Flemingostrea elegans, n. sp.: guide fossil to marine, lower Coniacian (Upper Cretaceous) strata of central New Mexico

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Abstract

The marine oyster *Flemingostrea elegans*, n. sp., appears suddenly in lower Coniacian (Upper Cretaceous) strata of central New Mexico. It has no immediate ancestor in the Western Interior of the United States and has not been found anywhere outside central New Mexico. *Flemingostrea elegans* occurs in nearshore sandstones in the Mulatto Tongue of the Mancos Shale in Socorro County and the Gallup Sandstone of Lincoln County. This medium-sized oyster, with its distinctive terebratuloid fold, is an excellent guide fossil to the lower Coniacian, and is a great aid in distinguishing the Mulatto Tongue from other tongues of the Mancos Shale in Socorro County and in differentiating Coniacian from Turonian sandstones in Lincoln County. It occurs in great numbers, often as articulated shells, and is easily distinguished from all other Turonian through Coniacian oyster species by the fold in its lower valve. Its presence above coal beds in the lower part of the Crevasse Canyon Formation provides definitive evidence for a third cycle of transgression/regression of the western shoreline of the Late Cretaceous Seaway as far south in New Mexico as central Socorro County.

The Santonian dwarf species, *Flemingostrea nanus* (Johnson 1903), known only from Santa Fe County, New Mexico, is redescribed and illustrated. *Flemingostrea nanus, F. elegans*, n. sp., and the upper Cenomanian *F. prudentia* (White 1877) are the only species of *Flemingostrea* known from the Western Interior.

Ostrea elegantula Newberry 1876, which has been confused in the literature with *F. elegans*, n. sp., should be considered formally as a *nomen oblitum* (a forgotten name) and not used again. *Ostrea elegantula* was named but not described or illustrated by J. S. Newberry in his geological report of Captain J. N. Macomb's 1859 San Juan exploring expedition. F. B. Meek, who wrote the paleontological report on the Cretaceous fossils collected on that expedition, did not describe, illustrate, or mention it. Newberry's type specimens were illustrated in 1883 by C. A. White, again without description. Attempts to recover Newberry's type locality along the Canadian River, Colfax County, New Mexico, were unsuccessful.

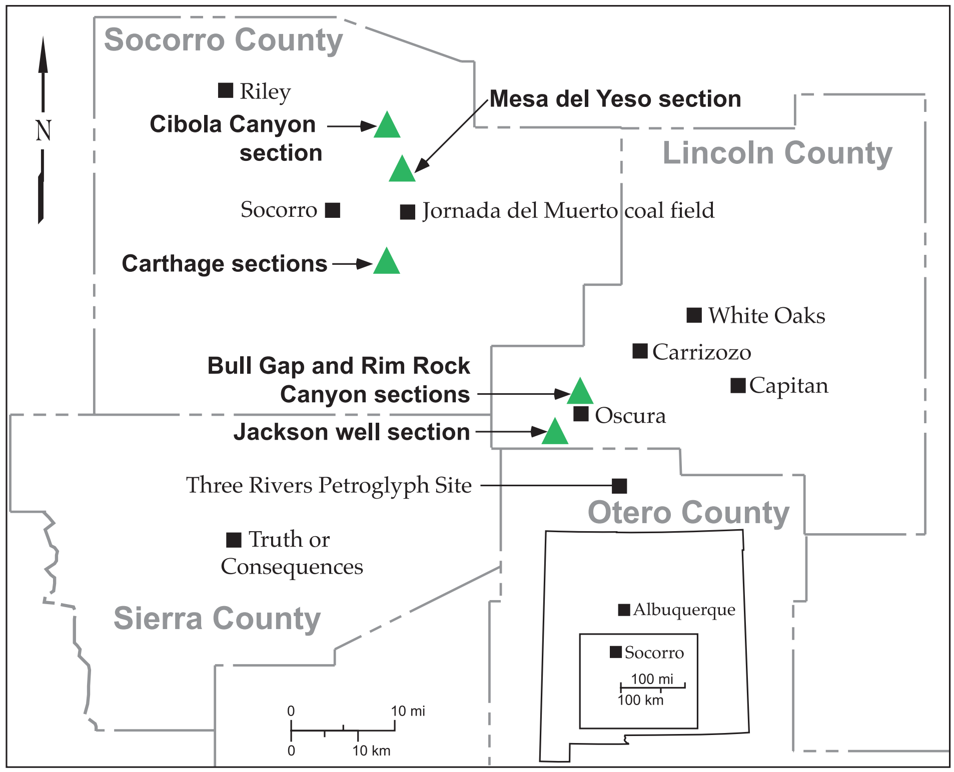

FIGURE 1—Map of central New Mexico showing locations in Socorro and Lincoln Counties mentioned in the text where *Flemingostrea elegans*, n. sp., has been collected.

Introduction

The shells of the distinctive lower Coniacian marine oyster *Flemingostrea elegans*, n. sp., occur in great numbers in thin, resistant, nearshore, sandstones in central New Mexico (Fig. 1).

Flemingostrea elegans can be differentiated from all Turonian or Coniacian oyster species in the Western Interior by a conspicuous, symmetrical, low-amplitude, terebratuloid fold that marks the adult part of the left (or lower) valve (Fig. 2). The right (or upper) valve of an adult shell has a prominent break in slope where it changes from flat to inclined downward. This downward inflection produces a tongue-like extension that makes the upper valve convex-up when viewed in living position and allows it to fit tightly into the fold on the lower valve (Fig. 3). Maximum convexity of the upper valve is at this change in inclination, which corresponds to the position of the adductor muscle pad or scar (Fig. 3). The articulated shells of *F. elegans* resemble brachiopods because of the terebratuloid fold.

Flemingostrea elegans is a medium-sized oyster, generally less than 50 mm high, and relatively slender. Articulated specimens are plano-convex in section, oval in outline with a height to length ratio of about 1.2, and slender with a height to thickness (of both valves) ratio of about 2.6. The thickness of an individual valve varies, with thicker valves occurring in coarser sandstones deposited in higher-energy environments. Ornamentation of both valves consists primarily of concentric growth lamellae, but about four out of every 10 lower valves have weak to moderate radial sculpture. The adductor muscle scar is large, subcentral, and kidney shaped.

Sedimentation rates in some of these nearshore environments were apparently high enough intermittently that the oysters were buried completely, often in life position, before the shell-closing adductor muscle deteriorated and relaxed, allowing the spring-like ligament to open the two valves. Completely articulated specimens are more common in friable sandstones, often with little or no attached matrix, than in coquinas. The more resistant coquinas form the tops of ridges in open countryside and may be the only exposed sandstone in the arroyos. The key to identifying *F. elegans* in the coquinas, where they usually occur as disarticulated valves, is the change in slope of the adult part of the upper valve (Fig. 4).

The stratigraphic occurrences of *F. elegans* chart a complex history for the movement of the western shoreline of the Late Cretaceous Seaway across central New Mexico during the early Coniacian (Fig. 5). These oysters occur in the Mulatto Tongue of the Mancos Shale in Socorro County, New Mexico, but are in the stratigraphically lower, but partially age equivalent, Gallup Sandstone in Lincoln County. The Mulatto Tongue is the uppermost of the three major tongues of

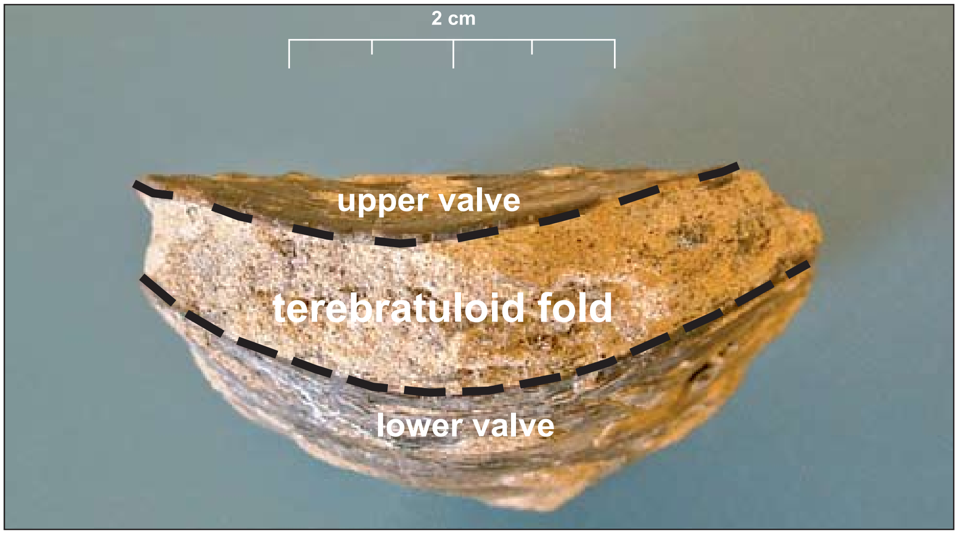

FIGURE 2—Ventral view of a paratype of *Flemingostrea elegans*, n. sp. (USNM 542213) from Carthage section 1, Socorro County, New Mexico, Mulatto Tongue of the Mancos Shale, USGS locality D14559, showing the distinctive terebratuloid fold in the lower valve. Note that the fold's axis lies along the line of symmetry of the shell. This unusually large specimen has an incomplete height of 50.4 mm, a length of 40.9 mm, and a thickness of 18.3 mm; it reaches maturity at a height of 37.1 mm. Its lower valve exhibits faint crinkles. Enlarged 2.2 ×.

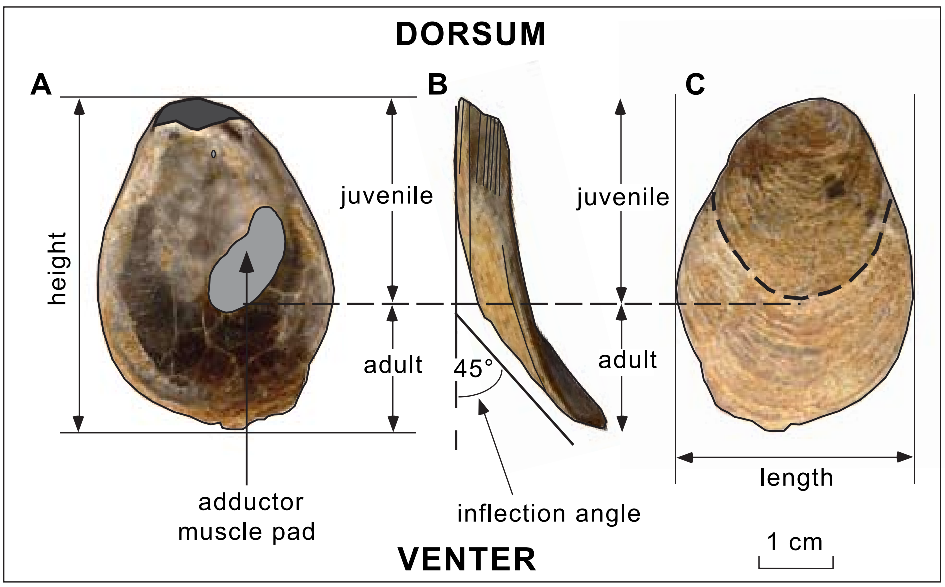

FIGURE 3—Three views of an upper (right) valve of *Flemingostrea elegans*, n. sp., showing key features and measurements discussed in the text. Paratype (USNM 542214) is from Cibola Canyon section, Socorro County, New Mexico, Dalton Sandstone Member of the Crevasse Canyon Formation(?), USGS locality D14500. **A—**interior view, **B—**side view (anterior), and **C—**exterior view. Side view **B** shows a 45° change in slope in the upper valve that occurs at maturity. This specimen, typical of the D14500 collection, has a height of 47.2 mm and a length of 33.6 mm. Approximately natural size.

Mancos Shale in Socorro County; it occurs 100–150 ft (30–45 m) above the top of the Gallup Sandstone and is separated from the Gallup by nonmarine beds in the Dilco Coal Member of the Crevasse Canyon Formation. Rock units with the same names in the two counties are generally diachronous because of differing rates of shoreline movements between the two counties. The age of the Gallup Sandstone in Lincoln County is well constrained by index species to the lower Coniacian; the Mulatto Tongue in Socorro County is less well constrained with an index species occurrence only in the underlying Gallup Sandstone. The assumptions inherent in Figure 5 are that: (1) deposition of the Dilco Coal Member in Socorro County lasted the entire time represented by the *Cremnoceramus deformis* Zone; (2) deposition of the Gallup Sandstone in Lincoln County lasted until the end of the time represented by the *C. crassus* Zone; and (3) the western shoreline retreated penecontemporaneously from both Socorro and Lincoln Counties at the end of *C. crassus* time. The age of the upper part of the Crevasse Canyon Formation in both counties is unconstrained by the collections discussed in this paper.

The implication of these biostratigraphic occurrences is that during the early Coniacian, Socorro County was emergent, then covered by the sea, then emergent again; whereas, Lincoln County was covered by seawater, then emergent. This means that during the early Coniacian the western shoreline of the Late Cretaceous Seaway was to the west and south of Lincoln County, but retreated from, then advanced across Socorro County. The seaway retreated from both counties penecontemporaneously probably during the early part of the middle Coniacian. In Socorro County the shells of *F. elegans* occur in sandy strata deposited during the third major transgression (T3 of Molenaar 1983) of the Late Cretaceous Seaway across New Mexico; those from Lincoln County in the Gallup Sandstone occur in strata deposited during the second major regression (R2 of Molenaar 1983) of the seaway.

The resistant shell beds are so conspicuous in the field in Socorro County that they are reliable indicators that can distinguish the marine beds in the Dalton Sandstone Member of the Crevasse Canyon(?) or the Mulatto Tongue of the Mancos Shale from the underlying, nonmarine beds of the Dilco Coal Member of the Crevasse Canyon Formation. In Socorro County, *F. elegans* occurs in the Mulatto Tongue approximately 100 ft (30 m) above the first and only occurrence of the lower Coniacian inoceramid bivalve *Cremnoceramus erectus* (Meek) in the Gallup Sandstone. In Lincoln County, New Mexico, where the rocks are more fossiliferous, there is better biostratigraphic control: *F. elegans* occurs in the Gallup Sandstone with *C. erectus* near the base of its range and *C. crassus* (Petrascheck) near the top of its range. See Figure 5.

In published records, this new oyster species has been misidentified as *Ostrea anomioides* Meek (e.g., Cobban 1986, p. 88, fig. 6H–I), as *O. elegantula* Newberry (e.g., Darton 1928, pp. 75–76), as *Flemingostrea* aff. *prudentia* (Arkell 1986, p. 75), and as *F. elegantula* (Hook and Cobban 2007, fig. 3). This repeated misidentification is primarily the result of the morphological similarity of upper valves of immature individuals of *elegans* to *anomioides*, *elegantula*, and *prudentia*. (Compare Fig. 3C with Figs. 14B, C, and G.)

Stephenson (1936, pp. 2 and 7) discussed the close morphological relationship between *O. elegantula* and *O. anomioides* but thought there was a significant age difference. Dyman et al. (2000, fig. 4) have shown conclusively that *O. anomioides* is confined to upper Albian rocks in western Montana; lower valves of adults of both *O. anomioides* and *O. elegantula* lack the characteristic low-amplitude fold of *F. elegans*.

The upper valve of *F. elegans* is so similar morphologically to the only illustrated upper valve of *Ostrea elegantula* (White 1883, pl. XXXVI, fig. 5; reproduced as Fig. 14C) that I referred this new species to *F. elegantula* in the initial drafts of this paper. In addition, this new species has been identified as *F. elegantula* on a columnar section for northern Socorro County

FIGURE 4—Photograph of a coquina, whitened, paratype (USNM 542215), of *Flemingostrea elegans*, n. sp., from the Jackson well section of Lincoln County, New Mexico, Gallup Sandstone, USGS locality D6770. **a**—upper valve, **b**—lower valve, and **c**—internal mold of the marine bivalve *Cyprimeria* sp. Reduced 0.5 ×.

(Hook and Cobban 2007, fig. 3). T. W. Stanton, in Darton (1928, pp. 75–76), referred specimens of this new species to *O. elegantula* in Upper Cretaceous faunal lists from northern Socorro County. However, these identifications have proven to be incorrect because detailed examination of the woodcuts of the type specimens (White 1883, pl. XXXVI, figs. 5–7; reproduced as Figs. 14C–E) revealed that *O. elegantula* lacks the adult, low-amplitude fold present in *F. elegans*. Although there has been confusion about which specific name to use for this oyster, there has been no confusion about its biostratigraphic importance: It is an excellent guide fossil to the lower Coniacian.

In the sections of this paper that follow, *Flemingostrea elegans*, n. sp., is described and illustrated with specimens from Socorro and Lincoln Counties, New Mexico. Its geologic range is restricted to the lower Coniacian. Its geographic range is (at present) restricted New Mexico. Type and reference localities will be described and illustrated. Working out the stratigraphy of *F. elegans* has increased the number of major cycles of transgression and regression of the Late Cretaceous Seaway that have affected central New Mexico from two to three. As this new information is incorporated into geologic quadrangle maps in Socorro County, it will add considerable stratigraphic and structural detail to areas formerly mapped as undifferentiated Crevasse Canyon Formation.

Stratigraphy

The purpose of this portion of the paper is to establish a reasonable stratigraphic framework for the marine beds containing *F. elegans* and associated fauna in Socorro and Lincoln Counties. It is neither to define the exact boundaries between stratigraphic units, nor to impose a paleontologically defined stratigraphic nomenclature on central New Mexico. However, the presence of *F. elegans* in shaly strata above coal beds in Socorro County implies that the depositional environment changed from nonmarine to marine and necessitates a change in stratigraphic nomenclature of either formation or member rank.

In central Socorro County the base of the upper part of this intertongued marine sequence rests on a paludal shale that contains a thin coal bed. In the stratigraphic sections that follow, the boundaries between the intertongued units have been drawn on the basis of lithology, not environment of deposition. Existing stratigraphic names have been used, rather than defining new stratigraphic units. For example, in Figures 6 and 7 the contact between the Dilco Coal Member and the Mulatto Tongue is drawn between a nonmarine sandstone below and a nonmarine shale above because the nonmarine/marine contact, which is higher in the section, is a shale on shale contact.

