UPPER CRETACEOUS FORAMINIFERA IN SANTONIAN TO MAESTRICHITIAN DEPOSITIONAL SEQUENCES IN THE NEW JERSEY COASTAL PLAIN

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ABSTRACT—Analysis of benthic foraminifera in the Santonian to Maestrichtian in the New Jersey coastal plain indicates a relationship between the appearance of new species and depositional sequences. Data on species of the genera Gavelinella, Praebulimina, Globorotaloides, and Bolivinoides suggest that the evolution of species correlates with the hiatus that separates sequences. Evolution of benthic foraminifera, at least in shelf environments, may occur due to stresses brought about by the transition from falling to rising sea level. New species appear for the first time, as they do in the New Jersey coastal plain, in the transgressive system tracts.

Key words: Upper Cretaceous, benthic foraminifera, depositional sequences, New Jersey

INTRODUCTION

The coastal plain of New Jersey lies along the western edge of the Baltimore Canyon Trough, a large sedimentary basin which extends along the United States Middle Atlantic states (Fig. 1). The Baltimore Canyon Trough extends seaward beneath the continental shelf to the upper continental slope. The Baltimore Canyon Trough is composed of a seaward-thickening wedge of Mesozoic and Cenozoic sedimentary rocks which overlie a warped and faulted crystalline basement.

The sediments in the Baltimore Canyon Trough were initially deposited when North America and Africa separated during early Mesozoic time. The sediments that accumulated in the Baltimore Canyon Trough consist of limestones, sandstones, sands, shales, and clays (Poag, 1979). A deeply buried thick sequence of limestone of Jurassic and Early Cretaceous age is identified in exploration wells and in multi-channel seismic reflection profiles of the trough. A carbonate bank or reef representing the lower Cretaceous shelf edge lies beneath the present-day upper continental slope.

Overlying the limestone sequence are Upper Jurassic and Lower Cretaceous nonmarine and shallow marine sandstones and shales (Poag, 1979). These sediments thin beneath New Jersey and lie upon crystalline basement rock. Where penetrated in wells they are nonmarine to shallow marine in character. The Upper Cretaceous and Tertiary marine section that forms the major part of the New Jersey coastal plain belongs to a marine cycle that began during Albian time and transgressed over the Atlantic margin, bringing sea level over the New Jersey area for the first time since the Atlantic began to open.

The sediments consist of fluvial sands, gravels, and variegated clays; coastal deposits of beach, lagoon, marsh, and related deposits; inner shelf sediments consisting of shore face sands with characteristic Ophiomorpha trace fossil assemblages and offshore micaceous clay and silty, thinly bedded fine sands; mid and outer shelf clay, glauconite sands and glauconitic clays, often extensively burrowed; and slope deposits composed of calcareous clays and silts. The formations corresponding to these various facies were deposited during major cycles of sea level change and are genetically related to sedimentary units that have been penetrated in wells in the Baltimore Canyon Trough and in Deep Sea Drilling Project (DSDP) sites on the New Jersey slope.

The Albian rise in sea level was the beginning of a long-term trend of high stand of sea level that flooded the New Jersey margin until late Eocene time. Superimposed on this long-term trend of high sea levels were numerous cycles of sea level rise and fall during which the formations of the coastal plain were deposited. The deposition of sand, silt, and clay composing these formations was controlled by cycles of rising and falling of sea level.

SEQUENCE STRATIGRAPHY

The coastal plain of New Jersey has long been known for its stratigraphic record of transgressive formations but no attempt had been made to fit them into a depositional sequence framework. The concept of a depositional sequence as developed by the Exxon group (Haq and others, 1987; Posamentier and Vail, 1988; Vail and others, 1977, 1984) is based on unconformity-bounded sequences of strata which are genetically linked by a cycle of rising and falling sea level. Deposition is controlled by the rate at which sea level rise and fall is changing, by the rate of subsidence of the basin, and by sediment supply. A depositional sequence is divided into stratal patterns called systems tracts (Posamentier and Vail, 1988). A systems tract is composed of one or more depositional systems and their corresponding set of lithofacies. The systems tract is deposited during a specific part of a sea level cycle. The five systems tracts that are identified by the Exxon group are highstand deposits, transgressive deposits, lowstand wedge, fan deposits, and shelf-margins wedge. Only two of the systems tracts are recognized in the Cretaceous and
Tertiary of the New Jersey coastal plain. They are the high-stand deposits and the transgressive deposits. These systems tracts are deposited when sea level is rising at its greatest rate (transgressive deposits) and when sea level rise slows and begins to fall (highstand deposits). The three other systems tracts are deposited during low stand of sea level and thus they are deposited farther out in the basin. Unconformities develop in the coastal plain when these systems tracts are deposited.

In the New Jersey coastal plain, the transgressive deposits of a depositional sequence are characterized by being fine-grained and by containing authigenic glauconite, often in abundance. They have sharp basal contacts where they unconformably overlie a lower sequence. The high-stand deposits are sands and silts which grade from the underlying transgressive deposits and in turn are overlain unconformably by the transgressive deposits of the sequence above. Studies of sequence stratigraphy (Olsson and Wise, 1986; Olsson and Sheridan, 1988; Olsson and Sikora, 1989) have identified ten stratigraphic intervals (Fig. 2) that can be correlated with the sequences of Haq et al. (1986).

