U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES AND THE U.S. DEPARTMENT OF ENERGY - SAVANNAH RIVER SITE

OPEN-FILE REPORT 97-155
SHEET 1 OF 2

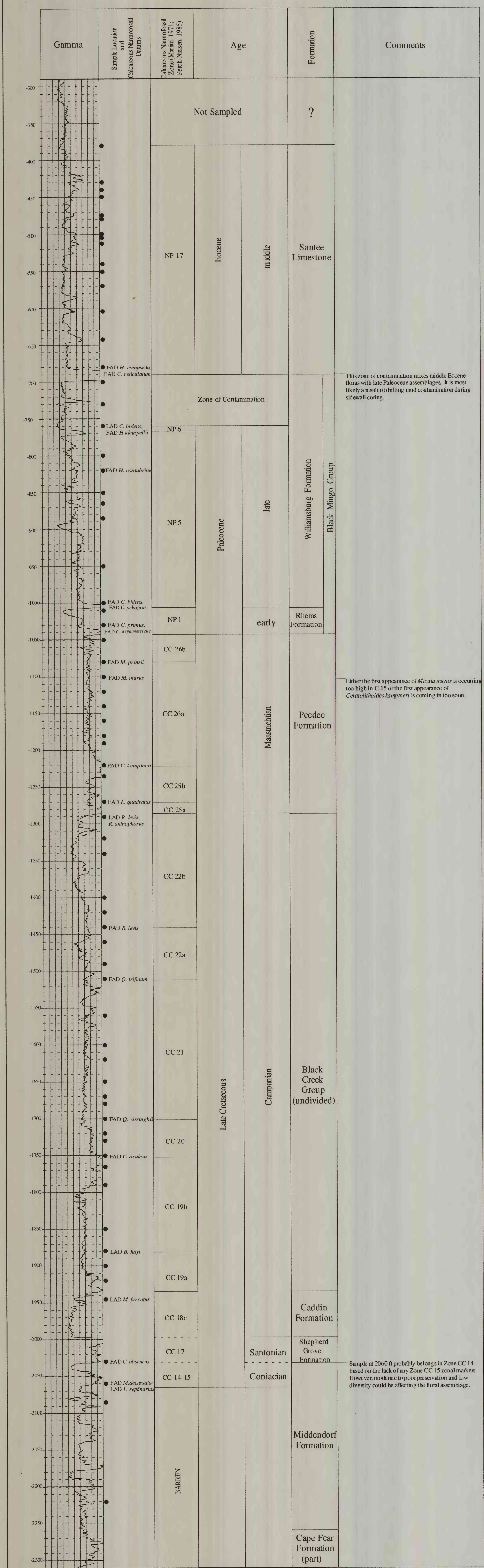

Figure 2. Figure showing the gamma ray log, sampling interval, calcareous nannofossil datums and ages of sediments from Core C-15.

