

## Cephalopods from the Cretaceous-Paleogene (K-Pg) boundary interval on the Brazos River, Texas, and extinction of the ammonites

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### ABSTRACT

We report on new collections of cephalopods (ammonites and nautilids) from the Cretaceous-Paleogene (K-Pg) successions of the Corsicana and Kincaid formations exposed along the Brazos River in Falls County, Texas. An abundant fauna of eight species comprising four genera of ammonites is described from the Corsicana Formation, including *Discoscaphites mullinaxorum* n. sp. The presence of abundant aptychi (probably lower jaws) of *Discoscaphites* and *Eubaculites*, as well as juvenile specimens, indicates a living population that experienced little postmortem drift. The lytoceratid genus *Gaudryceras* is also reported for the first time from the Brazos River area. Presence of the index taxon *Discoscaphites iris* (Conrad, 1858) indicates that the fauna belongs to the *D. iris* Range Zone, the highest ammonite range zone in North America. Correlation with new and existing microfossil data indicates that the fauna represents the uppermost Maastrichtian, and comparison with published records further suggests that this is the most diverse *D. iris* Zone fauna yet reported from the

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Gulf and Atlantic Coastal Plains of North America. Three ammonite genera are recorded from the basal units of the K-Pg event deposit at Brazos, which likely represents deposition in the immediate aftermath of the Chicxulub impact event. A single specimen of the nautilid *Eutrephoceras* is reported from the Danian Kincaid Formation, less than 300 kyr after the K-Pg boundary. These data provide new information on the differing fate of these cephalopod groups during the K-Pg mass extinction and add to the picture of diverse and abundant Maastrichtian ammonite faunas prior to the Chicxulub impact event.

## INTRODUCTION

The Cretaceous-Paleogene (K-Pg) mass extinction event 66 Ma ago was responsible for the disappearance of more than 70% of marine species worldwide (e.g., Bambach et al., 2004). Most evidence points to the Chicxulub asteroid impact on the Yucatán Peninsula and associated rapid global environmental change as the ultimate cause of the extinction (Alvarez et al., 1980; Schulte et al., 2010), with potential drivers including global darkness and food chain collapse (Sheehan and Hansen, 1986), rapid climatic changes (Vellekoop et al., 2014; Brugger et al., 2017), and ocean acidification (Henehan et al., 2019). The role the Deccan Traps Large Igneous Province (LIP) may have played in the crisis is the subject of ongoing debate given recent high-precision dating that emphasizes the close temporal overlap between this episode of LIP volcanism, the Chicxulub impact, and mass extinction (Schoene et al., 2019; Sprain et al., 2019; Hull et al., 2020). Ammonoid cephalopods (ammonites) are among the most prominent victims of this crisis, while closely related nautilids survived into the Cenozoic (Landman et al., 1983; 2014; 2015). The record of ammonite extinction has been extensively studied in the Atlantic and eastern Gulf Coastal plains of North America (Landman et al., 2007a; Witts et al., 2018). However, important gaps remain in this record, especially in the western part of the Mississippi Embayment.

Outcrops of the K-Pg boundary along the Brazos River and its tributaries in Falls County, Texas, are crucial in deciphering the shallow marine record of the mass extinction event because of their abundantly fossiliferous nature and apparent stratigraphic continuity (e.g., Hansen et al., 1987; 1993; Aberhan and Kiessling, 2015). This is reflected in the extensive body of work (> 50 publications) dedicated to the geology and paleontology of a relatively small ~3 km<sup>2</sup> area to the south of the Texas Rt. 413 bridge (fig. 1). These sections, which span the contact between the Upper Cretaceous (Maastrichtian) Corsicana Formation and lower Paleogene (Danian) Kincaid Formation (Smith and Pessagno, 1973; Yancey, 1996), have proved controversial. This is primarily due to the presence of complex and laterally variable siliciclastic deposits coincident with the K-Pg boundary, ascribed either to rapid depositional processes related to the Chicxulub impact event and its aftermath (Bourgeois et al., 1988; Smit et al., 1996; Yancey and Liu, 2013) or non-catastrophic sea-level change (Gale, 2006; Keller et al., 2007; papers in Keller and Adatte, 2011). Similar discussions have focused on other successions around the Gulf of Mexico, proximal (< 1500 km distance) to the Chicxulub crater (Schulte et al., 2010) where high energy deposition is most likely to have occurred immediately following impact (Sanford et al., 2016; Witts et al., 2018; Gulick et al., 2019).

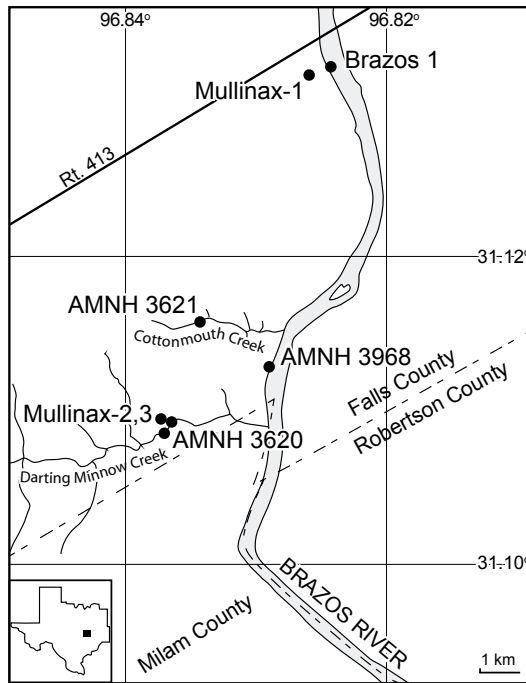


FIGURE 1. Locality map of the Brazos River area south of Texas Rt. 413 in southern Falls County, Texas, showing outcrops (AMNH locs. 3620, 3621, 3968, Brazos 1) and drill cores (Mullinax-1-3) mentioned in the text.

Intense debate has also focused on the precise placement of the K-Pg boundary at Brazos based on lithostratigraphic and biostratigraphic grounds. This has included (mis)interpretation of volcanic ash beds (referred to as “yellow clay” in some papers) in the Corsicana Formation as impact ejecta layers and evidence for a pre-K-Pg timing of the Chicxulub impact event (e.g., Keller et al., 2007; Keller and Adatte, 2011). Recent work has sought to resolve these issues and develop a stratigraphic framework that can be accurately correlated to the international timescale (e.g., Hart et al., 2012, 2019; Yancey and Liu, 2013; Leighton et al., 2017). Additional research has also better defined the K-Pg boundary based on the GSSP at El Kef, Tunisia, and elsewhere (Molina et al., 2006; 2009).

Here we report on new collections of fossil cephalopods (ammonites and nautilids) made since 2015 in the Brazos River area by the American Museum of Natural History (AMNH) and partner institutions. A Cretaceous fauna of six genera comprising 11 species occurs below the K-Pg boundary. Based on the recognition of the zonal taxon in our samples, this fauna belongs to the uppermost Maastrichtian *Discoscaphites iris* Range Zone—the highest ammonite zone in North America. We also describe the first occurrence of the nautilid genus *Eutrephoceras* from the lowest Paleogene (Danian stage) of Brazos. New collections are integrated with existing macrofossil data and material from cores taken in the area (Hansen et al., 1987; Kennedy et al., 2001; Keller et al., 2011). As well as providing a taxonomic reassessment, we place the cephalopod fauna in context using microfossil (calcareous nannofossil, foraminiferal, and dinoflagellate) biostratigraphy, assess the occurrence of these taxa relative to the K-Pg boundary, and discuss implications for the fate of cephalopod groups during the K-Pg mass extinction.

## GEOLOGIC AND STRATIGRAPHIC SETTING

Upper Cretaceous and lower Paleogene sediments of the Brazos River sections in Falls County, Texas, are part of an open marine succession deposited along the western margins of the proto-Gulf of Mexico, close to the mouth of a remnant Western Interior Seaway (Kennedy et al., 1998; Landman et al., 2004a; 2004b). The shoreline is estimated to have been ~100 km to the west at the central Texas uplift, and the shelf-slope margin 150 km to the southeast (Galloway et al., 2000). Regional dip is ~2° to the south. The Cretaceous portion of the succession is represented by the Corsicana Formation (sensu Smith and Pessagno, 1973). This unit is equivalent to both the Kemp Clay and Corsicana Formation of earlier studies of Upper Cretaceous stratigraphy in Texas (e.g., Adkins, 1933; Stephenson, 1941; Kennedy and Cobban, 1993a). In the study area, it is a dark gray to light gray laminated mudstone with minor siltstone and occasional thin (10's of cm thick) sandstone layers (fig. 2A–C). A 3 mm thick orange weathering volcanic ash layer also occurs in the Corsicana Formation located ~30 cm below the K-Pg boundary in Cottonmouth Creek (fig. 2B). This unit was previously misinterpreted as a layer of altered impact spherules related to the Chicxulub impact (e.g., Keller et al., 2007). Mineralogical analysis and preliminary U-Pb dating of zircons from this layer confirmed a volcanic rather than meteoritic origin and produced a range of dates, including one within error of 65.95 Ma (Hart et al., 2012).

The base of the Corsicana Formation is not well defined, but in cores taken in the Brazos River area, the formation attains a thickness in excess of 40 m (Keller et al., 2011; Abramovich et al., 2011). Kennedy and Cobban (1993a) suggested a total thickness of ~70–90 m (250–300 ft) for the formation throughout Texas (see also Smith and Pessagno, 1973). The Corsicana Formation is abundantly fossiliferous, especially in its upper portion, with well-preserved but often crushed aragonitic molluscan macrofossils exhibiting original shell material and a diverse calcareous microfossil fauna (Jiang and Gartner, 1986; Hansen et al., 1987; Kennedy et al., 2001; Abramovich et al., 2011; Hart et al., 2012; fig. 2D–F). Paleoenvironmental analysis suggests deposition in a mid-outer shelf setting

FIGURE 2. Outcrops of the Corsicana and lower Kincaid formations along the Brazos River and its tributaries, Falls County, Texas. **A.** Close-up of the contact between the Corsicana Formation (CF) and the basal K-Pg event deposit (mudstone-clast-bearing unit (U1) and ejecta spherule-rich sandstone (U2) units highlighted) at AMNH loc. 3620, waterfall section in Darting Minnow Creek (DMC-W). White dashed line marks the K-Pg boundary. Geologic hammer is approximately 32.5 cm in length. Photo courtesy of Linda Ivany. **B.** Outcrop of the uppermost Corsicana Formation and overlying K-Pg event deposit at AMNH loc. 3621 (Cottonmouth Creek). The white arrow points to a ~3 mm thick orange weathering volcanic ash in the Corsicana Formation. The K-Pg boundary and base of U1 (mudstone-clast-bearing unit) is located ~30 cm above this horizon. Note hummocky cross-stratified sandstones forming the top of the outcrop. **C.** Contact between dark mudstones of the Corsicana Formation and K-Pg event deposit at AMNH loc. 3968 (Riverbank South). White dashed line marks the K-Pg boundary. At this locality thin U2 (ejecta-spherule-rich sandstone) forms the base of the event deposit overlain by a hummocky cross-stratified sandstone. Pickaxe handle below the K-Pg boundary is approximately 23 cm in length. **D.** *Discoscaphites iris* microconch in situ in the uppermost Corsicana Formation, 1 m below the K-Pg boundary at AMNH loc. 3620. Scale bar to right is in cm. **E.** Multiple specimens of *Eubaculites carinatus* in situ in the Corsicana Formation, ~20 cm below the volcanic ash at AMNH loc. 3621. Visible horizontal portion of geologic hammer is approximately 13.5 cm in length. **F.** Specimen of *Gaudryceras* sp. as extracted from the uppermost Corsicana Formation, 1 m below the K-Pg boundary at AMNH loc. 3620. Note small oyster attached to the shell at the aperture. Scale bar = 1.5 cm.



below storm wave base, with depth estimates of 75–100 m based on the ratio of benthic:planktonic foraminifera (Yancey and Liu, 2013; Woelders and Speijer, 2015).

The Corsicana Formation is overlain by the Littig and Pisagh members of the Kincaid Formation (Yancey, 1996; fig. 3). The lithostratigraphic contact, an irregular surface with up to 2 m relief across the Brazos outcrop belt, marks the K-Pg boundary (Hansen et al., 1993; Hart et al., 2012; Yancey and Liu, 2013; Hart et al., 2019; fig. 2A, C). The irregular nature of this surface is the result of preexisting relief on the Cretaceous seafloor, which was perhaps enhanced by deposition of the overlying units. Directly above this surface is a complex sequence of coarse-grained sediments referred to as the K-Pg “boundary complex,” “event bed,” or “event deposit” (figs. 2A, 3). This sequence exhibits lateral variations in thickness, in some outcrops and cores reaching thicknesses of ~2 m, while elsewhere being entirely absent (Adatte et al., 2011; Hart et al., 2012; Yancey and Liu, 2013). Stratigraphic changes can occur over distances of 10 m or less within the same outcrop. This sequence has been subdivided in some previous studies into as many as six units (labelled B–G by Hansen et al., 1987; see also Hansen et al., 1993; Smit et al., 1996; and Schulte et al., 2006), some of which may repeat or be absent in any given outcrop.

Despite this complexity, a generalized succession of four sediment types is recognizable across the K-Pg boundary in the Brazos River successions: (1) a basal mudstone-clast-bearing unit with rare impact ejecta (unit B of Hansen et al., 1987) overlain by (2) ejecta-spherule-rich coarse sandstone (units C and D), followed by (3) cross-bedded sandstone and siltstone (units D and E), and capped by (4) an upward-fining settling layer of siltstone and mudstone (units E–G) that often contain one or a series of weak iridium anomalies and the last appearance of diagnostic Cretaceous microfossils (Hansen et al., 1987; 1993; Yancey, 1996; Smit et al., 1996; Schulte et al., 2006; Yancey and Liu, 2013).

This sequence has had multiple interpretations: as one or several tsunami deposits resting on an erosional surface caused by the Chicxulub impact event (Bourgeois et al., 1988; Smit et al., 1996; Schulte et al., 2006; Hart et al., 2012), impact seismic-induced mass flow deposits overlain by tempestites recording the passage of large storms (Yancey, 1996; Yancey and Liu, 2013), or as a series of lowstand deposits formed in submarine channels under normal marine conditions associated with sea-level fall and subsequent transgression (Keller and Adatte, 2011). In this latter hypothesis, the K-Pg boundary was placed at the top of the event deposit, coincident with the highest occurrence of identifiably Cretaceous microfossils. This hypothesis is not well supported on either sedimentological or paleontological grounds (see discussions in Bralower et al., 2010; Hart et al., 2012, 2019; Yancey and Liu, 2013).

