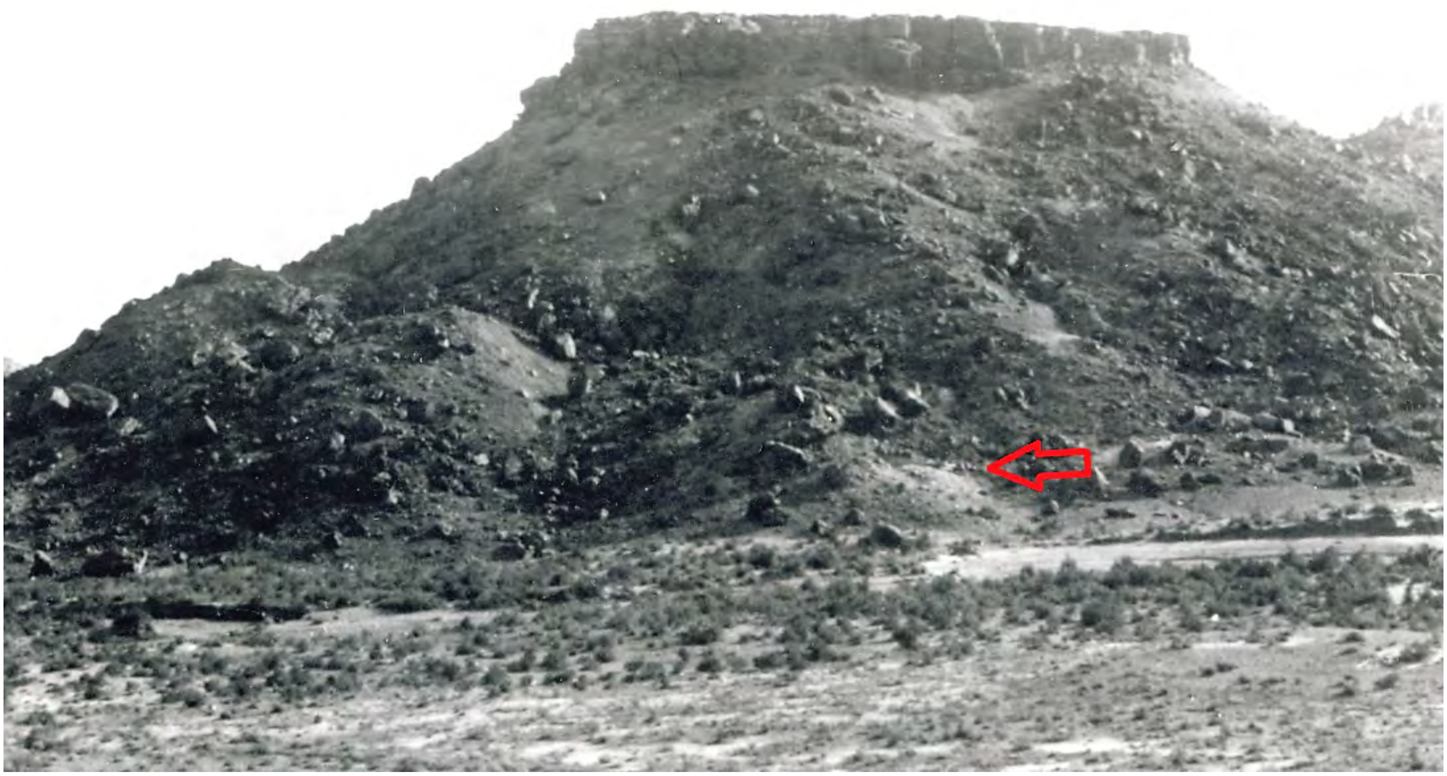

Figure 16. View of Riggs Hill from the south in 1900. Quarry 13 in its early stages is visible to the lower right of the center of the photo, with a light patch of debris rock below it (arrow). Courtesy of Field Museum of Natural History.

Figure 17. Quarry 13 looking west in 1900, as the excavation was underway. Courtesy of Field Museum of Natural History.

other museums moved in.

On the evening of July 27, Riggs presented a lantern-slide lecture in downtown Grand Junction, detailing their work in the area and the history of dinosaurs in the western states. A Grand Junction newspaper article reporting on the talk mentioned Riggs's low-key manner and the strong round of applause afterwards, but consistently misspelled the paleontologist's name as "Prof Briggs," not the last time Riggs would be the victim of spelling mistakes related to his work in the area.

