

DISTRIBUTION OF VERTEBRATE FAUNAS IN THE CEDAR MOUNTAIN FORMATION, EAST-CENTRAL UTAH

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ABSTRACT

The Cedar Mountain Formation in east-central Utah preserves three distinct dinosaur-dominated vertebrate faunas in strata separated by unconformities. The oldest fauna is preserved in the basal Yellow Cat Member of the Cedar Mountain Formation in the area east of the San Rafael Swell and includes an abundant new genus of polacanthid ankylosaur related to *Polacanthus*, *Iguanodon ottingeri*, a sail-backed iguanodontid, a camarasaurid and titanosaurid sauropods, a new genus of theropod similar to *Ornitholestes*, and the giant dromaeosaurid *Utahraptor ostrommaysorum*. The polacanthid, iguanodontids, and titanosaurid indicate close temporal geographic ties to the Barremian of Europe, where similar dinosaurs occur. The Poison Strip Sandstone and Ruby Ranch Member preserve a fauna including the nodosaurid *Sauropelta*, the primitive iguanodontid *Tenontosaurus*?, sauropods assigned to *Pleurocoelus*, dromaeosaurid teeth, an unidentified large theropod, and *Acrocanthosaurus*. This fauna compares well with those documented from the Cloverly Formation, Arundel Formation, and Trinity Group characteristic of North America's apparently endemic Aptian-Albian dinosaur fauna. A sharp break from carbonate-nodule-bearing, non-smectitic strata to carbonaceous, highly smectitic strata marks the base of the Mussentuchit Member in the western San Rafael Swell region. This member is dated as straddling the Albian/Cenomanian boundary on palynological and

radiometric age estimates. The preserved fauna includes a small nodosaurid *Animantarx ramaljonesi*, a small ornithopod, a primitive lambeosaurid hadrosaur, ceratopsian teeth, pachycephalosaur teeth, tiny sauropod teeth, a dromaeosaurid, cf. *Richardoestes* teeth, cf. *Paronychodon* teeth, and an early tyrannosaurid. This fauna is remarkably similar to those of the Campanian and Maastichtian of western North America. As the only likely ancestors of the hadrosaur and ceratopsian are from the Early Cretaceous of Asia, the dramatic shift to faunas typical of the North American Late Cretaceous is interpreted to be the result of opening migration corridors to and from Asia through Alaska at the end of the Early Cretaceous, when migration to eastern North America was still possible. The overlying middle to upper Cenomanian Dakota Formation preserves a dinosaur fauna much like that of the Mussentuchit fauna with the notable absence of sauropods. The fossil record in the Cedar Mountain Formation of east-central Utah can be divided as follows: (1) a basal Barremian iguanodontid-polacanthid fauna with European affinities predating common flowering plants; (2) a middle Aptian-middle Albian *Tenontosaurus-Pleurocoelus* fauna, perhaps representing an impoverished recovery fauna following a major Lower Cretaceous extinction event (endemic to North America); (3) an Albian-Cenomanian boundary fauna dominated by lambeosaurine hadrosaurids with Asian affinities, when flowering plants were co-dominant, which continued until the end of the Cretaceous.

INTRODUCTION

Historically, the Lower to “middle” Cretaceous terrestrial strata of the Cedar Mountain Formation have been considered to be largely unfossiliferous (Stokes, 1944, 1952; Young, 1960). The uppermost Cedar Mountain Formation in the western San Rafael Swell had been established as late Albian, based on palynomorphs, by Tschudy and others (1984). Ages based on freshwater bivalves, ostracodes, charophytes, and plants, while not as accurate, are compatible (Mitchell, 1956; Stokes, 1952; Young, 1960). The Cedar Mountain Formation has subsequently been considered as a homogenous Aptian-Albian unit in most regional studies (for example, Lawton, 1985, 1986; Heller and others, 1986; Heller and Paola, 1989; Baars and others, 1988).

Additionally, the North American terrestrial vertebrate record has been considered to be very poor overall for the “middle” Cretaceous, the notable exception being the Aptian-Albian Cloverly fauna of southern Montana (Ostrom, 1970). Largely correlative faunas are known from the Antlers Formation of Oklahoma, Arkansas, and northern Texas (Stovall and Langston, 1950; Langston, 1974, Cifelli and others, 1997a), the Paluxy and Twin Mountains Formations of central Texas (Langston, 1974; Winkler and others, 1989; 1990), and the Arundel Formation of Maryland (Gilmore, 1921; Kranz, 1989, 1996).

Recent research has indicated that there are three distinct faunas in the Cedar Mountain Formation of east-central Utah (Kirkland, 1996b; Kirkland and others, 1997). In addition to the fauna similar to the well known Cloverly fauna, there are both a distinct earlier and a later fauna. Improved biostratigraphic resolution within this time interval indicates a more complex regional history during the Early to “middle” Cretaceous than previously recognized.

THE CEDAR MOUNTAIN FORMATION AND ITS VERTEBRATE FAUNAS

The term Cedar Mountain Shale was designated by Stokes (1944) for the drab variegated slope-forming sedimentary rocks lying between the Buckhorn Conglomerate and the Dakota Formation, with a type section on the southwest flank of Cedar Mountain, Emery County, Utah. He characterized the Cedar Mountain Shale as having slopes covered with abundant carbonate nodules that are often septarized with agate, barite, and other fillings. Additionally, Stokes (1944) noted an abundance of elongate sandstone lenses (ribbon sandstones) that represent abandoned river channels. He also noted the pres-

ence of polished chert pebbles (“gastroliths”).

Stokes (1952) renamed the formation the Cedar Mountain Formation and included the Buckhorn Conglomerate as its basal member (figure 1). His measured type section (section 9, T. 18 S., R. 10 E. of the Salt Lake Base Line and Meridian) is 123.6 meters thick. He recognized that the Burro Canyon Formation of western Colorado (Stokes and Phoenix, 1948) was largely equivalent to the Cedar Mountain Formation and recommended using the Colorado River as the dividing line between these formations (Stokes, 1952).

Young (1960), recognizing the continuity of the two formations, proposed that the term Burro Canyon be abandoned in favor of Cedar Mountain Formation. This proposal has been ignored by subsequent authors (Craig, 1981). Young (1960) recognized several regionally extensive sandstones in the Cedar Mountain Formation that were useful for correlation (figure 1).

Based on correlations of regionally persistent sandstone units, Young (1960) proposed that calcareous mudstones assigned to the Cedar Mountain passed eastward into the carbonaceous sandstones and shales of his Naturita Formation. The more refined biostratigraphy developed by Kirkland and others (1997) permit more refined correlations across Utah that preclude correlating any sandstone bed within the Cedar Mountain Formation with any specific sandstone bed within the Dakota Formation to the east across central Utah. However, subsurface data presented by Molenaar and Cobban (1991) indicate that the upper Cedar Mountain Formation correlates with the upper Dakota Formation northwestward across the Uinta Basin. Young's (1960) sandstone correlations suffered from this lack of biostratigraphic control, but these regionally persistent sandstone units mark major breaks in sedimentation as indicated by the dramatic faunal changes documented herein. Thus Young's (1960) recognition of these sandstones represents a significant, if belatedly utilized, breakthrough in our understanding of the Cedar Mountain Formation.

In addition to the basal Buckhorn Conglomerate of the western San Rafael Swell, four additional members of the Cedar Mountain Formation have been defined (Kirkland and others, 1997). In ascending order, based on lithostratigraphic and biostratigraphic relationships, these are Yellow Cat Member, Poison Strip Sandstone, Ruby Ranch Member, and Mussentuchit Member (figure 1).

