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Abstract

Rudistids are uncommon fossils in Upper Cretaceous rocks of the Western Interior of the United States. Since 1856 there have been fewer than 40 occurrences noted in the literature, many of these without descriptions or illustrations. Only six of these occurrences are from New Mexico. Therefore, the discovery of two fragments of solitary radiolitid rudistids and one fragment of a small bouquet from a sandy concretionary bed in the lower tongue of Mancos Shale in Lincoln County, New Mexico, is of some importance. Associated fossils in the concretions include the ammonites *Spathites rioensis, Morrowites depressus,* and *Collignoniceras woollgari woollgari,* placing the rudistid bed in the lower part of the middle Turonian *C. woollgari* Zone. Although specifically indeterminate, the rudistids are probably conspecific with a large rudistid bouquet composed of *Durania cornupastoris* that was described and illustrated from rocks in the same zone in the Greenhorn Limestone of Colorado.

Introduction

Rudistids (or rudists) are an extinct group of aberrant, inequivalved bivalves that were generally attached to the substrate by either the right or left valve; they could be solitary or gregarious, but not colonial. When gregarious, they could form large wave- and current-resistant structures called reefs. Since 1775 when they were illustrated for the first time, they have been classed as brachiopods, corals, cephalopods, or cirripeds. Deshayes (1825) appears to have been among the first naturalists to determine that the group belonged in the Bivalvia (Dechaseaux 1969, p. N749). In most rudistids the larger (attached) valve ranges from conical to gently curved to spirally coiled and from 2 cm to 2 m in length and 8 mm to 0.6 m in diameter. The smaller (free) valve ranges from flat to slightly convex and lidlike to conical, or coiled. In some cases the larger (free) valve was coiled and the smaller (attached) valve was conical to slightly coiled. Shell wall thickness could vary from less than 2 mm to more than 10 cm. Their geologic range extends from the Upper Jurassic to the Upper Cretaceous.

Even though Late Cretaceous marine faunas from the Western Interior of the United States are dominated by mollusks, rudistid bivalves are uncommon elements (Fig. 1), presumably because the boreal waters of the Western Interior Seaway were too cold. The lone exception is the Niobrara Formation of Kansas, where rudistids are relatively abundant (Cobban et al. 1991, p. D2). Cobban et al. (1991, pp. D2–D3) provide a summary of rudistid occurrences in the Western Interior as of 1990; this summary is updated in the Appendix. A web catalog of worldwide occurrences of rudistids can be found at **http://www.paleotax.de/rudists/locality.htm#MU.**

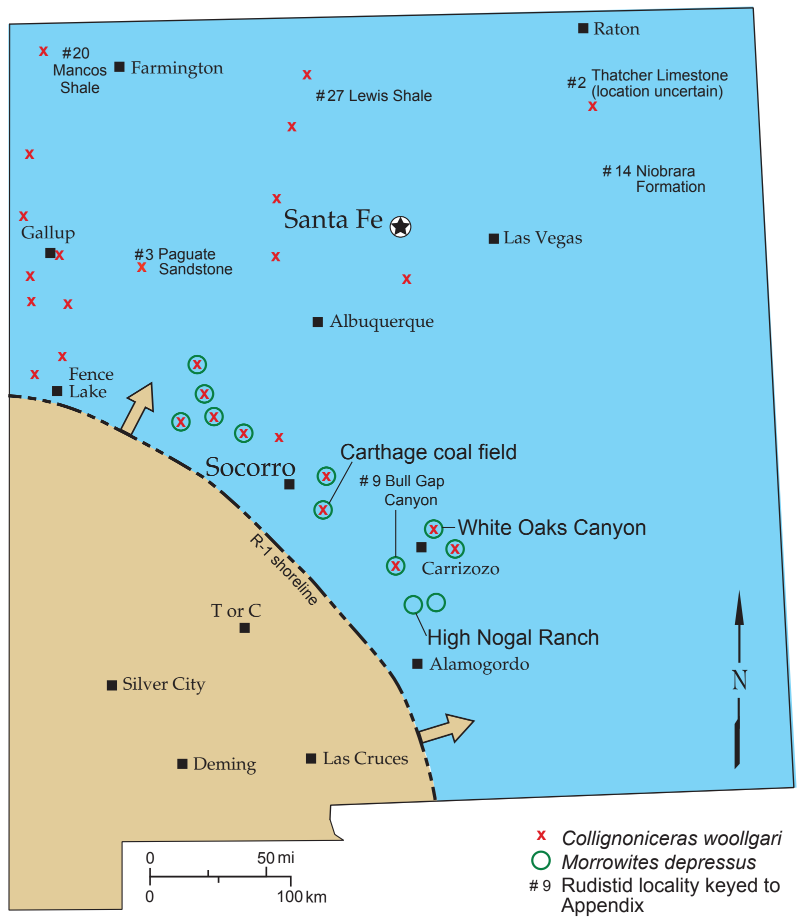

FIGURE 1—Map of New Mexico showing cities, key outcrops (including Bull Gap Canyon), and the approximate position of the regressing (R-1) western shoreline of the Late Cretaceous seaway at the beginning of time during which the ammonites *Collignoniceras woollgari* and *Morrowites depressus* lived (early–middle Turonian). The shoreline's position is shown midway between Truth or Consequences—where nonmarine strata of the Carthage Member of the Tres Hermanos Formation were being deposited— and Bull Gap Canyon—where marine strata of the lower tongue of the Mancos Shale containing the rudistid bed were being deposited. Modified from Kennedy et al. 2001, fig. 16.

Hall and Meek (1856, p. 380, pl. 1, fig. 3a-f) described the first rudist from the Western Interior from the Campanian Pierre Shale at Sage Creek, South Dakota, as the new species *Caprinella coraloidea*. At that time, it was the northernmost occurrence of a rudistid in North America. Since then, Hall and Meek's species has been reassigned to the genus *Ichthyosarcolites.* Caldwell and Evans (1963) redescribed Hall and Meek's holotype and described a Campanian specimen of *I. coraloidea* from the Bearpaw Shale of Saskatchewan, Canada, making it the northernmost rudist in the Western Interior.

