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The Late Cretaceous oyster *Cameleolopha bellaplicata* (Shumard 1860), guide fossil to middle Turonian strata in New Mexico

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Abstract

Cameleolopha bellaplicata (Shumard 1860) is an easily recognized fossil oyster that occurs abundantly in sandy strata in Arizona, Colorado, New Mexico, Utah, and Texas, where it is restricted to the middle Turonian ammonite zones of *Prionocyclus hyatti* and *P. macombi*. It is a distinctive, medium-sized, plano-convex, ribbed oyster that has an undulating or zigzag margin and a small to nonexistent attachment scar; it occurs in great numbers, usually as original shells. In central New Mexico, *C. bellaplicata* is an excellent guide fossil to the Fite Ranch Sandstone Member of the Tres Hermanos Formation, which was deposited as nearshore sands during the second major transgression of the Late Cretaceous seaway in the state.

Since 1965 *Cameleolopha bellaplicata* has been split, erroneously, into two chronological subspecies: a supposedly older, more coarsely ribbed form, *C. bellaplicata novamexicana* (Kauffman), that was thought to be restricted to the middle part of the *Prionocyclus hyatti* Zone, and a younger, more delicately sculptured form, *C. bellaplicata bellaplicata* (Shumard), that ranges into the overlying *P. macombi* Zone. Although the two subspecies have type localities in Socorro County, New Mexico, and Grayson County, Texas, respectively, their supposed chronostratigraphic relationship could not be established at either type locality because the two supposed subspecies do not occur together at either type locality. Presumably, this chronostratigraphic relationship was established in Huerfano County, Colorado, where the ranges of the two morphotypes were interpreted to lie one above the other within the *P. hyatti* Zone and with no zone of overlap.

However, the chronological separation of the morphotypes by ammonite zone was based on a misidentification of the prionocyclid ammonite that occurs with the holotype of *Cameleolopha bellaplicata novamexicana*. Initially, only fragments of large individual prionocyclids were found; they were identified as *Prionocyclus hyatti*. Recent collections of ammonites from the type area of *C. b. novamexicana* contain small diameter internal molds that are unequivocally the younger *P. macombi*, rather than the older *P. hyatti*; associated fauna includes *Inoceramus dimidius* White, which substantiates assignment of the holotype of *C. b. novamexicana* to the younger *P. macombi* Zone. With the index ammonite identified correctly, there is no chronostratigraphic basis for the subspecies separation. A reinterpretation of the original morphometric data shows that the presumed differences between the subspecies are subtle and represent normal species variation.

Beginning in the late 1940s, strata that are now included in the Tres Hermanos Formation in New Mexico and Arizona were correlated with and included in the stratigraphically higher Gallup Sandstone. In the late 1970s, collections of *Cameleolopha bellaplicata* and its descendant *C. lugubris* from the Zuni and Acoma Basins in west and west-central New Mexico were instrumental in establishing that the Tres Hermanos Formation in central New Mexico is older than the oldest part of the Gallup Sandstone in its type area near Gallup, New Mexico. The upper part of the Tres Hermanos Formation was deposited during the transgressive phase (T-2) of the second major depositional cycle in the seaway, whereas the Gallup Sandstone was deposited during the regressive phase (R-2) of the same cycle.

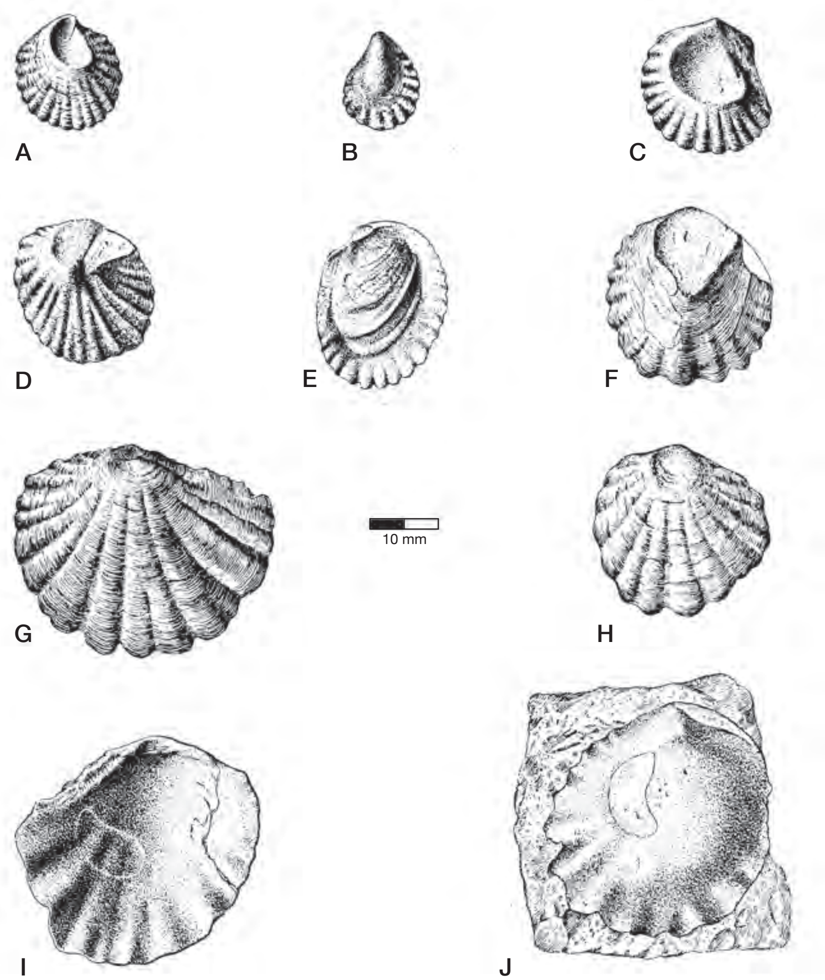

FIGURE 1—The *Cameleolopha lugubris* group consists of two formally named species, *C. lugubris* (**A**, **B**, **C**, and **E**) and *C. bellaplicata* (**D**, **F**, **G**, **H**, **I**, and **J**). *Cameleolopha lugubris*: **A—**Lower (left) valve from New Mexico. **B—**Upper (right) valve from Huerfano Park, Colorado. **C** and **E—**External and internal views of lower valves from Mancos, Colorado; and *C. bellaplicata*: **D** and **F**—Lower valves from Huerfano Park, Colorado. **G—**Lower valve from near Pueblo, Colorado. **H—**Lower valve from near Sherman, Texas. **I—**Interior of lower valve from Huerfano Park, Colorado. **J—**Interior mold of an upper valve from Huerfano Park, Colorado. This diagram was used originally by Stanton (1893, pl. 4) to show his concept of the group as single species that varied from a small, dwarf form with a large attachment scar, *Cameleolopha lugubris* Conrad 1857 to a medium-sized form with a small to absent attachment scar, *C. bellaplicata* Shumard 1860. *Cameleolopha lugubris* became the namebearer for the species because it had date priority. One of Conrad's (1857, pl. 10, fig. 5b) type specimens from east of the Red (now Canadian) River, Colfax County, New Mexico, is shown as specimen "**A**." Specimens are at 90%.

Introduction

Late Cretaceous oysters of the *Cameleolopha lugubris* group (Fig. 1) are common, generally abundant, and easily identifiable members of middle through late Turonian faunas in the southern part of the Western Interior of the United States. This is especially true in New Mexico where the older and larger of the two named species of the group, *C. bellaplicata* (Shumard 1860), is a guide fossil to the

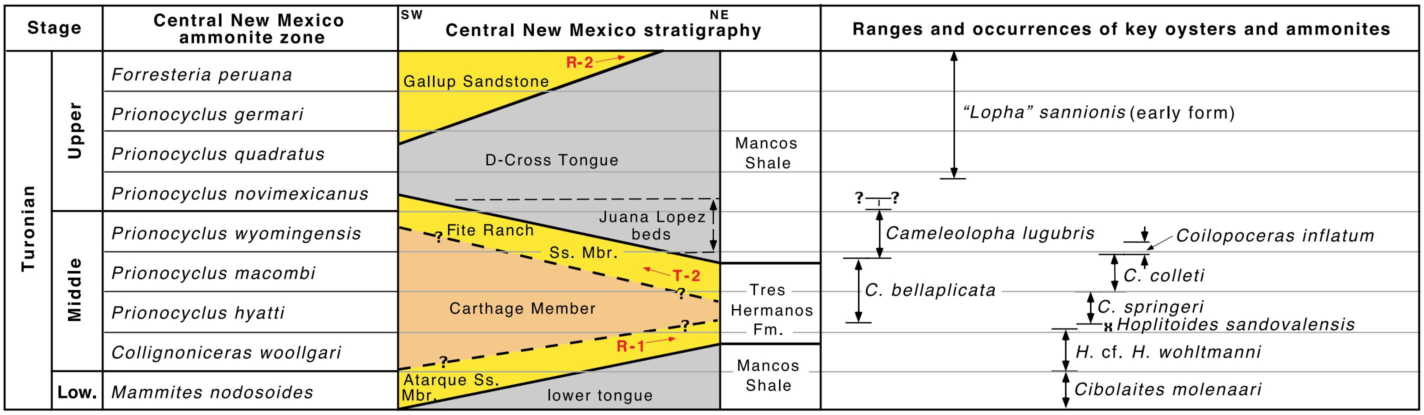

FIGURE 2—Central New Mexico chronostratigraphic diagram in which lower through upper Turonian (Upper Cretaceous) strata are plotted against the zonal ammonite index species. This highly generalized diagram shows the geometry of the Tres Hermanos Formation as it wedges out to the northeast into the Mancos Shale. The Atarque Sandstone Member rises stratigraphically from southwest to northeast during the initial regression (R-1) of the Late Cretaceous seaway, whereas the Fite Ranch Sandstone Member rises stratigraphically from the northeast to southwest during the second major transgression (T-2) of the seaway. The Gallup Sandstone was deposited during the second major regression (R-2) and rises stratigraphically from southwest to northeast. The biostratigraphic ranges of key oyster and ammonite species discussed in the text are shown on the right. Control points used to construct the diagram are labeled in Figure 3. Color key: gray = marine shale, yellow = marine sandstone, and brown = nonmarine strata.

upper part of the Tres Hermanos Formation, and the younger, smaller species, *C. lugubris* (Conrad 1857), is a guide fossil to the base of the overlying Mancos Shale, especially to the Juana Lopez Member.

Cameleolopha bellaplicata (Shumard 1860) is a medium-sized, plano-convex oyster with 8–27 generally simple plicae (ribs) that radiate from the beak. Secondary ornamentation consists of concentric lamellae that intersect the ribs. The general absence of attachment scars on preserved left valves indicates the species lived unattached as adults on the sea floor. Its left valve is larger and more convex than that of *C. lugubris*, giving it a more robust appearance and making it better suited to higher-energy, nearshore environments. The type specimens of *C. bellaplicata* came from the upper Eagle Ford Shale of Grayson County, Texas, but were described without definitive stratigraphic and bioststratigraphic information. The specific name, *bellaplicata*, is in reference to the beautiful ribs on what Shumard (1860, p. 609) regarded as a handsome oyster.[1]

Originally assigned to the form-genus *Ostrea*, *Cameleolopha bellaplicata* appears in many faunal lists as *Lopha bellaplicata*. Many collections from Colorado (Kauffman 1965) and New Mexico (Hook et al. 1983) show that *C. bellaplicata* is confined to the middle Turonian and ranges from the *Prionocyclus hyatti* Zone through the lower three-quarters of the *P. macombi* Zone (Fig. 2). Kauffman (1965) recognized two non-overlapping chronological subspecies: a supposedly older, more coarsely ribbed form, *C. b. novamexicana*, confined to the middle part of the *P. hyatti* Zone, and a younger, more finely ribbed form, *C. b. bellaplicata*, that ranged upward into the overlying *P. macombi* Zone. However, recent collections from the Carthage coal field, New Mexico, indicate that Kauffman's (1965) type specimens of *C. b. novamexicana* occur in association with *P. macombi*, i.e., at a higher—not lower—biostratigraphic level than his presumably stratigraphically higher collections of *C. bellaplicata bellaplicata*, which occur with *P. hyatti* in Texas.

The other named species in the group, *Cameleolopha lugubris* (Conrad 1857), is a thumbnail sized, finely plicate oyster with 10–24 ribs and a relatively large attachment scar; in New Mexico it occurs in great numbers at the base of the Juana Lopez Member of the Mancos Shale (Dane et al. 1966). *Cameleolopha lugubris* ranges from the upper part of the *Prionocyclus macombi* Zone through the entire *P. wyomingensis* Zone, and possibly into the base of the *P. novimexicanus* Zone, but does not co-occur with *C. bellaplicata* at the base of its range. The specific name is in reference to its apparently doleful or mournful appearance (at least to Conrad).

Hook and Cobban (1980a, fig. 5H, I). have discussed, illustrated, and demonstrated the biostratigraphic utility of *Cameleolopha lugubris* (as *Lopha lugubris*). Illustrations of both *C. bellaplicata* and *C. lugubris*, designated as species of the genus *Lopha*, can be found in Kauffman (1977b, pl. 9, figs. 12–16 and 18–20). New Mexico and Texas provided the type localities for both named species in the group, each of which was described more than 150 yrs ago. *Cameleolopha bellaplicata* is particularly common in nearshore sandstones in central New Mexico (Fig. 3), where it is generally abundant in the middle Turonian Fite Ranch Sandstone Member of the Tres Hermanos Formation (Fig. 2). *Cameleolopha lugubris*, the name-bearer of the group, has a greater geographic distribution than its ancestor, *C. bellaplicata*, and occurs throughout the Western Interior of the United States (see Hook and Cobban 1980a, fig. 1) and in Texas. In central New Mexico *Cameleolopha lugubris* often forms calcarenitic coquinas in the lower part of the D-Cross Tongue of the Mancos Shale that lies just above the abundant occurrences of *C. bellaplicata* in the Fite Ranch Sandstone Member.

This paper focuses on the older named species of the group, *Cameleolopha bellaplicata*, which has been referred to the following genera in the geologic literature: initially *Ostrea*, then *Lopha*, *Alectryonia*, and *Nicaisolopha*, and, now, *Cameleolopha*. To reduce confusion in this paper, *bellaplicata* will be assigned to the genus *Cameleolopha* consistently, even in cases where the original author assigned *bellaplicata* to one of the other four genera.

The historical summary that follows provides brief biographies of Dr. B. F. Shumard, who named *C. bellaplicata* and was the first state geologist of Texas, and his brother, Dr. G. G. Shumard, who collected the type specimens of *C. bellaplicata*. A revised biostratigraphy for the subspecies, *C. b. novamexicana*, based on better preserved specimens of the associated index ammonite at its type area, provides the framework for showing that subspecies designations within *C. bellaplicata* are unnecessary. A previously unpublished measured section at the Carthage coal field, New Mexico, puts *C. bellaplicata* into stratigraphic and biostratigraphic context within the original type area for *C. b. novamexicana*. A reinterpretation of the original, published morphometric data, supplemented by data on additional collections of *C. bellaplicata* from the Carthage coal field and from Texas, show that the presumed differences between the subspecies represent normal species variation.

The purposes of this paper, which is the first of three related papers on middle and upper Turonian strata of New Mexico, are (1) to show that there are no biostratigraphic

[1]Fielding B. Meek, the great 19th century paleontologist of the Western Interior thought otherwise and referred to *Cameleolopha bellaplicata* as "…one…of two **peculiar** oysters described by Dr. Shumard, from Cretaceous rocks of Texas…" (Meek 1876a, p. 124).

FIGURE 3—Map of New Mexico showing locations where *Cameleolopha bellaplicata* has been collected (red dots) and the approximate position of the western shoreline of the Late Cretaceous seaway at the end of time during which *C. bellaplicata* lived. Each dot represents at least one collection containing *C. bellaplicata* but can represent several nearby collections. The two dots just off the map west of Gallup, New Mexico, are from collections along the Nutria monocline in Arizona. The line of section for Figure 10 is shown as a dashed line; each "x" represents a numbered measured section used as a control point.

or morphological reasons to subdivide *Cameleolopha bellaplicata* into subspecies, and (2) to demonstrate the biostratigraphic importance of the oyster *Cameleolopha bellaplicata* in the southern part of the Western Interior, particularly New Mexico.

Background

The Shumards

Benjamin Franklin Shumard (1820–1869) received his M.D. degree in 1843 after having spent two years at Jefferson Medical College in Philadelphia and two terms at the Medical Institute of Louisville, Kentucky (Young 1994, p. 149). He became interested in paleontology while practicing medicine in Kentucky. By 1846 he had given up medicine to devote his time to geology. From 1846 to 1849 he worked for the geological surveys of Iowa, Wisconsin, and Minnesota; in 1850 he accompanied a geological survey to Oregon. In 1853 Dr. Shumard was appointed paleontologist and assistant geologist of the Missouri Geological Survey. He resigned to become chief geologist of Texas on August 28, 1858, under appointment of Governor Hardin R. Runnels.

The state geologist's duty, according to an act of the Texas State Legislature of February 10, 1858, was to make as speedily as possible "…a thorough and complete geological survey of the State, so as to determine accurately the quality and characteristics of the soil and its adaptation to agricultural purposes; the species of produce to which the soil in different sections is adapted; its mineral resources, their location and capacities; and generally everything relating to the geological and agricultural character of the State." Hill (1887, p. 30) thought that Shumard's "…life of training and his experience in geologic surveys gave him every qualification for the position."

However, Hill (1887, p. 30), in his account on the history of the geology of Texas, noted that there appeared to be some truth to the rumor that the Governor of Texas had "…intended to appoint Dr. G. G. Shumard to the office of State Geologist, but by a clerical error, the name of his brother, Dr. B. F. Shumard, was inserted in the original commission. This being before the days of rapid communication it was impossible to remedy the error, and Dr. G. G. Shumard gracefully accepted the position of assistant State Geologist." Young (1994, p. 143), in his biography of the Shumards, suggests otherwise, because he found that there is no record of Dr. G. G. Shumard's applying for the job. However, George made an excellent second-in-command because he had been the geologist and surgeon on Captain R. B. Marcy's 1852 expedition to explore the area of the Red River, which forms the present-day boundary between Texas and Oklahoma.

After selecting his staff, Shumard organized the Texas Geological Survey into field parties that began work in January 1859. He made detailed surveys of Burnet and Rush Counties and partial surveys of Travis, Bastrop, Washington, Fayette, and Young Counties; his brother, George (1825–1867), made detailed surveys of Grayson, Fannin, and Cass Counties and partial surveys of Bowie, Red River, and Lamar Counties (Hill 1887, p. 30).

Politics came into play early in the existence of the Texas Survey: Dr. B. F. Shumard was fired on November 1, 1860, 21 months after taking office, by the newly elected governor of Texas, General Sam Houston. Governor Houston replaced Shumard, a non-Texan, with Francis E. Moore, Jr., a native Texan (Young 1994, p. 144). After being dismissed as state geologist, Shumard left Texas for St. Louis in 1860 just before the beginning of the Civil War. He returned to his first profession, medicine, and in 1866 was appointed Professor of Obstetrics at the University of St. Louis. Shumard was reinstated temporarily by the Texas legislature in April 1861 in the same act that suspended the geological survey because of the impending Civil War. In that act, Shumard was assigned the task of preparing a final report, which he did not live to complete.

During the Civil War, the Texas state capitol was occupied by Confederate troops. The laboratories and museum of the geological survey were turned into a munitions factory; rock and fossil specimens were "…taken away as curiosities or wantonly destroyed and many of the precious notes and maps were scattered to the winds" (Hill 1887, p. 35).

At the time of his death from pneumonia on April 14, 1869, B. F. Shumard was president of the St. Louis Academy of Science and a member of the Geological Society of London, the Geological Society of France, the Imperial Geological Society of Vienna, and the Academies of Science of Philadelphia, Cincinnati, and New Orleans. His brother George quit geology after 1860 and returned to medicine in Ohio, where he was appointed surgeon general of Ohio (Young 1994, p. 150). He held that position at the time of his death in 1867.

According to Young (1994, p. 143), the Shumards made three principal contributions to the geology of Texas. First, they advanced the state of knowledge of the Cretaceous of Texas. Second, they determined that not all mountains in the Southwest had granitic cores. Third, they discovered the marine Permian of Texas.

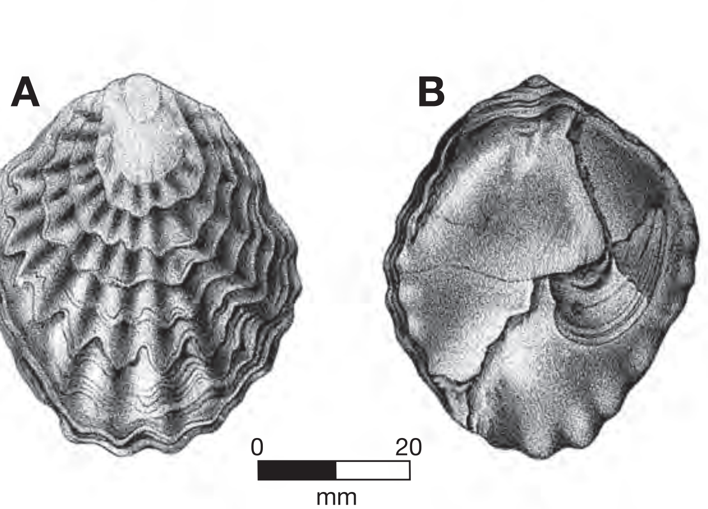

FIGURE 4—Line drawings of one of the "type" specimens of *Cameleolopha bellaplicata* sent by B. F. Shumard to C. A. White and reproduced in White (1879, pl. 8, figs. 2a–b). This specimen is presumed to have been destroyed in a fire at the St Louis Academy of Science (Kauffman 1965, p. 58.) **A—**Exterior view of an upper (right) valve. **B—**Interior view of the same valve. Collected near Sherman, Grayson County, Texas, by Dr. G. G. Shumard. Data from this specimen are plotted with a dark blue circle in Figure 6.

As part of their first contribution—advancing knowledge of the Cretaceous—B. F. Shumard described (but did not illustrate) the oyster *Cameleolopha bellaplicata* in a paper in the *Transactions of the St. Louis Academy of Science* of 1860. This paper is titled "Descriptions of new Cretaceous fossils from Texas*".[2] Charles A. White, another medical doctor turned paleontologist (see Hook and Cobban 1981, p. 52 for a brief biography), redescribed *Cameleolopha bellaplicata* in 1877 and illustrated it in part with figures based on photographic copies of Dr. Shumard's drawings (White 1879, p. 277; Fig. 4). In addition to describing the biostratigraphically important middle Turonian oyster, *C. bellaplicata*, in his 1860 paper, Shumard described *Baculites gracilis*, which as *Sciponoceras gracile*, was used for many years as an index ammonite for a zone in the Upper Cenomanian of the Western Interior (e.g., Cobban 1984).