Buckhorn Conglomerate

The Buckhorn Conglomerate was defined as a formation by Stokes (1944) for exposures below the dam at Buckhorn Reservoir on the southwest flank of Cedar

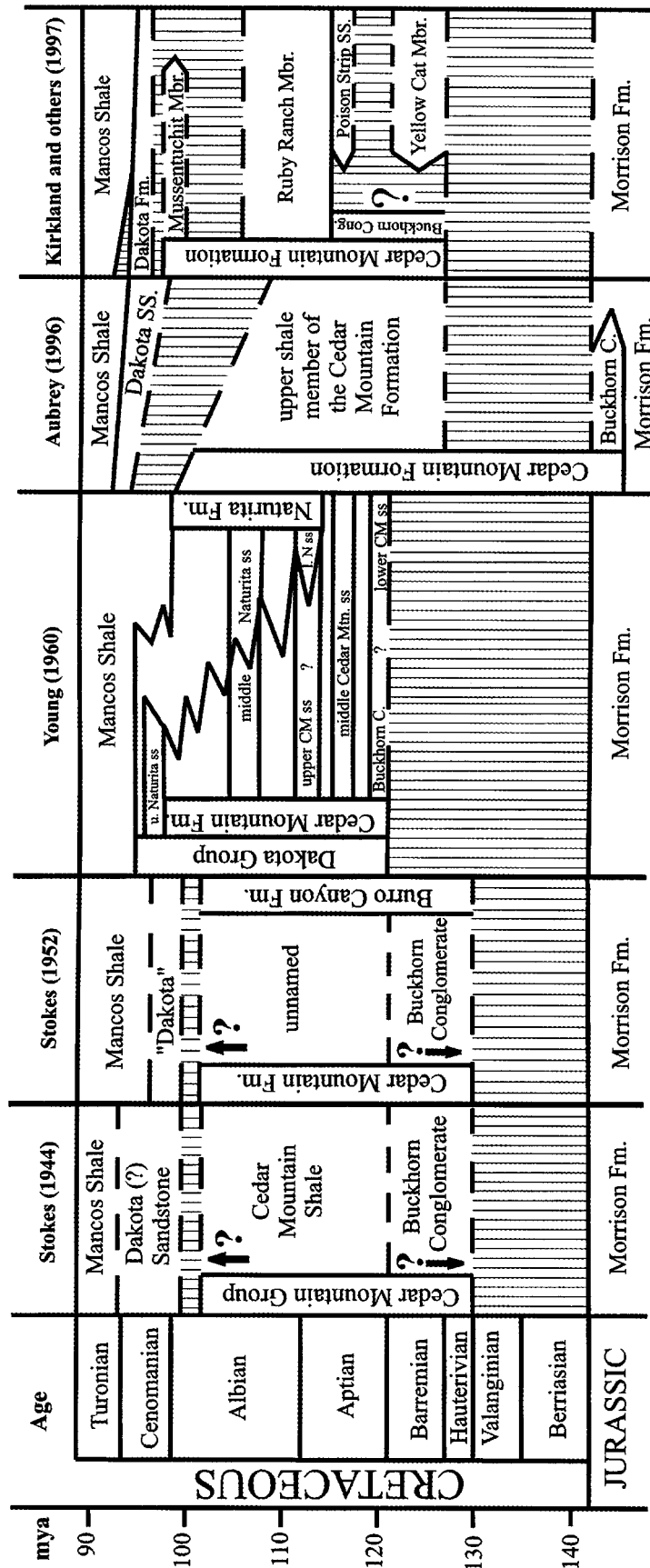


Figure 1. History of nomenclature for Upper Jurassic through "middle" Cretaceous in east-central Utah. Time scale from Obradovich (1993). After Kirkland and others (1997).

Mountain where its exposed thickness is 7.5 meters. At the type locality the pebbles have an average diameter of 3 centimeters and are composed mostly of black chert. The member is largely trough-crossbedded with flow directions to the northeast. The Buckhorn Conglomerate is best developed in the northern San Rafael Swell area. Because of its discontinuous nature, Stokes (1952) subsequently included the Buckhorn Conglomerate as the lower member of the Cedar Mountain Formation. Young (1960) also noted that the member is discontinuous and found that it could not be correlated to any specific sandstone east of the San Rafael Swell (figure 1).

Aubrey (1996, 1998) proposed that the Buckhorn Conglomerate is separated from the overlying strata of the Cedar Mountain Formation by a calcrete horizon and that it intertongues with the Morrison Formation and should be considered Upper Jurassic. Currie (1997) also recognized this calcrete horizon in the area of northeastern Utah and northwestern Colorado near Dinosaur National Monument and proposed that it was a sequence-bounding unconformity within the Lower Cretaceous. No fossils have been recovered from the Buckhorn Conglomerate beyond reworked late Paleozoic invertebrates and its correlation to the basal members of the Cedar Mountain Formation to the east is still problematic.

Yellow Cat Member

The Yellow Cat Member is exposed in the northern Paradox Basin in a belt extending from the west side of the ancestral Uncompahgre Uplift west of Dewey Bridge, Utah, to the east side of the San Rafael Swell (figure 2). At most exposures, the Yellow Cat Member extends from the basal calcrete of the Cedar Mountain Formation in this region (Aubrey, 1996, 1998; Kirkland and others, 1997) up to the base of a regionally extensive sandstone ledge (middle sandstone of Young, 1960; Poison Strip Sandstone of Kirkland and others, 1997). These sediments consist mostly of interbedded mudstone, with interbeds of sandstone and limestone. These mudstones tend to be mauve toward the base and pale green toward the top. They differ from those of the Morrison in being drabber and less strongly variegated. In addition, the mudstones in the Yellow Cat Member are not smectitic.

The basal calcrete is not always present and at some sites there is a shale-on-shale contact, although common polished chert pebbles ("gastroliths") are generally found at the best pick for the contact (Stokes, 1944; 1952) suggesting a deflation surface. At other sites, the basal calcrete is a complex of superimposed calcretes or there may be several calcretes and the contact is picked at the

top of the lowest calcrete above smectitic mudstones of the Brushy Basin Member of the Morrison Formation. Aubrey (1996, 1998) utilized the base of the calcrete as the base of the Cedar Mountain, however the basal surface is often gradational. His argument assumes that this calcrete represents a complex soil horizon developed on the Morrison paleosurface. However, while distinct soil features are recognized in many places, in other areas such as below the type section of the Ruby Ranch Member, overlying lucustrine sediments may be a control on the development these carbonates. The uppermost Morrison below the calcrete is often non-smectitic, root-mottled, and a brick red color, perhaps reflecting the period of exposure, oxidation, and soil formation between deposition of the Morrison Formation and the onset of Cedar Mountain deposition.

The type section of the Yellow Cat Member of the Cedar Mountain Formation is near the Gaston Quarry (figure 3) west of the Yellow Cat Road (Kirkland and others, 1997). At this site, the Cedar Mountain Formation is 45.9 meters thick and the basal Yellow Cat Member measures 24 meters thick. At 6.7 meters below the overlying Poison Strip Sandstone, there is an interval of limestone and shale interbeds which Young (1960, figure 6, section 37) used to mark the base of the Cedar Mountain Formation in this area. Therefore, a major portion of the Yellow Cat Member had been included in the Brushy Basin Member of the Morrison Formation.

The Yellow Cat fauna includes abundant specimens of a new genus of polacanthid ankylosaur related to *Polacanthus*, *Iguanodon ottingeri* (Galton and Jensen, 1979), perhaps a distinct genus of sail-backed iguanodontid, titanosaurid and camarasaurid sauropods, a new genus of theropod most similar to *Ornitholestes*, and the giant dromaeosaurid *Utahraptor ostrommaysorum* (Kirkland and others, 1991; Kirkland, Burge, Britt, and Blows, 1993; Kirkland and others, 1997; Kirkland and others, 1995; Kirkland, 1993, 1996a; Kirkland, Burge, and Gaston, 1993; Britt and others, 1996; Britt and Stadtman, 1997; Carpenter and others, 1996). In addition, turtles, crocodilians, and a sphenodontian have been recognized (Kirkland and others, 1997). Fish appear to be locally abundant, but have been identified only from isolated remains (table 1). Hybodont sharks have been identified on the basis of a small fragment of dorsal fin spine and several spiral coprolites rich in ganoid scales. Important vertebrate quarries in this member include Brigham Young University's Dalton Well Quarry (figure 4), which preserves a diverse fauna dominated by sauropods (Britt and others, 1996; Britt and Stadtman, 1997), and College of Eastern Utah Prehistoric Museum's Gaston Quarry (figure 3), which preserves a less