Mudge (1876, p. 216) was probably the first to note the occurrence of rudists in the Cretaceous chalk of Kansas, where they are fairly abundant; Williston (1897, p. 239) referred to these beds as "Rudistes Beds." Logan (1898, p. 494, pl. 115, pl. 119, fig. 1) was the first to describe the Kansas rudists as the new species *Radiolites maximus*

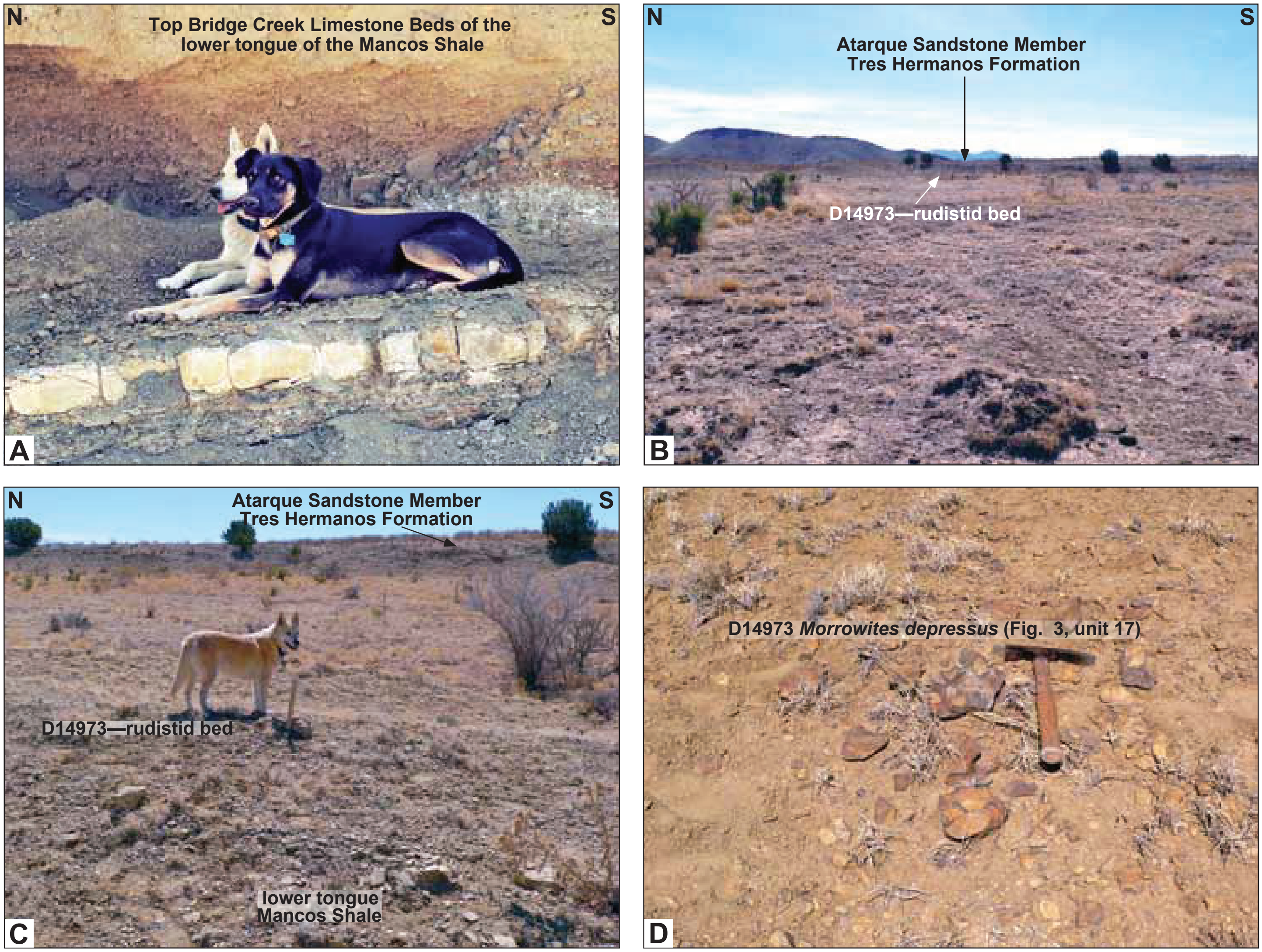

FIGURE 2—Photographic gallery of the rocks and fossils from the Bull Gap Canyon area of Lincoln County, New Mexico. **A**—Outcrop view, looking east, of the uppermost limestone of the Bridge Creek Limestone Beds of the lower tongue of the Mancos Shale exposed in the SE¼NW¼SE¼ sec. 24 T9S R9E., Bull Gap Canyon 7.5-min quadrangle, Lincoln County, New Mexico. This bed (Fig. 3, unit 10) contains the inoceramid *Mytiloides puebloense*; its base marks the boundary between the Cenomanian Stage (below) and the Turonian Stage (above). The 200 ft (61 m) of section between this bed and the sandy beds that contain the rudistid are covered everywhere in the area (see Fig. 3). Field companions Eisenhower (front) and Yeso are shown for scale. **B**—View looking east from near the top of the Bridge Creek Limestone Beds across the almost entirely covered outcrop of the upper part of the lower tongue of the Mancos Shale. High area in the near foreground on the south is held up by the Atarque Sandstone Member of the Tres Hermanos Formation. Outcrop of the sandy beds containing the rudistid support the hill and swale in the center of the photograph. This area is 0.4 mi (0.7 km) southeast of that shown in Fig. 2A in SE¼SE¼SW¼ sec. 24 T9S R9E, Bull Gap Canyon 7.5-min quadrangle, Lincoln County, New Mexico. **C**—Closer view, looking east, of the sandy interval near the top of the lower tongue of the Mancos Shale shown in Fig. 2B. Hammer and Yeso for scale on unit 17 of measured section (Fig. 3) that yielded the large solitary rudistid (Fig. 4C, D). **D**—Close-up view, looking east, of internal molds of *Morrowites depressus* that have weathered out of unit 17, the sandy concretion bed that yielded the first rudistid. Same locality as Fig. 2C.

from the Campanian Niobrara Chalk; *R. maximus* was described in more detail and illustrated by Miller (1968, pp. 37–38, pl. 4, figs. 6–8; 1970 pl. 1, fig. 2).

Since Hall and Meek's (1856) work on the Campanian of South Dakota, rudists from the Western Interior have been reported or described from every stage of the Upper Cretaceous, with occurrences in New Mexico, Arizona, Colorado, Wyoming, Montana, Kansas, and Saskatchewan (Appendix). The six occurrences in New Mexico (Fig. 1) are typical: they range in age from the Cenomanian to Santonian; the taxonomic assignment of the specimens has varied from very generalized ("rudistids") to a specific identification (*Ichthyosarcolites coraloidea*); and the documentation of the occurrence has varied from an observation, to placement in a measured section, to a description with illustration(s).