From the last week in July, when they started the dig, until the second week of September, when they shipped the material by train to Chicago, Riggs and the crew uncovered and removed a humerus, femur, articulated dorsal series, sacrum, two caudals, and several ribs of a large sauropod (figure 18). Menke took a number of photographs of the quarry and their work as it progressed. Riggs suspected from the first day, based on the large size, that it was a new taxon. Many residents of Grand Junction came out to tour the quarry, to the point that it became disruptive to the crew's work. Riggs, about 31 at the time, wrote letters to his girlfriend back in Chicago (they would marry after the 1901 field season) describing camp life and how comfortably he'd set things up, and he mentioned the younger Menke's letter writing to multiple women back in Chicago. Riggs's future bride told him in a return letter that she suspected that he missed her, although she knew he would likely deny that (Brinkman, 2010).

After shipping their material out on September 11, Riggs, Menke, and Barnett returned to the Midwest, and then the work of uncovering the material began. Within several years, Riggs had named the new sauropod (FMNH 25107) *Brachiosaurus altithorax*, more

Figure 18. View of Quarry 13 showing vertebrae, ribs, femur, and sacrum of *Brachiosaurus* during excavation. Courtesy of Field Museum of Natural History.

or less the "deep-chest arm-lizard" (Riggs, 1903a). *Brachiosaurus* is one of the largest and rarest sauropods in the Morrison Formation, and it has still only been found at a handful of localities in the unit (Foster, 2001b), but closely related Late Jurassic brachiosaurids have been found as far away as Portugal and Tanzania (Paul, 1988; Mateus, 2006; Taylor, 2009). Assuming it was similar in the cervical region to *Giraffatitan*, *Brachiosaurus* was adapted for browsing relatively high in trees, above most other sauropod species, with a long neck, a raised shoulder region, and a relatively short tail.

In 1901, Riggs and his crew returned to Colorado, this time to the Fruita area, to collect a partial apatosaurine skeleton from the Brushy Basin Member just across the Colorado River from town at Quarry 15. The study of this specimen (FMNH 25112) led Riggs to propose the synonymy of *Apatosaurus* and *Brontosaurus* (Riggs, 1903b), and this assessment stood largely uncontested until Tschopp and others (2015) suggested that the individual was an as yet undetermined apatosaurine within a clade including both *Apatosaurus* and *Brontosaurus* as valid genera.

Ironically, as Riggs likely worked Quarry 15 one day in May of 1901, and unbeknownst to either party, Henry F. Osborn and John B. Hatcher rode past on the train less than a mile north of the site, on their way out to the Green River, Utah, area to investigate Morrison outcrops (and for Osborn, of the AMNH, to work on luring Hatcher away from the Carnegie Museum; Brinkman, 2010). Riggs may never have known how close he came to having his rival institutions find out about his Grand Junction-Fruita finds before even publishing the *Brachiosaurus* work.

Riggs returned to Grand Junction years later, in 1938, for the dedication of a plaque and monument to *Brachiosaurus* at Quarry 13 produced by a local service group (figure 19). A similar monument for the *Apatosaurus* was installed at Quarry 15 near Fruita in a second ceremony on that same trip. Unfortunately, the names of the dinosaurs on each plaque were misspelled.

Harley Armstrong and Dave Wolny of the MWC returned to Quarry 13 in 1989 and installed the replica vertebrae seen at the site today (figure 19). Wolny found a partial caudal centrum and a few other fragments from the pit, which are now on display at the MWC's Dinosaur Journey museum in Fruita (MWC 435). The properties on which both Riggs quarries (13 and 15) are located were donated to and are now managed by the MWC (in cooperation with the BLM, which manages adjacent public land access, in the case of Quarry 15). Very small bone fragments are still abundant in Quarry 13, and many of these may well derive from eroded elements of the *Brachiosaurus* skeleton. Please leave these in place for future visitors to discover also.

Note – Most of the information for this section is taken from copies of letters between Riggs and other

Figure 19. View of Riggs's Quarry 13 c. 2010 showing the stone monument plaque installed in 1938 and the concrete vertebrae marking the site of the find (installed 1989).

Field Columbian Museum employees, receipts for tickets and shipments during the trip, Harold Menke's field photos, and contemporary Grand Junction newspaper articles, from the Field Museum of Natural History and the Loyd Files Research Library at the MWC. Another key source has been Paul Brinkman's *The Second Jurassic Dinosaur Rush: Museums and Paleontology in America at the Turn of the Twentieth Century* (University of Chicago Press, 2010). Black and white photos included here are all by Harold Menke and are courtesy of the Field Museum of Natural History by way of the Loyd Files Research Library at the MWC.

MYGATT-MOORE QUARRY

The Mygatt-Moore Quarry is a deposit of several thousand dinosaur bones in the Brushy Basin Member of the Morrison Formation in western Colorado. The quarry appears to be an attritional deposit of a relatively restricted diversity of dinosaurs, with few other non-dinosaurian taxa, that accumulated in an ephemeral pond deposit in an overbank setting.

