Cretaceous stratigraphy and biostratigraphy, east-central New Mexico

Spencer G. Lucas, Barry S. Kues, and Adrian P. Hunt
2001, pp. 215-220. https://doi.org/10.56577/FFC-52.215

in:

Geology of Llano Estacado, Lucas, Spencer G.;Ulmer-Scholle, Dana; [eds.], New Mexico Geological Society 52nd Annual Fall Field Conference Guidebook, 340 p. https://doi.org/10.56577/FFC-52

This page is intentionally left blank to maintain order of facing pages.

CRETACEOUS STRATIGRAPHY AND BIOSTRATIGRAPHY, EAST-CENTRAL NEW MEXICO

SPENCER G. LUCAS[1], BARRY S. KUES[2] AND ADRIAN P. HUNT[3]
[1]New Mexico Museum of Natural History, 1801 Mountain Rd. NW, Albuquerque, NM 87104; [2]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; [3]Mesalands Dinosaur Museum, Tucumcari, NM 88401

Abstract.—Cretaceous strata exposed in east-central New Mexico belong to the (in ascending order) Tucumcari, Mesa Rica, Pajarito, Romeroville, Graneros and Greenhorn formations. The Mesa Rica, Pajarito and Romeroville formations are the Dakota Group in this region. The Tucumcari Formation is as much as 25 m thick and is mostly marine shale and minor bioturbated sandstone and limestone. The Mesa Rica Sandstone is mostly cross bedded and ripple laminated quartzarenite as much as 43 m thick. The Pajarito Formation is as much as 30 m thick and is mostly silty mudstone and bioturbated quartzarenite. The Romeroville Sandstone is <10 m of bioturbated and cross bedded quartzarenite. The Graneros Shale is as much as 67 m of shale, and the Greenhorn Formation consists of the Lincoln (up to 34 m of shale and calcarenite), Hartland (up to 11 m of shale and bentonite) and Bridge Creek (up to 9 m of limestone and shale) members. We document a specimen of the late Albian ammonite *Mortoniceras leonense* from the lower Mesa Rica Sandstone. The Tucumcari, Mesa Rica and Pajarito formations are of late Albian age, whereas the Romeroville, Graneros and (most of) the Greenhorn formations are of Cenomanian age. The youngest Cretaceous strata preserved in east-central New Mexico are early Turonian beds of the upper part of the Bridge Creek Member of the Greenhorn Formation.

INTRODUCTION

Cretaceous strata exposed in east-central New Mexico (Fig.1) are mostly rocks of Early Cretaceous (late Albian) age and a few outliers of early Late Cretaceous age. First studied in 1853 by Marcou, these strata have been more intensively studied since the 1970s. Here, we review their lithostratigraphy and biostratigraphy.

LITHOSTRATIGRAPHY

Cretaceous strata in east-central New Mexico belong to the following formations (in ascending order): Tucumcari, Mesa Rica, Pajarito, Romeroville, Graneros and Greenhorn (Fig. 2). The Mesa Rica, Pajarito and Romeroville formations are the Dakota Group in east-central New Mexico. Here, we summarize the lithostratigraphy of these units.

Tucumcari Formation

Marcou (1889) first used the term "Tucumcari Beds" to refer to the strata at Pyramid Mountain southwest of Tucumcari (sec. 19, T9N, R29W) where he collected the type specimens of "*Gryphaea dilatata* var. *tucumcarii*" (= *Texigryphaea pitcheri*) (Marcou, 1855, 1858). Lucas and Kisucky (1988) designated this the type section of the Tucumcari Formation (Shale). At the type section, the Tucumcari Formation is ~9 m thick and is mostly olive-gray to yellowish-brown silty mudstone and shale with minor beds of yellowish-brown and yellowish-orange, muddy bioturbated sandstone (Lucas and Kisucky, 1988; Kues and Lucas, 2001). Another minor lithotype of the Tucumcari Formation is dark yellowish-brown, fossiliferous limestone.

These lithotypes characterize the Tucumcari Formation throughout its outcrop belt in east-central New Mexico. Maximum thickness is ~25 m, and the Tucumcari Formation everywhere rests disconformably on the Upper Jurassic Morrison Formation. Locally, a 1-2 m thick bed of sandstone at the base of the Tucumcari Formation is the Campana Sandstone Bed of Holbrook et al. (1987). The Mesa Rica Sandstone conformably to disconformably overlies the Tucumcari Formation throughout east-central New Mexico.

Outcrops of the Tucumcari Formation form a short, often covered, slope beneath cliffs of the Mesa Rica Sandstone. The Tucumcari Formation is present throughout much of Quay County and extends into adjacent parts of Guadalupe County.