Paleoslope studies and depositional sequences

Depositional sequences and their transgressive and highstand systems tracts were first used in the New Jersey coastal plain and Atlantic margin to construct paleoslope models of Cretaceous foraminiferal paleobathymetric distributions (Olsson and Nyong, 1984; Nyong and Olsson, 1984; Olsson and Sikora, 1988). These studies showed that benthic foraminifera occurrences were controlled by rise and fall in sea level. The most obvious pattern is the shifting along depositional dip (paleoslope) of benthic foraminiferal assemblages in transgressive and highstand deposits which reflects the movement of species along the paleoslope as sea level rose and fell.

In this study we focus on the distribution of foraminifera in Santonian to Maestrichtian depositional sequences in a coastal plain well (BTMA, Fig. 3) in order to illustrate how sequences can be characterized by their foraminiferal content (benthic and planktonic). Furthermore, we point out several examples of benthic foraminiferal phylogeny which appear to be related to the depositional sequences. This suggests that sea level rise
and fall is a major controlling factor in the evolution of benthic foraminifera. The same may be true for planktonic foraminifera although concurrent climatic factors may work with sea level change to cause evolution and extinction in this group.

THE BTMA WELL

The BTMA Well is located (Fig. 1) in an updip part of the New Jersey coastal plain. It was drilled as a municipal water supply well to a depth of 533 m (1750 ft.) to basement. The top of the Cretaceous section was encountered at 140 m (460 ft.). The 393 m (1290 ft.) of Cretaceous section contains the entire marine record of the New Jersey coastal plain. The Albian to Turonian sequence stratigraphy and paleobathymetry have been discussed by Olsson and Sikora (1988, 1989) and Sikora (1989).

Depositional sequences were identified by correlating the planktonic foraminiferal biostratigraphy with the lithology and geophysical logs of the well (Fig. 3). A depositional sequence is identified on the geophysical log as a coarsening-upward succession of clays and silts to sands. The clays and silts are glauconitic and represent the transgressive systems tract of the sequence. They contain benthic foraminiferal assemblages indicative of the deepest paleobathymetry of the sequence. They generally have transgressive sands at their base and are replaced upward by sands of the highstand systems tract. The highstand sands contain the shallowest paleobathymetric assemblages of the sequence. The unconformities that separate the sequences (Fig. 3) are indicated by either sharp shifts in the geophysical log or by biostratigraphic data (missing zone(s)) and paleobathymetric data (abrupt changes in foraminiferal benthic assemblages).

Almost all the unconformities recognized in the Cretaceous of the coastal plain are type one unconformities (Fig. 3). Type one unconformities develop when sea level falls below the shelf break (Haq et al., 1987). When this occurred the coastal plain was exposed to erosion. Consequently, this type of unconformity is easier to identify in the coastal plain. Type two unconformities are not as prominent in the coastal plain since they

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develop when sea level did not fall below the shelf break. Recognition of these unconformities requires detailed analysis of fluctuations in foraminiferal assemblages (Olsson and Sikora, 1988; Sikora, 1989).

Six sequence boundaries are recognized in the BTMA Well in the Santonian to the Maestrichtian (Fig. 3). All but one correspond to type one unconformities. The depositional sequences bounded by these unconformities are the framework within which the benthic and planktonic foraminifera are analyzed. They, consequently, allow comparisons of the paleobathymetric distribution of benthic species, the tracing of phylogenetic lineages of benthic species, and the relationship of the evolution of benthic species to cycles of sea level change.

BENTHIC FORAMINIFERA IN DEPOSITIONAL SEQUENCES

The first study in the New Jersey coastal plain on the stratigraphic distribution of species of a benthic foraminifera was by Petters (1977a) on the phylogeny of the genus Bolivinoides. He showed that the evolution of species of Bolivinoides produced excellent stratigraphic markers in the Upper Cretaceous section of New Jersey. Paleoslope studies in the Upper Cretaceous of New Jersey show that Bolivinoides was adapted to an outer shelf environment. Olsson and Sikora (1989) suggested that speciation of Bolivinoides correlated with depositional sequences. For instance, the first species of Bolivinoides, B. strigillatus, occurs in the lower Campanian sequence UZA 3.5. Bolivinoides culverensis is present in middle Campanian sequences UZA 4.1–4.3 and B. decoratus occurs in the upper Campanian to lower Maestrichtian sequence UZA 4.4. This correlation indicates that speciation in this genus may have been controlled by sea level cycles. We point out in our study of the BTMA Well other associations of benthic species with depositional sequences which also indicate a sea level control on the evolution of benthic species.

Paleoslope studies of Cretaceous benthic foraminifera in the New Jersey margin (Nyang and Olsson, 1984; Olsson and Nyong, 1984; Sikora and Olsson, 1988) show that the genus Gavelinella was adapted to shelf, slope, and abyssal environments. Speciation events beginning in the Albian led to the development of numerous species which occupied specific paleoenvironments. Studies on the evolution of Gavelinella in the Cretaceous of Western Europe have identified a number of phylogenetic rela-
tionships between species (Price, 1977; Edwards, 1981; Hart and Swiecicki, 1988). These studies have focused on the stratigraphy of species and their utility for correlation.

In this study we focus on the evolution of four morphogenetic groups of Gavelinella which based on paleo-slope studies occupied shelf environments during Santonian to Maestrichtian time. These are: the Gavelinella infrequens ( Morrow), Gavelinella nelsoni (W. Berry) group, the Gavelinella tenesseensis (W. Berry)—Gavelinella pinguis (Jennings) group, the Gavelinella texana (Cushman)—Gavelinella dumblei (Applin) group, and the Gavelinella minima (Vieux)—Gavelinella compressa (Olsson) group.

