Biostratigraphy of the Middendorf Formation (Upper Cretaceous) in a Corehole at Myrtle Beach, South Carolina

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Prepared in cooperation with the South Carolina Water Resources Commission

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By GREGORY S. GOHN, HARRY J. DOWSETT, and NORMAN F. SOHL

Prepared in cooperation with the South Carolina Water Resources Commission

Biostratigraphic analysis of Santonian microfaunas and macrofaunas in a subsurface marine facies of the Middendorf Formation

U.S. GEOLOGICAL SURVEY BULLETIN 2030

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Biostratigraphy of the Middendorf Formation (Upper Cretaceous) in a Corehole at Myrtle Beach, South Carolina

By Gregory S. Gohn, Harry J. Dowsett, *and* Norman F. Sohl

Abstract

This report describes the biostratigraphy and generalized lithostratigraphy of a subsurface marine facies of the Upper Cretaceous Middendorf Formation encountered in a corehole drilled at Myrtle Beach, South Carolina. Whereas most outcrop and subsurface sections of the Middendorf Formation consist of fluvial to marginal-marine sediments containing few if any calcareous fossils, the section at Myrtle Beach contains abundant planktic foraminifers, calcareous nannofossils, ostracodes, and macroinvertebrates. The corehole section of the Middendorf consists of two lithologic subunits, a lower section of dense, olive-gray, calcareous silty clay (68 ft thick) and an upper section of calcareous, clayey and silty, fine sand containing abundant bivalves (45 ft). An overlying 15 ft of grayish-olive-green, calcareous, silty and sandy clay is assigned to the Shepherd Grove Formation.

Planktic foraminifers from the lower calcareous clay include *Dicarinella concavata*, *Globotruncana arca*, *Globotruncana linneiana*, *Marginotruncana marginata*, and *Rosita fornicata*. These species indicate assignment of the Middendorf to the chronozones of the *Dicarinella concavata* Zone and the *Dicarinella asymetrica* Zone. The presence of the nannofossil *Lithastrinus septenarius* in the same interval indicates assignment to the chronozones of zones CC13 through CC16 (undifferentiated) of Perch-Nielsen (1985). The Santonian oyster *Ostrea cretacea* is abundant in the macrofossiliferous fine sand in the upper part of the formation. The ostracodes *Brachycythere nausiformis*, *Veenia quadrialira*, *Schizoptocythere*? *compressa*, and "*Cythereis*" *veclitella* indicate assignment of the Middendorf section to the chronozone of the *Veenia quadrialira* Zone of Hazel and Brouwers (1982). The presence of these species and chronozones and the absence of the single-keeled foraminiferal genus *Globotruncanita* and the nannofossil *Aspidolithus parcus* indicate a Santonian age for the Middendorf Formation at Myrtle Beach. The transition from microfossiliferous marine clays in the lower part of the Middendorf to nearshore oyster-rich sands in the upper part indicates a general shoaling-upward trend within the unit.

Manuscript approved for publication April 13, 1992.

INTRODUCTION

Calcareous fossils rarely are reported from the Upper Cretaceous Middendorf Formation of South Carolina. Of the existing reports, most refer to limited occurrences of fossils in marginal-marine beds. Now, however, an uncommon opportunity to study abundant calcareous fossils from a fully marine section of the Middendorf Formation is afforded by a continuously cored test hole drilled by the South Carolina Water Resources Commission (SCWRC) at Myrtle Beach, Horry County (fig. 1). In this report, we discuss planktic foraminifers, calcareous nannofossils, ostracodes, and macroinvertebrates from the Middendorf Formation of the Myrtle Beach core, following a brief review of the regional stratigraphy of that unit and a description of the Middendorf section in the core.

The Myrtle Beach corehole (SCWRC–5S–f1; USGS–HO–973) was drilled to a depth of 1,427 ft below a surface elevation of approximately 20 ft. Upper Cretaceous sediments constitute the entire corehole section between the top of basement-rock saprolite at 1,397 ft and the base of a surficial-sand unit at 80 ft (Brenda Hockensmith, SCWRC, written commun., 1989). The drill site is located at the Myrtle Beach water treatment plant near the intercoastal waterway in the northeastern quarter of the Myrtle Beach 7.5-min quadrangle (fig. 2).

Acknowledgments

We are indebted to Joffre Castro (SCWRC) for providing access to the SCWRC Myrtle Beach core. We also wish to thank Brenda Hockensmith (SCWRC) for allowing us to review her lithologic descriptions of the core. Thanks are also extended to U.S. Geological Survey (USGS) Volunteer-for-Science Xenedee Bradley for prepar-

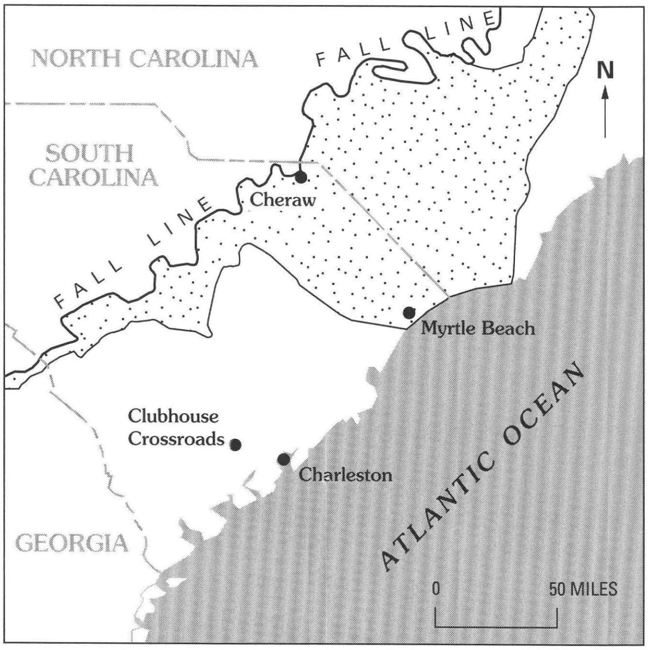

Figure 1. Regional map showing localities in the South Carolina Coastal Plain discussed in the text. The Cretaceous outcrop belt is stippled.