Shumard's (1860, pp. 608–609) description of *Cameleolopha bellaplicata*, which is reproduced in the Systematic paleontology section of this paper (p. 84), was designed to aid the field geologist, while fulfilling all the paleontological requirements for defining a new species. The collector was his brother, George, who made a detailed survey of Grayson County as part of his official duties with the Texas Geological Survey. According to Kauffman (1965, p. 58), the holotype of *C. bellaplicata* was destroyed in a fire at the St. Louis Academy of Science. Kauffman (1965, p. 58, pl. 3, fig. 11) selected a neotype from the Eagle Ford Shale at USGS locality 7539, 2.5 mi east of Eagle Ford, Dallas County, Texas. Fortunately, White (1879, pl. 8, figs. 2a–b and 1883, pl. XLVII, fig. 3) illustrated an upper valve of *C. bellaplicata* from Shumard's type lot using photographic copies of Shumard's original (unpublished) figures. White's (1879) figures are reproduced as Figure 4.

The next two sections of the paper will establish two fundamental points. The first is that *Prionocyclus macombi*, not the older *P. hyatti*, is the zonal index ammonite that occurs in the Carthage coal field, New Mexico, with Kauffman's (1965) holotype for the subspecies *Cameleolopha bellaplicata novamexicana*. That, of course, means that specimens from the type area of the supposedly older, more coarsely ribbed morphotype, *C. b. novamexicana*, are in fact younger than the more finely ribbed morphotype, *C. b. bellaplicata*, from either Huerfano Park, Colorado, or Grayson County, Texas. The second is, that once the coarsely ribbed morphotype of *C. bellaplicata* in the undoubted *P. hyatti* Zone from Huerfano Park, Colorado, is treated as normal species variation, then the vast majority of *C. b. novamexicana* specimens from Carthage fall within the limits of Kauffman's (1965) measured morphometric variation for the species. Together, these two points establish that there is neither a chronostratigraphic nor a morphometric basis for subspeciation.

Revised biostratigraphy

This section of the paper documents the events and process that resolved the controversy surrounding the age of the *Cameleolopha bellaplicata novamexicana* fauna at Carthage. Appendix 1 contains an analysis of the middle Turonian biostratigraphic framework erected by Kauffman (1965, 1977a, b) for the southern part of the Western Interior. That middle Turonian framework was subdivided in part to accommodate *C. b. novamexicana* as a key index fossil. However, the misidentification of the index ammonite that occurs with the holotype of *C. b. novamexicana* at Carthage, means that *C. b. novamexicana* was placed too low in the zonal scheme.

Determining the biostratigraphic age of the sandstone at Carthage that contains the type specimen of the ammonite *Coilopoceras colleti* Hyatt 1903 had been a vexing problem for more than 60 yrs when Kauffman (1965) described *Cameleolopha bellaplicata novamexicana* from the same rocks. The fauna associated with *Coilopoceras colleti* included fragments of large diameter prionocyclids, and numerous species of age indeterminate bivalves and gastropods, but lacked inoceramids. This fauna indicated only that the rocks were middle or upper Turonian (see updated faunal list at Carthage in Hook 1983, p. 171).[3]

When Hook started work in 1976 at the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, he was assigned the task of working out the stratigraphic and paleontologic relationships of the Upper Cretaceous in central and southern New Mexico. Much of this work was to be done in the context of an ongoing cooperative study with the USGS on Upper Cretaceous coal deposits. He began his portion of the project at the nearby Carthage coal field. Early in the study, he contacted Cobban for what has become a lifelong collaborative effort. A key problem identified by Cobban at that time was the age of the *Coilopoceras colleti* fauna, which included *Cameleolopha bellaplicata novamexicana*. Did this fauna occur with *Prionocyclus hyatti* or the younger *P. macombi*?

For many years after Hyatt's (1903) publication, *Coilopoceras colleti* was known only from Carthage. That situation changed in 1963 with a large collection of ammonites and inoceramids from a single concretion in the Mancos Shale at Llaves, Rio Arriba County, New Mexico, approximately 70 mi (112 km) northwest of Santa Fe (Fig. 3). That large concretion (USGS locality D4395) yielded several specimens of *C. colleti*, *Prionocyclus macombi*, and *Inoceramus* aff. *dimidius* White, but lacked oysters.[4]

[2]The "*" indicated the following footnote in Shumard's (1860) paper. "The interesting series of fossils described in this paper have [sic.] been collected during the progress of the Geological and Agricultural Survey of Texas. …It is intended to publish more extended descriptions, with figures illustrating the species, in our Geological Report." Shumard published neither a geological report (as required by the Act of the Texas Legislature) nor the extended description of fossils with illustrations.

[3]The placement of the middle/upper Turonian boundary has varied from the top of the *Prionocyclus hyatti* Zone (e.g., Hook 1983, fig. 1) to the top of the *P. wyomingensis* Zone (Fig. 2), where it is today. Cobban et al. (2006) recount the history of the changing concept of this boundary.

[4]*Coilopoceras colleti* remains a rare ammonite today, known definitely from only four localities outside the Carthage and Llaves areas, all in New Mexico (Cobban and Hook 1980, p. 15).

Cobban and Hook (1980, table 1, locality 4) and Walaszczyk and Cobban (2000, p. 10, locality 76) were in error in reporting that the Llaves concretion, USGS locality D4395, came from the base of the Juana Lopez Member of the Mancos Shale. A measured section made by Hook in 2007 in the Llaves area has refined the stratigraphy. The zone of limestone concretions that yielded the fauna of D4395 is 4 ft (1.2 m) below the basal calcarenite of the Juana Lopez Member; it occurs in the 9-ft-(2.7-m-) thick, unnamed tongue of Mancos Shale that lies between the top of the Semilla Sandstone Member and the base of the Juana Lopez Member. The basal Juana Lopez calcarenite contains abundant specimens of *Cameleolopha lugubris* (D14617). However, a newer collection (D14567) from the *Coilopoceras colleti*-bearing concretions contains two left valves of *Cameleolopha lugubris*, but none of *C. bellaplicata*. D14567 is the only collection known in which *Coilopoceras colleti* occurs with *Cameleolopha lugubris*; the usual oyster associate of *Coilopoceras colleti* is *Cameleolopha bellaplicata*, and the usual coilopocerid associate of *Cameleolopha lugubris* is *Coilopoceras inflatum*. This collection provides the limits for the lowest occurrence of *C. lugubris* and the highest occurrence of *C. colleti* in Figure 2.

However, *Cameleolopha bellaplicata* was not found in the strata below the D14567 collection at Llaves, undoubtedly because sandstones representing the nearshore, high-energy environment that *C. bellaplicata* inhabited are absent, presumably because the area was too far offshore at that time, approximately 60 mi (96 km) north of the northernmost occurrence of *C. bellaplicata* (Fig. 3).The upper 100 ft (30 m) of Mancos Shale below the Juana Lopez Member is well exposed at the Llaves section; it consists primarily of noncalcareous clay shale that contains many concretions. A concretion 50 ft (15 m) below the base of the Juana Lopez Member yielded *Prionocyclus hyatti* (D14566), indicating that the rocks were of the correct age to have contained *C. bellaplicata*; they simply represented the wrong environment. The Llaves locality (D14567) did establish an upper biostratigraphic limit on the range of *Coilopoceras colleti* at the base of the range zone of *Cameleolopha lugubris*, in the upper part of the *P. macombi* Zone. It suggested, but did not prove, that the prionocyclid at Carthage was *P. macombi*.

By the late 1970s, field work and collecting in the Upper Cretaceous of west-central New Mexico had bracketed the *Cameleolopha bellaplicata novamexicana*-bearing sandstone at Carthage between the middle Turonian *Collignoniceras woollgari woollgari* fauna at the base of the Tres Hermanos Formation and the upper Turonian *Prionocyclus novimexicanus* fauna near the base of the overlying D-Cross Tongue of the Mancos Shale (Cobban and Hook 1979, fig. 3A). In that figure, *C. b. novamexicana* was shown to occur with *P. macombi*. However, that identification was still based only on large adult specimens.

In the revision of the Upper Cretaceous Tres Hermanos Sandstone, Hook et al. (1983, table 2) divided the formation into three members and established a principal reference section within the Carthage coal field for the formation along with type sections for the Carthage (middle) and Fite Ranch Sandstone (upper) Members. The type locality of *Cameleolopha bellaplicata novamexicana* (Kauffman) occurs at the base of the Fite Ranch Sandstone Member, about a mile from the member's type section.[5] Fossils are abundant in the 20-ft-(6-m-) thick, yellow sandstone that forms bold cliffs near the base of the Fite Ranch Sandstone Member. Hook et al. (1983, table 2) show the following fauna from USGS Mesozoic locality D10354 at the base of the Fite Ranch Sandstone at its principal reference section: *C. b. novamexicana* in association with *Coilopoceras colleti*, and *Prionocyclus macombi* (early form). The "early form" reference indicates that the large prionocyclid specimens from Carthage had arched venters, rather than the smooth venters of the late form (Kennedy et al. 2001, p. 95). However, the specific identification of the prionocyclid was based to a large extent on regional stratigraphic relationships. Kauffman's subspecies name was used by Hook et al. (1983, table 2) in the description of the principal reference section of the Tres Hermanos Formation because that section is within the type area of *Cameleolopha bellaplicata novamexicana*. However, Hook et al. (1983) did not assign subspecies names elsewhere in west-central New Mexico; in the graphic cross sections from Carthage to the southern Zuni Basin and from the southern Zuni Basin to Gallup, they show *C. bellaplicata* without subspecies designation as a key fossil at several localities.

In his paper on mid-Cretaceous ammonite zones of the Western Interior, Cobban (1984, fig. 2) subdivided the middle Turonian ammonite zones of *Prionocyclus hyatti* and *P. macombi* into the following subzones based on species of the Coilopoceratidae.

Zone	Subzone
Prionocyclus macombi	*Coilopoceras inflatum* *Coilopoceras colleti*
Prionocyclus hyatti	*Coilopoceras springeri* *Hoplitoides sandovalensis*

In the section of the paper in which he presented faunal criteria for recognizing the zones and subzones, Cobban (1984, p. 86) states that "In the type area of the Fite Ranch Member near the former coalmining town of Carthage in south-central New Mexico, *C. colleti* is found with *P. macombi*, [*Cameleolopha*] *bellaplicata novamexicana* Kauffman,…."

Kennedy (1988, fig. 4) found that Cobban's (1984) zonation worked well in the Dallas, Texas, area, near Shumard's (1860) type area, but had difficulty in applying Kauffman's chronostratigraphic, subspecific names to oysters from the Arcadia Park Formation. Kennedy referred oysters that occurred with *Prionocyclus hyatti* and *Coilopoceras springeri* to *Cameleolopha cf. bellaplicata novamexicana*. Those oysters appearing abundantly higher in the section, but still with *P. hyatti*, he assigned without question to *Cameleolopha bellaplicata bellaplicata*.

In August 2003 a large, well-preserved, unambiguous specimen of *Prionocyclus macombi* (D14477) was collected from 17 ft (6 m) below the top of the normally nonmarine Carthage Member of the Tres Hermanos Formation on the Mesa del Yeso quadrangle approximately 20 mi (32 km) north of Carthage (Hook and Cobban 2007, fig. 3). The basal 3 ft (1 m) of the overlying Fite Ranch Sandstone Member yielded several internal molds of *Cameleolopha bellaplicata* (D14471). This occurrence, which would have been seaward of Carthage by approximately 18 mi (29 km) at the time of deposition of the upper Carthage Member, indicates that the shoreline of the transgressing T-2 seaway had not reached the Mesa del Yeso quadrangle until *P. macombi* time and that the overlying occurrence of *C. bellaplicata* could not be in the *P. hyatti* Zone. This occurrence strongly indicated that the basal Fite Ranch Sandstone at Carthage had to be of *P. macombi* age.

In November 2006 the first well-preserved, internal mold of a small-diameter prionocyclid was collected from the basal Fite Ranch Sandstone Member in the Carthage area. This specimen (Fig. 5A) from locality D14542 demonstrates very clearly that at a small diameter this ammonite has the single ventrolateral tubercles of *Prionocyclus macombi*, as opposed to the double ventrolateral tubercles of *P. hyatti*. Since 2007 six specimens of *Inoceramus dimidius* (from localities D14562, D14690, D14962, D14995, D15016) have been added from the basal Fite Ranch Sandstone Member at Carthage. *Inoceramus dimidius* is known to occur with *P. macombi* and *P. wyomingensis*, but does not occur with *P. hyatti* (Fig. 2).

Figure 5 shows side views of the first two, small-diameter specimens of the prionocyclid that were collected from the base of the Fite Ranch Sandstone Member in the Carthage area. Both are unequivocally *Prionocyclus macombi*. Figure 5A is an incomplete internal mold of a gracile individual from locality D14542, 86 mm in diameter with an intercostal width of 17 mm. Note the single ventrolateral clavi. Figure 5B is an internal mold of a better-preserved and almost complete robust individual from locality D14962, 112 mm in diameter with an intercostal width of 29 mm. The body chamber occupies slightly more than half a whorl, although it is incomplete. There are 14 bullate umbilical tubercles on the outermost whorl; each supports a primary rib that terminates in a

[5]A photograph of the type locality of *Cameleolopha bellaplicata novamexicana* (Kauffman) appears in the photo gallery, Fig. 9A.

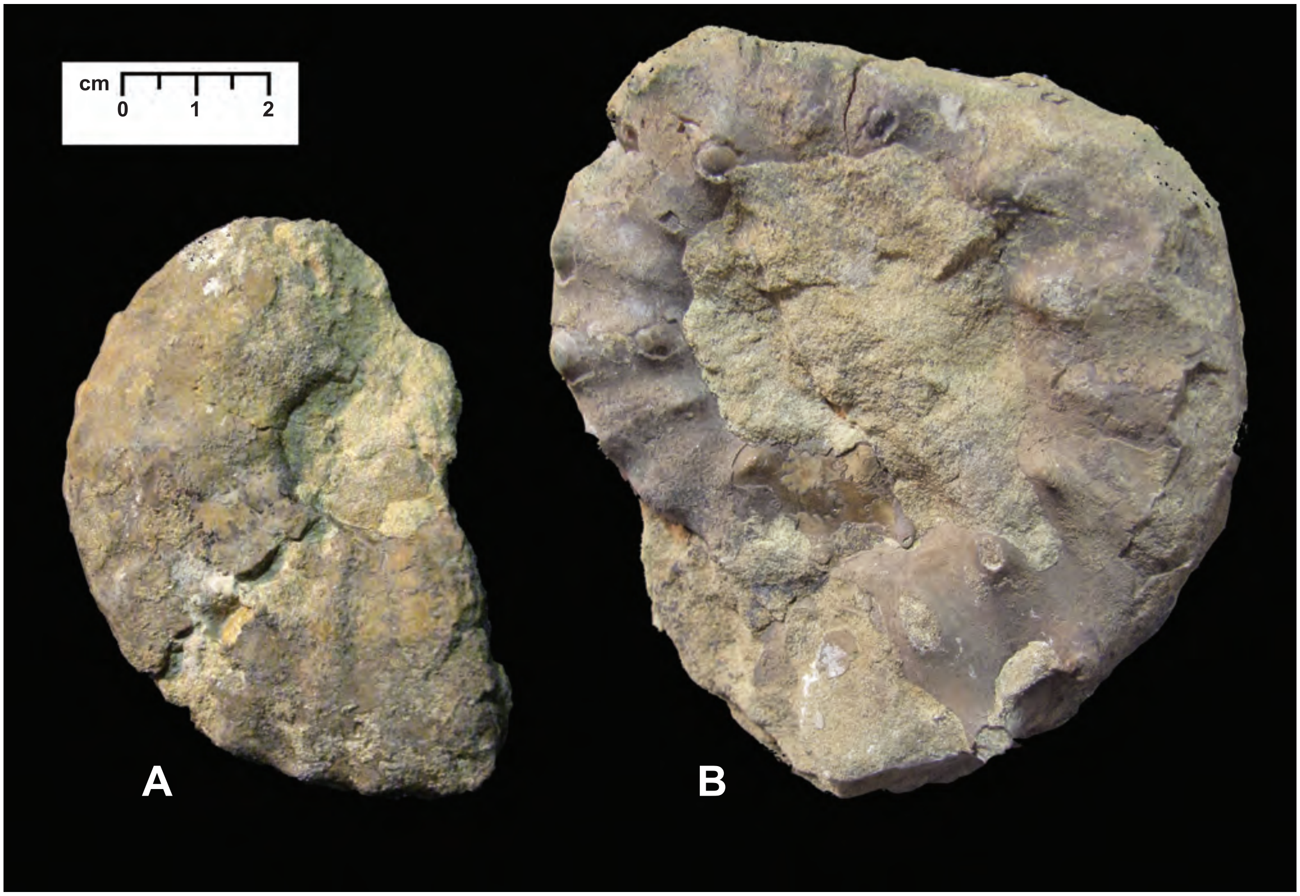

FIGURE 5—Side views of internal molds of small-diameter prionocyclids collected from the base of the Fite Ranch Sandstone Member of the Tres Hermanos Formation in the Carthage coal field, Socorro County, New Mexico. These specimens bear the single ventrolateral tubercles of *Prionocyclus macombi* Meek, rather than the double ventrolateral tubercles of *P. hyatti* Stanton. Associated fossils include *Cameleolopha bellaplicata* (Shumard), *Coilopoceras colleti* Hyatt, *Pholadomya* sp., and *Inoceramus dimidius* White. This fossil assemblage is from the middle Turonian *Prionocyclus macombi* Zone. **A—**USNM 545192, a gracile individual from USGS Mesozoic locality D14542. **B—**USNM 545193, a robust individual from USGS Mesozoic locality D14962. Locality information in Appendix 3 can be found online at http://geoinfo.nmt.edu/repository/index.cfm?rid=20110001. Specimens are natural size.

single, bullate to slightly clavate ventrolateral tubercle. Matrix on the back side of the specimen has preserved two small spines emerging from these tubercles. The arched venter is capped by a keel notched into about three clavi for each rib.[6]

The discovery of these small-diameter prionocyclids with single ventrolateral tubercles allows an unequivocal assignment of the Carthage specimens of *Cameleolopha bellaplicata* to the *Prionocyclus macombi* Zone. This assignment in turn leads to the conclusion that the Carthage specimens could not form the ancestral stock for the species, which was described from the older *P. hyatti* Zone of Texas. A reexamination of the original morphometric data used to define the two subspecies, which follows in the next section, indicates that the morphologic variation seen in the Carthage specimens is normal species variation, not indicative of subspecies rank.

Comparison of subspecies of *Cameleolopha bellaplicata*

The differences noted by Kauffman (1965, pp. 53–55) between the two "morphologically similar" subspecies of *Cameleolopha bellaplicata* were subtle. Among other features *Cameleolopha bellaplicata bellaplicata* was thought to have a more rounded or subquadrate outline, a less oblique shell, and a less convex left valve with smaller, narrower, more numerous, and more extensively bifurcating ribs. In other words, *C. b. novamexicana* was a more robust, more coarsely ribbed variant of the more delicately sculpted *C. b. bellaplicata*.

Table 1 is adapted from data presented by Kauffman (1965, tables 2 and 5), quantifies some of these differences in terms of averages for 15 of the 37 parameters Kauffman used to characterize the two subspecies. These averages are based on 75 specimens for *Cameleolopha bellaplicata novamexicana* (67 left valves and 8 right valves) and on 285 specimens for *C. b. bellaplicata* (173 left valves and 112 right valves).

In 11 of these 15 quantitative categories the differences between the two subspecies are negative (-), meaning that average value of the parameter for *Cameleolopha bellaplicata bellaplicata* is larger than *C. b. novamexicana*. Discounting the parameters expressed as percentages above, this means that *C. b. bellaplicata* has the larger shell with more ribs than *C. b. novamexicana*. Quantitatively, the differences are generally small and might not be great enough to distinguish one subspecies from another. For example, the difference in average height of left valves is less than 1 mm. Surprisingly, this 2.1% difference in height is positive (+), meaning that *C. b. novamexicana* has a larger average height than *C. b. bellaplicata*.

In both subspecies the overwhelming shape of the valves is ovate, with height greater than length (H > L) at least 70% of the time; but the shape is variable with more than

[6]The slender morphotype is interpreted to represent the male of the species; the robust form, the female. Kennedy et al. (2001, p. 29) in their study of the Turonian members of the ammonite subfamily Collignoniceratinae, which includes the prionocyclids, state that "…Most species seem to consist of two major forms, a gracile one that has whorls higher than wide, and a more robust form that has broader whorls, a wider umbilicus, and stronger ornamentation. These may represent sexual dimorphs."

TABLE 1—Comparison of 15 morphometric parameters used to characterize the two subspecies of *Cameleolopha bellaplicata*, adapted from Kauffman (1965, tables 2 and 5).

	C. b. bellaplicata	*C. b. novamexicana*	difference
Height			
Left	38.7 mm	39.5 mm	+0.8 mm
Right	37.3 mm	36.3 mm	−1.0 mm
Length			
Left	37.5 mm	35.9 mm	−1.6 mm
Right	34.6 mm	32.5 mm	−2.1 mm
Width			
Left	13.4 mm	15.7 mm	+2.3 mm
Right	7.4 mm	8.7 mm	+1.3 mm
Percent of valves with:			
H > L	70%	78.6%	+8.6%
L > H	25%	21.4%	−3.6%
L = H	5%	0.00%	−5%
Average # ribs at valve margin			
Left	16.4	14.4	−2.0
Right	15.9	13.9	−2.0
Area of inscribing rectangle			
Left	14.51 cm^2	14.18 cm^2	−0.33 cm^2
Right	12.90 cm^2	11.80 cm^2	−1.10 cm^2
Rib density*			
Left	1.13/cm^2	1.02/cm^2	−0.11/cm^2
Right	1.23/cm^2	1.18/cm^2	−0.05/cm^2
Difference	0.10/cm^2	0.16/cm^2	—

*not calculated by (Kauffman 1965)

TABLE 2—Ontogenetic variation in rib density on left valves of *Cameleolopha bellaplicata bellaplicata*; from Kauffman (1965, table 2).

	Rib count (average)	Height (cm)	Length (cm)	Area (cm^2)	Density (/cmH)	Density (/cm^2)
	14.0	1.00	0.97	0.97	14.00	14.45
	15.8	2.00	1.94	3.88	7.90	4.08
	17.9	3.00	2.91	8.72	5.97	2.05
	18.4	4.00	3.88	15.50	4.60	1.19
	18.0	5.00	4.84	24.22	3.60	0.74
Avg.	**16.4**	**3.87**	**3.75**	**14.51**	**4.24**	**1.13**

TABLE 3— Ontogenetic variation in rib density on left valves of *C. b. novamexicana*; from Kauffman (1965, table 5).

	Rib count (average)	Height (cm)	Length (cm)	Area (cm^2)	Density (/cmH)	Density (/cm^2)
	11.5	1.00	0.91	0.91	11.50	12.65
	15.0	2.00	1.82	3.64	7.50	4.13
	13.8	3.00	2.73	8.18	4.60	1.69
	14.8	4.00	3.64	14.54	3.70	1.02
	16.0	5.00	4.54	22.72	3.20	0.70
Avg.	**14.4**	**3.95**	**3.59**	**14.18**	**3.65**	**1.02**

20% longer than high (L > H). *Cameleolopha bellaplicata novamexicana* averages two fewer ribs at the valve margin than *C. b. bellaplicata*, but is more inflated with a total width (thickness of both valves) that is 2.6 mm greater. Rib density (ribs/cm^2) is slightly greater in *C. b. bellaplicata* on both valves. However, within a subspecies there are greater absolute and percentage differences in rib density between the smaller right valve and larger left valve than there are between subspecies when comparing the same valve.