New Mexico's Upper Cretaceous rudistids

The oldest rudistid occurrence in the Western Interior is from the Thatcher Limestone Member of the Graneros Shale in northeastern New Mexico. This occurrence is in the middle Cenomanian *Conlinoceras tarrantense* Zone, indicating that the rudistids established a presence in the Western Interior soon after the Late Cretaceous seaway entered New Mexico. This was merely an observation made by W. J. Kennedy (in Cobban et al. 1991, p. D2) with no locality data and no specific determination of the rudistid.

The second oldest occurrence is from dark-brown-weathering sandstone concretions in the Paguate Tongue of the Dakota Sandstone in McKinley County at USGS Mesozoic locality D7333. The fragmentary rudistid has affinities to *Ichthyosarcolites*. Associated fossils include *Inoceramus rutherfordi*, *Ostrea beloiti*, *Acanthoceras amphibolum*, and *Turrilites acutus* (Cobban et al. 1991, p. D2). This faunal assemblage places the rudistid in the middle Cenomanian *A. amphibolum* Zone, four standard ammonite zones higher than the previous Graneros Shale specimen. See Cobban et al. (2006, fig. 1) for the standard zonal table for the Upper Cretaceous of the Western Interior.

The third oldest occurrence is from two localities in the lower tongue of the Mancos Shale at Bull Gap Arroyo, Lincoln County (Figs. 1–3). The three fragmentary specimens from USGS Mesozoic localities D14973 and D15025 are referred to cf. *Durania cornupastoris*. Associated fossils place these rudistids low in the middle Turonian *Collignoniceras woollgari* Zone, 15 standard ammonite zones above the previous Dakota Sandstone specimen. These Bull Gap rudistids will be discussed in detail in the next section of the paper.

The third youngest occurrence is from 50 ft (15 m) above the base of the lower shale unit of the Smoky Hill Shale Member of the Niobrara Formation in Colfax County. Scott et al. (1986, p. 31) report only that a rudist had been discovered. Cobban et al. (1991, p. D2) assign this oyster-encrusted specimen to *Durania* aff. *D. austinensis* from USGS Mesozoic locality D11432. Scott et al. (1986, p. 14) report *Cremnoceramus browni* from the same interval as the rudist, which places the interval in the lower Coniacian *Scaphites ventricosus* Zone, 11 standard ammonite zones above the Bull gap rudistids.

The second youngest occurrence is from 658 ft (200 m) below the top of the Mancos Shale in San Juan County. Reeside (1924, p. 11) records *Sauvagesia* cf. *S. austinensis* from the middle Santonian *Clioscaphites vermiformis* Zone, three standard ammonite zones above the previous occurrence.

The youngest occurrence in New Mexico is from 25 ft (7.6 m) below the Huerfanito Bentonite in the Lewis Shale in Rio Arriba County at USGS Mesozoic locality D13719. Fassett et al. (1997, p. 230) referred this specimen to Hall and Meek's (1856) species, *Ichthyosarcolites coraloidea*, and placed it in the upper Campanian *Didymoceras nebrascense* Zone, 18 standard ammonite zones above the previous occurrence.

Bull Gap Canyon rudistids

The three rudistid fragments collected from sandy limestone concretions in the lower tongue of the Mancos Shale south of Bull Gap Canyon, Lincoln County, New Mexico, are from two localities approximately 0.32 mi (0.51 km) apart. The largest and best preserved fragment is from USGS Mesozoic locality D14973 in the SE¼ SE¼SW¼ sec. 24 T9S R9E, Bull Gap 7.5-min quadrangle. The two smaller fragments are from the same level at USGS Mesozoic locality D15025 in the SE¼SW¼SW¼ sec. 24 T9S R9E, Bull Gap