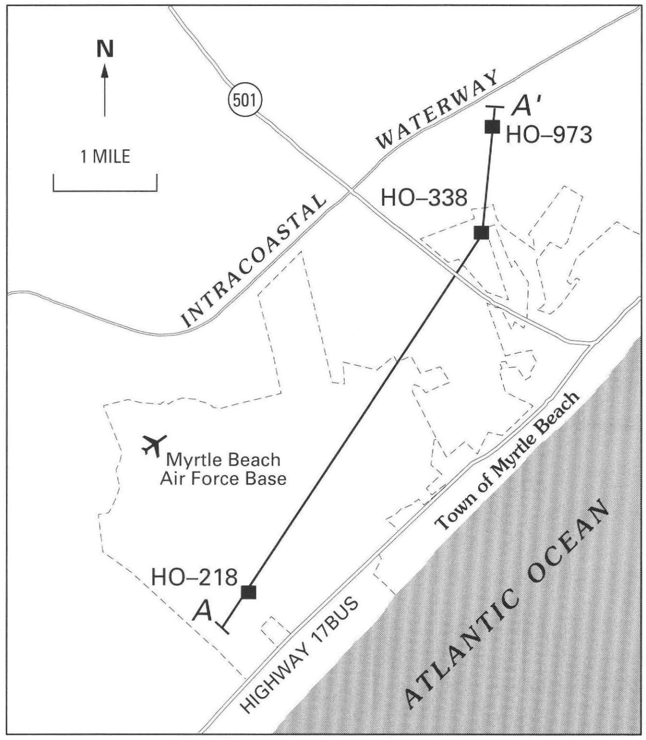

Figure 2. Location of the HO–973 corehole and two water wells, HO–338 and HO–218, in the Myrtle Beach area. Section *A–A'* is shown in figure 4.

ing the ostracode samples, to G. Lynn Wingard (USGS) for the scanning electron microscope (SEM) photographs of the ostracodes and mollusks, and to Kevin Foley (USGS) for the SEM photographs of the planktic foraminifers. Larry Harrelson (USGS) was of inestimable help in sampling the SCWRC core.

REGIONAL STRATIGRAPHY

The modern definition of the Middendorf Formation in the Cretaceous outcrop belt of North Carolina and South Carolina (fig. 1) was established primarily by Heron (1958) and Swift and Heron (1969), although this name had been applied intermittently to parts of the Cretaceous section in the Carolinas for decades (Sloan, 1907; Berry, 1914; Cooke, 1926; Dorf, 1952). Typical descriptions for outcrop sections of the Middendorf (for example, Swift and Heron, 1969; Woollen and Colquhoun, 1977; Sohl and Owens, 1991) refer to interbedded, noncalcareous clayey sands, sandy and silty clays, and quartz-pebble and clay-clast conglomerates, all of which occur in layers that tend to have lens or channel geometries. The most common sediment colors are light gray, white, and a variety of oxidation colors, although darker gray beds are locally present.

Swift and Heron (1969) considered the Middendorf sediments to be a fluvial facies that grades downdip into a marginal-marine facies represented by outcropping sediments now assigned to the Black Creek Group. However, Siple and others (1956), Woollen and Colquhoun (1977), Pavich and others (1980), and Owens (1989) indicated or implied marginal-marine (estuarine or delta-plain) paleoenvironments for the outcropping Middendorf in South Carolina on the basis of burrows, physical sedimentary structures, and sparse microfossils.

Recent regional studies tend to support the idea of lateral facies changes involving Middendorf sediments (Owens and Gohn, 1985; Gohn, 1990, 1992; Sohl and Owens, 1991) but in a manner different from that suggested by Swift and Heron (1969). In more recent reports, the concept of the Middendorf Formation is extended to include all of the sedimentary facies that are laterally contiguous and contemporaneous with the fluvial to marginal-marine facies of the traditional outcropping Middendorf Formation. That is, the Middendorf Formation, as used here, includes all the laterally and vertically gradational facies of a temporally unique sedimentary system and may consist locally of fluvial, marginal-marine, or marine facies. These facies constitute presently undefined stratigraphic subunits of member rank within the Middendorf Formation.

Lithologically similar but stratigraphically higher and demonstrably younger sedimentary systems (sets of contiguous facies) constitute the Black Creek Group above the Middendorf in the outcrop belt (Owens, 1989; Owens and Sohl, 1989). In the subsurface near Charleston (fig. 1), two marine units, the Shepherd Grove Formation and the overlying Caddin Formation, are present between the Middendorf and the Black Creek Group (Gohn, 1992). Below the Middendorf, the Cape Fear Formation is a distinctive unit that everywhere consists of oxidized sands and clays arranged in multiple fining-upward cycles. Each cycle consists of a lower clayey, feldspathic quartz sand or gravelly sand that rests on an erosional contact and grades upward into an overlying red-brown silty and sandy clay (Heron and others, 1968; Fallaw and others, 1990; Gohn, 1992).

MIDDENDORF FORMATION IN THE MYRTLE BEACH CORE

The contacts of the Middendorf Formation in the Myrtle Beach core are provisionally placed at depths of 961 ft and 848 ft; as a result, the formation thickness is estimated to be 113 ft (fig. 3). The lower contact separates greenish-gray, abundantly microfossiliferous, calcareous silty clay of the Middendorf from oxidized, reddish and brownish clays and poorly sorted sands of the underlying Cape Fear Formation. The upper contact is between macrofossiliferous clayey sand of the Middendorf and gray-green, moderately fossiliferous, calcareous silty clay of the overlying Shepherd Grove Formation.

The Middendorf section at Myrtle Beach consists of two lithologic subunits. Dense, olive-gray to dark-greenish-gray, dominantly massive to bioturbated, calcareous silty clay is present from the basal contact at 961 ft to about 893 ft. This 68-ft-thick clay contains abundant foraminifers, calcareous nannofossils, and ostracodes but only sparse macrofossils. Laminations of quartz silt and very fine sand are sparse near the base but increase upward in this interval.

Between 893 ft and the upper contact at 848 ft, the Middendorf consists of 45 ft of dark-greenish-gray to olive-gray to medium-dark-gray, macro- and microfossiliferous, clayey and silty, very fine to fine sand. The abundant macrofauna in this interval is dominated by small oysters that are locally concentrated in shell beds, some of which are indurated. Ostracodes are moderately abundant in this interval; however, benthic foraminifers are less common than below 893 ft, and planktic foraminifers are very sparse.

Above 848 ft, a 15-ft-thick section of grayish-olive-green, calcareous, silty and (very fine) sandy clay is assigned to the Shepherd Grove Formation. This clay contains trace amounts of silt- and sand-size lignitic plant material, mica, pyrite, sparse mollusk fragments, and moderately common ostracodes; no foraminifers were noted. This Shepherd Grove clay is similar lithically to the clay in the lower part of the Middendorf Formation but has a significantly reduced faunal and floral diversity and abundance.