History of Site and Research

The Mygatt-Moore Quarry is located in the middle of the Brushy Basin Member of the Morrison Formation in Mesa County, Colorado, just 2.5 km from the Utah-Colorado state line (figures 20 and 21). The quarry is one of several large bonebed deposits in mudstone in the Morrison and is well-known for having produced several type specimens as well as an abundance of dinosaur material.

The site was found in March 1981 by J.D. and Vanetta Moore and Pete and Marilyn Mygatt (figure 22), who happened across the first exposed bones while out hiking (Armstrong and Perry, 1985; Armstrong and others, 1987; Mygatt, 1991; Kirkland and Armstrong, 1992). The site was worked by Lance Eriksen and the MWC briefly around 1984 and has been excavated by the same institution every summer since 1987, with Harley Armstrong, then Brooks Britt, and then Rod Scheetz leading the efforts through the 2000 season (figure 23). The Dinamation International Society worked the site simultaneously with the MWC until 1998, with Jim Kirkland responsible for that organization's work. In this time, more than 4000 bones have been cataloged from the site (figures 24 and 25), and more than 20 individual dinosaurs are represented.

Stratigraphy and Paleoenvironmental Interpretations

The top of the Salt Wash Member of the Morrison Formation in Rabbit Valley is formed by the top of one or several tan, laterally continuous channel sandstones that can be traced across the valley (Armstrong and McReynolds, 1987). The Brushy Basin Member consists of approximately 100 to 140 m of gray, maroon, and greenish-gray claystone with numerous channel sandstones and thin splay sandstones and only a few, thin limestone beds; it lies above the Salt Wash Member of the Morrison and below the Cedar Mountain Formation (Burro Canyon Formation south of the Colorado River) in western Colorado (Peterson, 1988). The Mygatt-Moore Quarry occurs approximately 64 m above the base of the Brushy Basin, in a section in which the member is a total of 135 m thick. This puts the quarry near the top of the lower half of the Brushy Basin (47% of the way up in the section). The "fish layer" above the quarry serves as a useful marker bed that can be traced more than 500 m to the east of the quarry. The main quarry layer itself is a gray claystone and contains a significant percentage of silt-sized grains but also demonstrates a high abundance of carbonized plant debris, clayballs (some containing silt clasts themselves), and wood fragments.

The bone layer can be traced in outcrop for approximately 100 m east-west. Drilling uphill from the quarry to the northwest and west in June 2013 (figure 26) found the bone layer tens of meters away from the current edge of the quarry and indicates that the quarry probably measures at least 130 by 140 m. Like the Cleveland-Lloyd Quarry, the deposit appears to represent an ephemeral overbank pond that developed over time into a permanent lake (Foster and others, 2007; Hunt-Foster and Foster, 2014). Ash fall zircons from the bone layer gave a U/Pb age for the quarry of 152.3 ±0.2 Ma (Trujillo and others, 2014), placing the site near the Kimmeridgian-Tithonian boundary.

Figure 20. Location of the Mygatt-Moore Quarry in western Colorado, west of Fruita and Grand Junction.

Figure 21. The Mygatt-Moore Quarry during excavations in the 1990s. Photo by François Gohier (freelance photographer). Photograph courtesy of MWC.