Above the K-Pg event deposit, the Littig and Pisagh members of the Kincaid Formation are characterized by a 5–6 m succession of mudstones, sandstones and siltstones, including a series of prominent concretion and sandstone horizons useful for correlation across the Brazos River area (fig. 3). Directly above the K-Pg event deposit is a dark, pyrite-rich silty claystone (units G, I). This interval exhibits low macro- and microfossil content and bioturbation, all of which increase up-section, recording an initial return to background conditions and marine ecosystem recovery following the K-Pg mass extinction (Hansen et al., 1993; Aberhan and Kiessling, 2015; Leighton et al., 2017). Although water-depth estimates based

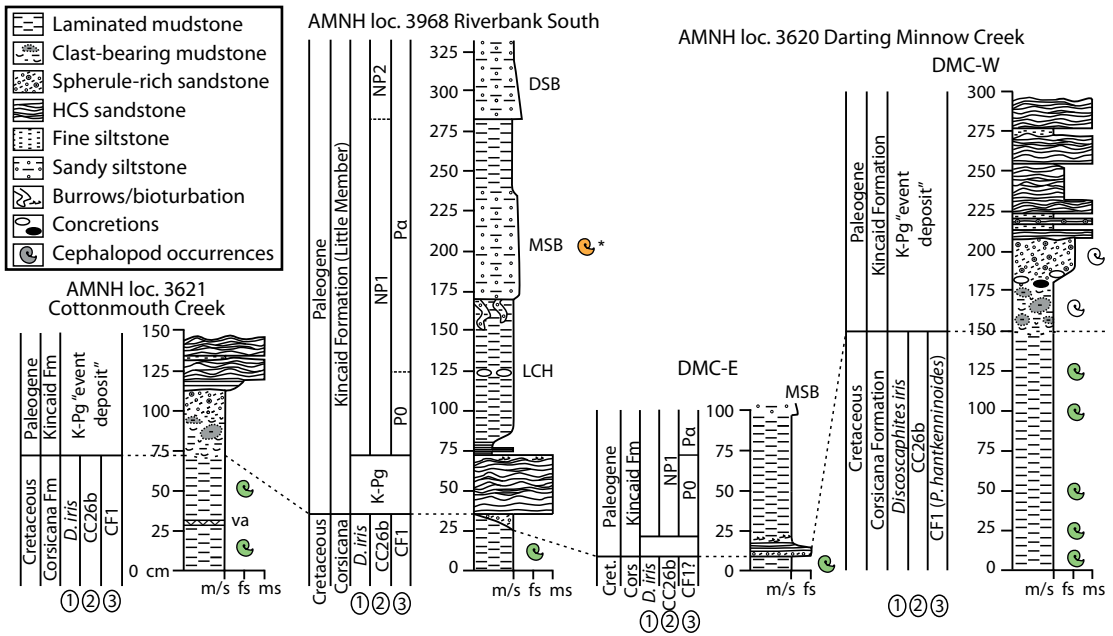


FIGURE 3. Litho- and biostratigraphic sections. K-Pg boundary shown as dashed line connecting outcrops. Biostratigraphy is illustrated for each section based on (1) ammonites, (2) calcareous nanofossils, and (3) planktonic foraminifera. Cephalopod-occurrence color code: green = Cretaceous; white = incorporated into K-Pg event deposit; orange = Paleogene. Abbreviations: **DSB**, Dirty Sandstone Bed; **LCH**, Lower Concretion Horizon; **MSB**, Middle Sandstone Bed; **va**, volcanic ash horizon at AMNH loc. 3621; \* single cephalopod occurrence from the MSB (*Eutrephoceras* sp.) collected at Darting Minnow Creek (AMNH loc. 3620), but illustrated on the stratigraphically continuous section at AMNH loc. 3698 from Hart et al. (2012) and Leighton et al. (2017). The DSB, LCH, and MSB concretionary marker beds can be found and correlated throughout the Brazos River area (e.g., Yancey, 1996; Hart et al., 2012).

on microfossils are difficult due to the effects of the mass extinction, a mid-outer shelf environment similar to that of the Corsicana Formation with variable water depths of 75–100 m below storm wave base has been suggested for the basal Littig Member (Hart et al., 2012; Yancey and Liu, 2013; Woelders and Speijer, 2015).

The most prominent unit in the lower Paleocene succession at Brazos is a 30 cm thick bioturbated quartz sand bed ~0.5–4 m above the event deposit, containing abundant macrofossils (some in place and others phosphatized and clearly reworked—including poorly preserved phosphatic fragments of baculitid ammonites) within a clayey mud matrix. *Thalassinoides* burrows penetrate up to 50 cm to 1 m below this bed and can be in-filled with material from this unit. This distinctive unit is often referred to as the Middle Sandstone Bed (MSB) (Yancey, 1996; Hart et al., 2012; Leighton et al., 2017), and is interpreted as a condensed zone and omission surface formed during late-stage transgression (Hansen et al., 1993; Yancey and Liu, 2013). It can be correlated to outcrops in the nearby Walker Creek and Littig Pit sections in Texas, where it forms the base of the Kincaid Formation, which unconformably overlies the Corsicana Formation with no stratigraphically complete K-Pg boundary (Jiang and Gartner, 1986; Yancey, 1996).

## PREVIOUS REPORTS OF CEPHALOPODS FROM THE BRAZOS RIVER OUTCROPS

Numerous studies have reported cephalopod occurrences from the Brazos River sections. Hansen et al. (1987) conducted the initial studies of the sedimentology and macrofossil diversity of the K-Pg boundary interval in the area, with “*Baculites* sp.,” “*Scaphites* sp.,” as well as ammonite protoconchs documented in a series of samples from the Corsicana Formation along the Brazos riverbed close to the Rt. 413 bridge (Brazos-1; fig. 1). They reported that ammonites occurred in large numbers comprising up to 70% biovolume in the uppermost Corsicana Formation and were labelled “core taxa” along with numerous benthic molluscan species. Further work by Hansen et al. (1993) documented new K-Pg exposures along the main Brazos River and its tributary Cottonmouth Creek, containing *Baculites* sp., *Discoscaphites* sp., *Scaphites* sp., and *Sphenodiscus* sp. below the K-Pg boundary. Small ammonite shell fragments were also noted to occur in decreasing abundance in sediments correlated to lowermost Paleocene foraminiferal zone P0 in the basal Kincaid Formation. However, Hansen et al. (1993) considered them reworked due to the lack of large fragments or complete specimens. In places in the Paleocene of the Brazos River sections as well as equivalent strata at Littig Pit and Walker Creek, ammonite shell material can be preserved in reworked phosphatic concretions in sediments as young as foraminiferal zone P1 (fig. 4).

Kennedy et al. (2001) reexamined material studied by Hansen et al. (1987) as well as new material collected along the Brazos riverbed south of the Rt. 413 bridge (equivalent to the Brazos-1 locality and upstream; fig. 1). They identified five ammonite species: *Pachydiscus* (*Pachydiscus*) *jacquoti jacquoti* Seunes, 1890, *Glyptoxoceras* cf. *rugatum* (Forbes, 1846), *Eubaculites carinatus* (Morton, 1834), *Discoscaphites sphaeroidalis* Kennedy and Cobban, 2000, and *Discoscaphites* cf. *gulosus* (Morton, 1934). Both *Pachydiscus* (*P.*) *jacquoti jacquoti* and *Glyptoxoceras* cf. *rugatum* occur at single localities estimated to be ~8 m and 4.45 m below the K-Pg boundary, respectively. All other ammonite taxa ranged throughout an 11.5 m thick section of the Corsicana Formation below the K-Pg boundary, with the authors noting that *Eubaculites carinatus* occurs in rock-forming abundance in parts of the section. In addition, the paper states that “reworked phosphatized and glauconitized fragments of *Eubaculites* and *Discoscaphites* occur in the matrix of the basal Kincaid conglomerate” (i.e., within the basal units of the K-Pg event deposit as presently defined (Yancey and Liu, 2013).

Several specimens of ammonites have been reported from the Mullinax-1 and Mullinax-3 drill cores, where their occurrences can be correlated directly to biostratigraphic data from planktonic foraminifera and nannofossils (Keller et al., 2011; Abramovich et al., 2011; Tantawy et al., 2011). *Discoscaphites iris* is recorded 9.2 m below the surface (mbs) in core Mullinax-3, corresponding to planktonic foraminiferal zone CF2 and calcareous nannofossil zone CC26b. The same taxon was also recorded “close to the top” of an interval 29.5–16.5 mbs in core Mullinax-1 (Abramovich et al., 2011), associated with zone CF2 and possibly the top of CF3. Leighton (2014) illustrated numerous examples of *Eubaculites carinatus* from the Corsicana Formation of the Mullinax-2 core (figs. 1, 4).

## MATERIAL AND METHODS

Fieldwork between 2015–2019 focused on the Corsicana Formation and outcrops of the K-Pg boundary at three localities (figs. 1–3): AMNH locality 3620 (Darting Minnow Creek:



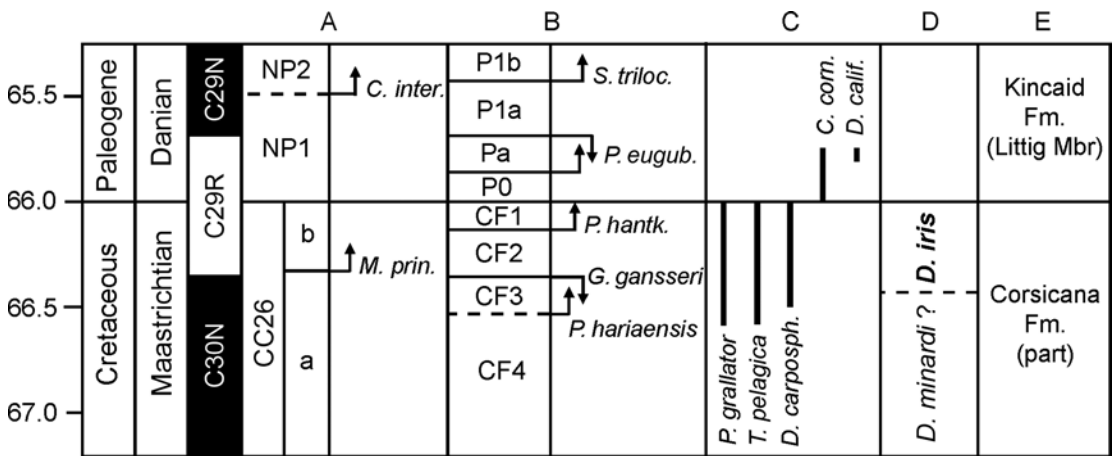


FIGURE 4. Biostratigraphic framework for the Brazos River K-Pg boundary successions and correlation to magnetostratigraphy and international timescale. **A.** Calcareous nannofossils based on the schemes of Perch-Nielsen (1985) for the Cretaceous and Martini (1971) for the Paleogene (see Tantawy et al., 2011). *M. prin* = *Micula prinsii*; *C. inter.* = *Cruciplacolithus intermedius*. **B.** Planktonic foraminifera based on the CF scheme of Li and Keller (1998) for the Cretaceous and Berggren and Pearson (2005) for the Paleogene. *P. hariaensis* = *Pseudoguembelina hariaensis*; *G. gansseri* = *Gannserina gansseri*; *P. hantk.* = *Plummerita hantkeninoides*; *P. eugub.* = *Parvularugoglobigerina eugubina*; *S. triloc.* = *Subbotina triloculinoides*. **C.** Dinoflagellate ranges based on Aydin (2013). *P. grallator* = *Palynodinium grallator*; *T. pelagica* = *Thalassiphora pelagica*; *D. carposph.* = *Disphaerogena carposphaeropsis*; *C. corn.* = *Carpatella cornuta*; *D. calif.* = *Damassadinium californicum*. **D.** Ammonites (this study). *D. iris* = *Discoscaphites iris*; *D. minardi* = *Discoscaphites minardi*. **E.** Lithostratigraphy (Smith and Pessagno, 1973; Yancey, 1996). Dashed lines indicate uncertainty in position/timing of boundary between range zone.

31° 06' 33.99 N, 96° 50' 13.12 W), AMNH locality 3621 (Cottonmouth Creek: 31° 06' 56.58 N, 96° 49' 57.71 W), and AMNH locality 3968 (Riverbank South, Hart et al., 2012; Leighton et al., 2017: 31° 06' 44.6 N, 96° 49' 46.0W). Macrofossil material from the Corsicana Formation of the Mullinax-1 (31° 07' 53.00 N, 96° 49' 14 W) and Mullinax-3 (31° 06.55' N, 96° 50.28 W) drill cores was also examined during a visit to Princeton University facilitated by G. Keller (fig. 1). The sampling distribution and occurrences of specimens is shown in figure 3 for each of the three field localities. Stratigraphic and occurrence data are also available in appendix 1. Specimens were extracted from outcrop using mechanical tools and treated with consolidate (Quick Shine floor finish) due to their fragile nature. At AMNH loc. 3620 several bulk samples were taken of the K-Pg boundary units for a separate study (Irizarry et al., 2018; 2019), and whole and fragmentary ammonite specimens were picked from these samples following mechanical breakdown in the laboratory.

Bulk sediment samples were also taken from all three AMNH localities for calcareous nannofossil analysis at the University of Copenhagen. AMNH locality 3621 (Cottonmouth Creek) was sampled at 10 cm intervals from 60 cm below to 20 cm above the volcanic ash layer at the waterfall section. AMNH locality 3620 (Darting Minnow Creek, DMC) was sampled at 1.25 m, 1 m, 50 cm, 25 cm, and 10 cm below the base of the K-Pg event deposit at the waterfall (DMC-W). Two samples were also taken downstream close to a farm track crossing (DMC-E),

where the event deposit thins to a single 10 cm thick fining-upward interval overlain by Paleocene mudstones and siltstones (Henehan et al., 2019); one sample from the Corsicana Formation immediately beneath this layer, and one from the Kincaid Formation ~5 cm above. A single sample was also taken from the Corsicana Formation 20 cm below the K-Pg boundary at AMNH locality 3968 (Riverbank South). Smear slides were prepared following the methodology described in Thibault and Gardin (2006). The results are based on the examination of a total of 100 fields of view (FOV). A semiquantitative analysis of the nannofossil assemblage was performed with a Leica DM750P polarizing microscope at a magnification of  $\times 1000$ .

#### BIOSTRATIGRAPHIC ANALYSIS AND CORRELATION

The Maastrichtian ammonite biostratigraphy for the Gulf Coastal Plain and correlation with microfossil biostratigraphy was revised by Larina et al. (2016) based on comparison with the well-studied record in the Atlantic Coastal Plain (Landman et al., 2004a; 2004b; 2007a). These studies recognized three upper Maastrichtian ammonite zones, from oldest to youngest, *Discoscaphites conradi*, *Discoscaphites minardi*, and *Discoscaphites iris*. Each zone is described as an interval zone in which the lower boundary is defined by the lowest occurrence of the index species and the upper boundary is defined by the lowest occurrence of the index species in the succeeding zone. Each zone also contains a distinctive assemblage of dinoflagellates and calcareous nannofossils (fig. 4).

The *Discoscaphites iris* Range Zone (Landman et al., 2004a; 2004b) is the highest ammonite zone in North America, and is characterized in the Atlantic Coastal Plain and eastern Gulf Coastal Plain by the cooccurrence of the index ammonite with (1) the calcareous nannofossil *Micula prinsii* Perch-Nielsen, 1979—the marker of the uppermost Maastrichtian Subzone CC26b in the scheme of Perch-Nielsen et al. (1985) or UC20d<sup>TP</sup> in the Tethyan scheme of Burnett (1998)—and (2) the dinoflagellates *Palynodinium grillator* Gocht, 1970, *Disphaerogena carposphaeropsis* Wetzel, 1933, and *Thalassiphora pelagica* (Eisenack, 1954) Eisenack and Gocht, 1960 (fig. 3; Landman et al., 2004a; 2004b; Larina et al., 2016). To better constrain the biostratigraphy and age of the cephalopod fauna below and above the K-Pg boundary at Brazos, we investigated the calcareous nannofossils from bulk sediment samples associated with macrofossils. We then compared these data with existing records of nannofossils, dinoflagellates, and planktonic foraminifera from outcrops and cores (fig. 4; Jiang and Gartner, 1986; Schulte et al., 2006; Abramovich et al., 2011; Tantawy et al., 2011; Aydin, 2013). Several important latest Maastrichtian biohorizons are identified at Brazos, although precise long-distance correlation is challenging as many planktonic foraminifera and calcareous nannofossil taxa show marked diachroneity in their first (FA) and last (LA) appearance datums and variation in morphology across different latitudes and different environmental settings (deep versus shallow water) during the Maastrichtian (Hart et al., 2012; Coccioni and Premoli-Silva, 2015; Thibault, 2016, 2018).

**NEW CALCAREOUS NANNOFOSSIL DATA AND COMPARISON WITH PUBLISHED MICROFOSSIL RECORDS:** For calcareous nannofossil biostratigraphy, the CC zonation of Sissingh (1977) modified by Perch-Nielsen (1985) is applied here. All outcrop samples examined from below the

K-Pg boundary at AMNH locs. 3620, 3621, and 3968 contained nannofossil taxa indicative of the upper Maastrichtian Subzone CC26 (e.g., *Micula murus* (Martini, 1961), *Nephrolithus frequens* Górká, 1957). *Micula prinsii*, the marker fossil of Subzone CC26b, occurs ~1 m below the K-Pg boundary at AMNH loc. 3620. This taxon has also been reported from below the K-Pg boundary in the interval above and below the volcanic ash horizon at AMNH loc. 3621 by Tantawy et al. (2011), consistent with preliminary U-Pb ages for the ash (Hart et al., 2012). Jiang and Gartner (1986) studied the calcareous nannofossil succession within an 18 m succession of the Corsicana Formation on the main Brazos Riverbed south of the Rt. 413 bridge (Brazos-1). They recorded rare *M. prinsii* from their stratigraphically lowest sample, ~18 m below the K-Pg boundary. There remains some disagreement about the age of the base of this subzone as the first appearance of *M. prinsii* appears to be diachronous (Thibault, 2018; Lees et al., 2018), but an age no older than 600 kyr prior to the K-Pg boundary characterizes most successions that contain this marker (see review in Thibault, 2018). In many sections around the globe, the first appearance of *M. prinsii* is either within the upper part of magnetochron C30N or close to the base of overlying chron C29R, around 350 kyr prior to the K-Pg boundary (Thibault and Husson, 2016; Thibault, 2018). The single sample from above the K-Pg event deposit at DMC-E contains *Markalius inversus* (Deflandre, in Deflandre and Fert, 1954) and frequent *Braarudosphaera bigelowii* (Gran and Braarud) Deflandre, 1947, suggesting correlation to lower Danian Zone NP1 or the *Markalius inversus* Zone of Martini (1971). This same zone has been recognized in the interval above the K-Pg event deposit at AMNH loc. 3621 by Tantawy et al. (2011), and in several Brazos cores by Schulte et al. (2006). Leighton et al. (2017) suggested the NP1-2 boundary occurs at the base of a distinctive marker horizon referred to as the Dirty Sandstone Bed (DSB) ~2.8 m above the K-Pg event deposit at AMNH loc. 3968.