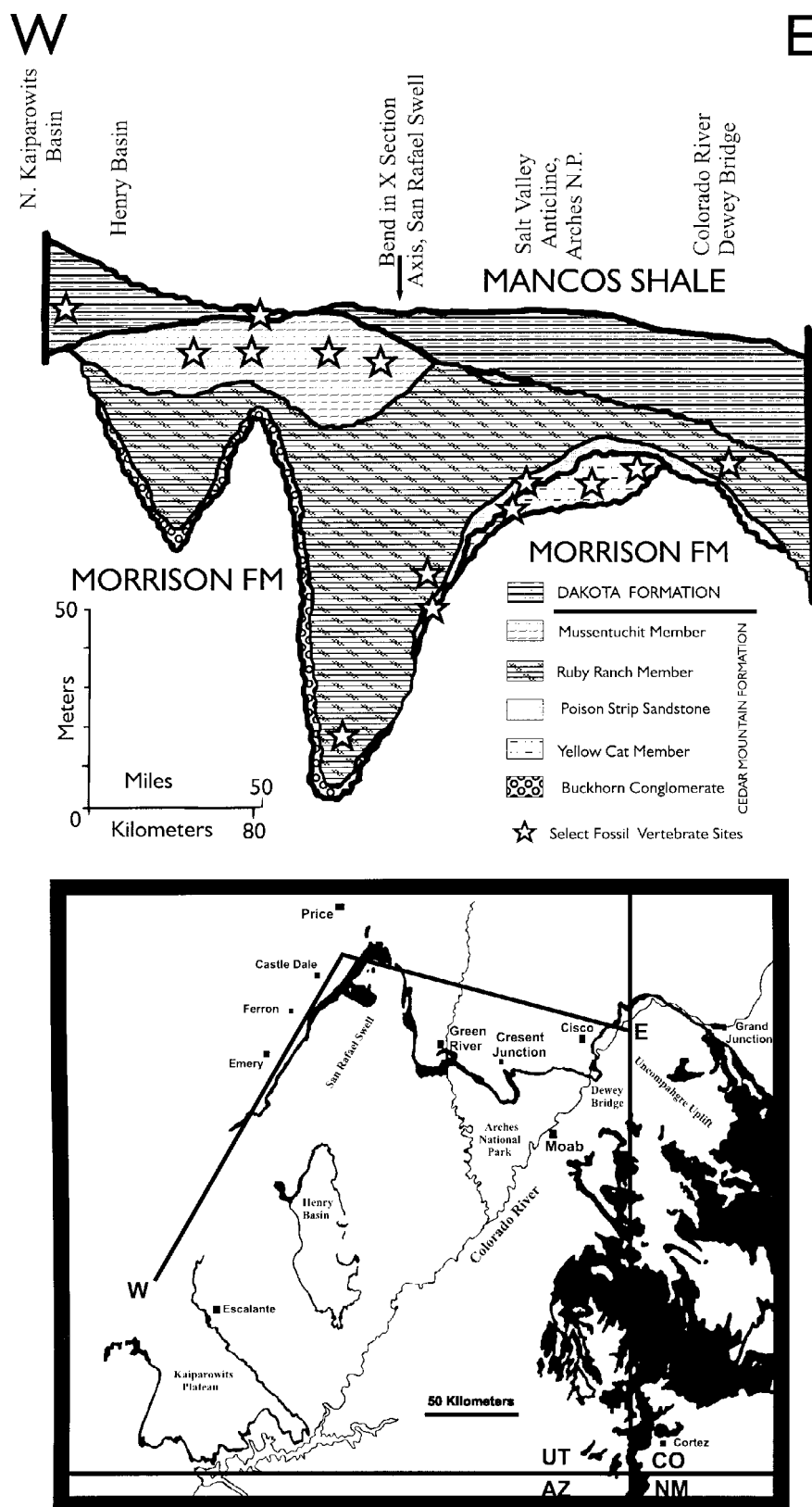


Figure 2. Cross section showing the distribution of “middle” Cretaceous units across eastern Utah discussed in text. Modified after Kirkland and others (1997). Base map showing distribution of Cedar Mountain, Burro Canyon, and Dakota Formations modified after Young (1960).

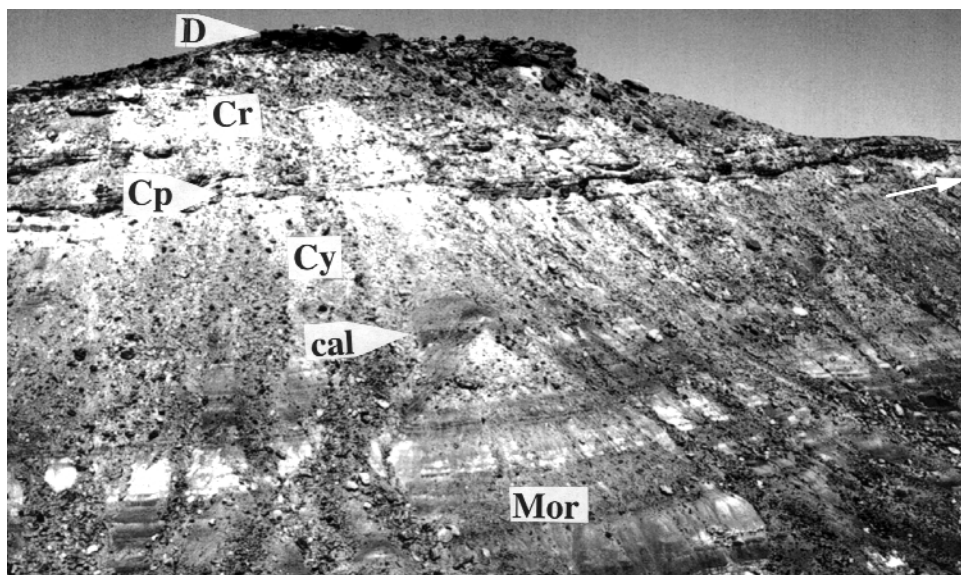


Figure 3. Type area of Yellow Cat Member of the Cedar Mountain Formation above Yellow Cat Flat near College of Eastern Utah Prehistoric Museum's Gaston Quarry. Arrow indicates position of Gaston Quarry. Abbreviations: cal, calcrete; Cp, Poison Strip Sandstone; Cr, Ruby Ranch Member; Cy, Yellow Cat Member; D, Dakota Formation; Mor, Morrison Formation.

Table 1. Yellow Cat Fauna (see text for repositories)

Class Osteichthyes

Subclass Dipnoi

Ceratodus undescribed new species

Subclass Actinopterygia

cf. *Semionotus* ? sp.

cf. *Amia* sp.

Class Reptilia

Order Chelonia

cf. *Glyptops* sp.

Order Rhynchocephalia

cf. *Toxolophosaurus* sp.

Order Crocodilia

indeterminate teeth

Order Theropoda

Family Dromaeosauridae

Utahraptor ostrommaysorum

Family uncertain

Nedcolbertia justinhofmanni

Order Sauropoda

Family Camarasauridae

undescribed new genus

Family Titanosauridae

undescribed new genus

Order Ornithopoda

Family Iguanodontidae

Iguanodon ottingeri

undescribed new genus

Order Ankylosauria

Family Polacanthidae

Gastonia burgei

yielded several isolated small theropod skeletons (figure 5) (Kirkland and others, 1997). Sites preserving isolated remains of iguanodontids, sauropods, and polacanthid ankylosaurs have also been found in the region by the Denver Museum of Natural History. Important collections of fossils from this interval are housed at the College of Eastern Utah Prehistoric Museum, Price, Utah; Earth Science Museum, Brigham Young University, Provo, Utah; Denver Museum of Natural History, Denver Colorado; and the Oklahoma Museum of Natural History, University of Oklahoma, Norman Oklahoma.

There is disagreement among the authors as to whether there are one or two iguanodontids in the Yellow Cat Member. Britt and Stadtman (1997) have proposed that the sail-backed iguanodontian is an adult specimen of *Iguanodon ottingeri* as both specimens occur together at the type locality. Kirkland and others (1997) have proposed that there are two iguanodontid taxa, a large sail-backed form and *I. ottingeri*; and a conservative small iguanodontian similar to or even conspecific with *I. lakotaensis* (Weishampel and Bjork, 1989). All the iguanodontid specimens collected at the Gaston Quarry and found as isolated specimens are similar to the type specimens of *I. ottingeri* and *I. lakotaensis*. Only further excavations will resolve this question.