An interesting analogy to this depositional situation between the Dilco Coal Member and the Mulatto Tongue exists in Socorro County within the Tres Hermanos Formation, which was deposited during an earlier cycle of transgression and regression of the western shoreline. The Carthage Member is the medial, marginal marine and nonmarine shaly part of the Tres Hermanos Formation that separates the lower Atarque Sandstone Member from the upper Fite Ranch Sandstone Member (Hook et al. 1983, p. 20). Both sandstone members are of marine origin. Initially in Socorro County, the Carthage Member was thought to be completely of nonmarine origin, and the Fite Ranch Sandstone, a coastal barrier sandstone, was thought to mark the beginning of the second transgression of the western shoreline into the county (see Hook et al. 1983, sheet 1B, section 59). Recent work on Sevilleta National Wildlife Refuge, 15 mi (24 km) to the north of Carthage, has shown that the upper 30 ft (10 m) of the Carthage Member is marine and that the contact between marine and nonmarine beds is a shale on shale contact (Hook and Cobban 2007, fig. 3). Subsequent collecting from the Carthage Member in the Carthage coal field (D14546) has confirmed that the upper 30 ft (10 m) of the Carthage Member is a gray marine shale that rests on approximately 35 ft (12 m) of red and purple paludal shales.

Structural complications in almost every area of Upper Cretaceous outcrop in the two counties mean that the boundaries will have to be established by detailed mapping at a scale of 1:24,000 or larger, which is beyond the scope of this work. The stratigraphic framework will have to be worked out with detailed correlations to better understood areas either within or outside Socorro and Lincoln Counties. Fortunately, preliminary geologic mapping at a scale of 1:24,000 is either in progress or completed on at least two quadrangles in Lincoln County (Bull Gap and Oscura), on two quadrangles in Socorro County (Mesa del Yeso and Cañon Agua Buena), and on one quadrangle in Otero County (Golondrina Draw) on which *F. elegans* has been found. The mapping of these quadrangles is supported by the federal StateMap Program, which is managed by the U.S. Geological Survey and the New Mexico Bureau of Geology and Mineral Resources.

Stages		Central NM fossil zone		Socorro County		Lincoln County
Coniacian	Middle	*Volviceramus involutus*		Crevasse Canyon Formation (unassigned member)		Dilco Coal Member Crevasse Canyon Fm.
		Volviceramus koeneni				
	Lower	*Cremnoceramus crassus*		Mulatto Tongue/Mancos Sh.	*	Gallup Sandstone
		Cremnoceramus deformis		Dilco Coal Member/CCF		
		Cremnoceramus erectus	*	Gallup Sandstone	*	
Turonian	Upper	*Forresteria peruana*	*	D-Cross Tongue Mancos Shale (upper part)	* *	D-Cross Tongue Mancos Shale (upper part)
		Prionocyclus germari	*			
		Prionocyclus quadratus	*			
		Prionocyclus novimexicanus	*		*	

FIGURE 5—Diagram showing the generalized correlation of upper Turonian through lower Coniacian (Upper Cretaceous) rock units between Socorro and Lincoln Counties, New Mexico. Molluscan fossil zones for central New Mexico are adapted from Cobban et al. (2008). A double-headed arrow shows the stratigraphic range of *Flemingostrea elegans*, n. sp., in each county. Generalized rock type and environment of deposition are color coded: gray—marine shale; yellow—marine sandstone; and brown—nonmarine sandstone, shale, and minor coal. A black band shows the approximate position of the major coal seam in the Dilco Coal Member in each county. An asterisk indicates the known occurrence of the index species to a range zone for the Turonian and Coniacian.

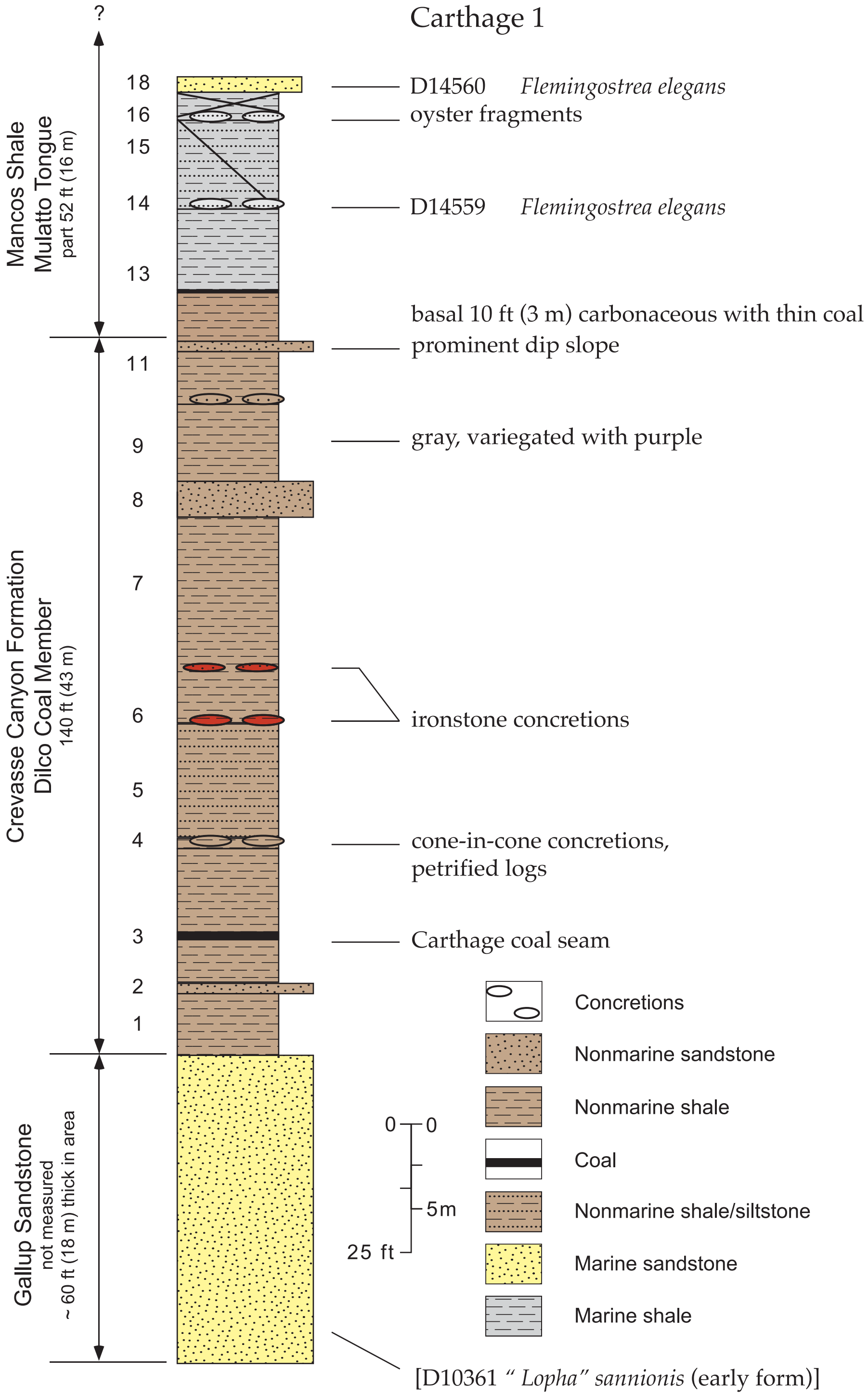

FIGURE 6—Carthage measured section 1 showing the positions of the collections of *Flemingostrea elegans* from the Mulatto Tongue of the Mancos Shale in relation to the underlying marine Gallup Sandstone and nonmarine Crevasse Canyon Formation. This section was measured in the NE¼ SE¼ SW¼ sec. 9 T5S R2E, Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico. [ ] indicates a collection from another locality. See Figure 1 for location.

Background

For many years, the geological evidence in Socorro County supported only the two earliest of the five major transgression/regression cycles of the western shoreline of the Late Cretaceous Seaway in New Mexico (e.g., Hook 1983 and Molenaar 1983). The earliest cycle, the Greenhorn Cycle, began in middle Cenomanian time and lasted until middle Turonian time; the second cycle, the Carlile Cycle, began in middle Turonian time and ended in early Coniacian time. Each of these two cycles encompasses several hundred feet of strata. The third cycle, if present, would encompass only a few tens to hundreds of feet of section because Socorro County would lie at or near the maximum southwestward position of the western shoreline of the seaway.

This third cycle, called here, informally, the Mulatto cycle, would have begun later in early Coniacian time and lasted until perhaps latest early Coniacian time if it were present in Socorro County. Initially, there was no modern evidence for the Mulatto cycle in Socorro County. However, it was difficult to discount the reports of marine fossils, including *Ostrea elegantula*, above the Mesaverde [Dilco] coal beds in Socorro County by such a renowned field geologist as N. H. Darton (1928, pp. 75–76), and by Gardner (1910, p. 455). If these marine faunas were stratigraphically above the coals and not older, ecologically similar bivalve faunas faulted into juxtaposition, then it would mean that there had been a third cycle of transgression/regression of the Late Cretaceous Seaway in Socorro County.

In 1978 *F. elegans*, identified in field records as *Ostrea anomioides*, was collected from a coquina (D10605) containing nothing but oysters at Carthage in the Crevasse Canyon Formation, an estimated 100 ft (30 m) above the Gallup Sandstone. At that time it was not known if *F. elegans* could have lived in brackish water or whether it was a purely marine oyster. With nothing but *F. elegans* in the rocks, this collection was assumed to represent a brackish water accumulation, indicating that the western shoreline had at least gotten close to Carthage. However, *F. elegans* (identified as *O. anomioides*) had been collected in 1968 in association with the Coniacian inoceramid *Cremnoceramus crassus* south of Carrizozo (D6770).

After returning to New Mexico in 2003, I collected what I thought was a brackish water fauna from a 1-ft-thick sandstone in the Crevasse Canyon Formation, approximately 130 ft (40 m) above the top of the Gallup Sandstone on the Sevilleta National Wildlife Refuge in northern Socorro County. Subsequently, this collection (D14479) was found to contain abundant *F. elegans* in association with the marine bivalves *Phelopteria* sp. and *Pleuriocardium curtum* (Meek and Hayden). This find, at one of Darton's (1928, p. 75) localities, constituted the first "modern" evidence for this third transgression into Socorro County and indicated, once again, that the early geologists working in New Mexico made astute and accurate observations.

In addition, in 2004 a marine fauna (D14482) with *F. elegans* was collected from a 7-ft (2-m)-thick, resistant sandstone above 60 ft (18 m) of what looked like marine shale and sandstone just south of Sevilleta National Wildlife Refuge on the Mesa del Yeso quadrangle. This locality is probably the same one reported by Darton (1928, p. 76) from 1 mi southeast of Mesa del Yeso containing *Ostrea* sp. This shaly section emerges out of the valley alluvium, so there is no stratigraphic context for the sandstone from below and there is an erosion surface approximately 30 ft (10 m) above D14482 (Fig. 8E). In 2007, another marine fauna

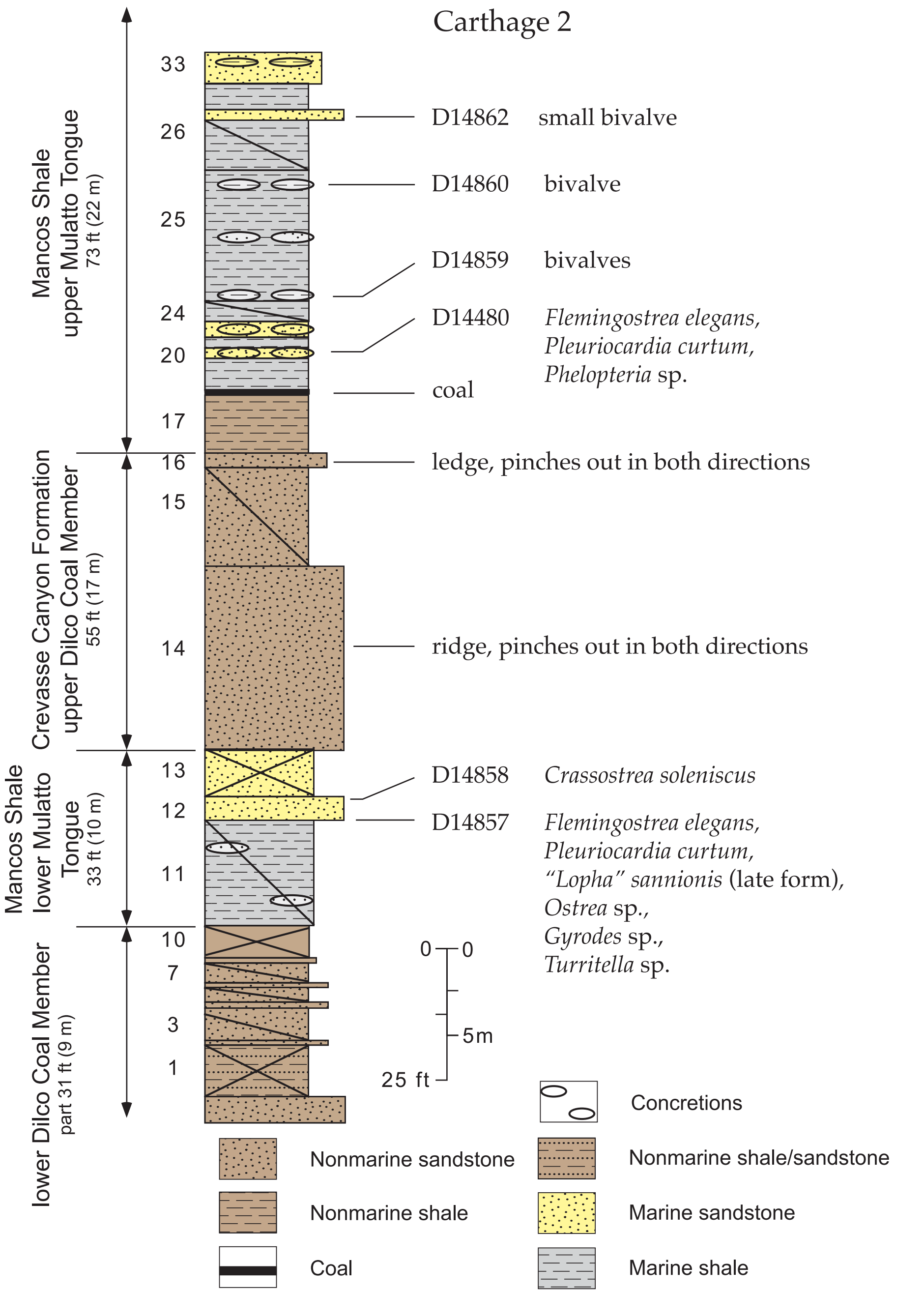

FIGURE 7—Carthage measured section 2 showing the positions of the collections of *Flemingostrea elegans* from two levels of Mulatto Tongue intertongued with the Crevasse Canyon Formation. This section was measured in the SE¼ NW¼ NW¼ sec. 15 T5S R2E, Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico. See Figure 1 for location and Figures 8A–C for outcrop images.

again with *F. elegans* was found above the coal at Carthage 1 (D14559).

Several older fossil collections that have direct bearing on the question of the position of the shoreline in Lincoln County have been found in the USGS Mesozoic Invertebrate Collections at the Federal Center in Denver, Colorado. These collections will be discussed in the section of the paper on Lincoln County.

All specimens of *F. elegans* collected in Socorro County, New Mexico, have come from marine rocks above the lowest (= major) coal seam in the Dilco Coal Member of the Crevasse Canyon Formation. These rocks include the undifferentiated Crevasse Canyon Formation, the Dalton Sandstone Member of the Crevasse Canyon Formation (?), and the Mulatto Tongue of the Mancos Shale. Specimens from southwest Lincoln County have come entirely from the Gallup Sandstone.

All of these formally named rock units have their type localities in the southern San Juan Basin, New Mexico, far to the northwest of Socorro and Lincoln Counties. The Gallup Sandstone (member of the Mesaverde Formation) was named by Sears (1925, p. 17) for three massive sandstones and interbedded shale and coal, 180–250 ft (55–76 m) thick, at the top of the Mancos Shale at the town of Gallup, McKinley County, New Mexico. The Crevasse Canyon Formation was named by Allen and Balk (1954, p. 91) for the 420–640 ft (128–195 m) of mostly nonmarine strata between the Gallup Sandstone and the Point Lookout Sandstone in the southwestern part of the San Juan Basin, 3 mi (5 km) southwest of Crevasse Canyon, San Juan County, New Mexico. The Dilco Coal Member (of the Mesaverde Formation) was named by Sears (1925, p. 17) for 240–300 ft (73–91 m) of coal-bearing strata above the Gallup Sandstone. The member was named for the village of Dilco (now Mentmore), approximately 5 mi (8 km) west of Gallup, McKinley County, New Mexico, where four coal beds were worked. The name Dilco is an abbreviation for the Direct Line Coal Company. The Dalton Sandstone Member (of the Mesaverde Formation) was named by Sears (1934, p. 17) for excellent exposures of approximately 100 ft (30 m) of (marine) sandstone at Dalton Pass, McKinley County, New Mexico. Allen and Balk (1954, pp. 91–92) raised the Gallup Sandstone to formational rank and reassigned the Dilco Coal and Dalton Sandstone Members to the Crevasse Canyon Formation. The Mulatto Tongue of the Mancos Shale was named by Hunt (1936) for 250–400 ft (76–122 m) of shale lying between the Dilco Coal and Dalton Sandstone Members of the Mesaverde Formation (now Crevasse Canyon Formation). The member was named for Canyon Mulatto, 9 mi (14.5 km) northwest of San Mateo, Cibola County, New Mexico.