The distribution of the Middendorf Formation and Shepherd Grove Formation, and parts of the Cape Fear Formation and Black Creek Group, in the immediate Myrtle Beach area is shown on the cross section in figure 4. The marine clay in the lower part of the Middendorf is continuous across the section and is seen on the spontaneous potential logs to grade upward into the macrofossiliferous sands. These locally cemented, oyster-rich sands at the top of the Middendorf are readily discerned on the electric logs by their high electrical resistivities (and, where cemented, by high acoustic velocities on sonic logs). The fine-grained Shepherd Grove section above the Middendorf shows considerable variation in thickness along the line of section, probably owing to erosion along the base of overlying sandy basal deposits of the Black Creek Group. Clayey, nodular, glauconitic quartz sand that characterizes the Caddin Formation between the Shepherd Grove and the Black Creek in the Charleston area (Gohn, 1992) apparently is absent (eroded?) at Myrtle Beach. Low-resistivity sands and intervening clays characterize the Cape Fear section. The 15-ft-thick fining-upward cycle at the top of the Cape Fear in the HO–973 corehole is particularly well displayed on the electric log (fig. 4).

PALEONTOLOGY

Previous Work

The only report of calcareous fossils from a Middendorf Formation outcrop in South Carolina is by Siple and others (1956). These authors (p. 1757) reported "a scarce, depauperate fauna" of foraminifers from a section of black, carbonaceous clay and interbedded coarse sand of the Middendorf (their Tuscaloosa Formation) near Cheraw (fig. 1). They considered this fauna to indicate a "basal Austin" or earlier Late Cretaceous age. Although Siple and others (1956) assigned this section to the Tuscaloosa Formation, it is now included in the Middendorf Formation on the regional map of Owens (1989); few, if any, modern workers still apply the name "Tuscaloosa" to outcrop sections in the Carolinas.

Calcareous fossils are somewhat more common in subsurface Middendorf sections. Hazel and others (1977), Hattner and Wise (1980), and Valentine (1982) reported mollusks, calcareous nannofossils, and sparse foraminifers and ostracodes from marginal-marine sediments in the upper part of the Middendorf Formation (as revised by Gohn, 1990, 1992) of the USGS-Clubhouse Crossroads #1 corehole, southern Dorchester County (fig. 1). Collectively, these fossils indicate a Santonian age for the Middendorf at Clubhouse Crossroads (Gohn, 1992). However, there are no reports of calcareous fossils from Middendorf sections in other stratigraphic test holes in South Carolina, and calcareous fossils in water-well cuttings from probable Middendorf sections are known only from a few wells (Boylan, 1982; Valentine, 1982).

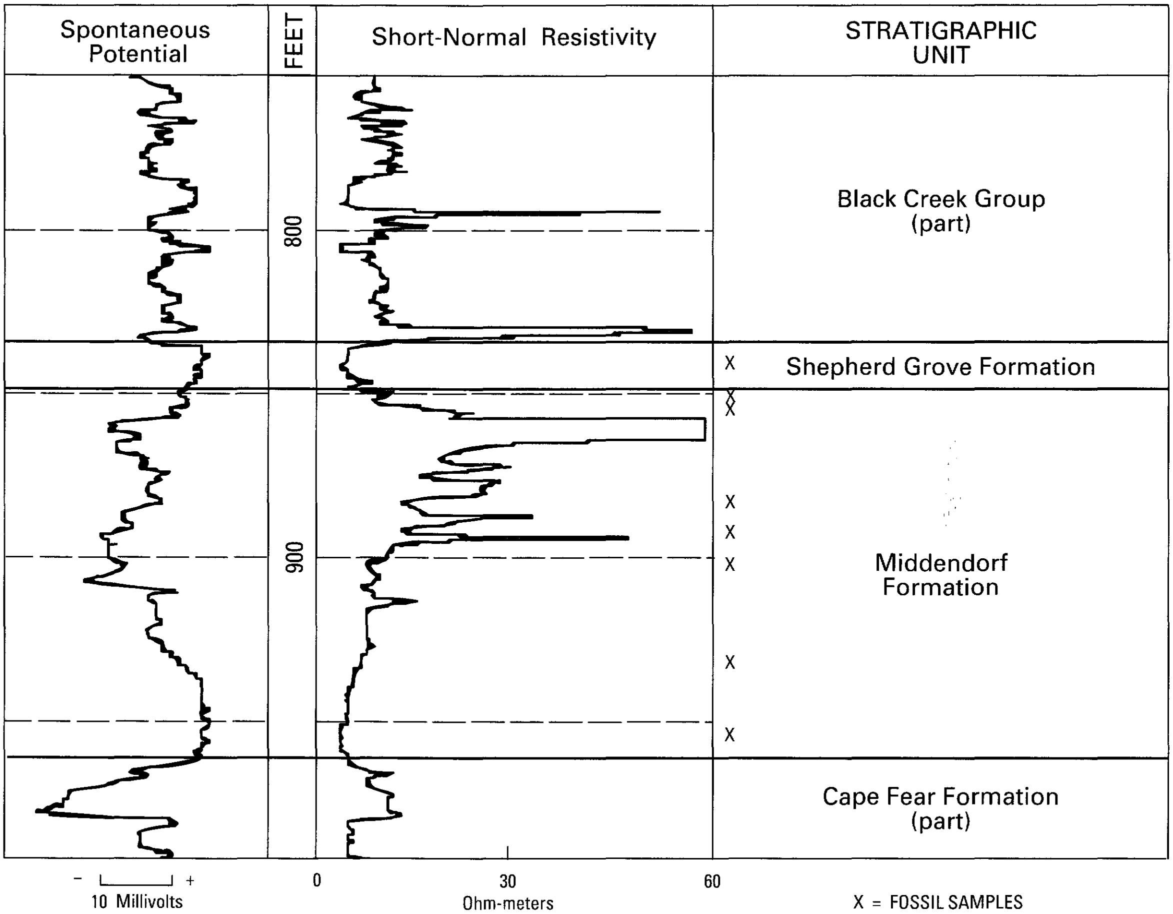

Figure 3. Electric log, sample distribution, contacts, and nomenclature for the Middendorf Formation and associated stratigraphic units in the Myrtle Beach core.