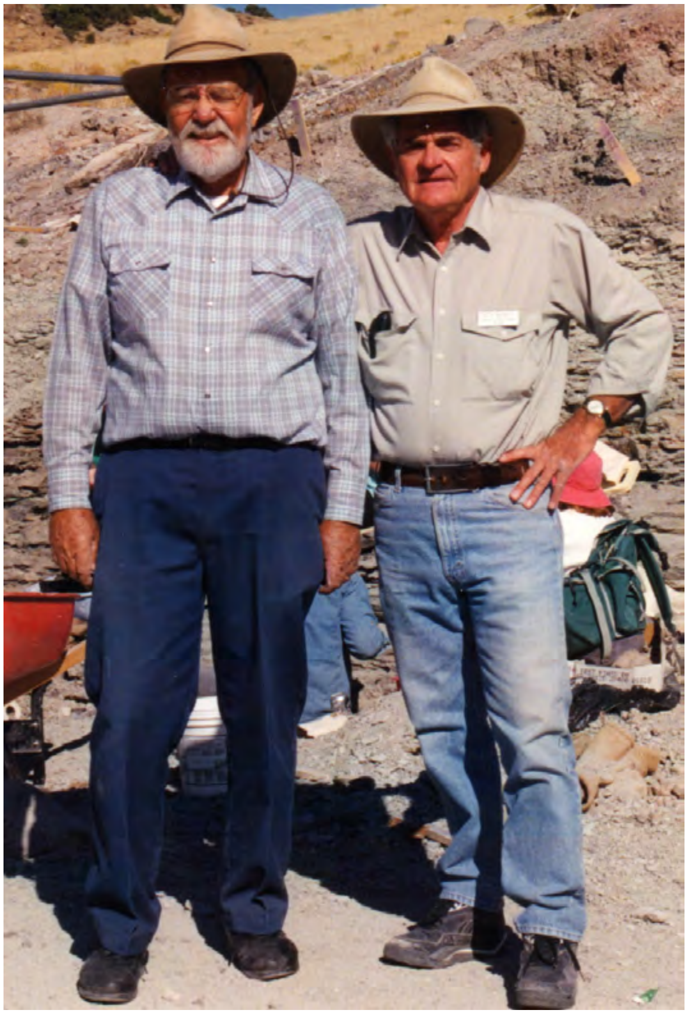

Figure 22. J.D. Moore (left) and Pete Mygatt (right) at the quarry that bears their families' names.

Biota, Taxonomy, and Major Discoveries

Paleobotany

The quarry bone layer, so rich in unidentifiable plant fragments, has also produced more than 14 identifiable species of fossil plants, including quillwort relatives, horsetails, ferns, tree ferns, ginkgoes, *Czekanowskia*, and a number of conifers (table 4; figure 27). These are preserved as abundant carbonized fragments in the quarry mudstone, but fossilized wood and pollen and spores are also common in the quarry (Tidwell and others, 1998; Hotton and Baghai-Riding, 2010).

Invertebrate Paleontology

The Mygatt-Moore Quarry has produced gastropods and conchostracans, though most of these have been found either just below or a bit above the quarry stratigraphically; very few of these invertebrate fossils were found in the bone layer itself. Two crayfish have been found stratigraphically above the main quarry, just above the greatest abundance of conchostracans (see table 4).

Vertebrate Paleontology

The vertebrate fauna of the Mygatt-Moore Quarry is relatively limited considering the number of bones the main layer has produced. Several small, indeterminate reptiles have been reported (King and Foster, 2014), one represented by a very small tooth (figure 28), and a single neosuchian crocodyliform bone has been found. Beyond this, the fauna consists of seven dinosaur genera: *Ceratosaurus*, *Allosaurus*, *Apatosaurus*, *Camarasaurus*, an indeterminate diplodocine, *Othnielosaurus*, and the type material of the polacanthid ankylosaur *Mymoorapelta* (Kirkland and Carpenter, 1994; Foster and others, 2007; table 4 and figure 29). Among this dinosaur material is a reasonable percentage of juvenile elements (figure 30). In addition, the "fish layer" approximately 2 m above the main bone layer has yielded the fish "*Hulettia*" *hawesi*, *Morrolepis*, and cf. *Leptolepis* (Kirkland, 1998; figure 31). Among the vertebrate material, by individual bone count and by MNI, *Allosaurus* and *Apatosaurus* are by far the most abundant taxa (Foster and others, 2007). The otherwise common Morrison Formation sauropod *Camarasaurus* is rare. Other notable vertebrate discoveries include two small, fragmentary dinosaur eggs (Bray and Hirsch, 1998) and possible coprolites of herbivorous dinosaurs (Chin and Kirkland, 1998). Several examples of dinosaur skin have been preserved in the quarry also (Foster and Hunt-Foster, 2011; figure 32).

Taphonomy and Models of Skeletal Accumulation

A sample inventoried in the MWC, including taxonomically unidentifiable material, consisted of nearly 1900 specimens. Although fragmentary bones were most abundant, teeth, vertebrae, and ribs were well represented, particularly those of *Allosaurus* and sauropods. The 2300+ mapped bones out of the Mygatt-Moore Quarry show a pattern of disarticulation and

Figure 23. Previous Mygatt-Moore Quarry principal investigators. (A) Harley Armstrong (dark blue shirt) and volunteers wrestle a field jacket into a truck at Mygatt-Moore in 1987; Armstrong worked at the site for MWC from the mid-1980s until 1993. (B) Jim Kirkland led the Dinamation International Society work at Mygatt-Moore until 1998. (C) Brooks Britt and volunteer Bonnie Carter working under an apatosaur sacrum in 1993; Britt worked the site for MWC from 1993 to 1998. (D) Rod Scheetz (left) overlapped with Britt and led work at the quarry from 1998 to 2000. Pete Mygatt is on the right in the photograph.

only slight association. Of the entire mapped sample only eight bones are in articulation with at least one other one.