Kauffman (1965, pp. 14–17) lists 12 evolutionary trends that he noted in [his] progressively younger species or subspecies in the *Cameleolopha lugubris* lineage. These trends included: (his #1) decrease in maximum size; (#6) increase in the number of proximal ribs, which led to an increase in plication density (number per unit area); and (#7) decrease in average width of ribs, which meant the oldest form had the coarsest ornamentation and the youngest had the finest. Other trends had to do with changes in convexity of the valves (#2, #3); variation in auricles (#4, #5), variation in rib bifurcation (#8); changes in the cardinal area (#11); and increase in density of chomata (#12).

The key biometric illustration in Kauffman's (1965) paper is a foldout chart (his fig. 2, between pp. 10 and 11) on which he plotted terminal rib number against area of the left valve for every measured specimen of the three morphotypes. This figure was cited by Kauffman (1965, pp. 14–17) to contain evidence for his trends of decreasing size (#1) and increasing rib density (#6) through time. This figure shows graphically that rib density on left valves increases progressively in younger species and subspecies, from 1.02/cm^2 in *Cameleolopha bellaplicata novamexicana* to 1.13/cm^2 in *C. b. bellaplicata* to 7.29/cm^2 in *C. lugubris*. This statistic, however, is misleading because the area of the inscribing rectangle (i.e., height of valve (H) * length of valve (L)), which is a proxy for the area of the valve, increases at a faster rate than does rib count. So, in comparing two average size specimens of *C. bellaplicata* and *C. lugubris* with the same number of ribs, the rib density/cm^2 of *C. lugubris* will be about six times greater than of *C. bellaplicata* because the average *C. bellaplicata* is about six times larger than the average *C. lugubris*.

Kauffman (1965, p. 11) found it "desirable" to contrast structures on adult valves of the two subspecies of *Cameleolopha bellaplicata* at equivalent sizes. Tables 2 and 3, extracted from Kauffman (1965, tables 2 and 5), show that rib density on the adult left valve decreases progressively in both subspecies of *C. bellaplicata* with increasing height, in this case in five increments of 1 cm, from 1.0 cm to 5.0 cm of height. So, the smaller the specimen, the greater the rib density. Therefore, rib density comparisons between subspecies should be made on individuals of approximately the same size.[7]

[7]Length data were not presented by Kauffman (1965), but were estimated by assuming that the ratio of height to length was constant for each subspecies. The lengths of the left valves for each 1.0 cm of height increase for each subspecies were estimated using the ratio of the average length for the entire subspecies sample divided by the average height for the entire subspecies sample. The averages for each variable are shown high-lighted in gray on the last line of each table. For *C. b. bellaplicata* the length is approximately 97% of the height; for *C. b. novamexicana*, approximately 91%.

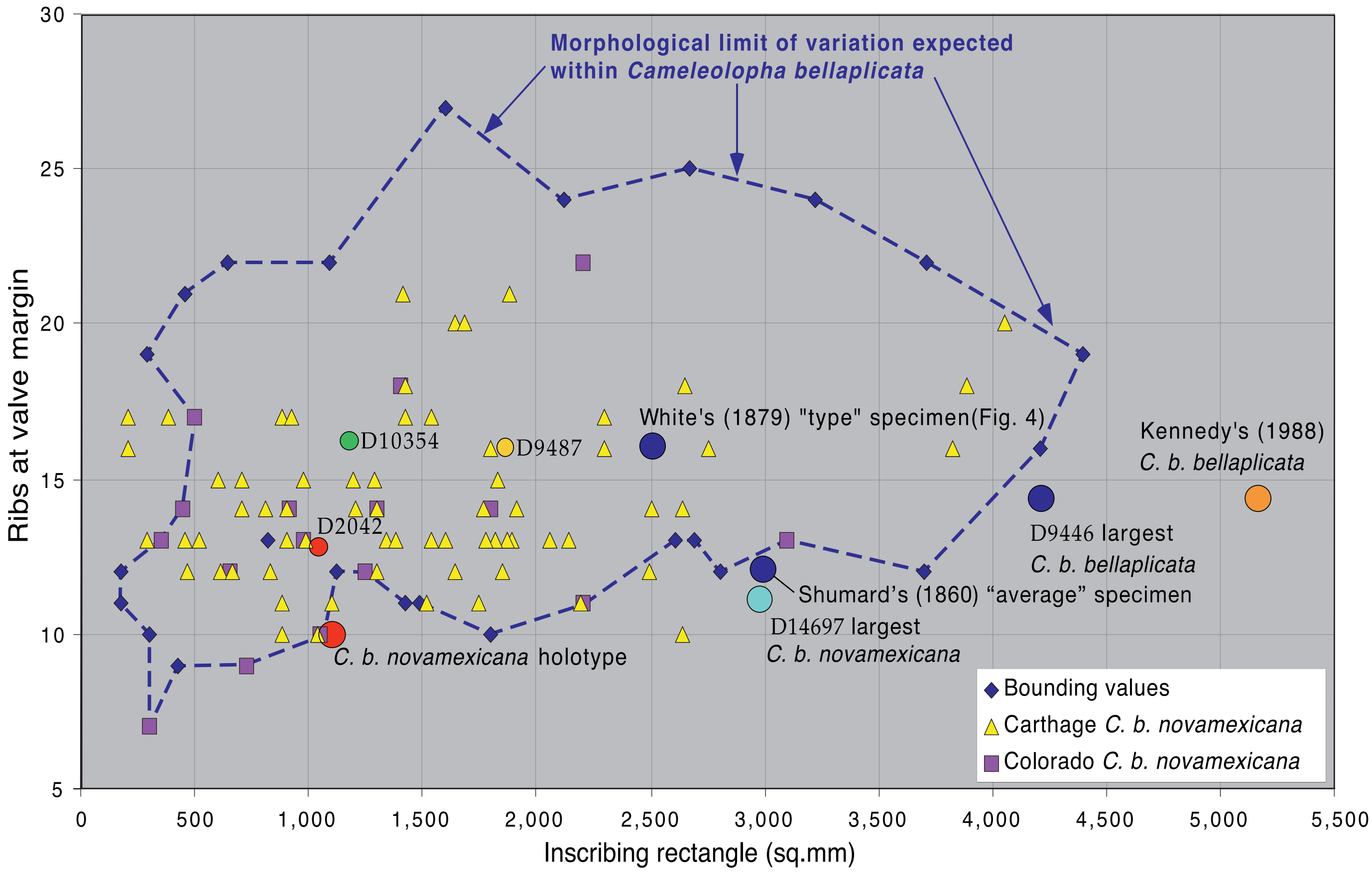

FIGURE 6—Graph of rib density on the left valves of several collections of *Cameleolopha bellaplicata* from New Mexico, Texas, and Colorado, modified from Kauffman (1965, fig. 2). In this scatter diagram, the number of ribs terminating at the valve margin is plotted against the area of the inscribing rectangle (= height × length) for the valve. The blue diamonds mark the bounding values of specimens assigned by Kauffman (1965, fig. 2A) to the subspecies *C. bellaplicata bellaplicata*; yellow triangles are for specimens from Carthage assigned to *C. b. novamexicana* by Kauffman (1965, fig. 2B); purple squares are for specimens from Colorado assigned to *C. b. novamexicana* by Kauffman (1965, fig. 2B), but known now to be variants of *C. bellaplicata*. The dashed blue polygon encloses the morphologic variation expected within the population of *C. bellaplicata* measured by Kauffman (1965). The vast majority of specimens from Carthage assigned to *C. b. novamexicana* by Kauffman fall within this bounding polygon. Six specimens from the type lot (D2042) of *C. b. novamexicana* from Carthage lie outside the bounding polygon. The four to the left represent immature individuals that, had they grown larger with or without increasing the number of ribs, would have moved within the bounding polygon. The two below the polygon are mature specimens; both are only slightly more coarsely ribbed than predicted. In addition, filled circles plot the positions of: one of Shumard's "type" specimens of *C. bellaplicata*, a right valve illustrated by White (1879) in dark blue (Fig. 4); Kauffman's (1965) type specimen of *C. b. novamexicana* in red; the largest specimen of *C. b. bellaplicata* from D9446 (Texas) in dark blue; the largest specimen of *C. b. novamexicana* from D14697 (Carthage) in light blue; the average specimen assigned to *C. b. novamexicana* from D2042 (Carthage) in red and from D10354 (Carthage) in green; and the average specimen of *C. bellaplicata* from D9487 (Texas) in gold. The specimen of *C. b. bellaplicata* illustrated by Kennedy (1988, pl. 23, figs. 26–27), from the Dallas–Ft. Worth, Texas, area, which plots outside the bounding polygon, is shown in orange for comparative purposes. (See discussion in Appendix 1.)

Kauffman's (1965, fig. 2) foldout chart is in two parts: figure 2A is a scatter diagram for all specimens measured from New Mexico, Colorado, and Texas; figure 2B for Colorado only. On each of the two graphs the number of plicae (ribs) is plotted against the area of the inscribing rectangle of the left valve. The morphological variation seen within each species or subspecies is highlighted by an enclosing polygon that connects the outer bounding values for each species or subspecies plotted on the scatter diagram. Of course, the polygons overlap because of transitional forms.

Using the average values for length and width of the left valves to obtain the average values for the areas of the inscribing rectangles in each species and dividing those values into average number of ribs at the margin of the shells yields the following rib densities: *Cameleolopha lugubris* (the youngest species) has a density of 7.29 ribs/cm^2; *C. bellaplicata bellaplicata* (the middle) has a density of 1.13 ribs/cm^2; and *C. b. novamexicana* (presumably, the oldest) has a density of 1.02 ribs/cm^2. This progressive increase among the three forms from 1.02 to 1.13 to 7.29 ribs/cm^2 through time makes a great evolutionary story, but it is based on an inverted biostratigraphic order for the subspecies of *C. bellaplicata*.

The great value of Kauffman's chart is that it shows quantitatively the morphological variation that can be expected within each of his subspecies. These data, when corrected biostratigraphically, can be used to determine if there is a rib-density difference between the Carthage specimens, which would have been assigned to *Cameleolopha bellaplicata novamexicana*, and the expanded *Cameleolopha bellaplicata* sample, which now includes the specimens from Colorado originally assigned to *C. b. novamexicana*, but now known to occur in the older *Prionocyclus hyatti* Zone. Kauffman's (1965, fig. 2A) chart has been redrawn using his data points, as Figure 6. Data plotted on this graph show that the majority of specimens that Kauffman assigned to *C. b. novamexicana* from Carthage lie within the morphological variation expected from the expanded sample of *C. b. bellaplicata* and, therefore, do not warrant subspecies designation on this key morphometric characteristic.

Two items to note about the data in Figure 6 are that: (1) the area of the inscribing rectangle for each data point had to estimated from the graph because the raw data for each specimen were not presented; and

(2) the *Cameleolopha bellaplicata novamexicana* data had to be separated into Colorado and Carthage subsamples. Item 2 (above) was easily accomplished because specimens assigned by Kauffman to *C. b. novamexicana* came from only two areas: Huerfano Park, Colorado, and Carthage, New Mexico. Both of Kauffman's graphs on his foldout figure were at the same scale and aligned vertically, one above the other. His figure 2A was a scatter diagram of all measured specimens, whereas his figure 2B was a scatter diagram of only the Colorado specimens. Therefore, it was relatively easy to determine which data points came from Carthage.

The datapoints representing these Colorado specimens are shown with purple squares in Figure 6; these specimens are now assigned to *Cameleolopha bellaplicata bellaplicata* because they occur in the *Prionocyclus hyatti* Zone. The remaining *C. b. novamexicana* specimens are from Carthage only and are shown as yellow triangles. The blue diamonds in Figure 6 represent the original bounding values (outer morphometric limits) for all specimens of *C. b. bellaplicata* from Kauffman's figure 2A; these specimens are from Colorado and Texas. The polygon in Figure 6 connects the bounding data points that are not from Carthage; that is, it shows the morphological variation expected from this large sample of *C. b. bellaplicata*.

Only six (of 66) plotted specimens from Carthage lie outside this bounding polygon. Four of these six specimens represent juveniles based on their small size, and had they maintained or increased the number of ribs as they matured, their data points would have moved inside the polygon as their areas increased. So, quantitatively, there is no difference between the subspecies *novamexicana* and *bellaplicata* in terms of rib density, which was presumed to be a major distinguishing characteristic. This result is not surprising because it is known now that the Carthage specimens, which include the holotype of *Cameleolopha bellaplicata novamexicana*, lie in the younger *Prionocyclus macombi* Zone rather than the older *P. hyatti* Zone.

Stratigraphy of *Cameleolopha bellaplicata*

All specimens of *Cameleolopha bellaplicata* from New Mexico have come from middle Turonian strata (as middle Turonian is defined today): either the Semilla Sandstone Member of the Mancos Shale, the Carthage and Fite Ranch Sandstone Members of the Tres Hermanos Formation, or the base of the Pescado Tongue or equivalent part of the D-Cross Tongue of the Mancos Shale. The strata containing *C. bellaplicata* were deposited during the waning stage of the initial regression, R-1, of the Late Cretaceous seaway (as the Semilla Sandstone) or during the early phase of the second transgression, T-2 (as all other rock units listed above). Usually, *C. bellaplicata* occurs in sandy, nearshore, high-energy environments, but is found occasionally in finer grained, slightly more offshore, deeper water, clay-rich environments. *Cameleolopha bellaplicata* is confined to the *Prionocyclus hyatti* and the overlying *P. macombi* Zones (Fig. 2). The distribution of all the USGS-Denver collections containing *C. bellaplicata* from New Mexico and adjoining parts of Arizona is shown in Figure 3.

The Semilla Sandstone was named by Dane et al. (1968) from a type section at Holy Ghost Spring, Sandoval County, New Mexico. La Fon (1981), whose research was published before the redefinition of the Tres Hermanos Formation (Hook et al. 1983), concluded that the Semilla was an offshore bar complex restricted to the type area. Hook et al. (1983) indicated that the Semilla was a more widespread unit of shelf sandstone and that it was the offshore (marine) equivalent of the (nonmarine) Carthage Member of the Tres Hermanos Formation (see Cobban and Hook 1989, fig. 2).

The D-Cross Tongue of the Mancos Shale was named by Dane et al. (1957) for exposures of Mancos Shale near D-Cross Mountain, northwest Socorro County, lying between the Tres Hermanos Formation and the Gallup Sandstone (both formations of today's usage). The Pescado Tongue of the Mancos Shale was named by (Pike 1947, p. 34) for exposures of Mancos Shale along Pescado Creek, southern McKinley County, lying between the Tres Hermanos Formation and the Gallup Sandstone. For more than 50 yrs, the name "Pescado Tongue" has been used for this shale tongue in the Zuni Basin and the name "D-Cross Tongue" elsewhere in New Mexico. By extension, the name D-Cross Tongue is also used for the shale lying between the Semilla Sandstone Member and the Gallup Sandstone. Fleming (1989) documented additional outcrops of the Semilla Sandstone in the Galisteo lowlands and Hagan and southern San Juan Basins.

Carthage syncline section

The Carthage coal field, Socorro County, is an isolated exposure of Upper Cretaceous that is a key control point in central New Mexico (Fig. 3) because it: (1) provides the lithologic and paleontologic links from the better known, more or less continuous exposures in the San Juan Basin to lesser known, isolated outcrops in central and southern New Mexico and (2) contains the principal reference section of the Tres Hermanos Formation and the type localities for the: (a) Carthage Member of the Tres Hermanos Formation and (b) Fite Ranch Sandstone Member of the Tres Hermanos Formation (Hook et al. 1983). It also contains the type locality for the middle Turonian ammonite *Coilopoceras colleti* Hyatt 1903; before this paper, it was also the type locality for the middle Turonian oyster *Cameleolopha bellaplicata novamexicana* (Kauffman 1965), which is now an invalid subspecies. Hook (2009, p. 25) reported that the lower tongue of Mancos Shale in the Carthage coal field contained more discrete ash beds of middle to late Cenomanian age than any other published section in the Western Interior; in addition the lower tongue contains the Cenomanian–Turonian boundary limestone. In this section of the paper a previously unpublished, but well-exposed, well-collected, stratigraphic section from the Carthage coal field is examined in detail. The purpose of this discussion is primarily to put the occurrences of *Cameleolopha bellaplicata* into stratigraphic and biostratigraphic context.

The Tres Hermanos Formation in the Carthage syncline was measured in the NE¼ sec. 10 T5S R2E, Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico, by S. C. Hook on November 1, 2007. This measured section is near the east end of the Upper Cretaceous outcrop belt in the coal field, just north of US–380 (Fig. 7). The rocks measured on the east flank of this doubly plunging syncline extend from just below the base of the Bridge Creek Limestone Beds of the lower tongue of the Mancos Shale through the top of the Tres Hermanos Formation. Approximately 7 ft (2 m) of D-Cross Tongue of the Mancos Shale is exposed on the west side of the synclinal axis, but this exposure of noncalcareous, clay shale is mostly covered by wind-blown sand (Qe) and is almost too small to map (Fig. 7). The basal 21 ft (6 m) of the D-Cross Tongue of the Mancos Shale shown in Figure 8 were measured at one of three, small "haystack" exposures of the basal D-Cross Shale, in the SW¼ sec. 9 T5S R2E, approximately 1.5 mi (2.4 km) to the southwest and composited to the syncline section.

The composite section (Fig. 8) encompasses 591 ft (180 m) of upper Cenomanian through upper Turonian strata that are fossiliferous from bottom to top and contains the Cenomanian–Turonian boundary limestone (Hook 2009, pp. 24–25). It is also the only section in the Carthage coal field to contain marine fossils in concretions in the upper portion of the mostly nonmarine Carthage Member of the Tres Hermanos Formation (Fig. 8, D14546). Similar concretions in the upper part of the Carthage Member elsewhere in the coal field are barren.

Only the Tres Hermanos Formation and D-Cross Tongue are shown with paleontologic and lithologic detail in Figure 8. The upper part of the lower tongue of the Mancos Shale, which is not shown, consists of: (a) 76 ft (23 m) of Bridge Creek Limestone Beds, including the Cenomanian–Turonian boundary limestone 29 ft (9 m) above the base; (b) 100 ft (30.5 m) of the calcareous shale unit; and (c) 120 ft (36.6 m) of the noncalcareous shale unit. The calcareous/noncalcareous shale units are separated from each other by a 7-inch-(18-cm-) thick bentonite. See Hook (2009) for a discussion of the lower tongue of the Mancos Shale in the Carthage coal field.

The contact of the lower shale tongue with the overlying Atarque Sandstone Member of the Tres Hermanos Formation is gradational;

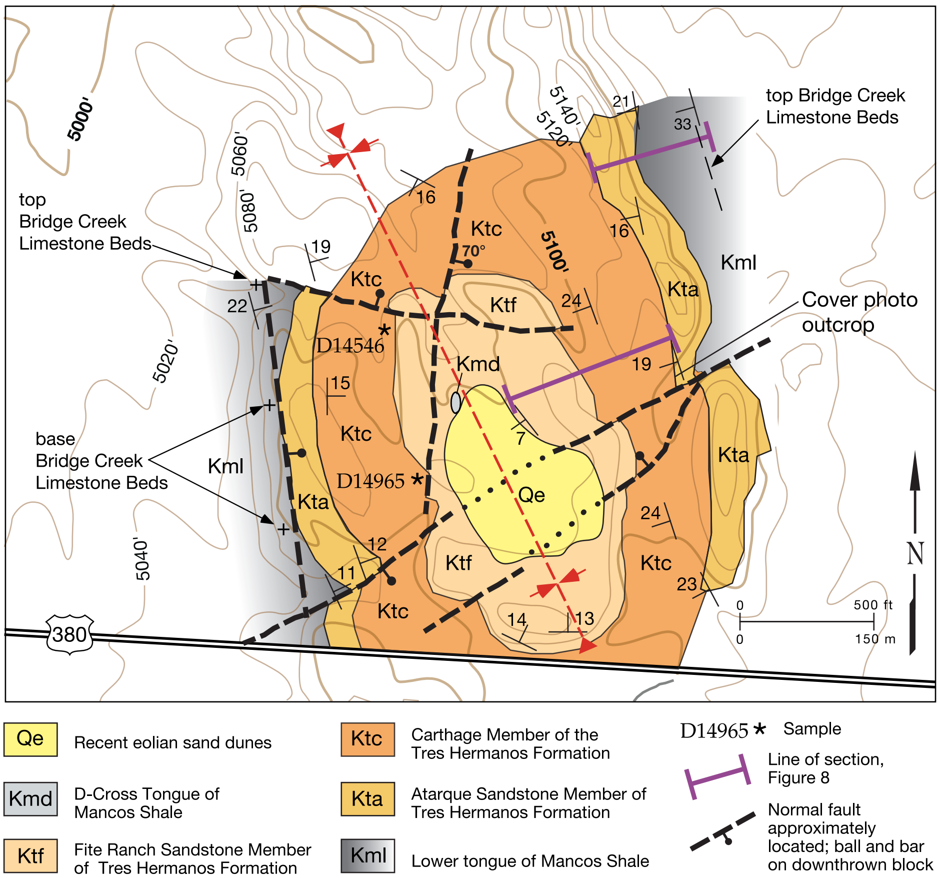

FIGURE 7—Reconnaissance geologic map of the Carthage syncline, exposed in the central portion of sec. 10 T5S R2E Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico, just north of US–380. The axis of the syncline trends approximately N26°W. Modified from an unpublished map by R. Chamberlin and D. Love.

the contact of the Fite Ranch Sandstone Member with the overlying D-Cross Tongue is sharp. The rubbly, rusty-brown-weathering sandstone at the top of the Fite Ranch Sandstone (Fig. 8, unit 62) is exposed along the axis of the syncline (Fig. 7) and contains *Cameleolopha bellaplicata* and *Pholadomya* sp. (D14553) along with white phosphate granules. Concretions that are 9 ft (2.7 m) above the base of the D-Cross Tongue contain *Prionocyclus novimexicanus* and *Inoceramus perplexus* (D14509). The absence of fauna from the upper part of the *P. macombi* Zone and the entire *P. wyomingensis* Zone, particularly *Cameleolopha lugubris*, suggests that the basal 9 ft of the D-Cross Tongue is at minimum a condensed interval. The large fragment of an Inoceramus sp. from an intermittently developed, 0.5-inch-(1-cm-) thick calcarenite, 5 ft (1.5 m) above the base (D14549) is not geniculate; it is, therefore, more likely to be *I. perplexus* than *I. dimidius*. These collections combined with the sharp contact between the D-Cross and Fite Ranch indicate there is an unconformity separating the two units. Hook et al. (1983, p. 22) suggested a disconformity for similar reasons between the two member-rank units as well.[8]

The measured thickness of the Tres Hermanos Formation in the syncline is 289 ft (88 m). The Tres Hermanos Formation (Fig. 8) consists of three members: a marine, regressive sandstone at the base, the Atarque Sandstone Member, 90 ft (27 m) thick; a mostly nonmarine core of carbonaceous shale, siltstone, and sandstone, the Carthage Member, 108 ft (33 m) thick; and an upper, transgressive marine sandstone unit, the Fite Ranch Sandstone Member, 91 ft (28 m) thick. These thicknesses are similar to those measured by C. M. Molenaar at the principal reference section of the Tres Hermanos Formation at Carthage in sec. 8 and 17 T5S R2E (Hook et al. 1983, pp. 17–18). There, the Tres Hermanos Formation is 277 ft (84 m) thick; the Atarque Sandstone Member is 86 ft (26 m) thick; the Carthage Member is 116 ft (35 m) thick; and the Fite Ranch Sandstone Member is 75 ft (23 m) thick. The total, measured thickness of the Tres Hermanos Formation at the syncline section is about 4% greater than at the reference section. However, the Fite Ranch Sandstone Member is about 20% greater, perhaps because of undetected dip decreases toward the axis of the syncline.