Socorro County

All the collections containing *F. elegans* from Socorro County have come from marine rocks that are stratigraphically above coal beds in the basal part of the Dilco Coal Member of the Crevasse Canyon Formation. At present these marine strata are either mapped as or included in the undifferentiated Crevasse Canyon Formation on Sevilleta National Wildlife Refuge (Baker 1981) and in the Carthage coal field (Anderson and Osburn 1983 [reproduced in Hoffman and Hereford 2009] and Cather 2007). In the Jornada del Muerto coal field they are included in the undifferentiated Mesaverde Group (Tabet 1979). Just north of the townsite of (the ghost town of) Carthage and just southeast of the southern boundary of the Sevilleta National Wildlife Refuge, these marine shales have been mapped as the D-Cross Tongue of the Mancos Shale (Anderson and Osburn 1983 and Cather et al. 2005). Stratigraphic names that now appear appropriate for these marine rocks are the Mulatto Tongue of the Mancos Shale in all areas and questionably the Dalton Sandstone Member of the Crevasse Canyon Formation on Sevilleta National Wildlife Refuge.

Carthage coal field area

In the Carthage area there are two measured sections approximately 2 mi (3 km) apart that support substantial collections of *F. elegans*.


S
N
Crevasse Canyon Formation
upper Mulatto Tongue
D14859 bivalves
D14480 F. elegans
coal bed
A
NW
Typical cone-in-cone concretion
SE
upper Mulatto Tongue
coal bed
B
NW
SE
upper Mulatto Tongue
C
E
D-Cross Tongue
W
D
S
ripple-marked sandstone
D14482 F. elegans
N
Mulatto Tongue
E
F
N
Sierra Blanca
S
BN&SF railroad
US–54
Gallup Sandstone
D14910 F. elegans
D14875 C. crassus
D14908 F. elegans
D-Cross Tongue
G
Cremnoceramus erectus
Cremnoceramus crassus
H

FIGURE 8—Outcrop photographs. **A**—The upper part of the Mulatto Tongue at Carthage 2 (Fig. 7) looking west. **B**—Upper Mulatto Tongue at Carthage 2 (Fig. 7) exposed along the dirt road approximately 500 ft (150 m) north of the ruins of the superintendent's house at the ghost town of Carthage in the SE¼ NW¼ NW¼ sec. 15 T5S R2E, Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico, looking northeast. **C**—Close-up view of the large cone-in-cone concretion shown in Figure 8B. **D**—Typical cone-in-cone concretion from the upper part of the D-Cross Tongue of the Mancos Shale, exposed approximately 50 ft (15 m) below the Gallup Sandstone at Carthage 1 (Fig. 6). **E**—Shaly beds of the Mulatto Tongue emerge from the alluvial cover at the Mesa del Yeso section (Fig. 10), looking west. **F**—Interference ripples on a burrowed sandstone bed from the *Flemingostrea* ridge at the Mesa del Yeso section (Fig. 8E). **G**—Classic ridge-valley-ridge topography formed by the lower part of the Gallup Sandstone at the Bull Gap section (Fig. 12), looking east with Sierra Blanca in the background. **H**—Beautifully preserved specimens of large *Cremnoceramus erectus* (late form) and small *C. crassus* from the second ridge of Gallup Sandstone (D14875 level, Fig. 8G).

The stratigraphically better constrained section is the one shown as Carthage measured section 1 (Fig. 6), which begins at the top of the Gallup Sandstone. Here, *F. elegans* has been collected from 1-ft (0.3-m)-thick bed of orange-weathering, sandy limestone concretions (unit 14 of measured section, USGS locality D14559) that is 167 ft (51 m) above the top of the Gallup Sandstone, and from a 3-ft (1-m)-thick bed of sandstone with ironstone concretions (unit 18 of measured section, USGS locality D14560) that is 189 ft (62 m) above the top of the Gallup Sandstone. The Dilco Coal Member of the Crevasse Canyon is at least 140 ft (46 m) thick, and the Mulatto Tongue of the Mancos Shale, whose upper contact was not determined, is at least 52 ft (16 m) thick. The lower contact of the Mulatto Tongue is drawn at a pronounced topographic break between a dark-brown, highly resistant sandstone and a carbonaceous shale (unit 13) that contains a thin coal bed approximately 10 ft (3 m) above its base. The 5-ft (1.5-m)-thick Carthage coal seam, which is 24 ft (7.3 m) above the base of the Dilco Coal Member, was mined at this location.

The Gallup Sandstone in the Carthage coal field is poorly fossiliferous, yielding only a few species of bivalves and gastropods, but no ammonites or inoceramids. USGS collection D10361 from approximately 2 mi (3 km) southeast of the measured section contains the early form of the oyster "*Lopha" sannionis* (White), regarded as latest Turonian by Hook and Cobban (1980, fig. 3). Hook et al. (1983, sheet 1B, section 59) were in error in showing "*Lopha" sannionis* in a collection (D11161) from the top of the Fite Ranch Sandstone Member of the Tres Hermanos Formation at Carthage. A re-examination of the collection shows that the specimen in question is a broken, upper valve of *Cameleolopha bellaplicata*. The first occurrence of "*L." sannionis* at Carthage is in the basal part of the Gallup Sandstone (D10361).

Carthage measured section 2 (Fig. 7), which is just north of the Carthage townsite, is not as well constrained stratigraphically because of structural complications. It begins somewhere above the main coal seam of the Dilco Member, but contains two tongues of marine rocks separated by nonmarine rocks, including a thin coal bed. At present, both of the shaly units have been assigned to the Mulatto Tongue and the nonmarine sandstone units to the Dilco. Thicknesses of units are approximate because of large increases in dip magnitude, usually on the updip side of a covered interval.

The lower Mulatto Tongue could be as much as 33 ft (10 m) thick, but occurs in a structurally complex area that is mostly concealed. However, a well-exposed 4-ft (1.2-m)-thick sandstone ledge near the middle of the interval contains a marine bivalve and gastropod fauna near its base (USGS locality D14857) that includes *F. elegans;* a more brackish water fauna containing abundant fragments of the oyster *Crassostrea soleniscus* (Meek) occurs at the top of the this sandstone (USGS locality D14858).

This fossiliferous bed, unit 12, is the only hard evidence for the initial incursion of the Mulatto shoreline into the Carthage area. The beds on either side of it, which are mostly to partly covered, may be nonmarine. Unit 11, the gray, noncalcareous shale below, appears marine, but does not contain fossils. If the underlying and overlying units are nonmarine, then unit 12 represents the extent of this incursion of the seaway. The lower fossil collection (USGS locality D14857) from unit 12 contains the most diverse marine fauna from the Mulatto Tongue and is the only Mulatto collection from Socorro County to contain "*Lopha" sannionis* (White) and *F. elegans*. "*Lopha" sannionis* is represented by a single specimen of the late form. The upper collection (USGS locality D14858) contains abundant broken and disarticulated specimens of *C. soleniscus*, but they do not occur in reef-like masses.

Coquina to reef-like beds of *C. soleniscus* seem to occur only in regressive sandstones in central New Mexico. A good example is in the regressive middle Turonian Atarque Sandstone Member of the Tres Hermanos Formation exposed on Sevilleta National Wildlife Refuge. On the refuge the top of the regressive Atarque Sandstone is a 6-ft (2-m)-thick, reef-like accumulation of *C. soleniscus* (see Hook and Cobban 2007, fig. 3).[1] It also appears to be the case for the top of the lower Coniacian Mulatto Tongue on the refuge (Hook and Cobban 2007, fig. 3), where an erosion surface rests on top of the *C. soleniscus* bed. A possible exception to this regressive "rule of thumb" was reported by Brown (1988) from the transgressive Borrego Pass Lentil of the Crevasse Canyon Formation (Coniacian) farther north in the southern San Juan Basin.

The presence of this thin marine unit in what was thought to be nothing but nonmarine Dilco, apparently above the Carthage coal seam, but below both a minor coal bed and the main body of the Mulatto Tongue indicates that there was a minor oscillation of the Mulatto shoreline in the Carthage area before the main transgression/regression. The thinness of this sandstone suggests that Carthage may have been very close to the turnaround point for the seaway at this time. This bed may have been covered or not fossiliferous at Carthage 1 (Fig. 6).

The upper Mulatto Tongue (Figs. 8A–C) is at least 73 ft (22 m) thick and composed primarily of gray, noncalcareous shale, with a thin coal bed near the base. The most conspicuous feature of the upper Mulatto, though, is not the resistant oyster bed (USGS locality D14480), but rather the many large calcareous concretions that the shale contains. These unusually large concretions (Figs. 8B, C) are elliptical, as much as 3 ft (1 m) high and 6 ft (2 m) long, and composed of bedded, fine-grained sandstone at the base, followed by bedded limestone and capped by a single cone-in-cone limestone layer as much as 6 in (15 cm) thick. Weathered prisms from the cone-in-cone layer litter the ground around the concretions (Fig. 8C).

The usual source of fossils is a thin ironstone layer that develops at the top of the sandstone layer in many large cone-in-cone concretions and often continues beyond the margins of the concretions as a distinct bed. These purplish-weathering ironstones are very fossiliferous near the base of the upper Mulatto at the D14480 level, where they yield an abundant and diverse fauna dominated by *F. elegans* (although no ammonites and no inoceramids). Higher in the section, the faunas are sparse and usually consist of one to a few small bivalves, for example at the D14862 level.

The basal carbonaceous shale, the higher cone-in-cone concretions, and the faunas of the upper Mulatto Tongue at Carthage 2 correlate very nicely with the Mulatto Tongue at Carthage 1 (compare Fig. 6 with Fig. 7).

In 2010, Gardner's (1910, p. 455, pl. XXI) Montana Group fossil locality was relocated in the SW¼ sec. 15 T5S R2E, approximately 50 ft (15 m) stratigraphically above the entrance to the Government coal mine, which is 1 mi (1.5 km) south of the townsite of Carthage. Gardner (1910, p. 455) listed four species of bivalves and two species of gastropods in his collection. The fossils from USGS locality D14917 consists almost entirely of the internal molds and impressions of oysters that occur in a 3-in-thick, fine-grained sandstone approximately 1 ft above a zone of very large, orange-weathering concretions in a shaly sequence. The calcareous shells of the oysters have been leached from the enclosing sandstone leaving a space around the internal mold, giving the rock a "worm-eaten" appearance. For the present, these oysters are

[1] *Crassostrea soleniscus* does not occur in the upper part of the Atarque Sandstone Member in the Carthage coal field area as reported by Cather (2007, description of maps units).

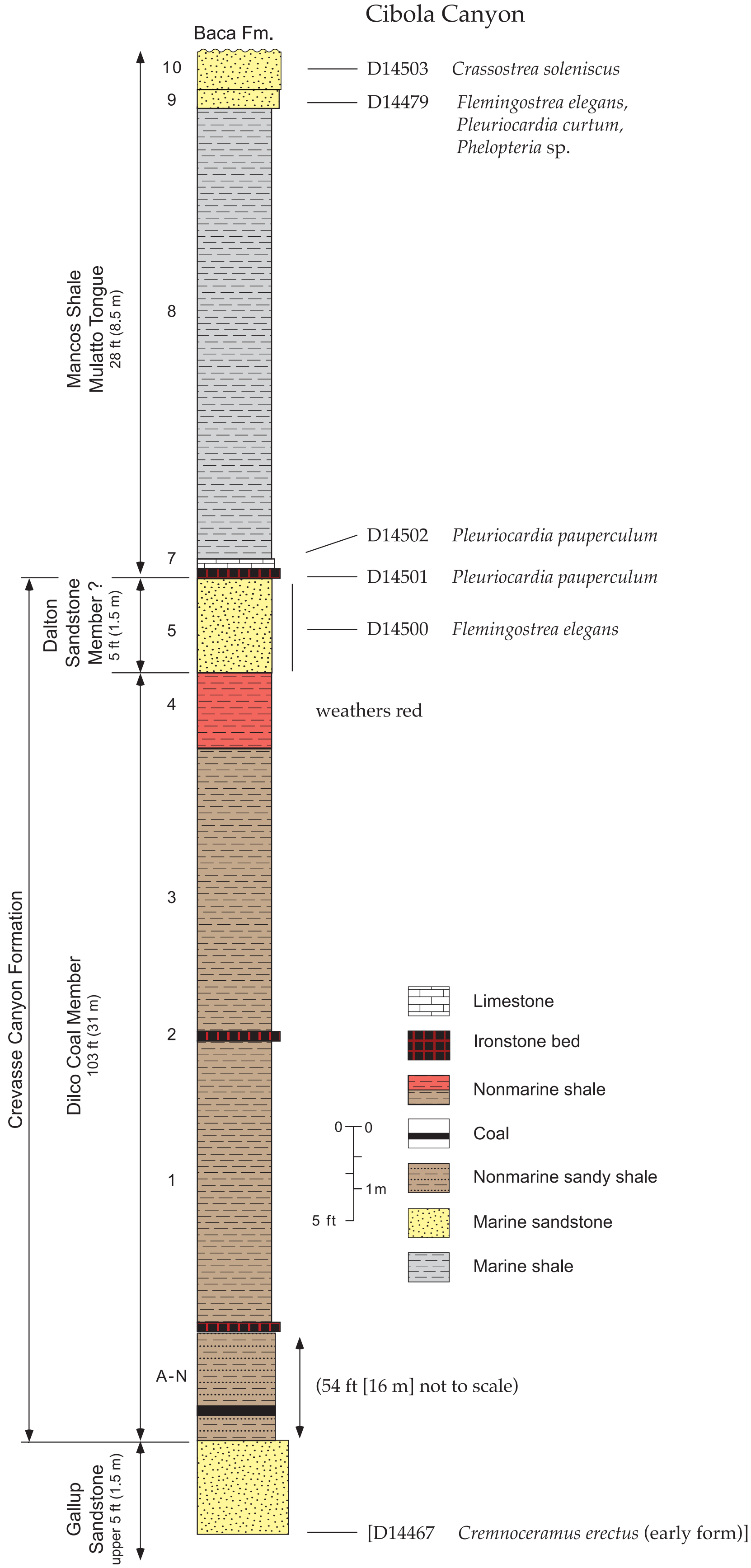

FIGURE 9—Cibola Canyon measured section showing the positions of the collections of *Flemingostrea elegans* from the Mulatto Tongue of the Mancos Shale and the Dalton Sandstone Member(?) of the Crevasse Canyon Formation. This section was measured on the slope below the hill with the spot elevation of 5,192 ft, located in the east-central portion of the La Joya 7.5-min quadrangle, Socorro County, New Mexico. [ ] indicates a collection from another locality. See Figure 1 for location.

referred to *Ostrea* sp. because they lack the characteristic terebratuloid fold of *Flemingostrea*. Internal molds of a single bivalve and a single snail were also collected from this level. Collection D14918, from approximately 5 ft (1.5 m) above D14917, yielded several specimens of *F. elegans*, preserved as original shell material, as well as a few gastropods and bivalves, including *Phelopteria* sp. and *Pleuriocardia* sp.

Both the Mulatto and the D-Cross Tongues of the Mancos Shale in the Carthage coal field consist of gray, noncalcareous shale that contains abundant, large, yellowish-orange-weathering, cone-in-cone concretions. These concretions are superficially similar, making the two tongues difficult to distinguish from each other in structurally complex areas. However, the cone-in-cone concretions in the Mulatto Tongue (Fig. 8C) tend to be larger and more elliptical than those in the D-Cross (Fig. 8D), and have bedded sandstone bases. The cone-in-cone structure is confined to the top of the Mulatto concretions (Fig. 8C), whereas it covers the entire D-Cross concretion (Fig. 8D). Weathered prisms from the Mulatto cone-in-cone layer commonly litter the ground (Fig. 8C).

Sevilleta National Wildlife Refuge area

In the northeast Socorro County, the best constrained section is the one from Cibola Canyon (Fig. 9) on the Sevilleta National Wildlife Refuge. This measured section begins at the top of the Gallup Sandstone and includes the Dilco coal bed mined at the Garcia y Goebel mine approximately 15 ft (5 m) above the base. Darton (1928, p. 75) made two collections of marine fossils from above the coal at this location. Stanton identified the abundant oyster from these two collections as *Ostrea elegantula*.

Here, articulated valves of *F. elegans* (D14500) occur in a 5-ft (1.5-m)-thick bed of very friable sandstone (unit 5) that is 103 ft (31 m) above the top of the Gallup Sandstone. Additional collections of *F. elegans* come from a 1-ft (30-cm)-thick bed of sandstone (D14479, unit 9) that is 133 ft (41 m) above the top of the Gallup Sandstone. The Dilco Coal Member of the Crevasse Canyon is about 103 ft (31 m) thick, and the Mulatto Tongue of the Mancos Shale, whose upper contact is an erosion surface, is at least 28 ft (8.5 m) thick. The 5-ft (1.5-m)-thick, fossiliferous sandstone (unit 5) is questionably referred to the Dalton Sandstone Member of the Crevasse Canyon. The presence of a *Crassostrea soleniscus* coquina (D14503) directly on top of the *F. elegans* sandstone (D14479) suggests that this 2-ft (61-cm)-thick, highly resistant sandstone (unit 10) is at or very near the top of the marine section.

