An anomalously large Exogyra from the Paguate Sandstone Tongue of the Dakota Sandstone (Cretaceous, middle Cenomanian)

Barry S. Kues and Orin J. Anderson

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New Mexico Bureau of Geology & Mineral Resources
New Mexico Institute of Mining & Technology
801 Leroy Place
Socorro, NM 87801-4796

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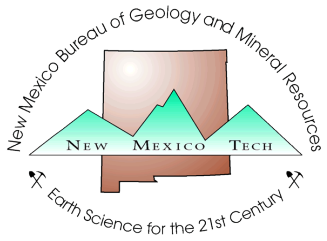

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An anomalously large *Exogyra* from the Paguate Sandstone Tongue of the Dakota Sandstone (Cretaceous, middle Cenomanian)

by *Barry S. Kues*, Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131-1116
and *Orin J. Anderson*, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

Abstract

A large, thick-shelled specimen of *Exogyra*, measuring 165 mm in height, from the Paguate Sandstone Tongue, is described and illustrated. This specimen, which is much larger than any oyster previously reported from the middle Cenomanian intertongued Dakota–lower Mancos sequence in New Mexico, is morphologically similar to *Exogyra whitneyi*, an early Cenomanian Tethyan (Texas, southern New Mexico) species. The presence of *E. whitneyi* or a closely related species in the Paguate Tongue is surprising because marine connections between southern and west-central New Mexico were absent from middle-early to middle-middle Cenomanian time and because no large exogyras of this type are known from this interval anywhere in the surrounding areas. The Paguate specimen possibly represents the separate, rapid evolutionary development of a small population of *E. whitneyi*-like oysters from an unknown ancestor in west-central New Mexico, rather than a relict population of *E. whitneyi* or an immediate descendant that migrated in from the Tethyan province to the south.

Introduction

The intertongued upper Dakota–lower Mancos sequence is well exposed and fossiliferous at many localities in west-central and northwestern New Mexico, and its faunas are diverse and well known (e.g., Cobban, 1977; Cobban and Hook, 1989). Ammonite biostratigraphy indicates that deposition of this sequence occurred during most of middle Cenomanian and the beginning of late Cenomanian time, from the *Conlinoceras tarrantense* through *Calycoceras canitaurinum* zones. Of the several Dakota–Mancos tongues and members in this sequence, the Paguate Tongue of the Dakota Sandstone contains the greatest diversity of marine invertebrates, with more than 60 molluscan species reported (Cobban and Hook, 1989). Recently, one of the authors (OA) discovered a specimen of an unusually large *Exogyra*, previously unknown in this sequence, in a Paguate outlier in southwestern Cibola County, New Mexico. This specimen is noteworthy not only because of its size but also because its affinities appear to be with a species, *Exogyra whitneyi* Böse, that is confined to early Cenomanian strata in Texas and southern New Mexico. We describe this specimen (11966, University of New Mexico paleontology collections) here and discuss some of the paleogeographic questions raised by its presence in the Paguate Sandstone Tongue.