The Tres Hermanos Formation at Carthage lies entirely within the middle Turonian. The lower half of the formation was deposited during the waning stage of the initial major regression, R-1, of the Late Cretaceous seaway in New Mexico; the upper half was deposited during the initial stage of the second major transgression, T-2, of the seaway (Fig. 8). Fossils from the base of the Atarque Sandstone Member indicate that it was deposited during the time represented by the middle Turonian *Collignoniceras woollgari woollgari* subzone of the *C. woollgari* Zone (D15012). Fossils indicative of the higher *Collignoniceras woollgari regulare* subzone of the *C. woollgari* Zone and the overlying *Prionocyclus hyatti* Zone have never been found in the Tres Hermanos Formation in the Carthage coal field. The upper part of the marine Atarque Sandstone Member could have been deposited during the time represented by the *C. w. regulare* subzone, especially because *C. woollgari woollgari* occurs in the shale well below the base of the Atarque elsewhere in the coal field. The lower 100 ft (30 m) or so of the nonmarine Carthage Member were probably deposited during the time represented by the *P. hyatti* Zone, whereas the upper 15 ft (5 m) were deposited during the early part of the *P. macombi* Zone (D14546). The entire Fite Ranch Sandstone Member was deposited during the time represented by the *P. macombi* Zone; *Cameleolopha bellaplicata* occurs both at the base (D14546) and top of the member (D14553).

The base of the Atarque contains *Spathites rioensis* (D14551), indicative of the *Collignoniceras woollgari woollgari* subzone of the *C. woollgari* Zone, as well as *C. woollgari woolgari* (D15012). The top of the Atarque is marked by a resistant, 3-ft-(1-m-) thick quartzite that is ripple marked and burrowed, and contains the *Skolithos* ichnofauna (D14552; Fig. 9D). The Fite Ranch carries a consistent *Prionocyclus macombi* Zone fauna from bottom to top that is dominated numerically by shells of *Cameleolopha bellaplicata* and internal molds of the bivalve *Pholadomya* sp. (D14547, D14548, and D14553), but also carries *P. macombi* (D14546 and D14548), and *Coilopoceras colleti* (D14965, D14547, and D14548).[9] The uppermost 15 ft (5 m) of the Carthage Member appears to be marine (Fig. 9E); septarian limestone concretions in the upper 3 ft

[8]Hook et al. (1983, p. 17, Sheet 1B) were in error showing *"Lopha" sannionis*, *Coilopoceras inflatum*, and *Prionocyclus macombi* in collection D11161 from the uppermost bed of the Fite Ranch Sandstone Member. The oyster is a poorly preserved fragment of *Cameleolopha bellaplicata*; there is no coilopocerid in the collection; and the prionocyclid is too poorly preserved to assign to a species. Further collecting from this rubbly bed throughout the Carthage area has failed to yield any ammonites or younger oysters.

[9]The largest known specimen of *Coilopoceras colleti* came from the base of the Fite Ranch Sandstone Member in the Carthage syncline (Figs. 7 and 8, D14965). D14965 is a portion of a highly inflated body chamber with a fold-like rib that has a whorl height of 10 inches (25 cm) and a whorl width of 8 inches (20 cm). The reconstructed diameter of this specimen is estimated to be 16.4 inches (41.5 cm) using techniques explained in Cobban and Hook (1981). Previously, the largest known specimen of *C. colleti*, also from Carthage, had a measured diameter of 32.2 cm (12.8 inches) (Cobban and Hook 1980, table 2; pls. 8 and 9).

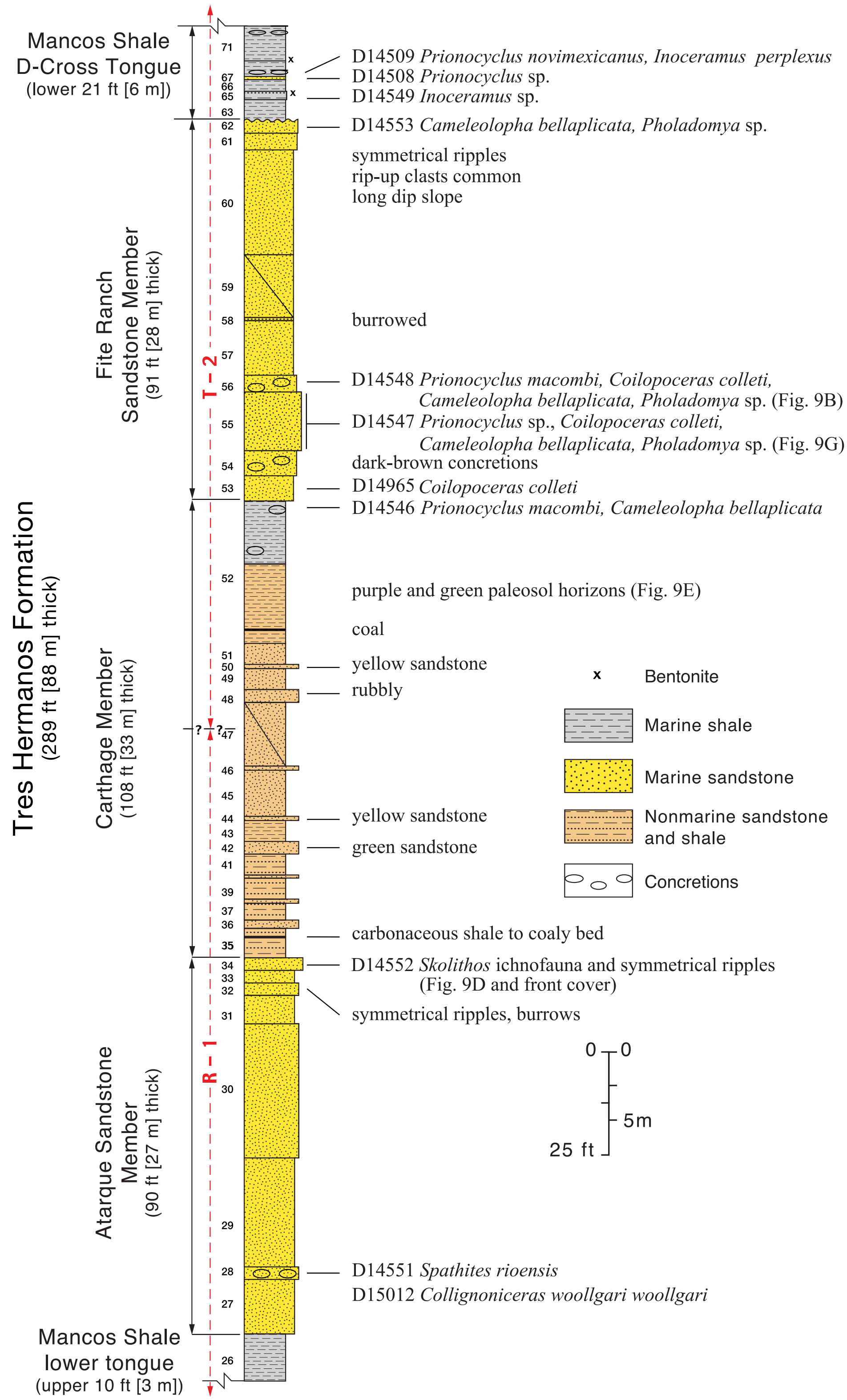

FIGURE 8—**The Carthage syncline measured section shows the positions of fossil collections ranging from the base of the Tres Hermanos Formation into the basal part of the D-Cross Tongue of the Mancos Shale.** The Tres Hermanos Formation was measured in the NE¼ sec. 10 T5S R2E Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico; the basal part of the D-Cross Tongue, in the SW¼ sec. 9 T5S R2E Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico. Lines of section are shown in Figure 7.

(1 m) contain *P. macombi* and *C. bellaplicata* (D14546). Conspicuous purple and green zones in the shale below D14546 but above a thin coal bed, contain carbonaceous roots and are interpreted as paleosols (Fig. 9E).

The Fite Ranch Sandstone Member is interpreted as a coastal barrier sandstone in Hook et al. (1983); it attains its greatest thickness in New Mexico in the Carthage coal field, where it is a minimum of 75 ft (23 m) thick. Fossils are extremely abundant in the lower 20–25 ft (6–8 m) cliff-forming sandstone (Fig. 9B). Hook (1983, p. 171) lists six species of bivalves, one oyster, three species of gastropods, and two species of ammonites from this unit. Since that list was compiled, the bivalve *Inoceramus dimidius* has been discovered, as well. In terms of numerical abundance, *Cameleolopha bellaplicata* and *Pholadomya* sp. are the dominate faunal elements. This yellow-weathering, cliff-forming unit is only weakly bedded due to extensive bioturbation; it weathers to large, rounded masses. The next 50 ft (15 m) or so of the member is barren of body fossils. *Cameleolopha bellaplicata* and *Pholadomya* sp. make one last appearance, often in some abundance, in the upper 3-ft-(1-m-) thick, rusty-brown-weathering, sandstone bed that marks the top of the Fite Ranch Sandstone. This rubbly weathering bed contains white phosphate granules that suggest it represents an erosion surface. Fossils are abundant in this rubbly weathering bed in the syncline (D14553) but are rare elsewhere in the coal field.

The basal portion of the D-Cross Tongue of the Mancos Shale is seldom exposed anywhere in the Carthage coal field. A very small exposure of the D-Cross Tongue peeks through the dune sands to the northwest along the axis of the Carthage syncline (areal extent exaggerated in Fig. 7). This noncalcareous, clay shale is approximately 7 ft (2 m) thick. No hard beds, concretions, fossils, or bentonites were observed at this outcrop.

The basal 21 ft (6 m) of the D-Cross Tongue of the Mancos Shale shown in Figure 8 was measured at a better exposure in the SW¼ sec. 9 T5S R2E Cañon Agua Buena 7.5-min quadrangle, Socorro County and composited to the syncline measured section. Here, the D-Cross consists primarily of noncalcareous shale with a thin zone of fossiliferous, pancake concretions, 9 ft (2.8 m) above the base, and a 4-inch-(10-cm)-thick bentonite, 13 ft (4 m) above the base. The thin, dark-brown, platy calcarenites of lower Juana Lopez aspect and fauna that Tabet (1979, pp. 6 and 14) noted in this part of the section in the Jornada del Muerto coal field, 10 mi (16 km) to the north (Fig. 3), are absent, as is *Cameleolopha lugubris*.

The presence of *Prionocyclus novimexicanus* (D14509) in the pancake concretions 9 ft (2.8 m) above the base of the D-Cross suggests that the basal part of the D-Cross Tongue at Carthage is the same age as the uppermost part of the Juana Lopez Member in the San Juan Basin, whereas the presence of *C. bellaplicata* in the rubbly-weathering sandstone with white phosphate granules at the top of the Fite Ranch (D14553) indicates that top of the Tres Hermanos is older than the base of the Juana Lopez. The inescapable conclusion is that there is an unconformity at or just above the top of the Tres Hermanos at Carthage. If there were beds of lower Juana Lopez aspect or fauna

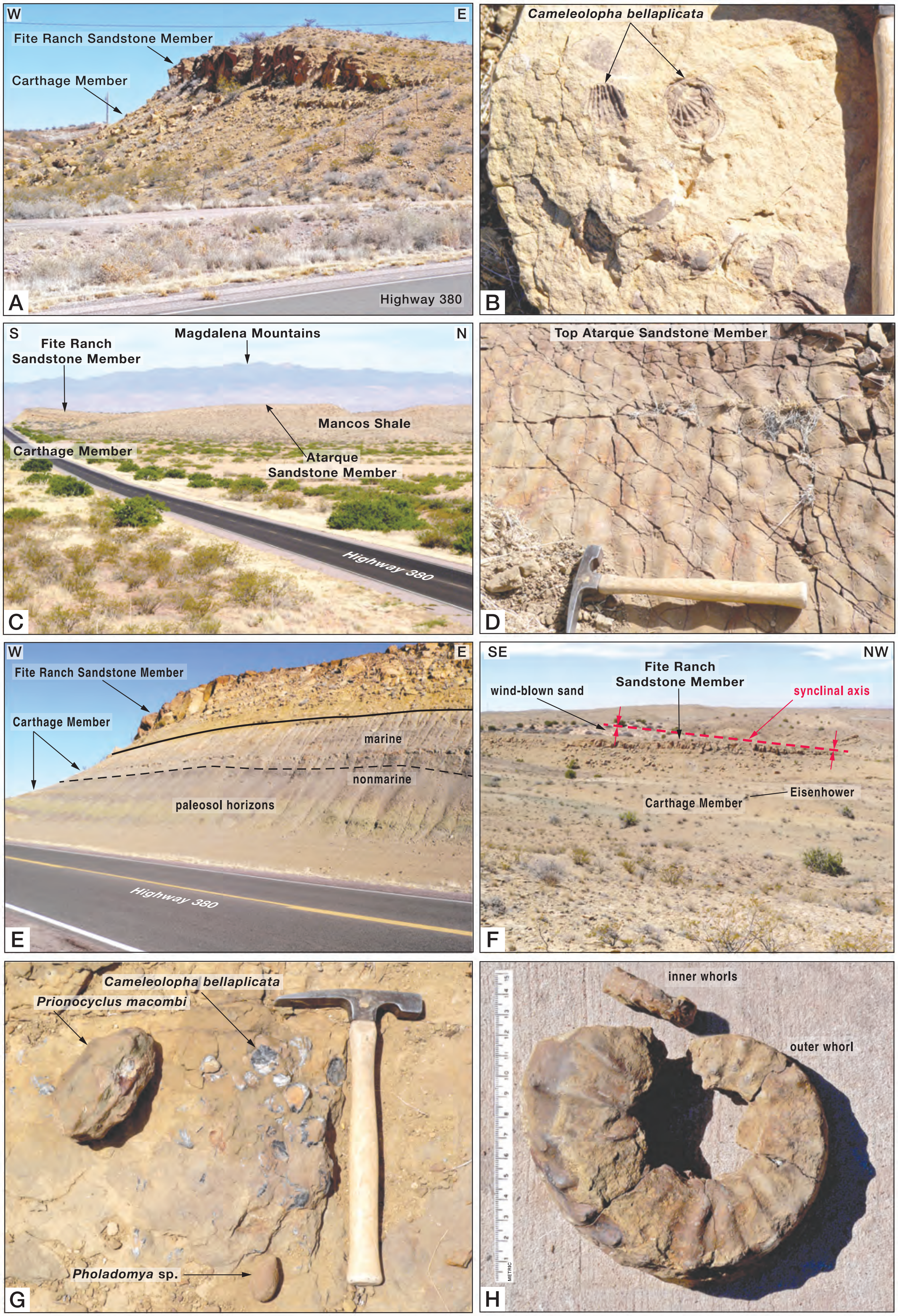
W
E
Fite Ranch Sandstone Member
Carthage Member
Highway 380
A
Cameleolopha bellaplicata
B
S
N
Magdalena Mountains
Fite Ranch
Sandstone Member
Mancos Shale
Carthage Member
Atarque
Sandstone Member
Highway 380
C
Top Atarque Sandstone Member
D
W
E
Fite Ranch Sandstone Member
Carthage Member
marine
nonmarine
paleosol horizons
Highway 380
E
SE
NW
Fite Ranch
Sandstone Member
wind-blown sand
synclinal axis
Eisenhower
Carthage Member
F
Cameleolopha bellaplicata
Prionocyclus macombi
Pholadomya sp.
G
inner whorls
outer whorl
METRIC
H

FIGURE 9—Photographic gallery of the Tres Hermanos Formation in the Carthage coal field, Socorro County, New Mexico. **A—**Outcrop view of USGS Mesozoic locality D2042. Fossils from the basal part of the Fite Ranch Sandstone Member at this location provided the type specimen of *Cameleolopha bellaplicata novamexicana* (Kauffman). View is to the northeast toward the NE¼ sec. 9 T5S R2E Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico. **B—**Typical hand specimen from the yellow, massive cliff-forming sandstone near the base of the Fite Ranch Sandstone Member. Shells of *C. bellaplicata* dominate the fauna from this level (D14547 in Fig. 9) and throughout the member. **C—**View of the Carthage syncline looking west toward the Magdalena Mountains. Resistant sandstones in the Tres Hermanos Formation stand in bold relief above softer shales. In this view, the Atarque Sandstone Member dips toward the west and the Fite Ranch Sandstone Member dips toward the north (see Fig. 8). **D—**Outcrop view of the extremely resistant, rippled, and burrowed sandstone that marks the top of the Atarque Sandstone Member (see cover) and is the last marine bed deposited in the area during the R-1 regression. Rock hammer is 13 in (33 cm) long. **E—**This spectacular roadcut through the Carthage syncline on the north side of US–380 exposes the upper, shaly part of the Carthage Member and the cliffs formed by the lower part of the Fite Ranch Sandstone Member, in the type area for each member. The contact between the two members is gradational; paleosols in the Carthage Member weather purple and green; a thin coal bed is exposed just west of the edge of the image. The approximate position of the marine/nonmarine contact in the Carthage Member is shown by a dashed line. View is toward the northwest. **F—**View southwest from the top of the Atarque Sandstone Member across the entire Carthage Member toward the core of the Carthage syncline in the vicinity of the measured section. Prominent yellow cliff in the near background is formed by the basal part of the Fite Ranch Sandstone. Wind-blown sand covers much of the core of the syncline, whose axis is approximated by a dashed red line. Note large black dog (Eisenhower) for scale near the top of the sandstone and shale unit of the Carthage Member. **G—**Fossils from the Fite Ranch Sandstone Member. This faunal assemblage from the D14548 level in Figure 8 is typical in both composition and preservation of that of the entire Fite Ranch. The oyster, *Cameleolopha bellaplicata,* dominates the fauna numerically and occurs as original shells. Specimens of the infaunal clam, *Pholadomya* sp., are abundant and occur as internal molds. The keeled ammonite, *Prionocyclus macombi*, is the dominate ammonite, preserved as internal molds, usually as fragments of large individuals. **H—**Internal mold of a well-preserved, medium-diameter prionocyclid from the cliff-forming sandstone at the base of the Fite Ranch Sandstone Member, D14547 level in Figure 9. Inner whorls removed and displayed above the outer whorl, which has a diameter of 15 cm. This specimen can be assigned unequivocally to *Prionocyclus macombi* Meek on the basis of the single ventrolateral tubercles present at small diameters. This robust individual, USNM 545194 was collected from USGS Mesozoic locality D15000.

here at one time, then they were removed by what has to have been submarine erosion. Hook et al. (1983, p. 22) were the first to draw attention to this unconformity at Carthage and noted that a similar unconformity was present at sections on and just south of the Sevilleta National Wildlife Refuge (Fig. 3), in the Zuni Basin, and along the Defiance monocline in Arizona. Since then, evidence for an unconformity of smaller time duration between the Tres Hermanos and D-Cross has been found at the north end of the Jornada del Muerto coal field as well.

Cameleolopha bellaplicata attains its greatest known stratigraphic (vertical) range in New Mexico at Carthage (Fig. 8); *Cameleolopha lugubris*, the younger species, does not occur at Carthage, although it has been found in sections to the north, northwest, south, and east. From its first occurrence at the Carthage syncline section, 1 ft (30 cm) below the top of the Carthage Member (D14546), to its last occurrence at the top of the Fite Ranch Sandstone Member (D14553), *C. bellaplicata* ranges through 92 ft (28 m) of section. This vertical range is entirely within the *Prionocyclus macombi* Zone in the Carthage area. In contrast, Kennedy (1988, fig. 4) shows a vertical range of 13 m (43 ft) for *C. bellaplicata* in the Arcadia Park Formation in the Dallas–Ft. Worth area, near its type locality, all within the *P. hyatti* Zone. Kauffman (1965, p. 3) reports that in Texas, *C. bellaplicata* generally "… occurs in the upper 25 ft of the Eagle Ford, but locally it has been reported ranging through as much as 70 feet of section." This 70 ft would be entirely within the *P. hyatti* Zone. Unfortunately, Kauffman does not cite references for this local range.

Biostratigraphic utility

In order for a fossil species to be a useful biostratigraphic indicator, it must, among other criteria, be easily recognizable. Unfortunately, this has not been the case for the lugubris group, at least in its early history. The species concept surrounding the lugubris group has undergone some radical changes since the 1850s. Originally, of course, the two species were considered distinct from the each other, although very little was known about the stratigraphic position of either form. Stanton (1893, pp. 58–59; Fig. 1) considered the group to be a single species that varied from a small, dwarf form with a large attachment scar, *Cameleolopha lugubris* (Conrad 1857), to a medium-sized form with a small to absent attachment scar, *C. bellaplicata* (Shumard 1860), to an even larger, but still medium-sized form, *C. blackii* (White 1880), which Kauffman (1965, p. 43) placed in synonymy with *C. bellaplicata bellaplicata*. Recently, Akers and Akers (2002, fig. 182) perpetuated this single-species concept by republishing five of Stanton's figures (1893, figs. 1, 3, 6, 7, and 9), which they identified as *Cameleolopha lugubris lugubris*. Three of their figures (6, 7, and 9) represent *Cameleolopha bellaplicata*. Although Böse (1913, pp. 47–48) recognized all three species in Mexico, Stanton's (1893) concept of a single variable species was used in the United States until Kauffman (1965) demonstrated the morphologic and biostratigraphic differences between the two species.

Kauffman (1965, fig. 1) showed the utility of using the *Cameleolopha lugubris* group biostratigraphically in the southern part of the Western Interior. *Cameleolopha bellaplicata* was confined to the upper part of the Blue Hill Member of the Carlile Shale, whereas *C. lugubris* was confined to the Juana Lopez Sandstone Member of the Carlile Shale in both Colorado and New Mexico. He showed a similar distribution in Texas between the upper Eagle Ford Shale with *C. bellaplicata* and the overlying, lower portion of the Austin Chalk with *C. lugubris*. Kennedy's (1988, p. 13, fig. 4) research in Texas indicated that *C. bellaplicata* was confined to the *Prionocyclus hyatti* Zone in the Arcadia Park Formation in the Dallas–Ft. Worth area; he does not record *C. lugubris* in the disconformably overlying Austin Chalk. Hancock and Walaszczyk (2004, fig. 2) redrafted this measured section for their paper on sea-level changes. Both Kennedy (1988) and Hancock and Walaszczyk (2004) referred the stratigraphically lowest occurrence of ribbed oysters in the Arcadia Park Formation to *C.* cf. *C. bellaplicata novamexicana*, presumably because they were unable to demonstrate that these oysters met the morphological criteria established for *C. b. novamexicana* by Kauffman (1965). (See Appendix 1 for details.)