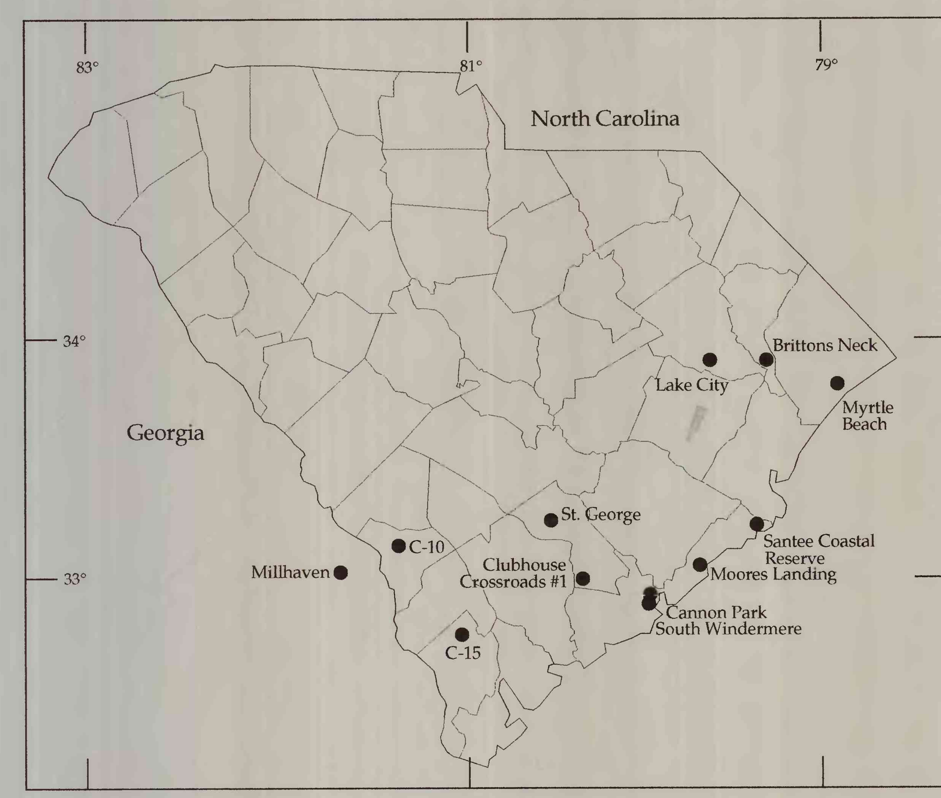

Figure 1. Map showing location of coreholes discussed in text.

The C-15 geohydrologic test hole was drilled in the South Carolina Coastal Plain near Gillisonville, Jasper County, during the Summer of 1996. The hole was drilled by a commercial drilling company for the South Carolina Department of Natural Resources. Funding for this project was provided by the U.S. Department of Energy - Savannah River Site.

The drill site is north of Gillisonville adjacent to Highway 278 at latitude 32°37′04″N and longitude 80°59′45″W (fig. 1), in the northwest corner of the Coosawhatchie 7.5′ quadrangle. The C-15 test was drilled to a total depth of 2,900 ft below a surface elevation of 65 ft. A full suite of commercial geophysical logs was run in the hole.

Samples from the C-15 test consist of drill cuttings and sidewall cores. Eighty-one of the sidewall cores were selected for biostratigraphic analysis by the U.S. Geological Survey. Of these 81 samples, 76 samples ultimately were processed for the study of Cretaceous and Cenozoic calcareous nannofossils. Processed samples between depths of 2,060 and 380 ft typically were productive; processed samples at depths of 2,730, 2,720, 2,700, 2,685, 2,220, 2,085, and 1,010 ft were barren of calcareous nannofossils (fig. 2).

Methods

Due to the paucity of material available from the sidewall cores, smear slides rather than settled slides were prepared for examination. Sample material was extracted from the central portion of each sidewall core (.75 inches in diameter by 1.0 inch long) by means of toothpicks, which decreased the possibility of sample contamination. Coverslips were affixed to the glass slides with Norland Optical Adhesive (NOA), a bonding agent that cures when exposured to ultraviolet light. Despite careful sampling procedures, contamination of some samples did occur. This contamination cannot always be avoided when using the sidewall coring method because the small diameter of the cores allows for easy penetration of drilling fluid, which may contain fossil contaminants. This type of contamination occurred specifically in porous limestone and sandstone units (fig. 2).

Samples were examined using a Zeiss Photomicroscope 3 and Axiophot 2. Standard light microscope techniques (crossed polarizers, transmitted light, phase constrast) were used at magnifications of x500 to x2,000. Preservation and diversity of calcareous nannofossils was generally better in the Cretaceous than in the Tertiary. However, preservation varied significantly due to etching or recrystallization, even within a specific sample. A simple code system is used to characterize preservational states:

G=good preservation
M=moderate preservation
P=poor preservation

Abundance levels using a 40X objective on the Axiophot 2 microscope (used for Cenozoic samples) and a 100X objective for the Photomicroscope 3 (used for Cretaceous samples) are recorded as follows:

A= abundant (>10 specimens per field of view)
C=common (1-10 specimens per field of view)
F=frequent (1 specimen per 1-10 fields of view)
R=rare (1 specimen per >10 fields of view)
B=barren

The zonal scheme of Martini (1971), in conjunction with secondary markers determined by Bybell to be useful for Atlantic coastal plain sediments, was used for Cenozoic calcareous nannofossils, and the zonal scheme of Sissingh (1977), as modified by Perch-Nielsen (1985), was used for dating the Cretaceous samples. Both of these schemes are useful for the biostratigraphic classification of mid-to low-latitude floral assemblages. Age estimates of biostratigraphic data were calibrated to the magnitic polarity time scale of Cande and Kent (1995). Age estimates for Cenozoic calcareous nannofossil datums were obtained from Berggren and others (1995).

The time scale of Gradstein and others (1995) was used for the Cretaceous. Age estimates for the Late Cretaceous calcareous nannofossil datums were based primarily on the findings of Erba and others (1995).

Calcareous nannofossil data and related information for the C-15 test hole are summarized on figures 2, 3, 4, and 5 and appendices 1 and 2. Figure 2 shows the natural gamma log for the C-15 section between 2,310 ft and 290 ft, sample locations, important calcareous nannofossil datums, calcareous nannofossil zones, and ages represented by the zones. The test-hole section also is assigned provisionally to lithostratigraphic units following Gohn (1992) for the Cretaceous section and Van Nieuwenhuise and Colquhoun (1982) and Ward and others (1979) for the Tertiary section. Figures 3 and 4 document the occurrences of calcareous nannofossil taxa in the studied samples. Figure 5 shows sedimentation rates in the C-15 test hole that were derived from the calcareous nannofossil data in the C-15 section.

Mesozoic Calcareous Nannofossil Biostratigraphy

Middendorf Formation - Zone CC 14 - Coniacian (?)

The Coniacian (?) Middendorf Formation extends from 2260 ft to 2060 ft. The only productive sample (2060 ft) was placed cautiously in Coniacian(?) Zone CC 14 (*Micula decussata* Zone) based on the presence of *Micula decussata* (FAD defines the base of Zone CC 14). Preservation in this sample was moderate and abundance and diversity were low. Because of the low diversity of the floral assemblage, this sample could possibly be slightly younger (Zone CC 15) than is recorded here. However, the lack of all three zonal markers for Zone CC 15 (*Reinhardtites anthophorous*, *Lithastrinus grillii*, and *Micula concava*) strongly supports placement within Zone CC 14. Only one other sample (2220 ft) from the Middendorf Formation was examined for calcareous nannofossil content and it was found to be barren.

Shepherd Grove Formation - Zone CC 17 - Santonian/Campanian

The Middendorf Formation is unconformably overlain by the Shepherd Grove Formation, which is represented here by one sample at 2030 ft. This sample is assigned an age of latest Santonian/earliest Campanian (Zone CC 17) based on the presence of *Calculites obscurus* and the absence of *Aspidolithus parcus parcus* . The Shepherd Grove Formation and Zone CC 17 typically are present as a much thicker package of sediments in the Clubhouse Crossroads #1 and Myrtle Beach cores (fig. 1) (Self-Trail, unpublished data).

Caddin Formation - Zone CC 18 - lower Campanian

The Caddin Formation unconformably overlies the Shepherd Grove Formation in C-15 and is placed in the *Aspidolithus parcus* Zone (Zone CC 18), which is represented by only one sample (1,945 ft). Zone CC 18 is based on the co-occurrence of *Marthasterites furcatus*, which has its last appearance at the top of Zone CC 18, with *Aspidolithus parcus parcus* (FAD defines the base of Zone CC 18). The presence of *A. parcus constrictus* further confines this sample to Subzone CC 18c.

