# 49. MAGNETOBIOSTRATIGRAPHY OF DEEP SEA DRILLING PROJECT LEG 72, SITES 515–518, RIO GRANDE RISE (SOUTH ATLANTIC)

W. A. Berggren<sup>2</sup>, N. Hamilton<sup>3</sup>, D. A. Johnson<sup>2</sup>, C. Pujol<sup>4</sup>, W. Weiss<sup>5</sup>, P. Čepek<sup>5</sup>, and A. M. Gombos, Jr.<sup>6</sup>

#### INTRODUCTION

This paper contains magnetobiostratigraphic correlation charts for each of the four sites occupied during DSDP Leg 72. Microfossil zonal boundaries and magnetic polarity determinations for Sites 515 through 518 are summarized in Figures 1 through 4, respectively. Our discussion focuses on the correlations derived for the Paleogene and late Cretaceous (Coniacian-Maestrichtian) of Site 516, because of the value of this site as a stratigraphic reference section for the South Atlantic. The Neogene magnetobiostratigraphy of Site 516 is treated in detail elsewhere (Berggren, Aubry, and Hamilton, this volume), and will not be discussed further in this synthesis chapter.

Unless otherwise specified, all core and section numbers in this paper refer to cores and sections of Hole 516F.

### PALEOGENE MAGNETOBIOSTRATIGRAPHY

A virtually complete Paleogene section (Sections 5-1 to 89-5; 208 to 965 m sub-bottom) is present in Hole 516F (Fig. 2). Good quality magnetic polarity stratigraphic data (Hamilton, this volume), the integration of biostratigraphic data of Pujol (this volume), and evolution of their correlation by reference to similar studies on the Contessa sections, Gubbio (Lowrie et al., 1982) and South Atlantic DSDP Sites 523 and 524 (Poore et al., in press) allow the assignment of the polarity reversal stratigraphy to the standard numbered anomaly sequence. Some numeric assignments are difficult because of the incomplete nature of the magnetic stratigraphic record; for instance, the series of normal "events" associated with middle-late Eocene biostratigraphy over the interval of Cores 45 to 77. Numeric assignment is based primarily on three correlations:

1) Lower Oligocene and uppermost Eocene calcareous nannoplankton and planktonic foraminiferal assemblages in Cores 35 to 36 and 39 are associated with Anomalies 13 and 15, respectively (cf. Lowrie et al., 1982; Poore et al., in press).

2) The base of Zone NP15 (based on first appearance datum *Nannotetrina fulgens*) between 76,CC and 77,CC

suggests that the normal polarity event of Cores 75 to 77 is Anomaly 21 (cf. Lowrie et al., 1982; Poore et al., in press).

3) The presence of the last appearance datum (LAD) of *Morozovella spinulosa* in Core 49 suggests that the sequence of normal events of Cores 45 to 52 represent Anomalies 17 and 18. The LAD of *M. spinulosa* occurs essentially simultaneously with the first appearance datum (FAD) of *Porticulasphaera beckmanni*, the nominate taxon of Zone P13, which essentially brackets the top of Anomaly 18 and base of Anomaly 17 (Lowrie et al., 1982).

Polarity assignments are made on the basis of this and other magnetobiostratigraphic correlations from the studies of Lowrie and others (1982) and Poore and others (in press), as shown in Figure 2.

# The Oligocene

The Oligocene/Miocene boundary is drawn here at the FAD of *Globorotalia kugleri* and LAD of *Reticulofenestra bisecta*, both of which occur in Section 5-1 (208 m) in Anomaly 6C (see Berggren, Aubry, and Hamilton, this volume). Further discussion of the reasoning for the choice of these criteria is given in Berggren, Kent, and Van Couvering (in press). The Eocene/Oligocene boundary lies within the interval of Cores 38 to 39 and is discussed in greater detail below.