The G. infrequens—G. nelsoni group occupied inner to middle shelf environments on the New Jersey Atlantic margin. The group (Figs. 4-3a–c, 6-6a–c) is characterized by an inflated low trochospiral test with 6.5–7 chambers in the ultimate whorl. The walls are coarsely perforate except where they are closed by the addition of calcite incrustation. This occurs on the inner whorl area of the dorsal side, on the apertural face and the axial periphery, and in the umbilical area. The aperture is umbilical to extraumbilical, reaching to the mid-point of the axial periphery, and it is bordered by a triangular-like lip or flap which extends into the umbilicus. Gavelinella infrequens ranges from the upper Albian (UZA 2.2) to the Santonian (UZA 3.3). It is replaced by G. nelsoni in the Campanian (UZA 3.4). Gavelinella nelsoni ranges to the lower Maestrichtian (UZA 4.4). The most significant morphologic difference between G. infrequens and G. nelsoni is the greater inflation of the last few chambers in G. nelsoni. Gavelinella nelsoni thus has a much more inflated test than does G. infrequens. This evolutionary change, it would appear, is related to sea level fall and rise (sequences UZA 3.3–3.4) which lead to selective pressures on G. infrequens.

The Gavelinella tenesseensis—Gavelinella pinguis group characterized inner shelf environments in the Campanian and Maestrichtian. The group (Figs. 4-5a–c, 6-7a–c) is characterized by an inflated very low trochospiral, almost planispiral test with 9–10 chambers in the ultimate whorl. The walls are coarsely perforate. In G. tenesseensis calcite incrustation covers the pores on the dorsal side inner whorl area and it also occurs as a partial umbilical rim. In G. pinguis calcite incrustation occurs along the sutures of the first few chambers of the ultimate whorl and as an umbilical rim. The aperture is umbilical-extraumbilical and extends over the axial periphery onto the dorsal side. It is bordered by a thin lip to short flap which extends into the umbilicus. Calcification buildup on the lips of previously formed chambers leads to an umbilical rim. Gavelinella tenesseensis is first identified in the lower Campanian (sequence UZA 3.4). It ranges to the upper Campanian (sequence UZA 4.3). Gavelinella pinguis first appears in sequence UZA 4.4 and ranges into sequence UZA 4.5 (uppermost Campanian to Maestrichtian). It is related to G. danica (Brotzen) of the Paleocene.

The Gavelinella texana—Gavelinella dumblei group was adapted to middle shelf to upper slope environments. The group (Figs. 4-1a–c, 4) is characterized by a flattened and compressed test with an axial periphery which is sharply angled to keeled. The test has about 10 chambers in the ultimate whorl and has a prominent raised umbo on the dorsal side. The wall is finely and densely perforate. Calcite incrustation occurs along sutures immediately surrounding the umbilicus. The incrustation occurs as tongue-like extensions which project into the umbilicus. The aperture is umbilical-extraumbilical and extends over the axial periphery onto the dorsal side. It is bordered by a prominent apertural flap which extends into the umbilicus. Calcite buildup also occurs along the apertural flaps of earlier-formed chambers. Gavelinella texana occurs in the Santonian to lowermost Campanian where it is present in sequences UZA 3.2 to 3.4. Gavelinella dumblei ranges from Campanian to lowermost Maestrichtian (sequences UZA 3.5 to 4.4).

The Gavelinella minima—Gavelinella compressa group occupied middle to outer shelf environments and was able to tolerate oxygen minimum conditions. The group (Figs. 4-2a–c) is characterized by a small, much compressed and flattened, button-shaped test with 9–10 chambers in the ultimate whorl. The wall is coarsely perforate but calcite incrustation closes the pores and covers the earlier formed chambers on both sides. The incrustation builds up first along the sutures where it can be viewed on the last formed chambers. The aperture is umbilical-extraumbilical and extends to the midpoint of the axial periphery. It is bordered by a triangular-shaped lip or flap which extends into the umbilicus. Gavelinella minima ranges from the Albian (sequence UZA 2.4) to the Turonian (sequence UZA 2.6) in the New Jersey margin. Gavelinella compressa occurs in the Santonian to the Maestrichtian (sequences UZA 3.2–4.5). Due to nonmarine deposition in the Coniacian and an unconformity in the upper Turonian, the upper range of G. minima and the lower range of G. compressa can not be determined.

Praebuliminids are important components of Cretaceous assemblages. In the New Jersey margin species of Praebulimina are first recorded in the Conenoman. Two morphotypes occur, one a smooth-walled finely perforate inflated form and the other a small triangular-shaped form, which is finely costate. The inflated forms are characterized by a number of species while the triangular forms have fewer species. In the Santonian to the Maestrichtian of New Jersey five species of the smooth-walled forms are recorded. These are Praebulimina aspera (Cushman and Parker), P. carseyae (Plummer), P. cushmani (Sandidge), P. kickapooensis (Cole), and P. ventricosa (Brotzen). These species characterize middle to outer shelf paleoenvironments. Praebulimina ventricosa (Fig. 5-2) occurs in Santonian sequences UZA 3.2–3.3, P. aspera in UZA 3.5 to 4.5, P. cushmani (Fig. 5-1) in UZA 3.5 to 4.4, P. carseyae (Fig. 5-4) and P. kickapooensis (Fig. 5-3) in UZA 4.4 to 4.5.