In contrast, palynologic studies have proved to be a reliable method for biostratigraphic analysis of the Middendorf Formation in outcrops and the subsurface. Several studies now assign the Middendorf to pollen zone V throughout the Carolinas and Georgia (Christopher and others, 1979; Christopher, 1982a; Prowell and others,1985). Pollen zone V, which Christopher (1979) divided into three formal zones, is Coniacian and Santonian in age (Christopher, 1982b; Gohn, 1992). At Myrtle Beach, pollen zone V occurs in cuttings at and below the 969- to 953-ft interval (highest studied sample) in the 10th Avenue water well (HO–338, fig. 4) located about 1 mi south of the HO–973 corehole (R.A. Christopher, data used in Gohn and others, 1978). We assign the 964- to 854-ft interval in the 10th Avenue well to the Middendorf Formation.

Planktic Foraminifers and Calcareous Nannofossils

Planktic foraminifers were studied in three samples from the lower marine clay of the Middendorf Formation (table 1), and calcareous nannofossils were studied in three Middendorf samples and one Shepherd Grove Formation sample. The foraminifers are moderately abundant and well preserved at 952.5 ft and 927.0 ft but are less abundant at 900.0 ft. Calcareous nannofossils are moderately abundant, are diverse, and show fair preservation at 952.5 ft and 900 ft, whereas they are distinctly less abundant and diverse, and significantly less well preserved, at 848.5 ft and at 837 ft in the Shepherd Grove Formation.

Foraminiferal genera in the Middendorf include *Archaeoglobigerina*, *Dicarinella*, *Globotruncana*, *Hedbergella*, *Heterohelix*, *Marginotruncana*, and *Rosita*. Following the zonation of Caron (1985), the presence of *Dicarinella concavata* with *Rosita fornicata* at 952.5 ft places this sample within the upper part of the chronozone of the *Dicarinella concavata* Zone or the lower part of the chronozone of the *Dicarinella asymetrica* Zone. The presence of *Globotruncana arca* with *D. concavata* and *R. fornicata* at 927.0 ft restricts this sample to the middle of the chronozone of the *Dicarinella asymetrica* Zone. The absence of *D. concavata* and the presence of *Globotruncana linneiana* with *Marginotruncana marginata* place the

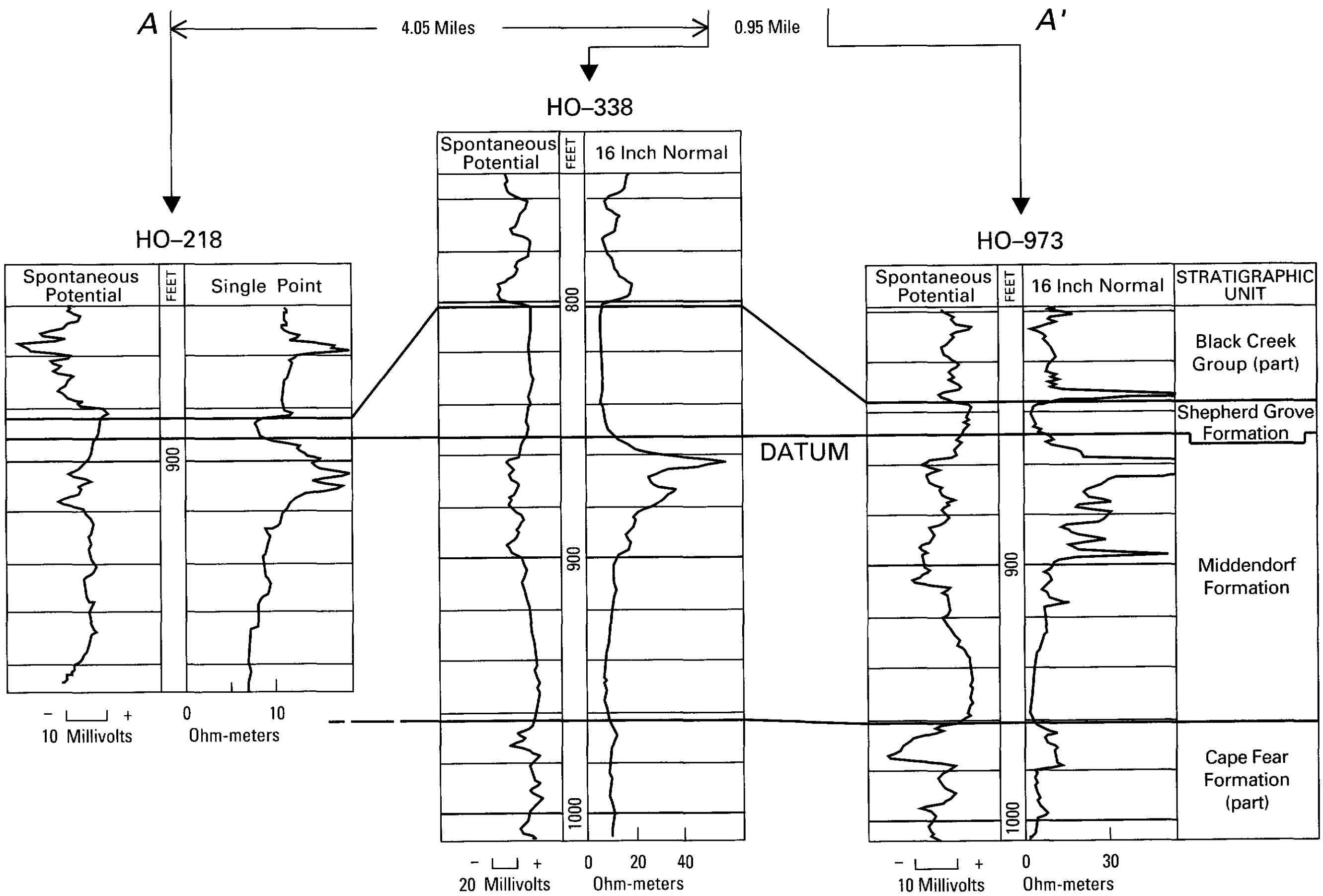

Figure 4. Electric-log cross section showing the distribution of the Cape Fear Formation (part), Middendorf Formation, Shepherd Grove Formation, and Black Creek Group (part) in corehole HO–973 and two water wells drilled at Myrtle Beach. The location of the cross section is shown in figure 2; depths are in feet. Drill hole HO–973 is the cored section described in this report. Datum is the Middendorf-Shepherd Grove contact.

900.0-ft sample in the upper part of the chronozone of the *Dicarinella asymetrica* Zone.