We recognize approximately 5 to 6 planktonic foraminiferal datum events in the Oligocene (see Fig. 2). The FADs of Globigerinoides primordius as rare (255 m) and common (215 m) components in the assemblages are stratigraphically below the FAD of Globorotalia kugleri (208 m, Anomaly 6C). This record is consistent with findings of this taxon elsewhere in pre-Aquitanian (= pre-Miocene) stratigraphic levels. The FAD of Globigerina angulisuturalis is in Core 24, upper Anomaly 11, and the LAD of Chiloguembelina is in Core 20, middle of Anomaly 9, consistent with the records of this datum level in DSDP Site 522 (Poore et al., in press). The LAD of Chiloguembelina (correlative with the NP23/24 boundary) has recently been suggested as a more reliable criterion for the recognition of the Chattian/Rupelian boundary (see discussion in Berggren, Kent, and Flynn, in press) and is essentially coincidental with the NP23/ 24 boundary (between between 18,CC and 19,CC) in Hole 516F as well. The LAD of Pseudohastigerina (Core 31; in the reversed interval just below Anomaly 12) is identical to that seen in DSDP Site 522 (Poore et al., in press).

<sup>&</sup>lt;sup>1</sup> Barker, P. F., Carlson, R. L., Johnson, D. A., et al., *Init. Repts. DSDP*, 72: Washington (U.S. Govt. Printing Office).

<sup>&</sup>lt;sup>2</sup> Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Dept. of Geology, University of Southampton, Southampton, United Kingdom. Université de Bordeaux, 33405 Talence, France.

Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover 51, West Germany.

<sup>&</sup>lt;sup>6</sup> Exxon Production Research Co., P.O. Box 2189, Houston, Texas.



Figure 1. Magnetostratigraphy and biostratigraphy of Site 515, showing key diatom and radiolarian datum levels.

### The Eocene

Biostratigraphic determination of the Eocene/Oligocene boundary presents somewhat of a problem in Hole 516F. The upper part of the range of the *Globorotalia cerroazulensis cocoaensis* group and *Globigerinatheka semiinvoluta* exhibits sporadic, rare occurrences. The Eocene/Oligocene boundary is drawn by Pujol (this volume) and Čepek (personal communication, 1982) in Core 39 (incomplete Anomaly 15) on the basis of the supposed disappearance of these groups and the rosetteshaped discoasters. Elsewhere, the Eocene/Oligocene boundary lies at a level approximately midway between Anomalies 13 and 15 (Lowrie et al., 1982; Poore et al., in press), and one wonders whether a hiatus may be present in Hole 516F.

A more likely explanation appears to be the intense dissolution that characterized the later part of the Eocene at this site and that may have selectively removed less-resistant taxa from the stratigraphic record. A "trace" occurrence of the solution-resistant taxon *semiinvoluta* is noted by Pujol (this volume) as high as Section 38-1. If this is indeed a true, *in situ* occurrence and if the Eocene/Oligocene boundary is drawn at this level, it would lie approximately midway between (the preserved parts of) Anomalies 13 and 15, in conformity with the studies of Gubbio and the South Atlantic cited above.

The "LAD"s of *Globorotalia cocoaensis* and *Globigerinatheka semiinvoluta* are perhaps not true datum events. Rather they are plotted in Figure 2 merely because of their general importance in upper Eocene biostratigraphy.

The lack of diagnostic taxa renders biostratigraphic subdivision within the Eocene difficult. The LAD of *Morozovella spinulosa* (Core 49) is a distinct event that serves to identify the Anomaly 17 to 18 interval because of its close association elsewhere with the FAD of *Porticulasphaera beckmanni* and the association of the latter taxon with the upper part of Anomaly 18 (Lowrie et al., 1982). This magnetobiostratigraphic correlation (in Hole 516F) is consistent with the NP17/18 boundary (46,CC to 47,CC) at a level identified as upper Anomaly 17, because the LAD of *Chiasmolithus grandis* and the FAD of *Chiasmolithus oamaruensis* (taxa used to determine the NP17/18 zonal boundary) have been recorded from the upper part of Anomaly 17 at DSDP Site 522 (Poore et al., in press).