The Gallup Sandstone on Sevilleta National Wildlife Refuge near the principal reference section for the Dakota Sandstone (Hook and Cobban 2007) contains large, dark-brown-weathering, highly fossiliferous concretions that yielded many specimens of lower Coniacian index fossil *Cremnoceramus*

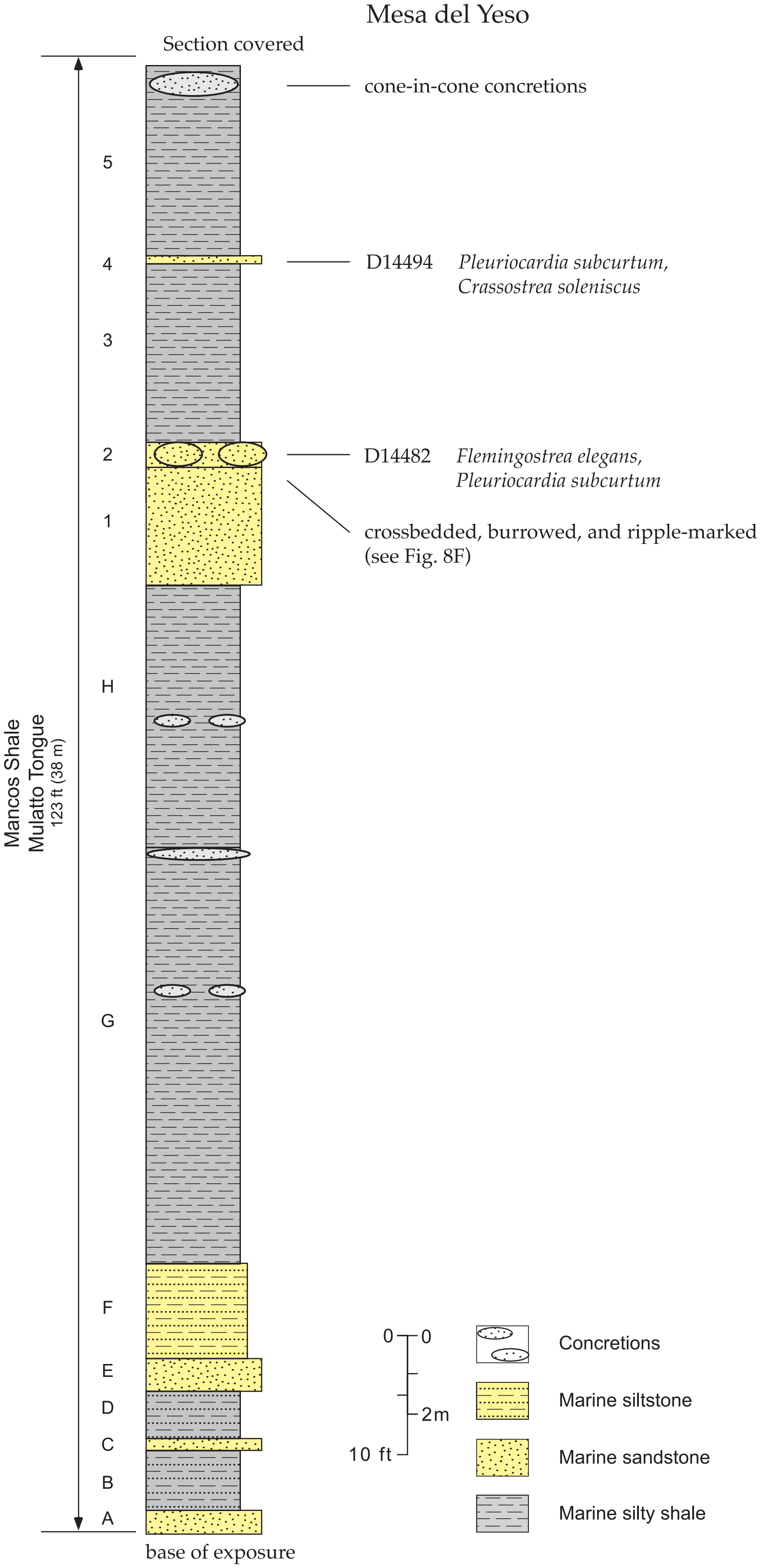

FIGURE 10—Mesa del Yeso measured section showing the positions of the collections of *Flemingostrea elegans* from the Mulatto Tongue of the Mancos Shale. This section was measured in the NW¼ sec. 32 T1S R5E, Mesa del Yeso 7.5-min quadrangle, Socorro County, New Mexico. See Figure 1 for location and Figures 8E and F for outcrop images.

erectus (Meek). Collection D14467 is from an outcrop approximately 2 mi (3 km) south of the Cibola Canyon measured section.

Farther to the southeast, the 123-ft (38-m)-thick section of sandy shale (Fig. 10) that emerges out of the alluvium (Fig. 8E) about a quarter of a mile southeast of Mesa del Yeso and the refuge's southern boundary in NW¼ sec. 32 T1S R5E, was initially one of the most puzzling Cretaceous sections in Socorro County. A 10-ft (3-m)-thick resistant bench of fine-grained, ripple-marked (Fig. 8F) and crossbedded sandstone, 80 ft (24 m) above the base of the section, stands in stark relief to the surrounding gray shales. The ripple marks have wavelengths of approximately 70 mm and amplitudes of approximately 10 mm. This bench is capped by a 2-ft (61-cm)-thick, even more resistant, purplish-weathering, sandstone concretion zone that is extremely fossiliferous. Fossils from this level (D14482) consist almost entirely of shells of *Flemingostrea elegans* and *Pleuriocardia subcurtum*. Initially, this shaly outcrop was thought to be the D-Cross Member of the Mancos Shale because of the similarity of this fossiliferous sandstone to the marker sandstone of Baker (1981) in the D-Cross Tongue on Sevilleta National Wildlife Refuge.

In 2004, when the D14482 collection was made, the D-Cross Tongue was the uppermost marine shale known from Socorro County. So, assignment to the D-Cross seemed to be the only viable choice. However, the faunas from the two sandstones are quite different; D11205 from the D-Cross marker sandstone is dominated by the early form of the oyster *"Lopha" sannionis* (see Hook and Cobban 2007, fig. 3), whereas the Mesa del Yeso fauna is dominated by *F. elegans*. The section at Cibola Canyon (Fig. 9) established that there were marine strata above the Gallup dominated by *F. elegans*. Consequently, all 123 ft (37 m) of this measured section have been assigned to the Mulatto Tongue. The lower 80 ft (24 m) of the outcrop consists of interbedded sandstones and silty shales, part of which may be nonmarine, but contain no fossils. Cone-in-cone concretions similar to those from the Mulatto Tongue at Carthage (Fig. 8C) have recently been observed at the east end of the outcrop belt approximately 20 ft (6 m) above the D14482 level. This Mesa del Yeso outcrop of Mulatto Tongue is mapped as the D-Cross Tongue on the preliminary geologic map of the Mesa del Yeso 7.5-min quadrangle (Cather et al. 2005).This outcrop was also visited by Darton (1928, p. 76), where he collected *Ostrea* sp. (= *F. elegans*) and *Cardium curtum* (= *P. subcurtum*).

Other areas

Jornada del Muerto coal field—Near the north end of the Jornada de Muerto coal field (Fig. 1), abundant *F. elegans* have been collected from an 8-in (20-cm)-thick, fine-grained sandstone (D14561) that is 116 ft (35 m) above the Gallup Sandstone and 60 ft

(18 m) above a 2-ft (61-cm)-thick coal bed in the Dilco. A resistant *C. soleniscus* coquina occurs 10 ft (3 m) above D14561. Most of the section between the top of the Gallup and the coquina is soft and covered. It is impossible to tell from field evidence which units below D14561 are marine. A conservative estimate for the thickness of the Mulatto Tongue in this area is 32 ft (9.8 m), which includes 20 ft (6 m) of the mostly covered, gray, noncalcareous, silty shale just below D14561 and the 10 ft (3 m) of the overlying shale up through the coquina. The Gallup Sandstone is unfossiliferous. The youngest fossils (D10571) in the D-Cross Tongue include the early (upper Turonian) form of "*L.*" *sannionis* from a limestone 15 ft (5 m) below the Gallup.

Riley—In northwestern Socorro County near Riley, Chamberlin et al. (2008) have mapped a 3-ft (1-m)-thick sandstone at the top of what they called the Dalton Sandstone Member of the Crevasse Canyon. This sandstone contains *C. soleniscus*, *P. pauperculum*, and *Phelopteria* sp. (D14627 and D14799), but not *F. elegans*. USGS locality D14627 is approximately 150 ft (46 m) above the top of the Gallup Sandstone and 40 ft (12 m) above the main Dilco coal bed. This fauna is similar to that generally associated with *F. elegans* to the southeast. Its stratigraphic position above the major Dilco coal bed along with its thinness suggests that the Riley, New Mexico, area was very near the turnaround point for the Mulatto sea. Additionally, a 1-ft (0.3-m)-thick sandstone, 14 ft (4.3 m) above D14627 contains abundant plant fragments, including a delicate leaf impression.

Lincoln and Otero Counties

Specimens of *F. elegans*, including the type lot, from Lincoln County, New Mexico, have come entirely from the Gallup Sandstone.

The best constrained collections of *F. elegans* are from the Gallup Sandstone southwest of Carrizozo. There, the basal lower Coniacian index inoceramid *Cremnoceramus erectus* occurs below *F. elegans* near the top of the D-Cross Tongue, and the uppermost lower Coniacian index inoceramid *Cremnoceramus crassus* occurs with *F. elegans* in the upper third of the Gallup Sandstone. Details of these occurrences are given below for the Jackson well and Bull Gap/Rim Rock measured sections.

Three older collections made between 1911 and 1925 contain *F. elegans*. These older collections have labels indicating they came from (1) above a Dilco coal bed in the Capitan area (USGS locality 13495), from (2) an unassigned sandstone in the White Oaks area (8071), and from (3) an unassigned sandstone, probably the Gallup, south of Carrizozo (7449). Otero County has yielded four collections of *F. elegans*, three from the Mancos Shale on the Mescalero Apache Indian Reservation and one from south of Three Rivers from the Gallup Sandstone.

Jackson well section

The Gallup Sandstone is extremely thick in Lincoln County compared to Socorro County. The most complete stratigraphic section is exposed along Jackson Draw. In 1968, E. R. Landis and W. A. Cobban (USGS) measured almost 400 ft (122 m) of sandstone and siltstone that they assigned to the Gallup Sandstone. The total thickness of the Jackson well section (Fig. 11) includes several mostly to partly covered intervals that may include some intertongued marine shale, but nothing thick enough to map as a separate unit. They placed the contact between the Gallup Sandstone and the Dilco Coal Member of the Crevasse Canyon at the top of a 15-ft (5-m)-thick pale-yellowish-brown, laminated sandstone (Fig. 11, unit 25). Above that is a 60-ft (18-m)-thick covered interval that contains a spoil pile from a Dilco coal prospect near the top. Although the top of the D-Cross Shale is not exposed along Jackson Draw, the fossils from the lowest resistant beds exposed are consistent with being at or near the base of the Gallup.

The lower 300 ft (91 m) of the Jackson well section is fossiliferous and lies entirely within the lower Coniacian. *Cremnoceramus erectus* appears first in the section approximately 120 ft (37 m) above the base (unit 10, D6767); it ranges through approximately 30 ft (10 m) of section to unit 14 (D6768). At both levels it is associated with the late form of "*Lopha*" *sannionis* and *Pleuriocardia curtum*. *Cremnoceramus crassus* appears in unit 17, approximately 214 ft (65 m) above the base of the Gallup and ranges through unit 23 (D6771), 300 ft (91 m) above the base, where it occurs in a coquina composed of *F. elegans*. *Flemingostrea elegans* has been observed but not collected in the section at approximately the D6765 level (unit 3), 12 ft (4 m) above the base, where it occurs with the late form of "*Lopha*" *sannionis*. *Flemingostrea elegans* ranges through almost 300 ft (91 m) of section, about three-quarters of the Gallup Sandstone exposed at Jackson Draw.

Approximately 50 ft (15 m) above the coal prospect, Landis and Cobban observed, but did not collect, poorly preserved, brackish-water bivalves (*Corbicula*? sp.) in a limy concretion interval. This observation suggests that the western shoreline may have advanced across southwestern Lincoln County after formation of the Dilco coal swamps. Ongoing mapping in the region may reveal the presence of the higher marine tongue (Mulatto Tongue?) in this area and the Capitan area where *F. elegans* has been reported from above the coal.

Cobban (1986) illustrated the following species from the Gallup Sandstone at the Jackson well section: *Cremnoceramus crassus* (identified as *Inoceramus erectus*, D6770, fig. 4A); *Legumen* sp. (D6765, fig. 4C); the late form of "*Lopha*" *sannionis* (D6768, fig. 6C, E); *Psilomya* sp., D6770 (fig. 8I-a); *Flemingostrea elegans* (as *Ostrea anomioides*, D6770, fig. 8I-b); *Pleuriocardia* sp., D6770, (fig. 8I-c); and *Liopistha* sp., D6775 (fig. 9M).

Bull Gap/Rim Rock Canyon section

The Bull Gap/Rim Rock Canyon section (Fig. 12) is one of the more important sections in Lincoln County because it is the only one in the county in which the upper part of the D-Cross Tongue of the Mancos Shale contains fossils that allow it to be dated definitively as early Coniacian. *Cremnoceramus erectus*, index fossil to the basal lower Coniacian, and *Scaphites frontierensis*, an ammonite formerly thought to be confined to the higher *C. deformis* Zone (Kennedy and Cobban 1991, p. 86), have been collected from large, orange-weathering limestone concretions in the D-Cross Shale, approximately 60 ft (18 m) below the base of the Gallup Sandstone (D12655).

In addition the type-lot specimens of *Flemingostrea elegans* (D14910), which exhibit beautiful preservation of completely articulated shells (Fig. 13), were collected here, approximately 118 ft (36 m) above the base of the Gallup (Fig. 8G). The lower 160 ft (49 m) of the Gallup Sandstone are well exposed, very fossiliferous (Fig. 8H), and laid out classically as two ridges separated by a valley (Fig. 8G). The section also contains the remnants of a 5-ft (1.5-m)-thick *Crassostrea soleniscus* oyster reef (D14907); broken fragments of the extremely thick shells of *C. soleniscus* litter the ground.

The dip slope of the first ridge is an extremely resistant, 4-in (10-cm)-thick coquina of *F. elegans* (D14908) that rests on top of the reef and is 41 ft (12.5 m) above the base of the Gallup. A poorly preserved cremnoceramid (*C. erectus*?) was observed on top of this bed.

Cremnoceramus crassus (D14875), index fossil to the upper lower Coniacian (Fig. 5), occurs in a limy, relatively coarse sandstone just below the top of the second ridge, approximately 134 ft (41 m) above the base of the Gallup. *Cremnoceramus crassus*, a relatively small species, occurs with abundant, well-preserved, late forms of *C. erectus* (Fig. 8H). Surprisingly, the middle lower Coniacian guide fossil, *C. deformis*, does not occur in this section or any other section in Lincoln County.

Normal marine faunas dominated by inoceramids and *F. elegans* alternate with brackish-water faunas dominated by *C. soleniscus* in this section, suggesting that the western shoreline advanced then retreated in this area a few times. However, there is no sedimentary evidence that the area was ever subaerially exposed during deposition of the initial 150 ft (50 m) of the Gallup Sandstone. Neither the top of the Gallup nor base of the Crevasse Canyon is exposed where this section was measured, just west of US–54.

Cobban (1986) illustrated the following species from the D-Cross Tongue of the Mancos Shale and the Gallup Sandstone at the Bull Gap/Rim Rock Canyon section: *Forresteria* sp. (D12655, fig. 4I, J); and *Cremnoceramus erectus* (D12660, fig. 5H and D12655, fig. 6B).

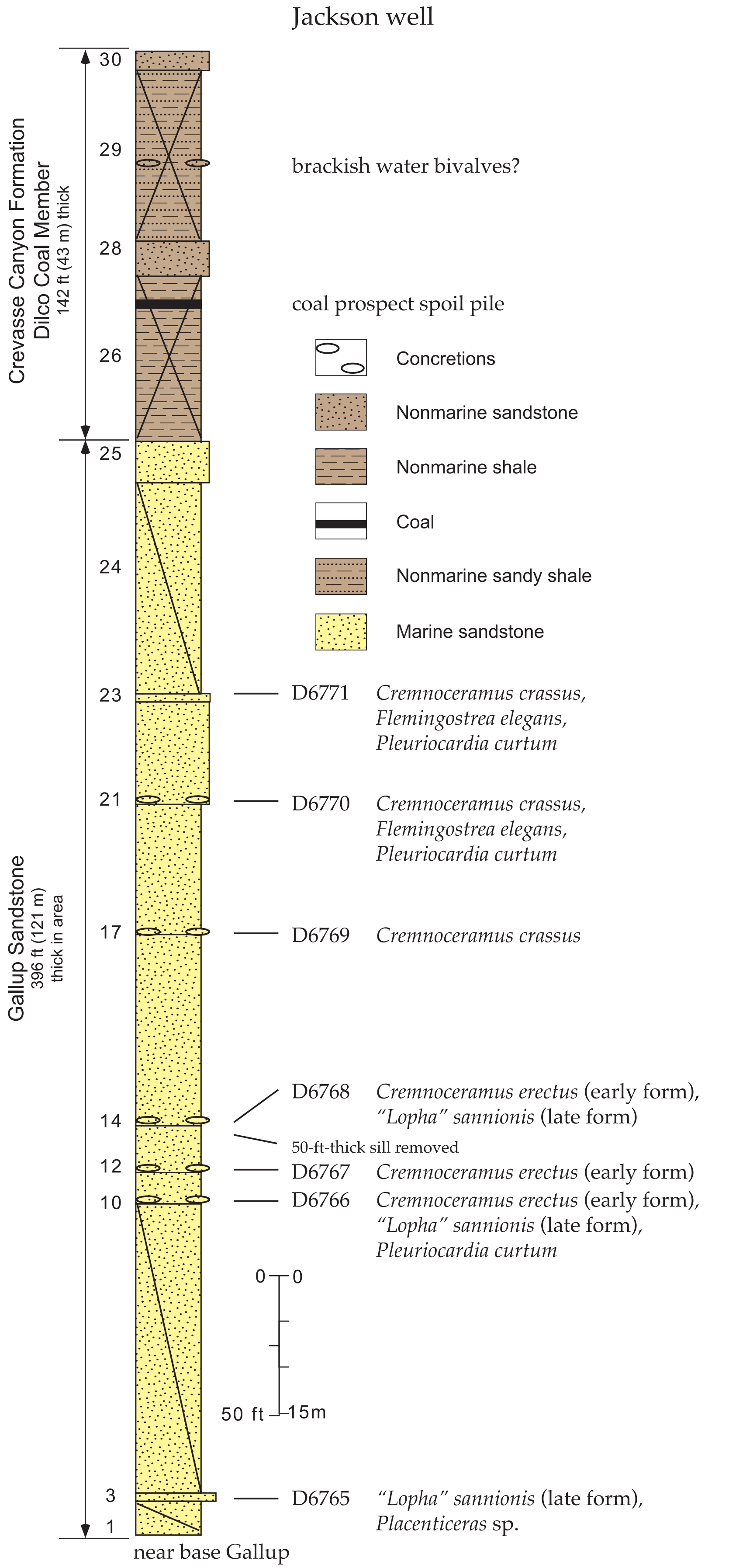

FIGURE 11—Jackson well measured section showing the positions of the collections of *Flemingostrea elegans* from the Gallup Sandstone. This section was measured in the SW¼ sec. 13 T10S R8E, Oscura 7.5-min quadrangle, Lincoln County, New Mexico. See Figure 1 for location.