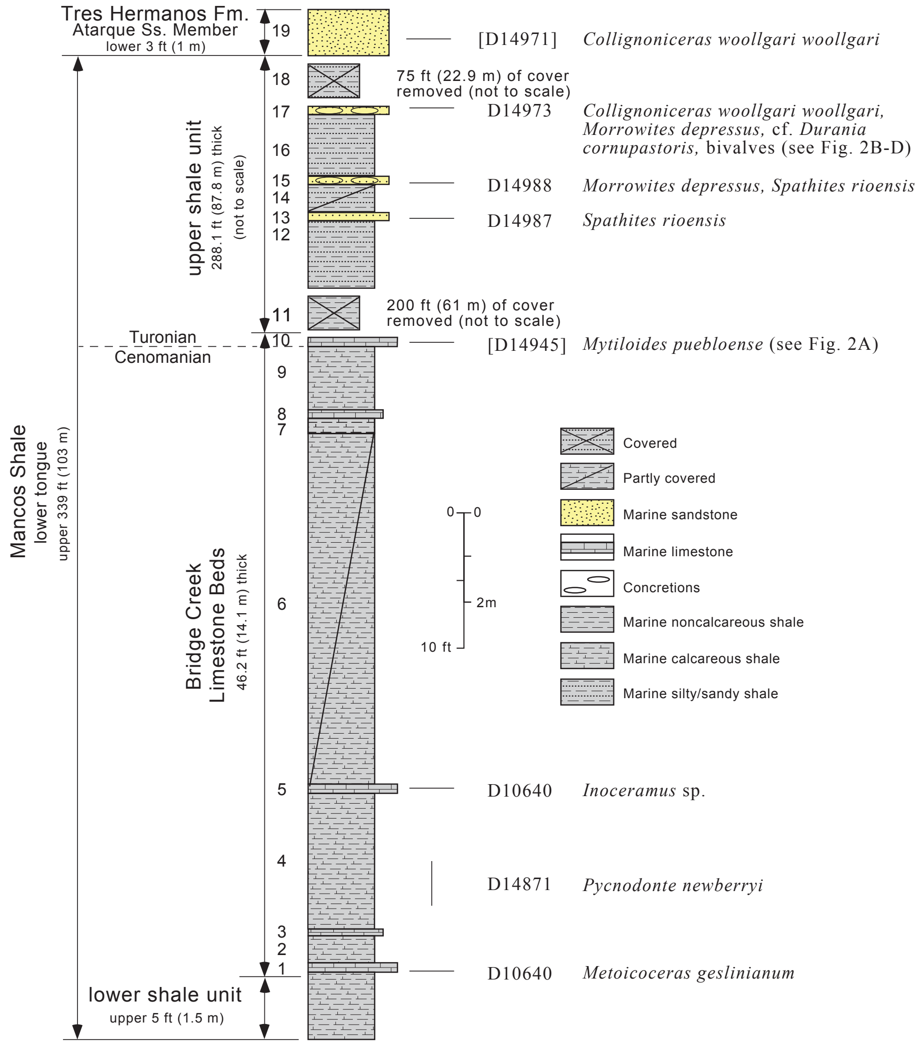

FIGURE 3—Graphic section of the upper 339 ft (103 m) of the lower tongue of the Mancos Shale showing lithology and positions of key fossil collections (collection numbers shown in [brackets] if projected into this section). The rudistid (Fig. 4C, D) was recovered from unit 17, a 6 inch- (15 cm-) thick concretionary sandstone that also yielded *Morrowites depressus* (Fig. 2D) and *Collignoniceras woollgari woollgari* (Fig. 4A, B).

7.5-min quadrangle. Geographically, locality D15025 is 0.32 mi (0.51 km) due east of D14973; geologically, it lies in the hanging wall block of a normal fault that juxtaposes the rudistid bed against the base of the Bridge Creek Limestone Beds in the footwall.

The rudistid bed at locality D14973 is 213 ft (65 m) above the top of the Bridge Creek Limestone Beds of the lower tongue of the Mancos Shale and 75 ft (23 m) below the base of the Atarque Sandstone Member of the Tres Hermanos Formation (Fig. 3). Although much of the Mancos Shale section both above and below the rudistid occurrence is covered, the section between the base of the Bridge Creek Limestone Beds and the base of the Atarque Sandstone Member of the Tres Hermanos Formation appears to be stratigraphically complete. However, reliable dip and strike measurements could be made on only the limestone beds within the Bridge Creek interval; the sandy beds containing the rudistid produced only an approximate set of measurements. The much better exposed, but lithologically and biostratigraphically similar, section at the Carthage coal field, 40 mi (65 km) to the northwest (Fig. 1; Hook et al. 2012, fig. 5), suggests that the stratigraphic interval between the base of the Bridge Creek Limestone and the base of the Atarque Sandstone Member at Bull Gap could be about 20% too great. This interval at Carthage is 275 ft (84 m), whereas at Bull Gap Canyon, it is 339 ft (103 m).

Measured section

The graphic section at Bull Gap Canyon (Fig. 3) is drawn to emphasize: (1) the relative position of the rudistid bed within the upper part of the lower tongue of the Mancos Shale; (2) the lithology and thickness of the sandy beds in which the rudistid occurs; (3) the lithology and thickness of the Bridge Creek Limestone Beds; and (4) the paleontology of this part of the lower tongue of Mancos Shale and the overlying Atarque Sandstone. At the same time, Figure 3 de-emphasizes the thickness of the two large covered intervals in the upper shale unit of 200 ft (61 m) and 75 ft (22.9 m), which together comprise not only 81% of the measured section, but also 100% of the thickness error.

Three thin, resistant, concretionary sandstones interbedded with silty shale (Fig. 3, units 13–17) form an inconspicuous hill about three-quarters of the way between the base of the Bridge Creek Limestone and the base of the Atarque Sandstone Member of the Tres Hermanos Formation (Fig. 2B). The rudistid (D14973) is in a 6 inch- (15 cm-) thick sandy concretionary bed (unit 17) at the top of this series that forms a prominent dip slope. A 200 ft- (61 m-) thick, soft, covered interval (unit 11) separates this outcrop from the top of the Bridge Creek; a 75 ft- (23 m-) covered interval (unit 18) separates it from the base of the Atarque.

The Bridge Creek Limestone Beds of the lower tongue of the Mancos Shale are 46.2 ft (14.1 m) thick and consist of five thin limestone beds interbedded with four highly calcareous shale beds (Fig. 3, units 1–10). The lowest bed (unit 1) is a hard, dense, very dark gray, almost lithographic limestone that weathers pale yellowish orange and is 8 inches (20 cm) thick. It breaks with a conchoidal fracture and forms a prominent ledge. The other limestone beds are not as hard or resistant, are a lighter gray, weather to an off white, and do not form as conspicuous an outcrop. All five limestone beds tend to pinch and swell along strike.

Surprisingly, the Bridge Creek Limestone Beds are only sparsely fossiliferous in the Bull Gap Canyon area, especially the lower four limestone beds. The hard, dense limestone at the base of the beds has yielded only one ammonite species, *Metoicoceras geslinianum* (D10640), indicative of the upper Cenomanian *Euomphaloceras septemseriatum* Zone. Only a few very small *Pycnodonte newberryi* shells (D14871) have been collected as float from the shale (unit 4) between the second and third limestones in the sequence. However, this collection constitutes the easternmost occurrence of *P. newberryi* in New Mexico. Fragments of inoceramids have been observed in the lower four limestone beds, but are specifically indeterminate, e.g., D10640 from unit 5.

The uppermost of the five limestone beds (unit 10) is quite fossiliferous in Bull Gap Canyon itself, where several very nice internal molds of the inoceramid *Mytiloides puebloense* (D14945) have been collected from an inch or so below the top of the bed. In New Mexico, *M.* *puebloense* is the most common indicator of the basal lower Turonian *Watinoceras devonense* Zone. The base of unit 10 is the Cenomanian–Turonian stage boundary; its top is the upper lithologic boundary of the Bridge Creek Limestone Beds in the area. The higher, thin calcarenites that lie in the *Mammites nodosoides* Zone and form the top of the Bridge Creek at Carthage are not present at Bull Gap. These calcarenites are either covered or, more likely, not developed at Bull Gap.