### The Paleocene

The Paleocene/Eocene boundary is placed here between Cores 81 and 82, at approximately 895 m sub-bottom (based on the LAD of *Morozovella velascoensis*). This level is situated within Zone NP10-11 (undifferentiated) and within an interval of uncertain magnetic polarity between what is clearly Anomaly 25 (Cores 82 to 84) below and probably Anomaly 24 (Cores 80 and 81) above. This magnetobiostratigraphic correlation is consistent with that suggested for Gubbio (Lowrie et al., 1982) and for the South Atlantic, DSDP Leg 74 (Shackleton and Boersma, personal communication, 1982). Paleocene magnetobiostratigraphic correlations in Hole 516F are shown in Figure 2. They agree well with those for Gubbio (Alvarez et al., 1977; Lowrie et al., 1982), and for DSDP Legs 73 (Poore et al., in press) and 74 (Shackleton and Boersma, personal communication, 1982) in the South Atlantic. A more detailed discussion of the relationships of various Paleocene datum levels to magnetostratigraphy and to Paleocene chronostratigraphy is presented in Berggren, Kent, and Flynn (in press).

## The Cretaceous/Tertiary Boundary

The Cretaceous/Tertiary boundary is drawn in Section 89-5 (approximately 965 m sub-bottom) on the basis of the extinction of Late Cretaceous globotruncanids and the top of the *Micula mura* Zone. This level is situated a short distance down in the reversed interval below Anomaly 29 and agrees well with the boundary's magnetobiostratigraphic determination at Gubbio (Alvarez et al., 1977), the South Atlantic (Poore et al., in press; Shackleton and Boersma, personal communication, 1982), and in the boundary stratotype section at Stevns Klint, Denmark (Mörner, 1982).

# MESOZOIC MAGNETOBIOSTRATIGRAPHY

Analysis of the correlation between the biostratigraphic and magnetobiostratigraphic record in the later part of the Mesozoic (Late Cretaceous) is as yet, at an early stage. Direct correlation was treated initially in a preliminary manner by Alvarez and others (1977) for the Cenomanian to Maestrichtian interval at Gubbio, Italy. Van Hinte (1976) and Thierstein (1976) suggested possible magnetobiostratigraphic correlations based on an integration of radiometric, biostratigraphic, and geomagnetic data. The improvement in coring technique (and recovery) of the *Glomar Challenger* is now making possible the integration of more reliable magnetobiostratigraphic data from the deep sea and the development of a more reliable magnetochronologic scale for the Mesozoic.

Estimates of the magnetobiochronology of the standard Late Cretaceous chronostratigraphic units depends upon an accurate biostratigraphic framework. The biostratigraphic framework of Late Cretaceous stages has been discussed by Berggren (1964) and more recently by Thierstein (1976), van Hinte (1976), and Sissingh (1977, 1978).

The Campanian/Maestrichtian boundary is interpreted here in the sense of Berggren (1964), van Hinte (1976), Thierstein (1976), and Sissingh (1977, 1978), namely, in the inclusion of the Craie de Gulpen (Cr4) as its lower unit. The Campanian/Maestrichtian boundary, in this sense, corresponds to the base of the Acanthoscaphites tridens (Tethyan) Zone and the Belemnella lanceolata ("Boreal") Zone, the top of Globotruncana calcarata (van Hinte, 1976) and lies within the lower part of the Tetralithus trifidus Zone (Bukry, 1973). Sisingh (1977, 1978) has subsequently equated this zone with a series of zones: Tetralithus trifidus (22), Tranolithus phacelosus (23), Rheinhardtites levis (24), and the lower part of the Arkhangelskiella cymbiformis (25)



Figure 2. Magnetostratigraphy and biostratigraphy of the Paleogene and Cretaceous of Site 516, showing important calcareous microfossil datum levels. The Neogene of Site 516 is treated in a separate chapter by Berggren, Aubry, and Hamilton (this volume). Alternate placements of the Campanian/Maestrichtian boundary (1055 or 1085 m sub-bottom depth) and of the Santonian/Campanian boundary are indicated.