Mesa Rica Sandstone

The most conspicuous Cretaceous unit in east-central New Mexico is the Mesa Rica Sandstone, which forms bold cliffs that cap the edges of the Llano Estacado and its northerly erosional

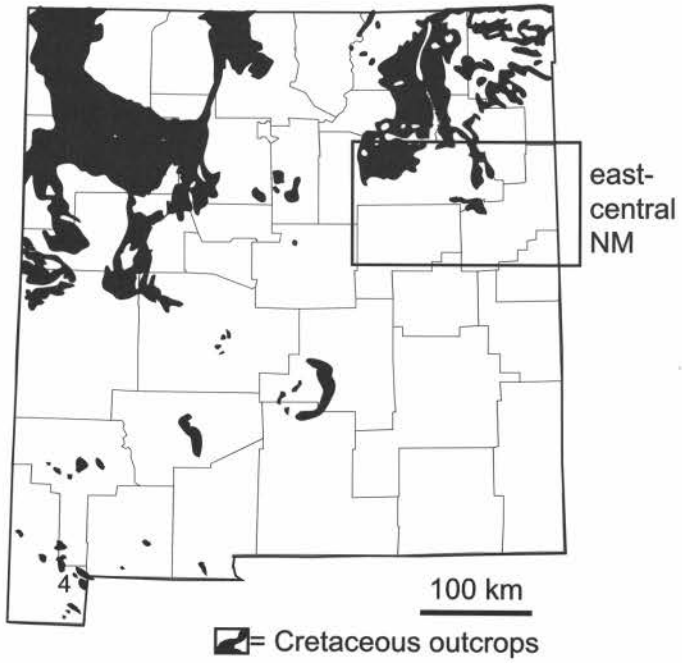

FIGURE 1. Distribution of Cretaceous strata in New Mexico (after Dane and Bachman, 1965) and location of east-central New Mexico.

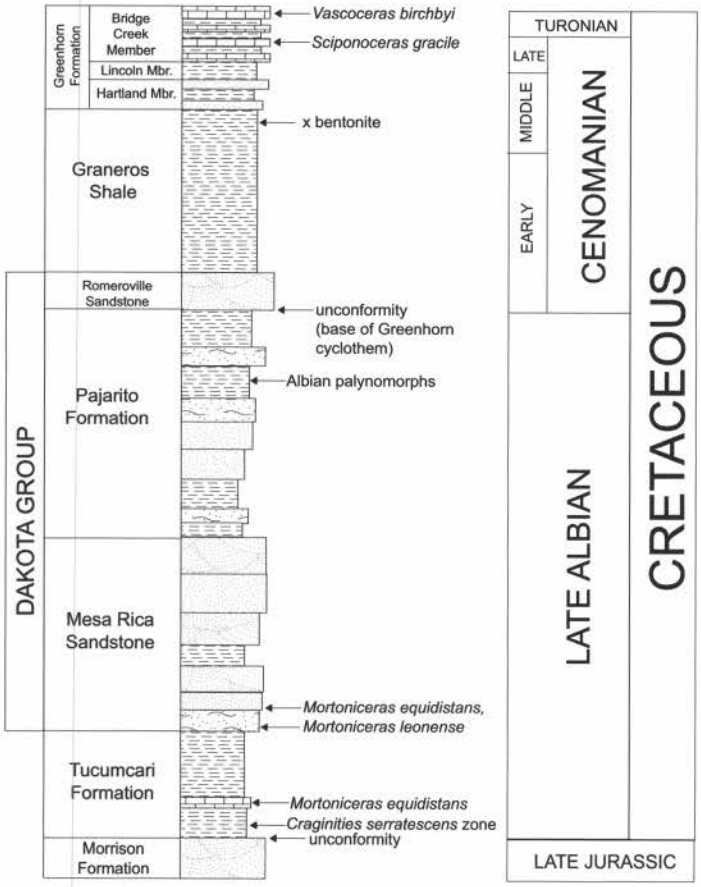

FIGURE 2. Generalized Cretaceous stratigraphic section in east-central New Mexico, key biostratigraphic indicators and age assignments.

outliers in the Canadian River drainage, such as Mesa Redonda, Tucumcari Mountain and Liberty Mesa in Quay County and Mesa Rica in Quay and Guadalupe Counties. It also forms bold cliffs along the edge of the Canadian escarpment from San Miguel to Harding Counties..

Dobrovolny and Summerson (in Dobrovolny et al., 1946) named the Mesa Rica Sandstone, and Lucas and Kisucky (1988) designated and described a type section on the southwestern face of Mesa Rica (sec. 5, T11N, R26E) in eastern Guadalupe County. Several workers earlier referred to the Mesa Rica Sandstone informally as the lower sandstone member (unit) or lower braided alluvial interval of the Dakota Group (Sandstone) (e.g., Bejnar and Lessard, 1976; Gilbert and Asquith, 1976; Stone, 1984).

At its type section, the Mesa Rica Sandstone is 24.5 m thick and consists of two sandstone intervals separated by light-gray and purple, variegated mudstone. The sandstones are yellowish-brown and yellowish-orange, very fine- to fine-grained quartzarenites that are trough cross bedded, ripple-laminated and laminated with some minor bioturbation. Maximum thickness of the Mesa Rica Sandstone is 43 m, and throughout east-central New Mexico its lithotypes are similar to those of the type section.