The next higher fossil in the section occurs at the base of the sandy interval that contains the rudistid. Several very well preserved internal molds of *Spathites rioensis* (D14987) have been recovered from unit 13, a 7 inch- (18 cm-) thick, light-brown-weathering, fine-grained sandstone. *Spathites rioensis* is the oldest of three chronologic species in central New Mexico and is indicative of the lower part of the lowermost middle Turonian *Collignoniceras woollgari* Zone, four standard ammonite zones higher than the *Watinoceras devonense* Zone. Fragments of the very large ammonite *Morrowites depressus* (D14988) are present with *S. rioensis* in a 6 inch- (15 cm-) thick concretionary sandstone, 2.0 ft (61 cm) higher. Approximately 4.5 ft (1.37 m) higher, the best rudistid fragment (D14973) was found in a 6 inch- (15 cm-) thick concretionary sandstone (unit 17). Associated fossils include *Collignoniceras woollgari woollgari*, *Morrowites depressus,* calcareous worm

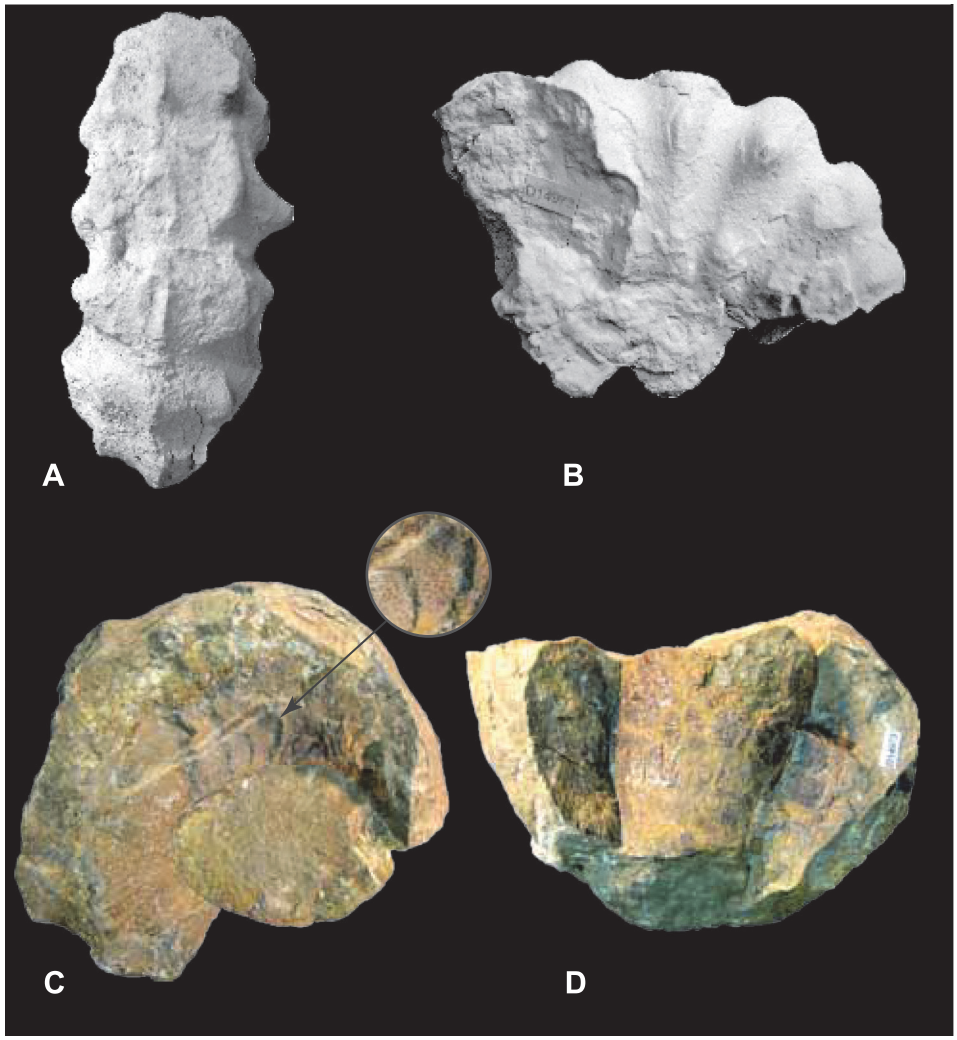

FIGURE 4—Plate of two key fossils from unit 17, a 6 inch- (15 cm-) thick concretionary sandstone that is 213 ft (65 m) above the top of the Bridge Creek Limestone Beds and 75 ft (22.9 m) below the base of the Atarque Sandstone Member (see Fig. 3). **A, B**—Top (ventral) and side views, respectively, of a whitened fragment of *Collignoniceras woollgari woollgari* (USNM 558703), X1. Top view shows the clavate keel in which there is one clavus for each set of double ventrolateral tubercles. The inner ventrolateral tubercles are bullate, and the outer tubercles are clavate. The side view reveals a moderately evolute ammonite with prosoradiate ribs that arise from bullate umbilical tubercles. **C, D**—Top and side views, respectively, of the rudistid cf. *Durania cornupastoris* (USNM 558700), unwhitened, X0.6. Top view reveals a transverse section across the rudistid showing the thick shell wall composed of polygonal cells (inset X2) and an elliptical mantle cavity that was filled with sediment. Side view reveals a fractured, irregular longitudinal section that shows the shell and mantle cavity tapering downward. The rudistid is shown unwhitened because the whitening agent obscured the telltale polygonal wall structure. Both specimens are from USGS Mesozoic locality D14973 in the SE¼SE¼SW¼ sec. 24 T9S R9E, Bull Gap Canyon 7.5-min quadrangle, Lincoln County, New Mexico.