The ages of these foraminiferal zones, and the ages of the calcareous nannofossil and ostracode zones discussed in following sections, depend in large part upon which biostratigraphic datum is chosen to mark the Santonian-Campanian Stage boundary. Foraminiferal zonations published during the past decade are about evenly divided between using the first appearance datum of the single-keeled genus *Globotruncanita* (and particularly the first appearance of *G. elevata*) or the younger extinction datum of the genus *Dicarinella* (and particularly *D. asymetrica*) to mark the stage boundary. Among nannofossil workers, the first appearance of *Aspidolithus parcus* is frequently taken to indicate the Santonian-Campanian boundary. Dowsett (1989) recently considered the distribution of these and other planktic species relative to the stage boundary and included their distribution in the European stratotypes of the Santonian and Campanian Stages. We follow his preference for using the first appearance datum of *Aspidolithus parcus*, which occurs between the two foraminiferal datums, to mark the stage boundary.

Accordingly, the Middendorf samples at 952.5 ft and 927.0 ft assigned to the upper *Dicarinella concavata* or lower to middle *Dicarinella asymetrica* chronozones are of Santonian age. The sample at 900.0 ft assigned to the upper part of the *Dicarinella asymetrica* chronozone is early Campanian in age. Alternatively, the decreased abundance of foraminifers at 900.0 ft, compared to lower in the Middendorf, and the general shoaling-upward nature of the section, suggests that *Dicarinella concavata* may be absent at 900.0 ft only for environmental reasons. In that case, the entire marine clay in the lower part of the Middendorf would be Santonian. The presence of *Heterohelix reussi* in all three samples also supports a Santonian (or older) age (table 1), according to some authors (for example, Caron, 1985), but not according to others (for example, Pessagno, 1967).

A Coniacian and Santonian age for at least the lower part of the Middendorf section also is suggested by the

Table 1. Distribution of selected stratigraphically important fossils in a corehole at Myrtle Beach, South Carolina

[Numbers are sample depths in feet. X, present; —, absent. Unmarked columns indicate unstudied samples]

	952.5	927.0	900.0	886.5	876.0	851.0	848.5
Foraminifers							
Archaeoglobigerina cretacea	X	—	—				
Dicarinella concavata	X	X	—				
Globotruncana arca	—	X	—				
Globotruncana linneiana	—	—	X				
Heterohelix reussi	X	X	X				
Marginotruncana marginata	X	—	X				
Rosita fornicata	X	X	X				
Calcareous nannofossils							
Calculites ovalis	X		X				
Eiffellithus eximius	X		X				
Lithastrinus septenarius	X		X				
Marthasterites furcatus	X		X				
Mollusks							
Anomia argentaria					X	—	—
Camptonectes sp.					—	—	X
Lima acutilineata?					—	X	—
Lima cf. L. oxypleura					X	X	—
Lima sp.					—	—	X
Ostrea cretacea					X	X	X
Ostracodes							
Asciocythere macropunctata	—	—	—	—			X
Brachycythere nausiformis	X	X	X	X			X
"*Cythereis*" *veclitella*	X	—	—	—			—
Schizoptocythere? *compressa*	X	—	—	—			X
Veenia quadrialira	X	X	X	X			—

calcareous nannoflora. Samples at 952.5 ft and 900 ft contain *Lithastrinus septenarius* in addition to other species, some of which are listed in table 1. Perch-Nielsen (1985) restricts *L. septenarius* (seven-rayed species of *Lithastrinus*) to her Coniacian and Santonian zones CC13 through CC16. The absence of *Aspidolithus parcus* in these samples and at 848.5 ft and 837 ft also supports an age older than Campanian for the Middendorf Formation and the lower part of the Shepherd Grove Formation, although the poor preservation and low diversity of the nannofloras in the two higher samples make this assertion questionable in part.

Regionally, Dowsett (1989) recorded the *Dicarinella asymetrica* Zone in the Tombigbee Sand Member of the Eutaw Formation and in the basal part of the overlying Mooreville Formation (with *Aspidolithus parcus*) at Plymouth Bluff, eastern Mississippi (also see Smith and Mancini, 1983). Planktic foraminifers of Santonian age rarely are reported from the Atlantic Coastal Plain, due in large part to the predominantly marginal-marine nature of Santonian sediments throughout this province. An exception is Zarra's (1989) report of *Dicarinella concavata*, *D. primitiva*, and additional species of *Dicarinella* and *Marginotruncana* from the subsurface of eastern North Carolina.

Ostracodes

Ostracodes were examined from six Middendorf Formation samples and one Shepherd Grove Formation sample (837 ft) of the Myrtle Beach core (table 1). Specimens are well preserved and abundant in all six samples; at the lower three depths, hundreds of valves were recovered from dry samples as small as 100 g.

Stratigraphically important species in the Middendorf samples include *Brachycythere nausiformis*, "*Cythereis*" *veclitella*, *Schizoptocythere*? *compressa*, and *Veenia quadrialira* (table 1). These species indicate assignment of the studied Middendorf section to the chronozone of the *Veenia quadrialira* Interval Zone of Hazel and Brouwers (1982; also see Dowsett, 1989). *Brachycythere nausiformis* is restricted to the *Veenia quadrialira* Zone on the range charts of Hazel and Brouwers (1982), and the lowest occurrence of *V. quadrialira* defines the base of that Zone. The lowest occurrence of *S.*? *compressa* is also at the base of the *V. quadrialira* Zone. "*Cythereis*" *veclitella* occurs throughout this Zone and in the over- and underlying zones.

Most of the Middendorf and Shepherd Grove ostracodes represent undescribed species. The Cytherideidae are represented by several undescribed forms, including three moderate-size species of *Haplocytheridea*. A small suboval species that has large pits and an antimerodont hinge resembles species of *Antibythocypris* and *Clithrocytheridea*, although described Coastal Plain species of these genera are significantly younger than the faunas described here. A large, rounded species that has abundant small pits on the lateral surface and an indistinct dorsomedian sulcus is tentatively assigned here to *Fossocytheridea*? new species 1. In addition to these undescribed forms, three valves of *Asciocythere macropunctata* were found at 848.5 ft.

Two new species of *Fissocarinocythere* also are present. *Fissocarinocythere* new species 1 from the Middendorf is more strongly inflated than *F. pittensis* and is smaller than *F. gapensis*. This new species also differs from these described species in the position of transverse ribs along the ventral surface. The less common *Fissocarinocythere* new species 2 in the Shepherd Grove is similar to *F. gapensis* but also differs in the position of ventral transverse ribs and in other ornamental details. Additional genera represented by undescribed species include *Brachycythere* (two species), *Orthonotacythere*, *Eocytheropteron*, and *Loxochoncha*. Specimens representing several species of *Cytherella* are common to abundant at and below 886.5 ft but are absent at 848.5 ft and very sparse in the Shepherd Grove at 837.5 ft.