Dane et al. (1966) demonstrated that *Cameleolopha lugubris* was a dominate faunal element of the Juana Lopez Member of the Mancos Shale in the San Juan Basin of New Mexico. They documented three, non-overlapping forms of lugubris: a coarsely plicate form in the lower Juana Lopez; a finely plicate form in the middle; and a finely plicate to smooth form in the upper.[10] Two years later, Dane et al. (1968) defined the stratigraphically lower Semilla Sandstone Member of the Mancos Shale in the southern San Juan Basin. The Semilla Sandstone lies entirely within the *Prionocyclus hyatti* Zone, one ammonite zone below the Juana Lopez Member. At the type locality for the Semilla Sandstone, *Cameleolopha bellaplicata* occurs abundantly throughout the member, which is 69 ft (21 m) thick. However, only the supposedly younger subspecies, *C. b. bellaplicata*, was recognized.

Many measured sections in the Acoma, Zuni, and southern San Juan Basins of west-central New Mexico show that *Cameleolopha bellaplicata* is confined to the top of the Tres Hermanos Formation or the basal few feet of the overlying tongue of Mancos Shale; *C. lugubris* occurs higher in the section in the Mancos Shale tongue, usually at the base of the Juana Lopez beds (see, e.g., Hook et al. 1983, sheet 1 and Molenaar et al. 1996).

10This smooth form may be a different species. Hence, the question marks on the uppermost portion of the range for *Cameleolopha lugubris* in Figure 2.

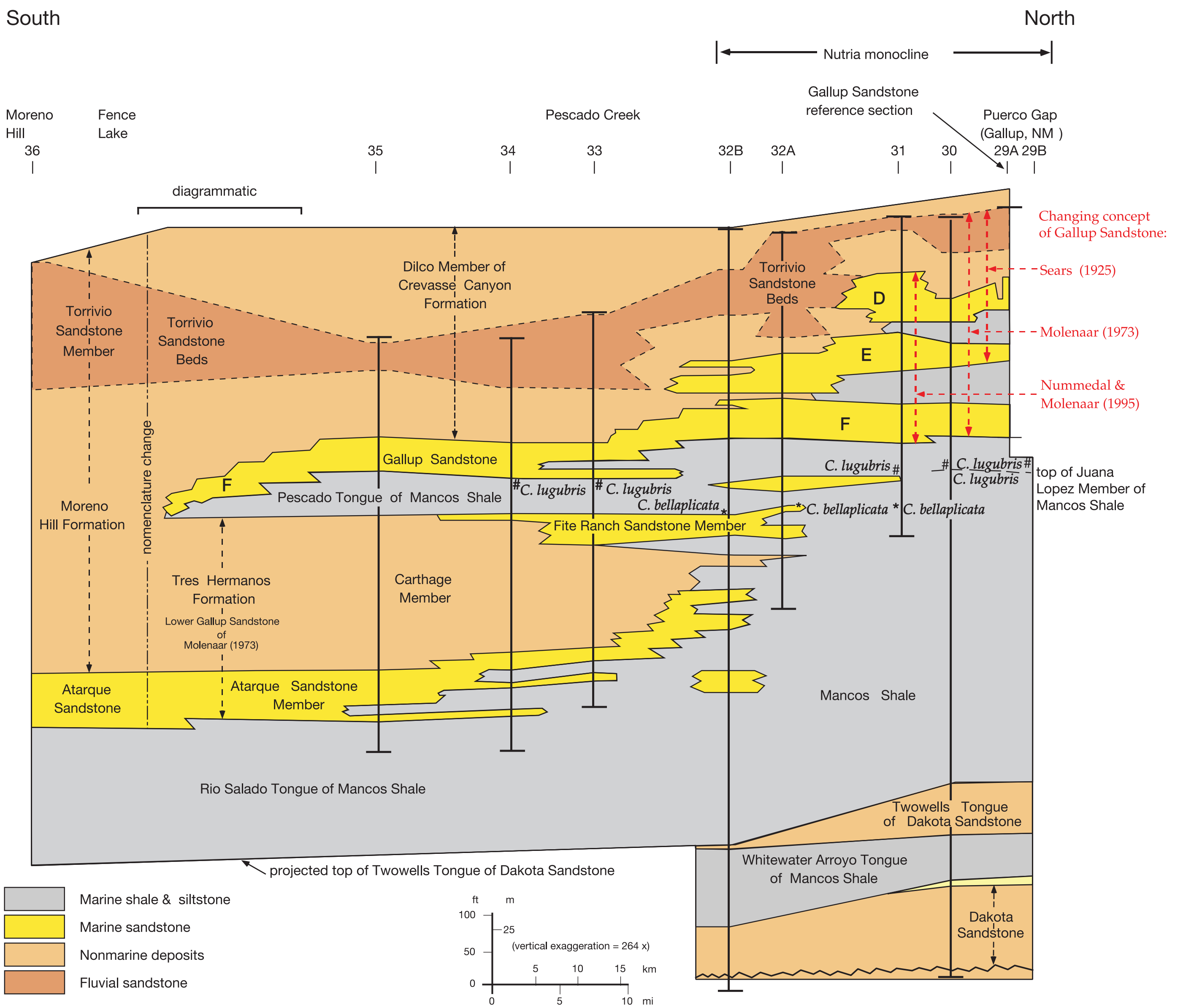

FIGURE 10—Upper Cretaceous stratigraphic cross section in western New Mexico from Moreno Hill in the southern Zuni Basin north to Gallup in the southern San Juan Basin. The stratigraphic positions of the oysters *Cameleolopha bellaplicata* (*) and *C. lugubris* (#) were instrumental in correlating rock units from the better known San Juan Basin in the north to basins to the south and southeast, including the Carthage coal field. Before 1983, the Tres Hermanos Formation was called the lower member of the Gallup Sandstone; the Fite Ranch Sandstone Member of the Tres Hermanos Formation was correlated with the "F" sandstone; and the top of the Juana Lopez was correlated to the middle of the Carthage Member. The changing concept of which sandstone beds and environments of deposition have constituted the Gallup Sandstone is highlighted on the right side of the diagram from the original definition of Sears (1925) through the addition of the "F" sandstone by Molenaar (1973) to the redefinition by Nummedal and Molenaar (1995) that removed all units of nonmarine origin from the Gallup Sandstone including the Torrivio Sandstone Member. Simplified and modified from Molenaar (1983b, fig. 3); the line of section is shown in Figure 3.

The Gallup Sandstone controversy

In the late 1970s, the most contentious stratigraphic issue in New Mexico involved the correlation and composition of the Upper Cretaceous Gallup Sandstone, an important aquifer and petroleum reservoir in the southern San Juan Basin. The biostratigraphy of the *Cameleolopha lugubris* group was instrumental in resolving the position of the lower boundary of the Gallup Sandstone in central and northwest New Mexico.

The Gallup Sandstone (then a 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 that occur at the top of the Mancos Shale at the town of Gallup, McKinley County, New Mexico (Fig. 10, control point 29A). The controversy about the upper contact revolved around the environment of deposition of the uppermost sandstone unit in the Gallup: in the type area the top of the Gallup was placed by Sears (1925) at the top of a (nonmarine) fluvial sandstone named the Torrivio Member of the Gallup Sandstone by Molenaar (1973, p. 980). Farther north in the San Juan Basin, the top of the Gallup was placed at the top of a (marine) regressive coastal barrier sandstone. The lithostratigraphers thought the top of the Gallup should be at the top of the Torrivio; the genetic stratigraphers thought the top should be at the top of the uppermost marine sandstone.

This issue was resolved in favor of lithostratigraphy rather than genetic stratigraphy (environment of deposition) because the nonmarine (Torrivio) sandstone was included in Sears's (1925) original definition of the Gallup Sandstone. So, the Torrivio Sandstone remained a member of the Gallup Sandstone rather than becoming a part of the overlying (nonmarine) Crevasse Canyon Formation (see for example, Hook et al. 1983, sheet 1; and Molenaar 1983b, p. 34). Molenaar, (1983b, p. 34) recounts the history of this controversy and concludes by saying that at a meeting of interested participants in Denver, Colorado, on February 2, 1978, the Geologic Names Committee of the U.S. Geological Survey "…recommended that the upper coarse-grained pink sandstone described by Sears (1925), the Torrivio Member of Molenaar (1973), be retained as the top of the Gallup Sandstone." Hook (1983, p. 170), in his study of marine Upper Cretaceous rocks of Socorro County, New Mexico, offered this solution: "Where map scale permits, the marine shale tongues that separate marine sandstones [within the Gallup Sandstone]…can be mapped as tongues of Mancos Shale. Nonmarine shale tongues in the upper part of the Gallup can be mapped as tongues of the Crevasse Canyon. The Torrivio Member…is not recognized in Socorro County. Consequently, the top of the Gallup Sandstone is placed at the top of the uppermost marine sandstone…."

However, 12 yrs later, Nummedal and Molenaar (1995, p. 307) removed the Torrivio Sandstone from the Gallup and designated it as a member of the Crevasse Canyon Formation. At the principal reference section of the Gallup (Molenaar 1983b, p. 33 and fig. 12; Fig. 10, control point 29A) the top of the Gallup Sandstone is now at the top of the D sandstone (Molenaar's unit 9), and the overlying shales and sandstones through the Torrivio (unit 19), all formerly considered part of the Gallup, are parts of the Crevasse Canyon Formation. Molenaar et al. (1996) in a USGS Oil and Gas Investigations Chart used the Torrivio Sandstone as a member of the Crevasse Canyon Formation and showed it to be separated from the Gallup Sandstone by a coaly sequence in the Dilco Member of the Crevasse Canyon. This USGS publication implies acceptance of this redefinition by the Geologic Names Committee of the U.S. Geological Survey.[11]

The Tres Hermanos problem

The lower boundary of the Gallup Sandstone was more difficult to solve because it involved correlation of rock units over large distances and often between widely scattered, isolated outcrops, rather than a definition of what constituted the Gallup Sandstone. Molenaar (1974) divided the Gallup into a series of coastal barrier sandstones that he designated informally by the letters A (highest) through F (lowest) to facilitate correlation and to separate out tongues of Mancos Shale (Fig. 10). The "F" sandstone is the base of the Gallup Sandstone at the principal reference section of the Gallup Sandstone established by Molenaar (1983b). The "F" sandstone was not included in Sear's (1925) original description of the Gallup, according to Molenaar (1983b, p. 32) "...probably because it is so poorly exposed in the immediate area and thus was difficult to map. However, this sandstone bed is a prominent bed to the south and east of the Gallup area and is herein included in the Gallup." The "F" sandstone is a 40-ft-(12-m-) thick, regressive sandstone that lies above a thin calcarenite at the top of the Juana Lopez Member of the Mancos Shale that contains *Cameleolopha lugubris* and *Inoceramus dimidius* (D11261). This calcarenite bed is at the top of a 10 ft (3 m) section of interbedded shale and calcarenite (Molenaar 1974, fig. 2; Hook et al. 1983, sheet 1A, section 29B). Relative to the type and reference sections of the Juana Lopez, this bed would lie nearer the member's base, probably in the *P. macombi* Zone. Regardless of its absolute position in the Juana Lopez, this bed establishes that the "F" sandstone lies above or within the overlapping range zones of *C. lugubris* and *I. dimidius*. The "F" sandstone lies above the top of the Juana Lopez Member and at the top of the Mancos Shale in the Gallup area (Fig. 10).

Logically, the "F" sandstone would have to be at the top of the highest tongue of Mancos Shale to the south in the Zuni Basin. This highest tongue was named the Pescado Tongue of the Mancos Shale by Pike (1947, p. 34), who placed the base of the Pescado Tongue at the top of the lower member of the Gallup Sandstone. The key fossil collected by Pike from the Pescado Tongue was *Cameleolopha lugubris*, which, though probably identified using the single-species concept of Stanton, meant that the lower member of the Gallup Sandstone had to be older than the "F" sandstone. Pike (1947, p. 35) named two other member-rank units from exposures farther to the south in the Zuni Basin that he called the Horsehead Tongue of the Mancos Shale and the Atarque Member of the Mesaverde Formation. These two member-rank units were later found to be equivalent to the Pescado Tongue and the lower part of the Gallup, respectively, by Molenaar (1973, p. 94). The name "Horsehead Tongue" was abandoned as unnecessary, whereas the "Atarque" member was used interchangeably, but erroneously, with the lower member of the Gallup by Molenaar (1973, p. 94).

Molenaar (1973, figs. 2, 9, 10, and 12) following Pike's (1947) lead, miscorrelated his "F" sandstone from the Gallup principal reference section with the top of the stratigraphically lower Atarque member of the Gallup Sandstone in the southern Zuni Basin. As correlated by Molenaar (1974) the "F" sandstone defined both the base (not the top!) of the Pescado Tongue of the Mancos Shale and the top of the lower tongue of Gallup, the Atarque member, in the Zuni Basin. It was used to define the base of the D-Cross Tongue of the Mancos Shale and top of the lower Gallup in the Acoma Basin and at Carthage (Molenaar 1974, fig. 5), Truth or Consequences, and areas to the east. The Atarque member of the Gallup Sandstone in all those areas is 200–300 ft (60–100 m) thick and consists of (1) a basal regressive sandstone, (2) a medial nonmarine unit, and (3) an upper transgressive sandstone. Today, those three units are known as members of the Tres Hermanos Formation: (1) Atarque Sandstone Member, (2) Carthage Member, and (3) Fite Ranch Sandstone Member (see Fig. 10).

The Juana Lopez Member is more poorly developed in the Acoma Basin and at the isolated outcrops to the southeast than it is in the southern Zuni Basin, thus making correlation in those areas more difficult than in the Zuni Basin. Nonetheless, Molenaar (1974, fig. 5) correlated the Atarque member of the Gallup (= Tres Hermanos Formation of today's usage) in the Zuni Basin with equivalent rocks in the Acoma Basin and in the isolated outcrops to the southeast. The correlation of the rock units between basins was correct; the problem was that these rocks were part of a sequence that was considerably older and lower than the Gallup Sandstone and should not have been referred to the Gallup Sandstone.

At the time of Molenaar's (1974) work, only the most basic information was known about the Upper Cretaceous in the Zuni and Acoma Basins and isolated outcrops to the southeast. This basic information included the following facts: (1) the basal part of the Juana Lopez Member of the Mancos Shale was characterized by *Cameleolopha lugubris*; (2) the stratigraphically lower Semilla Sandstone Member of the Mancos Shale contained *C. bellaplicata*; (3) the Atarque member of the Gallup Sandstone was stratigraphically below the top of the Juana Lopez Member; and (4) the upper part of the middle Mancos Sandstone at Carthage, which was correlated with the Atarque member of the Gallup Sandstone, contained abundant *C. bellaplicata*. The implication of this information was that if the correlation with Carthage were correct, then the Atarque member of the Gallup was older than the "F" sandstone in the Gallup area.

The late 1970s were an unprecedented time of research and discovery by members of the United States Geological Survey (USGS) and the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) in the stratigraphy and biostratigraphy of the Upper Cretaceous of New Mexico. One of the problems undertaken during that time was the correlation of the marine

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[11]Nummedal and Molenaar (1995, fig. 5) and Molenaar et al. (1996, cross sections A–A′ and B–B′) show both the upper and lower contacts of the Torrivio Sandstone to be within the Dilco Member of the Crevasse Canyon Formation, making the Torrivio a **member-rank** unit within a **member–rank** unit. In Figure 10, this oversight is corrected: the Torrivio is shown as a **bed-rank** unit within the Dilco Member of the Crevasse Canyon Formation.

Upper Cretaceous in the Acoma and Zuni Basins. This correlation work was where *Cameleolopha bellaplicata* proved its worth as guide fossil.

C. M. Molenaar (USGS), W. A. Cobban (USGS), and S. C. Hook (NMBMMR), working together (Hook et al. 1983), were able to demonstrate that the wedge of marine and nonmarine rocks that split the Mancos Shale into two major tongues in central and southern New Mexico was the middle Turonian Tres Hermanos Formation and not the Upper Turonian lower member of the Gallup Sandstone. The two named members of the *Cameleolopha lugubris* group were instrumental in making this correlation. Collections of fossils made between 1976 and 1980 from the top of the "lower tongue of Gallup Sandstone" and the base of the overlying tongue of Mancos Shale from numerous outcrops in the Zuni and Acoma Basins have shown an almost unvarying pattern: *C. bellaplicata* occurs in the Fite Ranch Sandstone Member of the Tres Hermanos Formation and *C. lugubris* occurs in the basal part of the overlying Mancos Shale tongue, often in association with *Inoceramus dimidius* (Hook et al. 1983, chart 1). The only variation to this occurred at the Upper Nutria section (Fig. 10, control point 32B) in the Zuni Basin, where *C. bellaplicata* occurred about 5 ft (2 m) above the base of the Pescado Tongue of the Mancos Shale (Hook et al. 1983, chart 1). Other key fossils that occurred near the base of the overlying Mancos Shale tongue, but not in the same bed, included, in ascending order, *Scaphites warreni*, *S. ferronensis*, and *S. whitfieldi*, which are common faunal elements in the Juana Lopez Member. So, all the paleontological evidence indicated that rocks variously called the middle Mancos sandstone or the Atarque member of the Gallup Sandstone were biostratigraphically lower in the section than both the top of the Juana Lopez Member and the base of the Gallup Sandstone.

As a result of the greatly improved biostratigraphic resolution that the collections afforded, the Tres Hermanos Formation was redefined so it could be used for the miscorrelated "F" sandstone or Atarque member of the Gallup Sandstone. Although the three coauthors were in agreement on the correlations presented in Hook et al. (1983, p. 12 and chart 1), they were in disagreement on the stratigraphic nomenclature to use. Cobban and Hook thought that the name "Tres Hermanos" was an intrinsic part of the Upper Cretaceous nomenclature of New Mexico and should be preserved by a revision that set specific stratigraphic and geographic boundaries on the formation and was in compliance with the American Code of Stratigraphic Nomenclature. Molenaar thought that it would be better to apply a new name and abandon the name "Tres Hermanos" because of the vagueness of the original definition (Herrick and Johnson 1900) and the confusion surrounding its application. The consensus at an informal meeting of the USGS Geologic Names Committee on January 10, 1979, was that the name "Tres Hermanos" would continue to be used even if abandoned by the USGS. Therefore, the Tres Hermanos Sandstone was redefined as the Tres Hermanos Formation.

The Tres Hermanos Formation as redefined (Hook et al. 1983) has met the tests of both time and mappability. It has been mapped on several quadrangles in the Zuni Basin (e.g., Anderson 1987) and the Acoma Basin (e.g., Osburn 1984; Chamberlin et al. 2005), at Carthage (e.g., Anderson and Osburn 1983; Cather 2007), on Sevilleta National Wildlife Refuge (Cather et al. 2005). In 2010 it was used on several quadrangles mapped in Lincoln and Otero Counties as part of the StateMap Program. It appears also as a map unit on the newest Geologic Map of New Mexico (New Mexico Bureau of Geology and Mineral Resources 2003). A great part of this success is owed to the biostratigraphic utility of the lowly oyster, *Cameleolopha bellaplicata* (Shumard 1860).

Systematic paleontology

Family Ostreidae
Rafinesque-Schmaltz, 1815
Subfamily Lophinae Vyalov
1936, p. 19
Genus *Cameleolopha* Vyalov
1936, p. 20

Type species—*Ostrea cameleo* Coquand 1869, p. 149.

Description—Stenzel (1971, p. N1164) characterizes this plano-convex genus as small, orbicular, oval to spatulate shells as much as 6 cm in height that have 12–20 angular, narrow crested, dichotomous, and intercalating radial ribs on both valves that continue to the commissure. The right valve is flat, whereas the left valve is convex to gibbous. Auricles are generally absent but never large.

Stratigraphic distribution—Upper Cretaceous (Cenomanian through Turonian).

Geographic distribution—North Africa (Algeria), Mexico, and the United States (Western Interior and Texas).

Discussion—The two named species of the *Cameleolopha lugubris* group have been assigned to no fewer than five genera or subgenera since their publication more than 150 yrs ago. Both Conrad (1857) and Shumard (1860) assigned their new oyster species to the form genus *Ostrea*, which is Latin for oyster. By the time Meek (1876b) published his memoir on the invertebrate fossils of the upper Missouri country, *Ostrea* had been subdivided into three subgenera. White (1879, p. 276) assigned *O. bellaplicata* to the subgenus *Alectryonia*. In *Alectryonia*, surface ornamentation consists of strong plications that impart a zigzag character to the valve margin. Kauffman (1965, pp. 28–30) was the first to place the entire *lugubris* group in the genus *Lopha*. He noted (p. 29) that "…Perhaps the most important distinction between *Lopha* and *Ostrea* is the shape of the muscle scar…", which is comma-shaped in *Lopha*. He noted that *Alectryonia* and *Lopha* are objective synonyms having the same type species, *Lopha crista-galli* Linné. *Lopha*, however, has date priority over *Alectryonia*.

Kennedy (1988, p. 11, fig. 4, and pl. 23, figs. 26, 27) in his paper on the late Cenomanian and Turonian ammonites of Texas is the first author to assign *bellaplicata* to the genus *Nicaisolopha*. Aqrabawi (1993, p. 85), in his work on the Upper Cretaceous oysters of Jordan, assigned both *bellaplicata* and *lugubris* to the genus *Nicaisolopha*, which he emended to be more inclusive. Hook and Cobban (2007, fig. 3) followed his lead, but think now that assignment to *Cameleolopha* is a better fit because of the large number of radial ribs in *bellaplicata*, some of which bifurcate. Stenzel (1971, pp. N1164–N1165) defined *Cameleolopha* as small shells (to 6 cm high), with 12–20 angular, narrow-crested, dichotomous radial **ribs** that continue to the commissure, whereas *Nicaisolopha* includes medium-sized shells (as high as 11 cm) with 4–7 large radial, nondichotomous **folds** at the commissure.

Aqrabawi (1993, p. 85) emended Stenzel's (1971, pp. N1164–N1165) definition of the genus *Nicaisolopha* and attributed both *lugubris* and *bellaplicata* to it. *Nicaisolopha*, as emended, has the following major characteristics: (1) shell small to medium size; (2) outline subcircular or oval to subtriangular; (3) chomata clearly visible; (4) subequivalve to inequivalve and biconvex, left valve more convex to cup-like; (5) attachment area variable, very small to large; (6) sculpture of concentric growth lamellae crossed by a few undulating, simple, rarely dichotomous, radial **folds** that diverge from the umbo; and (7) adductor muscle imprint kidney-like to comma-like, about twice as long as high, situated postero-ventrally to subcentrally.[12]

Zakhera (in Zakhera et al. 2001, p. 83) placed *bellaplicata* in the genus *Cameleolopha*, but within a new subgenus, *Hyotissocamelo*, that included shells with distinct chomata and 10–27 radial ribs with rounded crests that branch dichotomously to trichotomously. At this time, it appears that assignment to *Cameleolopha* is warranted, but that further splitting to the subgenus *Hyotissocamelo* may not be necessary. The key factor in this generic assignment is that *bellaplicata* has numerous radial **ribs** that may bifurcate (*Cameleolopha*), rather than fewer, larger **folds** that do not bifurcate (*Nicaisolopha*).