Comparison with the record from dinoflagellate taxa also suggests an expanded latest Maastrichtian section in the Brazos River area. Aydin (2013) studied the record of dinoflagellates from a section of the Corsicana Formation close to that sampled by Jiang and Gartner (1986) (Brazos-1), as well as the basal Kincaid Formation at AMNH loc. 3968. She reported the FA of *Palynodinium grillator*, *Thalassiphora pelagica*, and *Disphaerogena carposphaeropsis* in two samples ~31 and ~30 m below the K-Pg boundary. Published data from the eastern Gulf Coastal Plain (e.g., Firth, 1987; Edwards et al., 1999) indicate that these taxa are good markers for the latest Maastrichtian. Similar marker taxa for the early Danian (e.g., *Carpatella cornuta* Grigorovich, 1969, *Damassadinium californicum* (Drugg, 1967)) occur in the 2 m of Kincaid Formation outcropping above the K-Pg event deposit at AMNH loc. 3968.

Planktonic foraminifera are also abundant at Brazos (Abramovich et al., 2011; Hart et al., 2012; Leighton et al., 2017). The uppermost Corsicana Formation in all the outcrop sections and cores Mullinax-1–3 contains the latest Maastrichtian marker taxon *Plummerita hantkeninoides* (Brönnimann, 1952) (Abramovich et al., 2011; Hart et al., 2012; Leighton et al., 2017). This is indicative of the *P. hantkeninoides* Zone or CF1 in the scheme of Li and Keller (1998), which is apparently ~3 m thick at Brazos. This zone is well defined globally in Maastrichtian shallow and deep-water successions (Keller et al., 2008; Coccioni and Premoli-Silva, 2015; Thibault et al., 2016; Razmjooei et al., 2018). The LA of *Gansserina gansseri* (Bolli, 1951) and

the FA of *Pseudoguembelina hariaensis* Nederbragt, 1991, occur 7.3 m and ~18 m, respectively below the K-Pg boundary in core Mullinax-1 defining the base of zones CF2 and CF3, respectively. Like *M. prinsii*, these are well-dated biohorizons in many shallow marine successions. The base of CF2 is late Maastrichtian in age and correlates close to the base of magnetostratigraphic C29R or the upper portion of chron C30N. The base of CF3 is often less well defined but occurs well within magnetostratigraphic C30N (Li and Keller, 1998; Coccioni and Premoli-Silva, 2015). Above the K-Pg event deposit, early Paleocene foraminiferal zones P0, P $\alpha$ , and P1a-b have all been recognized in the Kincaid Formation at Brazos (Abramovich et al., 2011; Schulte et al., 2006; Hart et al., 2012; Leighton et al., 2017) based on the biostratigraphic scheme of Berggren and Pearson (2005). The sequence of foraminifera FAs in the P0 biozone at Brazos is reminiscent of the expanded lowermost Paleocene section at the K-Pg boundary GSSP in El Kef, Tunisia (Molina et al., 2006).

**BIOSTRATIGRAPHIC SUMMARY:** Biostratigraphic analysis confirms correlation of the *Discoscaphites iris* Range Zone within the Corsicana Formation at Brazos with the upper part of calcareous nannofossil Subzone CC26b (Larina et al., 2016), and planktonic foraminiferal zones CF1 (*Plummerita hantkeninoides*), CF2, and possibly the upper part of CF3 (*P. hariaensis*) (Abramovich et al., 2011). Dinoflagellate evidence also confirms overlap with the ranges of *Palynodinium grallator*, *Thalassiphora pelagica*, and *Disphaerogena carposphaeropsis* (fig. 4). These data add to the large body of evidence that the Brazos River sections preserve an expanded and essentially continuous record of biotic change across the K-Pg boundary. The presence of the older *Discoscaphites minardi* ammonite Range Zone could not be confirmed. An investigation of the Mullinax-1 drill core by the present authors led to the identification of a poorly preserved ammonite that we tentatively assigned to *Discoscaphites minardi* Landman et al. 2004b in Mullinax-1 at a depth of 23.33 mbs correlating to planktonic foraminiferal zone CF3. However, in the eastern Gulf and Atlantic Coastal plains, *D. minardi* is also present and especially abundant in the lower part of the *D. iris* range zone (Landman et al., 2004a; 2004b; Larina et al., 2016). Thus, refining the upper Maastrichtian ammonite biozonation in Texas requires additional study. The Corsicana Formation fauna redescribed by Kennedy and Cobban (1993a) from northeast Texas (see also Stephenson, 1941) contains *Discoscaphites conradi* (Morton, 1834) and *Hoploscaphites* (formerly *Jeletzkytes*; see Landman et al., 2010) *nebrascensis* (Owen, 1852), indicating that stratigraphically lower portions of the formation include the older *D. conradi* Range Zone (Landman et al., 2004a; see also Woehr, 2013).

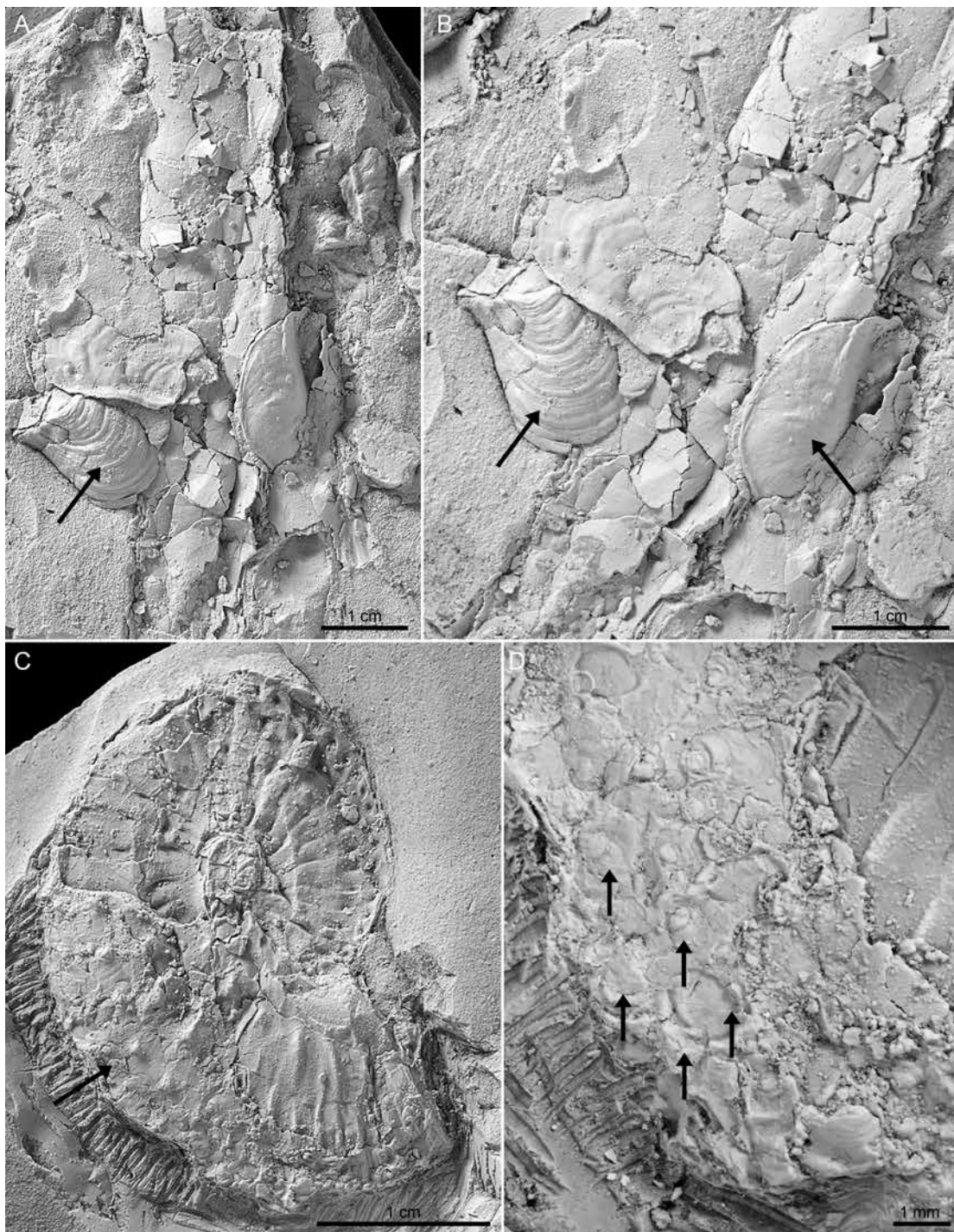
#### AMMONITE-OYSTER ASSOCIATIONS AND AMMONITE PALEOECOLOGY

Ammonites occur abundantly throughout exposures of the Corsicana Formation at all localities we have investigated in the Brazos River area (fig. 3; appendix 1), as previously noted by Hansen et al. (1987) and Kennedy et al. (2001). *Eubaculites* occur in flood abundance in some horizons within the uppermost 1.5 m below the K-Pg boundary at both AMNH locs. 3620 and 3621 (fig. 2E), perhaps indicating an ecological signal such as postspawning mortality (Landman et al., 2007b). The presence of aptychi (jaws) of *Eubaculites* and *Discoscaphites*

(including at least one jaw preserved inside a body chamber) as well as the abundance of juvenile specimens in all studied sections are indicators of a living population not affected by significant postmortem drift. By contrast, the fragmentary nature of specimens of *Sphenodiscus lobatus* could indicate that they floated into the site after death (as suggested by Sessa et al. (2015) for the contemporaneous Owl Creek Formation in Mississippi). Although most specimens are preserved parallel to the bedding plane, the occurrence of several *Discoscaphites* oblique to the bedding plane indicates relatively rapid burial or the presence of soft substrates on the sea floor.

Many specimens of *Eubaculites carinatus* and one specimen of *Discoscaphites iris* are also associated with oysters, which provide clues about the benthic paleoenvironment at Brazos during the latest Maastrichtian (fig. 5). AMNH 112069 is a large fragment of a body chamber of *E. carinatus* 95.2 mm in length, with a maximum whorl height of 16.7 mm. It is surrounded on the dorsal and ventral sides by oysters as much as 17.2 mm long. AMNH 108185 is a specimen of *Discoscaphites* sp. 32.7 mm in diameter. It is encrusted with tiny oysters 1.2 mm in length on the outer flanks of the body chamber. They do not appear on the phragmocone, but the outer wall of the phragmocone is not preserved. Hansen et al. (1987) observed similar ammonite-oyster associations in their study of the Brazos River sites. These occurrences suggest that the waterlogged ammonites settled to the bottom, providing additional evidence for a benthic environment characterized by soft-substrate conditions. They were then encrusted by oysters to form submarine islands as envisioned by Kauffman (1981) for similar ammonite-oyster associations in the Jurassic Posidonia Shale. For further discussion of these communities, see also Taylor and Wilson (2003).

The fauna in the Corsicana Formation of the Brazos River area includes representatives of three of the four widely recognized suborders of post-Triassic ammonoid cephalopods (Lytocerotina, Ammonitina, Ancylocerotina; fig. 6). The absence of the fourth (Phyllocerotina), and rarity of Lytocerotina and Ammonitina common in other Maastrichtian sections, is not surprising. Distribution patterns of latest Cretaceous ammonites indicate that the phylloceratids, lytoceratids, and many ammonitids are common only in deeper-water (> 100–150 m) (Landman et al., 2015), suggesting a strong paleoenvironmental and paleoecological control. The Brazos fauna by contrast conforms to a general pattern exhibited by shallow-water northern hemisphere late Maastrichtian ammonite assemblages, in that it is numerically dominated by individuals belonging to the families Baculitidae (the genus *Eubaculites*) and Scaphitidae (the genus *Discoscaphites*) (e.g., Kennedy, 1993; Jagt, 2002; Machalski, 2005a; 2005b; Landman et al., 2014). Both genera are thought to have been adapted to shallow water depths (Hewitt et al., 1996), and based on facies associations, aptychi morphology, and stable isotope analyses, were probably nektobenthic planktivores (Landman et al., 2012; Sessa et al., 2015). The occurrence of two species of *Sphenodiscus* is another indicator of the relatively shallow depths at Brazos, or the proximity of these environments, as these ammonites are most frequently found in shallow nearshore deposits (Ifrim et al., 2005; Ifrim and Stinnesbeck, 2010). The rare presence of lytoceratids (*Gaudryceras*) and desmoceratids (*Pachydiscus*) does, however, indicate a mixing of taxa from different water depths in the Corsicana Formation, which together with forami-



niferal depth determinations suggest Brazos might occupy a more distal position compared to some other late Maastrichtian shallow-water assemblages from the Gulf and Atlantic Coastal plains of North America (fig. 6).

Combining our data with those of Kennedy et al. (2001), the fauna in the upper Corsicana Formation contains 11 (possibly 12) species in six genera. This makes it the most diverse fauna reported to date from the uppermost Maastrichtian *Discoscaphites iris* Zone in the United States (fig. 6; Landman et al., 2004a, 2004b, 2007a). Despite our large collections of scaphitids we are unable to confirm the occurrence of *Discoscaphites gulosus* in the Corsicana Formation as suggested by Kennedy et al. (2001) based on fragmentary material. This species is characterized by the presence of five rows of tubercles on the flanks and venter, but the crushed nature of the Brazos fossils in many cases precludes an accurate count of the number of tubercle rows to definitively differentiate this taxon from *D. iris*. Similarly, we did not find any examples of *Pachydiscus* (*Pachydiscus*) *jacquoti jacquoti* or *Glyptoxoceras* cf. *rugatum* in collections from the Corsicana Formation, suggesting these taxa are only rarely present. *D. minardi* is also provisionally included in this faunal list following recognition of a poorly preserved example in the Mullinax-1 drill core.

#### RELATION TO THE K-PG BOUNDARY, MASS EXTINCTION, AND RECOVERY

The stratigraphic distribution of the fauna from the Corsicana Formation demonstrates that ammonites are present and abundant in upper Maastrichtian sediments immediately below the K-Pg boundary, as in other North American successions (figs. 2, 3, 6; e.g., Landman et al., 2007a; 2015; Witts et al., 2018). We have observed hundreds of complete and fragmentary ammonite specimens in the uppermost Maastrichtian exposures of the Brazos River sections (see appendix 1 for stratigraphic distributions and abundance of specimens based on AMNH and UNM collections). We also report the occurrence of the genera *Discoscaphites*, *Eubaculites*, and *Sphenodiscus* in the basal two units of the K-Pg event deposit itself (mudstone-clast-bearing unit with rare impact ejecta, and ejecta-spherule-rich coarse sandstone). These examples are interesting because they include the only truly three-dimensional specimens in our collections, suggesting differential preservation compared to the underlying Corsicana Formation. Unlike the specimens studied by Kennedy et al. (2001) from the base of the K-Pg event deposit, they do not all appear to be phosphatized or glauconitized. UNM 15489 (*Sphenodiscus pleurisepta* (Conrad, 1857)) includes original aragonitic shell material and preservation of delicate tubercles on the flanks. Several 3-D specimens (AMNH 111960: *Eubaculites carinatus*; AMNH 111961: *Discoscaphites iris*; and UNM 15493 and 15527: *Eubaculites latecarinatus* (Brunnschweiler, 1966)) are infilled with fine-grained gray micritic matrix quite different from that in the

FIGURE 5. Ammonite-oyster associations, AMNH loc. 3621, Corsicana Formation, up to 1 m below the volcanic ash, Cottonmouth Creek, Falls County, Texas. **A, B.** Oysters associated with a specimen of *Eubaculites carinatus*, AMNH 112069. The oysters are surprisingly large, more than 1 cm in length. **C, D.** Oysters associated with a specimen of *Discoscaphites iris*, AMNH 108185. The oysters are only 1 mm in length and encrust the outer flanks of the shell. They appear only on the body chamber, but the outer shell wall of the phragmocone is missing.

