



Late Paleocene examples of residual coloration and embryonic features in juvenile marine mollusks from Northwest Louisiana

Lloyd N. Glawe, John F. Anderson, and Dennis E. Bell

ABSTRACT

Marine mollusks have been instrumental in resolving the Paleogene stratigraphy of the Gulf Coastal Plain within the southern United States. The present investigation documents the occurrences of microscopic, pre-adult specimens of late Paleocene molluscan species in a set of nearly continuous, virtually unweathered, subsurface cores 2158 feet (658 meters) in total length from northwest Louisiana. The duration of the cored sequence is estimated to extend from about 60 Ma to about 55 Ma; the strata contain the world-wide Paleocene *Planorotalites pseudomenardii* zone. Although millions of years old, the mollusk shells of our study display partially degraded coloration ranging from pale yellow to pale orange to pale red. The probable origin of the coloration is biogenic; the preserved coloration is attributed to rapid burial in a deltaic sedimentary environment. Some of the shells exhibit fragile embryonic features, including protoconchs of gastropods and prodissoconchs of bivalves.

This investigation delineates an important paleontologic boundary within the late Paleocene; extends the known stratigraphic range for nine molluscan species in Louisiana; documents a stratigraphic range of about 600,000 years duration for the guide-fossil oyster, *Odontogryphaea thirsae* (Gabb, 1861); and contributes to the paleontology and paleobiology of 25 late Paleocene molluscan species by describing for the first time their residual shell coloration and/or embryonic features.

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FIGURE 1. Geographic setting and location of the study well in northwest Louisiana. The Carter #2 Well location is indicated by ⊕.

INTRODUCTION

Marine Mollusca have contributed to the development of paleontology and stratigraphy of the Atlantic and Gulf Coastal Plain, USA. Most of the Paleogene species of mollusks were originally described from the classic fossiliferous beds exposed along historic river bluffs in the coastal plain of Alabama (Conrad, 1833; Lea, 1833; Whitfield, 1865; Heilprin, 1881; Gregorio, 1890; Heilprin, 1891; Aldrich, 1895; Harris, 1897). It soon became evident that many of these species were present in fossiliferous beds exposed elsewhere in the Gulf Coastal Plain. A stratigraphic correlation between Marthaville, Louisiana, and Nanafalia, Alabama, based on specimens of the oyster *Odonotogryphaea thirsae* (Gabb, 1861) was proposed by Harris (1899). Stratigraphic paleontology and the regional correlation by marine mollusks became widely accepted (Palmer, 1937; Murray, 1961; Toulmin, 1977). Harris's proposed correlation has been substantiated by planktic Foraminifera of the world-wide *Planorotalites pseudomenardii* Range Zone (see Smith, 1966; Stainforth et al., 1975; Glawe, 1989; Mancini and Tew, 1995). In addition, Paleogene mollusks of the northern Gulf Coastal Plain have provided a well-documented example of speciation (Glawe, 1969), numerous examples of residual color patterns (Dockery, 1980; Swann and Kelley, 1985), and an understanding of environmental and biological controls on the diversity and ecology (Sessa et al., 2012).

Marine Mollusca continue to make contributions to paleontology and paleobiology. The present investigation describes the shell coloration and embryonic features of well-preserved microscopic mollusk shells in Paleocene-Wilcox cores from the Carter Oil Co. Louisiana Longleaf Lumber #2 well. This well is located in northwest Louisiana (Sec. 26, T. 6 N., R. 11 W., Sabine Parish). The geographic setting of the well location is shown in Figure 1. Previous studies of the benthic Foraminifera from the Carter #2 cores indicate that the Wilcox paleoenvironments range from hyposaline and normal marine lagoons to normal marine inner shelf (Glawe, 1995). The Wilcox mollusk shells at the Carter #2 well are interpreted to represent juveniles rather than dwarfs (see section on Juveniles vs dwarfs).

STRATIGRAPHY

At the Carter #2 well, a nearly continuous set of cores (~8 cm in diameter) was recovered from the drilling depth-interval of 500 ft to 2,658 ft (152 m to 810 m) (see Figure 2). The vertical borehole was drilled through essentially horizontal strata. Stratigraphic units encountered at the well are assigned to the Wilcox Group, a 2700 foot-thick (900 m), deltaic sequence of Late Paleocene and Early Eocene siliciclastic formations (Murray, 1961; Glawe, 1995; Glawe and Bell, in press).

The base of the Marthaville Formation serves as the boundary between the traditional Upper and Lower Wilcox (Figure 2). The geologic age for core sample 1507 ft is established by planktic foraminiferal correlation with the Nanafalia Formation of Alabama, which has a radiometric age of about 57 Ma (Glawe, 1989; Mancini and Tew, 1995).