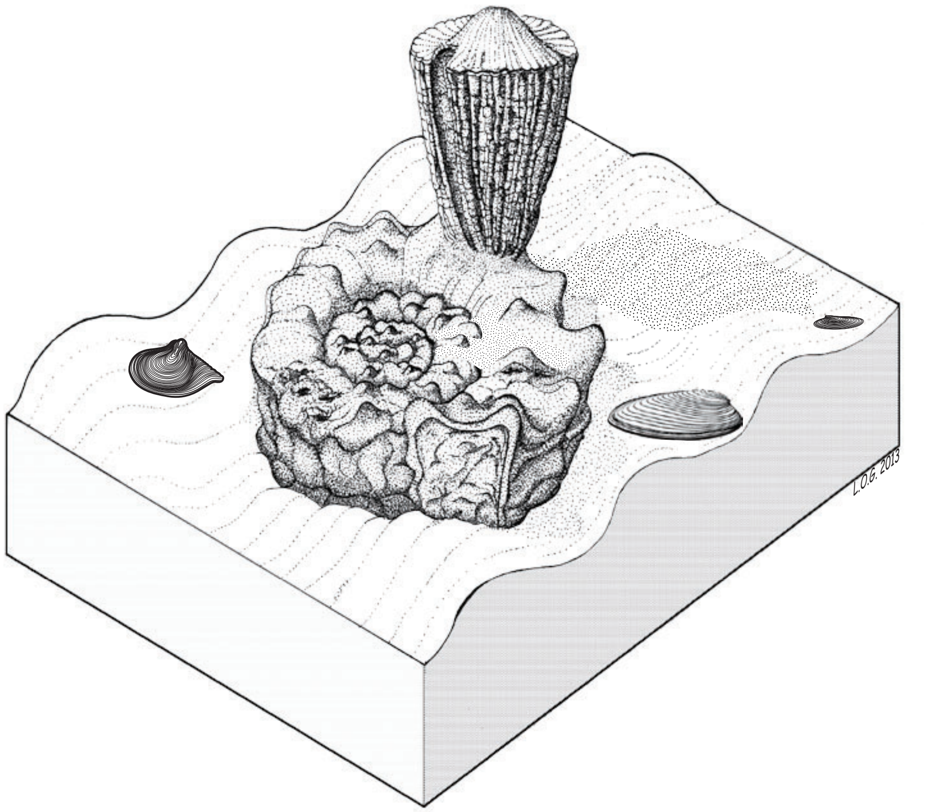

FIGURE 5—Hypothetical reconstruction of the middle Turonian (Late Cretaceous) sea floor at Bull Gap Canyon, Lincoln County, New Mexico. The lone rudistid from USGS Mesozoic locality D14973 is shown attached to an exhumed, "prefossilized " internal mold of the ammonite *Morrowites depressus*. See text (p. 18) for details. Living bivalves shown on the sea floor include the genera *Phelopteria*, *Mytiloides*, and *Cymbophora*. Rudistid is based on Kauffman and Sohl's (1979, fig. 1G) line drawing of *Durania*. Bivalves are based on drawings in Stanton (1893, pl. 9, fig. 7; pl. 14, fig. 2; and pl. 27, fig. 17). Reconstruction by Leo Gabaldon (New Mexico Bureau of Geology and Mineral Resources).

tubes, and a few fragments of large, but indeterminate bivalve internal molds. These ammonites reveal the *C. woollgari woollgari* Subzone, just as *S. rioensis* did at the base of the interval.

A 1979 collection made by the authors from this entire sandy interval (units 13, 15, and 17) contained a more diverse fauna but did not include a rudistid. Cobban (1986, p. 81) listed the following fossils from USGS locality D10643: calcareous worm tubes, *Phelopteria gastrodes*, *Mytiloides hercynicus*, *Camptonectes platessa*, *Cymbophora* sp., *Tragodesmoceras socorroense*, *Placenticeras cumminsi*, *Spathites rioensis**, *Morrowites depressus**, *Collignoniceras woollgari woollgari**, and *Baculites yokoyamai*. An asterisk indicates that Cobban (1986) illustrated a specimen from locality D10643.

A specimen of *Collignoniceras woollgari woollgari* (D14971) collected as float from the basal part of the Atarque Sandstone Member of the Tres Hermanos Formation indicates that both Atarque Sandstone and the upper part of the lower tongue of the Mancos Shale lie within the *C. woollgari woollgari* Subzone.

Systematic paleontology

Family Radiolitide
Gray 1847

Inequivalve rudistids in which the right (attached) valve is conical and the left (free) valve is operculiform; the surface of the right valve is without furrows but has two concave, flat, or convex siphonal bands separated by an interband. The ligamental ridge can be present or absent. Stratigraphic range: Lower Cretaceous (Barremian) through Upper Cretaceous (Maastrichtian).

Subfamily Sauvagesinae
Douvillé 1908

Right valve is composed of cells that are polygonal in transverse section and prismatic in longitudinal section. Stratigraphic range: Lower Cretaceous (Albian) through Upper Cretaceous (Maastrichtian).

Genus *Durania*
(Des Moulins 1826)

Type species—*Hippurites cornupastoris* Des Moulins 1826

Right valve is cylindrical but can be short or elongate; left valve is operculiform. Siphonal bands can be concave, smooth, or ribbed. The ligamental ridge is absent, but bifurcating radial furrows are present on the upper surface of the outer wall in many species. Stratigraphic range: Upper Cretaceous (Turonian–Maastrichtian). Geographic range: Europe, North Africa, Asia, South America, and North America.

cf. ***Durania cornupastoris***
(Des Moulins 1826)
Figure 4C, D

Durania cornupastoris (Des Moulins); Skelton in Cobban et al. (1991, pp. D3–D7, fig. 1, pls. 1–3)

Description—The best preserved of the three rudistid specimens from Bull Gap Canyon is a fragment of the right (attached) valve of a large solitary individual (USNM 558700) from USGS Mesozoic locality D14973 (Fig. 4C, D). The specimen appears to be conical and has an elliptical cross section with a maximum diameter of 98.6 mm, a height of 81.4 mm, and a maximum shell wall thickness of 20.9 mm. This rudistid is the nucleus of a cannonball-type concretion with a diameter of at least 100 mm. The sandy limestone concretion is broken to expose a transverse section of the rudistid, revealing the telltale polygonal structure of a sauvagesinae radiolitid (Fig. 4C). The longitudinal (radial) structures necessary to place the specimen in a genus or species are not preserved or obscured by the outer part of the concretion. The elliptical mantle cavity of the specimen, which filled with sediment after the death of the individual, has a maximum diameter of 49.6 mm and a minimum diameter of 37.2 mm.

The other two specimens (not illustrated) are of right valves of smaller individuals from USGS Mesozoic locality D15025. The solitary rudistid (USNM 558702) is preserved in a portion of a sandy limestone concretion 51 mm long by 42 mm wide by 16 mm deep. A broken surface formed within the concretion cuts across the rudistid in a transverse orientation and reveals an elliptical cross section with a maximum diameter of 18.33 mm and a minimum diameter of 15.03 mm; the shell wall is 1.33 mm thick. The second specimen (USNM 558701) is a small association of two closely spaced individuals that are preserved on the outer surface of a fragment of sandy limestone concretion that is 73 mm long by 65 mm wide by 26 mm deep. The better preserved of the two has an elliptical cross section with a maximum diameter of 20.32

mm, a minimum diameter of 15.26 mm, and a shell wall thickness of 2.01 mm. It is separated by 11 mm of matrix from the second individual. The orientation of the outer surface of the concretion relative to the rudistid makes it impossible to get exact measurements, but the two individuals are of similar size. Both individuals show polygonal structures.