The Mesa Rica Sandstone grades upward into the Pajarito Formation. However, the placement and nature of its basal contact has been the subject of some disagreement. Normally, the contact between the Mesa Rica and underlying Tucumcari Formation is readily placed at the sharp contact of the Mesa Rica basal sandstone bed on the uppermost shale bed of the Tucumcari Formation. However, at San Jon hill, south of San Jon in the roadcuts of NM Highway 39 (sec. 19, T9N, R31E and vicinity), a 5.6-m thick, massive-to-laminar sandstone full of shell debris is at the contact of the Tucumcari and Mesa Rica formations. Largely because the fossils from this sandstone are both abundant (normally, the Mesa Rica Sandstone is sparsely fossiliferous) and mostly represent the same taxa present in underlying strata of the Tucumcari Formation (see below), several workers have assigned this sandstone to the Tucumcari Formation (Griggs and Read, 1959; Scott, 1970, 1974; Mateer, 1985, 1987). However, formations are cartographic units having contacts mapped at points of significant lithologic contrast. Therefore, as advocated by Lucas and Kisucky (1988), we include this fossiliferous sandstone at San Jon Hill in the Mesa Rica Sandstone.

Pajarito Formation

Dobrovolny and Summerson (in Dobrovolny et al., 1946) introduced the name Pajarito Shale. Lucas and Kiscuky (1988) designated and described a type section just south of Mesa Rica in the Pajarito Creek drainage of western Quay County (sec. 6, T11N, R29E) and also described a reference section that well exposes the top of the Pajarito Formation along a tributary of Burro Creek in Harding County (sec. 8, T18N, R27E).

At the type section, the Pajarito is at least 29 m thick and consists of interbedded yellowish-orange and brown, quartzose, generally bioturbated sandstone and light-gray silty mudstone. The formation is as much as 30 m thick in east-central New Mexico and forms a slope, or ribbed cliff, between the Mesa Rica Sandstone and the overlying Romeroville Sandstone. The Pajarito Formation is the middle shale member (unit) or meanderbelt interval of the Dakota Sandstone (Group) of some previous workers (Bejnar and Lessard, 1976; Gilbert and Asquith, 1976; Stone, 1984). The contact of the Romeroville Sandstone above the Pajarito Formation is a disconformity.

Romeroville Sandstone

Kues and Lucas (1987) and Lucas and Kisucky (1988) used the term Romeroville Sandstone to refer to the upper unit of the Dakota Group in northeastern New Mexico, and Lucas (1990) formally defined the unit. Dobrovolny et al. (1946) referred to this unit as the Dakota Sandstone, and it was the upper sandstone member (unit) or marine sand interval of the Dakota Sandstone (Group) of some earlier workers (Bejnar and Lessard, 1976; Gilbert and Asquith, 1976; Stone, 1984).

At its type section at Romeroville Gap near Las Vegas, San Miguel County, the Romeroville Sandstone is 3.5 m thick and consists of pale orange and dark yellowish-orange, trough cross bedded and bioturbated (esp. *Ophiomorpha*), quartzarenite sandstone. A thickness of <10 m is characteristic of the Romeroville Sandstone throughout east-central New Mexico. The Romero-

ville Sandstone has a sharp, scoured base, so it overlies the Pajarito Formation with evident disconformity. Indeed, locally, the Romeroville Sandstone is absent, and the Graneros Shale rests directly on the Pajarito Formation (Lucas et al., 2000).

Graneros Shale

Outside of the Raton basin, outcrops of post-Romeroville Upper Cretaceous strata are rare in east-central New Mexico. This is because Neogene erosion associated with deposition of the Ogallala Group has removed most of the post-Romeroville Cretaceous section. The exceptions to this are Upper Cretaceous outliers near Roy in Harding County (T20N, R25-26E) and in the Bonita fault zone southeast of Tucumcari in Quay County (T8N, R32E, and T9N, R33E) (Dobrovolny et al., 1946; Wanek, 1962; Lucas et al., 2000; Lucas and Heckert, 2001).

At the sections near Roy, the Graneros Shale is poorly exposed, and has an estimated thickness of 20 m. The Graneros Shale is much better exposed in Quay County, where it is ~67 m thick and consists mostly of dark gray, light brownish-gray and grayish-orange shale. Subordinate rock types are a few thin (<0.3 m thick) beds of calcarenite, siltstone and air fall bentonitic ash. The Graneros Shale forms slopes and low, rolling hills in east-central New Mexico. It conformably overlies the Romeroville Sandstone or disconformably overlies the Pajarito Formation where the Romeroville is absent. The Greenhorn Formation conformably overlies the Graneros Shale.