The main bone layer is approximately 1 m thick, and the occurrence of bones within this interval is concentrated near the basal 33 cm or so. The quarry appears to show a random orientation of the bones at Mygatt-Moore. Azimuth orientations of bones from the quarry, measured off the map and categorized as either bidirectional or unidirectional, suggest that indeed the orientation is random. Bones out of the Mygatt-Moore Quarry, as noted above, are often broken and fragmen-

Figure 24. Field work at the Mygatt-Moore Quarry mostly involved medium- to large-sized jackets. (A) An *Apatosaurus* scapula ready to remove in 2001. (B) Lowering a sauropod dorsal vertebra in its jacket onto a transport trailer in 2001 are (left to right): Don Kerven, Don Chaffin, and Joshua A. Smith (Museum of Western Colorado). (C) City of Fruita backhoe lifts out an apatosaur scapulocoracoid in 2012. (D) MWC volunteers ready a sauropod pubis in field jacket for lowering onto a flatbed trailer, 2013.

tary, but a large number are fairly well preserved and complete. Breakage, abrasion, and corrosion of bones is fairly common. Evidence of trampling and scavenging are common as well, including bones broken in place, material on edge in the mudstone, shed teeth of carnivores (figure 33), and carnivore tooth marks on bones.

Characteristics of the quarry sediment and the bones contained in it suggest that the site was a topographic low near a fluvial system into which calcium carbonate nodules, clayballs, silt, and skeletal material were washed; both lithologic and skeletal material appear to have had both local and more distant sources.

Figure 25. Uncovering a juvenile sauropod pubis in the main bone layer at Mygatt-Moore Quarry in 2001.

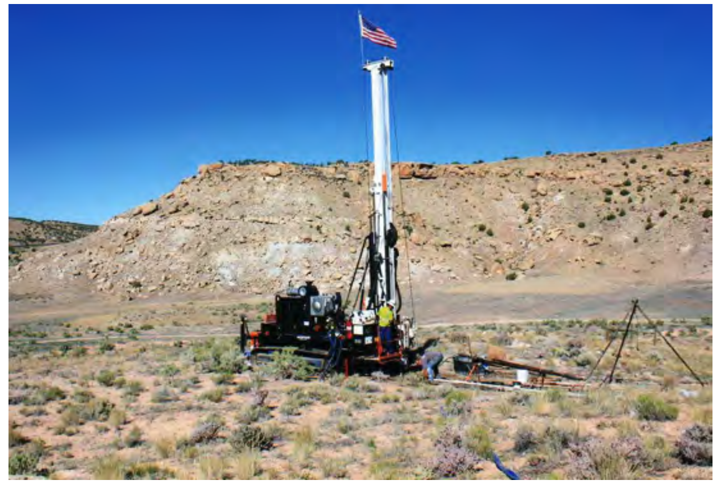

Figure 26. Core drilling nearly 100 m southwest of the Mygatt-Moore Quarry in 2013 confirmed that dinosaur bone and the mudstone with plant debris characteristic of the quarry bone layer extend at least that far under the hill.

Although there is a component of allochthonous and very worn bone fragments, well-preserved elements were probably derived from animals that died in or very close to the quarry setting. It appears that carcasses were being scavenged at the site, but it is unclear if any of the animals were killed by predators there; direct evidence of miring is lacking.

Current Research

Ongoing work at the Mygatt-Moore Quarry every season continues to produce interesting material (figure 34), including large diplodocid elements such as a scapulocoracoid and a femur, the latter measuring 1876 mm in length. A small jaw of *Othnielsosaurus* was identified at the site less than 10 years ago, and a 2 mm tooth (figure 28) and other small reptile remains have been found in the same recent time period. The site continues to produce new and important data, especially regarding the taphonomy of the deposit. An extensive taphonomic study of the quarry, started in 2010, is nearing completion.

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Table 4. Biota of the Mygatt-Moore Quarry in western Colorado, Morrison Formation. Plant listing based on Tidwell and others (1998) and Hotton and Baghai-Riding (2010). * indicates a type specimen from the Mygatt-Moore Quarry.