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[12]Kauffman (1965, pp. 36, 48, and 67) used the term "denticles" rather than "chomata." These denticles are very clear on some of his photographs of *Cameleolopha lugubris*, e.g., Kauffman (1965 pl. 1, figs. 16–18).

***Cameleolopha bellaplicata* (Shumard 1860)**
Figure 1, specimens D, F, G, H, I and J; Figure 4; Figures 9B and G; and Figure 11

Ordinarily, this section of the paper would contain a detailed description of *Cameleolopha bellaplicata* (Shumard 1860) with a long list of attributed specimens, the synonymy. However, (1) Shumard's (1860) original description, which is reproduced below, is adequate with minor changes; (2) Kauffman's (1965) paper has both a detailed description based on morphometric data from hundreds of specimens and a detailed synonymy; and (3) the previous discussion has shown why there is no need to split *C. bellaplicata* into subspecies. So, the synonymy will be updated from that in Kauffman (1965) and Shumard's (1860) description will be augmented with additional morphometric data based on collections housed by the USGS in Denver that come from the type area of *C. bellaplicata* in Texas and from the type area of *C. b. novamexicana* in the Carthage coal field.

Synonymy [updated from Kaufman (1965)]

?*Ostrea* (*Gryphaea*?) *uniformis*, Meek; Meek (1876a, p. 124, pl. I, fig. 2a–e).

?*Ostrea uniformis* Meek; White (1883, p. 302, pl. XLVIII, figs. 6, 7).

?*Ostrea uniformis* Meek; Stanton (1893, pp. 59–60, pl. III, figs. 3, 4).

Lopha bellaplicata bellaplicata (Shumard); Kauffman et al. (1976, pl. 13, figs. 11, 15, 16, and 18–20).

Lopha bellaplicata novamexicana Kauffman; Kauffman et al. (1976, pl. 13, figs. 12–14).

Lopha bellaplicata bellaplicata (Shumard); Kauffman (1977b, pl. 9, figs. 11, 15, 16, and 18–20).

Lopha bellaplicata novamexicana Kauffman; Kauffman (1977b, pl. 9, figs. 12–14).

Lopha bellaplicata; Smith et al. (1983, fig. 1–60.9).

Lopha bellaplicata novamexicana; Osburn and Arkell (1986, fig. 3e).

Lopha bellaplicata (Conrad [sic]); Cobban (1986, fig. 9F–I).

Nicaisolopha bellaplicata bellaplicata (Shumard 1860); Kennedy (1988, pl. 23, figs. 26, 27).

Lopha bellaplicata (Shumard); Cobban and Hook (1989, fig. 9S).

Lopha bellaplicata (Shumard); Kirkland (1996, pl. 49G).

Not *Lopha bellaplicata*; Lucas and Estep (1998, fig. 5H–J).

Lopha bellaplicata bellaplicata (Shumard, 1860); Akers and Akers (2002, fig. 180).

Lopha lugubris lugubris (Conrad 1857); Akers and Akers (2002, fig. 211 [part]).

Discussion—The reader is referred to Kauffman's (1965) paper for a complete listing of unquestioned species assigned to *Cameleolopha bellaplicata* as of that date. The additional species described before 1965 that is placed questionably in the synonymy above is *Ostrea* (*Gryphaea*?) *uniformis* Meek. This species is morphologically unusual, has not been collected again anywhere in the Western Interior, and has been forgotten or, at very least, ignored since 1893. Therefore, it warrants further discussion.

Meek (1876a) described the Cretaceous fossils collected by Dr. J. S. Newberry on Captain J. N. Macomb's 1859 San Juan exploring expedition in New Mexico and Colorado. One of those fossils, *Ostrea uniformis*, is a small, ribbed oyster with a large centrally located fold and three or four smaller plications on either side of the fold that do not bifurcate. The only illustrated specimen (Meek 1876a, fig. 2a–c) is a left valve with a length of 1.16 inches (3.96 cm) and a height of 1 inch (2.54 cm). Meek thought that *O. uniformis* had a peculiar shell that could not be confused with any other species. In fact Meek thought that the medial fold—and the plications on either side of it—gave the free margin of the shell the zigzag appearance of some Paleozoic brachiopod.

Meek (1876a, p. 124), thinking his species might be related to *Cameleolopha bellaplicata*, one of two peculiar oysters described from Texas by Shumard, sent sketches of his species to Shumard. Shumard replied that it was most nearly like his *C. bellaplicata*, but clearly distinct because of *C. bellaplicata*'s larger size and distinct concentric ornamentation. Small size is not necessarily a diagnostic species criterion for oysters; the left valve of a single individual, which is all Meek (1876a, pl. I, fig. 2a–e) illustrated, although he mentions other specimens, may be a juvenile. Specimens of *C. bellaplicata* illustrated by (Cobban 1986) from the Lincoln County, New Mexico, tend to be small. Some of Kauffman's (1965) illustrated specimens of *C. bellaplicata novamexicana*, e.g., his plate 7, figs. 1–3, lack distinct concentric ornamentation. The presence of a large central fold with three smaller ribs laterally on each side of it, suggests that *O. uniformis* may be a species transitional between the genera *Nicaisolopha* Vyalov 1936 and *Cameleolopha* Vyalov 1936.

The type specimen and only known examples of *Ostrea uniformis* came from the middle Cretaceous section at Pagosa Springs, Colorado (Meek 1876a, p. 124). The middle division was a reconnaissance stratigraphic unit employed by Newberry (1876), who collected the specimens, in his pioneering work on the geology of New Mexico, Colorado, and Utah. It was a heterogeneous unit, 1,200–1,500 ft (366–457 m) thick that contained *Prionocyclus macombi* Meek, among many fossils (Meek 1876a, p. 121). A stratigraphic unit that thick at the Carthage coal field, for example, beginning at the top of the Dakota Sandstone, would contain middle Cenomanian through lower Coniacian strata. Stanton (1893, pp. 59–60), who may have had access to Newberry's original collections, indicated that *O. uniformis* was associated with *Cameleolopha lugubris* at Pagosa Springs. However, Stanton (1893, p. 58), did not place *O. uniformis* in synonymy with (his broadly defined) *C. lugubris*.

Two end member possibilities seem plausible. First, *Ostrea uniformis* is a variant of *Cameleolopha bellaplicata* because of its morphologic similarity and stratigraphic position. Second, it is a distinct species that bridges the morphological gap between *Cameleolopha* and *Nicaisolopha*. The only other oyster in that part of the section is *Cameleolopha lugubris*; *O. uniformis* is too large and coarsely ribbed for assignment to *C. lugubris*, and it lacks an attachment scar. For the time being, *O. uniformis* is assigned questionably to *C. bellaplicata*.

Based on shell morphology and regional collections, the three illustrated specimens that Lucas and Estep (1998, fig. 5H–J) assigned to *Cameleolopha bellaplicata* from the Davis Well area (Fig. 3) of the southern San Andres Mountains are the late Turonian oyster "*Lopha" sannionis* (see Fig. 2). Each of their specimens (which are shown enlarged between 1.9 and 2.5 times) has six or fewer ribs and a curved axis; both characteristics are indicative of "*L." sannionis*. At the very least, their stratigraphic assignments of *C. bellaplicata* to the Rio Salado Tongue of the Mancos Shale and the Atarque Sandstone (Lucas and Estep 1998, p. 194) are suspect.[13]

If their stratigraphic assignments were correct, then *Cameleolopha bellaplicata* would occur in lower Turonian, not middle Turonian strata, but only in the southern San Andres Mountains. Surprisingly, Lucas and Estep (1998, p. 189, New Mexico Museum of Natural History locality L-3481) report that they collected the upper Turonian bivalve *Mytiloides incertus* (Jimbo), the lower Turonian ammonite *Cibolaites molenaari* Cobban and Hook, and the middle Turonian oyster *Cameleolopha bellaplicata* (Shumard) from the lower Turonian Rio Salado Shale Tongue of the Mancos Shale. Both the bivalve, which they identified correctly, and oyster, when correctly identified, indicate that their collection L-3481 came

[13]By assigning the lower shale tongue at Davis Well to the Rio Salado Tongue of the Mancos Shale Lucas and Estep (1998, p. 194) imply the presence of the Twowells Tongue of the Dakota Sandstone in the section; by definition (Hook et al. 1983, p. 24) the Rio Salado Tongue lies between the Twowells Tongue and the Tres Hermanos Formation or the Atarque Sandstone. Lucas and Estep's (1998, fig. 3) columnar section at Davis Well does not show the Twowells Tongue. In addition, by raising the Atarque Sandstone Member of the Tres Hermanos Formation to formational rank as the Atarque Sandstone, they imply that this marine sandstone deposited during the R-1 regression, is the last marine unit deposited in the area, and that the remaining portion of the sequence will be nonmarine and assigned to the Moreno Hill Formation (McLellan et al. 1983). Once again, this is not the case. Lucas and Estep (1998) show two additional marine units above their Atarque Sandstone: the D-Cross Tongue of the Mancos Shale and the Gallup Sandstone.

from the upper Turonian D-Cross Tongue of the Mancos Shale.

All documented collections of *Cameleolopha bellaplicata* have come from middle Turonian strata: in New Mexico that means the Semilla Sandstone Member of the Mancos Shale, the Carthage and Fite Ranch Sandstone Members of the Tres Hermanos Formation, or the base of the Pescado or equivalent D-Cross Tongue of the Mancos Shale. In addition, collections made by Hook and Cobban near Davis Well in the southern San Andres Mountains in 1977 and 1980 and by G. O. Bachman, USGS, in 1960, include *"Lopha" sannionis* from the D-Cross Tongue of the Mancos Shale, but do not include *C. bellaplicata* from any level. That earlier collecting indicated that the Upper Cretaceous stratigraphic section in the southern San Andres Mountains was nonmarine during the time represented by the *Prionocyclus hyatti* and *P. macombi* Zones.

Seager (1981, pp. 33–34, and sheet 3) measured nearly 300 ft (~100 m) of marine and nonmarine sandstone that split the Mancos Shale into a lower tongue, 228 ft (70 m) thick, and the D-Cross Tongue, 158 ft (48 m) thick, in the Upper Cretaceous near Davis Well; he assigned these sandstones to the Tres Hermanos Sandstone Member of the Mancos Shale. Seager's (1981) interpretation of nonmarine strata was based in part on the presence of in situ petrified wood near the top of his Tres Hermanos Sandstone Member. In contrast, Lucas and Estep (1998, pp. 187–188, 196) show less than 72 m (236 ft) of strata at their Davis Well measured section from the base of the Mancos Shale to the top of the Gallup Sandstone, including only 14 m (46 ft) assigned to the Tres Hermanos. The nearest (complete) Upper Cretaceous section to Davis Well is in the Caballo Mountains, east of Truth or Consequences, New Mexico (Fig. 3). There, Seager and Mack (2003, pp. 38–46) measured 315 m (1,033 ft) from the base of the lower tongue of Mancos Shale to the top of the Gallup Sandstone, including 105 m (344 ft) for the Tres Hermanos Formation, which has a nonmarine core. Obviously, the stratigraphic and biostratigraphic assignments made by Lucas and Estep (1998) of the Upper Cretaceous in the southern San Andres Mountains are in need of revision. In Figure 3, the paleogeographic map of New Mexico, the Davis Well area is shown to be landward of the transgressing shoreline at the end of *Cameleolopha bellaplicata* time.

Types—According to Kauffman (1965, p. 58), the holotype of *Cameleolopha bellaplicata* was destroyed in a fire at the St. Louis Academy of Science. Kauffman (1965, p. 58) selected a neotype (his pl. 3, fig. 11) from the Eagle Ford Shale at USGS locality 7539, 2.5 miles east of Eagle Ford, Dallas County, Texas.

Description—Shumard's (1860, pp. 608–609) original description has not been surpassed for brevity and usefulness.

"Shell of medium size, ovate or subcircular, anal and palial borders rounded; buccal border subtruncate; valves unequal. Superior [right] valve usually flat, but sometimes concave or even gently convex; hinge margin oblique, nearly straight; beak obtusely angular, angle from 105°–115°. Inferior [left] valve convex, most prominent along the middle, and sometimes obtusely subangulated; beak acute, prolonged, situated nearest the buccal side, and slightly curved towards the opposite side; muscular impressions large, moderately excavated, elongate-ovate, upper edge concave. Surface of valves marked with prominent, concentric, waved, imbricating laminae of growth and form, and from ten to fourteen elevated, obtusely angulated costae [ribs], which originate near the beaks, and radiate to the margins." One addition and one change to Shumard's description are needed to facilitate field identification; these modifications are apparent from study of the larger collections available now. The change is that ribs on the left valve can vary from 8 to 27 and on the right valve from 6 to 23 (Kauffman 1965, table 2). The addition is that the attachment scar on the left valve is predominantly small to absent, rarely large.

"In many specimens before me all of the ribs are simple, but in others some of them are bifurcated. In a few individuals they are sharply angulated at their extremities. The concentric laminae are generally more distinct and more strongly marked on the superior than inferior valve. The dimensions of an average specimen are:—Length, 1⁹⁄₁₀ inches [48.3 mm]; width, from beak to base, 2³⁄₁₀ inches [58.4 mm]; thickness, ⁸⁄₁₀ inch [20.5 mm]."[14]

"This handsome oyster occurs in the greatest abundance in fine-grained sandstone, and blue indurated marl, towards the top of the [Upper] Cretaceous, near Sherman, in the bluffs of Post-Oak Creek, and various localities in Grayson County. It is found in connection with remains of …, *Ostrea congesta*, and *Corbula graysonensis*."

Of the associated fauna: *Ostrea congesta* Conrad 1857 is a long-ranging, small, encrusting oyster found often in colonies attached to other shells. It is now referred to the genus *Pseudoperna*. It ranges from the Turonian through the Santonian. *Corbula graysonensis* is a small bivalve of unknown range. Neither of these fossils is particularly diagnostic as a biostratigraphic indicator.

Additional morphometric data

Morphometric data based on three substantial collections of *Cameleolopha bellaplicata* housed at the Denver Federal Center are presented below. These collections are from the following localities: (1) D9487, 35 beautifully preserved, matrix-free, large specimens collected by J. D. Powell from the Eagle Ford Formation, near the type

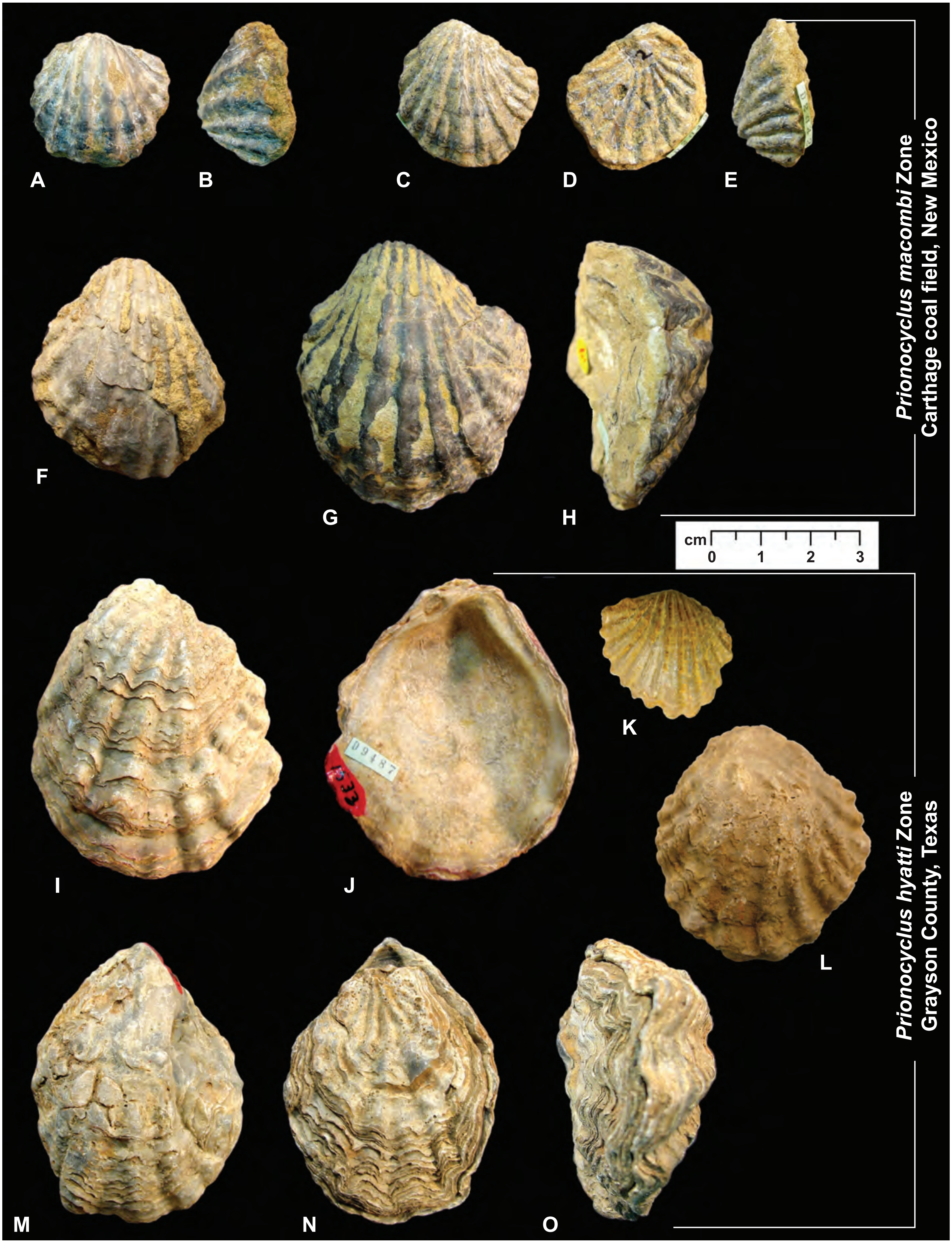
FIGURE 11—Representative specimens of *Cameleolopha bellaplicata* from New Mexico (USGS Mesozoic Invertebrate localities D2042 [**A–E**] and D10354 [**F–H**]) and Texas (D9487 [**I–O**]). D2042 is the collection from which Kauffman (1965) chose the holotype for *C. b. novamexicana*; D10354 is from the same level in the Fite Ranch Sandstone Member of the Tres Hermanos Formation elsewhere in the Carthage coal field, Socorro County, New Mexico; and D9487 is from the Eagle Ford Formation, near Shumard's (1860) type locality for *C. bellaplicata*, Grayson County, Texas. **A–B** (USNM 545195): exterior views of the left valve and ventral margin, respectively, of specimen 15. **C–E** (USNM 545196): exterior views of left valve, right valve, and ventral margin, respectively, of specimen 2. **F** (USNM 545197): exterior view of the left valve of specimen 13. **G–H** (USNM 545198): exterior views of left valve and ventral margin, respectively, of specimen 19. **I–J** (USNM 545199): exterior and interior views, respectively, of the left valve of specimen 1533. **K** (USNM 545200): exterior view of the left valve of specimen 1549. **L** (USNM 545201): exterior view of the left valve of specimen 1585. **M–O** (USNM 545202): exterior views of the left valve, right valve, and ventral margin, respectively, of specimen 1534. All specimens are shown natural size. Measurements made on these specimens can be found in Appendix 2.

Text continued from previous column.

locality, Grayson County, Texas (Fig. 11I–M); (2) D2042, 23 specimens collected by W. A. Cobban from the base of the Fite Ranch Sandstone Member of the Tres Hermanos Formation, Carthage area, Socorro County, New Mexico (Fig. 11A–E); and (3) D10354, 21 specimens collected by S. C. Hook and others from another locality at the base of the Fite Ranch Sandstone Member of the Tres Hermanos Formation, Carthage area, Socorro County, New Mexico (Fig. 11F–H). The D9487 collection is from the older *Prionocyclus hyatti* Zone, whereas the D2042 and D10354 collections are from the younger *P. macombi* Zone. Only those specimens in these collections that had whole or mostly complete left valves were measured so that height, length, and total rib count could be compared among the collections. These collections provide data on 35 specimens that would have been assigned previously to *C. bellaplicata bellaplicata* (D9487) and 42 specimens that would have been assigned previously to *C. bellaplicata novamexicana* (D2042

Text continued on page 86, column 1.

[14](1) The only specimen from Shumard's collection that was illustrated (White 1879, pl. 8, figs. 2a–b and 1883, pl. XLVII, fig. 3) is a right valve (Fig. 4), that has a height of 50.5 mm; a length of 43.1 mm, and 18 ribs at the valve margin; (2) Shumard (1860, p. 609) used of the term "width" of the oyster shell in the same sense that "height" is used today; and (3) Shumard's "average" specimen is plotted in Figure 6. It falls just below the bounding polygon, suggesting that it would have been assigned to *C. bellaplicata novamexicana* had it been collected between 1965 and 2011.


A
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L
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cm 0 1 2 3
Prionocyclus macombi Zone
Carthage coal field, New Mexico
Prionocyclus hyatti Zone
Grayson County, Texas

TABLE 4—Morphometric comparison of collections of *Cameleolopha bellaplicata* from Texas and New Mexico.

	D9487 (TX)	D2042 (NM)	D10354 (NM)	Combined
Height (H)				
Left	45.5 mm	32.8 mm	35.1 mm	38.5 mm
novamexicana holotype		33.7 mm		
Length (L)				
Left	40.6 mm	29.6 mm	30.1 mm	33.4 mm
novamexicana holotype		32.7 mm		
H/L				
Left	1.13	1.10	1.15	1.12
novamexicana holotype		1.03		
Width				
Left	15.0 mm	14.4 mm	13.6 mm	14.3 mm
Percent				
H > L	82.9%	65.2%	85.7%	78.5%
L > H	08.6%	21.7%	09.5%	12.7%
L = H	08.6%	13.0%	04.8%	08.9%
Average number ribs at valve margin				
Left	15.9	12.8	16.2	15.1
novamexicana holotype		10		
Inscribing rectangle				
Left	18.90 cm^2	10.29 cm^2	11.62 cm^2	14.46 cm^2
novamexicana holotype		11.02 cm^2		
Rib density				
Left	0.93/cm^2	1.62/cm^2	2.05/cm^2	1.42/cm^2
	3.59/cmH	4.24/cmH	5.17/cmH	4.19/cmH
novamexicana holotype		0.91/cm^2		
		2.97/cmH		
Rib count range				
Left	10–21	10–20	12–22	10–22
n =	35	23	21	79

and D10354). The raw data for each specimen in these collections are in Appendix 2.[15]

The largest specimen of *Cameleolopha bellaplicata* in the USGS collections in Denver is a left valve from USGS locality D9446, collected by J. D. Powell in Texas, presumably near the type locality, from 14 in (37 cm) below the contact with the Austin Chalk. This specimen, #638, has a height of 70.1 mm, a length of 59.6 mm, width of 24.8 mm, and an area of 41.8 cm^2. There are at least 14 ribs at the ventral margin, yielding a rib density of 0.33 ribs/cm^2 and 2.00 ribs/cmH. This specimen is plotted in Figure 6, where it falls just outside the right edge of the bounding polygon established by Kauffman's (1965) sample. However, Kauffman (1965, p. 64) measured a few even larger specimens that he referred to *C. b. novamexicana*: the maximum length of the left valve of one specimen is 90 mm and the maximum width of the left valve of another is 61 mm. The largest specimen of *C. bellaplicata* from New Mexico in the Denver collections is a left valve in matrix from the Fite Ranch Sandstone in the Carthage coal field at locality D14697. This valve has a height of 55.3 mm and a length of 53.9 mm and at least 12 ribs that extend to the ventral margin. These measurements yield an area of 29.8 cm^2 with a rib density of 0.47 ribs/cm^2 and 2.53 ribs/cmH. This specimen is plotted in Fig. 6, where it falls just below the bounding polygon established by Kauffman's (1965) sample, suggesting that there is still more morphometric variation to be found within populations of *C. bellaplicata*.