Following Dowsett (1989), the first appearance datum of the calcareous nannofossil *Aspidolithus parcus* is equated with a very low position in the *Alatacythere cheethami* Zone above the *Veenia quadrialira* Zone. On this basis, the *Veenia quadrialira* Zone is Santonian in age. Regionally, Hazel and Brouwers (1982, p. 168) placed the "upper part of the unnamed marly chalk of the Austin Group in central Texas," part or all of the Bonham Marl of northeast Texas, and part of the Tokio Formation of southwest Arkansas in the *Veenia quadrialira* Interval Zone. Dowsett (1989) placed the lower part of the Tombigbee Sand Member of the Eutaw Formation in the Mississippi-Alabama border area within the *Veenia quadrialira* Zone.

Swain (1952), Brown (1958), and Brown and others (1972) reported *Brachycythere nausiformis* from numerous drill holes in eastern North Carolina; for example, Brown's (1958) report of *B. nausiformis* in the Clarendon Waterworks well in Wilmington. This distribution of *B. nausiformis*, as well as Zarra's (1989) report of Santonian foraminifers, suggests that marine or marginal-marine facies of the Middendorf are fairly extensive in North Carolina. Indeed the type localities of *Brachycythere nausiformis*, *Veenia quadrialira*, and *Asciocythere macropunctata* are the Esso Standard Oil-Hatteras Light number 1 and number 2 wells in Dare County, N.C. (Swain, 1952).

Macrofossils

Macrofossils were studied in three Middendorf Formation samples from the upper half of the unit (table 1). Mollusks are abundant and well preserved in all three samples, and a variety of other macrofaunal elements also is present.

The oyster *Ostrea cretacea* Morton strongly dominates the mollusk fauna. *Anomia argentaria*, *Camptonectes* sp., and species of *Lima* are present in significantly smaller numbers. A single internal mold of a snail, probably a turritellid, was noted at 851.0 ft. Additional macrofossils include branching and encrusting bryozoa, encrusting and free serpulid worms, *Clione*-sponge and barnacle borings in the oysters, worn bone fragments, fragments of shark and crocodillian teeth, a single barnacle plate (at 848.5 ft), and fish scales.

From a biostratigraphic standpoint, the only significant macrofaunal species is *Ostrea cretacea*. Its type locality is in the Tombigbee Sand Member of the Eutaw Formation at Erie Bluff on the Tombigbee River, Ala. (Stephenson, 1923, p. 135). In western Alabama, *O. cretacea* occurs through about 10 to 15 ft of strata, but eastward in areas near the Chattahoochee River valley in Russell County, it ranges through about 130 ft of section. All of the outcrop occurrences of *Ostrea cretacea* in the eastern Gulf Coastal Plain appear to be in Santonian strata (Sohl and Smith, 1980).

Along the Atlantic seaboard, the only outcrop occurrence of *O. cretacea* is in the Magothy Formation of New Jersey, from which an internal mold of dubious affinities was assigned to this species by Weller (1907, pl. 42, fig. 11). Although this taxonomic assignment cannot be satisfactorily determined, its stratigraphic position in the Cliffwood beds of the Magothy is compatible with its known stratigraphic range elsewhere.

Undoubted specimens of *Ostrea cretacea* have been reported from the subsurface of the Carolinas. Stephenson (1923, p. 136; 1956, p. 240) reported *O. cretacea* in cuttings at and below 1,725 ft from the Charleston Consolidated Railway and Lighting Company well in Charleston, S.C. In North Carolina, he recorded this species from cuttings of the Clarendon Waterworks well, Wilmington, at and below depths of 720 ft, and from 1,365 to 1,380 ft in the Fort Caswell well. The Clarendon well is the same well from which Brown (1958) reported *Brachycythere nausiformis* as high as 840 ft (samples were unavailable to Brown from 840 to 670 ft).

Ostrea cretacea also occurs in cores from a sand in the upper part of the Middendorf Formation (as revised by Gohn, 1992) in the USGS-Clubhouse Crossroads #1 corehole. At Clubhouse Crossroads, *O. cretacea* occurs about 40 ft below the highest occurrence of the nannofossil *Eprolithus floralis* (reported as *Lithastrinus floralis*) in the overlying Shepherd Grove Formation (Hazel and others, 1977; Hattner and Wise, 1980; Gohn, 1992). Perch-Nielsen (1985) placed the highest occurrence of *E. floralis* at the top or within the Santonian. In addition, Valentine (1982, p. 18) reported a "rich Santonian (nannofossil) assemblage" from just below the interval containing *O. cretacea*.

Biostratigraphic Summary

The planktic foraminifers, calcareous nannofossils, mollusks, and ostracodes from the Middendorf Formation of the Myrtle Beach core collectively indicate a Santonian age. The marine clay in the bottom half of the formation yields foraminiferal faunas assignable to the chronozones of the *Dicarinella concavata* and *Dicarinella asymetrica* Zones, nannofloras assignable to the chronozones of zones CC13 through CC16, and ostracode faunas that represent the chronozone of the *Veenia quadrialira* Zone. The chronozone of the *Veenia quadrialira* Zone also is present in the mollusk-rich clayey sands of the upper part of the formation that contain abundant specimens of the Santonian oyster *Ostrea cretacea*. Biostratigraphic correlation of the Middendorf Formation with the Eutaw Formation of Alabama is strongly suggested by comparison of their respective faunas and floras (Sohl and Smith, 1980).

Biofacies and Paleoenvironments

The lithologic and paleontologic information for the Middendorf Formation section at Myrtle Beach suggests an upward trend in sedimentary paleoenvironments from low-energy, offshore-marine sedimentation to higher energy, nearshore-marine deposition. The calcareous marine clay that constitutes the lower part of the formation (961 to 893 ft) contains abundant and diverse planktic faunas and floras and benthic faunas. An upward increase in the quartz sand content and an upward decrease in the abundance of planktic fossils suggest a shoaling transition to the overlying clayey, oyster-rich sands.

The macrofauna in the shelly sands and shell beds between 893 ft and 848 ft suggests a nearshore-marine to perhaps restricted-marine environment of deposition. *Ostrea cretacea* dominates the fauna from this interval, including the fragmented fraction of the studied samples. The amount of fragmented and worn shell material suggests a high-energy regime or at least periodic storm activity. The oyster specimens are about half the size of specimens commonly found in the Alabama outcrop area; this difference suggests an area either of poorer nutrient production or of high sedimentation rate and rapid burial. The low diversity of the assemblages suggests a stressed environment, possibly of lower salinity, but probably not as low as present-day oyster-bank environments. The presence of clionid sponge borings indicates at least occasional periods of near-normal marine salinity.