In stratigraphic order, the Marthaville, Pendleton, Sabinetown, and Carrizo comprise the Upper Wilcox Formations in Louisiana (Glawe, 1989). Much of the Lower Wilcox, the entire Marthaville, and most of the Pendleton are present within the cored sequence (Figure 2). The Wilcox Group at the Carter #2 well is represented by poorly sorted and poorly cemented deltaic sandstones and shales containing predominantly quartz, glauconite, and carbonaceous material. Thin beds of lignite occur commonly in the Lower Wilcox. The cored Wilcox sequence has 42 thin zones containing mollusk shells.

The Paleocene-Eocene boundary in Louisiana occurs within the Sabinetown Formation (after Berggren, 1965). The radioactive age of this boundary in Alabama has been dated at about 54 Ma by Mancini and Tew (1995). From the thick-

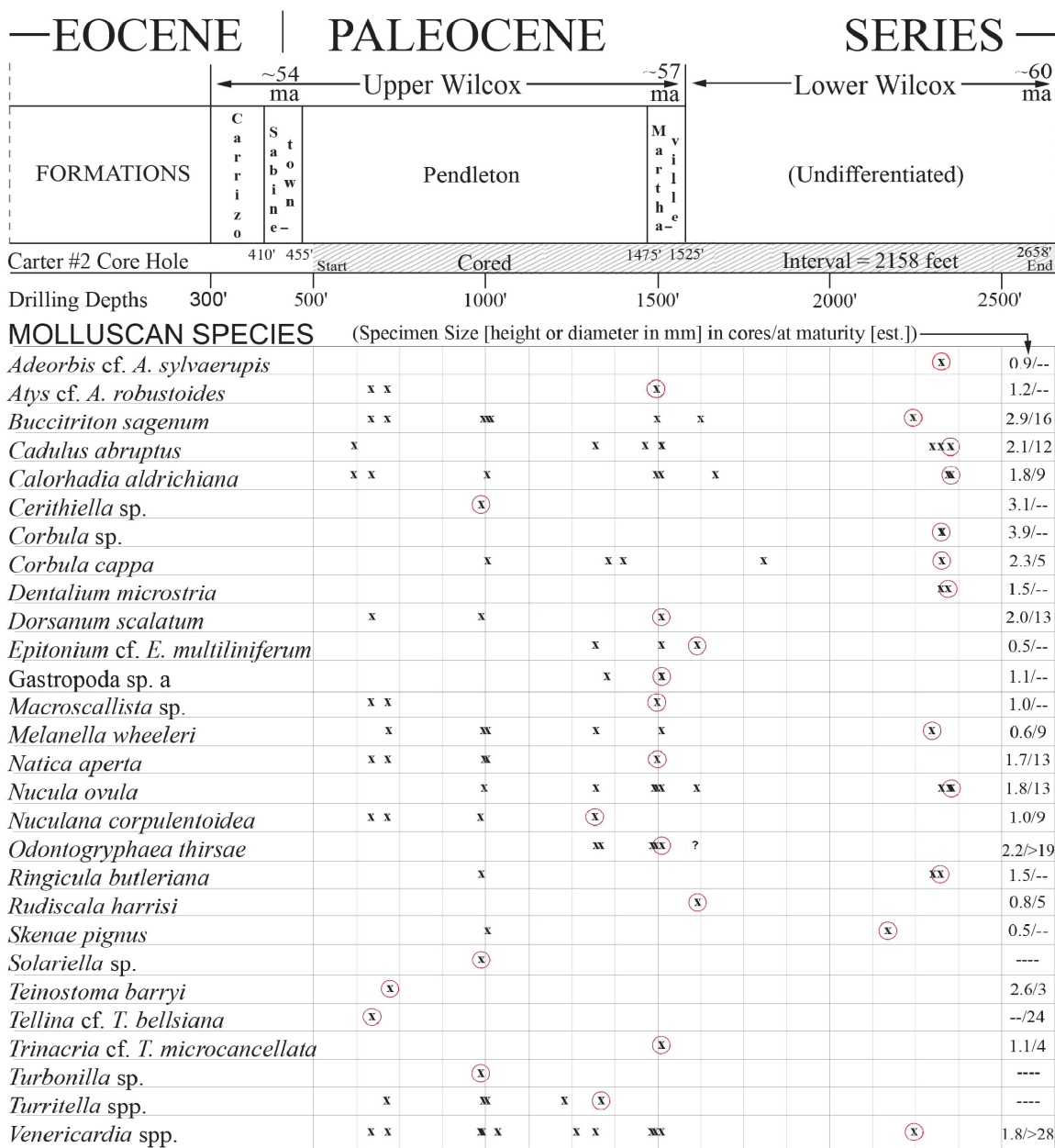


FIGURE 2. Occurrences of Paleocene Wilcox molluscan species by their drilling depths in feet at the Carter #2 Core Hole (Sabine Parish, Louisiana). The first occurrence for each species encountered in the cores is circled in red. Occurrence data are listed in Table 1. Stratigraphic terminology and Geologic Ages are explained in the text.

ness and age data indicated in Figure 2, the cored interval at the Carter #2 well is estimated to represent a stratigraphic record of about 6 million years duration.