The polacanthid ankylosaurs, iguanodontids, and titanosaurid sauropods indicate close temporal and geographic ties to the Barremian of Europe (Blows, 1993; Norman, 1988). This correlation is also supported by the presence of the charophyte *Nodosoclavator bradleyi*, which is not known in strata younger than Barremian (Niel Shudack, personal communication; Kirkland and

diverse fauna dominated by polacanthid ankylosaurs. Both of these sites are in the upper third of the Yellow Cat Member. At the base of the Yellow Cat Member 1.5 kilometers east of the Gaston Quarry, one horizon has

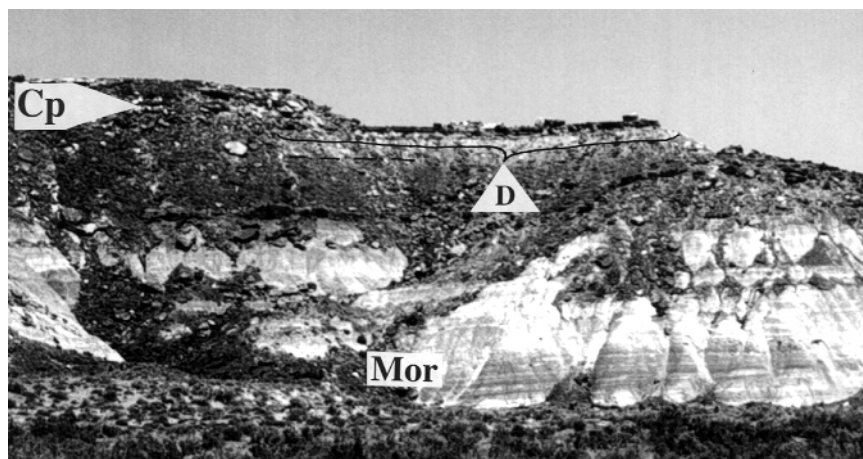


Figure 4. The Brigham Young University's Dalton Wells Quarry indicated by D and brackets. Abbreviations: Cp, Poison Strip Sandstone; Mor, Morrison Formation.

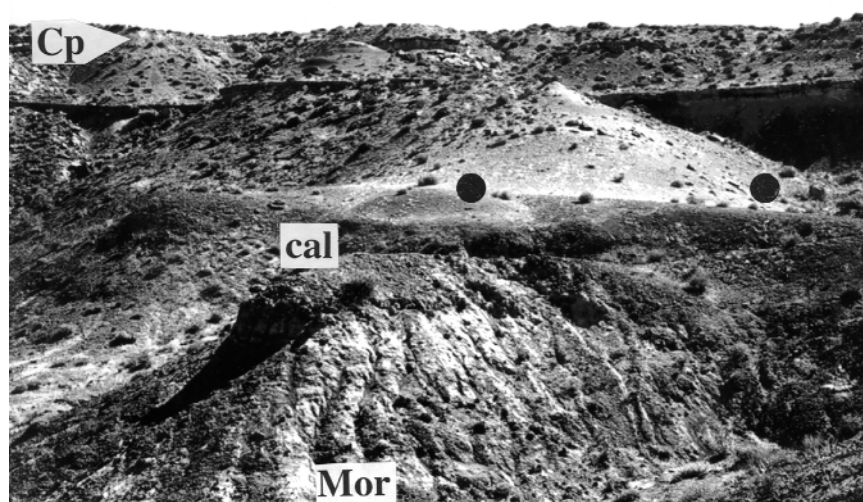


Figure 5. College of Eastern Utah Prehistoric Museum's small theropod sites indicated by dots just to the east of the Gaston Quarry. Abbreviations: Cp, Poison Strip Sandstone; cal, calcrete.

others, 1997). Furthermore, the dinosaurs indicate a close correlation with the Lakota Formation at Buffalo Gap, South Dakota (Kirkland, 1992; Kirkland, Burge, and Gaston, 1993; Kirkland and others, 1997; Lucas, 1993) (figure 6). Kirkland and others (1997) estimated that 20 to 25 million years of Earth history may be represented by the hiatus between Morrison and Cedar Mountain deposition based on radiometric age estimates at the top of the Morrison Formation (Kowallis and others; 1998) and the age of correlative dinosaur-bearing strata (Obradovich, 1993; Dyman and others, 1994).

The thickness of the Yellow Cat Member may vary by tens of meters over several kilometers of outcrop. Together with the observed differences in its basal contact, this lateral variation in thickness may in part reflect the topography of the erosional surface formed on the upper Jurassic strata during the earliest Cretaceous.

The distribution of the Yellow Cat Member provides an important constraint on the beginning of Sevier thrust-

ing. Aubrey (1996, 1998) has postulated that thrusting may have begun in the Barremian based on the recognition of this basal Cedar Mountain fauna (Kirkland, 1992). As a rule, subsidence caused by loading in the proximal foreland basin is almost instantaneous geologically, (Turcotte and Schubert, 1982), indicating that age estimates from the sediment wedge formed proximal to the thrust belt provide a bracket for the beginning of thrusting. However, because the Barremian sediments of the Yellow Cat Member pinch out to the west (figure 2), they would seem to preclude the onset of Sevier thrusting until at least the Aptian and hence provide additional support to previously published dates for the onset of thrusting (Lawton, 1985, 1986; Heller and others, 1986; Heller and Paola, 1989).

The distribution of the Yellow Cat Member from the Uncompahgre Uplift to the San Rafael Swell is compatible with the proposal by Aubrey (1996) that the distribution of these sediments was controlled by salt tectonics

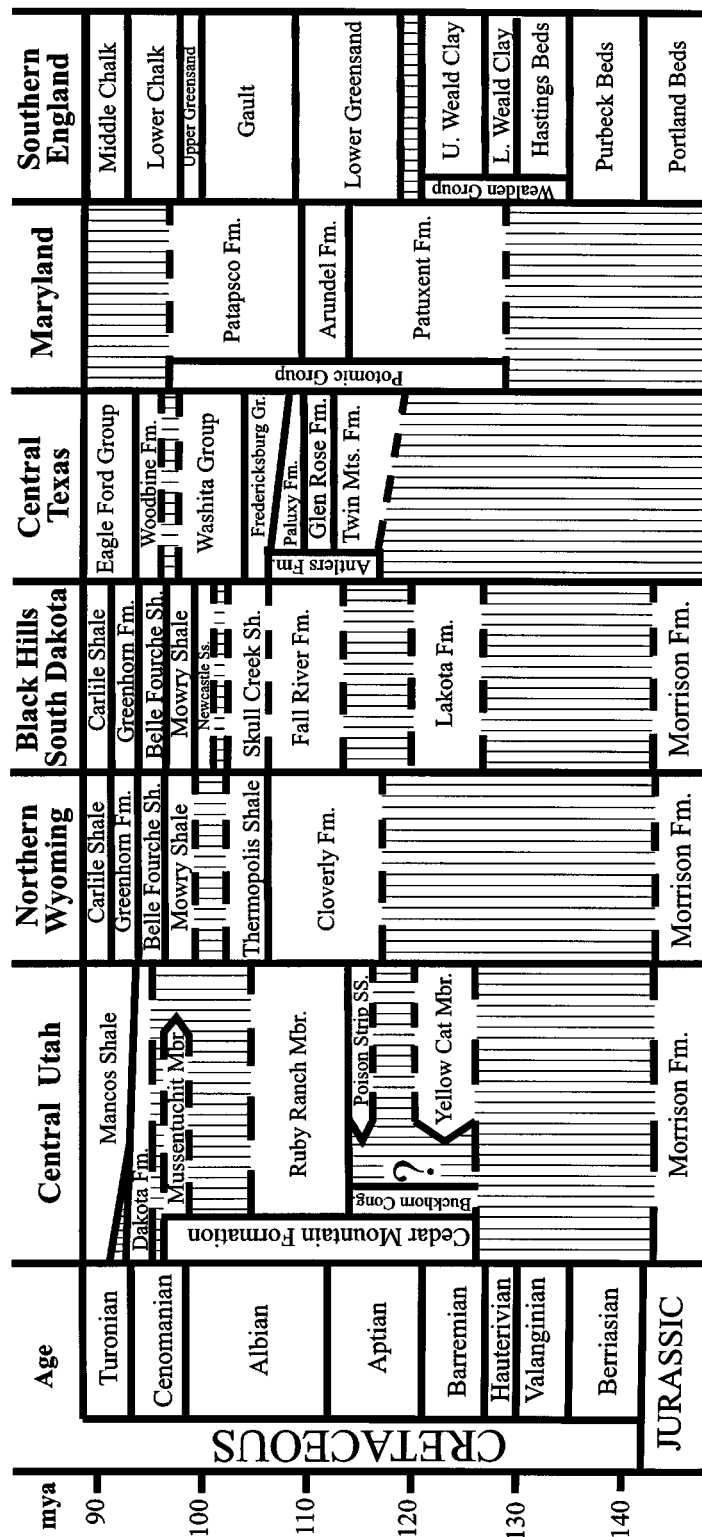


Figure 6. Correlation chart showing age relationships of stratigraphic units discussed in text. Vertical lines denote unconformities. Time scale from Obradovich (1993). Data from Benton and Spencer (1995), Dymov and others (1994), Hancock and others (1993), and Winkler and others (1995). Modified after Kirkland and others (1997).