Two species of Globorotalites are identified in Santonian to lower Maestrichtian sequences in the New Jersey margin, G. michelinianus (d’Orbigny) and G. subconicus (Morrow). These species are characteristic of middle to outer shelf environments. Globorotalites
subconicus (Fig. 5-11) occurs in the Santonian (sequences UZA 3.2–3.3) whereas G. michelinianus ranges from the lower Campanian to lowermost Maestrichtian (sequences UZA 3.4–4.4). It is possible that the lowermost range of G. michelinianus species may belong to a third species, G. conicus (Carsey), but this requires further investigation. In the Turonian and Conomanian G. umbilicus (Loetterle) occurs in shelf environments. Thus it appears likely that this Globorotalites group is another example of speciation related to depositional sequences in shelf environments during sea level fall and rise.

In addition to the species groups discussed above, there are several species that appear to characterize certain depositional sequences and, at least, in the New Jersey margin help to identify sequences. Their utility probably lies in their restriction to shallow inner shelf facies where they appear consistently rather than to stratigraphic restrictions. These include two calcareous species and five agglutinated species.

The calcareous species are Lenticulina pseudoseceans (Cushman) and Kypriopyxa christneri (Carsey). They both occur in the Campanian. Lenticulina pseudoseceans (Fig. 5-12) is characteristic of inner shelf deposits of sequences UZA 3.5–4.3, while K. christneri (Fig. 5-9) occurs most frequently in inner shelf deposits of UZA 3.5.

Among the agglutinates Penerina redbankensis Olsson (Fig. 5-10) occurs in Maestrichtian shallow shelf facies (UZA 4.4–4.5) whereas Clavulina trilistera (Cushman) (Fig. 5-5) occurs most frequently in shallow shelf facies in Maestrichtian and Campanian sequences UZA 3.1–4.5. Pseudogaudryina capitosa (Cushman) (Fig. 5-6) and Gaudryina rudita (Cushman) (Fig. 5-8) are most characteristic of shallow shelf facies in the Campanian (UZA 3.5–4.3). Arenobuliminina americana Cushman (Fig. 5-7) appears in the Santonian (UZA 3.2–3.3)

PLANKTONIC BIOSTRATIGRAPHY

The planktonic biostratigraphy of the Upper Cretaceous of the New Jersey coastal plain has been reported on by Olsson (1964), Olsson and Wise (1986) and Petters (1977b). Marker species for the standard zonation shown in Fig. 2 are present but often rare in the shelf sediments of the coastal plain. Nevertheless, a number of other less restricted species are abundant or frequent enough to be useful in identifying sequences. The more typical ones are illustrated in this paper. Rugoglobigerina macrocephala Brønnimann (Fig. 6-2) occurs frequently in the upper Maestrichtian UZA 4.5 sequence. Archeoglobigerina creteca (d’Orbigny) (Figs. 7-2a–b), Globotruncan a bulloides Vogler, and Globotruncan a linneiana (d’Orbigny) (Figs. 7-4, 5a–b) are common to abundant in the Campanian (sequences UZA 3.4–4). Archeoglobigerina blowi Pessagno (Figs. 7-3a–b) is more common in the Santonian to middle Campanian sequences UZA 3.2–3.5 as is Rosita fornicata manaurenensis (Gandolfi) (Figs. 6-1a–b). Sequences UZA 3.4–3.5 in the upper Santonian to lower Campanian are characterized by frequent Ventilabrella browni Martin (Fig. 6-4). Archeoglobigerina bosquensis Pessagno, Marginotruncan a marginata (Reuss), and Marginotruncan a pseudolineana Pessagno (Figs. 7-1a–c, 6-3, 5, respectively) are common in Santonian sequences UZA 3.2–3.4.

CONCLUSIONS

The depositional sequence is the package of sedimentary facies that is deposited during a cycle of sea level rise and fall. Depositional sequences are unconformity bounded except where the unconformity merges to its correlative conformity which represents the chronostratigraphic boundary of depositional sequences. Since the unconformities are developed during sea level fall, continental margins contain the stratigraphic signal of sea level lowering either in the physical evidence of an unconformity or by paleontological evidence that indicates a hiatus. The paleontological evidence may be biostratigraphic (missing zone(s)) or paleoecological (abrupt changes in paleobathymetric assemblages). The paleontologic aspect of unconformities and their associated hiatuses has focused our attention on the paleontologic record that is preserved in the transgressive and highstand deposits in the New Jersey coastal plain. Furthermore, since the magnitude of each cycle of sea level change was not constant during the Cretaceous in the coastal plain (Olsson and Nyong, 1984; Olsson and Sikora, 1988, 1989; Olsson and Sheridan, 1988) the distribution of benthic species in inner shelf to outer shelf and upper slope environments is well established along paleoslope transects.

In this study we have analyzed the stratigraphic distribution of selected benthic species from inner to outer shelf environments in Santonian to Maestrichtian depositional sequences noting the phylogenetic relationships of species of Gavelinella, Praebuliminina, and Globorotalites. These relationships and others (i.e., Bolivinoides) suggest strongly that speciation of these groups is due to selective pressures brought about by cycles of sea level change. In the coastal plain new species appear in the transgressive systems tracts, which suggests that their evolution is related to the selective pressures of a rising sea level across the continental shelf. Evolution may occur in any environment on the shelf.