METHODS

Methods used in the study of marine-mollusk juveniles from the Carter #2 cores include: 1) selection and preparation of samples, 2) identifica-

tion and illustration of species, 3) determination of stratigraphic occurrences, and 4) description of shell coloration and embryonic features.

Selection and Preparation of Samples

Forty-two horizons in the cores containing macroscopic shell fragments are sampled for the study of microfossils. Each sample represents approximately a 3 cm-thick segment of the vertical

cores that has been split parallel to the bedding. Standard micropaleontologic techniques after Kummel and Raup (1965) are used for the preparation of samples and extraction of microfossils. The microfossils included mollusk shells, foraminifers, and ostracods.

Identification and Illustration of Mollusks

Identification of the microscopic mollusk shells of our study is based on an interpretation of the juvenile features of molluscan species that are described and illustrated in the literature. Since most descriptions of fossil mollusks are based on the shell morphology of mature specimens (Glawe et al., 2011), juvenile features within these descriptions are limited. The best resources for the description of the juvenile features of molluscan species are from type specimens and high-quality illustrations. Descriptions of mollusks in the faunal units of Louisiana by Barry and LeBlanc (1942) combined with these authors' type and figured specimens housed in the Louisiana State University Paleontology Museum are the primary references for identification of the microscopic mollusks. The original descriptions and illustrations for a few additional molluscan species are of secondary importance.

Large taxonomic groups of mollusks occurring in the Wilcox of the Gulf Coastal Plain such as the *Venericardia planicosta* group (Gardner and Bowles, 1939) and the Turritellidae (Bowles, 1939) contain morphologically similar species. Some of these species may be chronospecies comparable to the taxa of the Oligocene *Pecten perplanus* stock from the southeastern United States studied by Glawe (1969). Since discrimination between some chronospecies within genera based solely on immature specimens is uncertain, the occurrences of pre-adult specimens of *Venericardia* and *Turritella* in our study are identified as *Venericardia* spp. and *Turritella* spp.

Photomicrographs of the molluscan shells in Figure 3 are produced by using a Nikon Microscope Camera System (consisting of a SMZ800 microscope with SPOT FLEX hardware, SPOT software, HELICON FOCUS software, NI-150 Fiber optic illuminator, and NCL 150 ring light). Glare on shiny shells is "healed" with PHOTOSHOP software. Measurements of shells are made under a dissecting microscope by using either a calibrated ocular micrometer or a calibrated 1 mm slide. Measurements of shell height for the figured specimens are included in the explanation of Figure 3.

Stratigraphic Occurrences

Plots of the stratigraphic occurrences of molluscan species in the Carter #2 cores by their drilling depths beneath the Kelly Bushing are shown in Figure 2 by the letter "x"; first occurrences are circled in red; raw occurrence data are listed in Table 1. The *Odontogryphaea thirsae* bed at a drilling depth of 1507 ft (Figure 2) correlates stratigraphically with the *O. thirsae* zone of the Marthaville Formation at Marthaville, Louisiana (Andersen, 1960, 1993). The radioactive ages for the Sabintown and Marthaville shown in Figure 2 are determined by chronostratigraphic correlation of planktic foraminiferal zones recognized in the Carter #2 cores to the classic Wilcox localities in Alabama having radioactive age determinations (Smith, 1966; Stainforth et al., 1975; Glawe, 1989; Mancini and Tew, 1995). The ~60 Ma age given for the Lower Wilcox sample at 2658 ft represents an estimate based on the rate of deposition calculated for Upper Wilcox deposits at the Carter #2 well.

Predicated on the first occurrences of marine molluscan species in core samples from the Carter #2 well, the most important paleontologic boundary within the Wilcox Group lies within the Marthaville Formation. Of the 28 species or species groups occurring in the Carter #2 cores, seven have first occurrences in the Marthaville Fm. (see Figure 2). This observation supports the common practice of subdividing the Wilcox Group into an Upper and Lower Wilcox at the base of the Marthaville (Glawe, 1989).