Plants	**Animals**
Lycopodiophyta	Gastropoda
Isoetales	*Viviparus* (?) *reesidei*
Isoetaceae indet.	Arthropoda
Pteridophyta	Branchiopoda
Cyatheales indet.	Conchostraca indet.
Osmundales	Malacostraca
Osmundaceae indet.	Decapoda
Sphenophyta	Indet. Crayfish
Equisetales	Chordata
Equisetum cf. *burchardii*	Osteichthyes
Cycadophyta	Palaeoniscoidea
Cycadeoidales	*Morrolepis schaefferi**
Otozamites sp.	Neopterygii
Cycadolepis (?) sp.	Halecostomi indet.
Jensenispermum redmondii	"*Hulettia*" *hawesi**
Ginkgophyta	Teleostei
Ginkgoales	cf. *Leptolepis*
Ginkgo (?) sp.	Reptilia
Czekanowskiales	Reptilia indet.
Czekanowskia turneri (?)	Pterosauria (?) indet.
Coniferophyta	Crocodylomorpha
*Brachyphyllum rechtenii**	Neosuchia
Brachyphyllum sp. A	Goniopholididae indet.
Behuninia provoensis	Dinosauria
Steinerocaulis radiates	Saurischia
Conites sp.	Theropoda
*Protocupressinoxylon medlynii**	Ceratosauria
*Mesembrioxylon carterii**	*Ceratosaurus* sp.
*Xenoxylon moorei**	Tetanurae
Unidentified conifer	Allosauridae
	Allosaurus fragilis
	Sauropoda
	Diplodocidae
	Apatosaurinae
	Apatosaurus louisae
	Diplodocinae indet.
	Macronaria
	Camarasaurus sp.
	Ornithischia
	Ankylosauria
	*Mymoorapelta maysi**
	Ornithopoda
	Othnielosaurus consors

Figure 27. Although plant fragments are abundant in every piece of matrix from the bone layer at Mygatt-Moore Quarry, identifiable plant remains are rare.

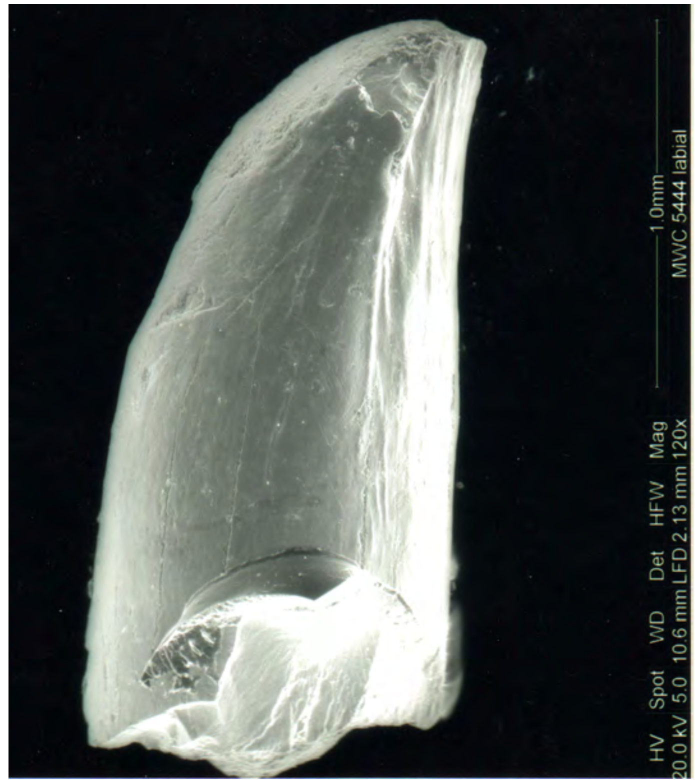

Figure 28. Small tooth of an unidentified reptile from the Mygatt-Moore Quarry, found by MWC volunteer Richard Peirce during screenwashing of matrix from a field jacket containing a femur of a juvenile sauropod.