We hypothesize that shelf species become increasingly stressed during sea level fall and that selective extinctions may occur. The disruption of species populations during low stand of sea level may create the potential for selection to occur as sea level begins to rise. Broader and more extensive environments develop as the sea increas-

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Fig. 4. 1a–c: Gavelinella texana (Cushman), 1a. spiral view, 1b. umbilical view, 1c. edge view, from BTMA Well, Santonian, ×100; 2a–c: Gavelinella compressa (Olsson), 2a. spiral view, 2b. umbilical view, 2c. edge view, from BTMA Well, middle Campanian, ×100; 3a–c: Gavelinella infrequens (Morrow), 3a. umbilical view, 3b. edge view, 3c. spiral view, from BTMA Well, Santonian, ×100; 4: Gavelinella dumblei (Applin), from BTMA Well, umbilical view, upper Campanian, ×100; 5a–c: Gavelinella pinguis (Jennings), 5a. spiral view, 5b. umbilical view, 5c. edge view, from BTMA Well, Maesticrian, 1a, c ×100, 1b ×80.
ingly floods the continental margin. Adaptive strategies of the more stressed species may lead to evolutionary change in the newly emerging environments.

Depositional sequences, therefore, provide an excellent framework within and between which to study evolution of benthic foraminifera. Paleo slope transect studies applied to sequences allow a broad range of environments to be analyzed so that lineages of species can be studied within the environments to which they were adapted. It would appear that this approach will provide many opportunities to compare evolution of benthic species within and between basins on a wide regional scale.

SYSTEMATICS

All figured specimens are deposited in the Department of Geological Sciences, Rutgers University, New Brunswick, New Jersey.

Family Verneulinidae
Genus Clavulina Cushman, 1926
Clavulina trilatera Cushman, 1926
Fig. 5-5

Remarks.—Clavulina trilatera is identified by its triangular test, distinct angles and nearly horizontal sutures.

Occurrence.—Clavulina trilatera is a very common species in the Upper Cretaceous of the Gulf Coast, Navarro and Taylor Groups. In the BTMA Well it is common in the Campanian and Maestrichtian (Sequences UZA 3.1–4.5).

Genus Gaudryina d’Orbigny 1839
Gaudryina rudita Sandidge, 1932
Fig. 5-8

Gaudryina rugosa d’Orbigny. Cushman, 1931, p. 20, pl. 1, figs. 9–10.

Remarks.—Gaudryina rudita is characterized by its short and small triserial portion, a much longer biserial portion, and a broad apertural end.

Occurrence.—Gaudryina rudita is a very common species in the Navarro and Taylor of the Gulf Coast. In the BTMA Well the species is most common in the Campanian (Sequences UZA 3.5–4.3).

Genus Pseudogaudryinella Cushman, 1936
Pseudogaudryinella capitosa (Cushman)
Fig. 5-6

Pseudogaudryinella capitosa Cushman, 1933, p. 52, pl. 5, figs. 8a–e.
Pseudogaudryinella capitosa Cushman, 1937, p. 139, pl. 19, fig. 12

Remarks.—G. capitosa Cushman is identified in having indistinct chambers in the early portion and a rather smooth face of the triangular portion. Sutures are indistinct and slightly depressed.

Occurrence.—G. capitosa has been reported from various parts of the Taylor and Austin of the Gulf Coast. The species is most characteristic of the Campanian (Sequences UZA 3.5–4.3) in the BTMA Well.

Family Valvulinidae
Genus Arenobulimina Cushman, 1927
Arenobulimina americana Cushman, 1936
Fig. 5-7
Arenobulimina presti (Reuss). Cushman, 1931, p. 303, pl. 34, figs. 13a–b.
Arenobulimina americana Cushman, 1936, p. 44, pl. 4, figs. 9a–b.

Remarks.—Arenobulimina americana Cushman is characterized by its short and broad test, truncate aperture and last-formed whorl making almost the entire surface of the test.

Occurrence.—A. americana is widely distributed in the Cretaceous of the Gulf Coastal Plain. In the BTMA Well it appears in the Santonian (Sequences UZA 3.2–3.3).

Genus Pernerina Cushman, 1933
Pernerina redbankensis Oslosson, 1960
Fig. 5-10
Pernerina redbankensis Oslosson, 1960, p. 8, pl. 1, figs. 22, 23.

Remarks.—This species is identified by its small, subspherical test, flattened apertural face and internal pillars.

Occurrence.—P. redbankensis was originally reported from the Maestrichtian Redbank Formation of the New Jersey coastal plain. It occurs in the Maestrichtian (Sequences UZA 4.4–4.5) in the BTMA Well.

Family Nodosariidae Ehrenberg, 1839
Genus Kyphopyx Cushman, 1929
Kyphopyx christneri (Carsey)
Fig. 5-9
Frondicularia christneri Carsey, 1926, p. 41, pl. 6, fig. 7.
Kyphopyx christneri (Carsey). Cushman, 1929, p. 1, pl. 1, figs. 1–7.

Remarks.—Kyphopyx christneri is identified in having a heart-shaped test with chambers overlapping chevron-shaped adult chambers, and plate-like sutures.

Occurrence.—K. christneri ranges from the Austin Chalk to the Taylor Marl in the Gulf Coastal Plain. In the BTMA Well the species occurs most frequently in the Campanian (Sequence UZA 3.5).

Genus Lenticulina Lamarck, 1804
Lenticulina pseudeocans (Cushman)
Fig. 5-12
Robulus pseudeocans Cushman, 1938a, p. 32, pl. 5, fig. 3.