Figure 7. The Brigham Young University's Bodily's Nodosaur Site on west side of Arches National Park. Arrow points to site. Abbreviations: Cm, Mussentuchit Member; Cp, Poison Strip Sandstone; Cr, Ruby Ranch Member; Cy, Yellow Cat Member; D, Dakota Formation; Mor, Morrison Formation.

during the Early Cretaceous as reported by Doelling (1988). Variation in local subsidence rates due to salt tectonics might help explain the rapid thinning and thickening observed in the Yellow Cat Member. Additionally, lacustrine sediments such as algal- and mudcracked limestones are common in the Yellow Cat Member (Britt and Stadtman, 1997; Kirkland and others, 1997). Lacustrine sediments are compatible with the formation of small basins due to salt tectonics.

The presence of numerous calcareous nodules representing paleosols indicates that the Yellow Cat Member was deposited under a semiarid monsoonal climate similar to that interpreted for the underlying Morrison Formation (Dodson and others, 1980, Wing and Sues, 1992). The widespread occurrence of viviparid snails, fish, freshwater turtles, and crocodilians suggest there may have been more standing water than indicated for the Late Jurassic of the Colorado Plateau (Dodson and others, 1980). The floras recorded for the Barremian are generally devoid of angiosperms other than a low diversity of pollen types, which first appear in the middle Barremian (Hughes and others, 1979). This would indicate that a flora dominated by non-flowering plants much like that of the of the Jurassic was present (Wing and Sues, 1992).

Poison Strip Sandstone

The cliff-forming middle Cedar Mountain sandstone unit of Young (1960) marks the top of the Yellow Cat Member in eastern Utah (figure 1). It commonly contains gray and white chert pebbles. In some places there are several sandstones that are probably genetically related to each other, while rarely in other places there is only a thin crevasse splay or, locally, no sandstone at all. This

sandstone above the Yellow Cat Member has been named the Poison Strip Sandstone (Kirkland and others, 1997). It caps the escarpment exposing the upper Morrison Formation throughout the area from Green River, Utah to the Utah-Colorado border. This sandstone forms one of the most persistent and distinctive stratigraphic intervals in the entire Cedar Mountain Formation of eastern Utah. In some areas in the Poison Strip region south of Cisco, Utah, large scale (5 meters and greater) epsilon cross-bedding indicates that a large, meandering river system was mostly responsible for its deposition.

The Poison Strip Sandstone is clearly equivalent to Young's (1960) middle Cedar Mountain sandstone east of the San Rafael Swell. However, the middle Sandstone unit as used by Young (1960) in the western San Rafael Swell area is well above sites preserving an Aptian-lower Albian fauna, such as at the Long Walk Quarry (DeCourten, 1991; Kirkland and others, 1997), and appears to be an unrelated sandstone of more limited extent. Without the biostratigraphic control provided by the vertebrate faunas preserved in the Cedar Mountain Formation, Young's (1960) miscorrelation of these sandstones across the San Rafael Swell is understandable.

Sedimentologically the Poison Strip Sandstone is clearly distinct from the trough cross-bedded conglomerate of the Buckhorn Member of the Cedar Mountain Formation in the San Rafael Swell area. Although apparently in the same stratigraphic positions, there is no means of correlation between the genetically distinct Buckhorn Conglomerate and the middle sandstone of Young (1960) in eastern Utah. In the western San Rafael Swell area, no fossils have been found in the Buckhorn Conglomerate at the base of the Cedar Mountain Formation; thus it is impossible as yet to date the Buckhorn. Additionally, Currie (1997) describes the Buckhorn Conglomerate as

representing an isolated river system flowing to the northeast from the San Rafael Swell across the extreme northwestern corner of Colorado into Wyoming.

The Poison Strip Sandstone is named for the typical exposures of this unit along the Poison Strip south-southwest of Cisco, Utah. The type section is on the south-west end of the Poison Strip east-northeast of the Ring-tail Mine (Kirkland and others, 1997) (figure 4). The type section of the Poison Strip Sandstone measures 5.4 meters thick. The sandstone is fine- to medium-grained with matrix supported black, gray, and white chert pebbles, trough cross-bedded, and becomes slabby with pale greenish mudstone partings toward the top of the member. The Poison Strip Sandstone is economically significant in this area because it is the primary target in the Cisco Oil and Gas Field to the northeast (Larry Moyer, personal communication, 1995).

On the northeast side of Arches National Park, Bodily (1969) described a large ankylosaur as cf. *Hoplitosaurus* sp. from in, or just above this unit (figure 5). Coombs (1971) referred the taxon to the Cloverly nodosaurid ankylosaur, *Sauropelta*. Just north of this site a second specimen of *Sauropelta* was recently discovered by researchers from the Denver Museum of Natural History. These fossils indicate the Poison Strip Sandstone is close to the same age as the overlying Ruby Ranch Member, which also contains *Sauropelta*. The College of Eastern Utah Prehistoric Museum has recovered parts of an ornithopod from their Price River Quarry from a conglomeratic sandstone at the base of the Cedar Mountain Formation, southeast of Wellington, Utah (Burge, 1996). The ornithopod appears to represent *Tenontosaurus* and suggests that the conglomeratic sandstone southeast of Wellington correlates to the Poison Strip Sandstone. The sparse, small, black, gray, and white chert pebbles are also similar to those in the Poison Strip Sandstone. Large conifer logs and the cycads, *Cycadeoidea* and *Monanthasia* (William Tidwell, personal communication, 1997) are present locally within the Poison Strip Sandstone in the area around Arches National Park.

Ruby Ranch Member

The Ruby Ranch Member extends across the entire outcrop belt of the Cedar Mountain Formation and in strata assigned to the Burro Canyon Formation east of the Colorado River (figure 2). The Ruby Ranch Member overlies the Poison Strip Sandstone from at least the Utah-Colorado border region westward to the eastern San Rafael Swell and overlies the Buckhorn Conglomerate on the west side of the San Rafael Swell. From approximately the crest of the Salt Valley Anticline at

Arches National Park eastward, the upper contact of the Ruby Ranch Member is clearly with the base of the Dakota Formation. On the west side of the San Rafael Swell, a sharp break from carbonate nodule-bearing, non-smectitic strata to carbonaceous, highly smectitic strata marks the contact between the Ruby Ranch Member and the overlying Mussentuchit Member. A conglomerate unit rich in quartzite lies between these members along the northeastern side of the San Rafael Swell that is equivalent for the most part to Young's (1960) middle Naturita sandstone (Mark Kirschbaum, personal communication, 1996; Kirkland and others, 1997).

On the west side of Arches National Park a smectitic interval is present at the top of the Cedar Mountain Formation. This interval potentially correlates with the Mussentuchit Member of the western San Rafael Swell (figure 2). The report of a hadrosaur femur (Galton and Jensen, 1979) from this area may lend support to that correlation. Additionally, Brigham Young University's "Movie Valley" ankylosaur from the same area, may also be from this level based on the black color of the bones, which uniquely characterizes bones preserved in the Mussentuchit Member among units in the Cedar Mountain Formation.

The Ruby Ranch Member consists of drab, variegated mudstones with minor sandstone and limestone layers. Perhaps most characteristic of this interval are the abundant carbonate nodules that often are so abundant as to form a pavement covering the exposed slopes. The abundance of these nodules makes prospecting for fossils in this interval difficult. In addition, ribbon sandstone bodies holding up ridges that may extend for a kilometer or more are typical of this interval (Young, 1960; Harris, 1980; DeCourten, 1991; Kirkland and others, 1997). A substantial portion of the northwestward thickening observed in the Cedar Mountain Formation across the San Rafael Swell (for example, Stokes, 1952; Young, 1960) is represented by this interval. There is also a considerable thinning and thickening of this interval along the west side of the San Rafael Swell.