AMNH/USGS LOC. NO.	STATE	TX	AK	MO	3458	3460	3481	3461	3483	3525	3526	USGS R6374	NJ		3335, 3372
													MD	AL	
					Arkadelphia	Owl Creek	Owl Creek	Owl Creek	Prairie Bluff	Prairie Bluff	Prairie Bluff	Severn	New Egypt	Tinton	
<i>Eutrephoceras</i> spp.															
<i>Gaudyceras</i> sp.															
<i>Pachydiscus</i> ( <i>P.</i> ) <i>jacquoti jacquoti</i>															
<i>Pachydiscus</i> ( <i>N.</i> ) <i>mokotibensis</i>															
<i>Sphenodiscus pleurisepta</i>															
<i>Sphenodiscus lobatus</i>															
<i>Sphenodiscus</i> sp.															
<i>Glyptoxoceras</i> c.f. <i>rugatum</i>															
<i>Baculites</i> spp.															
<i>Eubaculites carinatus</i>															
<i>Eubaculites latecarinatus</i>															
<i>Discoscaphites iris</i>															
<i>Discoscaphites sphaeroidalis</i>															
<i>Discoscaphites gulosus</i>															
<i>Discoscaphites minardi</i>															
<i>Discoscaphites jerseyensis</i>															
<i>Discoscaphites mullinaxorum</i>															
<i>Trachyscaphites alabamensis</i>															

FIGURE 6. Occurrences and spatial distribution of cephalopod taxa reported from the upper Maastrichtian *Discoscaphites iris* range zone in the Atlantic and Gulf Coastal Plains of the United States (AK= Arkansas; AL = Alabama; MD = Maryland; MO = Missouri; MS = Mississippi; NJ = New Jersey; TX = Texas). Localities arranged on a general north-south transect from right to left. The ? next to *D. gulosus* from Texas reflects that we have not recognized this taxon in our extant collection of *Discoscaphites* from Brazos. *Discoscaphites minardi* is tentatively listed as occurring at Brazos (dashed line) after discovery of a poorly preserved specimen in the Mullinax-1 drill core. Similarly, *Eubaculites latecarinatus* is not found in the Corsicana Formation in our collections, but several specimens are found in the basal units of the K-Pg event deposit suggesting it inhabited this area during the late Maastrichtian. Data derived from a survey of AMNH Invertebrate Paleontology Collections, UNM Paleontology Collections (Landman et al., 2004a; 2004b; 2007; Larina et al., 2016; Witts et al., 2018; and this study).



underlying Corsicana Formation, and no original aragonitic shell material present. These specimens may represent allochthonous clasts.

Ammonites have been described from numerous other clastic K-Pg ejecta-bearing deposits around the Gulf of Mexico, but interpretation of these records has varied. Lawton et al. (2005) reported ammonites within a sequence of channelized ejecta-bearing sandstones coincident with the K-Pg boundary in the offshore La Popa basin in Mexico. They noted that fossils in these sandstones were filled with micrite or calcareous siltstone, suggesting exhumation and basinward reworking from fine-grained substrates by a tsunami backflow generated by the Chicxulub impact. Stinnesbeck et al. (2017) discovered specimens of *Sphenodiscus* within similar ejecta-bearing sandstone units in the Las Encinas Formation, also in Mexico, but interpreted both the ammonites and associated impact ejecta as reworked by sea-level changes as opposed to representing primary deposition. At a site in Union County, Mississippi (AMNH loc. 3481), Witts et al. (2018) reported individuals of *Discoscaphites iris*, *Eubaculites carinatus*, and *Eubaculites latecarinatus* preserved within a 30 cm thick sandstone unit containing well-preserved impact spherules, including hollow specimens of baculitid ammonites with body chambers and phragmocones infilled with impact ejecta and sandstone lithologically identical to the matrix of the rest of this spherule bed. The sedimentology, geochemistry, and stratigraphic disposition of this unit supported the hypothesis that it was deposited rapidly by depositional processes operating in proximal settings in the immediate aftermath of the Chicxulub impact event (e.g., seismically induced debris flows, tsunamis, and large storms) (Sanford et al., 2016; Gulick et al., 2019). The evidence does not favor these deposits representing a lag deposit or forming because of a sea-level lowstand (see also Hart et al., 2013; Savrda, 2018).

Similar dynamic impact-related processes have been invoked to explain the deposition of the two ammonite-bearing units at the base of the Brazos K-Pg event deposit (Yancey, 1996; Yancey and Liu, 2013; Irizarry et al., 2018; Irizarry et al., 2019), suggesting ammonites found in this interval may have been alive at the time of the Chicxulub impact. Despite the reported occurrence of fragments in strata above the K-Pg event deposit, there is currently no definitive evidence for the longer-term survival of any ammonites into the early Paleogene at Brazos. The only specimens we have observed are a few small, worn, and obviously reworked phosphatized fragments of *Eubaculites* in the Middle Sandstone Bed of the Kincaid Formation (fig. 3). This is unlike other sites in the Atlantic Coastal Plain, and northern Europe where a few widespread genera may have briefly survived into the Danian (Machalski and Heinberg, 2005; Landman et al., 2014; Vellekoop et al., 2020).

The first report of the nautilid genus *Eutrephoceras* from the Paleocene (Danian) of the Brazos River area suggests this taxon inhabited this region in the aftermath of the K-Pg mass extinction. The single poorly preserved specimen found in the Middle Sandstone Bed correlates to calcareous nannofossil zone NP1 and planktonic foraminiferal zone P $\alpha$ , <300 kyr after the Chicxulub impact event (figs. 3, 4). The absence of nautilids from the Corsicana Formation conforms to a regional pattern, as they are generally rare in the latest Maastrichtian sections of the Gulf Coastal Plain (fig. 6). For instance, in extensive AMNH and UNM collections from the type locality of the richly fossiliferous Owl Creek Forma-

tion in Tippah County, Mississippi (AMNH loc. 3460), only two specimens of *Eutrephoceras* have ever been found compared to hundreds of ammonites and benthic mollusks (Kennedy and Cobban, 2000; Sessa et al., 2015). Although nautilids have been reported from the Kincaid Formation in Texas previously (e.g., the genera *Cimomia* and *Hercoglossa* by Miller, 1947), stratigraphic control on these occurrences is poor. This is therefore the earliest recorded Cenozoic occurrence in the Gulf Coastal Plain, and one of the earliest reports globally of a Cenozoic nautilid cephalopod. Due to the poor preservation of this individual, further refinement of the record of nautilid cephalopods in the early Paleogene will require the discovery of additional stratigraphically constrained specimens from Brazos and elsewhere.

The differential extinction of ammonites vs. nautilids at the K-Pg boundary has been well studied. It is thought that the ammonites were susceptible to extinction due to their small embryonic size and planktonic mode of life after hatching, coupled with potentially higher metabolic rates and a reliance on plankton as a food source (Kruta et al., 2011). Nautilids with their large benthic hatchlings, lower metabolism, and longer embryonic stage were able to weather the storm of environmentally deleterious conditions (particularly in surface waters) following the Chicxulub impact event (Sheehan and Hansen, 1986; Henehan et al., 2019; Tajika et al., 2020). The small geographic range of many ammonite species, compared with the large range of cooccurring nautilids, may also have been an important factor (Landman et al., 2014).

The compilation of cephalopod occurrence data from numerous sites belonging to the *Discoscaphites iris* Range Zone in the Atlantic and Gulf Coastal plains (fig. 6) represents a single time slice just prior to the K-Pg mass extinction, and can be read as a record of the health of the group during the latest part of the Cretaceous in this region (see Koch, 1996 for similar data from benthic mollusks). Taken together with these new data from the Brazos River successions, the compilation adds to growing evidence that there was no significant diminution in diversity and certainly not in the abundance of ammonites during the latest Maastrichtian. While survival into the early Paleogene and delayed extinction is possible for some ammonite taxa with wide geographic ranges (e.g., Machalski and Heinberg, 2005; Landman et al., 2014), a sudden mass extinction event at the K-Pg boundary related to the Chicxulub impact remains the leading hypothesis for the worldwide disappearance of the group, rather than a gradual deterioration driven by other factors such as volcanism, or longer-term climatic or sea level changes.

#### REPOSITORIES

The repository of each specimen described in the text is indicated by a prefix, as follows: AMNH, Division of Paleontology (Invertebrates), American Museum of Natural History, New York; ANSP, the Academy of Natural Sciences of Philadelphia; and UNM, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico.

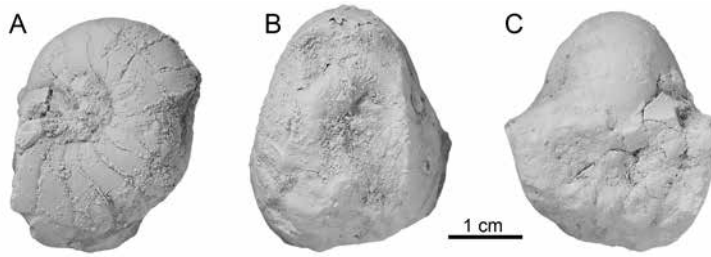


FIGURE 7. *Eutrephoceras* sp., UNM 15495, Middle Sandstone Bed, AMNH loc. 3620, basal part of the Paleogene (Danian), Kincaid Formation, Falls County, Texas. A, left lateral; B, ventral; C, apertural.

### SYSTEMATIC PALEONTOLOGY

Subclass Nautiloidea Agassiz, 1847

Order NAUTILIDA Agassiz, 1847

Superfamily Nautilitaceae de Blainville, 1825

Family Eutrephoceratidae Miller, 1951

*Eutrephoceras* Hyatt, 1894

TYPE SPECIES: *Nautilus Dekayi* Morton, 1834: 291, pl. 8, fig. 4, by original designation by Hyatt, 1894: 555.

*Eutrephoceras* sp.

Figure 7

**MATERIAL:** One small phragmocone UNM 15495 from the Middle Sandstone Bed (Yancey, 1996; Hart et al., 2012), Kincaid Formation (Littig Member), from an outcrop just west of a culvert upstream of the waterfall section at AMNH loc. 3620.

**DESCRIPTION:** The specimen is a wholly septate steinkern 31.6 mm in diameter with a whorl height of 26.5 mm at the adoral end. The septa are closely spaced with 13 septa in the last whorl. The specimen bears traces of another whorl.

**REMARKS:** The holotype of *Eutrephoceras dekayi* ANSP 19484 is the original of Morton (1834: pl. 8, fig. 4), from the “marls of Monmouth and Burlington counties, New Jersey,” by subsequent designation by Whitfield (1892: 243, pl. 37, figs. 2, 3) and is illustrated by Landman et al. (2004a: 41, figs. 17–21). This species was more fully documented by Landman et al. (2017) who relied on conspecific material from the U.S. Western Interior, as Hyatt (1894) had done previously. They concluded that the species is early Maastrichtian, suggesting that younger forms (e.g., late Maastrichtian) should be carefully scrutinized to determine whether they conform to the description of this species. The present specimen is assigned to *Eutrephoceras* based on its size, shape, and suture pattern. However, because it is only a fragment of a phragmocone, it cannot be identified to species level.

**OCCURRENCE:** This genus is worldwide and is reported from the Campanian to the Eocene. In Texas, it has been reported from the Upper Cretaceous (Campanian-Maastrichtian) Navarro Group of Hunt, Navarro, and Kaufman counties (Emerson et al., 1994), and the Eocene Cook Mountain Formation of Leon County (Miller, 1947). To our knowledge, UNM 15495 is the only reported specimen of *Eutrephoceras* from the Brazos River localities.

Order AMMONOIDEA Zittel, 1884

Suborder LYTOCERATINA Hyatt, 1889

Superfamily TETRAGONITOIDEA Hyatt, 1900

Family GAUDRYCERATIDAE Spath, 1927

*Gaudryceras* de Grossouvre, 1894

**TYPE SPECIES:** *Ammonites mitis* Hauer, 1866: 305, pl. 2, figs. 3, 4, by subsequent designation by Boule et al., 1906: 183 (11).

*Gaudryceras* sp.

Figure 8

**MATERIAL:** One small specimen AMNH 111956 from the Corsicana Formation 1 m below the K-Pg boundary at AMNH loc. 3620 (Darting Minnow Creek).

**DESCRIPTION:** Diameter of the specimen is 15.6 mm. It is entirely septate and mostly covered with shell (fig. 2F), with a tiny bit of suture exposed. It is serpenticonic with UD = 8.9 mm. The rate of whorl expansion is low. The ornament consists of thin lirae that are convex on the umbilical wall and shoulder and straight and prorsiradiate on the middle and outer flanks. They cross the venter with a slight adoral projection.

**REMARKS:** Because of the small size of this specimen, it is impossible to identify it to the species level (R. Hoffmann and Y. Shigeta, personal commun., 2019). However, it is the only specimen of *Gaudryceras* ever found at Brazos and one of only a handful of lytoceratid ammonite specimens described from the Maastrichtian of North America (Cobban and Kennedy, 1995; Kennedy et al., 2000).

**OCCURRENCE:** *Gaudryceras* is worldwide in its distribution and is reported from the Maastrichtian of Tunisia, Zululand, and Pondoland, South Africa (Klinger and Kennedy, 1979), Madagascar, south India, Japan, western Australia, California, Chile, and the Antarctic Peninsula. The closest occurrences of this genus to the Brazos River locality are in the lower Campanian of Travis County, Texas (Young, 1963), the lower upper Maastrichtian Corsicana Formation near San Antonio, Bexar County, Texas (Woehr, 2013), the upper Campanian Saratoga Chalk of Arkansas (Kennedy and Cobban, 1993b), and the Maastrichtian Méndez Formation of northeastern Mexico (Ifrim et al., 2004).

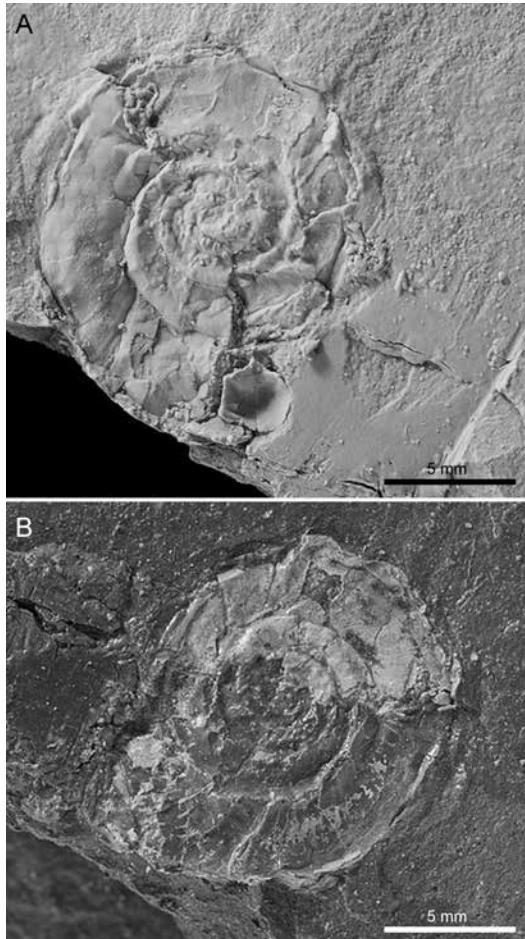


FIGURE 8. *Gaudryceras* sp., AMNH 111956, AMNH loc. 3620, Corsicana Formation, 1 m below the K-Pg boundary, Darting Minnow Creek, Falls County, Texas. **A**, **B**. Part and counterpart.