Stratigraphic occurrences of juvenile specimens of molluscan species at the Carter #2 well modify the stratigraphic ranges for Louisiana Wilcox fossils compiled by Wasem and Wilbert (1943, p. 192-194). Subsurface core data fill-in and extend the known stratigraphic ranges for certain mollusks (Figure 2). Species of mollusks having extensions to their ranges in Louisiana include: the gastropods *Buccitriton sagemum* (Conrad, 1833), *Dorsanum scalatum* (Heilprin, 1891), *Melanella wheeleri* Palmer, 1937, *Teinostoma barryi* LeBlanc, 1942 in Barry and LeBlanc, 1942; the bivalves *Calorhadia aldrichiana* (Harris, 1897), *Nuculana corpulentoidea* (Aldrich, 1895), *Tellina bellsiana* Aldrich, 1921, *Trinacria microcancellata* Barry, 1942 in Barry and LeBlanc, 1942; and the scaphopod *Cadulus abruptus* Meyer and Aldrich, 1886. These stratigraphic range extensions prove that certain molluscan species are not as limited stratigraphically as previously proposed. Particularly noteworthy, *Nuculana corpulentoidea* is not confined to the middle of the Pendleton Formation as stated by

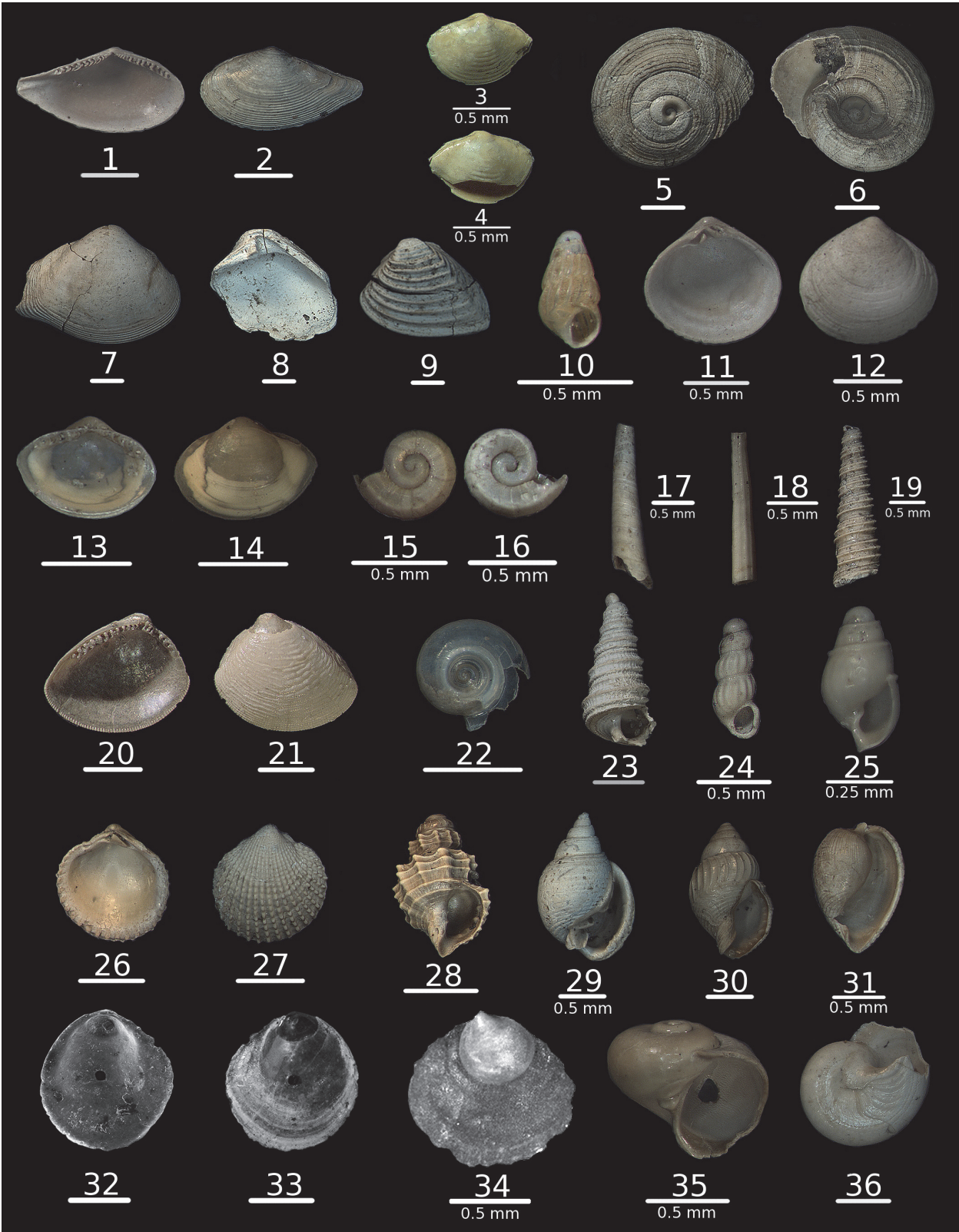


FIGURE 3 caption next page.