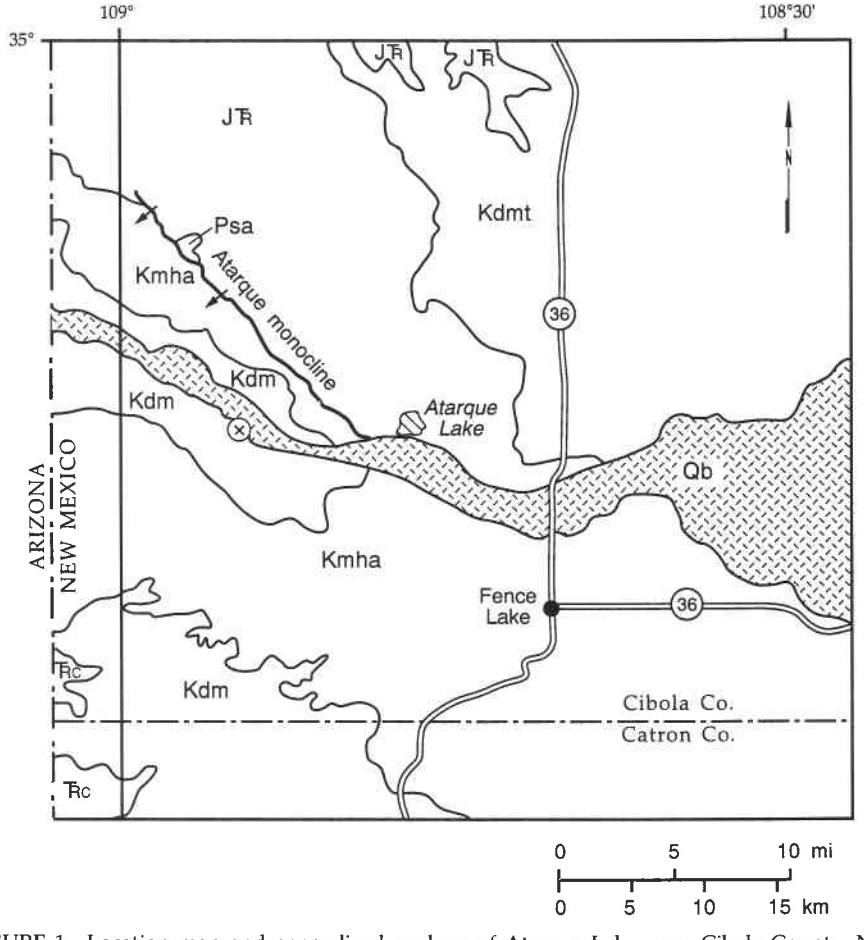

FIGURE 1—Location map and generalized geology of Atarque Lake area, Cibola County, New Mexico. ⊗ marks locality where UNM-11966 was collected from the Paguate Tongue of the Dakota Sandstone. **Psa**, San Andres Limestone; **JR**, Jurassic and Triassic rocks (Entrada Sandstone and Chinle Group); **Kdm**, intertongued upper Dakota–lower Mancos Shale; **Kmha**, Moreno Hill Formation and Atarque Sandstone; **Kdmt** designates area to the northeast with more complex stratigraphy that includes the Tres Hermanos Formation; **Qb**, Jaralosa Draw lobe of North Plains basalt flow. Tertiary sedimentary units not shown. Base map from Dane and Bachman, 1965.

Stratigraphy

The units of the intertongued Dakota–Mancos sequence were initially named in the Laguna area, northeastern Cibola County, by Landis et al. (1973). Cobban (1977) summarized and illustrated the diverse fauna. Hook et al. (1980) extended this terminology into the southern Zuni Basin, and it has been used subsequently in mapping and coal-resource evaluation work by McClellan et al. (1983), Anderson (1987), and Campbell (1989). Small, isolated outcrops of the Paguate Tongue occur in the area west of Atarque Lake (Fig. 1), both north and south of the Jarolosa Draw lobe of the North Plains basalt field (Anderson, 1987). The Paguate has been identified in this area, in the Venadito Camp quadrangle, on the basis of stratigraphic position (above the lowest part of the Mancos Shale and below the Whitewater Arroyo Shale Tongue of the Mancos Shale), as well as by its concretionary lithology and characteristic molluscan fauna locally. The specimen discussed here was collected from the middle of the Paguate Tongue at an isolated outlier (Fig. 2) in the SE¼SE¼ sec. 11 T6N R20W, Cibola County, about 8 mi (13 km) east of the New Mexico–Arizona border. Abundant specimens of *Exogyra levis* Stephenson and *Pycnodonte* cf. *P. kellumi* (Jones) occur in the upper part of the Paguate at this outcrop (Fig. 3). The Paguate fauna in this area is restricted to the *Acanthoceras amphibolum* ammonite zone, approximately in the middle part of the middle Cenomanian stage (Cobban and Hook, 1989).

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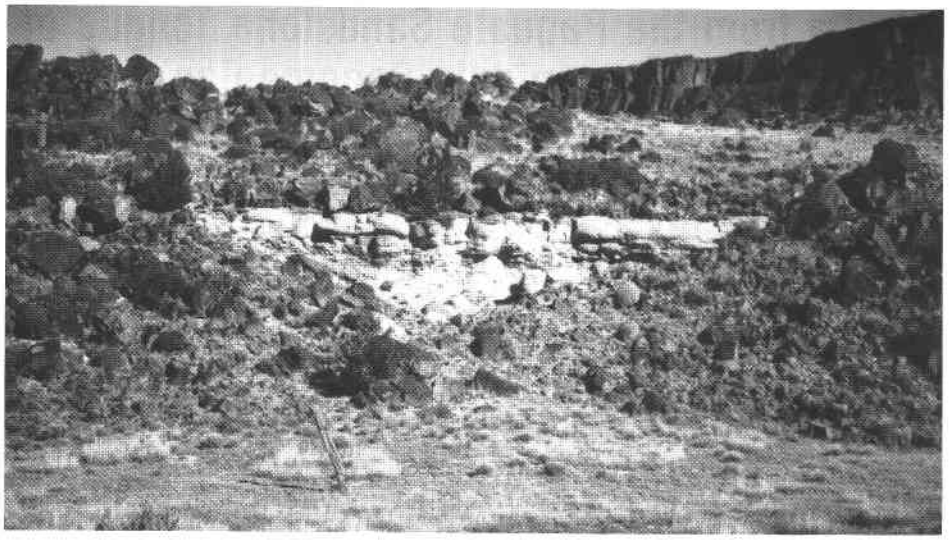

FIGURE 2—View to northwest of outcrop of Paguate Tongue (the light-colored unit). Specimen of *E.* cf. *E. whitneyi* was collected from transitional unit at base of blocky, spheroidal weathering unit in upper part of exposure. Talus and colluvium are derived from overlying Quaternary basalt flow (Jaralosa Draw lobe of North Plains basalt flow).