Other areas

Three older collections from Lincoln County, New Mexico, that contain *F. elegans* have been found in the USGS Mesozoic Invertebrate fossil collections stored at the Federal Center in Denver, Colorado. These collections were made between 1911 and 1925 and have Washington, D.C., locality numbers, which are not preceded by the Denver letter "D." These collections were made in the Capitan, White Oaks, and Carrizozo areas.

Capitan—Washington collection 13495 contains several oysters identified originally as "*Ostrea elegantula*, Newb." The label indicates they were collected 1.5 mi (2.4 km) northwest of Capitan, New Mexico, from lower Colorado beds, on the west side of a fault, south 600 ft (183 m) from locality H-29. They are from a sandy clay at the top of a 25 ft (7.6 m) sandstone above a coal bed. They were collected by a geologist by the name of Hansen on May 26, 1925. The collection consists of six black specimens of *F. elegans*, including one articulated specimen 2.51 cm long by 3.13 cm high by 1.12 cm thick with a well-developed terebratuloid fold. One upper valve is 1.19 cm thick. This collection, which appears to be from a unit above a Dilco coal, indicates that the Capitan area experienced the Mulatto transgression of the seaway following the Gallup regression.

Bodine (1956) in a study of the Capitan coal field reports several fossiliferous beds in what he called the Mesaverde group. All his fossils are from either his lower sandstone member or the lower part of his middle shale unit; all the coals occur in the upper part of his middle shale unit. *Flemingostrea elegans* (D 10471) was collected from unit 14 of his lower sandstone unit, a 4-ft (1.2-m)-thick, very fossiliferous, quartzose sandstone that is 55 ft (17 m) below the middle shale (Bodine 1956, p. 20, table 1). Bodine (1956, p. 7) reports *Cardium pauperculum* from the base of the middle shale. Both of these localities are from below the major coal seams in the Crevasse Canyon Formation; they would probably be placed in an intertongued sequence of Gallup Sandstone and Mancos Shale using the more refined stratigraphic nomenclature available at this time.

White Oaks—Washington collection 8071 is a small lot containing *F. elegans* and the marine snail *Turritella* sp. This collection was made 2 mi (3.2 km) east of White Oaks. It came from 16 ft (4.9 m) above the top of the sandstone mentioned at locality 212, from beds of Benton age. Carroll H. Wegemann collected these fossils on October 18, 1912, as part of the White Oaks project (Wegemann 1914). There is no record of locality 212. One beautiful specimen of *F. elegans* is 4.44 cm high by 3.19 cm long by 2.79 cm thick. According to Wegemann (1914, p. 430) collection 8071 came from 65 ft (20 m) above the base of his formation 2, a 400-ft (122-m)-thick mixed

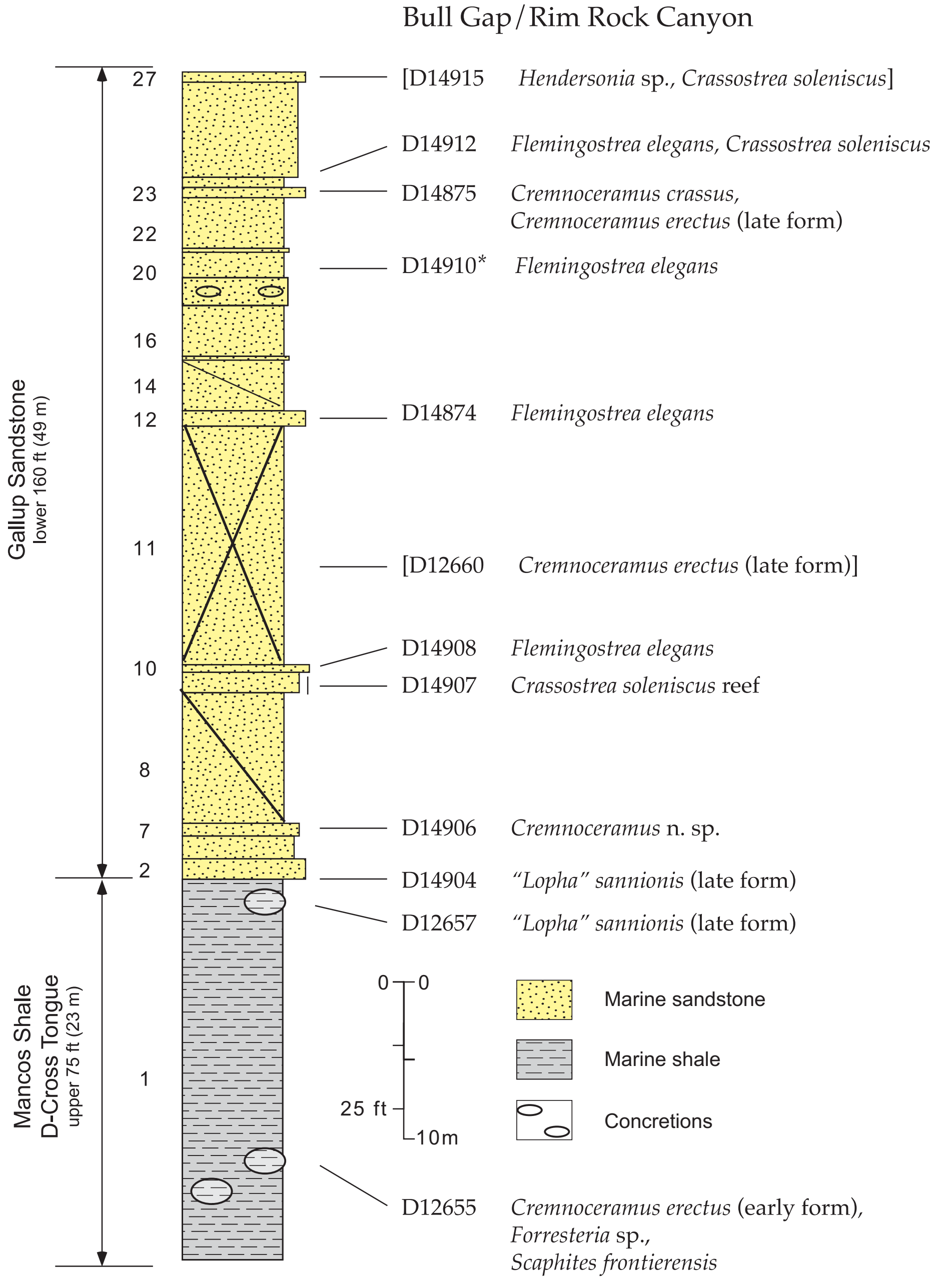

FIGURE 12—Bull Gap/Rim Rock Canyon measured section showing the positions of the collections of *Flemingostrea elegans* from the Gallup Sandstone. Units 1–25 of this section were measured in the SW¼ sec. 17 T9S R8E, Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico; units 26–27 were measured in the SW¼ sec. 8 T9S R8E. An asterisk (*) indicates the type lot collection; [ ] indicates a collection from Rim Rock projected into strata from Bull Gap. See Figure 1 for location and Figures 8G–H for outcrop images.

lithology unit below the coal-bearing formation. Another collection, 8072, from near the top of formation 2, also contained *F. elegans*. In both collections *F. elegans* was identified as *Ostrea* sp. by T. W. Stanton.

Carrizozo—Washington collection 7449 contains several specimens of *F. elegans* along with specimens of the marine gastropods *Pugnellus* sp., *Turritella* sp., *Gyrodes* sp., and the marine bivalve *Cyprimeria* sp. It was collected on the east slope of Willow Hill, on the east side of the railroad, approximately 4 mi (6.4 km) and a little east of Coyote Hill, Tularosa Basin, south of Carrizozo, New Mexico. It contains two medium-sized, articulated specimens of *F. elegans*, one with crinkles. One specimen is 4.1 cm high by 3.74 cm long by 1.76 cm thick. The collection was made by O. E. Meinzer in 1911 and is the fifth of five fossil collections that Meinzer and Hare (1915, p. 65) list from the Cretaceous of the Tularosa Basin. A note added later in different handwriting indicates the collection is probably from the "Montana Group."

Systematic paleontology

Genus *Flemingostrea* Vredenburg, 1916

Type species—*Ostrea flemingi* D'Archiac and Haime, 1853, from the lower Eocene of Pakistan (Stenzel 1947, p. 174).

Diagnosis—medium- to large-sized oyster with subequal, ovate to triangular valves and a prominent, broad (terebratuloid) fold opposite to the hinge that appears gradually in later growth, creating a hump in the profile of the left (lower) valve and a tongue-like extension in the right (upper) valve. Right valve during early growth is flat. Many species have regularly spaced concentric growth rings that are generally evenly spaced. Attachment scars are small to absent. The adductor muscle imprint is relatively large and kidney shaped. The shell wall can be exceptionally thick in the umbonal area.

Occurrence—*Flemingostrea* occurs in Cenomanian (Upper Cretaceous) through the Miocene (Tertiary) rocks in North and South America, Africa, Asia, and Russia.

Discussion—Stenzel (1959, p. 32) states that "A peculiarly folded shell, showing in a terebratuloid fold at the margin opposite the hinge, is characteristic of the genus…" He (p. 32) documents the following evolutionary trends within *Flemingostrea*: (1) gigantism, (2) progressive development of radial sculpture from feeble frills of the foliaceous lamellae to spinose processes, and (3) progressive change in shell outline from ovate to orbicular to triangularly distorted. Surprisingly, all of these trends except development of spines, are evident to some degree within the populations of *F. elegans* recorded within the lower Coniacian of New Mexico. Stenzel (1959, p. 32) notes further that these evolutionary changes occurred slowly and feebly, "…so that the species do not differ materially from each other."

Distribution—There are only three species of the genus *Flemingostrea* known from the Western Interior. The oldest species, *F. prudentia* (White) (see p. 49, Figs. 14F–G), occurs in the upper Cenomanian *Metoicoceras mosbyense* Zone. Cobban and Hook (1984, fig. 4) show the known distribution of *F. prudentia* in an arcuate belt of brackish-water rocks that is parallel to the western shoreline of the Late Cretaceous Seaway during *M. mosbyense* time in the Black Mesa–Kaiparowits Plateau area of Arizona and Utah. The middle species, *F. elegans,* n. sp., occurs in the lower Coniacian of central New Mexico. The youngest species, *F. nanus* (Johnson), redescribed below, is from the Santonian of New Mexico.

***Flemingostrea elegans*, n. sp.**
Figures 2, 3, 4, 13

Ostrea elegantula; Darton (1928, pp. 75–76).
Ostrea anomioides; Osburn and Arkell (1986, p. 40).
Flemingostrea aff. *prudentia*; Arkell (1986, pp. 75–76).
Ostrea anomioides Meek; Cobban (1986, p. 88, fig. 6H–I).
Ostrea elegantula White; Cather et al. (2005, description of map units).
Flemingostrea elegantula; Hook and Cobban (2007, p. 79, fig. 3).

Types—Holotype, specimen no. 51, Appendix, p. 56, (USNM 542207), USGS locality D14910, Fig. 13A;

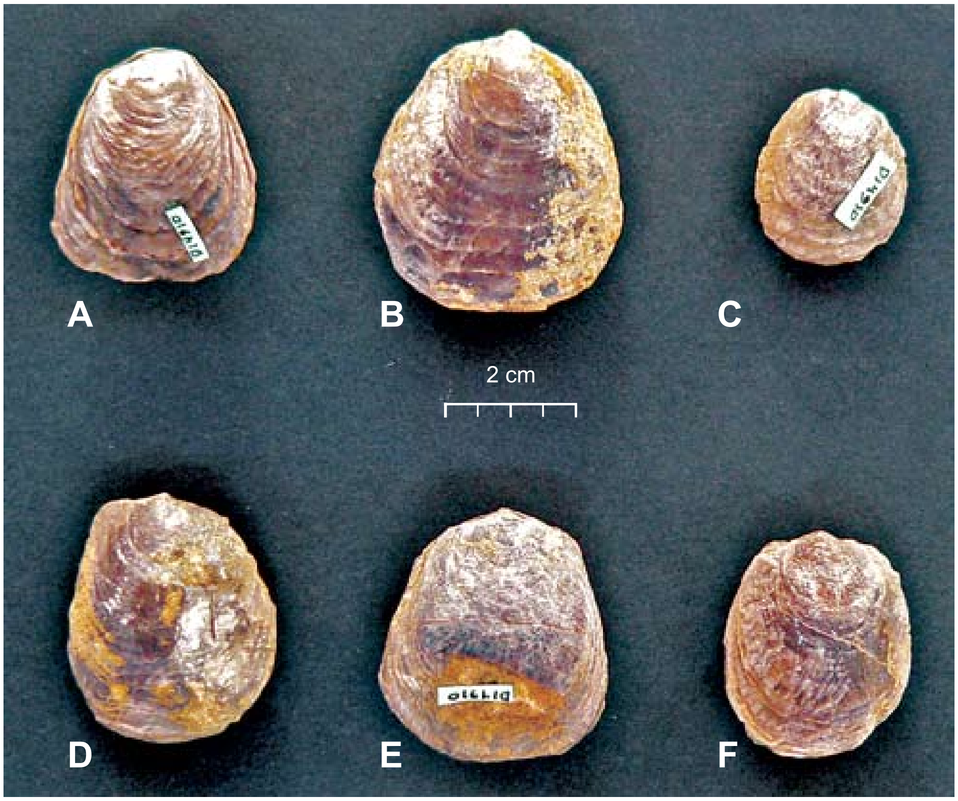

FIGURE 13—External views of the type specimens of *F. elegans*, n. sp., all from USGS locality D14910 at Bull Gap Canyon, Lincoln County, New Mexico. **A—**Upper valve of the holotype, specimen no. 51 (USNM 542207). **B—**Lower valve with crinkles and a small attachment scar, paratype, specimen no. 52 (USNM 542208). **C—**Lower valve with a small attachment scar, paratype, specimen no. 56 (USNM 542212). **D—**Lower valve, paratype, specimen no. 54 (USNM 542210). **E—**Upper valve of a paratype, specimen no. 55 (USNM 542211). **F—**Lower valve with crinkles, paratype, specimen no. 53 (USNM 542209). The largest specimen, **B**, has a height of 41.4 mm and a length of 36.7 mm. Reduced 0.9 ×.

Paratypes, specimen nos. 52–56, Appendix, (USNM 542208–542212), USGS locality D14910, Fig. 13B–F;

Paratype (USNM 542213), USGS locality D14559, Fig. 2;

Paratype (USNM 542214), USGS locality D14500, Fig. 3; and

Paratype (USNM 542215), USGS locality D6770, Fig. 4.

Description—*Flemingostrea elegans* conforms to most of the features of the genus but is quite variable in size, shape, and valve thickness. The species is of medium size with subequal valves. Specimens from the type lot (see Appendix, p. 56), collected at the Bull Gap/Rim Rock Canyon section, are typical of the species. These 67 specimens average 32.3 mm in height, 28.1 mm in length, and 13.2 mm in thickness. The largest illustrated specimen, paratype USNM 542213 (Fig. 2) is the largest specimen collected from the Carthage area, with a minimum height of 50.4 mm, a length of 40.9 mm, and a thickness of 18.3 mm. Although this paratype's dimensions are about 1.5 times greater than the averages for the type lot, they are not out of line with the maximum dimensions measured: a maximum height of 41.5 mm, a maximum length of 39.9 mm, and a maximum thickness of 23.3 mm. However, an incomplete (broken) specimen from the type lot was probably similar in size: specimen no. 31 from the type lot has a reconstructed height[2] of 47.9 mm, a measured length of 39.9 mm, and a measured thickness of 23.3 mm.

An articulated shell is plano-convex and develops a prominent, broad terebratuloid fold in later adult growth. Upper (right) valves appear to be composed of a series of stacked, calcite plates, each about a millimeter thick (Figs. 3B and C); they are initially flat and subcircular before changing inclination abruptly in mature growth. Individual valves range from almost circular to oval. All specimens have short hinge lines with small, but prominent, slightly off-center beaks that project only a millimeter or two beyond the hinge line.

Upper (right) valves are flatter than lower valves, but conform to the shape of the lower valve. The adductor muscle scar is reniform (i.e., bean shaped); is relatively large, about one-third of the valve height; about 1.5 times as high as long; and subcentrally located (see Fig. 3A). Upper valves have concentric ornamentation almost exclusively; about 40% of lower valves may develop some radial elements that augment the concentric growth bands and produce the crenulations that Stephenson (1936) called crinkles (Figs. 13B and F). Chomata (small denticles located near the hinge line) are absent.

The articulated paratype USNM 542213 from Carthage (Fig. 2) has faint radial "gashes" out to a length of 16 mm. These gashes radiate outward from the beak, forming angles of approximately 45° with respect to the hinge line and giving the shell a crenulated appearance. This specimen, which is not complete, has a minimum height of 50.4 mm, a length of 40.9 mm, and a thickness of 18.3 mm. The upper valve changes slope and becomes mature at a height of 37.1 mm. The valves of this specimen are open approximately 8 mm at the ventral margin, and the shell is filled with matrix. Its ventral view, therefore, shows the terebratuloid fold that is characteristic of the genus *Flemingostrea* (Fig. 2).

Attachment scars are absent on all but a few of specimens. Only three specimens in the type lot have attachment scars (see Appendix, p. 56); all are small, less than 2 mm across; two of these specimens are illustrated (Figs. 13B and C). No individual in any of the collections grew on another. The calcitic valves of *F. elegans* are generally preserved as original shell material. Internal molds are probably the result of breakage of the shells after they weather free from the matrix.