FIGURE 3. Residual coloration and embryonic features of Paleocene Wilcox juvenile mollusks. All figured specimens are from Carter #2 core, Sabine Parish, Louisiana (except for 3.32, 3.33). Descriptions of shell coloration are made by comparisons with Geological Society of America Rock-Color Chart (1970). Figured specimens: **1**, bivalve *Calorhadia aldrichiana* (Harris, 1897); LV interior with light brownish gray coloration (GSA R-CC 5 YR 6/1), height 1.79 mm, USNM 546627, drilling depth 1507 ft, Marthaville Fm., showing prominent taxodont hinge and subtle curvature within shell posterior for siphons; **2**, LV exterior of previous specimen showing prominent growth lines and produced posterior; **3**, bivalve *Nuculana corpulentoidea* (Aldrich, 1895); double valve, LV exterior view with grayish yellow coloration (GSA R-CC 5 Y 8/4), height 1.01 mm, USNM 546628, drilling depth 715 ft, Pendleton Fm., medial portion of valve corpulent with concentric ridges; **4**, RV view of previous specimen with broken ventral margin, valve height 0.94 mm; **5**, gastropod *Adeorbis* cf. *A. sylvaerupis* Harris, 1899; apical view, diameter 3.66 mm, USNM 546629, drilling depth 2327 ft, Lower Wilcox, showing spiral and growth line ornamentation; protoconch (828 microns in diameter) recognizable in the center by smooth whorls that increases in size with growth; **6**, umbilical view of previous specimen that reveals the protoconch with three or four whorls, a sediment-filled shell, and broken aperture; **7**, bivalve *Corbula* sp. of Barry and LeBlanc, 1942; RV exterior, height 3.89 mm, USNM 546630, drilling depth 2327 ft, Lower Wilcox; shell exterior of this unnamed species is characterized by fine radial ornamentation and by prominent concentric threads along ventral margin; Barry and LeBlanc report this species from the Logansport Fm.; **8**, bivalve *Corbula cappa* Barry, 1942 in Barry and LeBlanc, 1942; RV interior of an incomplete specimen, USNM 546631, drilling depth 1805 ft, Lower Wilcox, showing hinge with prominent socket; **9**, bivalve *Corbula cappa* Barry, 1942 in Barry and LeBlanc, 1942; LV exterior, height 3.31 mm, USNM 546632, drilling depth 1805 ft, Lower Wilcox, with prominent concentric ridges; **10**, gastropod *Epitonium* cf. *E. multiliniferum* Aldrich, 1921; apertural view with grayish orange coloration (GSA R-CC 10 YR 7/4), height 0.52 mm, USNM 546633, drilling depth 1315 ft, Pendleton Fm., showing sinuous axial ornamentation and a protoconch; **11**, bivalve *Macrocallista* sp. RV interior, height 0.97 mm, USNM 546634, drilling depth 667 ft, Pendleton Fm., showing blade-like cardinal and lateral teeth; **12**, RV exterior of previous specimen showing indistinct growth lines and a prosogyral beak; **13**, bivalve *Trinacria* cf. *T. microcancellata* Barry, 1942 in Barry and LeBlanc, 1942; LV interior with coloration, height 1.12 mm, USNM 546635, drilling depth 1507 ft, Marthaville Fm., specimen with "taxodont" dentition; **14**, LV exterior of previous specimen showing prosogyral beak and prominent growth lines, but without radial ornamentation; **15**, gastropod *Skenae pignus* (Gregorio, 1890), convex side with grayish orange coloration (GSA R-CC 10 YR 7/4), diameter 0.55 mm, USNM 546636, drilling depth 1006 ft, Pendleton Fm., showing a nearly planispiral coil with faint growth lines; **16**, concave side of previous specimen; **17**, scaphopod *Cadulus abruptus* Meyer and Aldrich, 1886; side view, height 2.07 mm, USNM 546637, drilling depth 1507 ft, Marthaville Fm., showing a slightly curved shell with growth lines and broken aperture; **18**, scaphopod *Dentalium microstria* Heilprin, 1881; side view with grayish orange coloration (GSA R-CC 10YR 7/4), height 1.52 mm, USNM 546638, drilling depth 2324 ft, Lower Wilcox, showing prominent radial ribs; **19**, gastropod *Turritella* cf. *T. eurynome* Whitfield, 1865 side view of broken specimen, height 2.76 mm, USNM 546639, drilling depth 713 ft, Pendleton Fm., characterized by three subequal spiral lirae per whorl; **20**, bivalve *Nucula ovula* Lea, 1833; LV interior, height 1.79 mm, USNM 546640, drilling depth 1496 ft, Pendleton Fm., showing prosogyral, ovate shell with taxodont hinge and pale red coloration (GSA R-CC 10R 6/2); ventral margin exhibits short, radial ribbing; **21**, LV exterior of previous specimen shows irregular concentric ornamentation, faint radial lines, and an internal mold of prodissoconch; **22**, gastropod sp. umbilical view, diameter 1.10 mm, USNM 546641, drilling depth 1351 ft, Pendleton Fm., transparent, cinder cone volcano-shaped shell with very faint growth lines and a deep umbilicus; **23**, gastropod *Cerithiella* sp. apertural view with bluish white coloration (GSA R-CC 5B 9/1), height 3.11 mm, USNM 546642, drilling depth 987 ft, Pendleton Fm., showing spiral and radial ornamentation and a protoconch with different axis of coiling than the conch; **24**, gastropod *Rudiscula harrisi* Palmer, 1937; apertural view with yellowish gray coloration (GSA R-CC 5Y 8/1), height 0.83 mm, USNM 546643, drilling depth 1612 ft, Lower Wilcox, showing curved axial ribs and an apertural lip; **25**, gastropod *Melanella wheeleri* Palmer, 1937; apertural view with yellowish gray coloration (GSA R-CC 5Y 8/1), height 0.55 mm, USNM 546644 drilling depth 1507 ft, Marthaville Fm., exhibiting a sutural collar; **26**, bivalve *Venericardia densata pendletonensis* Gardner and Bowles, 1939; interior with grayish orange coloration (GSA R-CC 10YR 7/4), height 1.79 mm, USNM 546645, depth 668 ft, Pendleton Fm., showing internal ribbing along ventral margin; **27**, RV exterior of previous specimen exhibiting denticulations on ribs; **28**, gastropod *Dorsanum scalatum* (Heilprin, 1891); apertural view with light brown (GSA RCC 5YR 6/4) and grayish orange (GSA 10YR 7/4) coloration on shell, height 2.00 mm, USNM 546646, drilling depth 987 ft, Pendleton Fm., showing development of external ornamentation on the whorls from radial lines to spiral lines to nodes; small, internal nodes are visible on the outer lip of aperture; **29**, gastropod *Ringicula butleriana* Aldrich, 1895; apertural view, height 1.52 mm, USNM 546647, drilling depth 2299 ft, Lower Wilcox, showing spiral grooves on shell exterior, prominent columellar folds; **30**, gastropod *Buccitriton sagemum* (Conrad, 1833); apertural view with grayish orange coloration (GSA R-CC 10YR 7/R), height 2.90 mm, USNM 546648, drilling depth 666 ft, Pendleton Fm., showing a similar development of ornamentation as observed in *Dorsanum scalatum* except *B. sagemum* lacks the development of prominent nodes on whorls; **31**, gastropod *Atys* cf.