Black Creek Group - Zones CC 19, 20, 21, and 22 - Campanian

The undivided Black Creek Group overlies the Caddin Formation in C-15 and is Campanian in age. It is comprised of several calcareous nannofossil zones. The *Calculites ovalis* Zone (CC 19) is represented within the Black Creek Group at C-15 by samples from 1,920 through 1,765 ft. This zone is commonly broken into two subzones (CC19a and CC 19b) based on the LAD of *Bukryaster hayi*. This species has its last occurrence in C-15 at 1,880 ft, placing the samples at 1,850, 1,840, 1,790, and 1,765 ft in Subzone CC 19b. Zone CC 19 is usually present in South Carolina as a relatively thick sequence of sediments (Self-Trail and Gohn, 1996).

The *Ceratolithoides aculeus* Zone (Zone CC 20) of the Black Creek Group is unusually thin in C-15. This zone is defined as extending from the FAD of *Ceratolithoides aculeus* to the FAD of *Quadrum sissinghii* and is present from 1,750 to 1,720 ft in C-15. By comparison, Hattner and Wise (1980) reported a thickness of almost four hundred feet for this zone from the Clubhouse Crossroads #1 core.

Quadrum sissinghii , first occurrence defines the base of the *Quadrum sissinghii* Zone (CC 21), occurs from 1,700 ft to 1,290 ft in C-15. This zone is 140 feet thick in this core and has its top at 1,510 ft, where the first appearance of *Quadrum trifidum* delineates the base of Zone CC 22 (*Quadrum trifidum* zone). Zones CC 21 and CC 22 are late Campanian in age. The top of Zone CC 22 is truncated at 1,290 ft by an unconformity that spans the Campanian/Maastrichtian boundary and delineates the Black Creek Group/Peedee Formational contact.

Peedee Formation - Zones CC 25 and 26 - late Maastrichtian

The Peedee Formation at C-15 unconformably overlies the Black Creek Group and consists of two distinct sedimentary packages (fig. 2). The lowermost section, from 1,285 to 1,235 ft, contains *Lithraphidites quadratus*, placing these samples in the middle of the *Arkhangelskiella cymbiformis* Zone (CC 25b). This late Maastrichtian sedimentary package rests on late Campanian sediments, recording a hiatus of approximately 5 my duration. The upper sedimentary package contains *Ceratolithoides kamptneri* (FAD at 1,220 ft), *Micula murus* (FAD at 1,100 ft) and *Micula prinsii* (FAD at 1,080 ft), placing these samples in Zone CC 26 (the *Nephrolithus frequens* Zone). It should be noted that the first appearance of *M. murus* occurs at 1,100 ft, 120 ft above the first occurrence of *C. kamptneri* (fig. 3). The exact age and biostratigraphic placement of these two species is still somewhat questionable (Self-Trail and Gohn, 1996). Further study will be needed in order to document their true biostratigraphic ranges. Subzone CC 26b, based on the presence of *Micula prinsii* (FAD and LAD defines the boundaries of Subzone CC 26b), is recognized from 1,080 to 1,050 ft in core C-15. The occurrence of this species is rare in South Carolina, and it typically only occurs in the most downdip cores (Self-Trail, unpublished data). Hattner and Wise (1980) did not record its presence in the Clubhouse Crossroads #1 core. The sample at 1,050 ft was the youngest sample recorded from the Late Cretaceous in C-15.

Cenozoic Calcareous Nannofossil Biostratigraphy

Black Mingo Group

Rhems Formation-Zone NP 1-early Paleocene

Although C-15 contains both upper Maastrichtian (1,080 -1,050 ft) and lower Danian (1,030 ft) samples, the actual Cretaceous/Tertiary boundary falls within the unsampled interval between these two samples. According to the gamma log (fig. 2), the K/T boundary probably occurs at 1,040 ft. However, based on the floral assemblage recorded from sample 1,030 ft, it is unlikely that a complete K/T boundary interval is present at this site.

The lowermost Danian Rhems Formation extends from approximately 1,040 to 1,005 ft. A sample from 1,030 ft is placed in the upper part of Zone NP1 based on the presence of *Cruciplacolithus primus* and *Cruciplacolithus asymmetricus*, which are absent from the lower part of Zone NP 1 (Van Heck and Prins, 1987). A sample from 1,010 ft contains a few unidentifiable calcareous nannofossil specimens.