Figure 2. (Continued).

943

٢



Figure 3. Magnetostratigraphy and biostratigraphy of Site 517. See Figure 1 for key.  $G_{\cdot} = Globorotalia$ .

zones. The Campanian/Maestrichtian boundary is correlative with a level in Subzone A of the Tranolithus phacelosus Partial-Range Zone (Sissingh, 1977, 1978). These biostratigraphic correlations of the Campanian/ Maestrichtian boundary are correlative with the Globotruncana elevata/Rugotruncana subcircumnodifer zonal boundary in the Gulf Coast of North America (Pessagno, 1967, 1969). The uppermost Campanian (G. calcarata Zone) is characterized by the initial appearance of Globotruncanella havanensis (Premoli Silva and Boersma, 1977) and the basal Maestrichtian by an assemblage characterized by Globotruncana arca, G. fornicata, G. contusa, in addition to the initial appearance of such forms as G. aegyptiaca, G. gagnebini, G. falsostuarti, G. tricarinata, and G. trinidadensis. The middle Maestrichtian may be recognized by the initial appearance of Globotruncana gansseri and upper Maestrichtian by that of the distinctive Abathomphalus mayaroensis.

The biostratigraphic position of the Santonian/Campanian boundary is more difficult to determine with planktonic foraminifers. It is biostratigraphically subsequent to the LAD of *Globotruncana concavata* (van Hinte, 1976) and appears to be approximately equivalent to the *Lucianorhabdus cayeuxii* (16)/*Calculites obscurus* (17) calcareous nannoplankton zonal boundary (Sissingh, 1977, 1978).

DSDP Hole 516F terminated (Core 128) at a sub-bottom depth of 1270.6 m in basalt. The oldest fossiliferous sediments above basement are in Core 124, and belong to the *Marthasterites furcatus* Zone of undifferentiated Coniacian to Santonian age. Planktonic foraminifers occur as low as Core 122, but the faunas in the interval of Core 122 to Section 114-5 consist of poorly preserved, exclusively double-keeled globotruncanids and other taxa; a middle to late Santonian age was suggested for Section 117-1 (Weiss, this volume).

The upper Cretaceous (approximately Coniacian to Maestrichtian) is present between Sections 89-5 and 125-1 (approximately 965-1252 m) in Hole 516F. In this 287 m section, ten calcareous nannoplankton zones are recognized; only five planktonic foraminiferal zones, and three nonzonal intervals are recognized over the same interval because of generally poor preservation and lack of low-latitude zonal markers (Weiss, this volume). Only a few definitive datum levels have been determined (FAD G. arca: 1155 m; Globotruncanella havanensis: 1065 m; Globotruncana falsostuarti: 1055 m; and A. mayaroensis: 1016 m), but these serve as important points of correlation. The relationship between these datum levels and the magnetic polarity stratigraphy is shown in Table 1.

Weiss (this volume) locates the Campanian/Maestrichtian boundary in Section 101-3 of Hole 516F (approximately 1055 m sub-bottom), primarily based on the initial appearance of *Globotruncana falsostuarti* and a faunal association typical of the Maestrichtian (*G. aegyptiaca*, *G. gagnebini*, *G. arca*, *G. fornicata*, and *G.*  trinidadensis) above an unzoned interval (Sections 104-4 to 101-4) in which Globotruncanella havanensis and Globotruncana scutilla make their first appearance. Unfortunately, typical lower Maestrichtian elements as G. tricarinata or Rugotruncana subcircumnodifera and up-



Figure 4. Magnetostratigraphy and biostratigraphy of Site 518. See Figure 1 for key.