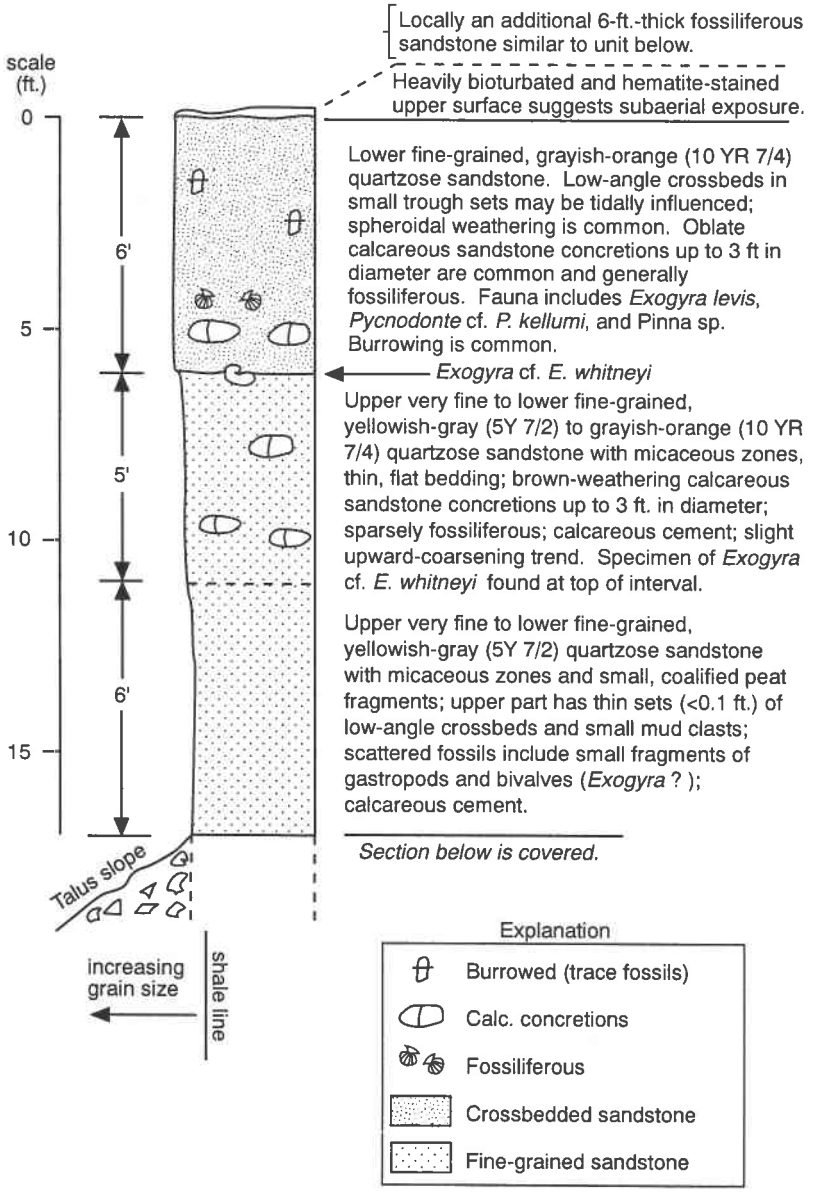

FIGURE 3—Measured section of Paguate Tongue, SE¼SE¼ sec. 11 T6N R20W, Cibola County, New Mexico (measured by O. Anderson, Sept. 1993).

Description of specimen

UNM-11966 (Figs. 4A, C, D) is an articulated specimen displaying most of the left (larger) valve, with the right valve present but almost completely covered with matrix. The surface of the left valve is severely worn and extensively perforated with holes and canals of boring sponges, thus obscuring surficial details of the valve. The specimen is approximately 165 mm high; restoration of missing portions of the ventral margin suggests an original height of 175⁺ mm. Estimated original length is 115 mm and width is approximately 70 mm. The left valve is thick and massive. The beak is inflated, gently coiled against the posterodorsal valve surface, and is strongly inclined, such that it approximately parallels and slightly overhangs the hingeline. The outer surface of the beak is depressed rather than convex, suggesting a 40-mm-long attachment scar. In lateral profile, the valve surface is moderately and evenly convex from beak to ventral margin, with the maximum valve width slightly above midheight. In dorsal (beak up) view (Fig. 4D), the profile from anterior to posterior margin is strongly convex, flattening slightly across the umbonal midline. Valve ornamentation is poorly preserved, but examination of the less-worn valve surfaces yielded no indication of significant radial ribbing and slight suggestion of lamellate growth lines.