FIGURE 3 caption next page.

Figure 3 caption continued.

A. robustoides Aldrich, 1895; apertural view with grayish orange coloration (GSA R-CC 10 YR 7/4), height 1.24 mm, USNM 546649, drilling depth 666 ft, Pendleton Fm., showing loose coiling with spiral grooves in outer shell; axial liration in posterior and sigmoid liration in anterior; **32**, bivalve *Odontogryphaea thirsae* (Gabb, 1861); RV interior, height 2.20 mm, ULM-38, Nanafalia Landing on Tombigbee River, Alabama, Nanafalia Fm., barely showing posterior adductor muscle scar; **33**, RV exterior of previous specimen showing a low convex shell with internal mold of prodissoconch and a tapered bore hole; **34**, bivalve *O. thirsae* (Gabb, 1861); RV exterior, height 1.00 mm, ULM-40, drilling depth 1507 ft, Marthaville Fm., exhibiting an early dissoconch stage (juvenile) with an attached prodissoconch (height 0.42 mm); **35**, gastropod *Natica aperta* Whitfield, 1865; apertural view with grayish orange coloration (GSA R-CC 10 YR 7/4), height 1.70 mm, USNM 546650, drilling depth 668 ft, Pendleton Fm., showing a low trochospiral coil slightly flattened on top, and an upper columellar lip reflected over the umbilicus; aperture reveals a hole in the body whorl and an inner shell layer with crinkled texture; **36**, gastropod *Teinostoma barryi* LeBlanc, 1942; umbilical view with somewhat iridescent coloration, maximum diameter 2.62 mm, USNM 546651, drilling depth 713 ft, Pendleton Fm., shell exhibits low, curved ridges extending from a callous-filled umbilicus toward the shell margin where spiral punctate lines are present; outer lip of aperture is missing. Scale bars equal 1 mm unless labeled otherwise. Figured specimens are deposited in the U.S. National Museum (USNM), Washington, DC and in the University of Louisiana Monroe (ULM) Natural History Museum, Monroe, LA. Digital images are produced by light photography, except for SEM image 3.32. Images 3.33 and 3.34 are from Glawe et al. (2011). Original descriptions of species are indicated by author and year of publication; the complete bibliographic sources are included in the REFERENCES section.

Wasem and Wilbert (1943); the species range extends throughout the Pendleton (see our Figure 2).

The bivalve, *Odontogryphaea thirsae* (Gabb, 1861), is a well-known Late Paleocene fossil in the northern Gulf Coastal Plain (Glawe, et al., 2011). Its stratigraphic range at the Carter #2 well extends from near the base of the Marthaville Formation to the lower part of the overlying Pendleton (Figures 2, 3.32-34). A single, poorly preserved specimen from a core depth of 1611 ft is similar to *O. thirsae*, but its identification is uncertain; therefore, this occurrence is indicated in Figure 2 and Table 1 by a question mark (?).