Suborder AMMONITINA Hyatt, 1889

Superfamily ACANTHOCERATOIDEA de Grossouvre, 1894

Family SPHENODISCIDAE Hyatt, 1900

Genus *Sphenodiscus* Meek, 1871

TYPE SPECIES: *Ammonites lenticularis* Owen, 1852: 579 (*non* Young and Bird, 1828: 269, fig. 5), by original designation, = *Ammonites lobata* Tuomey, 1856: 168.

*Sphenodiscus lobatus* (Tuomey, 1856)

## Figure 9A

*Ammonites lenticularis* Owen, 1852: 579, pl. 8, fig. 5.

*Ammonites lobatus* Tuomey, 1856: 168.

*Sphenodiscus pleurisepta* (Tuomey, 1854). Cobban and Kennedy, 1995: 61, fig. 3a, v.

*Sphenodiscus lobatus* (Tuomey, 1856). Cobban and Kennedy, 1995: 12, figs. 6.2, 6.3, 8.4, 8.6–8.11, 12.18, 12.19, 16.16, 16.17 (with full synonymy).

*Sphenodiscus lobatus* (Tuomey, 1856). Kennedy and Cobban, 1996: 802, fig. 2.4–2.6, 2.13, 2.14, 2.19, 2.21.

*Sphenodiscus lobatus* (Tuomey, 1856). Kennedy et al., 1997: 4, figs. 3–8, 9A–I, 10.

*Sphenodiscus lobatus* (Tuomey, 1856). Landman et al., 2004a: 28, fig. 12.

*Sphenodiscus lobatus* (Tuomey, 1856). Landman et al., 2004b: 51, figs. 23–25.

*Sphenodiscus lobatus* (Tuomey, 1856). Landman et al., 2007a: 58, figs. 26–28.

**TYPE:** The holotype, from Noxubee County, Mississippi, is lost (fide Stephenson, 1941: 434).

**MATERIAL:** Three fragments AMNH 112039, 112070, and 112085, all from the upper 1 m of the Corsicana Formation just below the K-Pg boundary, and one fragment AMNH 135054 from the basal unit (mudstone-clast-bearing conglomerate) of the K-Pg event deposit itself.

**DESCRIPTION:** AMNH 112070 is a fragment of a phragmocone, AMNH 112085 is a fragment of the outer flanks of a body chamber, and AMNH 135054 is a single small chamber with part of the septum. All show the characteristic smooth flanks indicative of this species.

**REMARKS:** In contrast to the preservation of whole scaphites and baculitids, all the specimens of *Sphenodiscus lobatus* in our collection are fragmentary. This suggests that perhaps the shells floated into the area after death and may have lived closer to shore, which is consistent with isotopic evidence from shell samples of this species from the age-equivalent Owl Creek Formation in Mississippi (Sessa et al., 2015).

**OCCURRENCE:** The few fragments are from the top 1 m of the Corsicana Formation (AMNH loc. 3620 and AMNH loc. 3621) and the basal unit of the overlying K-Pg event deposit at AMNH loc. 3620. *Sphenodiscus lobatus* has also been reported from the Corsicana Formation in Navarro County, Texas (Kennedy and Cobban, 1993a; see also Stephenson, 1941, 1955). It occurs in the Escondido Formation in Texas (Böse, 1928) and northern Mexico. Elsewhere in Mexico, it occurs in the Maastrichtian Cerro del Pueblo Formation of the Difunta Group at Rincón Colorado, Coahuila (Ifrim et al., 2004, 2005). On the eastern Gulf Coastal Plain, it occurs in the upper part of the Ripley Formation in Mississippi and the Prairie Bluff Chalk in Alabama and Mississippi (Cobban and Kennedy, 1995). On the Atlantic Coastal Plain, it occurs in the top of the Tinton Formation, the upper part of the Navesink Formation, the lower part of the New Egypt Formation, and as reworked material at the base of the Hornerstown Formation in Monmouth County (Weller, 1907; Reeside, 1962; Gallagher, 1993; Landman et al., 2004a, 2007a) and in the upper part of the Navesink Formation in Gloucester County, New Jersey (Gallagher, 1993; Kennedy et al.,

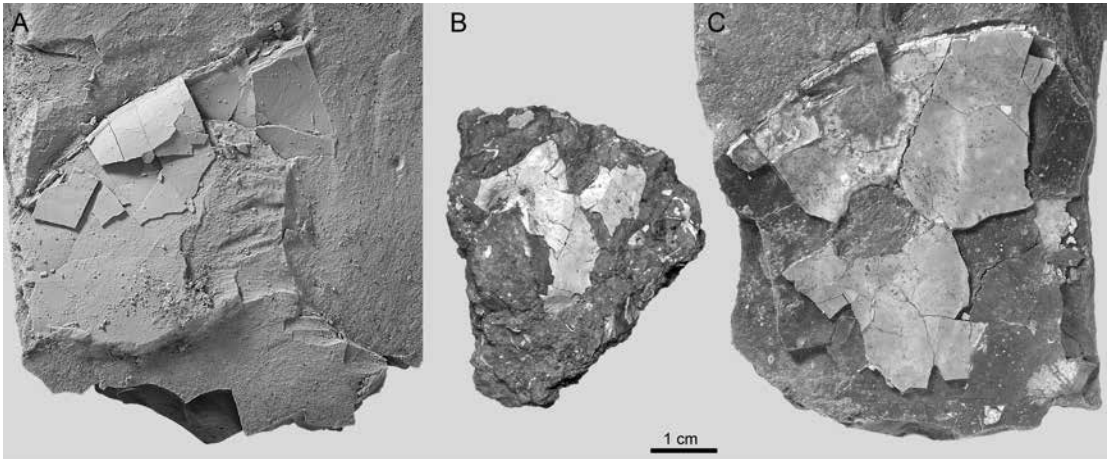


FIGURE 9. A. *Sphenodiscus lobatus* (Toumey, 1856), AMNH 112085, AMNH loc. 3620, Corsicana Formation, Falls County, Texas. B, C. *Sphenodiscus pleurisepta* (Conrad, 1857), AMNH loc. 3620, Falls County, Texas. B. UNM 15489, K-Pg event deposit at the base of the Kincaid Formation. C. AMNH 116378, Corsicana Formation, 1.25 m below the K-Pg boundary.

1995; Kennedy and Cobban, 1996); in the Providence Sand in the Chattahoochee River area, Alabama and Georgia; in the upper part of the Peedee Formation in North Carolina (Landman et al., 2004a); and in the Severn Formation in Prince Georges County, Maryland (Kennedy et al., 1997). In the Western Interior, this species occurs in the *Hoploscaphites nicolletii* and *H. nebrascensis* Zones of the Fox Hills Formation in north-central South Dakota (Landman and Waage, 1993) and in the *H. nebrascensis* Zone of the Pierre Shale in southeastern South Dakota and northeastern Nebraska (Kennedy et al., 1998).

### *Sphenodiscus pleurisepta* (Conrad, 1857)

#### Figure 9B, C

*Ammonites pleurisepta* Conrad, 1857: 159, pl. 15, fig. 1.

*Sphenodiscus lenticularis* (Owen). Kellum, 1962: 68, pl. 4, figs. 3, 4; pl. 5, fig. 1; pl. 6, figs. 1, 2.

*Sphenodiscus pleurisepta* (Conrad, 1857). Cobban and Kennedy, 1993: 58, figs. 1, 3t.

*Sphenodiscus pleurisepta* (Conrad, 1857). Cobban and Kennedy, 1995: 12, fig. 8.5 (with full synonymy).

*Sphenodiscus pleurisepta* (Conrad, 1857). Kennedy et al., 1996: 11, figs. 4A, 5–12.

*Sphenodiscus pleurisepta* (Conrad, 1857). Kennedy et al., 1997: 9, figs. 9J, 11–14.

*Sphenodiscus pleurisepta*. Larson et al., 1997: 91.

*Sphenodiscus pleurisepta* (Conrad, 1857). Landman and Cobban, 2003: 17, figs. 12–15.

**TYPE:** The holotype is USNM 9888, said to be from “Jacun, 3 miles below Laredo,” but is probably from Maverick County, Texas, in the Escondido Formation of the Rio Grande Region (Stephenson, 1941, 1955).

**MATERIAL:** One nearly complete specimen when found, now fragmentary (AMNH 116378), from the Corsicana Formation 1.25 m below the K-Pg boundary at AMNH loc. 3620, Darting Minnow Creek, Falls County, Texas, and one fragmentary specimen (UNM 15489) from the basal unit (mudstone-clast-bearing conglomerate) of the K-Pg event deposit also at AMNH loc. 3620.

**DESCRIPTION:** AMNH 116378 is a specimen with the body chamber preserved, ~12 cm in diameter. The body chamber bears a hole 12.1 mm in diameter. UNM 15489 is a fragment of the umbilical portion of a body chamber. Both show the characteristic rows of nodes on the smooth flanks that distinguish this species from *S. lobatus*.

**REMARKS:** Like *Sphenodiscus lobatus*, *S. pleurisepta* is rare at Brazos, although the presence of a complete specimen suggests that it may not have experienced postmortem floating.

**OCCURRENCE:** The two specimens of *Sphenodiscus pleurisepta* come from the top 1.25 m of the Corsicana Formation and basal ~20 cm of the Kincaid Formation, Falls County, Texas. This species has also been reported from the Corsicana Formation in Navarro County, Texas (Kennedy and Cobban, 1993a; see also Stephenson, 1941, 1955). It occurs in the Escondido Formation in Texas (Böse, 1928) and northern Mexico. It also occurs in the Maastrichtian Cerro del Pueblo Formation of the Difunta Group at Rincón Colorado, Coahuila (Ifrim et al., 2004; Ifrim et al., 2005). On the eastern Gulf Coastal Plain, it occurs in the upper part of the Owl Creek Formation in Missouri, Mississippi, and Tennessee and in the Prairie Bluff Chalk in Alabama and Mississippi (Cobban and Kennedy, 1995). On the Atlantic Coastal Plain, it occurs in the top of the New Egypt Formation and as reworked material at the base of the Hornerstown Formation in Monmouth County, New Jersey (Weller, 1907; Reeside, 1962; Gallagher, 1993; Landman et al., 2004a, 2004b) and in the Severn Formation in Prince Georges and Kent Counties, Maryland (Kennedy et al., 1997). In the Western Interior, this species occurs in the *Hoploscaphites birklundae* Zone of the Pierre Shale in Meade and Pennington counties, South Dakota (Kennedy et al., 1996) and in the upper part of the Pierre Shale and Fox Hills Formation in Weld County, Colorado (Landman and Cobban, 2003).

Despite possible postmortem drift of *Sphenodiscus lobatus* specimens, these new data suggest that both species of sphenodiscid cooccur in the Corsicana Formation of the Brazos River area immediately below the K-Pg boundary. Poorly preserved examples of both *S. lobatus* and *S. pleurisepta* are also found in the basal unit of the K-Pg event deposit itself. As noted above, this is different from the Maastrichtian deposits of the U.S. Western Interior, with *S. pleurisepta* present in the *Hoploscaphites birklundae* Zone, being replaced by *S. lobatus* in the overlying *Hoploscaphites nicolletii* Zone. A similar situation was noted by Ifrim et al. (2005), and Ifrim and Stinnesbeck (2010) in their studies of Maastrichtian ammonite faunas from Mexico. These authors suggested that the two sphenodiscid species may have inhabited slightly different environments, explaining why they are rarely found together in the same outcrop or bed. In the U.S. Gulf Coastal Plain, both species range to the top of the Maastrichtian (Landman et al., 2015), and appear to cooccur at three localities in the *Discoscaphites iris* Range Zone (fig. 6): in the Owl Creek Formation in Mississippi (AMNH loc. 3460) and Missouri (AMNH loc. 3458) (Larina et al., 2016) and the Corsicana Formation at Brazos.



## Suborder ANCYLOCERATINA Wiedmann, 1966

## Superfamily TURRILITOIDEA Gill, 1871

## Family BACULITIDAE Gill, 1871

[= EUBACULITINAE Brunnschweiler, 1966]

Genus *Eubaculites* Spath, 1926

TYPE SPECIES: *Baculites vagina* Forbes var. *ootacodensis* Stoliczka, 1866: 199, pl. 90, figs. 14, ?15, by original designation by Spath, 1926: 80.

*Eubaculites carinatus* (Morton, 1834)

## Figure 10A–J, N–S

*Eubaculites carinatus* (Morton, 1834) figs. 29–35

*Baculites carinatus* Morton, 1834: 44, pl. 13, fig. 1.

*Baculites lyelli* d'Orbigny, 1847: pl. 1, figs. 3–7.

*Baculites tippaensis* Conrad, 1858: 334, pl. 3, fig. 27.

*Baculites spillmani* Conrad, 1858: 335, pl. 35, fig. 24.

*Baculites sheromingensis* Crick, 1924: 139, pl. 9, figs. 1–3.

*Eubaculites lyelli* (d'Orbigny, 1847). Kennedy, 1987: 195, pl. 27, figs. 5–8; pl. 32, figs. 13, 14 (with full synonymy).

*Eubaculites carinatus* (Morton, 1834). Klinger and Kennedy, 1993: 218, text-figs. 7a–e, 21–30, 31a–g, 32–35, 36e, f, 37, 38, 42a, 52g, h.

*Eubaculites carinatus* (Morton, 1834). Kennedy and Cobban, 2000: 180, pl. 2, figs. 1–23, 27, 28; text figs. 3, 4 (with additional synonymy).

*Eubaculites carinatus* (Morton, 1834). Kennedy et al., 2001: 168, fig. 4a, e.

*Eubaculites carinatus* (Morton, 1834). Landman et al., 2004a: 35, fig. 15P, Q.

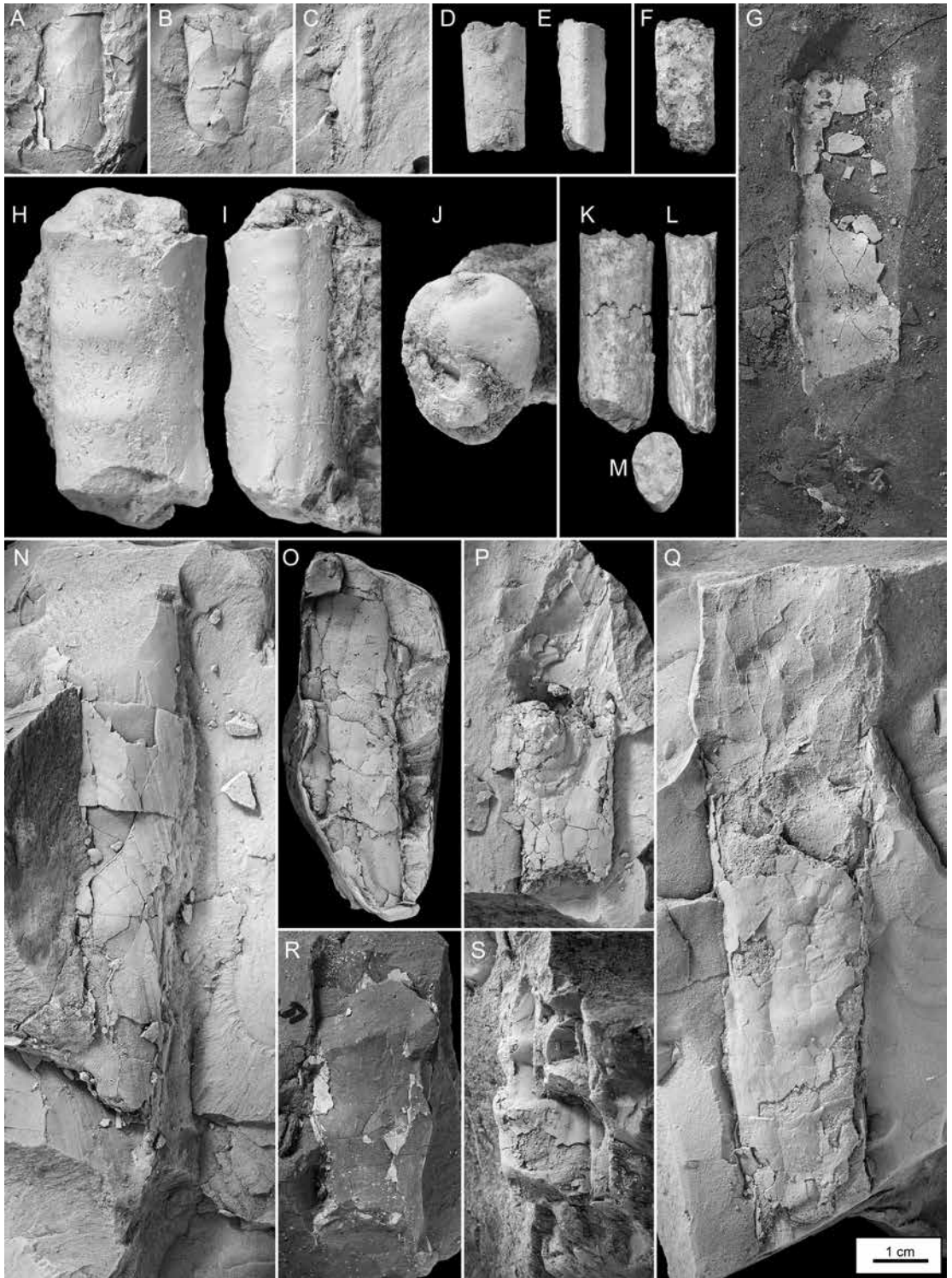
*Eubaculites carinatus* (Morton, 1834). Landman et al., 2004b: 55, figs. 27–29, 30A, B, 33U–Y.