Taxonomic discussion

The fauna of the Paguate and related tongues of the upper Dakota–lower Mancos sequence in west-central New Mexico has been well summarized and illustrated by Cobban (1977) and Cobban and Hook (1989). No exogyras of this size and form have been documented from these units, nor from coeval strata to the southeast in Lincoln County (Cobban, 1986). The largest Paguate exogyras, *E. trigeri* (Coquand) and *E.* cf. *E. oxyntas* (Coquand), only rarely attain a height of 100 mm. Typical specimens of *E. trigeri* possess a left valve of low convexity, with prominent lamellate growth lines (e.g., Cobban, 1977, pl. 17, figs. 7–10), that differs considerably from the much larger, more convex specimen

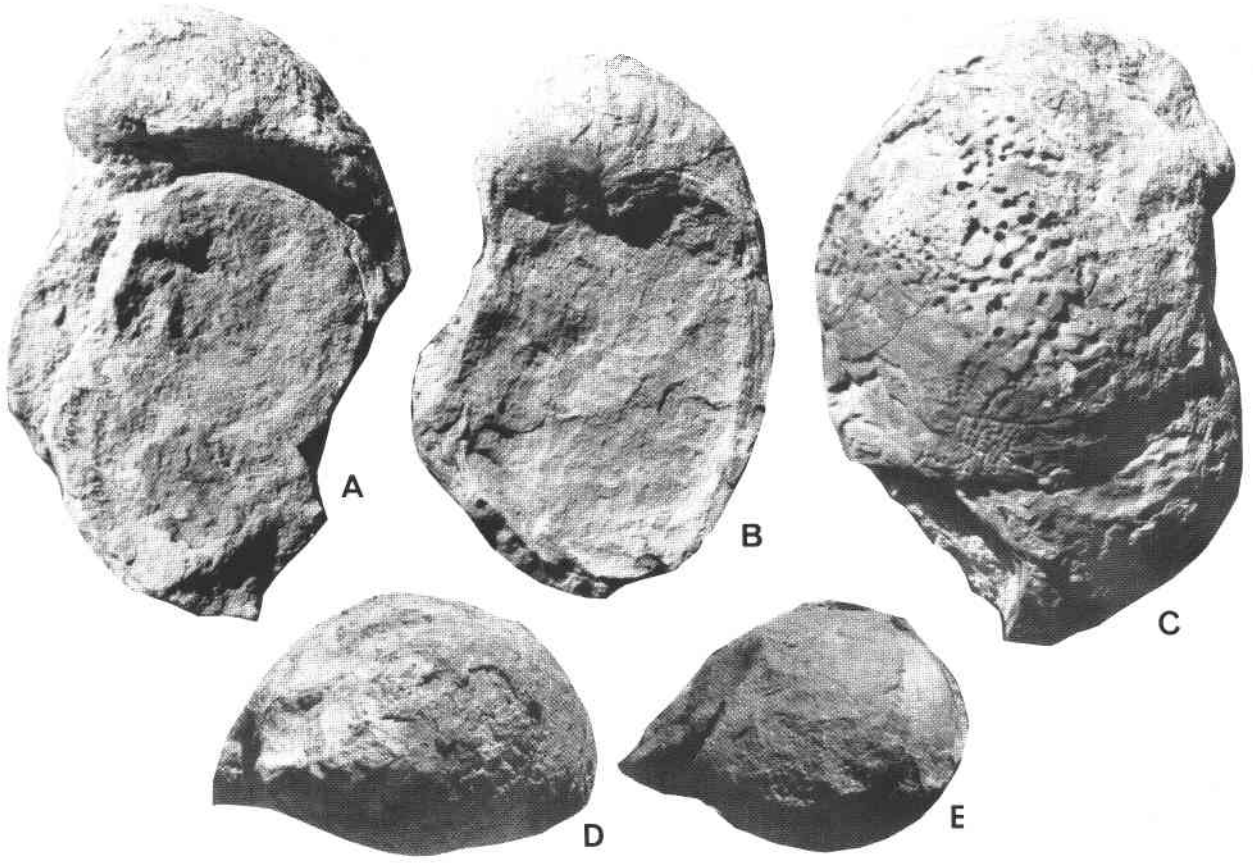

FIGURE 4—*Exogyra* cf. *E. whitneyi* (UNM 11966; Paguate Sandstone Tongue, Cibola County), and *E. whitneyi* (UNM 11971; Del Rio clay, Cerro de Cristo Rey); all × 0.5. **A, C, D,** *E.* cf. *E. whitneyi,* right (**A**), left valve exterior (**C**) and dorsal (**D**) views. **B, E,** *E. whitneyi,* right (**B**) and dorsal (**E**) views.

discussed here. *E.* cf. *E. oxyntas* has prominent, closely spaced radial costae. Cobban (1977, p. 20) did note specimens with "very massive thick shells that are much distorted by large attachment scars" in the Whitewater Arroyo Shale Tongue overlying the Paguate Tongue, and he suggested that they might be unusual representatives of *E. trigeri.* Possibly these specimens are conspecific with UNM-11966; if so, however, it is very doubtful that this taxon is an aberrant form of *E. trigeri,* given the differences noted above. Specimens identified by Cobban (1977, pl. 9, figs. 12–20) as *E. trigeri* from the Paguate Tongue in northwestern Catron County, near the Atarque Lake locality, appear to be somewhat more convex and less lamellate than typical specimens. However, these Paguate specimens differ significantly from UNM-11966 in having a less-convex and more-lamellate left valve, with a smaller beak, and in attaining only one-third its size. A relatively large, unornamented, convex species from the Cubero Sandstone Tongue (below the Paguate) was identified by Cobban (1977, pl. 5, figs. 23–28) as *E.* sp. A. Compared to UNM-11966, *E.* sp. A has a much smaller, less-curved beak, a more symmetrical profile along the principal growth axis of the valve, and a more strongly arched left valve; it is also less than half as large as UNM-11966.