Williamsburg Formation - Zones NP 5-6 - late Paleocene

The Rhems Formation is overlain unconformably by the upper Paleocene Williamsburg Formation, which extends from 1,005 to 690 ft in C-15. The interval from 1,000 to 850 ft can be placed in the lower part of Zone NP 5 based on the presence of *Chiasmolithus bidens* (FAD in Zone NP 5) and the absence of *Heliolithus cantabriae* (FAD in upper half of Zone NP 5) and *Heliolithus kleinpellii* (FAD defines base of Zone NP 6). The genus *Fasciculithus* is uncommon in this interval, and the species *Fasciculithus tympaniformis* (FAD defines the base of Zone NP 5), which first was observed at 850 ft, is considered by the authors to be an unreliable marker in Atlantic Coastal Plain sediments. The samples from 820 and 800 ft are placed in the upper part of Zone NP 5 because they do contain the species *Heliolithus cantabriae*. A sample from 760 ft is placed in Zone NP 6 based on the presence of *Heliolithus kleinpellii* and the absence of any Zone NP 7 indicators.

The overlying two samples (730 and 700 ft) are from an interval that contains a mixture of late Paleocene and middle Eocene floras (fig. 4). This mixing probably is the result of contamination from the overlying Santee Limestone due to drilling mud inclusion. Lithologically, this interval of the Williamsburg Formation consists of a porous limestone that would easily be penetrated by drilling fluid.

Santee Limestone - Zone NP 17 - middle Eocene

The Williamsburg Formation is overlain unconformably by the middle Eocene Santee Limestone, which extends from 690 ft to at least 380 ft (uppermost studied sample). Sediments from 680 through 380 ft are assigned to Zone NP 17 based on the absence of *Chiasmolithus bidens/solitus* (LAD defines the top of Zone NP 16), the presence of *Helicosphaera compacta* (FAD near the top of Zone NP 16) and the absence of any indicators of Zone NP 18 or younger zones. *Chiasmolithus bidens* gradually evolves into *Chiasmolithus solitus* and these two species are not separated for the purposes of this paper. The samples from 500 to 380 ft are more poorly preserved than the underlying samples, and although there is a slight possibility that this interval could be younger in age, the authors consider the most probable placement of the interval to be within Zone NP 17.

Sediment Accumulation Rate

Ages and core depths for calcareous nannofossil datums that were used to calculate sediment accumulation rate are listed in Table 1 and plotted in Figure 5. Sediment accumulation rates were calculated using calcareous nannofossil datums from the interval between 2060 and 380 ft. This 1680-ft cored interval ranges in age from 81 Ma to 37 Ma. Sediment accumulation rates for the middle Eocene were not calculated due to the paucity of datums present at this site. Much of the early Eocene and part of the late Paleocene are represented by a disconformity.

High sediment accumulation rates for the Coniacian (?) through Campanian section at hole C-15 reflect a dominance of nearshore clastic sedimentation. Rates throughout this time average 33 m/my (109 ft/my). This contrasts sharply with the sedimentation rate for the Maastrichtian through Danian section, which averages approximately 16 m/my (52 ft/my), or about half the sedimentation rate recorded for the Campanian (fig. 5). It should be noted that age estimates for the first occurrences of *Micula prinsii, Micula murus*, and *Ceratolithoides kamptneri* (late Maastrichtian marker species) appear to be diachronous, and therefore should be viewed with caution when used to calculate sedimentation rates. Sedimentation rates increased during the late Paleocene and averaged approximately 32 m/my (104 ft/my) (fig. 5).