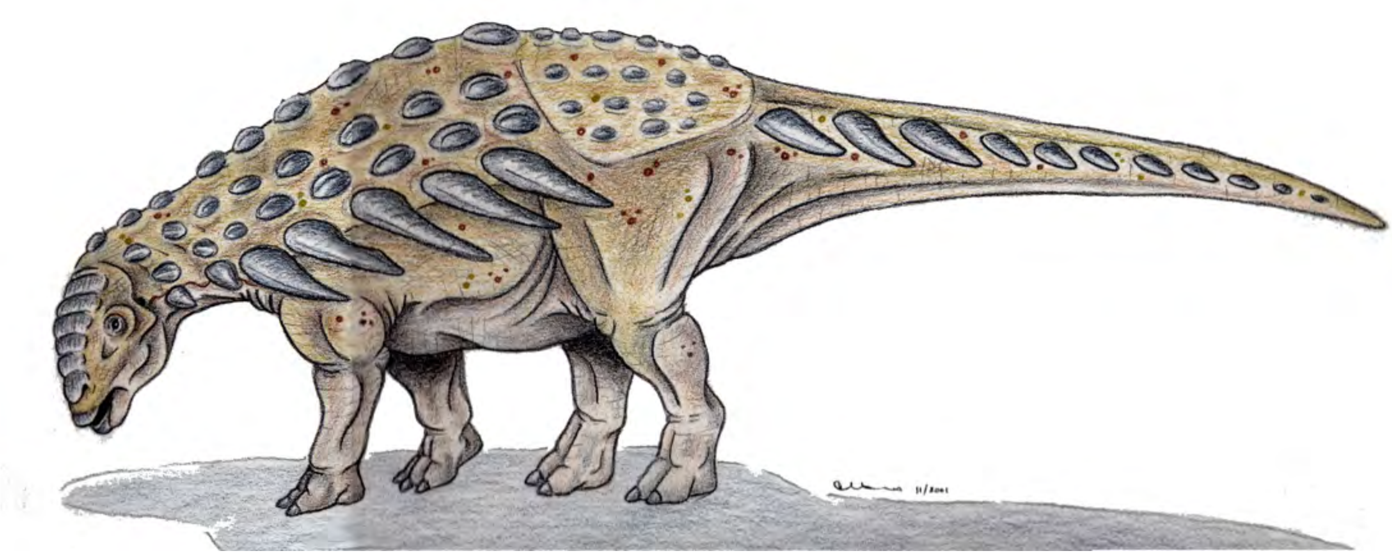

Figure 29. Reconstruction of the polacanthid ankylosaur *Mymoorapelta* by Thomas Adams (Witte Museum). Courtesy of MWC.

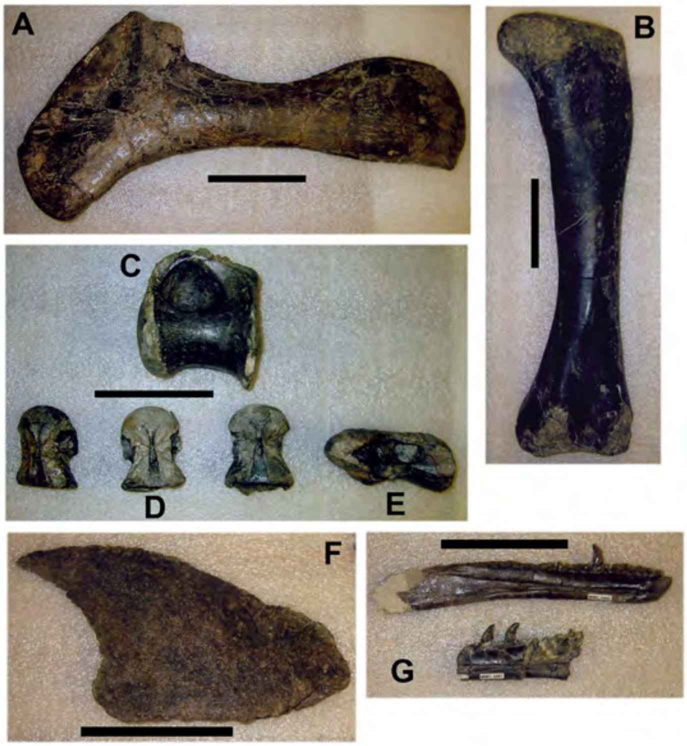

Figure 30. Juvenile and ankylosaur material from the Mygatt-Moore Quarry. (A) Left scapula of juvenile apatosaur. (B) Left femur of juvenile diplodocid. (C) Dorsal of juvenile sauropod in left lateral view. (D) Three cervical vertebrae of juvenile sauropods in dorsal view. (E) Cervical vertebra of juvenile sauropod in left lateral view. (F) Lateral spine of *Mymoorapelta*. (G) Lingual view of left dentary (top) and right dentary fragment (bottom) of juvenile *Allosaurus* found in 2002. All scale bars = 10 cm.