Two species of *Exogyra* from the Cenomanian of the Western Interior–Texas area attain the unusually large size, thick valves, and general valve proportions of UNM-11966, but neither has been reported from the middle Cenomanian. The first is *E. forresteri,* which Reeside (1929) established as a variety of *E. olisiponensis* Sharpe, the same taxonomic rank he accorded *E. oxyntas,* now considered a separate species. This species group occurs in strata in Utah that are significantly younger than the Paguate Tongue (Cobban, 1977), in the upper Cenomanian ammonite zone of *Metoicoceras mosbyense* (Kauffman et al., 1978; Cobban, 1984, p. 80). Cobban's tentative identification of *E.* cf. *E. oxyntas* in the Paguate and Whitewater Arroyo Tongues suggests that *E. oxyntas,* at least, ranges into the middle Cenomanian in west-central New Mexico. Of these species, which typically display well-developed radial ribs, only *E. forresteri* attains exceptionally large sizes, and it is further characterized by a reduction in the size and extent of the radial ribs (Reeside, 1929). However, the left valve of *E. forresteri* is considerably wider relative to height (width/height = 0.60; see Reeside, 1929, pl. 69, fig. 4) than is true of UNM-11966, and maximum convexity is attained rather abruptly about one-third of the distance from the beak to the ventral margin. The left valve of UNM-11966 has a width/height ratio of 0.41 and is more gently convex, with maximum width at about mid-height. *E. forresteri* also has a more acutely convex antero-posterior profile whereas UNM-11966 is more broadly convex. This specimen, though strongly worn, lacks even residual evidence of radial ribs, suggesting that such ribs were very subdued or lacking on the valve before it was worn. Because of these differences, we do not believe that UNM-11966 is conspecific with *E. forresteri,* or with its smaller, more highly ribbed relatives, *E. oxyntas* and *E. olisiponensis.*

A second species bearing on the identity of the Paguate specimen is *E. whitneyi* Böse. This southern (Tethyan) species is known only from strata of early- to middle-early Cenomanian age in Texas and southern New Mexico. Böse (1910) originally described this species, as *E. ponderosa* var. *clarki* (in part), from what are now named the upper Anapra and Del Rio formations at Cerro de Cristo Rey and illustrated a specimen about 190 mm high (Böse, 1910, pl. 23, fig. 17; pl. 24, fig. 6; pl. 25, fig. 8). Later, Böse (1919) named the species *E. whitneyi,* and other specimens were described and illustrated by Adkins (1928) and Stanton (1947). Cobban (1987) reported it in the upper nodular zone of the Sarten Sandstone in the Cooke's Range, southwestern New Mexico, which he equated with the Buda ☞

Limestone, which overlies the Del Rio Formation at Cerro de Cristo Rey and in Texas. Lucas et al. (1988, figs. 7N, Q) illustrated examples of *E. whitneyi* from the same interval of the Sarten in the Cooke's Range. Comparison of UNM-11966 with specimens of *E. whitneyi* from the Del Rio Formation of Cerro de Cristo Rey and upper Sarten Sandstone of the Cooke's Range reveals many similarities in addition to large size. The left valve of *E. whitneyi* lacks radial ribs and displays only muted growth lamellae, similar to the inferred ornamentation of the Paguate specimen. Further, the curvature and orientation of the beak, width/height relationships, and curvature and convexity proportions of *E. whitneyi* closely resemble those of UNM-11966. In many specimens of *E. whitneyi*, the beak is either somewhat more prominent and extended than in the Paguate specimen or is distorted by large attachment scars along its outer surface. *E. whitneyi* appears to be slightly narrower (i.e. the left valve length/height ratio is smaller) than UNM-11966. A typical example of *E. whitneyi* from the Del Rio Formation at Cerro de Cristo Rey is illustrated (Figs. 4B, E) for comparison with the Paguate specimen. Based on morphological similarities, the Paguate specimen is most closely related to, if not conspecific with, *E. whitneyi*, although better specimens, with unworn external valve surfaces, are required from the Paguate Tongue for definite identification. Here, we refer UNM-11966 to *E.* cf. *E. whitneyi*.