Greenhorn Formation

The youngest Cretaceous strata preserved in east-central New Mexico are assigned to the Upper Cretaceous Greenhorn Formation. Greenhorn strata overlie the Graneros outcrops near Roy in Harding County and in the Bonita fault zone of Quay County (Dobrovolny et al., 1946; Wanek, 1962; Lucas et al., 2000; Lucas and Heckert, 2001).

Three Greenhorn members are present in east-central New Mexico: (1) the basal, Lincoln Member is a few persistent ledges of calcarenite and slopes of calcareous shale, 34 m thick in the Bonita fault zone, but only 8.3 m thick near Roy; (2) the medial Hartland Member is bentonitic shale with three distinctive bentonite beds, 9 m thick in the Bonita fault zone and 11 m thick near Roy; and (3) the upper, Bridge Creek Member is interbeds of ledge-forming limestone and medium-gray calcareous shale, at least 4.1 m thick near Roy and at least 9 m thick in the Bonita fault zone. The Ogallala Group rests directly on the Bridge Creek Member at both locations and the uppermost beds of the Bridge Creek Member have been eroded away, so its thickness is a minimum.

BIOSTRATIGRAPHY

Tucumcari Formation

The Tucumcari Formation, in its main outcrop belt in Quay and eastern Guadalupe Counties, contains two, biostratigraphically distinct marine assemblages (Kues, 1997; Kues and Lucas, 2001). The basal assemblage from San Jon hill includes a late occurrence of the oyster *Ceratostreon texanum* (Roemer), and is succeeded slightly higher by the lowest occurrence of *Peilinia levicostata* Kues, an interval equivalent to the upper Albian *Craginites serratescens* zone of Young (1967). Brand and Mattox (1972) reported a fragmentary specimen of *C.* cf. *C. serratescens* (Cragin) from the basal Tucumcari at San Jon Hill, but we have not collected specimens of this ammonite. Older Albian strata, some containing *Texigryphaea navia* (Hall) and ammonites of the *Adkinsites bravoensis* zone, are present in Lower Cretaceous outliers in Roosevelt County, New Mexico (Kues, 1986), and in some of the playa lake exposures of west-central Texas discussed by Brand (1953).

The stratigraphically higher assemblage that occurs in the Tucumcari Formation, and above the basal assemblage at San Jon hill, is probably entirely within the *Mortoniceras equidistans* zone. Young (1967) and Cobban (1985) noted that in many areas of Texas, *M. equidistans* (Cragin) occurs with *Eopachydiscus marcianus* (Shumard), but extends higher in the section than that species. However, Young (1967, table 4) identified only the *M. equidistans* zone above the *C. serratescens* zone within the Tucumcari Formation, and this appears to us to be correct. Although *E. marcianus* (and its synonym *E. laevicaniculatum* [Roemer in Lasswitz]) have been reported from the Tucumcari Formation (Kues et al., 1985), separate zones for *E. marcianus* and *M. equidistans* cannot be distinguished. *M. equidistans* is present near the base of the Tucumcari Formation at Pyramid Mountain (Kues and Lucas, 2001), and co-occurs with *E. marcianus* as high as the basal unit of the overlying Mesa Rica Sandstone (Cobban, 1985, pl. 1). The Tucumcari Formation therefore is of early late to middle late Albian age (Fig. 2).

Mesa Rica Sandstone

Most of the Mesa Rica Sandstone represents a south-southeasterly prograding fluvio-deltaic complex (Holbrook and Dunbar, 1992). Only the lower part of the Mesa Rica Sandstone yields marine fossils that are of biostratigraphic significance, and these are indicative of the upper Albian *Mortoniceros equidistans* zone. *Mortoniceras equidistans* is found in the basal Mesa Rica Sandstone at several localities (Kues et al., 1985; Cobban, 1985; Lucas and Hunt, 2000), and a bivalve-dominated assemblage that shares most taxa with the underlying Tucumcari Formation is present in the lowermost sandstone bed of the Mesa Rica Sandstone at San Jon hill (Kues, 2001).

Here, we document a specimen of *Mortoniceras leonense*, MDM 212, from the basal Mesa Rica Sandstone just south of Tucumcari in T10N, R29E (Fig. 3). This specimen is moderately evolute, has a squarish whorl section and sparse ribs and a diameter of 250 mm. The 17 widely spaced ribs are rectiradiate and have strong nodate ventrolateral tubercles and somewhat weaker umbilical tubercles. The ventral keel becomes weak on the outer whorl. The specimen well matches but is much larger than specimens Cobban (1987) referred to *M.* aff. *M. leonense* from the Mojado Formation in southwestern New Mexico.