Using the radioactive age and thickness data indicated in Figure 2, the duration of the known stratigraphic range for *O. thirsae* in northwest Louisiana is estimated to represent about 600,000 years. In addition to high abundance and widespread distribution in late Paleocene beds of the northern Gulf Coast, *O. thirsae* has a relatively short stratigraphic range. Thus, the species is an ideal guide fossil. *O. thirsae* has been used to correlate beds within the Marthaville Formation of Louisiana (Anderson, 1960;1993) and beds within the Nanafalia Formation of Alabama (LaMoreaux and Toulmin, 1959; Toulmin, 1977). Better understanding of the actual stratigraphic ranges of species within ancient provinces should clarify the local and regional stratigraphy as well as permit an improved interpretation of species migration.

Shell Coloration and Embryonic Features

Late Paleocene (~60 to ~54 Ma) juvenile mollusk shells of our study are very well-preserved;

this unusual preservation may be related to the rapid burial of Wilcox deposits in a deltaic environment. Although extremely old, many of the shells exhibit pale coloration and/or fragile embryonic features.

The descriptions of shell coloration are based on comparisons with the Geological Society of America (GSA) Rock-Color Chart (1970).

The shells in Figures 2 and 3 having coloration range from grayish yellow (GSA Rock-Color 5YR 8/4) such as Figure 3.3, 3.4 to grayish orange (GSA Rock-Color 10 YR 7/4) such as Figure 3.10, 3.15, 3.26, 3.28, 3.30, 3.31, 3.35 to pale red (GSA Rock-Color 10R 6/2) such as Figure 3.20. The most colorful shell (Figure 3.28) exhibits light brown coloration (GSA Rock-Color 5YR 6/4) with grayish orange spiral and radial ornamentation (GSA Rock-Color 10 YR 7/4). There are no trends in molluscan shell coloration observed within the cored sequence at the Carter #2 well, indicating that the preserved coloration is biologic rather than diagenetic.

Shell coloration in our fossil material occurs as three main categories: pale yellow, pale orange, and pale red. This range in coloration is similar to the range of shell coloration observed in typical museum collections of Recent seashells from present-day beaches in the Gulf of Mexico. The paleness of shell coloration in the material of our study suggests that partial degradation of the original shell coloration has occurred (see Curry, 1999). One of our shells (Figure 3.36) is somewhat iridescent.

Embryonic features observed in the molluscan material include protoconchs of gastropods

TABLE 1. Occurrence data by drilling depths in feet for Paleocene molluscan species or species groups in the Carter #2 Wilcox cores from Sabine Parish, Louisiana. Plots of occurrence data are shown in Figure 2. Most of the species are illustrated in Figure 3.

Adeorbis cf. *A. sylvaerupis* Harris, 1899: 2327;
Atys cf. *A. robustoides* Aldrich, 1895: 666, 668, 713, 715, 1496;
Buccitriton sagemum (Conrad, 1833): 666, 667, 668, 713, 717, 987,993, 1006, 1015, 1496, 1612, 2246;
Cadulus abruptus Meyer and Aldrich, 1886: 618, 1316, 1464, 1508, 1511, 2298, 2324, 2353;
Calorhadia aldrichiana (Harris, 1897): 616, 618, 667, 1006, 1495, 1508, 1666, 2346, 2353;
Cerithiella sp.: 987;
Corbula sp.: 2326, 2327;
Corbula cappa Barry, 1942 in Barry and LeBlanc, 1942: 1006, 1351, 1397, 1805, 2327;
Dentalium microstria Heilprin, 1881: 2324, 2325, 2344;
Dorsanum scalatum (Heilprin, 1891): 668, 986, 987, 1508;
Epitonium cf. *E. multiliniferum* Aldrich, 1921: 1315, 1509, 1611;
Gastropod sp.a: 1351, 1508, 1510;
Macrocallista sp.: 666, 667, 715, 1496;
Melanella wheeleri Palmer, 1937: 717, 993, 1006, 1316,1508, 2299;
Natica aperta Whitfield, 1865: 666, 667, 668, 713, 715, 717, 986, 987, 993, 1006, 1496;
Nucula ovula Lea, 1833: 986, 987, 1316, 1488, 1496, 1507, 1612, 2324, 2344, 2353;
Nuculana corpulentoidea (Aldrich, 1895): 666, 713, 715, 986, 1316;
odontogryphaea thirsae (Gabb, 1861): 1316, 1332, 1482, 1491, 1508; 1611?
Ringicula butleriana Aldrich, 1895: 987,2299, 2324;
Rudiscula harrisi Palmer, 1937: 1612;
Skenae pignus (Gregorio, 1890): 1006, 1666;
Solariella sp.: 987;
Teinostoma barryi LeBlanc, 1942 in Barry and LeBlanc, 1942: 713;
Tellina cf. *T. bellsiana* Aldrich, 1921: 667;
Trinacria cf. *T. microcancellata* Barry, 1942 in Barry and LeBlanc, 1942: 1508;
Turbonilla sp.: 668, 715, 986;
Turritella spp.: 713, 987, 1006, 1228, 1332;
Venericardia spp.: 666, 667, 668, 713, 715, 717, 986, 993, 1036, 1262, 1316, 1482, 1491, 1510, 2246.