Etymology—The specific name *elegans* (handsome) is in homage to Dr. John Strong Newberry's early contributions to the geology of New Mexico and a way to retain the flavor of his species *elegantula* (quite handsome). For a variety of reasons detailed in a later section of the paper (see p. 51), Newberry's species name is unacceptable and should be treated as a *nomen oblitum*, a forgotten name.

Occurrence—Collections come from 35 localities in central New Mexico, primarily in Lincoln and Socorro Counties but also from Valencia, Bernalillo, and Otero Counties. The best-dated occurrences are in Lincoln County, where the lowest occurrence of *F. elegans* is with or above *Cremnoceramus erectus* (Meek) and the highest occurrence is with or above *C. crassus* (Petrascheck). These two species of *Cremnoceramus* date occurrences of *F. elegans* as early Coniacian. At the Bull Gap/Rim Rock Canyon section (Fig. 12), *F. elegans* occurs in beds above the last occurrence of *C. crassus*, suggesting that it may range higher in the section.

Type lot—The holotype and five paratypes all come from USGS locality D14910, NE¼ SW¼ SW¼ sec. 17 T9S R8E, Bull Gap 7.5-min quadrangle, Lincoln County, New Mexico (Fig. 8G). The types and 61 other well-preserved specimens are from a 5-ft (1.5-m)-thick, soft, slope-forming sandstone interval that is 118 ft (36 m) above the base of the Gallup Sandstone. This unit seems to be the source of completely articulated, loose specimens that roll down the scarp slope of the second Gallup ridge. The specimens from the type locality do not represent a random sample; they were collected

[2]The height was reconstructed by multiplying its length of 39.9 mm by the average H/L aspect ratio of 1.2 from the Appendix (p. 56).

because they were well preserved. They represent articulated specimens or complete internal molds.

The holotype, USNM 542207, (Fig. 13A) is a matrix-free, completely articulated specimen that is 34.1 mm high by 27.9 mm long by 17.8 mm thick. The shell outline is oval with the height 1.22 times greater than the length. Judging by the point of inflection on the upper valve, it reached maturity at a height of approximately 20.7 mm. Both valves lack radial elements.

The 67 specimens from D14910 have: (1) an average height of 32.3 mm, with a range of 20.5 mm to 41.5 mm; (2) an average length of 28.1 mm, with a range of 15.8 mm to 39.9 mm; (3) an average thickness (inflation, measured across both valves) of 13.2 mm, with a range of 5.8 mm to 23.3 mm; and (4) an average maturation height of 20.3 mm, with a range of 13.4 mm to 26.5 mm. On average the height is 1.2 times the length on specimens for which both measurements could be obtained, meaning that the specimens from the type lot tend to be oval in outline. However, the range is from 0.99 (circular) to 1.34 (elongate oval). *Flemingostrea elegans* tends to be a slender species with an average height that is 2.6 times greater than the average thickness. However, the ratio of height to thickness ranges from 1.92, fairly plump, to 3.76, thin. Twenty-five of the specimens have radial elements, including two right valves; this represents 40% of the subsample that could have preserved crinkles. Four of the specimens are internal molds that do not show external characteristics of the valves.

Measurements for the entire 67-specimen type lot including the holotype and five paratypes can be found in the Appendix on p. 56. The most subjective measurement in this table is that for height at maturity, which was generally made on the upper valve from the beak to the approximate inflection point. This measurement was even more subjective when only the lower valve was available. Then, this partial height was measured from the beak to the estimated point where the fold deformed the shell into a hump. Interestingly enough, this calculated maturation height of 20.3 mm is almost exactly what Stenzel (1971, p. N1150) indicated in his description of the (larger members of the) Tribe Flemigostreini: "[The] Terebratuloid fold makes its appearance at [a] fairly advanced stage of growth, commonly when [the] shell reaches a height of approximately 2 cm. At that place growth changes its direction, and a prominent smooth hump in [the] shell profile is the result."[3]

Paleoecology—*Flemingostrea elegans*, n. sp., is an epifaunal suspension feeder that occurs in nearshore sandstones, often in association with normal marine bivalves such as *Pleuriocardia* spp. and *Phelopteria* sp., but also with (and above and below) the brackish-water oyster *Crassostrea soleniscus* (Meek). The nearshore, high-energy environments in which it is found often had sedimentation rates high enough to bury fully articulated shells. This indicates that there were at least occasionally high influxes of fresh water into the seaway. This suggests that *F. elegans* was able to tolerate a relatively wide range of salinities from normal marine to brackish, but always on the seaward side of the shoreline.

The lack of attachment scars on all but a few of the more than 200 specimens in the collections indicates that *F. elegans* was a free-lying oyster as an adult, probably with the lower valve partially buried in the sediment on the sea floor. One unillustrated specimen has a smooth subcircular scar approximately 7.9 mm in diameter.

Discussion—*Flemingostrea elegans* occurs in great numbers and always in sandstones, indicating a preference for high-energy environments. The closer the environment was to the shoreline, the thicker the shell and the less likely the valves are to be articulated or in life position. For example, at the Cibola Canyon section (Fig. 9) the thickest right valve from the low-energy environment at the D14500 level is 4.8 mm; a typical right valve from the high-energy environment at the D14479 level is 7.9 mm.

Articulated shells, for example those from the type lot (D14910), are indicative of an environment of deposition with a relatively high, intermittent sedimentation rate. In living oysters the ligament acts like a spring to hold the valves open; the adductor muscle keeps the valves closed. Thus, when the oyster dies and the muscle deteriorates and relaxes, the shell opens and the valves are at the mercy of waves and currents. Thus, the beautiful preservation of articulated valves at USGS locality D14910 indicates this population of oysters was buried very rapidly to a depth where the weight of the overlying sediment was greater than the force exerted by the ligament.

Occurrences of *Flemingostrea elegans* are more often associated with abundant *Pleuriocardia curtum* (Meek and Hayden) or *P. subcurtum* (Meek) than with the lower Coniacian inoceramid zonal index species of *Cremnoceramus*.[4] Molenaar et al. (1996, fig. 2) show that *C. erectus* and *P. curtum* share a common range. This situation is advantageous for field recognition because the small heart-shaped "*cardiums*" with radial ribs that often weather white are easier to find and identify than the inoceramid.[5]

Flemingostrea elegans has been misidentified as *Ostrea elegantula*, *Flemingostrea prudentia*, and *Ostrea anomioides* for more than 100 yrs (see Fig. 14). For more detail the reader is referred to the discussion on the history and usage of *Ostrea elegantula* beginning on p. 51. The upper valves of all three species, especially in the immature stage, resemble each other. *Flemingostrea elegans* differs from both *O. elegantula* and *O. anomioides* in possessing a terebratuloid fold in the mature shell, which places it in the genus *Flemingostrea*. *Flemingostrea prudentia* has a curved axis and is more circular in outline (Figs. 14F and G). The superficial resemblance between *F. elegans* and *O. elegantula* falls apart in the details. First, *elegans* has a fold in the adult shell; *elegantula* does not. Second, *elegans* has a reniform adductor muscle scar; *elegantula* has an oval one (White 1883, pl. XXXVI, fig. 6; reproduced as Fig. 14E). Third, *elegans* lacks chomata, which *elegantula* has (see White 1883, pl. XXXVI, fig. 6; reproduced as Fig. 14E).

This description of *F. elegans* has emphasized attributes that a field geologist can recognize because this oyster species should be a useful field tool. Tree cover in the higher elevations in Lincoln County can make it very difficult to differentiate the Coniacian strata from similar-appearing Turonian strata, for example, sandstones in the Tres Hermanos Formation. Mapping occurrences of *Flemingostrea elegans* can help with this task.

Stephenson (1936) recorded *Ostrea elegantula* from the Santonian of the Gulf Coast. His Santonian specimens are probably a different species, more related to *O. bella* (Conrad) as illustrated by White (1883, pl. XXXIX, fig. 6). Akers and Akers (2002, p. 196) regard *O. bella* as a Campanian species in Texas. Both *O. bella* and Stephenson's *O. elegantula* are characterized by radial shell architecture and lack the terebratuloid fold characteristic of *Flemingostrea*. Also, Stephenson's species has chomata (numerous small denticles near the hinge), which *elegans* lacks and a much smaller adductor muscle scar than *elegans* has. See, for example, Stephenson (1936, pl. 1, fig. 9). The lack of the terebratuloid fold in both *bella* and Stephenson's *elegantula* indicates that they are not species of *Flemingostrea*.

Valves of juvenile *Flemingostrea elegans* bear a strong resemblance to *O. anomioides* Meek (Figs. 14 A and B) and have been misidentified as *O. anomioides*. However, *Ostrea anomioides* is a smaller, older species. Upper valves of the two are quite similar, but mature lower valves of *O. anomioides* lack the terebratuloid fold that places *elegans* in the genus *Flemingostrea*. *Ostrea anomioides* is now known to be an upper Albian species with a known distribution confined to western Montana (Dyman et al. 2000).

Stenzel (1959, pp. 32–33) assigns 11 species of oyster to the genus *Flemingostrea*, of which only the brackish-water form, *F. prudentia* (White 1877; Figs. 14F and G) occurs in the Western Interior. Eight of these eleven species occur in Cretaceous rocks, but only one of those eight, *F. oleana* (Stephenson 1945), is assigned to the lower

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[3]Stenzel (1959, pp. 32–33) did not include the dwarf species *Ostrea anomioides var. nanus* as part of the Tribe Flemigostreini. *Flemingostrea nanus* reaches maturity at a height of approximately 1 cm. See description of *F. nanus*.

[4]See Cobban (1986, figs. 4A, 4B) for illustrations of *C. crassus* (identified as *I. deformis*) and *P. curtum*, respectively.

[5]See Cobban (1986, fig. 8I) for typical examples; here, several specimens of "*cardium*" (labeled "c") are on a slab of sandstone associated with an upper valve of *F. elegans* (identified as *O. anomioides* Meek and labeled "b") and an unlabeled lower valve of *F. elegans* in the lower left of the photograph.

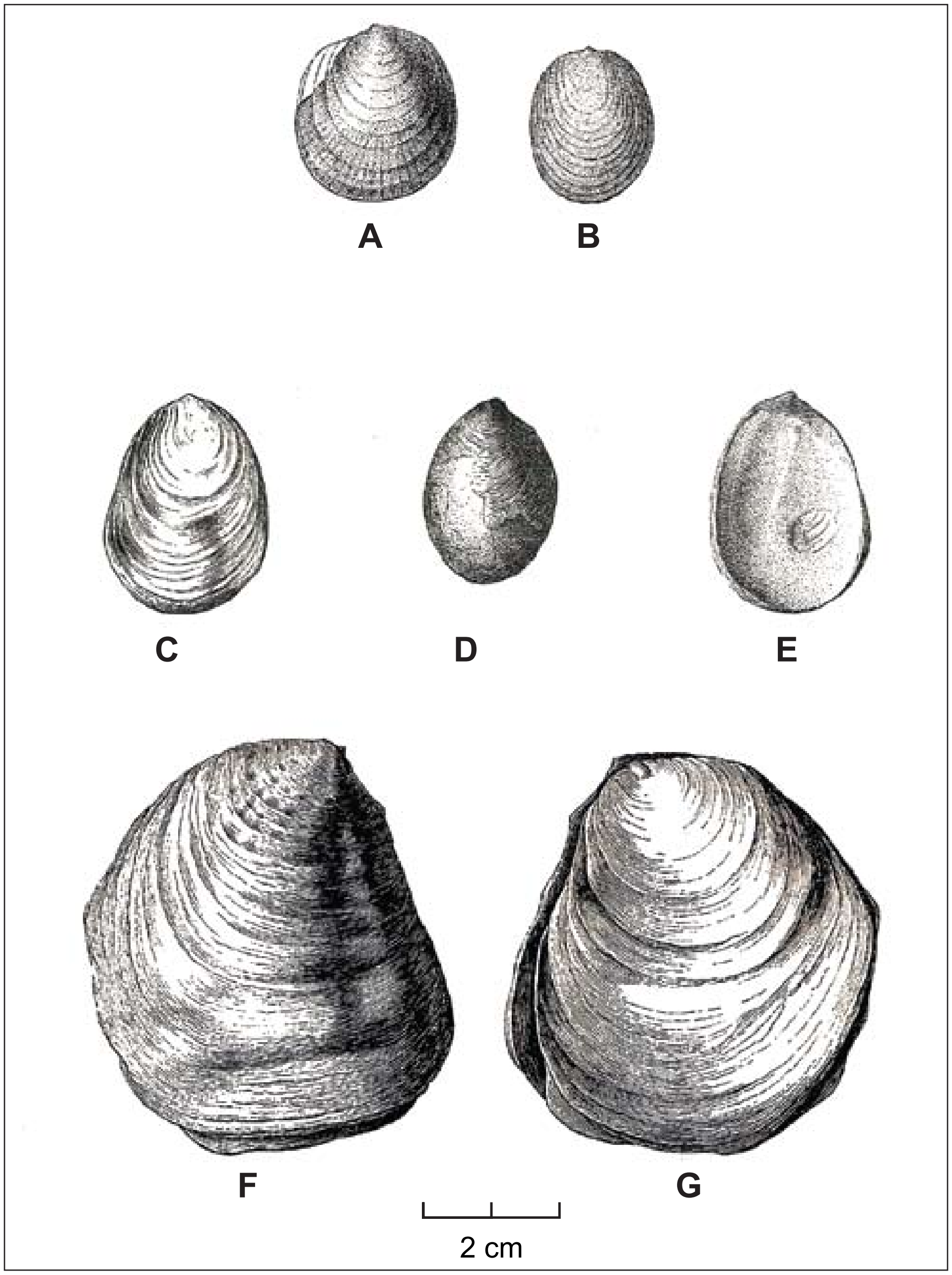

FIGURE 14—Comparison of three oyster species with which *Flemingostrea elegans*, n. sp., has been confused: *Ostrea anomioides* Meek (A, B); *O. elegantula* Newberry (C–E), and *Flemingostrea prudentia* (White) (F, G). All illustrations are from White (1883; A, B: pl. XXXIX, figs. 4, 5; C–E, pl. XXXVI, figs. 5–7; F, G: pl. XL, figs. 5, 6). **A—**Exterior view of a lower valve of *O. anomioides*. **B—**Exterior view of an upper valve of *O. anomioides*. **C—**Exterior view of an upper valve of *O. elegantula*. **D—**Exterior view of a lower valve of *O. elegantula*. **E—**Interior view of **C**. **F—**Exterior view of a lower valve of *F. prudentia*. **G—**Exterior view of an upper valve of the same specimen of *F. prudentia*. Reduced 0.9 ×.

Coniacian. Stephenson (1945) described *Ostrea oleana* from Jasper and Wayne Counties, Mississippi, where it is known only from core samples from deep petroleum wells. *Flemingostrea oleana* occurs in glauconitic sandstones just below beds with *Pycnodonte aucella* (Roemer), a species that is not known from New Mexico. It does, however, occur nearby in eastern Colorado (D14050) and in western Kansas, both in the basal part of the Fort Hays Limestone Member of the Niobrara Formation along with *Cremnoceramus deformis* (Hattin 1977, fig. 14). Stephenson's species, *oleana*, like most members of the genus, bears a strong resemblance to *F. elegans*. This is especially true in the aspect ratio of height to length in which an adult specimen of *oleana* has exactly the same aspect ratio of 1.2 as the type lot of *F. elegans* (Appendix, p. 57).

Flemingostrea oleana differs from *F. elegans* in the following three key characteristics. First, the terebratuloid fold in *F. oleana* is off center, located on the anterior side of the oyster; that is, the axis of the fold is on the right side of the left valve and the left side of the right valve in exterior views (see Stephenson 1945, figs. 1, 3, respectively). Second, *F. oleana* is a more inflated (plumper) species, with an adult height to thickness ratio of 1.9 versus 2.6 for *F. elegans*, and a juvenile of *oleana* has a ratio of 1.8. Most of the inflation occurs in the upper valve of *F. oleana*, which is more convex initially than the flat portion of the upper valve of *F. elegans*. This gives the juvenile portion shell a convexo-convex profile, rather than the plano-convex profile of *elegans*. Third, *F. oleana* lacks crinkles, the radial elements that characterize a little more than a third of the type sample of *F. elegans*. Stephenson (1945, p. 74), in distinguishing *F. oleana* from *F. battenesis* (described originally as *Ostrea johnsoni* Stephenson 1936) qualifies the lack of radial elements in *oleana* by saying that if they are present, then they are "…obscure and delicate." None are shown in his line-drawing illustrations (Stephenson 1945, figs. 1–7). *Flemingostrea battenesis*, which is probably a slightly younger species than *F. oleana*, has a more convex right valve and a sinusoidal commissure, the line of closure between the two valves.

Geographic distribution—*Flemingostrea elegans* is known only from lower Coniacian rocks in New Mexico with documented occurrences in Socorro, Lincoln, Santa Fe, Bernalillo, Otero, and Valencia Counties.

Flemingostrea nanus (Johnson 1903)

Figure 15

Ostrea anomioides var. *nanus* Johnson; Johnson (1903, p. 185, pl. 1, figs. 10a–d).

Ostrea anomioides var. *nanus* Johnson; Shimer and Blodgett (1908, p. 61).

Illustrated specimens—(USNM 542216–542221); USGS locality 22861, Fig. 15A–F. Johnson's (1903, pl. 1, figs. 10 a–d) four illustrated specimens, none of which is designated as the holotype, are apparently stored at Columbia University, in the paleontology collections under the acquisition number 14961.

Description—*Flemingostrea nanus* is a small oyster species that appears to be a scaled-down version of *F. elegans*. The shell is small, thin, plano-convex, ovate or circular in outline, and lacks an attachment scar. The lower valve is shallow with a small beak that projects just beyond a straight hinge line. The adductor muscle scar is subcentral, impressed, and subreniform. The upper valve is nearly flat and bears an indistinct muscle scar. The surfaces of both valves are ornamented with concentric growth lines, which are more prominent on the upper valve. Fine radiating striae can be seen near the anterior margin on the lower valve of a few specimens. The average specimen collected by Johnson (1903) has a height of 13 mm, a breadth of 10–13 mm, and a convexity of 3 mm. The average height of the six specimens in Figure 15 is 17.4 mm; the average length is 13.6 mm. Height at maturity for the specimens shown in Figure 15 is between 10.2 mm and 12.3 mm.