Marine ostracodes remain abundant in the 893- to 848-ft interval, although the numbers of benthic and planktic foraminifers are distinctly reduced. However, moderate changes in the composition of the ostracode faunas at the generic level are apparent. Species of *Haplocytheridea*, *Veenia*, and *Brachycythere* are still present in some numbers but constitute a lower percentage of the fauna than in the underlying clay. Instead, species of the smooth-valved genus *Cytherella* are the dominant form at 886.5 ft, and the finely pitted species assigned to *Fossocytheridea*? dominates and is restricted to the 848.5-ft sample. Specimens of *Fissocarinocythere* remain common, whereas "*Antibythocypris*" and ornate species of *Cytheropteron* and *Orthonotacythere* appear only at 848.5 ft.

The faunal component of the Shepherd Grove Formation (848 to 833 ft) is significantly reduced from that found in the Middendorf. Unstudied, typically fragmented mollusks are sparse throughout this section, and no foraminifers were noted in the ostracode sample at 837 ft. The ostracode fauna in that sample consists almost entirely of specimens representing two species of *Haplocytheridea*, as well as a few valves of *Fissocarinocythere* and cytherellids. The reduced diversity of this assemblage may indicate a nearshore to perhaps marginal-marine environment.

TAXONOMIC NOTES

Foraminifera

Archaeoglobigerina cretacea (d'Orbigny)

Globigerina cretacea d'Orbigny, 1840, p. 34, pl. 3, figs. 12–14.
Archaeoglobigerina cretacea (d'Orbigny). Pessagno, 1967, p. 317–318, pl. 70, figs. 3–7.

Dicarinella concavata (Brotzen)

Plate 1, figure 3

Rotalia concavata Brotzen, 1934, p. 66, pl. 3, fig. b.
Dicarinella concavata (Brotzen). Robaszynski and Caron, 1979, p. 71–78, pl. 54, figs. 1, 2, pl. 55, fig. 1.

Globotruncana arca (Cushman)

Pulvinulina arca Cushman, 1926, p. 23, pl. 3, fig. 1a–c.
Globotruncana arca (Cushman). Cushman, 1927, p. 169, pl. 28, fig. 15a–c.

Globotruncana linneiana (d'Orbigny)

Plate 1, figures 1, 2

Rosalina linneiana d'Orbigny, 1839, p. 106, pl. 5, figs. 10–12.

Globotruncana linneiana (d'Orbigny). Cushman, 1931, p. 90.

Heterohelix reussi (Cushman)

Plate 1, figures 5, 15

Gumbelina reussi Cushman, 1938, p. 11, pl. 2, fig. 6a, b.
Heterohelix reussi (Cushman). Pessagno, 1967, p. 263, pl. 85, figs. 1–9, pl. 86, figs. 1, 2.

Marginotruncana marginata (Reuss)

Rosalina marginata Reuss, 1845, p. 36, pl. 8, figs. 54a, b, 74a, b.
Marginotruncana marginata (Reuss). Robaszynski and Caron, 1979, p. 107–114, pl. 63, figs. 1, 2, pl. 64, figs. 1, 2.

Rosita fornicata (Plummer)

Plate 1, figure 4

Globotruncana fornicata Plummer, 1931, p. 198, pl. 13, figs. 4–6.
Rosita fornicata (Plummer). Robaszynski, Caron, Gonzalez, and Wonders, 1984, p. 250, pl. 38, figs. 1–5.

Mollusca

Ostrea cretacea Morton

Plate 1, figures 6, 7, 10

Ostrea cretacea Morton, 1834, p. 52, pl. 19, fig. 3. Gabb, 1861, p. 328; Coquand, 1869, p. 52, pl. 23, figs. 3, 4; White, 1884, p. 294; Johnson, 1905, p. 10; (?) Weller, 1907, p. 434, pl. 42, fig. 11; Stephenson, 1923, p. 134, pl. 28, figs. 8–17; Stephenson, 1956, p. 239, pl. 40, figs. 11, 12, pl. 42, figs. 1–17; Richards, 1958, p. 104, pl. 16, fig. 7; Sohl and Smith, 1980, pl. 2, figs. 3, 5.

Remarks.—The specimens of *Ostrea cretacea* from the Myrtle Beach corehole, figured on plate 1, have a shell outline, surface sculpture, hinge area, and adductor scar form and placement that fall well within the range of variability of the species as illustrated by Stephenson (1956). Although the specimens are smaller than those from the outcrop area of the Eutaw Formation figured in Stephenson (1956), they are comparable in size to other specimens assigned to the species from the subsurface of the Carolinas (Stephenson, 1923, pl. 28, figs. 8, 16, and 18).

The stratigraphic range and geographic occurrence of the species are discussed in the section "Macrofossils."

Ostracoda

Brachycythere nausiformis Swain

Plate 1, figure 13

Brachycythere nausiformis Swain, 1952, p. 80, pl. 8, figs. 44–47.
Brachycythere nausiformis Swain. Howe and Laurencich, 1958, p. 88, text fig. on p. 89; Swain and Brown, 1964, p. 28, pl. 3, fig. 3a–c; Hazel and Brouwers, 1982, p. 185, pl. 4, fig. 7, pl. 6, fig. 7.

"Cythereis" veclitella (Crane)

Plate 1, figure 12

Cythereis bicornis veclitella Crane, 1965, p. 219, pl. 6, fig. 6.
"Cythereis" veclitella (Crane). Hazel and Brouwers, 1982, p. 193, pl. 2, fig. 11.

Remarks.—*"Cythereis" veclitella* (Crane), 1965, *"Cythereis" bicornis* (Israelsky), 1929, and related species constitute a distinctive species complex that occurs in Santonian and early Campanian sediments of the Atlantic and Gulf of Mexico Coastal Plains (Hazel and Brouwers, 1982). Quadrate members of this complex having a continuous ventrolateral carina are considered to be *"Cythereis" veclitella* (Crane) (following Crane, 1965).

Fissocarinocythere new species 1

Plate 1, figure 9

Remarks.—Members of this species have a quadrate to elongate-rhombohedral outline; the ventrolateral ridge curves downward at the posterior end and joins with a double row of coarse reticulations along the ventral margin. The species is more strongly inflated than *Fissocarinocythere pittensis*.