Remarks.—Lenticulina pseudeocans is identified by its strongly umbonate test, acute and keeled periphery, and distinct and raised sutures:

Occurrence.—Lenticulina pseudeocans has been reported from the Gulf Coast Navarro Group. In the
BTMA Well it occurs most commonly in the Campanian
(Sequences UZA 3.5–4.3)

Superfamily Buliminacea Jones, 1875
Family Turrilinidae Cushman, 1927
Genus Praebulimina Hofer, 1953
Praebulimina caseyroa (Plummer)

Fig. 5-1

Bulimina caseyroa (Plummer), 1931, p. 179, pl. 8, fig. 9.

Remarks.—Praebulimina caseyroa is identified by its
large size and 4 slightly inflated chambers per whorl.

Occurrence.—This species was originally described
from Texas where it occurs in Austin, Taylor and lower
Navarro strata in the Gulf Coast. In the BTMA Well this
species is most typically developed in the Campanian
(Sequences UZA 3.4–4.4).

Praebulimina cushmani (Sandidge)

Fig. 5-1

Bulimina cushmani Sandidge, 1932, p. 280, pl. 42, figs. 18–19.
Praebulimina cushmani (Sandidge). Hofer, 1957, p. 188, figs. 228–229.

Remarks.—Praebulimina cushmani is characterized by
its wide, more robust and more inflated chambers. It
differs from Praebulimina caseyroa by its smaller size
and wider and more flaring test.

Occurrence.—This species was originally described
from the Upper Cretaceous Ripley Formation of
Alabama. The species is common in the Campanian
(Sequences UZA 3.4–4.3) in the BTMA Well.

Praebulimina kickapooensis (Cole)

Fig. 5-3

Bulimina kickapooensis Cole, 1938, p. 45, pl. 3, fig. 4.

Remarks.—This species is identified by its larger size,
higher, less inflated chambers and chamber arrangement.

Occurrence.—P. kickapooensis was originally described
from the Taylor Marl of Texas. In the BTMA Well this
species is most characteristic of the upper Campanian
and Maestrichtian (Sequences UZA 4.4–4.5).

Praebulimina ventricosa (Brotzen)

Fig. 5-2

Bulimina ventricosa Brotzen, 1936, p. 124, pl. 8, fig. 42, 43.
Praebulimina ventricosa (Brotzen). Hofer, 1957, p. 184, figs. 223a–n.

Remarks.—Praebulimina ventricosa is characterized by
rapidly expanding chambers in the last whorl and the
highly arched aperture.

Occurrence.—Hofer (1957) records this species in the
middle Santonian to the lower Campanian in northwest
Germany andolland. In the BTMA Well the species is
best developed in the Santonian (Sequences UZA 3.2–3.3).

Fig. 6, 1a-b: Rosita forniciata manurenensis (Gandolfi), 1a. spiral view, 1b. umbilical view, from BTMA Well, Campanian, ×100; 2: Rugoglobigerina macrocephala Brönniman, showing spiral view, from BTMA Well, upper Maestrichtian, ×100; 3: Marginotruncana marginata (Reuss), showing spiral view, from BTMA Well, Santonian, ×125; 4: Ventitubrilla browni Martin, from BTMA Well, Santonian, ×100; 6a: c: Gavelinella nelsoni (W. Berry), 6a. spiral view, 6b: umbilical view, 6c. edge view, from BTMA Well, Campanian ×150; 7a-c: Gavelinella tennesseensis (W. Berry), 7a. umbilical view, 7b. spiral view, 7c. edge view, from BTMA Well, Campanian, ×100.

Family Osangularidae Loeblich and Tappan, 1964
Genus Globorotalites Brozten, 1942
Globorotalites subconicus (Morrow)

Fig. 5-11

Globorotalia subconica Morrow, 1934, p. 200, pl. 30, figs. 11a–c.
Globorotalia subconica (Morrow). Ten Dam and Magne, 1948, p. 225,
figs. 4–5.

Remarks.—Globorotalia subconica is characterized by
its planoconvex, subconical test. G. subconicus differs from
G. micheliniana (d’Orbigny) in its smaller size and more lobate periphery.

Occurrence.—G. subconicus occurs in the Taylor marl
and particularly in the upper part of Austin chalk in the
Gulf Coast. In the BTMA Well the species typically
occurs in the Santonian and lower Campanian (Se-
quences UZA 3.2–3.5).

Family Anomalainidae Cushman, 1927
Subfamily Anomalaininae Cushman, 1927
Genus Gavelinella Brotzen, 1942
Gavelinella compressa (Olsson)

Figs. 4a–c

Gavelinella compressa Sliter. Olsson and Nyong, 1984, pl. 2, figs.
15–16.

Remarks.—Gavelinella compressa is characterized by
the small, much compressed, button-shaped test which is
coarsely perforate on the ventral side. Calcification of
the test walls is extensive, closing off pores and building
up along sutures. Olsson and Nyong (1984) inadvertently
recorded this species in the Campanian and Maestrichtian
of New Jersey as G. compressa Sliter. Although very
similar to Sliter’s species from the Campanian of
California, it lacks the dorsal boss of that species.

Occurrence.—In the Campanian and Maestrichtian
of New Jersey G. compressa is present in middle to outer
shelf environments, although in the Middle Paleocene,
where it was described, it ranges into inner shelf paleo-
depths. Thus, the species appears to be broad ranging in
shelf environments, Whether it tolerated oxygen minimum
conditions like its ancestral species G. minima (Vieux) in
the Turonian (Sikora, 1989) can not be established in
this study. Gavelinella compressa occurs in the BTMA
Well in the Santonian to Maestrichtian (Sequences UZA
3.2–4.3).