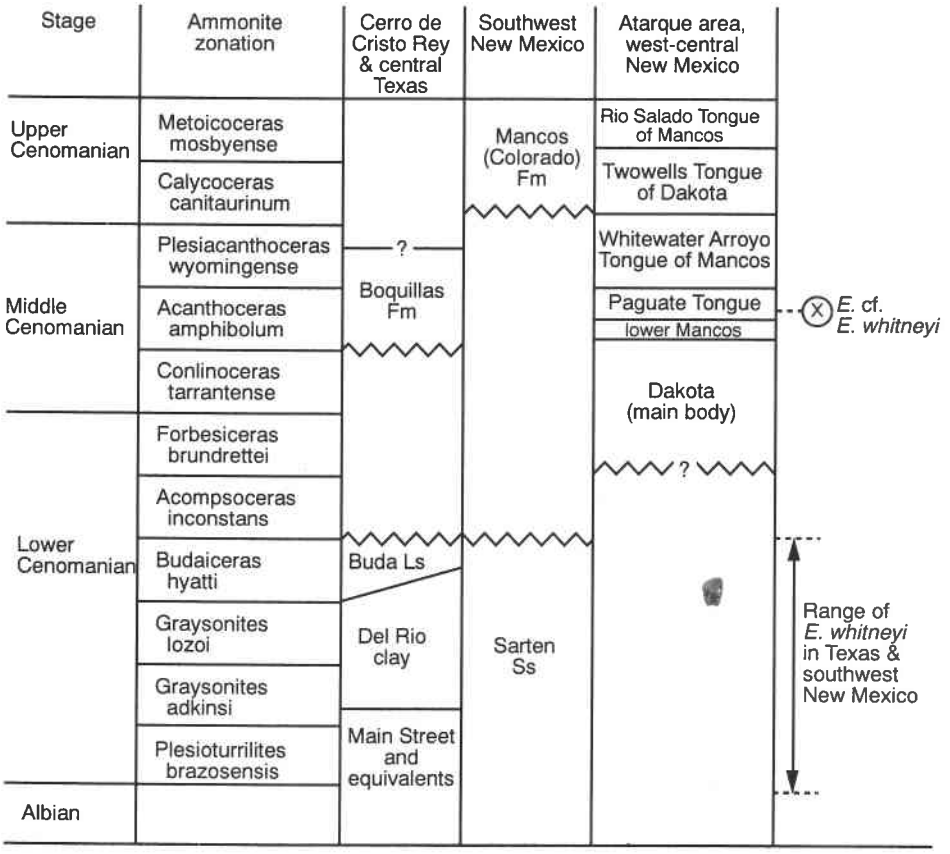

FIGURE 5—Cenomanian ammonite zones and stratigraphy in southern and west-central New Mexico, showing range of *E. whitneyi* in southern New Mexico and Texas and stratigraphic position of *E.* cf. *E. whitneyi* from the Paguate Tongue of the Dakota Sandstone. Zonation and correlations based on Cobban (1987), Kennedy et al. (1988), Lucas et al. (1988), and Cobban and Hook (1989).

Biostratigraphic and paleobiogeographic considerations

Exogyra whitneyi apparently became extinct in Texas and southern New Mexico in middle-early Cenomanian time, in the *Budaiceras hyatti* ammonite zone (Fig. 5). No exogyras of this type have been reported from the overlying Woodbine Formation (middle Cenomanian) of central Texas (Stephenson, 1952), or from the lower Boquillas Formation (of middle Cenomanian, *Acanthoceras amphibolum*, age), which unconformably overlies the Buda Formation at Cerro de Cristo Rey and other locations in Texas (Kennedy et al., 1988). In the Cooke's Range, the uppermost Sarten Sandstone is overlain unconformably by early-late Cenomanian strata of the Mancos Formation; strata coeval with the Paguate Tongue are absent (Cobban, 1987; Lucas et al., 1988).

Could a relict population of *E. whitneyi* or an immediate descendant species have survived into the middle-middle Cenomanian in west-central New Mexico? The persistent unconformities noted above indicate that marine sedimentation was absent in southern New Mexico from middle-early to about middle-middle Cenomanian time. Early Cenomanian strata in west-central New Mexico are nonmarine deposits of the lower Dakota Formation (lower Oak Canyon Member, or lower part of the Dakota main body; Cobban, 1977). Cobban and Hook (1984, fig. 2) demonstrated that ammonite-bearing marine environments first appeared in west-central New Mexico from the east during *Conlinoceras tarrantense* (early-middle Cenomanian) time, with deposition of the upper Oak Canyon Member and Cubero Sandstone Tongue, forming "Seboyeta Bay" (Fig. 6). The southern shoreline of this bay trended approximately east-west through the northern portions of Socorro and Lincoln Counties (Cobban et al., 1994, fig. 4); the marine Cenomanian record of the Carthage and Carrizozo areas begins in the middle-middle Cenomanian (Cobban and Hook, 1984; Cobban, 1986). Farther south, in the Love Ranch area of the southern San Andres Mountains, a restricted, 380-meter-thick "middle Cretaceous" section includes the Sarten Sandstone (Albian), overlain by Dakota and Mancos-correlative strata (Seager, 1981). Late Cretaceous marine invertebrates (listed by Bachman and Myers, 1969) appear to be limited to the upper part of the section and are of Turonian age (Seager, 1981; Kottlowski, written commun., 1994). Although more study of this sequence is needed, the lack of Cenomanian fossils suggests that a marine connection between this part of south-central New