The type section of the Ruby Ranch Member is at the Ruby Ranch homestead site southwest of Crescent Junction, Utah (Kirkland and others, 1997). The basal contact is with the Poison Strip Sandstone and the upper contact is with the base of the Dakota Formation. The type section is 33.1 meters thick. At 2.1, 14, and 16.6 meters above the base, ribbon sandstones, whose thalweg and cross-bed orientations represent eastward-flowing rivers are present. Overall, the drab, variegated mudstones have a pale purplish surface expression. The upper 8.5 meters is a pale, greenish-gray color perhaps due to bleaching by the overlying Dakota Formation.

This upper interval also includes fewer, but larger carbonate nodules.

The Ruby Ranch fauna (table 2) includes the primitive iguanodontid *Tenontosaurus*?, the large nodosaur *Sauropelta*, a sauropod assigned to *Pleurocoelus* (= *Astrodon*), dromaeosaurid teeth, an unidentified large theropod, and *Acrocanthosaurus* (Weishampel and Weishampel, 1983; DeCourten, 1991; Kirkland and others, 1997). This fauna is the least known of the Cedar Mountain faunas. Important vertebrate sites in this member include the University of Utah's Long Walk Quarry near Castledale (DeCourten, 1991), the College of Eastern Utah's Price River 2 and KEM sites southeast of Wellington, Utah, and the Oklahoma Museum of Natural History's Hotel Mesa Quarry (figure 8) just to the east of the Colorado River, and thus what properly should be considered a Burro Canyon Formation site (Kirkland and others, 1997). The site, from which the *Tenontosaurus* specimens were collected on the west side of the San Rafael Swell (Weishampel and Weishampel, 1983), has not been relocated, but the carbonate matrix surrounding the specimens indicates they are from the Ruby Ranch Member. Important collections of fossils from this member are housed at the College of Eastern Utah Prehistoric Museum, Price, Utah; Earth Science Museum, Brigham Young University, Provo, Utah; and the Utah Museum of Natural History, University of Utah, Salt Lake City, Utah.

This fauna compares well with those documented from the Cloverly Formation, Arundel Formation, and Trinity Group characteristic of North America's apparently endemic Aptian-Lower Albian dinosaur fauna (Kirkland, 1996b; Kirkland and others, 1997). Determining the age of these sediments more precisely is impossible at this time.

The abundant calcareous nodules indicate that the Ruby Ranch Member was deposited under a semiarid monsoonal climate similar to that interpreted for the

Table 2. Ruby Ranch Fauna (see text for repositories)

Class Chondrichthyes

Order Hybodontoida

Hybodus sp.

Class Reptilia

Order Crocodilia

indeterminate

Order Theropoda

Family Dromaeosauridae

cf. *Deinonychus* sp.

Family Allosauridae ?

undescribed new genus

cf. *Acrocanthosaurus* sp.

Order Sauropoda

Family Brachiosauridae

Pleurocoelus sp. = *Astrodon* sp.

Order Ornithopoda

Family Iguanodontidae

Tenontosaurus sp.

Order Ankylosauria

Family Nodosauridae

cf. *Sauropelta* sp.

underlying Morrison Formation (Dodson and others, 1980; Wing and Sues, 1992). The Aptian-Albian pollen record indicates that angiosperms were becoming a significant part of western interior floras at this time (Wing and Sues, 1992).

Mussentuchit Member

A sharp break from carbonate-nodule-bearing, non-smectitic strata to carbonaceous, highly smectitic strata marks the base of the Mussentuchit Member. The dramatic increase in the volume of volcanic ash preserved in the Mussentuchit Member indicates a significant increase in volcanic activity to the west. The member is dated as straddling the Albian-Cenomanian boundary based on palynology (Nichols and Sweet, 1993), subsurface correlations (Molenaar and Cobban, 1991), and radiometric age estimates (Cifelli and others, 1997b).

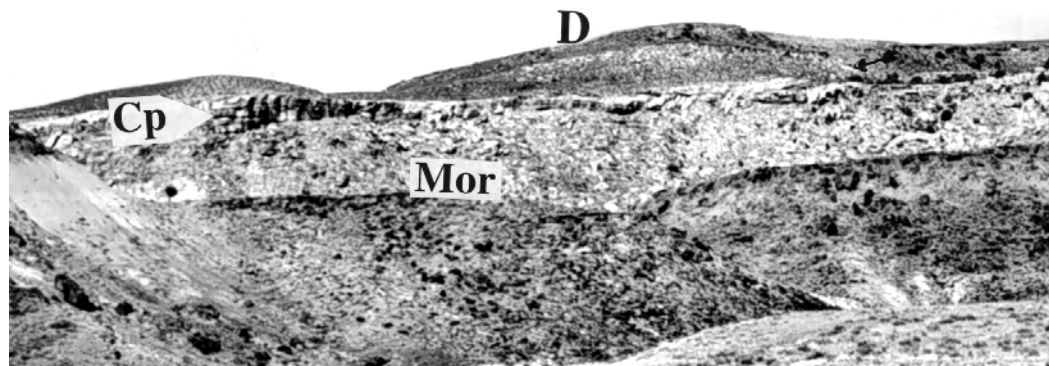


Figure 8. Oklahoma Museum of Natural History's Hotel Mesa Site indicated by arrow looking east across the Colorado River. Abbreviations: Cp, Poison Strip Sandstone; D, Dakota Formation; Mor, Morrison Formation.

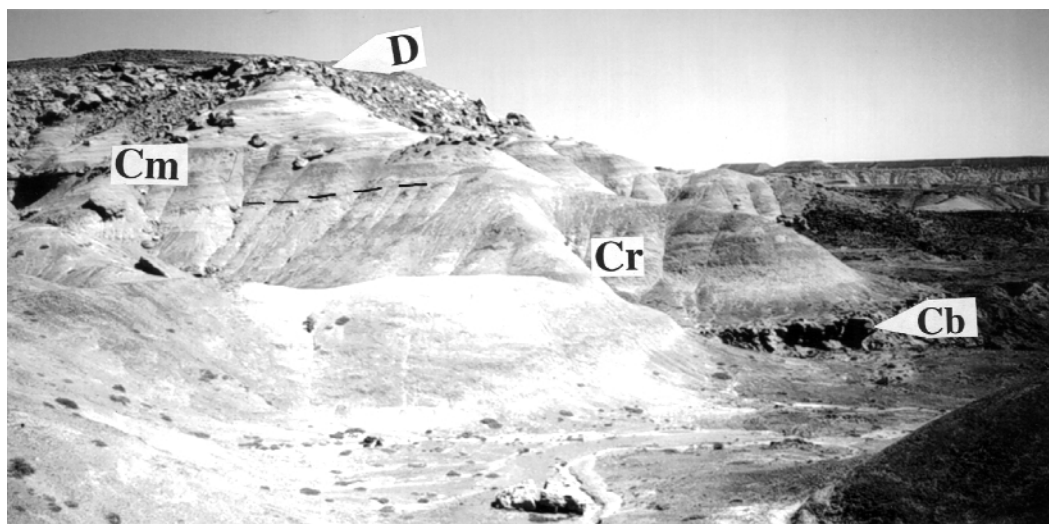


Figure 9. Type area of Mussentuchit Member of the Cedar Mountain Formation, Mussentuchit Wash near several of the Oklahoma Museum of Natural History's quarries. Dashed line indicates contact between Ruby Ranch and Mussentuchit Members. Abbreviations: Cb, Buckhorn Conglomerate; Cp, Poison Strip Sandstone; Cr, Ruby Ranch Member; Cy, Yellow Cat Member; D, Dakota Formation.