This fossil is an important addition to knowledge of the morphology of *M. leonense*. Conrad (1857, p. 160, pl. 16, figs. 2a-b)

introduced the taxon as *Ammonites leonense*, from Leon Springs, just west of the present town of Fort Stockton, Pecos County, Texas. Adkins (1927, p. 43, pl. 5, fig. 4) provided the only published photograph of the holotype and established its stratigraphic provenance as upper Albian, Duck Creek-equivalent beds. Early authors assigned the species to *Pervinquieria* (a junior synonym of *Mortoniceras*: Wright et al., 1996) or to *Schloenbachia* (valid species of which are not known from North America: Wright et al., 1996) and reported it from the Duck Creek and overlying Fort Worth formations of Texas and Oklahoma. Adkins (1928, p. 231) pointed out that many of the Fort Worth records (e.g., Adkins and Winton, 1919; Bullard, 1925, 1926; Winton, 1925) actually are of *Pervinquieria maxima* Lasswitz (now *Mortoniceras* (*Angolaites*) *maximus*: Kennedy et al., 1998, p. 29). Slocki (1967, p. 195) and McGill (1967, p. 228) reported *Mortoniceras leonense* as a common species in the Fort Worth Formation in northeastern Texas, but it is not certain if their specimens are true *M. leonense* or *M.* (*A.*) *maximus*. Cobban (1987) referred *Ammonites leonense* to *Mortoniceras* (it belongs in the subgenus *Mortoniceras*: Cobban, 1987; Wright et al., 1996).

The holotype of *M. leonense* illustrated by Conrad (1857) and redescribed by Cobban (1987, p. 8) was said by Adkins (1928, p. 230) to be a weathered "cast" (steinkern) of a relatively small specimen, probably a juvenile. The umbilical area is covered by matrix, and no sutures are preserved. The specimen has a diameter of ~ 83 mm, an umbilical ratio of 0.43, sparse, rectiradiate ribs, prominent ventrolateral and umbilical tubercles and a squarish cross section. The inner whorl of MDM 212 is very similar to the holotype, with a diameter of 92 mm, and an umbilical ratio of 0.44. The suture line of the Mesa Rica *M. leonense* is characteristic of *Mortoniceras* (e.g., Young, 1957; Cobban, 1987; Wright et al., 1996; Kennedy et al., 1998) in having deeply incised lobes and saddles with a broad E/L saddle, a narrow and deep L and a massive U2 (Fig. 3). However, the saddles are not bifid as in most other *Mortoniceras*, though L is irregularly trifid.

Mortoniceras leonense has been reported in faunal lists of the Tucumcari Formation by several authors (see Kues et al., 1985), but it has not been adequately documented by descriptions or illustrations. Its co-occurrence with *M. equidistans* in the basal Mesa Rica Sandstone is not surprising in view of the fact that Adkins (1927, p. 44) reported that it occurs with *M. equidistans* and two other *Mortoniceras* species (*M. whitei*, *M. kiliani*) now considered synonyms *of M. equidistans* (Cobban, 1985) at its type locality in West Texas. Although the basal Mesa Rica Sandstone is clearly in the *M. equidistans* range zone, its upper part lacks marine fossils, so its precise age relative to late Albian ammonite zones cannot be determined. However, it is likely that the entire Mesa Rica Sandstone encompasses no more that the upper part of the *M. equidistans* zone and succeeding *M.* (*Angolaites*) *lasswitzi* zone, given the apparent latest Albian age of the overlying Pajarito Formation (Fig. 2).

Pajarito Formation

The most common fossils in the Pajarito Formation are ornithopod dinosaur tracks (see Hunt and Lucas, 1998, for a review), but they do not provide a basis for a precise age assignment. Baltz (1990) reported Albian palynomorphs from the Pajarito Formation, and the presence of the marine bivalve *Peilinia levicostata* (reported as *Lopha quadriplicata* by Dobrovolny et al., 1946) in the Pajarito is also consistent with a late Albian age (Kues, 1997). Therefore, we assign the entire Pajarito Formation a late Albian age (Fig. 2).