and prodissoconchs of bivalves. Protoconch (in the general sense of the term after Schrock and Twenhofel, 1953) is represented in gastropods by an initial set of one to four smooth whorls; the coiling axis of the protoconch may be either the same or different than that of the later-formed conch. Fossil prodissoconchs are represented by either a larval shell still attached to the beak of dissoconchs or by an internal mold of the prodissoconch. Prodissoconchs are rarely preserved as free, larval shells (Glawe et al., 2011). Even if some larval shells should become detached from the beak of dissoconchs and preserved as fossils, their specific identifications are seldom possible.

An example of a protoconch having the same axis of coiling as the conch is illustrated by the gastropod *Adeorbis* cf. *A. sylvaerupis* Harris, 1899 (Figure 3.5). The conch shell is low trochospiral; the protoconch is distinguished by its smooth whorls. In Figure 3.6, three or four whorls of the protoconch are discernible within a deep umbilicus of the conch. Examples of gastropods exhibiting an abrupt change in the coiling axis between the protoconch and conch stages are shown in Figure

3.10 (*Epitonium* cf. *E. multiliniferum* Aldrich, 1921) and Figure 3.23 (*Cerithiella* sp.).

The larval shell (prodissoconch) of the oyster, *Odontogryphaea thirsae* (Gabb, 1861), in Figure 3.34 remains attached to an early dissoconch specimen; this is an unusual occurrence. In oysters, the dissoconch is composed of calcite, whereas the prodissoconch consists of the less-stable mineral, aragonite (Stenzel, 1964). Thus the fossil preservation of the prodissoconch in oysters occurs usually as an internal mold such as observed in Figure 3.33. Another example of an internal mold of the prodissoconch is shown by the bivalve of Figure 3.21. The examples above may assist in the recognition of embryonic features of mollusks shells that are discovered in other geological sequences or provinces.

JUVENILES VS DWARFS

Larval and juvenile growth stages of the normal-marine oyster, *Odontogryphaea thirsae* (Gabb, 1861), have been described from the same subsurface locality as the present study (Glawe et al.,

2011). Based on large collections of *O. thirsae* (Gabb) from Alabama outcrops, adults of the species have been determined to range in size from 20 to 50 mm in height. In our present study of subsurface cores, the height/ diameter of the various mollusk shells ranges from 0.5 to 3.9 mm. The height/ diameter of the microscopic specimens of our study are compared with the measurements reported in the original descriptions for each species (see Figure 2, right column). Measurements of the type material for molluscan species represent our best estimate of the mature/adult size.

Note that the Wilcox molluscan specimens from the Carter #2 core samples are smaller than the estimated mature size for most of the species listed in Figure 2. The fossil shells of our study are interpreted to be pre-adults; these microscopic specimens are represented by juveniles, not dwarfs. Dwarfism in mollusks has been described in studies of the hypersaline, modern Laguna Madre of central Texas (Parker, 1959), but hypersaline paleoenvironments are not recognized in the Wilcox at the Carter #2 core hole. The paleoenvironments described from the Wilcox cores are limited to either hyposaline and normal marine lagoons or normal marine inner shelf (Glawe, 1995; Glawe et al., in review).

CONCLUSIONS AND SIGNIFICANCE

- Stratigraphic occurrences of Mollusca from the Carter #2 cores modify the known Stratigraphic Ranges for some late Paleocene marine mollusks from northwest Louisiana.
- First occurrences of Mollusca provide a meaningful ~57 Ma Paleocene boundary that is corroborated by planktic foraminiferal correlations. In the absence of planktic Foraminifera or other well-defined chronostratigraphic groups, marine mollusks are usable for regional lithostratigraphic correlation within the Gulf Coastal Province of the southern United States.
- The duration of the stratigraphic range for the bivalve guide fossil, *Odontogryphaea thirsae* (Gabb, 1861) in northwest Louisiana is about 600,000 years. Relatively short stratigraphic ranges are essential for chronostratigraphic correlation.
- Descriptions of shell coloration and embryonic features of the late Paleocene mollusks of our study contribute to the paleontology and paleobiology of Mollusca. The preserved coloration may provide a better understanding of residual coloration. The residual colors in

ancient seashells may be relatable to the coloration observed in their modern analogs. Embryonic features of the fossil shells in this study may provide insight into the ontogeny and/or phylogeny of certain Paleocene mollusks.

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