Comparison of collections from Texas and New Mexico

Typical specimens from all three collections are shown as Figure 11. The measurement data from these collections are presented in the same format (Table 4) that is used in Appendix 2 to compare Kauffman's (1965) original data. All data are averages with the exception of that given for the left valve used as the holotype of *C. bellaplicata novamexicana* (Kauffman 1965, pl. 7, fig. 10), which is from USGS locality D2042. The holotype's individual measurements were obtained from Kauffman's plate, were not used in computing average values for D2042 collection, and are presented for comparative purposes only.

The specimens from the *Prionocyclus hyatti* Zone in Texas (D9487) are significantly larger in average height and length and about 1.7 times as large in area as those from the *P. macombi* Zone in New Mexico (D2042 and D10354), and their average rib count at the valve margin lies between those of the two New Mexico collections. However, rib density in the New Mexico collections is at least 1.7 times greater in terms of ribs/ cm^2 and as much as 1.4 times greater in terms of ribs/cm of valve height. Almost all of these statistics are contrary to what was predicted when *Cameleolopha bellaplicata* was subdivided into subspecies: *C. b. novamexicana* was supposed to be the more coarsely ribbed of the two and have a lower rib density. The vast majority of specimens from all three collections have oval shapes in which height is about 10% greater than length (H > L). See Appendix 2 for detailed measurements.

The holotype of *Cameleolopha bellaplicata novamexicana* is somewhat atypical of the D2042 collection as a whole. First, it has fewer ribs at the valve margin, 10 versus an average of 12.8, and its total rib count, 10, lies at the lower end of the range of the other 23 specimens from that locality, which is 10–20. Its rib density of 0.91 ribs/ cm^2 is closer to the Texas *bellaplicata* (0.93 ribs/cm^2) than to either of the Carthage collections (1.62/cm^2 and 1.65/cm^2); its rib density of 2.97/cmH is the only density that is less than 3.59/cmH and is, again, closer to that of the Texas *C. bellaplicata*. Its height is greater than its length, which is typical of all three collections. The average values for the inscribing area and rib count for these three collections are plotted in Figure 6 for comparison with Kauffman's collections. All three collections plot within the bounding polygon. The holotype of *C. b. novamexicana* is plotted as well. It falls just below the polygon.

The two small specimens from the Texas collection D9487 in Figure 11 invite comparison with similar size specimens figured from Carthage: (1) Specimen 1549 (Fig. 11K) from Texas is approximately the same size and shape as specimen 2 (Fig. 11C) from Carthage collection D2042. The Texas valve has 14 very finely sculpted ribs to the 16 more robust ribs of Carthage valve. At first glance, these two specimens seem to confirm Kauffman's morphometric (but not biostratigraphic) criteria for subspecies separation. However, rib density per cm^2 is similar—2.5 (TX) versus 2.2 (NM), whereas rib density per cm of

[15]The holotype of *Cameleolopha bellaplicata novamexicana* (Kauffman 1965, pl. 7, fig. 10) is from the USGS locality D2042 (Fig. 11A). Measurements made on the holotype from Kauffman's plate are compared with, but not included in the data from that collection.

height is virtually identical—6.0/cm (TX) versus 5.9/ cm (NM) and in length is identical at 5.9/cm. (2) Specimen 1585 (Fig. 11L) from Texas is approximately the same size and shape as specimen 19 (Fig. 11G) from Carthage collection D10354. The Texas valve has 19 robust ribs to the 22 robust ribs on the Carthage valve. Except for preservation differences, these two specimens appear to be from the same area; the robust ribs on both suggest they came from Carthage. However, rib density per cm^2 is similar—1.08 (TX) versus 0.96 (NM); rib density per cm of height is identical at 4.2/ cm, and almost identical in length at 4.9/cm (TX) versus 5.0/cm (NM).

These two side-by-side comparisons illustrate the morphologic diversity that exists within *Cameleolopha bellaplicata*. In Case 1, it appears that there are two morphotypes: a finely ribbed one from Texas and a coarsely ribbed one from Carthage. In Case 2, it appears as if the coarsely ribbed form occurs at both localities. Figure 6 graphically portrays the morphologic diversity in rib density that Kauffman (1965) measured within a sample of hundreds of specimens of *C. bellaplicata*. Measurements made on a photograph of a single specimen of *C. bellaplicata* from the *Prionocyclus hyatti* Zone in the Arcadia Park Formation in the Dallas–Ft. Worth area (Kennedy (1988, pl. 23, figs. 26–27) indicate there is more diversity to be discovered.

Kennedy's specimen is a large coarsely ribbed oyster that has 14 ribs and a height of 6.71 cm and a length of 7.61 cm, yielding an area of 51.1 cm ^{2} and rib densities of 0.27 ribs/cm^2 and 0.48 ribs/cmH. This unusual specimen, which is wider than high, is shown in Figure 6, where it plots far outside to the right of the bounding polygon for *C. bellaplicata*, indicating that more morphological variation should be expected within *C. bellaplicata*.

Paleoecology

Cameleolopha bellaplicata was an epifaunal suspension feeder that lived in nearshore sandy environments, commonly in association with normal marine bivalves such as *Pinna petrina* and the infaunal *Pholadomya* sp.; it is not known to occur with the brackish water oyster *Crassostrea soleniscus* (Meek). The nearshore, high-energy environments in which it is found had sedimentation rates that were occasionally high enough to bury and preserve fully articulated shells.

The lack of attachment scars on all but a few of the hundreds of specimens in the collections indicates that *Cameleolopha bellaplicata* was a free-lying oyster as an adult, probably with the lower valve partially buried in the soft sediment on the seafloor to provide stability. Machalski (1998, fig. 12) refers to oysters with a similar life position as "cup-shaped recliners." He indicates that the background sedimentation rates during the life cycles of cup-shaped recliners were relatively high. The D9487 collection is an anomaly, in that 12 of the 35 specimens measured (34%) have large (> 5 mm diameter) attachment scars. (Fig. 11L).

Only a few left valves of *Cameleolopha bellaplicata* show evidence of attachment to valves of other specimens of *C. bellaplicata*. Again, the D9487 collection is an anomaly in that four left valves have been used as attachment objects by other specimens of *C. bellaplicata*; all four specimens have large attachment scars. These two anomalies and the large average size of the shells suggest that this Texas collection was from an ideal environment in which the oysters proliferated to the point of overcrowding. Five of the valves from D9487 are noticeably deformed, perhaps because of competition for space. A good example of moderate deformation is specimen 1533 (Fig. 11I–J), in which the resilifer (rounded triangular indentation near top of Fig.11J) is shifted posteriorly (to the left) from the axis of growth.

Occurrence

Cameleolopha bellaplicata is known only from the southern part of the Western Interior with documented occurrences in Arizona, Colorado, New Mexico, Utah, and Texas. There are more than 50 USGS Mesozoic localities in New Mexico and adjacent Arizona, where *C. bellaplicata* occurs in nearshore sandstones associated with the waning part of the first regression (R-1) and the early part of the second major transgression (T-2) of the western shoreline of the Late Cretaceous seaway across the central part of New Mexico. All documented occurrences are in the middle Turonian ammonite zones of *Prionocyclus hyatti* and *P. macombi*.

Summary

The plicate, medium-sized oyster *Cameleolopha bellaplicata* is an excellent guide fossil to the middle Turonian strata in New Mexico. It occurs in vast numbers in nearshore sandstones of the Fite Ranch Sandstone Member of the Tres Hermanos Formation and can range up into the base of the overlying, deeper water Mancos Shale. Its immediate descendant, the smaller, thumbnail-sized oyster with large attachment scar *C. lugubris*, is a good guide fossil to the basal part of the overlying tongue of the Mancos Shale, especially the calcarenites of the Juana Lopez beds. Together, these two oysters were instrumental in deciphering the complex stratigraphic relationships between the Gallup Sandstone of the San Juan Basin and the older, complexly intertongued sandstones and shales in the Zuni and Acoma Basins to the south and southeast of the type section of the Gallup Sandstone.

Since 1965 *Cameleolopha bellaplicata* has been subdivided into two, supposedly, chronological subspecies: *C. bellaplicata novamexicana* (older) and *C. bellaplicata bellaplicata* (younger). Re-examination and recollection of fossils associated with *C. b. novamexicana* at its type locality reveal that it is in fact the younger form, occurring with the next younger zonal index ammonite *Prionocyclus macombi*. Therefore, there is no chronostratigraphic basis for subdividing the species. Reexamination of the original morphometric data reveals only subtle differences between the (supposed) subspecies; these minor differences are interpreted as normal species variation. Consequently, subspecific names are no longer needed or appropriate; they do not imply a (chrono) stratigraphic separation.

Geographically, *Cameleolopha bellaplicata* (Shumard) is confined to the southern half of the Western Interior with occurrences in the Four Corners states and Texas. Its descendant, *C. lugubris* (Conrad) has a wider distribution in the Western Interior, with occurrences ranging from New Mexico and Texas on the south to Wyoming, southeastern Montana, and southwestern South Dakota on the north. *Cameleolopha bellaplicata* is confined to the middle Turonian, ranging from the *Prionocyclus hyatti* Zone through the lower part of the *P. macombi* Zone. *Cameleolopha lugubris* ranges into the base of the upper Turonian and is confined to the upper part of the *P. macombi* Zone and the entire *P. wyomingensis* Zone. Their ranges do not overlap in New Mexico.

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and are housed at the Federal Center in Denver, Colorado. Illustrated specimens have been assigned USNM numbers and are reposited in the U.S. National Museum in Washington, D.C.

The specimen of *Prionocyclus macombi* shown as Figure 8H is from USGS Mesozoic locality D15000, the 15,000th numbered locality in the Western Interior reposited with U.S. Geological Survey in the Denver Federal Center. The first numbered collection was made from rocks of Greenhorn age in Douglas County, Colorado, on July 6, 1954. More than 2,500 (~17%) of those 15,000 collections are from New Mexico; underscoring the importance of the Upper Cretaceous in New Mexico to understanding the Late Cretaceous history of the Western Interior. Of those collections from New Mexico, more than 450 (~18%) are from Socorro County and about 150 (~33%) of these are from the Carthage coal field.

Two amateur fossil collectors donated key specimens from Carthage to the USGS. Hugo Lestiboudis, French International School, Washington, D.C., collected the first specimen of *Inoceramus dimidius* from the basal part of the Fite Ranch Sandstone Member in February 2007 as part of his high school's annual geological field trip to New Mexico. Susan Berry, Grant Middle School, Albuquerque, found the third specimen of *I. dimidius* from the Fite Ranch Sandstone Member at Carthage in July 2007 as part of the New Mexico Bureau of Geology "Rockin' Around New Mexico" summer geology workshop for New Mexico educators. To date (July 2011) only six specimens of this key index fossil have been found at Carthage.

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Appendix 1
Kauffman's biostratigraphy

Introduction

Kauffman's (1965, p. 1) paper on the oysters of the *Cameleolopha lugubris* group was among the first to "…demonstrate the feasibility of detailed systematic and evolutionary study, faunal zonation, and regional correlation based on oysters. It employs simple biometric analyses of large collections, from numerous localities, distinct stratigraphic levels, and diverse sediment types." This work features data on more than 700 specimens from 73 localities at various stratigraphic levels from the Carlile Shale of Colorado, New Mexico, and Kansas; the Mancos Shale of New Mexico; and the Eagle Ford Shale of Texas. There are more than 30 graphs comparing various morphological features of the three forms of *Cameleolopha*: *C. bellaplicata bellaplicata*, *C. b. novamexicana*, and *C. lugubris*. Five tables feature summary measurements, nine diagrams show evolutionary changes, and one diagram shows the biostratigraphic ranges of the three forms, all in a 92-page work. There are also eight plates of fossils. Altogether, a very detailed and exacting piece of research in which Kauffman (1965) also illustrates photographically several specimens that had previously been illustrated only by line drawings. These photographed specimens include one of Conrad's (1857) type specimens of *C. lugubris* (pl. 1, fig. 4), three specimens that Stanton (1893) used for his concept of *C. lugubris* (pl. 1, fig. 2; pl. 2, fig. 2; pl. 6, fig. 15); and two specimens illustrated by White (1879, 1884) as *C. blackii* (pl. 3, fig. 2; pl. 4, fig. 6). However, the revised biostratigraphy of the two subspecies of *C. bellaplicata* does not support Kauffman's (1965) evolutionary conclusions regarding them. His conclusions regarding the relationship between *C. lugubris* and *C. bellaplicata* remain as sound today as they were in 1965.

Kauffman's (1965) paper is based primarily on museum collections. He had first-hand knowledge of and made the collections from Huerfano Park, Colorado, the site of his dissertation work (Kauffman 1961). The vast majority of the other collections studied by Kauffman (1965, pp. 72–77) were made by other geologists. The oldest collection dates to 1887 and was made by John Wesley Powell. USGS geologists Timothy W. Stanton, Willis Lee, Lloyd W. Stephenson, and William A. Cobban are among other prominent geologists who made collections utilized by Kauffman (1965). Many of these older collections were not designed for population studies and probably consisted of only the best preserved, which usually means largest, specimens.

Stratigraphic and biostratigraphic positions on labels of older collections may have been the collecting geologist's best guess at the time the collections were made. In the six years before publication, Kauffman (1965, pp. 72–77) stated that he visited most of the localities not in his dissertation area to obtain stratigraphic data. He, therefore, felt certain of most of the stratigraphic assignments as shown in the localities list. The seven exceptions were shown with question marks following the stratigraphic assignment. Two of those exceptions were for collections from Carthage made by W. T. Lee in 1905; they were questionably referred to the Mancos Shale. So, only the stratigraphic, not biostratigraphic, assignment was in question.

Nonetheless, in order to do an evolutionary study on the oysters of the *Cameleolopha lugubris* group, Kauffman (1965) needed a biostratigraphic framework, which is presented in detail below, on a state by state basis. Based on his detailed Ph.D. research in Huerfano Park, he divided the lugubris group into three forms, from oldest to youngest: *C. bellaplicata novamexicana*, *C. bellaplicata bellaplicata*, and *C. lugubris*. The morphological differences between the small, plicate oyster with a large attachment scar (*C. lugubris*) and the stratigraphically lower, medium-sized, plicate oyster with a small or nonexistent attachment scar (*C. bellaplicata*, s.l.) were obvious. The differences noted by Kauffman (1965, pp. 53–55) between the two "morphologically similar" subspecies of *C. bellaplicata* were subtle and involved somewhat more subjective criteria, although they were the subject of many biometric graphs. Among other features, *C. bellaplicata bellaplicata* was thought to have a more rounded or subquadrate outline, a less oblique shell, a less convex left valve with smaller, narrower, more numerous, and more extensively bifurcating ribs. In other words, *C. bellaplicata novamexicana* was a fatter, coarser ribbed variant of the younger and more delicately sculpted *C. bellaplicata bellaplicata*.

Kauffman's (1965, p. 2) work suggested that the *lugubris* group "…had a Gulf Coast origin, or center of dispersal, in the United States, and reached its maximum development in abundance and size in these southern waters. Its immediate ancestor is unknown." In regard to this speculation on the Gulf Coast origin of the group, it is interesting to note that Kauffman (1965, p. 3) reported that "[*Cameleolopha*] *bellaplicata novamexicana* n. subsp. [the presumably older subspecies of the two] has not yet been found in Texas."

Texas

Kauffman (1965, p. 3) reports that in Texas, *Cameleolopha bellaplicata bellaplicata* occurs above the middle Turonian zone of *Collignoniceras woollgari*, but locally below the widespread middle-upper Turonian disconformity. He also reports (p. 4) "…that the zone of [*Cameleolopha*] *lugubris* lies predominantly above that of [*Cameleolopha*] *bellaplicata bellaplicata*, but their ranges overlap slightly…. They [the two species] are distinct in this zone of overlap, and do not intergrade [morphologically]. [*Cameleolopha*] *lugubris* does not range below this level, as does [*C.*] *bellaplicata bellaplicata*. It ranges upward, however, above the range of [*C.*] *bellaplicata bellaplicata*…."

New Mexico

Before the publication of his *Cameleolopha lugubris* group paper on October 6, 1965, Kauffman had been working with U.S. Geological Survey geologists C. H. Dane and W. A. Cobban on (1) the type section of Semilla Sandstone Member of the Mancos Shale and (2) a reference section for the overlying Juana Lopez Member of the Mancos Shale, both in the San Juan Basin of New Mexico. In July 1963 he remeasured and collected fossils from the type section of the Juana Lopez (Dane et al. 1966, p. H13). In June 1964 he collected fossils from both the type section of the Semilla Sandstone (Dane et al. 1968, p. F17) and the reference section of the overlying Juana Lopez (Dane et al. 1966, p. H10). Fossils identified from these collections indicated that: (1) the finely ribbed subspecies, *C. bellaplicata bellaplicata*, occurs with *Prionocyclus hyatti* in association with *Inoceramus howelli* White in the Semilla Sandstone Member of the Mancos Shale; and (2) that *C. lugubris* appears first at the base of the overlying Juana Lopez Member in association with *Inoceramus dimidius* White and *Prionocyclus macombi* Meek and ranges upward into beds at the top of the Juana Lopez Member containing *Prionocyclus novimexicanus* (Marcou) and *Scaphites whitfieldi* Cobban at the reference section.[16]

The holotype of *Cameleolopha bellaplicata novamexicana* (Kauffman 1965, p. 90, pl. 7, fig. 10), the coarsely ribbed, supposedly older subspecies of *C. bellaplicata*, is from "…a massive sandstone in the Mancos Shale, zone of [*Prionocyclus*] *hyatti*, [in the Carthage coal field, about 20 miles southeast of Socorro], Socorro County, New Mexico." There, the oyster occurs in vast numbers near

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[16]The coarsely ribbed, older subspecies, *Cameleolopha bellaplicata novamexicana* was not reported from rocks either below or within the Semilla Sandstone Member by Kauffman. In a re-description of the type section of the Juana Lopez Member, Hook and Cobban (1980b, table 1) include 130 ft (40 m) of section (their stratigraphic units 1–7), below the base of the Juana Lopez that is barren of *C. bellaplicata*. They do, however, show a collection containing *Prionocyclus hyatti* at 20 ft (6 m) below the base of the Juana Lopez, which indicates that these rocks are still in the *P. hyatti* Zone.

the base and at the top of the 70–90-ft-thick (21–27-m-thick) Fite Ranch Sandstone Member of the Tres Hermanos Formation, a fine-grained, coastal barrier sandstone that rests on top of the primarily nonmarine Carthage Member (Hook et al. 1983, pp. 20–21). At the time of Kauffman's work, the Tres Hermanos Formation in the Carthage coal field was known as the middle sandstone member of the Mancos Shale (Wilpolt and Wanek 1951) and was correlated with the lower part of the Gallup in the Zuni Basin (Pike 1947, p. 87). A photograph of the type locality of *C. b. novamexicana* is shown as Figure 9A.

The ammonite fossils associated with the holotype of *Cameleolopha bellaplicata novamexicana* in the collection from USGS locality D2042 include *Coilopoceras colleti* Hyatt and *Prionocyclus* sp. The type locality and for many years the only known occurrence of *Coilopoceras colleti* was the middle Mancos sandstone at Carthage (Hyatt 1903). The associated prionocyclid species was at that time (1965) known from only outer whorls and fragments of large adults, which meant that the middle Mancos sandstone was middle to late Turonian depending on the species of *Prionocyclus* the fragments represented.[17]

Kauffman (1965, pp. 70–71) identified the large prionocyclid fragments from USGS locality D2042 as *Prionocyclus hyatti* because he states that *Cameleolopha bellaplicata novamexicana* "…is commonly found in the middle Mancos Shale of New Mexico, in the zone of [*Prionocyclus*] *hyatti* (Stanton) (late-middle Turonian), well below the occurrence of [*C.*] *lugubris*. Its [meaning *C. lugubris*'s] position relative to [*C.*] *bellaplicata bellaplicata* in New Mexico is uncertain, however, since the latter is rare in this area, and the two have not yet been found associated." Kauffman (1965, p. 63) notes that for his study, *C. b. novamexicana* had been collected from four localities in New Mexico. All four of those localities are in the Carthage coal field (Kauffman 1965, p. 76, localities 62–66).[18]

Colorado

Kauffman (1965, p. 71) states that "The stratigraphic relationship between [*Cameleolopha*] *bellaplicata bellaplicata* and the subspecies *novamexicana* can be established in Huerfano Park, Colorado. Here, typical examples of [*C.*] *bellaplicata bellaplicata* are found throughout the Codell Sandstone Member ("*Pugnellus* Sandstone"). … Below this unit, in the upper part of the Blue Hill Shale Member, septarian limestone concretions contain scattered but characteristic examples of the subspecies *novamexicana*. …The two forms do not have overlapping ranges in this area, although rare individuals transitional between them occur as marginal variants of each form. This occurrence suggests, therefore, that [*Cameleolopha*] *bellaplicata novamexicana* is characteristic of the lower part of the [*Prionocyclus*] *hyatti* zone (Blue Hill Shale Member equivalents) and [*Cameleolopha*] *bellaplicata bellaplicata* marks the upper part of the [*P.*] *hyatti* zone (Codell Sandstone Member: "*Pugnellus* Sandstone" of older authors). If future collections prove this to be true over a broad area of the Western Interior, these ostreids will have particular importance as stratigraphic markers, since the faunas of these two units overlap in almost every other respect."

Threefold subdivision of the *Prionocyclus hyatti* Zone

Twelve years later, Kauffman (1977a,b) was sure that the two subspecies of *Cameleolopha bellaplicata* had attained that particular importance as stratigraphic markers. In his illustrated guide to biostratigraphically important Cretaceous macrofossils of the Western Interior, Kauffman (1977b, p. 240) indicates that the known ranges of macrofossils are good enough to subdivide the late-middle Turonian zone of *Prionocyclus hyatti* into three parts. *Cameleolopha bellaplicata bellaplicata* is indicative of the upper part of zone and [a specimen from Carthage of] *C. b. novamexicana* is indicative of the middle part of the zone. Kauffman (1977a, fig. 6) shows *Inoceramus flaccidus* White as indicative of the lower part of the *P. hyatti* Zone. However, a look at papers Kauffman published between 1965 and 1977 is instructive in determining why he subdivided the *P. hyatti* Zone into three parts.