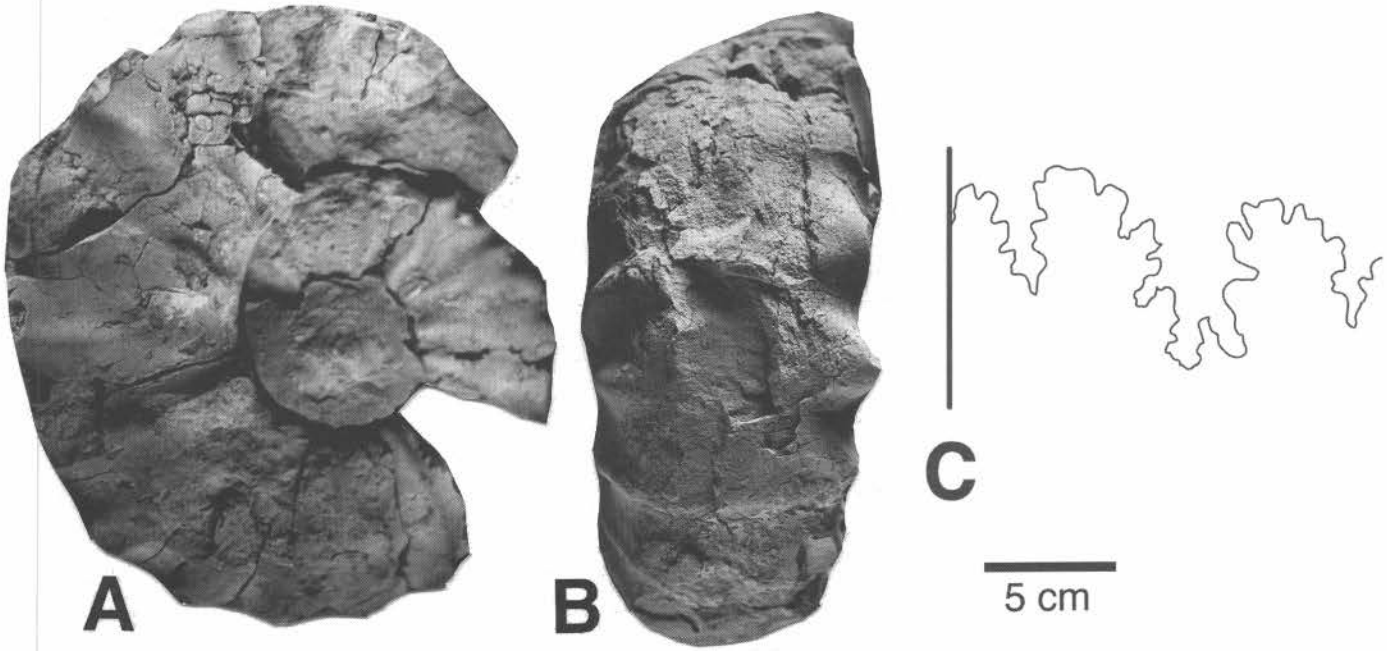

FIGURE 3. *Mortoniceras leonense* (Conrad) from the lower part of the Mesa Rica Sandstone south of Tucumcari, Quay County, MDM 212, lateral (A) and venter (B) views and suture line.

Romeroville Sandstone

No fossils of biostratigraphic significance are known from the Romeroville Sandstone. It disconformably overlies the upper Albian Pajarito Formation and is conformably overlain by the early Cenomanian Graneros Shale. Furthermore, the Romeroville Sandstone is the basal transgressive unit of the Greenhorn cyclothem of marine flooding of the Western Interior basin (Lucas, 1990; Lucas et al., 1998). Thus, it is most likely that the Romeroville Sandstone is of earliest Cenomanian age (Fig. 2).

Graneros Shale

No fossils of biostratigraphic value have been collected from the Graneros Shale in east-central New Mexico. Therefore, its age must be based on data from nearby Graneros sections in the Raton basin of northeastern New Mexico (Kauffman et al., 1969). These data indicate the Graneros Shale encompasses much of the lower Cenomanian-to lower middle Cenomanian interval of the "*Inoceramus" bellvuensis* through *Acanthoceras bellense* zones (also see Kauffman et al., 1993). Therefore, we assign an early to early middle Cenomanian age to the Graneros Shale in east-central New Mexico (Fig. 2).

Greenhorn Formation

Fossils from the Lincoln Member of the Greenhorn Formation in east-central New Mexico are shark's teeth and the characteristic small oyster *Ostrea beloiti* Logan (Lucas et al., 2000; Lucas and Heckert, 2001). No fossils are known from the Hartland Member, and ammonites and inoceramids are documented from the Bridge Creek Member (Lucas et al., 2000; Lucas and Heckert, 2001). These fossils are consistent with regional data that indicate the Lincoln, Hartland and lower Bridge Creek members are late Cenomanian in age, whereas the upper Bridge Creek member is early Turonian (e.g., Kennedy et al., 2000). At Roy, the youngest Bridge Creek bed is in the early Turonian zone of *Vascoceras birchbyi*, and in the Bonita fault zone, it is apparently the same age.

ACKNOWLEDGMENTS

Orin Anderson and William A. Cobban provided helpful comments on the manuscript.

REFERENCES

Adkins, W. S., 1927, The geology and mineral resources of the Fort Stockton quadrangle: University of Texas, Bulletin 2738, 166 p.

Adkins, W. S., 1928, Handbook of Texas Cretaceous fossils: University of Texas, Bulletin 2838, 385 p.

Adkins, W. S., and Winton, W. M., 1919, Paleontological correlation of the Fredericksburg and Washita formations in north Texas: University of Texas, Bulletin 1945, 128 p.

Baltz, E. H., 1990, Palynomorphic evidence of the age of Dakota Sandstone at Montezuma, New Mexico: New Mexico Geological Society, 41st Field Conference, Guidebook, p. 96.

Bejnar, C.R., and Lessard, R.H., 1976, Paleocurrents and depositional environments of the Dakota Group, San Miguel and Mora Counties, New Mexico: New Mexico Geological Society, 27th Field Conference, Guidebook, p. 157-163.