Etymology—Johnson (1903, pp. 113–114) used the varietal name *nanus* ("dwarf")

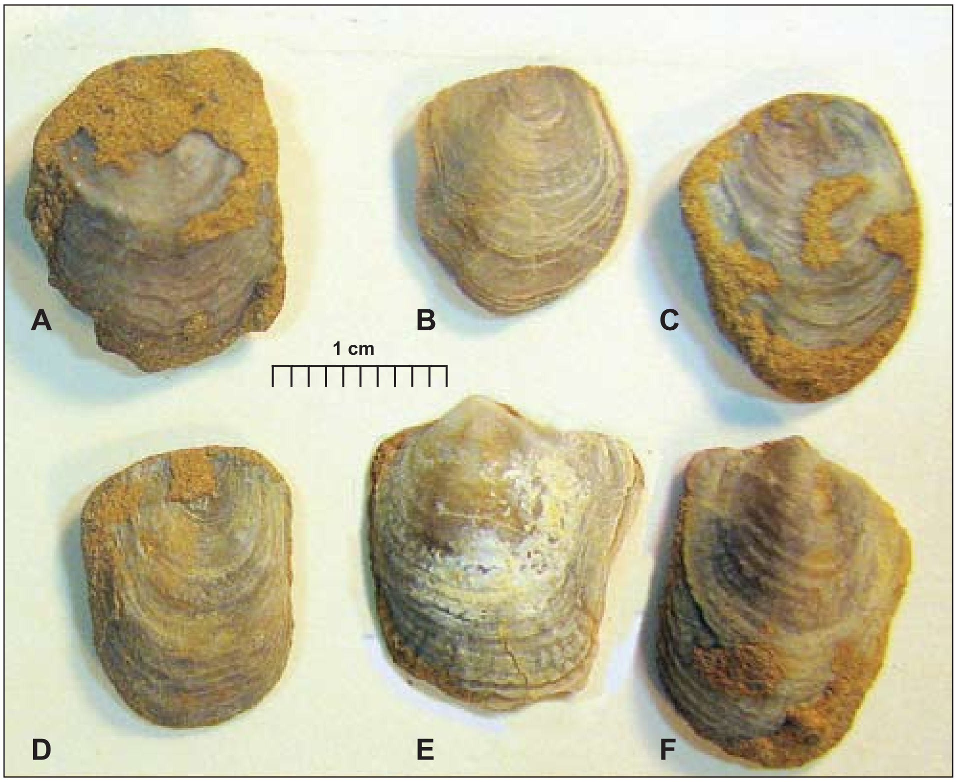

FIGURE 15—Exterior views of figured specimens of *F. nanus* (Johnson), all from USGS locality 22861 at the Tonque Arroyo section, Santa Fe County, New Mexico. **A**—Upper valve of USNM 542216 showing a well-developed change in slope. **B**—Lower valve of USNM 542217 showing minor radial elements. **C**—Upper valve of USNM 542218. **D**—Upper valve of USNM 542219. **E**—Lower valve of USNM 542220 showing well-developed crinkles. **F**—Lower valve of USNM 542221 showing well-developed crinkles. Specimen **A** has a height of 18.7 mm, a length of 10.3 mm, and reaches maturity at a height of 10.2 mm. Enlarged 2.3 ×.

because he realized his collection contained specimens of small adult individuals, not juveniles.

Occurrence—Johnson (1903, p. 114) collected this delicate shell from one horizon, where it occurs in great abundance, at two localities. The first is given as 1 mi west of Madrid in sandstones of Fort Pierre age. The other is in Achavica Arroyo, 1 mi (1.6 km) northwest of Grand Central Mountain.[6] Johnson does not state the localities of his figured specimens. I visited both localities and was unable to find his prolific bed. However, 1.3 mi (2 km) N 77° W of Grand Central Mountain, I collected *Inoceramus balticus* from limestone concretions in the basal Mesaverde Group (D14504). This inoceramid indicates that strata in the vicinity of the type area for *Flemingostrea nanus* are of Santonian to Campanian age, making them much younger than the Coniacian age strata containing *F. elegans*. The occurrence of *Ostrea anomioides* var. *nanus* Johnson reported by Shimer and Blodgett (1908, p. 61) "…in the northwest corner of the Albuquerque sheet, fifteen miles southeast of Cabezon" may be a misidentification. It was collected (p. 58) from a 40-ft-thick fossiliferous section along with the Cenomanian oyster *Pycnodonte newberryi*, the Turonian oyster *Cameleolopha lugubris*, and the Turonian ammonites *Collignoniceras woollgari* and *Prionocyclus hyatti*.

The illustrated specimens of *F. nanus* (Fig. 15) were collected at the Tonque Arroyo section, approximately 10 mi (16 km) southwest of Grand Central Mountain, from the Mesaverde Group, just beneath the first massive sandstone that underlies the coal zone, approximately 200 ft (61 m) above the soft Mancos shale tongue. There are more than 100 individual valves in the collection; the largest specimen (Fig. 15F) has a height of 18.9 mm and a length of 14.3 mm; it has well-developed crinkles. The collection was made by J. B. Reeside, Jr., and others on October 4, 1944. The collection has the Washington, D.C., collection number 22861.

Paleoecology—*Flemingostrea nanus* appears to have been a normal marine epifaunal suspension feeder. The lack of attachment scars on all specimens in the Washington collection (22861) indicates that *F. nanus* was probably a free-lying oyster as an adult, with the lower valve partially buried in the sediment on the sea floor. The valves are disarticulated, but not fragmented; a few have some attached fine-grained sandstone matrix. The small volumetric capacity of the shell combined with free-lying adults suggests that the optimum sedimentation rate was less than that for the larger *F. elegans*. These features indicate that *F. nanus* lived on an agitated bottom, but probably farther out to sea than did *F. elegans*.

Discussion—The description of *Flemingostrea nanus* was adapted from Johnson (1903, pp. 113–114). It reads much like the description of *F. elegans* above, with the notable exception of (1) size of the species, (2) the terebratuloid fold in the lower valve and the concomitant change in slope on the upper valve, and (3) crinkles. A typical adult valve of *Flemingostrea elegans* has about four times the area of a typical *F. nanus* and reaches maturity at a length of approximately 2 cm versus approximately 1 cm. Johnson may simply have overlooked the terebratuloid fold in his specimens, possibly because the shells are small and most are not articulated. Not every upper valve in the Washington collection shows the change in slope as well as the figured specimen shown as Fig. 14A. The number of individuals in Johnson's collection is unknown. Radial ornamentation–crinkles occur on about one-third of the lower valves of *nanus* in the Washington collection; Johnson described crinkles as fine radiating striae. Two lower valves with well-developed crinkles are shown as Figures 15E and F.

Stephenson (1936, p. 6) placed *Ostrea anomioides* var. *nanus* in synonymy with **his** *Ostrea elegantula*, which he regarded as a guide fossil to the lower Santonian (Stephenson et al. 1942) possibly because: (1) The two species as published resemble each other morphologically; (2) They are both relatively small species (*nanus* is about half the size of Stephenson's *elegantula*); and (3) They both have "elegant lamellae" or "crinkles," although only a small percentage of specimens in the 22861 collection has crinkles.

Johnson's variety *nanus* is treated as a valid species and not placed in synonymy with *elegans* primarily for two reasons: First, there is a profound age difference between the two species (early Coniacian for *elegans*; Santonian or Campanian for *nanus*.) Second, there is a profound size difference; adults of *elegans* are at least four times as large areally as adults of *nanus*.

Stenzel (1959, pp. 32–33) did not include *nanus* in a list of species he included in genus *Flemingostrea* most probably because Johnson's (1903, pl. 1, figs. 10a–10d) illustrations do not show the terebratuloid fold. Without access to collection 22861 that shows this feature unequivocally(see Fig. 15), *nanus* would have been kept in the genus *Ostrea*.

Geographic distribution—*Flemingostrea nanus* is confined to Santa Fe County, New Mexico, where it has been collected from three localities.

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[6]The name Grand Central Mountain no longer appears on modern topographic maps. It does, however, appear on older maps, for example, on the geologic map of the Cerrillos area (Disbrow and Stoll 1957, pl. 1). Grand Central Mountain is the highest point in the Cerrillos Hills, shown with no name but with the spot elevation of 6,976 ft, in the NE¼ of sec. 6 T14N R8E, on the Madrid 7.5-min quadrangle, provisional edition of 1990, Santa Fe County, New Mexico.

History and usage of *Ostrea elegantula* Newberry 1876 (or White 1883)

The history and confusion surrounding the use of *Ostrea elegantula* is an integral part of this paper. This is especially true because I confused this new species with *O. elegantula* through the initial drafts of this paper. The key to discovering the misidentification was well-preserved upper valves from several localities that showed conclusively that the adductor muscle scar in *F. elegans* is reniform. White's (1883, pl. XXXVI, fig. 6; reproduced as Fig. 14E) illustration of the interior of an upper valve of a paratype of *O. elegantula* shows that the adductor muscle imprint is oval. From that point it became obvious that Newberry's species lacked the terebratuloid fold in mature shells and had chomata. The fold is a generic character; the chomata, a specific characteristic.

Stenzel (1971, p. N964), in his exceptional treatise on fossil oysters, made the following comment on the importance of the adductor muscle scars. "The outlines and positions of the adductor muscle imprints are indicative of the interior anatomical topography of oysters. For this reason they are of utmost importance in the classification of fossil oysters."

Named, but not described or illustrated

Ostrea elegantula, the "...remarkably neat little *Ostrea*…" of Newberry (1876, p. 33), has been a source of biostratigraphic confusion since Newberry mentioned that his new species occurred in rocks exposed along the Santa Fe Trail near present-day Springer, New Mexico. The rocks to which Newberry referred are now known to be the upper Turonian Juana Lopez Member of the Mancos Shale (Hook and Cobban 1980).

Unfortunately, Newberry (1876, p. 33) did not describe his new species, but managed to confuse it in the text of his measured section along the Canadian River with both *Ostrea* [now *Cameleolopha] lugubris* and *Ostrea congesta.* By introducing the new species name without a description, Newberry rendered *Ostrea elegantula* a *nomen nudum*, a "naked name."

Some time later, Newberry sent the type specimens of *Ostrea elegantula*, which he had collected, presumably, in 1859, to C. A. White, an oyster specialist at the USGS in Washington, D.C. White illustrated two of them (Figs. 14C–E) as *Ostrea elegantula* Newberry in his review of the fossil Ostreidae of North America (White 1883, pl. XXXVI, figs. 5–7). White (p. 295) ascribed the authorship of the species to Newberry, who had neither a manuscript nor a published paper to support formal authorship as required today. White (1883, p. 295) did not describe the species, but indicated that it might be identical to *Ostrea bella* Conrad 1857, which he also illustrated (pl. XXXIX, fig. 6).[7]

Boyle (1893) in his catalog of North American Mesozoic invertebrates listed in chronological order every reference to North American Mesozoic invertebrate species published to that date. He showed Newberry as the author of the species, *Ostrea elegantula*, but gave the date of publication to White (1883). Boyle (1893, p. 209) did not have a separate entry for the date *O. elegantula* entered the literature as a new species, as he did for almost every other species in the catalog. The first mention of *O. elegantula* as a new species was, of course, Newberry (1876).

T. W. Stanton, in faunal lists for other geologists, either ascribed authorship to Newberry (Dumble 1895, p. 386; Vaughan 1900, p. 81; Lee 1917, pp. 177, 193, 202) or identified the species without the author's name (Darton 1928, pp. 75–76). Stephenson (1936, p. 6), however, felt that White was the species' author as did Shimer and Shrock (1944, p. 391). The first published identification of a fossil oyster as *O. elegantula* was made in Dumble (1895), soon after White (1883) illustrated Newberry's type specimens. So, regardless of the nomenclatural problems associated with *O. elegantula* that are recognized today, field geologists were using Newberry's species at the end of the nineteenth century.

Newberry (1876, p. 33) collected his "…remarkably neat little *Ostrea*" along the banks of the Red [Canadian] River in northeast New Mexico from "…ferruginous, laminated, sandy limestone…" These limestone beds are now known to be in the Juana Lopez Member of the Mancos Shale, which is of late Turonian age. Both T. W. Stanton and J. B. Reeside (as recorded in Stephenson 1936, p. 7) believed that Newberry's original age assignment was in error, because all later collections, as identified by T. W. Stanton, had come from younger beds in New Mexico and Texas. All of these later collections, with the exception of Stephenson's (1936) Alabama collections and his one specimen from the Hagan Basin, New Mexico, appear in the literature in faunal lists without illustrations or descriptions. None of these later collections was made in the presumed type area. Stanton (as quoted in Stephenson 1936, p. 7) doubted whether the cotype specimens came from the Canadian River area. He thought they may have come from younger beds of Montana age in the Hagan coal field near Uña del Gato, New Mexico.

Hook and Cobban (1980) located what they believed to be the site of Newberry's (1876, p. 33) measured section along the banks of the Canadian River in Colfax County, New Mexico. They were, however, unable to duplicate his collection of *O. elegantula*. They suspected (1) that the type specimens of *O. elegantula* (two of which were illustrated by White, 1883) were collected elsewhere and (2) that Newberry confused his new species with the oyster *Cameleolopha lugubris* (Conrad), a small species that is extremely abundant in Juana Lopez calcarenites along the banks of the Canadian River. Newberry's (1876, p. 33) description of the rocks in his measured section supports this second conclusion. The section includes a "Ferruginous, laminated, sandy limestone [the Juana Lopez Member of the Mancos Shale]…a great storehouse of fossils, of which, perhaps the most abundant is a remarkably neat little *Ostrea*, hitherto undescribed, which I have called *Ostrea elegantula*; one of the most common and widely distributed Middle Cretaceous fossils of New Mexico." The oyster that is extremely abundant in the Juana Lopez calcarenites is *C. lugubris*, which is one of the most widely distributed Cretaceous fossils in New Mexico.

Newberry completed the geologic field work along the Canadian River in 1859 and submitted his final report for the San Juan exploring expedition in 1860. Publication was delayed by the Civil War until 1876. In 1860 F. B. Meek prepared the paleontologic report on the Cretaceous fossils collected by Newberry; publication was also delayed by the Civil War until 1876. Both reports were published in a single volume (Macomb 1876). Included in Meek's (1876a, pp. 123–124; pl. 1, figs. 1a–d) report were a description and illustrations of *Ostrea lugubris* Conrad, but there was no mention of *O. elegantula*. Meek (1876a, p. 123) noted that *O. lugubris* "…seems to be a common and characteristic species in the lower portions of the Middle Cretaceous of New Mexico."

Lee (1917, pp. 177, 193, 202, and 213) collected specimens attributed to *Ostrea elegantula* Newberry in northeast New Mexico and Darton (1928, pp. 75–76) in west-central New Mexico. Darton's collections are from the Mulatto Tongue of the Mancos Shale exposed on or just outside the present-day Sevilleta National Wildlife Refuge, Socorro County, New Mexico, where many of my specimens were collected. Both Lee's (1917) and Darton's (1928) New Mexico collections are from Coniacian or younger rocks. Dumble's (1895, p. 386) collections from Presidio County, Texas, and Vaughan's (1900, p. 81) collections near San Carlos, Texas, are from rocks containing *Menabites* (*Delawarella) delawarensi*s (listed as *Schloenbachia delawarensis*) of early Campanian age (Cobban et al. 2008, p. 88).

Stephenson (1936, pl. 1, figs. 5–9) illustrated two well-preserved specimens from the Santonian of Alabama and one specimen from USGS locality 6778 from the Hagan Basin, New Mexico (his pl. 1, fig. 10) as *O. elegantula*. However, the left valves of his

[7]The two species appear to be distinct morphologically in White's illustrations. *Ostrea bella* is a smaller, more ovate species, and *O. elegantula* lacks the radial growth elements so prominent on *O. bella* that Stephenson (1936, p. 7) called crinkles. Cragin (1893, p. 199) cites a collection of 30 specimens of *O. bella* along with a single valve of *Exogyra ponderosa* Roemer from 2 mi south of Presido del Norte, Mexico. Akers and Akers (2002, p. 196) regard *O. bella* as a Campanian species, restricted to the *Exogyra ponderosa* Zone in west Texas.

illustrated specimens are "...ornamented with a series of delicate, slightly upraised, elegantly crinkled concentric lamellae, spaced 1 to 2 millimeters apart" (Stephenson 1936, p. 7). The cotypes of *O. elegantula* illustrated by White (1883, pl. XXXVI, figs. 5–7; reproduced as Figs. 14C–E) lack these crinkled lamellae, suggesting that Stephenson's specimens were misassigned based on the concept of the species used at that time. *Ostrea bella*, however, which White regarded as a possible synonym of *O. elegantula*, has these "elegant" lamellae.

White (1883, p. 295) in his discussion of *Ostrea elegantula* stated that "This form is probably identical with *Ostrea bella* Conrad, but as I am not quite certain of this, I give both names a place in this list. Professor Newberry's reference to his form was written before the publication of Conrad's description, but his report was not published until long afterward, in 1876."[8]

In his discussion of *Ostrea bella*, White (p. 292) states that *O. bella* "…is probably too closely like the form which is named *Ostrea elegantula* to be regarded as a distinct species." This apparent synonymy by White may have led Stephenson to misapply the name *O. elegantula* to his Santonian fossils. Stephenson (1936, p. 6), however, did not put *O. bella* in synonymy with *O. elegantula*. Stephenson (in Stephenson et al. 1942) regarded *O. elegantula* as a key index fossil to the lower Santonian and showed its range on the Geological Society of America's Chart No. 9—Correlation of the outcropping Cretaceous formations of the Atlantic and Gulf Coastal Plain and Trans-Pecos Texas.