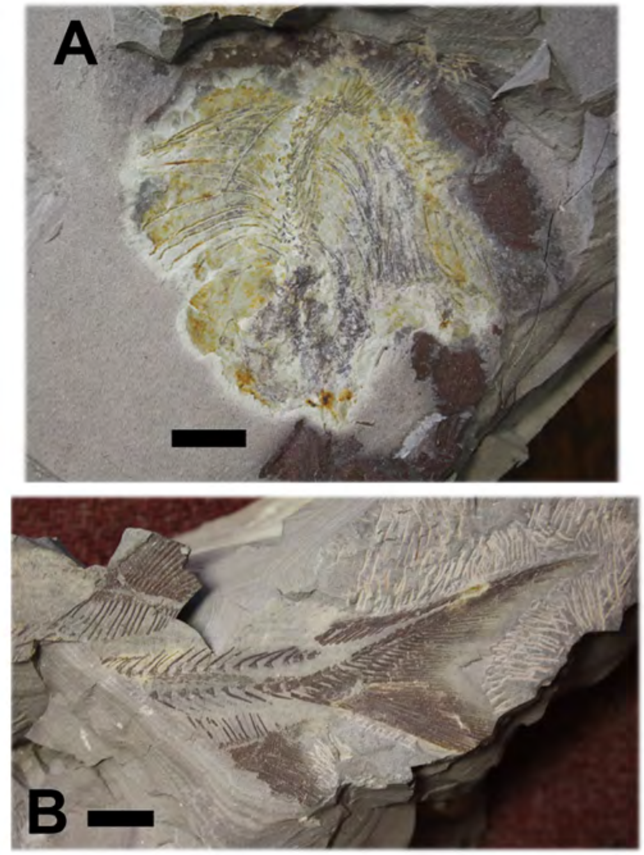

Figure 31. Fish from the Mygatt-Moore "fish layer." (A) Indeterminate fish skeleton, possibly cf. *Leptolepis*. (B) Posterior section and caudal fin of probable *Morrolepis*. Scales = 1 cm

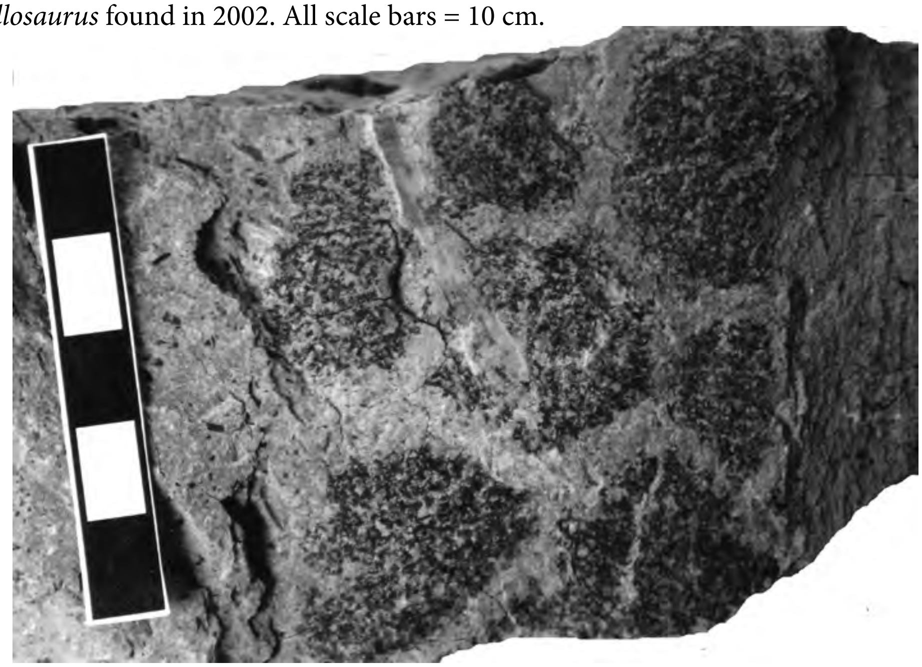

Figure 32. Section of sauropod skin with roughly hexagonal scale pattern found in Mygatt-Moore Quarry. Scale in cm (from Foster and Hunt-Foster, 2011).

Figure 33. Some of the more than 300 mostly shed theropod teeth found at the Mygatt-Moore Quarry, in the collections of MWC.

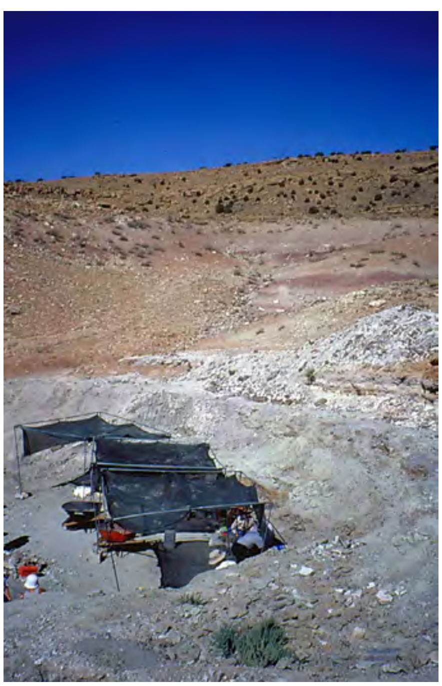

Figure 34. The Mygatt-Moore Quarry c. 2010, closing in on 30 field seasons of operation.

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