*Eubaculites carinatus* (Morton, 1834). Landman et al., 2007a: 64, figs. 29–35.

TYPE: The holotype, by monotypy, is ANSP 72866, the original of Morton (1834: pl. 13, fig. 1), from the Maastrichtian Prairie Bluff Chalk of Alabama.

MATERIAL: Approximately 40 specimens in the AMNH collections in the top 1 m of the Corsicana Formation at AMNH locs. 3620 and 3621, and as reworked material in the upper portion of the first unit (mudstone-clast-bearing unit) of the overlying K-Pg event deposit at the base of the Kincaid Formation, AMNH loc. 3620.

DESCRIPTION: Nearly all the specimens are crushed but bear weak to strong, slightly crescentic nodate swellings on the flanks. The largest specimen is AMNH 108203, which retains part of the body chamber. The whorl height at the broken end of the body chamber is 30.5 mm, suggesting that it is a macroconch. The only fully three-dimensional specimen is AMNH 111960 from the K-Pg event deposit. It is a fragment 58.0 mm long with a whorl height of 30.0 mm at its adoral end. It is completely septate suggesting that it is probably a macroconch. The



dorsum is very broadly rounded, and the dorsolateral margin is fairly sharply rounded. The inner flanks are broadly rounded with maximum width at one-third whorl height. The outer flanks converge to a tabulate venter bordered by a shallow longitudinal groove on each side. The flanks bear two prominent nodate swellings and the venter is covered with transverse ribs that project slightly forward, producing a serrated appearance.

**REMARKS:** Several specimens from the Corsicana Formation are associated with oysters and represent postmortem encrustations (fig. 5A, B). The whorl height of the largest specimen in our collection (30.5 mm) exceeds that of the largest specimen of this species at the age-equivalent Tinton Formation in Monmouth County, New Jersey (25.4 mm). However, the specimens in the Corsicana Formation do not approach the size of the largest specimens of this species from Argentina and Zululand, which are approximately 90 mm in whorl height (Klinger and Kennedy, 2001: 62). Our collection is too small to confirm the hypothesis of dimorphism in *Eubaculites carinatus*, as suggested by bimodal size distributions of specimens from South Africa and South American localities by Klinger and Kennedy (2001).

**OCCURRENCE:** Top 1 m of the Corsicana Formation at AMNH locs. 3620 and 3621, and basal Kincaid Formation at AMNH loc. 3620. We also found specimens of *Eubaculites carinatus* 17.68–18.29 mbs and 20.12–20.73 mbs in the Mullinax-1 core, correlated to planktonic foraminiferal zone CF3. The species has also been recorded throughout an approximately 11 m succession of the Corsicana Formation at Brazos by Kennedy et al. (2001). This species is widely distributed and, according to Henderson et al. (1992: 153), “is a useful indicator of middle to late Maastrichtian age and represents the last widely distributed heteromorph taxon to appear in the stratigraphic record.” On the eastern Gulf Coastal Plain, it is reported from the Owl Creek Formation in Mississippi, Missouri, and Tennessee (Kennedy and Cobban, 2000) and the Prairie Bluff Chalk in Alabama and Mississippi (Cobban and Kennedy, 1995). On the Atlantic Coastal Plain, it occurs in the Tinton and New Egypt formations, and as reworked material in the Hornerstown Formation in Monmouth and Gloucester counties, New Jersey (Kennedy and Cobban, 1996; Landman et al., 2004b; 2007a) and in the Severn Formation in Prince Georges and Anne Arundel counties, Maryland (Kennedy et al., 1997; Landman et al., 2004). It has also been reported from southeastern and southwestern France, northern Spain, Austria, the Netherlands, Zululand (South Africa), Mozambique, Madagascar, South India, Western Australia, Chile, Argentina, and California (Klinger and Kennedy, 1993; Klinger et al., 2001).

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FIGURE 10. *Eubaculites carinatus* (Morton, 1834) (A–J, N–S) and *E. latecarinatus* (Brunnschweiler, 1966) (K–M). **A, O, Q, S.** AMNH loc. 3621, Falls County, Texas. **B–N, P, R.** AMNH loc. 3620, Falls County, Texas. **A.** AMNH 112072. **B.** AMNH 108198. **C.** AMNH 108195. **D, E.** AMNH 108205, K-Pg event deposit at the base of the Kincaid Formation. **F.** AMNH 112091, K-Pg event deposit at the base of the Kincaid Formation. **G.** AMNH 112101. **H–J.** AMNH 111960, K-Pg event deposit at the base of the Kincaid Formation. **K–M.** UNM 15493, K-Pg event deposit at the base of the Kincaid Formation. **N.** AMNH 108207. **O.** AMNH 112021. **P.** AMNH 108204. **Q.** AMNH 108203. **R.** AMNH 112110. **S.** AMNH 108206.

*Eubaculites latecarinatus* (Brunnschweiler, 1966)

## Figure 10L, M

*Eubaculites otacodensis* (Stoliczka). Spath, 1940: 49 (pars), text-fig. 1c.

*Giralites latecarinatus* Brunnschweiler, 1966: 33, pl. 3, figs. 13, 14; pl. 4, figs. 1–5; text-figs. 17, 18.

*Giralites quadrisulcatus* Brunnschweiler, 1966: 35, pl. 4, figs. 11–14; text-fig. 20.

*Eubaculites ambindensis* Collignon, 1971: 18, pl. 646, fig. 2393.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Klinger, 1976: 91, pl. 40, fig. 1; pl. 41, fig. 3; pl. 42, figs. 2, 6; pl. 43, figs. 3, 4; text-figs. 11d, e.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Klinger and Kennedy in Klinger et al., 1980: 296, figs. 2a–c, 3a–d, 4a–c, 5d.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Henderson et al., 1992: 159, figs. 22L–N, 23N–P.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Klinger and Kennedy, 1993: 238, figs. 26A, 39–41, 42B, C, 43–49, 50A, 53A.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Kennedy et al., 1997: 20, figs. 15A–D, K, L, 16G, H, 19.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Klinger and Kennedy, 2001: 234.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Klinger et al., 2001: 287, pl. 10, figs. 4–9; text fig. 6.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Landman et al., 2004a: 34, figs. 13g–j, 14B.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Landman et al., 2004b: 63, figs. 30C, D, 31, 32.

*Eubaculites latecarinatus* (Brunnschweiler, 1966). Landman et al., 2007a: 72, figs. 36–38.

**TYPE:** The holotype, by original designation, is that of Brunnschweiler (1966: pl. 4, figs. 2–4) from the lower Maastrichtian nodule bed at the top of the Korojong Calcarenite, Carnarvon Basin, Western Australia.

**MATERIAL:** Two poorly preserved specimens (UNM 15493, UNM 15527) from the second unit (ejecta-spherule-rich coarse sandstone) of the K-Pg event deposit at the base of the Kincaid Formation, AMNH loc. 3620, Falls County, Texas.

**DESCRIPTION:** Although poorly preserved, both UNM 15493 and 15527 are three-dimensional. UNM 15493 is a wholly septate fragment 34.6 mm long, with a whorl height of 12.6 and 13.0 mm at the adapical and adoral ends, respectively. UNM 15527 is also a wholly septate fragment 11.3 mm long, with a whorl height of 13.4 and 13.6 mm at the adapical and adoral ends, respectively. Both specimens are smooth with a tabulate venter and lack any signs of ornament.

**REMARKS:** The smooth flanks, tabulate venter, and lack of ornament in both these specimens distinguish them from *E. carinatus*.

**OCCURRENCE:** This species is represented by only two specimens in the K-Pg event deposit at the base of the Kincaid Formation, Falls River, Texas. It is not recorded in the Corsicana Formation. *E. latecarinatus* is reported from several sites in New Jersey: the upper part of the New Egypt Formation and as reworked material at the base of the Hornerstown Formation, near Eatontown, northeastern Monmouth County; the top of the New Egypt Formation in the Crosswicks Creek Basin, southwestern Monmouth County; and the top of the Tinton Formation and as reworked material at the base of the Hornerstown Formation near Freehold, central Monmouth County (summarized in Landman et al., 2007a). It is also known from the Severn Formation, Prince Georges and Kent counties, Maryland (Kennedy et al., 1997; Landman et

al., 2004a). Additional specimens have been identified (but not illustrated) at the type section of the Owl Creek Formation in Tippah County, Mississippi (Landman et al., 2015; Sessa et al., 2015). Klinger and Kennedy (2001) reported this species from the Maastrichtian offshore Alaphard Group of Zululand, South Africa, south India, Madagascar, and Western Australia.

#### Lower jaws of *Eubaculites*

##### Figure 11A–D

**MATERIAL:** Four isolated specimens (AMNH 63310, 108281, 108287, and 135059) from the top 1 m of the Corsicana Formation at AMNH locs. 3620 and 3968.

**DESCRIPTION:** AMNH 63310 is the best-preserved specimen (fig. 11A). It is 18.1 mm long and 6.0 mm wide, yielding a length:width ratio of 3.0. It consists of a single calcitic valve (aptychus) exposed on the dorsal side. It is semilunate in shape with a broadly rounded lateral margin and a more sharply rounded posterior margin. The symphysal edge is straight and bordered by a flange. It is covered with fine lines that parallel the lateral and posterior margins. AMNH 108287 is 6.2 mm long and 2.3 mm wide, yielding a length:width ratio of 2.7. It also consists of a single calcitic valve (aptychus) exposed on the dorsal side. However, it retains traces of the black organic layer on the inside surface of the valve. AMNH 108281 and 135059 are less complete; they consist of single valves (aptychi) with traces of black material.

**REMARKS** Based on comparisons with the lower jaws of baculitid ammonites described in Landman et al. (2007b) and Kruta et al. (2011), these specimens can be attributed to *Eubaculites*.

#### Superfamily SCAPHITOIDEA Gill, 1871

##### Family SCAPHITIDAE Gill, 1871

##### Subfamily SCAPHITINAE Gill, 1871

##### Genus *Discoscaphites* Meek, 1871

**TYPE SPECIES:** *Ammonites conradi* Morton, 1834: 39, pl. 16, fig. 3, by original designation.

##### *Discoscaphites iris* (Conrad, 1858)

##### Figure 12A–N

*Scaphites iris* Conrad, 1858: 335, pl. 35, fig. 23.

*Scaphites iris* Conrad. Whitfield, 1892: 265, pl. 44, figs. 4–7.

*Discoscaphites iris* (Conrad). Stephenson, 1955: 134, pl. 23, figs. 23–30.

*Discoscaphites iris* (Conrad, 1858). Kennedy and Cobban, 2000: 183, fig. 5; pl. 3, figs. 3–35.

*Discoscaphites iris* (Conrad, 1858). Landman et al., 2004a: 39, figs. 15A, B, G–O, 17A–G, 18R.

*Discoscaphites iris* (Conrad, 1858). Landman et al., 2004b: 71, figs. 34E–W (*non* A–D = *Discoscaphites sphaeroidalis* Kennedy and Cobban, 2000), 35, 36A–H, K–Q, S–Z, l–p, 37A–I, 38, 39A–P, 41A–D.

*Discoscaphites iris* (Conrad, 1858). Landman et al., 2007a: 82, figs. 40-46, 47A-C.

*Discoscaphites iris*. Keller et al., 2011: 85, fig. 3E.

*Discoscaphites iris* (Conrad, 1858). Machalski et al., 2009: 375, fig. 2.

*Discoscaphites iris*. Sessa et al., 2015: 15563, fig. 1A-C.

*Discoscaphites iris*. Larina et al., 2016: 132, fig. 2B; 145, fig. 14.1-26

*Discoscaphites iris*. Witts et al., 2018: 150, fig. 2C; 156, fig. 7A-U.

*Discoscaphites iris*. Ferguson et al., 2019: 321.

**TYPE:** The holotype is the original illustrated in Conrad, 1858 (335, pl. 35, fig. 23), labeled ANSP 50989, from the bluffs of Owl Creek, Tippah County, Mississippi. See Landman et al. (2004b) for a more complete description of this specimen.

**MATERIAL:** A total of 27 specimens, mostly consisting of the body chamber or parts of the phragmocone and body chamber, plus numerous fragments, in the AMNH and UNM collections. The specimens are nearly equally divided between 13 microconchs and 14 macroconchs. All the specimens are crushed but retain their original aragonitic shell. The specimens are primarily derived from the top 1.5 m of the Corsicana Formation at AMNH locs. 3620, 3621, and 3968, but two (AMNH 111961 and AMNH 112037) also occur in the first (mudstone-clast-bearing) and second unit (ejecta-spherule-rich coarse sandstone) of the K-Pg event deposit at AMNH loc. 3620. *D. iris* is the most common scaphitid at Brazos, and as such, many of the abundant juvenile scaphitids present in these sections likely belong to this species, but because of their small size, they cannot be identified to the species level.

**MACROCONCH DESCRIPTION:** Although the specimens are crushed, it is possible to measure the maximum length (LMAX). They range from 37.2 to 61.6 mm with most specimens falling between 50 and 55 mm (fig. 13). AMNH 112082 and 108182 are examples of small and large specimens, respectively. The ratio of the size of the largest specimen to that of the smallest is 1.7. Specimens are tightly coiled with a small umbilicus. The body chamber occupies approximately one-half whorl. In passing from the phragmocone to the shaft, the whorl height increases slightly, and then decreases again at the aperture. As in other scaphitid macroconchs, the umbilical shoulder of the body chamber is straight and occasionally shows a slight bulge. The aperture is constricted and the angle of the aperture averages 30°.

The spire is covered by prorsiradiate ribs. They are broad and straight in AMNH 111959 and thin and slightly sinuous in AMNH 108178. Intercalation and branching occur at one-third and two-thirds whorl height. The ribs become broader and more widely spaced toward the adoral part of the spire. Two rows of ventrolateral tubercles are visible on the adapical part of the spire, although the outer row is difficult to discern because of crushing. An additional two rows of tubercles appear on the flanks soon thereafter.

The ornament on the body chamber consists of four rows of tubercles—umbilicolateral, flank, and inner and outer ventrolateral tubercles. The tubercles occur on broad, low convex ribs that

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FIGURE 11. Jaws of *Eubaculites* (A-D) and *Discoscaphites* (E-J). A. AMNH loc. 3968, Corsicana Formation, Falls County, Texas. B-J. AMNH loc. 3620, Corsicana Formation, Falls County, Texas. A. AMNH 63310. B. AMNH 108287. C. AMNH 135059. D. AMNH 108281. E. AMNH 108285. F. AMNH 108179. G. AMNH 108179. H. AMNH 108282. I. AMNH 63312. J. AMNH 63312.