First, Kauffman (1965) interpreted the morphologic variation in *Cameleolopha bellaplicata* that he saw in the Carthage, New Mexico, collections, as evolutionary, rather than normal species variation. The Carthage collections contain the holotype of *C. b. novamexicana* as well as the bulk of the measured specimens that Kauffman attributed to that subspecies. Of the 82 measured specimens of *C. b. novamexicana* plotted on Kauffman's (1965, fig. 2) foldout graph of rib density, 66 (80%) are from Carthage and 16 (20%) are from Huerfano Park. The Carthage collections were poorly constrained biostratigraphically with, at that time, only an undetermined species of *Prionocyclus* and *Coilopoceras colleti* as clues to its position. Kauffman assumed that the Carthage collections had to lie in the *P. hyatti* Zone because a *C. bellaplicata* morphotype similar to *C. b. novamexicana* occurred low in the *Prionocyclus hyatti* Zone of the well-constrained stratigraphic section at Huerfano Park, Colorado.

Dane et al. (1966, fig. 3) show that *Coilopoceras colleti* occurs with the early forms of both *Prionocyclus macombi* and *Lopha lugubris* in the lower part of the Juana Lopez Member of the Mancos Shale in the Juan Basin of New Mexico. The disclaimer in the figure caption explains that "…The member is divided arbitrarily into equal, lower, middle, and upper parts which have no lithologic significance." Nonetheless, this association suggests that the Carthage occurrence of *Cameleolopha bellaplicata novamexicana* could be no younger than the earliest (pre-*lugubris*) part of the *P. macombi* Zone.[19] In their Semilla Sandstone paper Dane et al. (1968, p. F9) report that *Coilopoceras colleti* occurs in the upper part of the *Prionocyclus hyatti* Zone in Huerfano Park, Colorado, in association with *Cameleolopha bellaplicata bellaplicata*, whereas the older species of *Coilopoceras*, *C. springeri*, occurs with *C. b. novamexicana* in the lower part of the *P. hyatti* Zone.

Dane et al.'s (1966, 1968) species identifications predict the following biostratigraphic sequence, with the zonal index ammonite species of *Prionocyclus* on the left, followed by the co-occurring species or subspecies of *Cameleolopha* and the co-occurring species of *Coilopoceras* on the same line to the right.

Prionocyclus macombi	*Cameleolopha lugubris*	*Coilopoceras colleti*
P. hyatti	*C. bellaplicata bellaplicata*	*C. colleti*
P. hyatti	*C. bellaplicata bellaplicata*	*C. springeri*

The only way that the *presumed* biostratigraphic position of the **Carthage collections** (shown below in **bold**) of *Cameleolopha bellaplicata novamexicana* and *Coilopoceras colleti* can be plugged into this zonal scheme is just above the base, because *C. b. novamexicana* is presumed to be the older oyster subspecies and *C. springeri* is the older coilopocerid species. This arrangement gives rise

[17]The several chronological species of *Prionocyclus* that were often used as zonal index species are virtually identical morphologically as adults. Determination of species requires either well-preserved inner whorls of adults or specimens of juveniles.

[18]*Cameleolopha lugubris* has never been found in the Carthage coal field either in the top of the Tres Hermanos Formation or in the overlying D-Cross Tongue of the Mancos Shale (see Hook et al. 1983, sheet 1). So, the position of *C. b. novamexicana* relative to *C. lugubris* was conceptual in 1965, based on Kauffman's identification of the prionocyclid from Carthage as *Prionocyclus hyatti*.

[19]Later work on the type and reference sections of the Juana Lopez Member (Hook and Cobban 1980b) indicated that the *Coilopoceras* occurring at the base of the member was a new species, not *C. colleti*. This new species was determined to be younger than *C. colleti* and described as the new species *C. inflatum* by Cobban and Hook (1980, pp. 19–24).

to a threefold division of the *Prionocyclus hyatti* Zone based on co-occurrence of subspecies of *Cameleolopha* and [one misidentified] species of *Coilopoceras*.

Prionocyclus macombi	*Cameleolopha lugubris*	*Coilopoceras colleti*
P. hyatti	*C. bellaplicata bellaplicata*	*C. colleti*
P. hyatti	***C. bellaplicata novamexicana***	***C. colleti***
P. hyatti	*C. bellaplicata novamexicana*	*C. springeri*

This threefold subdivision of the *Prionocyclus hyatti* Zone is similar to that proposed by Kauffman et al. (1976, p. 9, middle Turonian zones 18–20). Kauffman et al.'s (1976) zonation did not rely on species of *Coilopoceras*, but rather included key species of the bivalve *Inoceramus* along with co-occurring subspecies of *C. bellaplicata*. (The index species chosen by Kauffman et al. (1976, p. 9) for each zone is followed by its zone number):

Prionocyclus macombi	*Cameleolopha lugubris*	*Inoceramus dimidius* (21)
P. hyatti	*C. bellaplicata bellaplicata*	*I. howelli* (20)
P. hyatti	*C. bellaplicata novamexicana* (19)	*I. costellatus*
P. hyatti	*C. bellaplicata novamexicana*	*I. flaccidus* (18)

Revised biostratigraphy

The problems with the threefold division of the *Prionocyclus hyatti* Zone shown above based on co-occurring subspecies of *Cameleolopha bellaplicata* and the Coilopoceratidae are: (1) the prionocyclid associated with the type specimen of *C. b. novamexicana* at Carthage is the younger *P. macombi*, not the older *P. hyatti*; and (2) the coilopocerid associated with *C. b. bellaplicata* at the base of the *P. hyatti* Zone is *Coilopoceras springeri*, not *Coilopoceras colleti* (see Cobban and Hook 1980, pp. 23–24). Rearranging the occurrences to reflect the revised identities of the ammonites results in the following zonation (with species name changes underlined and the Carthage occurrence in **bold**):

P. macombi	*Cameleolopha lugubris*	*Coilopoceras colleti*
P. macombi	***C. bellaplicata novamexicana***	***C. colleti***
P. hyatti	*C. bellaplicata bellaplicata*	*C. springeri?*
P. hyatti	*C. bellaplicata novamexicana*	*C. springeri*

Once the prionocyclid ammonite species is correctly identified at Carthage, the problem with splitting *Cameleolopha bellaplicata* into subspecies becomes apparent. Identifying the coarsely ribbed variety of *C. bellaplicata* in the basal *Prionocyclus hyatti* Zone at Huerfano Park as *C. b. novamexicana*, which has its type specimen from and its type area at Carthage, results in an impossible evolutionary succession:

Cameleolopha bellaplicata novamexicana arises suddenly in the early part of *Prionocyclus hyatti* time and gives rise to *C. b. bellaplicata* during late *P. hyatti* time. *Cameleolopha b. bellaplicata* then gives rise to *C. b. novamexicana* during early *P. macombi* time. This evolutionary sequence is impossible because *C. b. novamexicana* arises at two different times from different ancestors.

The solution to this evolutionary impossibility with the oysters is simply (1) to do away with the subspecies of *Cameleolopha bellaplicata* so that they do not have to be accommodated arbitrarily into the ammonite zonation and (2) replace the threefold subdivision of the *Prionocyclus hyatti* Zone with a twofold subdivision based on species of the Coilopoceratidae. This results in the same zonal scheme that Cobban and Hook (1980, pp. 23–24) suggested from their study of the Family Coilopoceratidae.[20]

P. macombi	*Cameleolopha lugubris*	*Coilopoceras inflatum*
P. macombi	*C. lugubris*	*C. colleti*
P. macombi	***C. bellaplicata***	***C. colleti***
P. hyatti	*C. bellaplicata*	*C. springeri*
P. hyatti	[no *Cameleolopha*]	*Hoplitoides sandovalensis*

This proposed twofold subdivision of the *Prionocyclus hyatti* Zone based on co-occurring species of Coilopoceratidae works on the outcrop as well. Kennedy (1988, fig. 4)—in his classic work on the Eagle Ford Group faunas of Texas—suggests a similar subdivision of the *Prionocyclus hyatti* Zone in a columnar section that he calls a "generalized" faunal succession in the Arcadia Park Formation in the Dallas–Ft. Worth area. The lowest occurrence of *P. hyatti* is in septarian concretions in shale, where *P. hyatti* occurs in association with the coilopocerid ammonite *Hoplitoides sandovalensis*, but without oysters. Approximately 9 m above that, *P. hyatti* occurs, again in septarian concretions, with the coilopocerid ammonite *Coilopoceras springeri* and oysters identified as *Cameleolopha* **cf**. *C. bellaplicata novamexicana*.[21] In the upper part of the column, approximately 13 m higher, crushed specimens of *P. hyatti* in shale occur on either side of a thin sandstone containing abundant *C. b. bellaplicata*. Approximately 3 m higher, the uppermost 1 m of shale in the Arcadia Park Formation contains crushed ammonites identified as *Prionocyclus* cf. *macombi*, but no oysters. *Cameleolopha lugubris* does not occur in the succession at all, either above or below the unconformity separating the Arcadia Park Formation from the Austin Chalk.

Hancock and Walaszczyk (2004, fig. 2) in their study of mid-Turonian sea-level changes around Dallas, Texas, redraft the upper part of the same columnar section used by Kennedy (1988, fig. 4). Their figure caption indicates that the column is from a specific section, measured in 1973 (by Kennedy and Hancock), on Chalk Hill Road, Dallas. This outcrop is approximately 50 mi southeast of the type area of *Cameleolopha bellaplicata* (Hancock and Walaszczyk 2004, fig. 8). They also show the oyster occurring with *Prionocyclus hyatti* and *Coilopoceras springeri* in the lower part of the *P. hyatti* Zone as *Cameleolopha* cf. *C. bellaplicata novamexicana*, indicating their degree of doubt in the identification of the older subspecies. Interestingly, they show the oyster occurring with *P. hyatti* in the upper part of the zone as *C. bellaplicata*, s.s. The "s.s." following the species name indicates the identification is in the strictest sense of the original description. Similarly, their graphic section shows a disconformity between the Arcadia Park and the overlying Austin Chalk, but does not show any collections of *C. lugubris* either beneath or above the unconformity.

20 For completeness, *Coilopoceras inflatum* is shown as the youngest of the Coilopoceratidae and *Hoplitoides sandovalensis*, the ancestor of *C. springeri*, is shown as the oldest.

21 The authors' emphasis, not Kennedy's. The "cf." is the abbreviation for "confer," and denotes a degree of doubt in the identification of the oyster as the older, more coarsely ribbed subspecies, which Kauffman (1965, p. 3) indicated did not occur in Texas. Kennedy's (1988, pl. 23, figs. 26–27) illustrations of a single specimen of *Cameleolopha bellaplicata bellaplicata* from the upper subzone shows a coarsely ribbed oyster with 14 ribs and a height of 6.71 cm and a length of 7.61 cm, yielding an area of 51.1 cm^2 and rib densities of 0.27 ribs/cm^2 and 0.48 ribs/cmH. This unusual specimen, which is wider than high, is plotted in Figure 6, where it occurs outside the bounding polygon for *C. bellaplicata*, indicating that more morphological variation should be expected within *C. bellaplicata*.

Appendix 2

Table of measurements made on specimens from three substantial collections of *Cameleolopha bellaplicata* (Shumard) housed at the Denver Federal Center, Colorado. H = left valve height; L = left valve length; W = width (thickness) of left valve (LV); Ribs = rib count at left valve margin; Area = area of inscribing rectangle (H * L); R/H = ribs per cm of height; R/L = ribs per cm of length; ---- indicates that the measurement is not possible. AS = attachment scar; BV = both valves; LV = left valve; *Cb* = *Cameleolopha bellaplicata*.

TABLE 1—USGS Mesozoic Invertebrate Collection D9487 is from the Eagle Ford Formation, near the type locality of *C. bellaplicata*, Grayson County, Texas.

Specimen no.	H (cm)	L (cm)	H/L	W-LV (cm)	Ribs	Area (cm^2)	Ribs/cm^2	R/H (r/cm)	R/L (r/cm)	Notes
1524	3.95	3.87	1.02	1.61	14	15.29	0.92	3.5	3.6	
1532	5.72	4.29	1.33	2.16	15	24.54	0.61	2.6	3.5	
1533[1]	5.66	4.83	1.17	1.90	13	27.34	0.48	2.3	2.7	distorted
1534[2]	5.04	3.74	1.35	1.94	15	18.85	0.80	3.0	4.0	BV
1536	4.76	4.40	1.08	1.97	20	20.94	0.95	4.2	4.5	BV
1539	4.25	4.23	1.00	1.34	15	17.98	0.83	3.5	3.5	AS: 11.6 × 11.0 mm
1540	3.76	3.46	1.09	1.84	18	13.01	1.38	4.8	5.2	BV
1543	3.37	2.68	1.26	0.95	14	9.03	1.55	4.2	5.2	BV; distorted
1544	3.43	3.23	1.06	0.96	17	11.08	1.53	5.0	5.3	
1545	4.29	3.61	1.19	1.22	15	15.49	0.97	3.5	4.2	
1547	5.47	4.65	1.18	1.63	17	25.44	0.67	3.1	3.7	
1549[3]	2.35	2.39	0.98	0.82	14	5.62	2.49	6.0	5.9	
1550	5.29	5.24	1.01	1.49	20	27.72	0.72	3.8	3.8	AS: 10.1 × 17.3 mm
1551	4.65	4.57	1.02	1.34	17	21.25	0.80	3.7	3.7	AS: 7.4 × 5.2 mm
1552	5.24	5.58	0.94	1.99	20	29.24	0.68	3.8	3.6	BV; AS: 9.8 × 15.9 mm; *Cb* attached to LV
1553	3.63	3.61	1.01	1.01	11	13.10	0.84	3.0	3.0	AS: 10.5 × 14.6 mm
1554	4.61	4.05	1.14	1.90	13	18.67	0.70	2.8	3.2	BV; several attachment scars on LV
1557	5.26	3.97	1.32	1.71	13	20.88	0.62	2.5	3.3	BV; AS: 18.5 × 18.5 mm; corresponding xenomorph; *Cb* attached to LV
1559	5.33	3.95	1.35	1.41	16	21.05	0.76	3.0	4.1	AS: 9.5 × 14.8 mm; distorted
1560	5.05	4.01	1.26	1.44	17	20.25	0.84	3.4	4.2	distorted
1562	4.45	3.56	1.25	1.58	15	15.84	0.95	3.4	4.2	distorted; AS: 12.2 × 15.2 mm
1563	4.27	4.33	0.99	1.41	20	18.49	1.08	4.7	4.6	
1569	4.51	3.79	1.19	1.45	10	17.09	0.59	2.2	2.6	
1571	6.23	5.27	1.18	1.60	20	32.83	0.61	3.2	3.8	
1573	4.58	4.57	1.00	1.54	21	20.93	1.00	4.6	4.6	BV; AS: 10.1 × 8.8 mm
1577	4.65	4.82	0.96	1.06	12	22.41	0.54	2.6	2.5	
1578	4.89	4.89	1.00	2.39	12	23.91	0.50	2.5	2.5	BV; AS: 18.1 × 18.1 mm; corresponding xenomorph; *Cb* attached to LV
1581	3.96	3.84	1.03	1.54	20	15.21	1.32	5.1	5.2	AS: 5.2 × 8.0 mm
1583	3.34	2.86	1.17	1.14	14	9.55	1.47	4.2	4.9	BV
1585[4]	4.50	3.90	1.15	1.70	19	17.55	1.08	4.2	4.9	
1586	3.86	3.80	1.02	0.97	15	14.67	1.02	3.9	3.9	AS: 12.2 × 15.4 mm
1588	4.75	3.93	1.21	1.02	14	18.67	0.75	2.9	3.6	
1589	5.33	4.44	1.20	1.61	15	23.67	0.63	2.8	3.4	distorted
1559a	4.62	3.56	1.30	1.19	15	16.45	0.91	3.2	4.2	AS: 11.2 × 8.3 mm; *Cb* attached to LV
157	4.28	4.14	1.03	1.68	20	17.72	1.13	4.7	4.8	
SUM	159.33	142.06	39.44	52.51	556	661.75	32.7	125.71	139.92	
n =	35	35	35	35	35	35	35	35	35	
Average	4.55	4.06	1.13	1.50	15.89	18.91	0.93	3.59	4.00	
H > L			29	82.86%						
H < L			3	8.57%						
H = L			3	8.57%						

[1]USNM 545199
[2]USNM 545202
[3]USNM 545200
[4]USNM 545201

TABLE 2—D2042 is from the base of the Fite Ranch Sandstone Member of the Tres Hermanos Formation in the NE¼ sec. 9 T5S R2E Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico.

No.	H (cm)	L (cm)	H/L	W-LV (cm)	Ribs	Area (cm^2)	Ribs/cm^2	R/H (r/cm)	R/L (r/cm)	Notes
1	4.34	3.30	1.32	1.64	16	14.32	1.12	3.69	4.8	
2[1]	2.69	2.69	1.00	1.14	16	7.24	2.21	5.95	5.9	
3	2.84	2.89	0.98	1.19	10	8.21	1.22	3.52	3.5	
4	3.50	2.92	1.20	1.42	16	10.22	1.57	4.57	5.5	
5	4.95	4.03	1.23	2.71	12	19.95	0.60	2.42	3.0	
6	4.52	4.00	1.13	2.06	11	18.08	0.61	2.43	2.8	
7	4.25	3.34	1.27	1.42	10	14.20	0.70	2.35	3.0	
8	3.66	3.11	1.18	1.38	13	11.38	1.14	3.55	4.2	broken; minimum rib count
9	4.41	4.01	1.10	2.49	10	17.68	0.57	2.27	2.5	
10	4.60	3.78	1.22	1.94	20	17.39	1.15	4.35	5.3	large AS
11	4.01	3.74	1.07	1.81	12	15.00	0.80	2.99	3.2	
12	2.74	2.33	1.18	1.11	11	6.38	1.72	4.01	4.7	
13	3.42	3.05	1.12	1.46	10	10.43	0.96	2.92	3.3	
14	4.18	3.72	1.12	1.81	11	15.55	0.71	2.63	3.0	broken; minimum rib count
15[2]	2.62	2.63	1.00	1.28	14	6.89	2.03	5.34	5.3	
16	2.43	2.52	0.96	0.98	11	6.12	1.80	4.53	4.4	
17	2.01	2.09	0.96	1.16	11	4.20	2.62	5.47	5.3	
18	2.66	2.14	1.24	0.97	13	5.69	2.28	4.89	6.1	
19	2.62	2.38	1.10	1.08	14	6.24	2.25	5.34	5.9	
20	2.81	2.89	0.97	1.43	14	8.12	1.72	4.98	4.8	
21	1.94	2.46	0.79	0.93	11	4.77	2.30	5.67	4.5	
22	2.37	2.37	1.00	0.87	14	5.62	2.49	5.91	5.9	
23	1.81	1.66	1.09	0.89	14	3.00	4.66	7.73	8.4	
SUM	75.38	68.05	25.23	33.17	294	236.68	37.23	97.54	105.2	
n =	23	23	23	23	23	23	23	23	23	
Average	3.28	2.96	1.10	1.44	12.78	10.29	1.62	4.24	4.57	
holotype[3]	3.37	3.27	1.03		10	11.02	0.91	2.97	3.06	
H > L			15	65.22%						
H < L			5	21.74%						
H = L			3	13.04%						

[1]USNM 545196
[2]USNM 545195
[3]USNM 132267

TABLE 3—D10354 is from the base of the Fite Ranch Sandstone Member of the Tres Hermanos Formation in the SW¼ sec. 9 T5S R2E Cañon Agua Buena 7.5-min quadrangle, Socorro County, New Mexico.

No.	H (cm)	L (cm)	H/L	W-LV (cm)	Ribs	Area (cm²)	Ribs/cm²	R/H (r/cm)	R/L (r/cm)	Notes
1	2.24	2.00	1.12	0.89	16	4.48	3.57	7.14	8.00	
2	2.39	2.03	1.18	0.88	14	4.85	2.89	5.86	6.90	
3	1.98	1.75	1.13	0.73	12	3.47	3.46	6.06	6.86	
4	2.56	2.41	1.06	0.82	16	6.17	2.59	6.25	6.64	
5	2.01	2.20	0.91	0.68	16	4.42	3.62	7.96	7.27	
6	1.77	1.59	1.11	0.84	14	2.81	4.97	7.91	8.81	
7	2.79	2.65	1.05	1.28	10	7.39	1.35	3.58	3.77	
8	2.57	2.56	1.00	0.95	17	6.58	2.58	6.61	6.64	
9	3.07	2.52	1.22	1.26	19	7.74	2.46	6.19	7.54	
10	2.56	2.60	0.98	1.21	16	6.66	2.40	6.25	6.15	
11	3.08	2.50	1.23	1.14	15	7.70	1.95	4.87	6.00	
12	3.91	3.14	1.25	1.66	16	12.28	1.30	4.09	5.10	
13[1]	4.26	3.59	1.19	1.61	17	15.29	1.11	3.99	4.74	
14	4.08	3.51	1.16	1.54	18	14.32	1.26	4.41	5.13	AS: 1.23 × 0.87 snail-shaped
15	4.80	3.77	1.27	1.93		18.10				worn smooth
16	4.23	3.40	1.24	1.92	17	14.38	1.18	4.02	5.00	
17	4.22	3.58	1.18	1.74	17	15.11	1.13	4.03	4.75	
18	6.05	4.69	1.29	1.97	18	28.37	0.63	2.98	3.84	AS: 1.58 × 1.95 cm
19[2]	5.18	4.41	1.17	1.83	22	22.84	0.96	4.25	4.99	
20	4.73	3.91	1.21	1.96	16	18.49	0.87	3.38	4.09	
21	5.14	4.41	1.17	1.80	18	22.67	0.79	3.50	4.08	
SUM	73.62	63.22	24.14	28.64	324	244.12	41.09	103.34	116.29	
n =	21	21	21	21	20	21	20	20	20	
Average	3.51	3.01	1.15	1.36	16.20	11.62	2.05	5.17	5.81	
H > L			18	85.71%						
H < L			2	9.52%						
H = L			1	4.76%						

[1]USNM 545197
[2]USNM 545198

TABLE 4—Combined

Collection	H (cm)	L (cm)	H/L	W-LV (cm)	Ribs	Area (cm²)	Ribs/cm²	R/L (r/cm)
D9467	155.25	132.35	39.44	51.28	544	598.45	31.43	129.03
D2042	75.38	68.05	25.23	33.17	294	236.68	37.23	105.15
D10354	73.62	63.22	24.14	28.64	324	244.12	41.09	116.29
SUM	304.25	263.62	88.81	113.09	1,162	1,079.25	109.75	350.48
n =	79	79	79	79	78	79	78	78
Average	3.85	3.34	1.12	1.43	14.90	13.66	1.41	4.49
	D9487	D2042	D10354		Total			
H > L	29	15	18		62	78.48%		
H < L	3	5	2		10	12.66%		
H = L	3	3	1		7	8.86%		
Total	35	23	21		79			