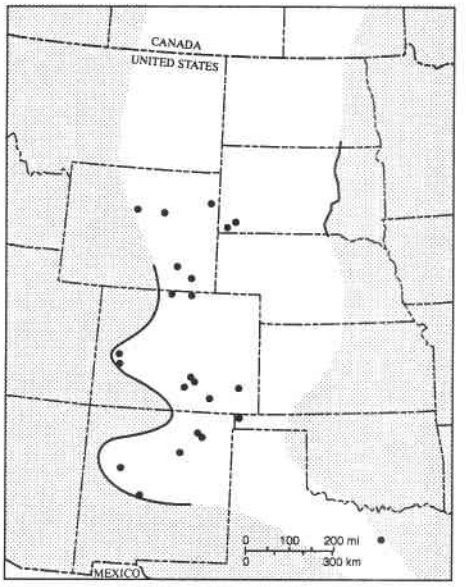

FIGURE 6—Shoreline configuration in New Mexico and other western states during early-middle Cenomanian time (zone of *Conlinoceras tarrantense*); prominent marine embayment in west-central New Mexico is Seboyeta Bay. Bold bounding line indicates relative certainty of shoreline position. Dots identify fossil localities in this zone (after Cobban et al., 1994).

Mexico and central and west-central New Mexico did not exist immediately prior to or during the initial development of the Seboyeta Bay in early-middle Cenomanian time. Later, continued eustatic sea-level rise expanded marine environments for the first time since the middle-early Cenomanian into southern New Mexico during *A. amphibolum* (middle-middle Cenomanian) time (Cobban and Hook, 1984, fig. 3; Carey, 1992, fig. 15). Given these paleogeographic considerations, a population of *E. whitneyi* or an immediate descendant could not have migrated northward from southern to west-central New Mexico between middle-early and middle-middle Cenomanian time.

Could a population of *E. whitneyi*-like oysters have migrated to west-central New Mexico by a more circuitous route? Early Cenomanian marine strata (lower Graneros Shale) are present in northeastern New Mexico and adjacent regions to the north, but these strata are virtually barren of molluscan fossils (Cobban and Scott, 1972; Kauffman et al., 1977). The earliest ammonite-bearing strata in this area are higher in the Graneros and are of early-middle Cenomanian age (Kauffman et al., 1978). Furthermore, no exogyras resembling *E.* cf. *E. whitneyi* have been reported from the Graneros.

To the southeast, in Texas, the Woodbine Formation unconformably overlies Washita Group (Buda and older) strata. The Woodbine occupies the same relative position in the early transgressive part of the Greenhorn cyclothem (T-6 transgression of Kauffman, 1984) as does the intertonguing Dakota–Mancos sequence in New Mexico (Kauffman et al., 1977). During the early Cenomanian, Western Interior marine environments were largely isolated from those of the Gulf Coast (Kauffman, 1984), and their endemic faunas include no exogyras that might be reasonable ancestors of the large Paguate form. As the transgression continued in the middle and late Cenomanian, Tethyan faunas spread northward from the Gulf Coast area into the southern Western Interior (Kauffman, 1984). The earliest ammonite-bearing Woodbine strata are of early-middle Cenomanian age (Kauffman et al., 1977; Cobban and Hook, 1984; Kennedy and Cobban, 1990), and by the time of Paguate deposition, numerous Woodbine ammonite and pelecypod species, including several species of oysters, had appeared in west-central New Mexico. However, Woodbine exogyras are small, and the fauna lacks any forms related to *E. whitneyi*. If *E. whitneyi* or a descendant survived in Texas after the early Cenomanian and subsequently migrated into west-central New Mexico, its remains have not been identified in middle Cenomanian strata in Texas.

Thus, the occurrence of an unusually large exogyra resembling *E. whitneyi* in the Paguate Sandstone Tongue is difficult to explain in the context of early-middle Cenomanian paleogeography and known faunal dispersal routes in the Texas–southern Western Interior region. An alternative possibility is that UNM-11966 is not related to *E. whitneyi*, but represents a species that very rapidly evolved an *E. whitneyi*-like morphology from an as yet unidentified ancestor in west-central New Mexico. Kauffman (1984, p. 291) noted a dramatic increase in faunal diversity in the southern Western Interior seaway resulting from increased rates of evolution caused in turn by rising temperature and salinity, and he also noted niche partitioning accompanying the mixing of northern and Tethyan faunal elements. This reached its height in the late Cenomanian, well after deposition of the Paguate Tongue, but the onset of these changes may have affected middle Cenomanian faunas in west-central New Mexico. Farther north, in Utah, large exogyras like *E. forresteri* evolved rapidly in the late Cenomanian from the *E. olisiponensis* species complex that was derived from Europe and Africa.