Only one obvious hiatus was recorded from the Cretaceous. This disconformity occurs across the Campanian-Maastrichtian boundary (75 Ma through 69 Ma) and comprises approximately 6 my. This same hiatus is recorded from nearshore sediments throughout the Atlantic Coastal Plain (Sugarman and others, 1995; Self-Trail and Bybell, 1995; Self-Trail and Gohn, 1996) and most likely represents a major sea-level regression during the Late Cretaceous. It is worthwhile to note that this hiatus does not appear in the deep-sea record off coastal South Carolina (Self-Trail, unpublished data).

Although it is apparant from the gamma log (fig. 2) and calcareous nannofossil data (fig. 3) that there is section missing from the Coniacian through Santonian interval at C-15, it was not recorded on the sediment accumulation rate curve due to a paucity of samples across this interval.

A small hiatus occurs between the lower Paleocene section (64 Ma) and the upper Paleocene section(61 Ma) and spans approximately 3 Ma. A larger hiatus spanning approximately 20 Ma occurs between the upper Paleocene section (58 Ma) and the middle Eocene section (38 Ma). Unlike the Cretaceous of South Carolina, thicknesses of Paleocene through Eocene sediments in the South Carolina Coastal Plain vary greatly from site to site (Bybell, unpublished data) and may reflect changes in continental sediment supply, or more likely, large variations in the amount of sediment that was eroded away as sea level rose and fell.

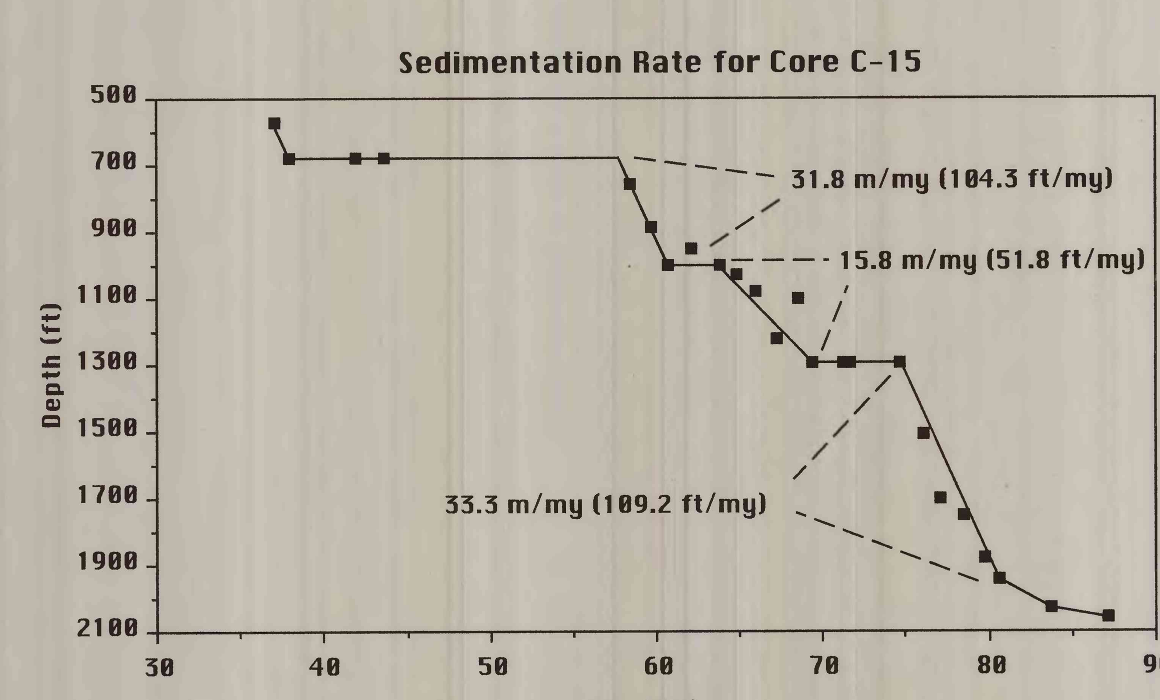

Figure 5. Age-depth relationship in Core C-15, based on calcareous nannofossil data.

CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY OF THE SCDNR TESTHOLE C-15, JASPER COUNTY, SOUTH CAROLINA

By
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