Fossocytheridea? new species 1

Plate 1, figure 14

Remarks.—Specimens have a suboval outline and are flattened ventrally. They have a densely and finely pitted lateral surface and a very shallow dorsomedian sulcus. Males (illustrated) are more broadly rounded posteriorly than anteriorly and are distinctly larger than females. This species also occurs in the Eutaw Formation at the Marvyn-Hurtsboro road exposure, northwestern Russell County, Ala. (Sohl and Smith, 1980, p. 400).

Schizoptocythere? compressa (Hazel and Paulson)

Plate 1, figure 11

Pterygocythereis (*Pterygocythereis*) *compressa* Hazel and Paulson, 1964, p. 1061, pl. 157, figs. 5–7; pl. 159, fig. 2; text figs. 2–7.

Schizoptocythere? *compressa* (Hazel and Paulson). Hazel and Brouwers (1982), p. 180, pl. 5, fig. 2.

Veenia quadrialira (Swain)

Plate 1, figure 8

Cythereis quadrialira Swain, 1952, p. 84, pl. 9, figs. 27–30.

Cythereis quadrialira Swain. Howe and Laurencich, 1958, p. 227, text fig. on p. 227; Swain and Brown, 1964, p. 31, pl. 3, fig. 8a–c.

Veenia quadrialira (Swain). Hazel and Brouwers 1982, p. 189, pl. 3, figs. 5, 9; Dowsett, 1989, p. 15, pl. 6, fig. 4.

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PLATE 1

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PLATE 1

[Figures 1–5, 8–9, 11–15, bar = 100 μ; figures 6, 7, and 10, bar = 1 cm]

Figures 1, 2. *Globotruncana linneiana* (d'Orbigny) (p. 8).
1. Umbilical view.
2. Abapertural view.

3. *Dicarinella concavata* (Brotzen) (p. 8).
Apertural view.

4. *Rosita fornicata* (Plummer) (p. 9).
Spiral view.

5, 15. *Heterohelix reussi* (Cushman) (p. 9).
5. Side view.
15 Apertural view

6, 7, and 10. *Ostrea cretacea* Morton (p. 9).
6. Interior view, right valve.
7, 10. Exterior views, right and left valves, respectively.

8. *Veenia quadrialira* (Swain) (p. 10).
Exterior view, left valve.

9. *Fissocarinocythere* new species 1 (p. 9).
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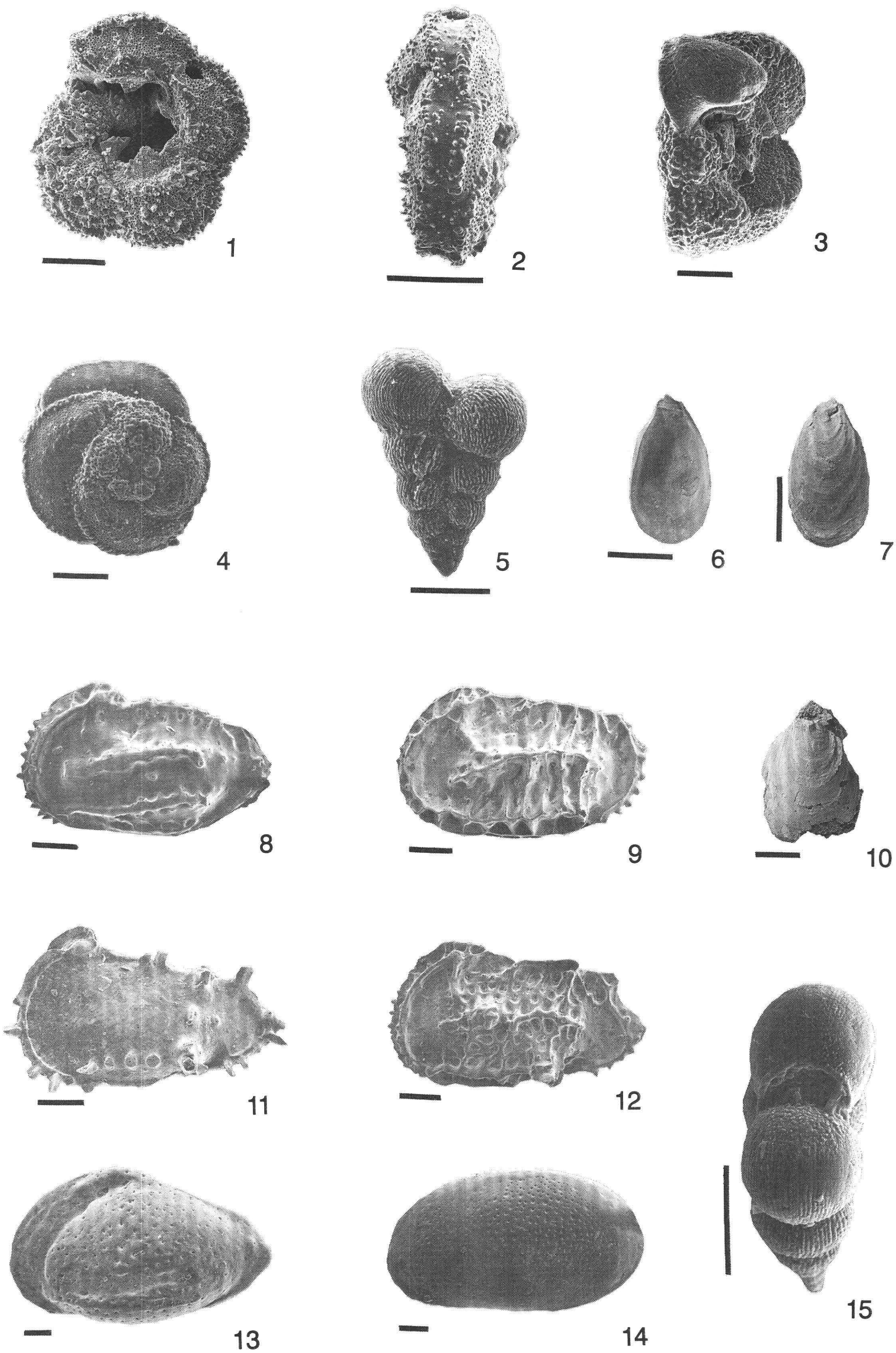
11. *Schizoptocythere*? *compressa* (Hazel and Paulson) (p. 9).
Exterior view, left valve.

12. "*Cythereis*" *veclitella* Crane (p. 9).
Exterior view, left valve.

13. *Brachycythere nausiformis* Swain (p. 9).
Exterior view, left valve.

14. *Fossocytheridea*? new species 1 (p. 9).
Exterior view, left valve.



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