No left (free) valves of rudistids have been found in the concretionary bed that yielded the right valves at Bull Gap Canyon.

Discussion—Skelton (in Cobban et al. 1991, pp. D3–D7) described a rudistid bouquet from the Greenhorn Limestone of Colorado and assigned the 28 conjoined individuals in the bouquet to *Durania cornupastoris* (Des Moulins 1826). The largest individuals in the bouquet had conical to cylindrical right valves as much as 80 mm in length. He noted (p. D5) that "The regular ribbing and the more finely ribbed radial bands of these specimens, together with their clear polygonal cell structure, immediately identify them as sauvagesinae radiolitids….The absence of any ligamentry invagination places them in the genus *Durania*….Thusfar, their classification presents no problems. Species assignment is problematical, however, because the species level taxonomy of the genus is in serious need of revision. At present, the literature is cluttered with typologically (and commonly stratigraphically) defined species, most of which deserve the oblivion of synonymy; far too many are based on small numbers of specimens, little allowance being made of the extent of intraspecific variability that might reasonably be expected in such sessile epifaunal forms by analogy with, for example, oysters."

Skelton (p. D5) felt that the Colorado specimens could have been assigned to either *Durania cornupastoris* (Des Moulins 1826) or *D. arnaudi* (Choffat 1891), which cooccur in the Turonian in Europe and form a morphological continuum. He further suggested that the two had been divided arbitrarily into two typological species that could be synonymized under the older species name, *D. cornupastoris*.

The material from Bull Gap Canyon consists of three specimens, two of which are of solitary individuals, and one in which two individuals may be part of a small bouquet. All three are not preserved well enough to show the longitudinal bands. The assignment of the Bull Gap specimens to cf. *Durania cornupastoris* is based primarily on stratigraphic occurrence in the middle Turonian *Collignoniceras woollgari* Zone and partially on overall resemblance to the material illustrated by Cobban et al. (1991, pls. 1–3). The rarity of rudistids in the Western Interior suggests very strongly that the Bull Gap Canyon occurrence is conspecific with that of the Colorado occurrence; both are in the *C. woollgari woollgari* Subzone.

Paleoecology—Radiolitid rudistids are an extinct group of sessile, filter-feeding, epifaunal bivalves with massive shells that were attached as larvae to objects on the sea floor and grew erect, perpendicular to the sea floor. They preferred shallow, warm, clear water of normal salinity and are commonly found in carbonate deposits. Although gregarious, they were not colonial. They lived as individuals and in conjoined groups that could contain a small number of individuals called bouquets or a large number of individuals called reefs.

The large size of the illustrated specimen (Fig. 4C, D) suggests that it had lived for some time, perhaps a year or so, and was attached to some large, heavy object on the sea floor. The attachment point would have been at the small end of its slightly conical shell. If it had been attached to a smaller or lighter object—such as a small ammonite's shell or clam's shell—the rudistid's high center of gravity and large surface area would have allowed currents to push it over into an unfavorable living position.

The paleogeography and stratigraphy at the measured section indicate that the rudistid lived in a nearshore environment—probably less than 35 mi (56 km) from the strand line (see Fig. 1)—on a relatively soft bottom of silty to sandy clay (Fig. 3). The relatively soft bottom conditions lead to the question of the nature of the holdfast object for a large, erect, heavy animal such as the illustrated rudistid (Fig. 4C, D). Kauffman and Sohl (1979, fig. 1) refer to *Durania* as a "…large, barrel-shaped [genus]," suggesting that it had a fairly large attachment area relative to other rudistid genera that would provide more stability on the sea floor. They (Kauffman and Sohl 1979, p. 725) state that the "…open cellular structure of the rudist shell permitted rapid growth without great expenditure of calcium carbonate, and this resulted in the construction of very large massive shells in short periods of time. Filling of these cells with fluid would have provided the necessary density to make the rudist shells stable on the sea floor as exposed epifaunal organisms."

One possibility as an attachment object is presented by the large ammonite *Morrowites depressus* (Fig. 2D; see Cobban, 1986, fig. 10 for a large specimen from the area). An oyster-encrusted internal mold of *M. depressus* was collected at USGS Mesozoic locality D15025 along with the two unfigured rudistid specimens. Hook and Cobban (1981, p. 13) interpret similar oyster-encrusted molds in New Mexico as evidence for discontinuity surfaces. The scenario they envision involves burial of the sediment-filled ammonite shell; dissolution of the aragonitic shell resulting in prefossilization of the sediment filling (internal mold); erosion of the sediment surrounding the hardened internal mold; and colonization by oysters (and, here, rudistids) of the discontinuous hardground provided by the internal mold(s), which form a lag deposit on the sea floor (Fig. 5). The mere presence of internal molds of at least two species of ammonites in this bed (Fig. 3, unit 17) indicates that their sediment-filled shells accumulated on the sea floor. Before complete burial, these shells could have acted as heavy, attachment sites for the rudistids, regardless of whether the internal molds were later prefossilized and eroded from the sediment.

Geologic occurrence—Middle Turonian lower tongue of the Mancos Shale, *Collignoniceras woollgari woollgari* Subzone of the *C. woollgari* Zone, 75 ft (22.9 m) below the base of the Tres Hermanos Formation and 213 ft (65 m) above the top of the Bridge Creek Limestone Beds of the lower tongue of the Mancos Shale.

Geographic occurrence—D14973: SE¼ SE¼ SW¼ sec. 24 T9S R9E, Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico; and D15025: SE¼SW¼SW¼ sec. 24 T9S R9E, Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico.

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Appendix

Compilation of Upper Cretaceous rudistid occurrences in the Western Interior of the United States from published records and unpublished collections housed in the USGS Mesozoic Invertebrate collections in the Denver Federal Center. These occurrences are arranged stratigraphically from lowest (no. 1) to highest (no. 37). Although rudistids are rare faunal elements in the Upper Cretaceous of the Western Interior, there is at least one occurrence from each stage. Geographically, they range from New Mexico (NM) on the south to Saskatchewan (SK), Canada, on the north. CSK = Cobban, W. A., Skelton, P. W., and Kennedy, W. J. (1991).