Thirty-eight years later, Hook and Cobban (1980) added to the confusion surrounding *O. elegantula* in their study of the Juana Lopez beds in northeastern New Mexico, in the presumed type area of *O. elegantula*. They (Hook and Cobban 1980, fig. 2) were able to find an outcrop that matched Newberry's (1876, p. 33) description, but were unable to duplicate his oyster fauna. They concluded (p. 42) that Newberry had confused *Cameleolopha lugubris* with his "...remarkably neat little *Ostrea*…," and that the types of *O. elegantula* were identical to the types of the later named and more widely recognized *O. beloiti* Logan 1899. Even though *O. elegantula* had date priority over *O. beloiti*, it had not been used in the literature for almost 40 yrs; whereas, *O. beloiti* had been used widely during that time. They, therefore, suggested that *O. elegantula* be regarded as a *nomen oblitum*, a forgotten name.[9] In a later paper on the occurrence of *O. beloiti* in Trans-Pecos Texas, Cobban and Hook (1980, p. 170) reiterated their suggestion that *O. elegantula* be considered a *nomen oblitum*, as did Kennedy et al. (1989, p. 112).

The confusion has continued in print into the new millennium with the publication of Texas Cretaceous Bivalves 2 by the Houston Gem and Mineral Society (Akers and Akers 2002). Their figure 167 (p. 196) contains a description of *O. beloiti* Logan 1899 in tabular format that is based on Stephenson's (1936) description of *O. elegantula*. Their figure 168 (p. 197) contains line drawings of four oyster shells in the center of the page labeled *Ostrea beloiti* Logan 1899. These drawings are four of the five figures that Stephenson (1936, plate 1, figs. 6–9) used to illustrate *Ostrea elegantula* White.

The new collections of oysters from lower Coniacian rocks in Socorro and Lincoln Counties that are similar to the figured types of *Ostrea elegantula* (in White 1883 and as Figs. 14C–E), indicated that Cobban and Hook (1980) were greatly in error. The types of *O. elegantula* are distinct morphologically from those of *O. beloiti*. Therefore, there is no need to treat *O. elegantula* as a *nomen oblitum* because of its (supposed) synonymy with *O. beloiti*.

Summary

The historical review has shown that *O. elegantula* Newberry is a species that (1) was named (and later illustrated), but never defined (a *nomen nudum*), (2) cannot be found at its type locality, (3) has been used in the literature over the last 130 yrs for at least three morphologically distinct oyster species that range in age from late Albian to Santonian, and (4) has been a source of confusion since it was named.

Despite all this confusion, I preferred to use *O. elegantula* Newberry as illustrated by White (1883, pl. XXXVI, figs 5–7; reproduced as Figs. 14C–E) for this new oyster species that is a key guide fossil to the lower Coniacian in west-central New Mexico. However, the obstacles to use of Newberry's name proved too difficult to overcome, even before I realized that the species *elegantula* could not be assigned to the genus *Flemingostrea*.

First, there would have been no type locality for *O. elegantula*. Most specimens of *F. elegans* come from nearshore sandstones. These sandstones represent high-energy, paleoenvironments that do not exist in lower Coniacian rocks exposed along the banks of the present-day Canadian River in northeast New Mexico where Newberry (1876, p. 33) indicated he collected the type specimens. Second, there is no record that Newberry was ever in Socorro or Lincoln Counties, the area in which *F. elegans* is most abundant.

Third, there is the "legality" of using the name *elegantula*. Although the International Code of Zoological Nomenclature (International Commission on Zoological Nomenclature 1999) makes a special provision for species names proposed before its adoption in 1931, it is doubtful whether *elegantula* meets all the criteria for an indication.

Newberry's (1876) geological report, in Macomb's "Report of the exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green Rivers of the great Colorado of the west in 1859" satisfies the publication and naming requirements of Article 11. Article 12 on names published before 1931 states that each name must be accompanied by a description or a definition or by an indication. An indication for a species name is satisfied by a description or illustration of the taxon that is being named. The discrepancy here is that the illustration of *Ostrea elegantula* appeared 7 yrs after the species name appeared in print.

This situation of having specific or generic names published in lists without formal descriptions and/or illustrations was apparently not uncommon in the paleontological literature of the United States in the later half of the nineteenth century. A similar case appears in Meek (1876b, p. 11), where he introduced the subgenus *Gryphaeostrea* Conrad 1865 with type species *Gryphaea vomer* Morton within the genus *Ostrea*. He noted (p. 11, footnote) that "…Mr. Conrad did not publish a diagnosis of this type, but merely gave the name in a list of fossils. At my request, however, he gave me in a manuscript the above diagnosis, and mentioned the above type."

Closer to the heart of the biostratigraphy used in this paper is the inoceramid *Cremnoceramus deformis* Meek. The date *C. deformis* was described is 1871, not 1877 as is often cited. "Although Meek only listed his new species in his paper of 1871, it is accompanied by a valid indication in the form of a reference to Hall's figure (1845, pl. 4, fig. 2)" (Walaszczyk and Cobban 2000, p. 88).

An analogous situation is the oyster species *Flemingostrea subradiata* (Cragin 1893). Cragin (1893, p. 200, pl. XLV, fig. 11) described and illustrated the new species *Ostrea carica* from the Upper Cretaceous Lewisville Sandstone Member of the Woodbine Formation of Denton County, Texas. He merely mentioned (p. 200) in the draft—not in the published paper—that he considered some of the specimens with the "…anterior part of both valves ornamented with more or less pronounced and rather numerous, narrow, radial plications…" to be a distinct species. In his manuscript he gave these forms the name *O. subradiata*. At the time of

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[8]Newberry's field work was completed in 1859, but the report's publication was delayed until 1876 by the outbreak of the Civil War. Conrad's description was published in 1857 in the Report of the U.S. and Mexican Boundary Survey, v. 1, pt. 2, p. 156. pl. 10, fig. 4a, b. Thus, if the two species were to be identical, then Conrad's name would have date priority.

[9]*Ostrea beloiti* occurs in an oyster coquina at the base of Lincoln Limestone Member of the Greenhorn Formation along the banks of the Canadian River (Hook and Cobban 1980, fig. 4) and is listed as *Gryphaea pitcheri* in Newberry's (1876, p. 33) section. They assumed, erroneously, that Newberry's collections of *O. elegantula* had come from this section and, therefore, had to have come from this lower coquina because the only other oyster in the section, *Cameleolopha lugubris*, occurred in the higher calcarenite.

publication he considered them as simply "…an individual phase of *O. carica*."

Stephenson (1952, pp. 75–76), however, in his work on Woodbine faunas of Texas, considered both *O. carica* and *O. subradiata* to be valid species. He (pp. 75–76) states that "Among 21 available shells that are believed to be cotypes of *carica* none show the characteristic radial costae [ribs] of *O. subradiata*. Costae are also wanting on the shells in the cluster illustrated by Cragin. Although the cotypes might conceivably be regarded as individual smooth variants, the absence of costae on so many examples, and the fact that many of them are elongated in outline, seem to justify treating the costate, subcircular to broadly subovate forms as a separate species. It seems desirable to preserve the name *subradiata*, which Cragin originally intended to apply to these costate shells, although the legality of ascribing authorship to him may be open to question." Stenzel (1959, p. 33) had no problem with the legality of Stephenson's assignment and placed *subradiata* (Cragin 1893, p. 200) in the genus *Flemingostrea*.

A forgotten name

I, like Lloyd Stephenson, find it desirable to honor one of the West's pioneer geologists by preserving a species name he proposed more than 100 yrs ago. However, there are too many problems associated with *Ostrea elegantula* to consider it a valid species. Accordingly, I feel that *Ostrea elegantula* Newberry should be considered formally as a *nomen oblitum*, a forgotten name, and that it should not be used for Upper Cretaceous oysters in New Mexico or elsewhere.

However, I, along with a long list of other geologists including T. W. Stanton, one of the giants of Western Interior paleontology, and N. H. Darton, arguably the greatest field geologist ever, have used Newberry's species name incorrectly for the similar lower Coniacian oyster species *Flemingostrea elegans*.

Although the outbreak of the Civil War delayed publication of Macomb's report until 1876, Newberry did not revise the text he submitted in 1860. In a prefatory note dated June 1, 1876, Newberry (1876) stated that …"[t]he observations made fifteen years ago, if accurately made, have equal value now as then; if inaccurate, it is only right that the credit of the correction of errors should belong to those who make such corrections. The geological narrative now given stands, therefore, just as written, and is a fair exponent of the state of our geographical and geological knowledge of the West at the date of its preparation. It is evident that to modify the report so as to conform to all the conclusions more recently reached, would be to falsify the record and greatly impair the independence and value of the statements it includes. The truth or error of these statements will soon be demonstrated by the extension of the explorations of other parties into this field. It is by just that credit or discredit of the trial to which the report is to be subjected should belong to the writer. Knowing that his work was done honestly, and believing that it was in the main accurately done, he accepts the entire responsibility of it, whether for praise or blame."

Although I was initially confused about the specific name to use for this new species of oyster, I was never confused about its biostratigraphic utility. *Flemingostrea elegans* is an ideal guide fossil: it occurs in great numbers, is easily identifiable, and is restricted geologically to lower Coniacian rocks and geographically to New Mexico. Dr. John Strong Newberry should be praised for his pioneering work on the geology of the Colorado Plateau and, specifically, in New Mexico. A brief biography of Newberry can be found in Chenoweth (1992).

I had hoped that Newberry's species name, *elegantula*, could be preserved through a complete redefinition. Unfortunately, that did not prove to be possible. I am, however, paying homage to Dr. Newberry's contributions to New Mexico's geology by using the name *elegans* (handsome), which is a variation of *elegantula* (quite handsome), for this new species of Upper Cretaceous oyster.

Accordingly, *Flemingostrea elegans* is described from and illustrated with specimens from Socorro and Lincoln Counties. This new species is restricted geologically to lower Coniacian strata and geographically (at present) to New Mexico. Reference stratigraphic sections at six localities in New Mexico are presented. *Flemingostrea elegans* is not conspecific with either the smaller and younger New Mexico oyster, *F. nanus* (Johnson 1903) or the penecontemporaneous Gulf Coast oyster, *F. oleana* (Stephenson 1945).

Conclusions

Flemingostrea elegans, n. sp., is an excellent guide fossil to lower Coniacian strata in central New Mexico. It is a medium-sized oyster that occurs in great numbers in the Mulatto Tongue of the Mancos Shale in Socorro County, New Mexico, and the Gallup Sandstone of Lincoln County, New Mexico. Its unique feature among late Turonian and early Coniacian oysters is a low-amplitude fold in the lower valve that developed when the oyster reached maturity. The upper valve is flat in the juvenile stage, but flexes abruptly downward at an angle at or exceeding 45° in the adult stage. It differs from contemporary oyster species like *"Lopha" sannionis* by having concentric rather than radial ornamentation; it differs from *Crassostrea soleniscus* in being much smaller and having thinner valves.

Flemingostrea elegans, n. sp., appears suddenly in the lowermost lower Coniacian inoceramid zone of *Cremnoceramus erectus* (Meek) and ranges through the uppermost lower Coniacian inoceramid zone of *Cremnoceramus crassus* (Petrascheck). It has no immediate ancestor in the Western Interior; although it could be succeeded by the Santonian *F. nanus* (Johnson), also known only from New Mexico. The only other species of *Flemingostrea* in the Western Interior is *F. prudentia* (White), an older species known only from upper Cenomanian, brackish-water strata from the Black Mesa–Kaiparowits Plateau area of Arizona and Utah.

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Appendix

Measurements made on the type-lot specimen of *Flemingostrea elegans*, n. sp., and a comparison with *F. oleana*. "—" indicates measurement not possible, B = both valves, R = right valve, L = left valve, I = internal mold, Unk = unknown. *See Figure 3 for key to measurements.

Specimen no.	Figure	Valve(s)	Crinkles	Height* (mm)	Length* (mm)	Thickness (mm)	Maturity* (mm)	H/L	H/T	Distorted	Notes
1		B	No	41.5	33.0	17.7	20.9	1.26	2.34	No	
2		B	Yes	35.4	31.5	15.1	23.1	1.12	2.34	No	
3		B	Yes	32.8	27.8	16.8	19.2	1.18	1.95	No	
4		B	Yes	32.5	27.9	13.7	21.4	1.16	2.37	Yes	
5		B	Yes	31.9	25.0	11.8	20.9	1.28	2.70	No	
6		I	Unk	32.8	28.8	12.2	20.1	1.14	2.69	No	internal mold
7		R	No	33.8	28.2	13.0	22.0	1.20	2.60	No	½ shell
8		R	No	26.6	26.3	11.5	20.4	1.01	2.31	No	½ shell
9		B	No	33.0	29.5	14.5	24.3	1.12	2.28	No	
10		B	No	36.5	30.0	17.0	26.4	1.22	2.15	No	
11		B	No	35.0	27.6	15.9	25.1	1.27	2.20	No	
12		B	No	33.9	25.9	14.5	19.6	1.31	2.34	No	
13		B	Yes	29.0	28.5	12.0	19.1	1.02	2.42	No	broken
14		B	Yes	32.8	32.2	11.4	21.3	1.02	2.88	Yes	
15		R	No	34.4	31.5	14.4	20.4	1.09	2.39	No	½ shell
16		B	No	30.8	29.3	14.8	22.1	1.05	2.08	No	
17		B	No	36.6	36.0	13.6	22.1	1.02	2.69	No	
18		B	No	33.5	28.1	8.9	21.4	1.19	3.76	No	broken
19		L	No	39.9	30.0	13.7	26.5	1.33	2.91	No	½ shell
20		L	Yes	24.9	22.3	8.4	15.1	1.12	2.96	No	½ shell
21		R	No	26.0	21.6	9.3	17.2	1.20	2.80	No	½ shell
22		I	Unk	37.0	31.8	9.9	20.7	1.16	3.74	No	internal mold
23		B	No	38.0	32.1	10.6	22.8	1.18	3.58	Yes	flattened
24		R	No	32.7	29.8	—	19.9	1.10	—	No	
25		R	No	33.4	25.0	—	19.6	1.34	—	No	
26		L	Yes	37.9	28.4	16.0	25.0	1.33	2.37	No	partial filling
27		B	Yes	38.8	37.2	14.3	20.5	1.04	2.71	No	
28		R	Yes	32.2	28.8	10.8	20.3	1.12	2.98	No	½ shell
29		R	No	34.8	30.8	—	19.7	1.13	—	No	
30		B	No	33.1	27.0	14.1	19.1	1.23	2.35	No	
31		B	No	—	39.9	23.3	21.1	—	—	No	broken/fat; no gape
32		L	Yes	39.3	34.9	—	24.5	1.13	—	No	
33		B	Yes	—	29.8	11.0	17.5	—	—	No	broken/skinny
34		B	No	32.6	27.0	8.7	18.5	1.21	3.75	No	
35		L	Yes	29.7	28.6	—	19.0	1.04	—	No	
36		R	No	31.5	27.6	—	19.7	1.14	—	No	
37		L	No	32.3	27.4	15.8	20.0	1.18	2.04	No	partial filling
38		L	Yes	24.6	24.8	—	20.0	0.99	—	No	
39		L	Yes	29.2	24.5	—	18.5	1.19	—	No	
40		I	Unk	21.1	20.6	8.0	17.5	1.02	2.64	No	internal mold
41		L	No	22.4	19.1	—	15.6	1.17	—	No	
42		B	No	35.9	31.6	10.1	24.2	1.14	—	No	
43		L	Yes	31.0	25.8	9.1	19.2	1.20	3.41	No	½ shell, small attachment scar
44		B	Yes	25.2	25.2	11.9	20.5	1.00	2.12	No	broken

Specimen no.	Figure	Valve(s)	Crinkles	Height* (mm)	Length* (mm)	Thickness (mm)	Maturity* (mm)	H/L	H/T	Distorted	Notes
45		B	No	22.8	21.9	8.9	14.8	1.04	2.56	No	
46		B	No	20.5	15.8	5.8	—	1.30	3.53	No	immature
47		B	No	—	25.7	10.7	17.7	—	—	No	
48		R	No	31.2	23.7	—	18.3	1.32	—	No	
49		B	No	—	26.7	14.3	21.7	—	—	No	
50		R	No	27.3	24.7	—	20.0	1.11	—	No	
51	13A	B	No	34.1	27.9	17.8	20.7	1.22	1.92	No	**holotype**, USNM 542207
52	13B	B	Yes	41.4	36.7	16.3	22.0	1.13	2.54	No	paratype, USNM 542208, small attachment scar
53	13F	B	Yes	33.3	27.0	15.2	15.8	1.23	2.19	No	paratype, USNM 542209, crinkles on both valves
54	13D	B	No	36.2	31.4	16.3	20.5	1.15	2.22	No	paratype, USNM 542210
55	13E	B	No	37.6	31.5	16.2	20.2	1.19	2.32	No	paratype, USNM 542211
56	13C	B	No	25.8	22.8	9.6	13.4	1.13	2.69	No	paratype, USNM 542212, small attachment scar
57		B	Yes	35.6	31.7	16.7	20.0	1.12	2.13	No	
58		B	No	32.9	27.1	14.1	19.6	1.21	2.33	No	
59		B	No	36.5	31.5	13.5	15.3	1.16	2.70	No	
60		B	No	32.4	26.5	13.7	14.9	1.22	2.36	No	
61		I	Unk	33.9	27.3	10.5	21.6	1.24	3.23	No	internal mold
62		R	No	38.9	30.4	—	23.6	1.28	—	No	
63		L	Yes	29.5	26.9	—	—	1.10	—	No	
64		B	Yes	34.5	25.8	15.7	23.4	1.34	2.20	No	
65		R	Yes	28.1	26.8	—	20.3	1.05	—	No	
66		L	Yes	25.7	25.3	—	—	1.02	—	No	
67		B	Yes	32.8	27.8	15.3	20.3	1.18	2.14	No	
Sum				2037.3	1881.6	684.4	1296.1	73.08	121.93		
n =				63	67	52	64	63	47		
Average				32.3	28.1	13.2	20.3	1.2	2.6		
F. oleana				60.0	50.0	32.0		1.2	1.9		
range from				20.5 mm	15.8 mm	5.8 mm	13.4 mm	0.99	1.92		
to				41.5 mm	39.9 mm	23.3 mm	26.5 mm	1.34	3.76		
			25 with crinkles (40%)								