Brand, J. P., 1953, Cretaceous of Llano Estacado of Texas: Bureau of Economic Geology, Report of Investigations 20, 59 p.

Brand, J. P., and Mattox, R. B., 1972, Pre-Dakota Cretaceous formations in northwestern Texas and northeastern New Mexico: New Mexico Geological Society, 23rd Field Conference, Guidebook, p. 98-104.

Bullard, F. M., 1925, Geology of Love County, Oklahoma: Oklahoma Geological Survey, Bulletin 33, 77 p.

Bullard, F. M., 1926, Geology of Marshall County, Oklahoma: Oklahoma Geological Survey, Bulletin 39, 101 p.

Cobban, W. A., 1985, The Lower Cretaceous ammonite *Schloenbachia leonenis* Conrad var. *equidistans* Cragin: U.S. Geological Survey, Bulletin 1641-A, 4 p.

Cobban, W. A., 1987, Ammonite faunas of the Sarten Sandstone (Cretaceous), Luna County, New Mexico: U. S. Geological Survey, Bulletin 1641-B, 17 p.

Conrad, T. A., 1857, Descriptions of Cretaceous and Tertiary fossils; *in* Emory, T A., Report on the United States and Mexican boundary survey, made under the direction of the Secretary of the Interior: U. S. 34th Congress 1st Session, Senate Executive Document 108, p. 141-174.

Dane, C. H., and Bachman, G. O., 1965, Geologic map of New Mexico: U.S. Geological Survey, scale 1:500,000.

Dobrovolny, E., Summerson, C. H., and Bates, R. L., 1946, Geology of northwestern Quay County, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Preliminary Map 62, scale 1:62,500.

Gilbert, J. L., and Asquith, G. B., 1976, Sedimentology of braided alluvial interval of Dakota Sandstone, northeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 150, 16 p.

Griggs, R. L., and Read, C. B., 1959, Revisions in stratigraphic nomenclature in Tucumcari-Sabinoso area, northeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 43, p. 2003-2007.

Holbrook, J. M., and Dunbar, R. W., 1992, Depositional history of Lower Cretaceous strata in northeastern New Mexico: Implications for regional tectonics and depositional sequences: Geological Society of America Bulletin, v. 104, p. 802-813.

Holbrook, J. M., Wright, R., and Kietzke, K. K., 1987, Stratigraphic relationships at the Jurassic-Cretaceous boundary in east-central New Mexico: New Mexico Geological Society, 38th Field Conference, Guidebook, p. 161-165.

Hunt, A. P., and Lucas, S. G., 1998, Tetrapod ichnofaunas from the Lower Cretaceous of northeastern New Mexico, USA: New Mexico Museum of Natural History and Science, Bulletin 14, p. 163-167.

Kauffman, E.g., Powell, J. D., and Hattin, D. E., 1969, Cenomanian-Turonian facies across the Raton basin: The Mountain Geologist, v. 6, p. 93-118.

Kauffman, E.g., Sageman, B. B., Kirkland, J. I., Elder, W. P., Harries, P. J., and Villamil, T., 1993, Molluscan biostratigraphy of the Cretaceous Western Interior basin, North America: Geological Association of Canada, Special Paper 39, p. 397-434.

Kennedy, W. J., Walaszczyk, I., and Cobban, W. A., 2000, Pueblo, Colorado, USA, candidate global boundary stratotype section and point for the base of the Turonian Stage of the Cretaceous, and for the Middle Turonian substage, with a revision of the Inoceramidae (Bivalvia): Acta Geologica Polonica, v 50, p. 295-334.

Kennedy, W. J., Cobban, W. A., Gale, A. S., Hancock, J. M., and Landman, N. H., 1998, Ammonites from the Weno Limestone (Albian) in northeast Texas: American Museum Novitates, no. 3236, 46 p.

Kues, B. S., 1986, Paleontology and correlation of a Lower Cretaceous (Albian) outlier in Roosevelt County, New Mexico: New Mexico Geology, v. 8, p. 88-94.

Kues, B.S., 1997, New bivalve taxa from the Tucumcari Formation (Cretaceous, Albian) New Mexico, and the biostratigraphic significance of the basal Tucumcari fauna: Journal of Paleontology, v. 71, p. 820-839.

Kues, B. S., 2001, Late Albian marine invertebrate fauna from the basal Mesa Rica Sandstone at San Jon Hill, New Mexico: New Mexico Geological Society, 52nd Field Conference, Guidebook.

Kues, B. S., and Lucas, S. G., 1987, Cretaceous stratigraphy and paleontology in the Dry Cimarron Valley, New Mexico, Colorado, and Oklahoma: New Mexico Geological Society, 38th Field Conference, Guidebook, p. 167-198.

Kues, B. S., and Lucas, S. G., 2001, Fauna of nearshore sandy facies of the Tucumcari Formation (Lower Cretaceous, Albian), Quay County, New Mexico: New Mexico Geological Society, 52nd Field Conference, Guidebook.