Gavelinella dumblei (Applin)

Fig. 4.4

Truncatulinida dumblei Applin, in Applin, Ellisor and Kniker, 1925, p. 99, pl. 3, fig. 6.

Remarks.—Gavelinella dumblei is identified in having
a nearly planispiral and much compressed test, very
distinct and numerous chambers and finely perforate
wall. It is larger than Gavelinella texana.

Occurrence.—G. dumblei (Applin) is a very common and
wide spread species in the upper beds of the Taylor
Group in the Gulf Coast. In the BTMA Well the species ranges from the Campanian to lower Maastrichtian (Sequences UZA 3.5–4.4).

Gavelinella infrequens (Morrow)  
Figs. 4-3a-c  
Valvulineria infrequens Morrow, 1934, p. 197, pl. 30, figs. 3a–c.  
Remarks.—Gavelinella infrequens is characterized by a coarsely perforate test with an open umbilicus into which project triangular lips. It is similar to Gavelinella nelsoni but its chambers are less inflated.  
Occurrence.—Gavelinella infrequens is recorded from beds of Austin age (Santonian) in the Gulf Coast. In New Jersey the species ranges from the Turonian to the Santonian (Sequences UZA 2.5–3.3). It is a common form in the Santonian in the BTMA Well.

Gavelinella nelsoni (W. Berry)  
Figs. 6-6a-c  
Anomalina nelsoni W. Berry, in Berry and Kelly, 1929, p. 14, pl. 2, figs. 19–21.  
Remarks.—Gavelinella nelsoni is characterized by its nautiloid coarsely perforate test and broadly rounded periphery. Gavelinella infrequens is similar but has less inflated chambers and a more open umbilicus.  
Occurrence.—G. nelsoni has been recorded in the Gulf Coast as a common species of the Navarro and upper Taylor. In the BTMA Well G. nelsoni is a characteristic species of the Campanian to lower Maastrichtian (Sequences UZA 3.4–4.4).

Gavelinella pinguis (Jennings)  
Figs. 4-5a-c  
Anomalina pinguis Jennings, 1936, p. 37, pl. 5, fig. 1.  
Gavelinella pinguis (Jennings). Olsson and Nyong, 1984, p. 68, pl. 1, figs. 1, 2.  
Remarks.—Gavelinella pinguis is identified in having a coarsely punctate test and inflated chambers. It differs from G. tenesseensis in its larger size and more inflated chambers.  
Occurrence.—G. pinguis was first described from the Maastrichtian of New Jersey where it is a common form. In the BTMA Well it is a common form in the uppermost Campanian and Maastrichtian (Sequences UZA 4.4–4.5).

Gavelinella tenesseensis (W. Berry)  
Figs. 6-7a-c  
Anomalina tenesseensis W. Berry, 1929, p. 13, pl. 12, figs. 13–15.  
Gavelinella pinguis (Jennings). Olsson and Nyong, 1984, p. 68, pl. 1, figs. 3–5.  
Remarks.—Gavelinella tenesseensis is characterized on the basis of its nearly planispiral test with coarsely perforate walls and slightly depressed sutures. It differs from G. pinguis in having much less inflated chambers and by its smaller size.  
Occurrence.—G. tenesseensis has been recorded from the Marlbrook Marl (Campanian) of Arkansas. It is common to abundant in the BTMA Well in the Campanian (Sequences 3.4–4.3).

Gavelinella texana (Cushman)  
Planulina texana Cushman, 1935, p. 69, pl. 12, figs. 3a–c.  
Remarks.—Gavelinella texana is characterized by its flattened, compressed test with a sharply angular to keeled periphery. The wall is finely perforate and the umbilicus is bordered by thickened sutural projections. Gavelinella dumbelei is larger with a tendency to uncoil.  
Occurrence.—G. texana is characteristic of the beds of Austin age in the Gulf Coast. In the BTMA Well this species is common and diagnostic of the Santonian (Sequences UZA 3.2–3.3), but ranges into the Campanian (Sequences 3.4–3.5).

Family Globotruncanidae Broten 1942  
Genus Archeoglobigerina Pessagoon, 1967  
Archeoglobigerina blowi Pessagoon, 1967  
Figs. 7-3a-b  
Remarks.—Archeoglobigerina blowi differs from A. cretacea in having a more lobate outline and only 4 instead of 5 chambers in the last whorl.  
Occurrence.—A. blowi is common in the Santonian and lower Campanian (Sequences UZA 3.2–3.5) of the BTMA Well. It ranges into the upper Campanian (Sequence 4.4).

Archeoglobigerina bosquensis Pessagoon, 1967  
Figs. 7-1a-c  
Archeoglobigerina bosquensis Pessagoon, 1967, p. 316, 317, pl. 60, figs. 10–12.  
Remarks.—Archeoglobigerina bosquensis differs from A. cretacea by its high trochospiral coil and absence of keels, and from A. blowi in having more chambers in the ultimate whorl. In the New Jersey material A. bosquensis shows a distinctive tegilla, although Pessagoon (1967) did not observe any tegilla in the type specimens from the Austin Chalk.  
Occurrence.—Archeoglobigerina bosquensis is common in the Santonian (Sequences 3.2–3.3) in the BTMA Well.