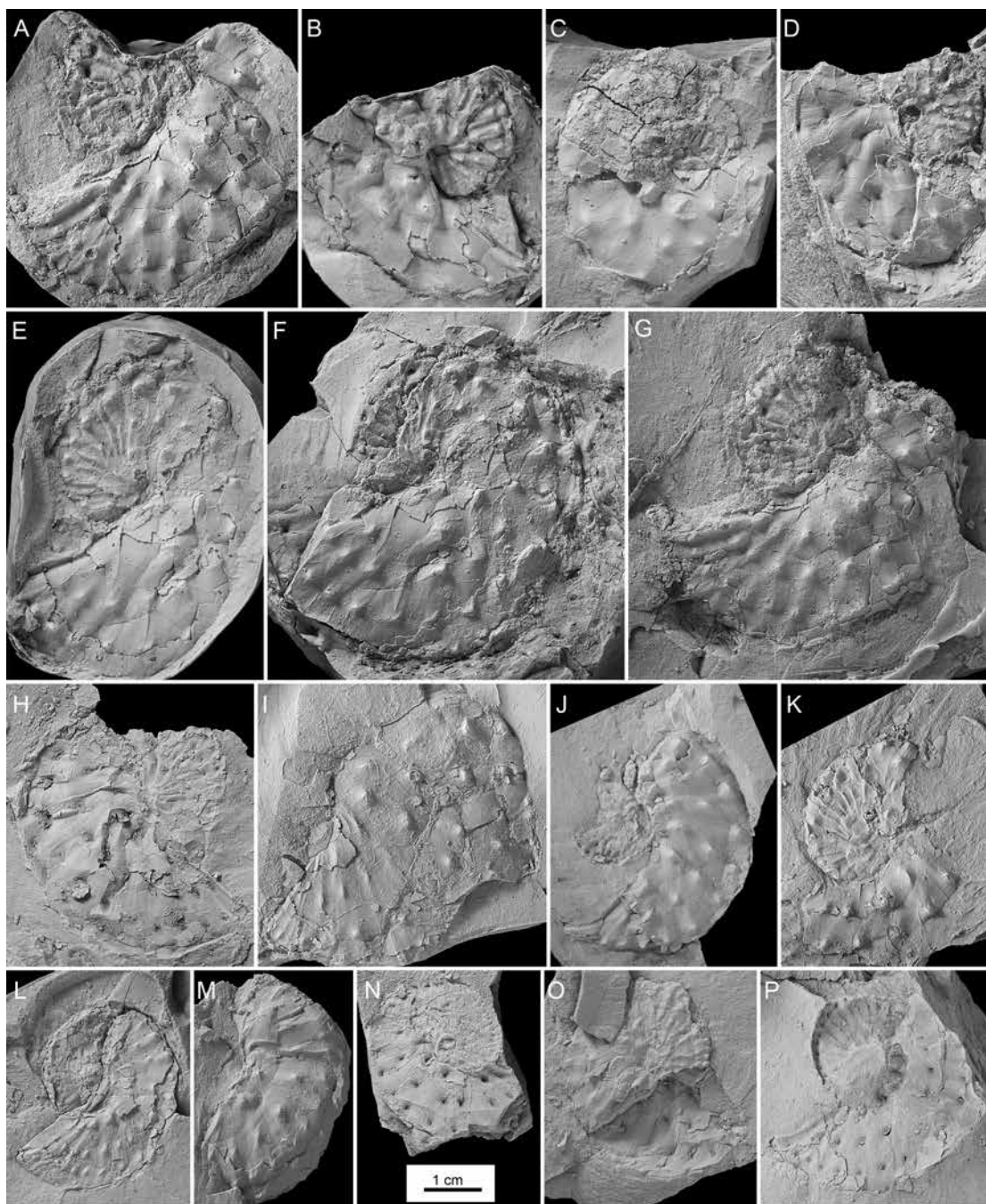


FIGURE 12. *Discoscaphites iris* (Conrad, 1858) (A–N) and *Discoscaphites sphaeroidalis* Kennedy and Cobban, 2000 (O, P), macroconch (A–I) and microconch (J–P). A, B, D, E, G–M, O, P. AMNH loc. 3620, Corsicana Formation, Falls County, Texas. C, F, N. AMNH loc. 3621, Corsicana Formation, Texas. A. AMNH 111962. B. AMNH 111959. C. AMNH 108177. D. AMNH 112075. E. AMNH 108175. F. AMNH 108188. G. AMNH 108178. H. AMNH 116348. I. AMNH 116346. J. AMNH 111963. K. AMNH 116351. L. AMNH 116347. M. AMNH 112038. N. AMNH 108186. O. AMNH 111957. P. AMNH 116345.



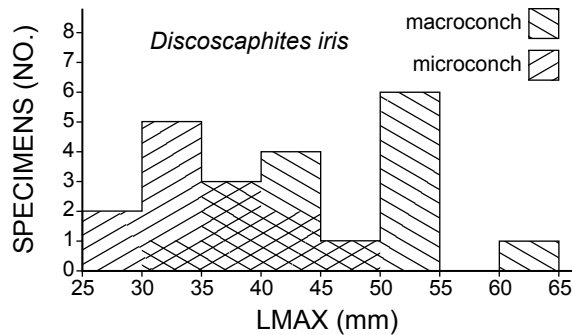


FIGURE 13. Measurements of specimens of *Discoscaphites iris* from the top of the Corsicana Formation, Falls County, Texas.

become more prominent on the hook. All the tubercles end in sharp points. The most prominent tubercles are the two umbilicolateral tubercles on the midshaft just below the umbilical margin (e.g., AMNH 198178). The flank tubercles are slightly smaller than the umbilicolateral tubercles and occur midway between the umbilicolateral and inner ventrolateral tubercles.

**MICROCONCH DESCRIPTION:** Microconchs are, on average, smaller than macroconchs. Microconchs range in LMAX from 25.1 to 42.6 mm with most specimens falling between 30 and 35 mm (fig. 13). AMNH 111963 (fig. 10J) and 108186 (fig. 10N) are examples of small and large specimens, respectively. The ratio of the size of the largest specimen to that of the smallest is 1.7. In passing from the spire into the body chamber, the whorl height increases slightly. As a result, the umbilical seam follows the curvature of the venter. The body chamber is slightly uncoiled and occupies approximately one-half whorl.

The ornamentation on the phragmocone consists of thin, slightly flexuous prorsiradiate ribs and two rows of ventrolateral tubercles. The prorsiradiate ribs on the body chamber are more poorly defined. They bear four rows of tubercles, of which the umbilicolateral tubercles are the most prominent. They are perched on the umbilical shoulder and attain their greatest height just adoral of midshaft.

**REMARKS:** In comparison to specimens of *Discoscaphites iris* from New Jersey and the eastern Gulf Coastal Plain, the specimens from the Brazos River localities are larger (fig. 13). For example, LMAX of the largest macroconch from the Brazos River locality is 61.6 mm whereas it is 54.2 mm from New Jersey (Landman et al., 2007a). In contrast, the specimen from Libya is still larger, with an estimated diameter of 80 mm (Machalski et al., 2009). At least one specimen associated with oysters represents postmortem encrustations (fig. 5C, D).

**OCCURRENCE:** This species is known from the upper part of the Corsicana Formation and the base of the Kincaid Formation along the Brazos River and its tributaries in Falls County, Texas. It has also been reported in the Mullinax-1 and Mullinax-3 cores from the Corsicana Formation in the same area (Keller et al., 2011). Elsewhere on the Gulf Coastal Plain, it occurs in the Owl Creek Formation in Mississippi, Tennessee, and Missouri (Stephenson, 1955; Sohl, 1960, 1964; Kennedy and Cobban, 2000). On the Atlantic Coastal Plain, it occurs in the upper part of the Tinton Formation and as reworked material at the base of the Hornerstown Formation, central Monmouth County; the upper part of the New Egypt Formation and as reworked

material at the base of the Hornerstown Formation in northeastern and southwestern Monmouth County (Landman et al., 2007a); and the upper part of the Severn Formation in Kent and Anne Arundel counties, Maryland (Landman et al. 2004a). It is the name bearer of the *Discoscaphites iris* Zone in the Gulf and Atlantic Coastal Plains, where it represents the upper part of the upper Maastrichtian, corresponding to the upper part of calcareous nannofossil Subzone CC26b (Landman et al., 2004a; 2004b; 2007a; Larina et al., 2016). This species has also been reported from the upper Maastrichtian of northwest Libya (Machalski et al., 2009).

*Discoscaphites sphaeroidalis* Kennedy and Cobban, 2000

Figure 12O, P

*Discoscaphites* sp. Stephenson, 1955: 135, pl. 23, figs. 20–22.

*Discoscaphites sphaeroidalis* Kennedy and Cobban, 2000: 185, pl. 1, figs. 1–11, text-fig. 6

*Discoscaphites sphaeroidalis* Kennedy and Cobban, 2000. Kennedy et al., 2001: 169, fig. 4b, c.

*Discoscaphites iris* (Conrad, 1858). Landman et al., 2004b: 71, fig. 34A–D.

*Discoscaphites sphaeroidalis* Kennedy and Cobban, 2000. Landman et al., 2007a: 92, figs. 47D, 48.

**TYPE:** The holotype is USNM 465615, a macroconch missing part of the hook. It is from the Owl Creek Formation at its type locality, 4 km northeast of Ripley, Tippah County, Mississippi.

**MATERIAL:** The material from Brazos consists of six specimens, three of which are identifiable as adult microconchs (AMNH 108185, 111957, and 116345) and three of which are fragments of adult microconchs (AMNH 108174, 108184, and 133094) from the top of the Corsicana Formation in Darting Minnow and Cottonmouth creeks (AMNH locs. 3620 and 3621), Falls County, Texas.

**MICROCONCH DESCRIPTION:** The three nearly complete specimens range in size from 31.6 to 36.1 mm. The phragmocone extends slightly below the line of maximum length and the body chamber occupies approximately one-half whorl. As shown in AMNH 116345 (fig. 12P), the aperture is constricted with a weak ventral projection.

The ornamentation on the phragmocone is well preserved in AMNH 11957 (fig. 12O). The ribs are narrow, long, and uniformly spaced. They bear four rows of tubercles, of which the inner ventrolateral row is the most prominent. The ribs on the body chamber are weaker, but the tubercles are stronger than those on the phragmocone. The tubercles are widely spaced on the shaft and more closely spaced on the hook. Both rows of ventrolateral tubercles extend to the aperture.

**REMARKS:** Because these specimens are crushed, no information is available about the shape of the whorl section, which is important for identifying this species and distinguishing it from *Discoscaphites iris*. However, the ornamentation on the phragmocone is well preserved and consists of narrow, long ribs, one of the defining features of this species. It is curious that our collection consists only of microconchs whereas other collections of this species contain both dimorphs (Kennedy and Cobban, 2000; Kennedy et al., 2001; Landman et al., 2007a). If macroconchs were present, they would be easily recognizable. Their absence is probably due to the small size of the collection.

**OCCURRENCE:** This species is known from the upper part of the Corsicana Formation along the Brazos River and its tributaries in Falls County, Texas. Kennedy et al. (2001) reported it as occurring throughout the top ~8 m of the Corsicana Formation. Elsewhere on the Gulf Coastal Plain, it occurs in the Owl Creek Formation in Mississippi and Missouri (Stephenson, 1955; Kennedy and Cobban, 2000). On the Atlantic Coastal Plain, it occurs in the upper part of the Tinton Formation and as reworked material at the base of the Hornerstown Formation, central Monmouth County, and in the upper part of the New Egypt Formation and as reworked material at the base of the Hornerstown Formation in northeastern Monmouth County (Landman et al., 2007a).

*Discoscaphites mullinaxorum*, new species

Figure 14

*Discoscaphites iris* Conrad, 1858). Kennedy and Cobban, 2000: pl. 3, fig. 21.

**DIAGNOSIS:** Small, closely coiled shell, with no gap between the phragmocone and body chamber; body chamber covered with thin, sharp, slightly flexuous lirae and four rows of tiny tubercles (umbilicolateral, flank, and two rows of ventrolateral tubercles); umbilicolateral and lateral tubercles are radially elongated.

**ETYMOLOGY:** This species is named after Ronnie and Jackie Mullinax, who have generously granted permission to scores of geologists and paleontologists to explore and collect fossils on their ranch and ensured the preservation of key outcrops for further study. Without their help, the K-Pg sections along the Brazos River would not be as well known worldwide as they are today.

**TYPES:** The holotype is AMNH 112086, a crushed microconch, from AMNH loc. 3620, from the top of the Corsicana Formation, Darting Minnow Creek, Falls County, Texas. The paratypes are AMNH 108188, 111958, and 112024, from the same locality.

**MATERIAL:** A total of 10 specimens, all of which are crushed microconchs, from the top 1.5 m of the Corsicana Formation, AMNH loc. 3620 (Darting Minnow Creek), Falls County, Texas.

**MICROCONCH DESCRIPTION:** LMAX averages 22.4 mm and ranges from 17.5 to 29.1 mm. The shell is closely coiled with a large umbilicus. The body chamber occupies approximately one-half whorl and terminates in a constricted aperture (fig. 14P). The whorl height gradually increases in passing from the phragmocone to the body chamber. The umbilical shoulder of the body chamber follows the curvature of the venter.

The ornament on the phragmocone consists of broad indistinct ribs. The body chamber is covered with thin, sharp, slightly flexuous lirae, especially on the adoral one-half. The lirae become less flexuous, coarser, and more closely spaced near the aperture (fig. 14Q, R).

Four rows of tubercles are present on the adoral one-half of the body chamber (fig. 14A, B, G, H). In the holotype, the umbilicolateral tubercles are bullate and increase in size toward the aperture. They are perched on the umbilical shoulder (fig. 14G, H). The flank tubercles are tiny and radially elongate; they are generally not associated with the lirae. Because of crushing, the outer ventrolateral tubercles are not exposed in the holotype, but all four rows of tubercles

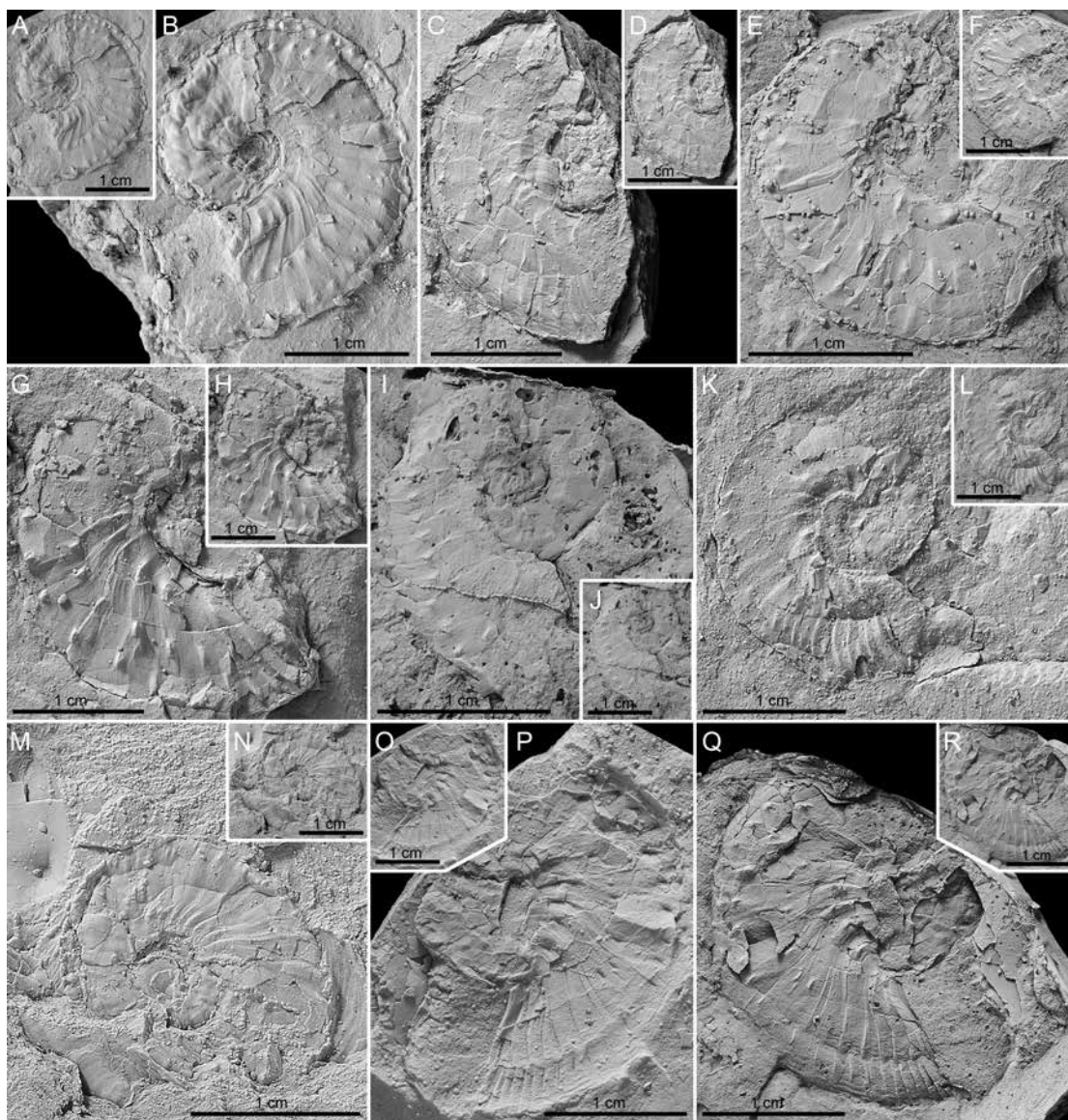


FIGURE 14. *Discoscaphites mullinaxorum* n. sp. A–H, K–P. AMNH loc. 3620, Corsicana Formation, Falls County, Texas. I, J. AMNH loc. 3621, Corsicana Formation, Texas. A, B. AMNH 111958, paratype. C, D. AMNH 112028. E, F. AMNH 112024, paratype. G, H. AMNH 112086, holotype. I, J. AMNH 112097. K, L. AMNH 116358. M, N. AMNH 108171. O, P. AMNH 108188, paratype. Specimens in boxes are  $\times 1$ , others are expanded.

are visible in AMNH 111958 (fig. 14A, B). The number of inner ventrolateral tubercles exceeds the number of flank tubercles.