Kues, B. S., Lucas, S. G., Kietzke, K. K., and Mateer, N. J., 1985, Synopsis of Tucumcari Shale, Mesa Rica Sandstone and Pajarito Shale paleontology, Cretaceous of east-central New Mexico: New Mexico Geological Society 36th Field Conference, Guidebook, p. 261-281.

Lucas, S. G., 1990, Type and reference sections of the Romeroville Sandstone (Dakota Group), Cretaceous of northeastern New Mexico: New Mexico Geological Society, 41st Field Conference, Guidebook, p. 323-326.

Lucas, S. G., and Heckert, A. B., 2001, Stratigraphy and biostratigraphy of an Upper Cretaceous outlier near Roy, Harding County, New Mexico: New Mexico Geological Society, 52nd Field Conference, Guidebook.

Lucas, S.G., and Hunt, A.P., 2000, The Lower Cretaceous ammonite *Mortoniceras equidistans* (Cragin) from the Mesa Rica Sandstone, Quay County, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 16, p. 97-100.

Lucas, S. G., and Kisucky, M. J., 1988, Type and reference sections of the Tucumcari, Mesa Rica and Pajarito formations, Cretaceous of east-central New Mexico: New Mexico Geology, v. 10, p. 82-89.

Lucas, S. G., Anderson, O. J., and Estep, J. W., 1998, Stratigraphy and correlation of Middle Cretaceous rocks (Albian-Cenomanian) from the Colorado Plateau to the Southern High Plains, north-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 14, p. 57-66.

Lucas, S. G., Estep, J. W., Pence, R., and Hunt, A. P., 2000, Upper Cretaceous outlier in Quay County, New Mexico: Stratigraphy and biostratigraphy: New Mexico Museum of Natural History and Science, Bulletin 16, p. 121-127.

Marcou, J., 1855, Résumé éxplicatif d'une carte geologique des Etats-Unis et des provinces ánglaisés de l'Amerique du Nord, avec un profil géologique allant de la Vallée du Mississippi aux côtes du Pacifique et une planche des fossiles: Société Géologique de France Bulletin, Series 2, v. 12, p. 813-936.

Marcou, J., 1858, Geology of North America, with two reports on the prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California, originally made for the United States Government. Zurich, Zürcher and Furrer, 144 p.

Marcou, J., 1889, American Neocomian and Chalk of Arkansas: American Geologist, v. 4, p. 357-367.

Mateer, N. J., 1985, Pre-Graneros Cretaceous stratigraphy of northeastern New Mexico: New Mexico Geological Society, 36th Field Conference, Guidebook, p. 243-246.

Mateer, N. J., 1987, The Dakota Group of northeastern New Mexico and southern Colorado: New Mexico Geological Society, 38th Field Conference, Guidebook, p. 223-236.

McGill, D. W., 1967, Washita Formation, north Texas, correlated to Georgetown Limestone, central Texas; *in* Hendricks, L., ed., Comanchean (Lower Cretaceous) stratigraphy and paleontology of Texas: Permian Basin Section SEPM, Publication 67-8, p. 219-239.

Scott, R. W., 1970, Stratigraphy and sedimentary environments of Lower Cretaceous rocks, southern Western Interior: American Association of Petroleum Geologists Bulletin, v. 54, p. 1225-1244.

Scott, R. W., 1974, Bay and shoreface communities in the Lower Cretaceous: Lethaia, v. 7, p. 315-330.

Slocki, S. F., 1967, Physical stratigraphy of the Georgetown Limestone equivalents in Tarrant, Denton, and Cooke Counties, Texas; *in* Hendricks, L., ed., Comanchean (Lower Cretaceous) stratigraphy and paleontology of Texas: Permian Basin Section SEPM, Publication 67-8, p. 183-216.

Stone, W. J., 1984, Dakota aquifer system in New Mexico; *in* Jorgenson, D. G., and Signor, D. C.,eds., Geohydrology of the Dakota aquifer: National Water Well Association, Proceedings of the C.V. Theis Conference, Oct. 5-6, 1982, p. 62-68.

Wanek, A. E., 1962, Reconnaissance geological map of parts of Harding, San Miguel, and Mora Counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map OM-208.

Winton, W. M., 1925, The geology of Denton County: University of Texas, Bulletin 2544, 86 p.

Wright, C. W., Calloman, J. H. and Howarth, M. K., 1996, Treatise on Invertebrate Paleontology Part L Mollusca 4: Boulder and Lawrence, Geological Society of America and University of Kansas, 302 p.

Young, K., 1957, Upper Albian (Cretaceous) Ammonoidea from Texas: Bureau of Economic Geology, Report of Investigations 28, 33 p.

Young, K., 1967, Ammonite zonations, Texas Comanchean (Lower Cretaceous); *in* Hendricks, L., ed., Comanchean (Lower Cretaceous) stratigraphy and paleontology of Texas: Permian Basin Section SEPM, Publication 67-8, p. 65-70.