The scarcity of remains of these large exogyras in the Paguate Tongue suggests a small population size; otherwise, intact specimens of the large, thick valves would be conspicuous and difficult to overlook during collection. Significantly, no specimens have been reported by previous workers. The worn, heavily bored state of the valve indicates a relatively long time of exposure on the seafloor before burial, suggesting little transportation after death. That this specimen has been reworked from older strata is possible, although long exposure on the seafloor better explains its worn, bored condition. Even if reworked, the possible marine strata in the area that might have been the source are only slightly older than the Paguate Tongue and thus would not affect the paleogeographic observations presented above. Given the questions the presence of an unusually large *Exogyra* in the Paguate Tongue raises, it is unfortunate that the specimen discussed here is rather poorly preserved. Better specimens are needed to assess in more detail the taxonomic status of this form and its relationships to other Cenomanian species in the Western Interior seaway.

ACKNOWLEDGMENTS—The New Mexico Bureau of Mines and Mineral Resources and the Department of Earth and Planetary Sciences, University of New Mexico supported this research. Frank E. Kottlowski, Spencer Lucas, and Jiri Zidek reviewed the manuscript and made helpful comments and suggestions. We thank Lynne Hemenway, who prepared the manuscript, and Kathy Campbell, who drafted the illustrations.

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Christina Lochman Balk honored by New Mexico Geological Society

For her many contributions to the New Mexico Geological Society (NMGS), Emerita Professor–Researcher Dr. Christina Lochman Balk has been awarded a plaque by the NMGS Executive Committee, a grateful acknowledgment of Christina's many services.

Christina wrote or was coauthor of stratigraphic correlation charts and lexicons for NMGS guidebooks: 1959 *West-central New Mexico*, 1964 *Ruidoso Country*, 1965 *Southwestern New Mexico II*, 1967 *Defiance–Zuni–Mt. Taylor Region*, and 1972 *East-central New Mexico*. She was co-editor of *Southwestern New Mexico II* in 1965 and coordinated the trail hike to (down) and from (5,000 ft up) Phantom Ranch in Grand Canyon for the 1958 Field Conference to northern Arizona. She served as treasurer of the society in 1972 and was awarded Honorary Membership in 1977. Dr. Balk attended, usually with many of her students, many of these autumn field conferences as well as the spring technical sessions. Most rewarding to the society was her chairing of the scholarship committee of NMGS for several decades, helping recommend grants for students' geologic projects.

Christina married Dr. Robert Balk March 15, 1947 and came to New Mexico with him in 1952. She was a stratigrapher for New Mexico Bureau of Mines & Mineral Resources 1955–57 and a professor of geology for New Mexico Institute of Mining & Technology 1957–1972. Since 1972 she has been an emerita professor. Christina taught classes and conducted research for many years after her retirement. She taught stratigraphy, paleontology, and sedimentation to both undergraduate and graduate students. Her extensive research centered on Cambrian stratigraphy and fossils and ranged from Canada, Montana, and South Dakota to New Mexico, Texas, Arizona, and northern Mexico. Christina organized the First Cambrian Symposium at the International Geological Congress in Mexico in 1956. She has published numerous articles in Journal of Paleontology (two Best Paper awards), GSA Bulletin, AAPG Bulletin, Rocky Mountain Geologist, and IGC Proceedings, as well as in NMGS and NMBMMR publications. Research grants to Dr. Balk came from the National Research Council, GSA, and NSF.

Christina was born in Springfield, Illinois, October 8, 1907 to David Julius and Nellia (Stanton) Lochman. She received her A.B. (1929) and M.A. (1931) from Smith College and Ph.D. from Johns Hopkins University (1933). Before coming to New Mexico, she was on the faculty of Mt. Holyoke College (1935–1947) and then a lecturer at University of Chicago (1947) and Johns Hopkins (1948–49).

A fellow of GSA, Christina is also a member of AAAS, PS, National Association of Geology Teachers, NMGS, Sigma Xi, and Phi Beta Kappa. Her influence as a teacher and advisor helped many geology students learn and enjoy our science. Professor Rena Mae Bonen, Baylor University, is just one (outstanding) example of Christina's prodigies. High school teachers enjoyed her summer geology courses, taught with Clay Smith. For a score of years, Christina was the stratigraphic compiler for NMBMMR, aiding in our computerization of stratigraphic nomenclature with USGS.

After 41 years in Socorro, Christina moved to Santa Fe to be near her niece. Perhaps she will have time to help NMGS with its 1995 field conference in that area. NMGS reflects credit on itself by honoring this first lady of New Mexico geology.

—Frank E. Kottlowski

Note: Christina Lochman Balk recently established the Robert and Christina Lochman Balk fellowship that she designated for the benefit of "graduate students in the field(s) of sedimentation, stratigraphy and/or paleontology at the New Mexico Institute of Mining and Technology."

Kues and Anderson (continued from p. 53)

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