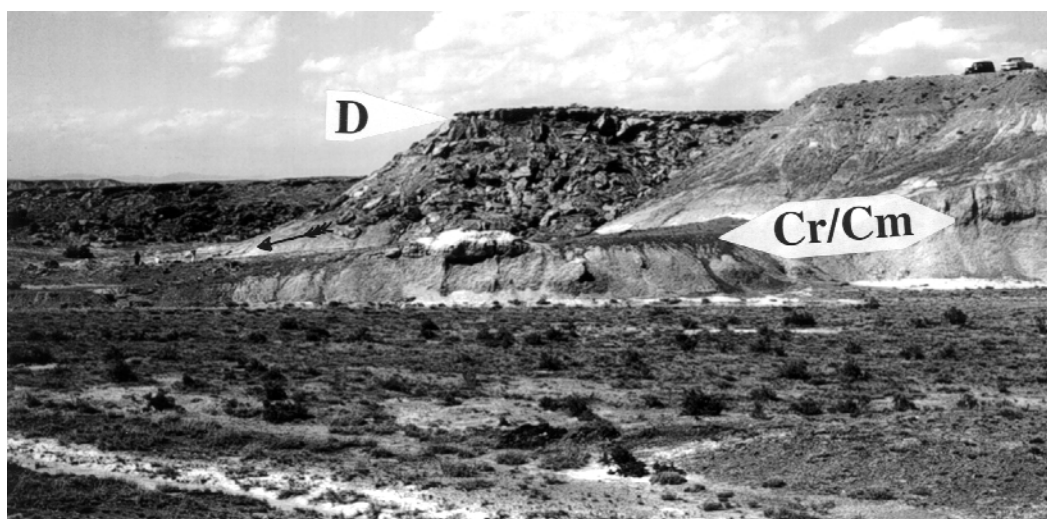


Figure 10. College of Eastern Utah Prehistoric Museum's Carol Site indicated by arrow northwest of Castledale, Utah. Abbreviations: Cr/Cm, contact between Ruby Ranch and Mussentuchit Members; D, Dakota Formation.

Stokes (1944) included this member in the Cedar Mountain Shale. However, he described the Cedar Mountain as having abundant carbonate nodules and did not mention that, at the top of the unit, the formation may lack such nodules.

Locally in the area of the southwestern San Rafael Swell south of Interstate 70, sandstone lenses near the top of the Cedar Mountain Formation compare well with the more extensive sandstone ledge typically used to define the base of the Dakota Formation (Stokes, 1944). This transition suggests that the top of the Cedar Mountain Formation may represent a period of nearly continuous sedimentation including the more carbonaceous overlying Dakota Formation. In fact, Young (1960) included the Mussentuchit Member in his Naturita Formation (Dakota Formation). The dramatic shift in the

sedimentology and paleontology at the base of this interval suggests that perhaps the Mussentuchit Member would be better included as a basal member of the Dakota Formation; the authors of this paper are not in full agreement as to whether this member should be included in the Cedar Mountain Formation or in the Dakota Formation (Kirkland and others, 1997). However, including the Mussentuchit Member in the basal Dakota Formation would mean that nearly every fossiliferous horizon in the area of the western San Rafael Swell attributed to the Cedar Mountain Formation (Katich, 1951; Stokes, 1952; Thayne and others, 1983, 1985; Thayne and Tidwell, 1984; Tidwell and Thayne, 1985; Jensen, 1970; Eaton and Nelson, 1991; Cifelli, 1993; Kirkland and Burge, 1994; Cifelli and others, 1997b, this volume), would have to be attributed to the Dakota Formation.

The upper smectitic portion of the Cedar Mountain Formation was designated the Mussentuchit Member by Kirkland and others (1997) with its type section south of Mussentuchit Wash (figure 9). At the type section, the member is 25 meters thick. A thin, discontinuous sandstone marks the base, where the non-smectitic mudstone rich in carbonate nodules is replaced by highly smectitic, gray mudstone. Several thin lenticular sandstones and lignitic horizons are present in the type section. The top of the member is at the base of a thick buff sandstone that forms the basal unit of the Dakota Formation along most of the western San Rafael Swell. Locally to the east of Ferron Utah, the Dakota Formation is missing (figure 2) and a horizon of dark chert pebbles and cobbles marks the base of the overlying Mancos Shale (Eaton and others, 1990; Kirkland and others, 1997).

The preserved dinosaur fauna includes a small nodosaurid *Animantarx ramaljonesi*, a small iguanodontid ornithomimid, a primitive lambeosaurid hadrosaur, ceratopsian teeth, pachycephalosaur teeth, tiny sauropod teeth, dromaeosaurid teeth, cf. *Richardoestesia* teeth, cf. *Paronychodon* teeth, and an early tyrannosaurid (Kirkland and Burge, 1994; Kirkland and Parrish, 1995; Burge, 1996; Carpenter and others, this volume). Teeth of a very small sauropod similar in morphology to those described as *Astrodon* are also present in this member marking the last occurrence of sauropods in North America prior to their reintroduction from South America in the late Maastrichtian (Lucas and Hunt, 1989). At the family level, this fauna is remarkably similar to those of the overlying Dakota Formation (Eaton and others, 1997) and those of the Campanian and Maastrichtian of western North America (Cifelli, Kirkland, and others, 1997b; Cifelli and others, this volume; Kirkland, 1996b; Kirkland and others, 1997). As the only likely ancestors of the hadrosaur, ceratopsian, and perhaps the tyrannosaurid are from the Early Cretaceous of Asia, the dramatic shift to faunas typical of the North American Late Cretaceous is interpreted to be the result of opening migration corridors to and from Asia through Alaska at the end of the Early Cretaceous, when migration to eastern North America was still possible (Kirkland, 1996b; Cifelli and others, 1997b).

Following an extensive screenwashing operation by the University of Oklahoma that resulted in thousands of catalogued specimens representing nearly 80 vertebrate taxa, Cifelli, Kirkland, Kirkland, and others (1997; and Cifelli and others, this volume, for complete faunal list) have characterized this fauna as the Mussentuchit local fauna for Mussentuchit Wash, where many of their best vertebrate sites are located.

In addition to the many important sites developed by

the Oklahoma Museum of Natural History, a number of other important vertebrate sites have been developed in the Mussentuchit Member by other institutions. Most of these sites are from the area east of Ferron and Castle Dale, Utah and include the Carol Site (figure 10), the Rough Road Quarry, Jensen's egg site, and Robison's Eggshell Quarry (Jensen, 1970; Nelson and Crooks, 1987; Pomes, 1988; Eaton and Nelson, 1991; Jones and Burge, 1995; Burge, 1996). Important collections from these sites are housed at the College of Eastern Utah Prehistoric Museum, Price, Utah; Sternberg Museum, Hays, Kansas; University of Colorado Museum, Boulder, Colorado; University of California, Museum of Paleontology, Berkeley, California; Brigham Young University, Earth Science Museum, Provo, Utah; and the Oklahoma Museum of Natural History, Norman, Oklahoma.

The most common dinosaur from the Mussentuchit Member is a primitive hadrosaurid (Kirkland and Burge, 1994; Kirkland and others, 1997). Common hadrosaurid teeth from Cedar Mountain Formation sites on the west side of the San Rafael Swell were first noted by Parrish (1991), although the locality horizon was not indicated in that abstract. The senior author has determined this primitive hadrosaurid to be somewhat like *Telmatosaurus* (Weishampel and others, 1993) from the Upper Cretaceous of eastern Europe and a bit more advanced than the iguanodontid *Probaena* (Rozhdestvensky, 1967; Norman, 1990) from the Lower Cretaceous of central Asia. More research is needed to determine its systematic position relative to the Hadrosaurinae and Lambeosaurinae (Sereno, 1986; Horner, 1990; Weishampel and Horner, 1990). However, the material discovered to date suggests lambeosaurine affinities.

Molenaar and Cobban (1991) have demonstrated through subsurface relationships that the uppermost Cedar Mountain Formation may correlate to the Mowry Shale to the northeast and may thus be of basal Cenomanian age. The Albian-Cenomanian boundary, on the basis of non-marine palynomorphs, has been placed at the first occurrence of tricolporate pollen grains (for example *Nyssapollenites*, rare in marine rocks) and oblique tetrads (Singh, 1975; Nichols and Sweet, 1993). Tschudy and others (1984) did not encounter these palynomorphs in their samples from the upper Cedar Mountain Formation near Castle Dale, Utah. The occurrence of these palynomorphs is diachronous across Alberta (Nichols and Sweet, 1993). In addition, with the older placement of the Albian-Cenomanian boundary (Cobban and Kennedy, 1989) by ammonite correlations to the type areas in Europe, it is likely that the palynomorph datum (first occurrence of tricolporate and oblique tetrad pollen) is above the base of the Cenomanian (Nichols

and Sweet, 1993).