No.	Stage	Zone	Formation	Member/Bed	State(s)	Taxon	USGS #	Reference	Source
37	Maastrichtian	*Hoploscaphites nicolleti*	Fox Hills Sandstone	Trail City Member	SD	*Ichthyosarcolites*? sp.	---	Speden (1970, p. 157)	Same
36	Campanian	---	Niobrara Chalk	---	KS	*Radiolites maximus*	---	Logan (1898, p. 494)	CSK
35	Campanian	[upper]	Pierre Shale	---	SD	*Caprinella coraloidea*	---	Hall and Meek (1856, p. 380)	CSK
34	Campanian	lower	Niobrara Chalk	Smoky Hill Member	KS	*Durania maxima*	---	Hattin (1982, fig. 31)	CSK
33	Campanian	*Baculites compressus*?	Pierre Shale	---	CO	rudist	D88	This paper	CSK
32	Campanian	*Baculites compressus*	Pierre Shale	---	CO	*Ichthyosarcolites*? *coraloidea*	D1349	CSK (1991, p. D3)	CSK
31	Campanian	*Baculites compressus*	Bearpaw Shale	---	MT	*Ichthyosarcolites*? *coraloidea*	D3576	CSK (1991, p. D3)	new
30	Campanian	*Exiteloceras jenneyi*	Pierre Shale	Monument Hill Member	MT	*Ichthyosarcolites*? *coraloidea*	23054	CSK (1991, p. D3)	CSK
29	Campanian	*Exiteloceras jenneyi*	Bearpaw Shale	Matador Sand Member	SK	*Ichthyosarcolites*? *coraloidea*	---	Caldwell and Evans (1963)	CSK
28	Campanian	*Didymoceras stevensoni*	Bearpaw Shale	---	MT	*Ichthyosarcolites*? *coraloidea*	D2630, D3567	CSK (1991, p. D3)	new
27	Campanian	*Baculites scotti*	Lewis Shale	---	NM	*Ichthyosarcolites coraloidea*	D13719	Fassett et al. (1997, p.229)	CSK
26	Campanian	*Baculites asperiformis*	Cody Shale	Claggett Member	MT	*Ichthyosarcolites*? *coraloidea*	21214	Richards (1955, p. 61)	CSK
25	Campanian	*Baculites* sp. (weak flank ribs)	Pierre Shale	Gammon Member	MT	rudist	22177	CSK (1991, p. D3)	CSK
24	Campanian	*Scaphites hippocrepis* III	Pierre Shale	Gammon Member	MT	*Ichthyosarcolites*? *coraloidea*	23641	CSK (1991, p. D3)	CSK
23	Campanian	*Scaphites hippocrepis*	---	---	CO	*Durania*	---	Kauffman (1984, p. 295)	CSK
22	Santonian	all	---	---	CO, KS, WY	*Durania*	---	Kauffman (1984, p. 295)	CSK
21	Santonian?	---	Niobrara	Smoky Hill Member	CO	rudist	D9059	This paper	CSK
20	Santonian	*Clioscaphites vermiformis*	Mancos Shale	---	NM	*Sauvagesia* cf. *S. austinensis*	---	Reeside (1924, p. 11)	CSK
19	Santonian	*Clioscaphites saxitonianus*	---	---	KS	*Durania maxima*	---	Hattin (1982, fig. 31)	new
18	Coniacian?	"of Niobrara age"	Mancos Shale	---	CO	rudist	D7763	This paper	CSK
17	Coniacian	lower	Cody Shale	---	WY	*Durania*	D13098	CSK (1991, p. D2)	CSK
16	Coniacian	*Scaphites depressus*	Mancos Shale	---	CO	*Sauvagesia* cf. *S. austinensis*	---	Reeside (1955, p. 87)	CSK
15	Coniacian	*Scaphites ventricosus*	---	---	WY	*Durania*	---	Kauffman (1984, pp. 293-294)	CSK
14	Coniacian	*Scaphites preventricosus*	Niobrara Formation	Smoky Hill Member	NM	*Durania* aff. *D. austinensis*	D11432	Scott et al. (1986, p. 31)	CSK
13	Coniacian	---	Niobrara Formation	Smoky Hill Member	KS	*Durania maxima*	---	Hattin (1982, fig. 32)	CSK
12	Coniacian	*Cremnoceramus deformis*?	Niobrara Formation	Fort Hayes Member	CO	*Durania niobrarensis* *	---	Griffitts (1949, pp. 471-472)	CSK
11	Coniacian	*Cremnoceramus deformis*	Niobrara Formation	Fort Hayes Limestone	CO	*Durania*	D6051-52	CSK (1991, p. D2)	CSK
10	Turonian	*Scaphites mariasensis*?	Niobrara Formation	Fort Hayes Limestone	CO	rudist	D3467	CSK (1991, p. D2)	CSK
9	Turonian	*Collignoniceras woollgari*	Mancos Shale	lower tongue	NM	cf. *Durania cornupastoris*	D14973, D15025	This paper	CSK
8	Turonian	*Collignoniceras woollgari*	Greenhorn Limestone	Bridge Creek Member	CO	*Durania cornupastoris*	---	CSK (1991, p. D2)	new
7	Turonian	*Collignoniceras woollgari*	Greenhorn Formation	Bridge Creek Limestone	CO	*Durania cornupastoris**	D11226	CSK (1991, p. D3-D7)	CSK
6	Cenomanian	upper?	Greenhorn Limestone	Bridge Creek Member	CO	*Sauvagesia*?	---	Dane et al. (1937, p. 214)	CSK
5	Cenomanian	middle	---	---	CO	radiolitid rudistids	---	Kauffman (1984, p. 291)	CSK
4	Cenomanian	*Euomphaloceras septemseriatum*	Mancos Shale	---	AZ	aff. *Sauvagesia*	D9019	CSK (1991, p. D2)	CSK
3	Cenomanian	*Acanthoceras amphibolum*	Dakota Sandstone	Paguate Tongue	NM	aff. *Ichthyosarcolites*	D7333	CSK (1991, p. D2)	CSK
2	Cenomanian	*Conlinoceras tarrantense*	Graneros Shale	Thatcher Limestone	NM	rudistids	---	observed	CSK
1	Cenomanian	*Conlinoceras tarrantense*	Graneros Shale	Thatcher Limestone	CO	radiolitid	---	Kauffman (1985, p.95)	CSK