REMARKS: This species differs from *Discoscaphites iris* in its smaller size, its flatter flanks, and more delicate ornament. In particular, the tubercles in *D. mullinaxorum* are thin and radially elongate, whereas they are conical and pointy in *D. iris*. Although our collection consists only of microconchs, Kennedy and Cobban (2000: pl. 3, fig. 21) illustrated a small macroconch

TABLE 1. Size of juvenile specimens of *Discoscaphites* sp. from AMNH locs. 3620 and 3621.

AMNH No.	AMNH loc.	LMAX (mm)
63319	3620	8.0
63320	3620	4.2
63221	3620	4.0
63322	3620	2.8
63323	3620	3.8
108172	3620	10.2
112030	3620	9.2
112031	3620	5.6
112040	3621	10.2
112056	3621	2.5
112058	3621	9.9
112064	3620	5.5
112066	3620	2.0
112077	3620	4.1
112076	3620	10.4
112079	3621	1.8
112083	3620	1.7
112084	3620	2.1

of this species, which they described as *D. iris*, from the upper part of the Owl Creek Formation in northeastern Mississippi. This macroconch is approximately 1.3× the average size of the microconchs in our collection. *Discoscaphites mullinaxorum* also resembles *D. minardi* Landman et al., 2004a, with its subdued ornament. However, the tubercles on the flanks of the body chamber in *D. mullinaxorum* are thin and radially elongate whereas they are rare or absent in *D. minardi*. In its subdued ornament, *D. mullinaxorum* also resembles *D. conradi*, but there are only four rows of tubercles in *D. mullinaxorum* compared to as many as six rows in *D. conradi*, sometimes even including a midventral row.

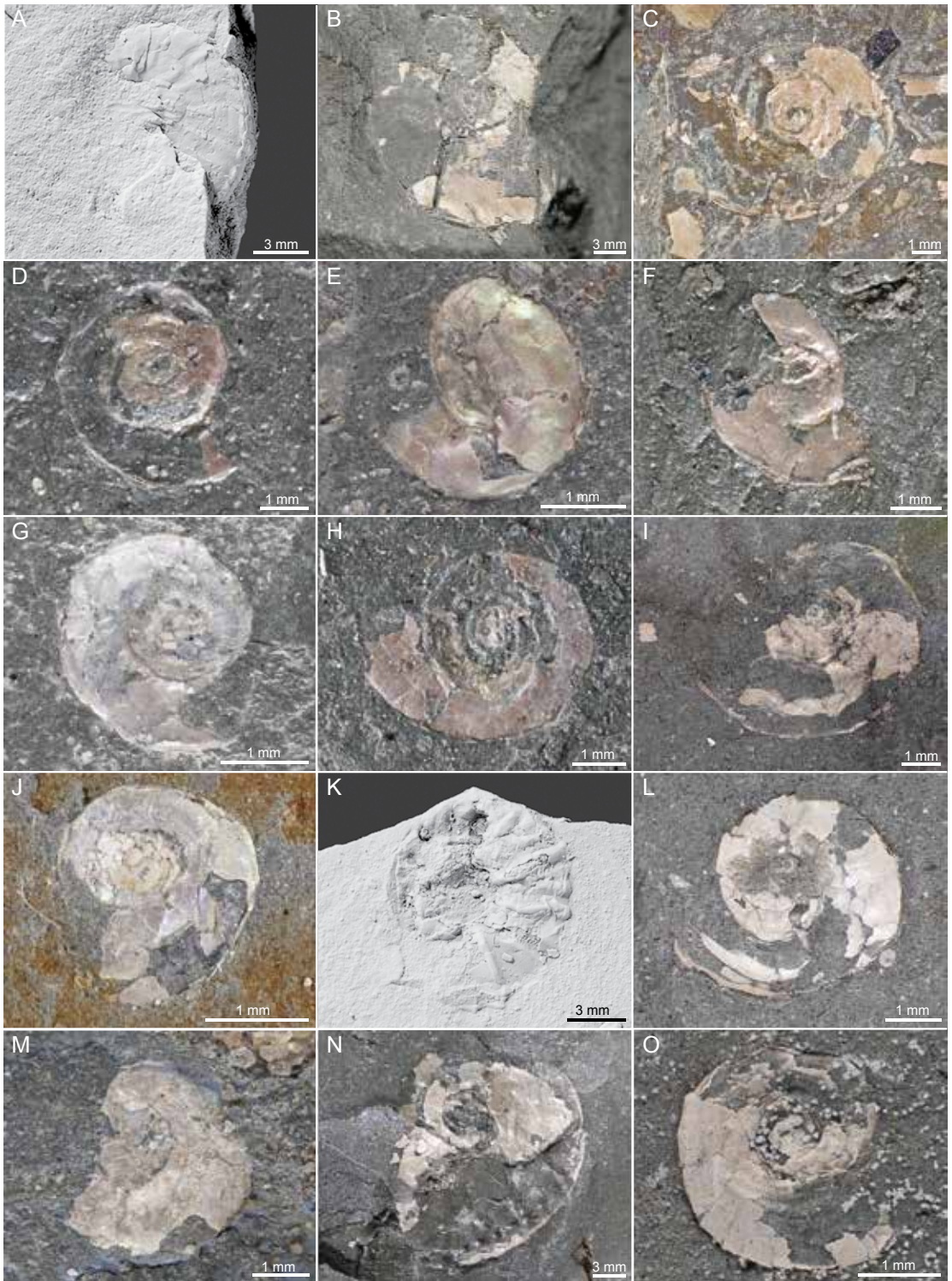
**OCCURRENCE:** This species is rare in the upper part of the Corsicana Formation along the Brazos River and its tributaries in Falls County, Texas. Elsewhere on the Gulf Coastal Plain, it occurs in the Owl Creek Formation in Mississippi (Kennedy and Cobban, 2000).

*Discoscaphites* sp.

Figures 15, 16

**MATERIAL:** All sites we studied at the Brazos River localities yield many small juveniles of *Discoscaphites* (fig. 15). Because of their small size, it is impossible to identify them to a species level.

**DESCRIPTION:** Juvenile specimens range in LMAX from 1.7 to 10.4 mm and retain part or all of their body chamber (fig. 15; table 1) Although the specimens preserve traces of the outer



shell wall, the ornamentation is subdued or absent. Several specimens show exquisite details of the microornamentation of the embryonic shell (ammonitella; fig. 16).

REMARKS: The presence of complete to nearly complete juveniles suggests that the animals lived at the site in which they are buried. All the specimens appear as isolated occurrences except for AMNH 63319, which occurs in a concentration of shell hash along with other juveniles and fish debris.

OCCURRENCE: All specimens are from the upper portion of the Corsicana Formation just below the K-Pg boundary at AMNH locs. 3620 and 3621, Darting Minnow and Cottonmouth creeks, respectively.

### Lower jaws of *Discoscaphites*

#### Figure 11E–J

MATERIAL: Four isolated specimens (AMNH 108284, 108179, 108282, 63317) and one preserved in situ (AMNH 63312) from the top 1.25 m of the Corsicana Formation at AMNH loc. 3620 and AMNH loc. 3621, Darting Minnow and Cottonmouth creeks, Falls County, Texas. The specimens consist of the outer calcareous valve (aptychus), although three of them also retain traces of the inner black layer

DESCRIPTION: Each valve is roughly triangular in outline. The ratio of valve length to valve width ranges from 1.4 to 1.9 in our sample. The symphyasal edge is straight and forms a flange that increases in height posteriorly. The anterior margin is nearly straight, the lateral margin is broadly rounded, and the posterior margin is sharply rounded. The ventral surface of each valve is covered with small folds that parallel the posterior margin.

Most of the jaws are preserved with only one valve exposed. However, in AMNH 63317 the two valves are folded folio style. As a result, the ventral surface of one valve and part of the dorsal surface of the other valve are exposed. AMNH 66312 occurs inside a very poorly preserved specimen of *Discoscaphites iris* surrounded by small oysters. The specimen of *D. iris* is 32.1 mm in maximum length, so that the ratio of LMAX to the length of the jaw is 2.3.

REMARKS: These specimens are similar to the lower jaws of scaphites illustrated from Maastriichtian deposits of South Dakota (Landman and Waage, 1993: figs. 37–41, 167E–I) and northern Europe (Birkelund, 1982: pl. 2, figs. 6, 7; Birkelund, 1993: pl. 17, figs. 2–4; Machalski, 2005b: fig. 26).

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FIGURE 15. Juveniles of *Discoscaphites* sp. A–L. AMNH loc. 3620, Corsicana Formation, Falls County, Texas. M–O. AMNH loc. 3621, Corsicana Formation, Texas. A. AMNH 108172. B. AMNH 112030. C. AMNH 63319. D. AMNH 63321. E. AMNH 112084. F. AMNH 63323. G. AMNH 112083. H. AMNH 63320. I. AMNH 112064. J. AMNH 112066. K. AMNH 112076. L. AMNH 112077. M. AMNH 112056. N. AMNH 112040. O. AMNH 112079.

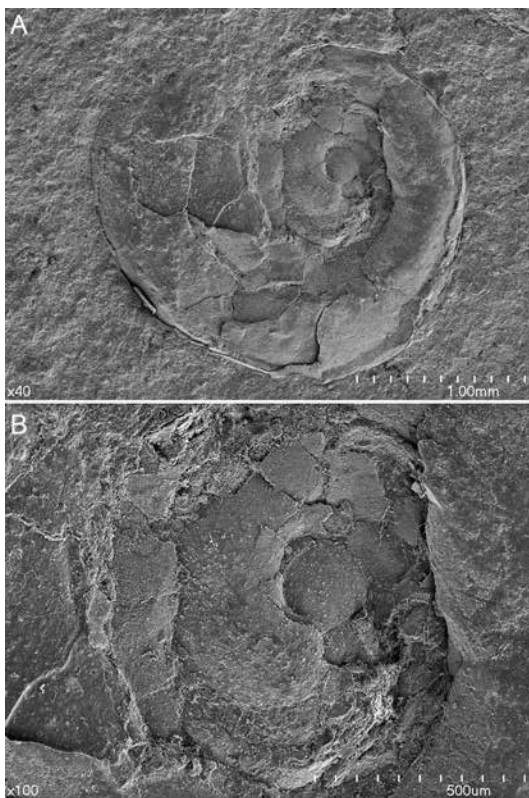


FIGURE 16. *Discoscaphites* sp., overview and close-up of ammonitella showing microornamentation, AMNH 112066, AMNH loc. 3620, Corsicana Formation, Falls County, Texas.

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## APPENDIX 1

STRATIGRAPHIC DISTRIBUTION AND ABUNDANCE OF AMMONITE TAXA  
FROM THE BRAZOS RIVER K-PG BOUNDARY SECTIONS

Stratigraphic abundance and distribution of ammonites from Cretaceous-Paleogene boundary sections along the Brazos River, based on quantitative examination of American Museum of Natural History (AMNH) and University of New Mexico (UNM) collections from AMNH localities 3620 (Darting Minnow Creek: DMC-W and DMC-E), 3621 (Cottonmouth Creek), and 3968 (Riverbank South).

AMNH loc. 3620 (DMC-W)		
Stratigraphic horizon	Taxon	Abundance
K-Pg Unit II (Ejecta-spherule-rich coarse sandstone)	<i>Eubaculites carinatus</i>	2
	<i>Eubaculites latecarinatus</i>	2
	<i>Discoscaphites iris</i>	1
	Scaphitid fragment	1
K-Pg Unit I (Mudstone-clast bearing unit)	<i>Eubaculites carinatus</i>	2
	<i>Eubaculites</i> sp.	1
	<i>Discoscaphites iris</i>	1
	<i>Sphenodiscus lobatus</i>	1
	<i>Sphenodiscus pleurisepta</i>	1
	Baculitid fragments	9
	Scaphitid fragment	1
20–30 cm below K-Pg	<i>Eubaculites carinatus</i>	14
	<i>Eubaculites</i> sp.	2
	<i>Discoscaphites iris</i>	12
	<i>Discoscaphites sphaeroidalis</i>	1
	<i>Discoscaphites mullinaxorum</i>	1
	<i>Discoscaphites</i> sp. (juvenile)	2
	Scaphitid aptychi	1
	Baculitid fragments	91
	Scaphitid fragments	67
50 cm below K-Pg	<i>Eubaculites carinatus</i>	1
	<i>Discoscaphites</i> sp. (aptychus)	1
	Baculitid fragments	3
1 m below K-Pg	Scaphitid fragments	13
	<i>Gaudryceras</i> sp.	1
	<i>Sphenodiscus lobatus</i>	2
	<i>Eubaculites</i> sp.	1
	<i>Discoscaphites iris</i>	9
	<i>Discoscaphites sphaeroidalis</i>	1
	<i>Discoscaphites mullinaxorum</i>	5
	<i>Discoscaphites</i> sp. (juvenile)	6
	Baculitid aptychi	2
	Scaphitid aptychi	3
	Baculitid fragments	25
Scaphitid fragments	162	

APPENDIX 1 *continued*

	<i>Sphenodiscus pleurisepta</i>	1
	<i>Discoscaphites iris</i>	12
	<i>Discoscaphites sphaeroidalis</i>	1
1.25 m below K-Pg	<i>Discoscaphites mullinaxorum</i>	1
	<i>Discoscaphites</i> sp. (juvenile)	6
	Scaphitid aptychi	1
	Baculitid fragments	2
	Scaphitid fragments	58
	<i>Discoscaphites iris</i>	2
1.5 m below K-Pg	<i>Discoscaphites mullinaxorum</i>	3
	<i>Discoscaphites</i> sp. (juvenile)	3
	Scaphitid fragments	40
<b>AMNH loc. 3620 (DMC-E)</b>		
<b>Stratigraphic horizon</b>	<b>Taxon</b>	<b>Abundance</b>
	<i>Discoscaphites</i> sp.	3
<10 cm below K-Pg	Baculitid fragments	6
	Scaphitid fragments	4
<b>AMNH loc. 3621 (Cottonmouth Creek)</b>		
<b>Stratigraphic horizon</b>	<b>Taxon</b>	<b>Abundance</b>
	<i>Sphenodiscus lobatus</i>	1
	<i>Discoscaphites iris</i>	1
Above volcanic ash (0–30 cm below K-Pg)	<i>Discoscaphites</i> sp.	1
	Baculitid fragments	14
	Scaphitid fragments	5
	<i>Eubaculites carinatus</i>	26
	<i>Discoscaphites iris</i>	5
Below volcanic ash (30– ~100 cm below K-Pg)	<i>Discoscaphites sphaeroidalis</i>	2
	<i>Discoscaphites</i> sp. (juvenile)	6
	Baculitid fragments	95
	Scaphitid fragments	50
<b>AMNH loc. 3968 (Riverbank South)</b>		
<b>Stratigraphic horizon</b>	<b>Taxon</b>	<b>Abundance</b>
	<i>Eubaculites carinatus</i>	2
	<i>Eubaculites</i> sp.	12
0–50 cm below K-Pg	<i>Discoscaphites</i> sp.	3
	Baculitid aptychi	1