A radiometric age estimate of 98.39 ± 0.07 million years B. P. (Cifelli, Kirkland, and others, 1997) places the fauna at, or just above, the Albian-Cenomanian boundary according to the most recent time scales for the Cretaceous, which have the boundary placed at 98.5 million years B. P. (Obradovich, 1993) or at 98.9 ± 0.6 million years B. P. (Gradstein and others, 1994). The date supports a correlation with the Mowry Shale to the northeast (figure 6).

The absence of calcareous nodules indicates that the Mussentuchit Member was deposited under a significantly wetter environment than were the lower members of the Cedar Mountain Formation. This wetter environment may be due to the transgression of the Mowry Sea into the area of the northeastern Uinta Basin (Wing and Sues, 1992). The North American plant record indicates that angiosperms were becoming a more important part of western interior floras at this time (Wing and Sues, 1992) and some of the earliest records of some angiosperm wood types are from this member (Tidwell, 1996).

A dramatic shift between Albian and middle Cenomanian faunas has been noted in Texas (Lee, 1995; Winkler and others, 1995). The new age estimates for the Mussentuchit Member indicate that this faunal turnover was even more dramatic than was previously thought. Thus, within the Cedar Mountain Formation there is a three-fold instead of a two-fold zonation of Cedar Mountain Formation based on dinosaurs (Kirkland, 1992, 1996b; Lucas, 1993): a basal Barremian iguanodont-polacanthid fauna with European affinities predating common flowering plants; a middle Aptian-middle Albian *Tenontosaurus-Pleurocoelus* fauna perhaps representing a depauperate fauna following a major Early Cretaceous extinction event (endemic to North America); and an upper latest Albian-lowest Cenomanian hadrosaur fauna with Asian affinities when flowering plants were co-dominant with gymnosperms. Biogeographic rather than floristic changes may account for most of the faunistic changes recorded at the end of the Albian as suggested by the dramatic shift to a dinosaur fauna dominated by taxa with an Asian ancestry (Kirkland, 1996b; Cifelli and others, 1997b, this volume).

CONCLUSIONS

Vertebrate fossils are present throughout the Cedar Mountain Formation of east-central Utah. It contains three distinct faunas, which are separated by intraformational unconformities. The recognition of these faunas combined with lithologic observations has permitted division of the Cedar Mountain Formation into five

members: the Buckhorn Conglomerate, the Yellow Cat Member, the Poison Strip Sandstone, the Ruby Ranch Member, and the Mussentuchit Member (Kirkland and others, 1997). Of these, only the Buckhorn Conglomerate has not yielded age-diagnostic fossils permitting its correlation with other strata.

The oldest fauna is preserved in the Yellow Cat Member and is dated as Barremian based on the occurrence of dinosaurs similar to those preserved in Barremian sediments of northwestern Europe, and based on the occurrence of charophytes not recorded in strata younger than Barremian. The middle fauna is preserved in the Poison Strip Sandstone and Ruby Ranch Member and is dated as broadly Aptian-Albian based on dinosaurs known to occur elsewhere in North America during the Aptian-Albian. The youngest fauna is preserved in the Mussentuchit Member and is precisely dated as overlapping the Albian/Cenomanian boundary at 98.39 ± 0.07 million years B. P. (Cifelli, Kirkland, and others, 1997).

The vertebrate faunas preserved in the Cedar Mountain Formation of east-central Utah provide a unique opportunity to study the transition of the terrestrial biota from an environment when angiosperms were rare until angiosperms were a major component of the flora. Additionally, these faunas record a shift from a Barremian fauna with European affinities to an Albian/Cenomanian fauna with Asian affinities. The transition from sediments largely devoid of carbonaceous material and containing abundant carbonate nodules, to sediments that are lignitic with no carbonate nodules, suggests increased rainfall in the region during the expansion of the Cretaceous Western Interior Seaway. Further research in the region is required to differentiate the relative effects of changes in the flora, climate, and biogeography on the terrestrial biota preserved in the Cedar Mountain Formation.

ACKNOWLEDGMENTS

We would like to thank the many people too numerous to count who have helped in the field, including many from the Utah Friends of Paleontology, Uncompahgre Plateau Paleontological Society, and the Western Interior Paleontological Society. Special thanks are extended to the Judd family of Castle Dale, Utah, the Jones family of Salt Lake City, Utah, the Gaston family of Knoxville, Tennessee, and the Corbett family of Raleigh, North Carolina. Robert Young of Grand Junction, Colorado is gratefully acknowledged for providing copies of his extensive field notes on the Cedar Mountain and Dakota Formations. Excavations were all undertaken under permits issued by the Bureau of Land

Management and the Utah School and Institutional Trust Lands Administration. Partial funding in support of this research was provided by the National Geographic Society (grants 4761-91 and 5021-92 to RLC; 5263-94 to JIK) and the National Science Foundation (grants BSR 8906992 and DEB 941094 to RLC). Special thanks are due to John Bird and Carl Limone, CEU Prehistoric Museum; Harold Bollan, Dinamation International Society; Randy Nydam, Oklahoma Museum of Natural His-

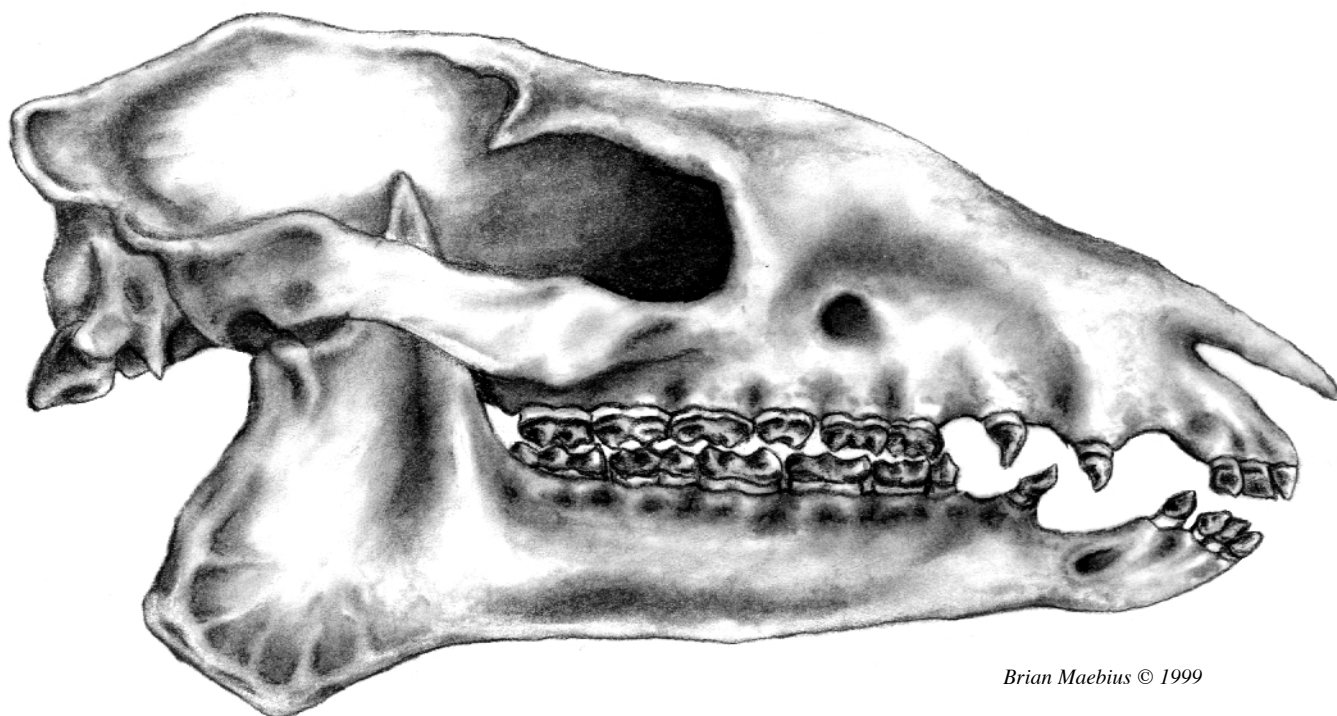
tory; Rod Scheetz, Museum of Western Colorado; Ken Stadtman, Brigham Young University; and Scott Madsen, Dinosaur National Monument for their skilled field assistance and preparation skills. Reviews of this manuscript by David D. Gillette, Louis L. Jacobs, and Mark Kirshbaum are gratefully acknowledged. Innumerable colleagues throughout our profession have aided this research with their knowledge, advice, encouragement, and camaraderie.

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