Archeoglobigerina cretacea (d’Orbigny)  
Figs. 7-2a-b  
Globigerina cretacea (d’Orbigny). Banner and Blow, 1960, p. 8–10, pl. 7, figs. 1a–c.  
Remarks.—Archeoglobigerina cretacea differs from A. blowi in having more chambers in the last whorls. The rounded periphery is marked by two faint keels and perforate peripheral bands.  
Occurrence.—Archeoglobigerina cretacea is a common to abundant species in the Santonian and Campanian (Sequences UZA 3.2–4.5) of the BTMA Well. It ranges into the lower Maastrichtian (Sequence 4.4).
Genus *Globotrunca* Cushman, 1927
*Globotrunca linneiana* (d’Orbigny)  
Figs. 7-9a-b
*Rosalina linneiana* d’Orbigny, 1839, pl. 10, figs. 10-12;  
*Globotrunca linneiana* (d’Orbigny). Bronnimann and Brown, 1956, p. 542, pl. 20, figs. 13-15, pl. 21, figs. 16-18.

**Remarks.** — *Globotrunca linneiana* is identified by its flattened test with two raised and widely spaced keels. It differs from *Marginotruncana pseudolinneiana* Pessagno in having an umbilical primary aperture, in the presence of tegilla, and from *G. ventricosa* in having an almost symmetrical biconvex profile.

**Occurrence.** — The stratigraphic range of this species is uppermost Santonian to Maestrichtian. It is common in the Campanian to lower Maestrichtian of the BTMA Well (Sequences UZA 3.4-4.4).

*Globotrunca bulboides* Vogler, 1941

Figs. 7-14
*Globotrunca linnei* (d’Orbigny) subsp. *bulloides* Vogler, 1941, p. 287, pl. 23, figs. 32-39;  

**Remarks.** — *Globotrunca bulboides* is characterized by its distinctly inflated chamber walls on both the spiral and umbilical sides. This species differs from *G. lapparenti* and *G. linneiana* in the inflation of its chambers and from *Marginotruncana marginata* (Reuss) in having an umbilical aperture and in the presence of a tegilla.

**Occurrence.** — *G. bulboides* has been reported from the upper part of the Santonian to the lower part of the Maestrichtian. In the BTMA Well it is common in the upper Santonian to lower Maestrichtian (Sequences UZA 3.2-4.4).

Genus *Marginotruncana* Hofker, 1956
*Marginotruncana marginata* (Reuss, 1845)  
Fig. 6-3
*Rosalina marginata* Reuss, 1845, p. 36, pl. 13, figs. 18a-b.

**Remarks.** — *Marginotruncana marginata* is distinguished from other species of *Marginotruncana* in having inflated chambers on both sides. This species differs from *G. bulboides*, which has similarly inflated chambers, in the presence of portici.

**Occurrence.** — In the BTMA Well the species occurs in the Santonian and lower Campanian (Sequences 3.2-3.5). It is common and more typically developed in the Santonian sequences.

*Marginotruncana pseudolinneiana* Pessagno, 1967  
Fig. 6-5

**Remarks.** — *Marginotruncana pseudolinneiana* is identified by having a flattened test, an umbilical and extra-umbilical primary aperture and two closely spaced keels. *Globotrunca linneiana* has a well-developed tegilla and two widely spaced keels.

**Occurrence.** — *Marginotruncana pseudolinneiana* is typically developed in the Santonian (Sequences 3.2-3.3) in the BTMA Well.

Genus *Rosita* Robaszynski, Caron, Gonzalez, and Wonders, 1984
*Rosita fornicata manuarensis* (Gandolfi)  
Figs. 6-1a-b
*Globotruncana fornicata manuarensis* Gandolfi, 1955, p. 41, pl. 2, figs. 1a-c; Barr, 1973, pl. 7, figs. 2a-c.

**Remarks.** — This subspecies of *R. fornicata* is characterized by its narrow crescent-shaped chambers and its two closely spaced keels.

**Occurrence.** — Barr shows this subspecies to have a Santonian (lower Campanian) to middle Campanian range. In the BTMA Well the subspecies occurs in the Santonian to middle Campanian (Sequences UZA 3.2-4.3).

Genus *Rugoglobigerina* Brönnimann, 1952
*Rugoglobigerina macrocephala* Brönnimann  
Fig. 6-2
*Rugoglobigerina macrocephala* Brönnimann, 1952, p. 25, pl. 2, figs. 1-3.

**Remarks.** — *Rugoglobigerina macrocephala* differs from other species of *Rugoglobigerina* in the rapid increase in the size of chambers. The last whorl is characterized with 4 chambers. The last chamber forms about half of the volume of the test.

**Occurrence.** — *R. macrocephala* is well developed in the upper Maestrichtian (Sequence UZA 4.5) in the BTMA Well.

Genus *Ventilabrella* Cushman, 1928
*Ventilabrella browni* Martin, 1972  
Fig. 6-4
*Ventilabrella browni* Martin, 1972, p. 85, pl. 1, figs. 3, 4; Petters, 1977, pl. 2, fig. 3.

**Remarks.** — This species is identified by heavy longitudinal costae and the coarsely perforate test.

**Occurrence.** — Martin described *V. browni* from the lower Taylor Marly (Campanian) of Texas and records its stratigraphic distribution in the lower and middle Campanian of the Gulf Coast. Petters (1977) first identified this species in the Santonian of New Jersey. In the BTMA Well, *V. browni* ranges from the Santonian into the lower Campanian (Sequences UZA 3.2-3.5). Martin suggests that *V. browni* evolved from the heterohelicid genus *Sigalia* and in turn gave rise in the Campanian to *V. glabrata* Cushman.

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