Table 1. Relationship between definitive datum levels and magnetic polarity stratigraphy in Hole 516F.

Datum level (FAD)	Sub-bottom depth (m)	Magnetic polarity stratigraphy	Remarks
1. Abathomphalus mayaroensis	1016	Reversed interval just below (com- bined) Anomaly 30-31	Within the Arkhangelskiella cymbiformis Zone
2. Globotruncana falsostuarti	1055	Early part of Anomaly 32	Approximately in the middle part of the Tetralithus trifidus Zone
3. Globotruncanella havanensis	1065	Reversed interval between Anom- lies 32 and 33	Just below the middle part of the T. trifidus Zone
4. Globotruncana arca	1155	Approximately mid- way between Anomalies 33 and 34	Within the Eiffellithus eximius Zone

Note: FAD = first appearance datum.

per Campanian forms as *Globotruncana calcarata* are missing at this site.

The Campanian/Maestrichtian boundary in Hole 516F is within the middle part of the Tetralithus trifidus Zone which, by correlation, is within the lower part of the Tranolithus phacelosus (23) Zone of Sissingh (1977); this location agrees with Sissingh's biostratigraphic placement of the Campanian/Maestrichtian boundary in terms of stratotype stratigraphy. This level lies in the lower part of Anomaly 32 and is approximately equivalent to the level of this boundary as estimated (predicted) by van Hinte (1976), although we disagree with his chronology for reasons presented below. Alvarez and others (1977, fig. 2) show the G. calcarata/G. tricarinata zonal boundary (= Campanian/Maestrichtian boundary) in the upper part of the Gubbio Normal Zone B+ (= Anomaly 33), as do Channell and Medizza (1981) in the Carcoselle section, Belluno Basin, Venetian Alps. The top of the late Campanian calcarata Zone is within the middle part of the trifidus (calcareous nannoplankton) Zone (van Hinte, 1976; Sissingh, 1977, 1978) and is situated about one-third of the way down from the top of Gubbio Polarity Zone B + (= Anomaly 33) in the Carcoselle section (Channell and Medizza, 1981). In the Carcoselle section, Tetralithus trifidus (= Quadrum trifidum) Total-Range Zone spans the interval from the top of Gubbio Polarity Zone D+ (= Anomaly 32) to the lower part of Gubbio Polarity Zone 6+ (= Anomaly 33) (Channell and Medizza, 1981), whereas in Hole 516 this zone spans the interval from just above Anomaly 32 to the upper part of Anomaly 33. We are as yet at an early stage in correlating biostratigraphic data to magnetobiostratigraphy. We would suggest that the differences noted here may be due to differences in taxonomic determination and biostratigraphic interpretation.

On the basis of the data received here we have two choices in determining the Campanian/Maestrichtian boundary in Hole 516F:

1) At a level *within* the *trifidus* zone approximately one-third of the way down from the top of Anomaly 33, in order to agree with the determination at Gubbio (Alvarez et al., 1977) and the Belluno Basin (Channell and Medizza, 1981). This level would be at approximately 1085 m sub-bottom (in Core 105) in Hole 516F.

2) At the FAD of *Globotruncana falsostuarti* and a faunal association typical of the Maestrichtian above an unzoned interval (Sections 104-4 to 101-4) in which *Globotruncanella havanensis* and *Globotruncana scutilla* made their first appearances. This level, chosen by Weiss (this volume), is at about 1055 m (Section 101-3) and lies in the lower part of Anomaly 32.

The fact that the FAD of *Globotruncana gansseri* (= middle Maestrichtian) is shown to occur within Anomaly 32 and within the uppermost part of the *Q. trifidum* Zone in the Belluno Basin (Channell and Medizza, 1981) suggests that the true position of the Campanian/ Maestrichtian boundary in Hole 516F may be closer to the first option suggested above, i.e., within the upper part of Anomaly 33. Both positions are shown, however, on Figure 2.

# AGE OF THE CAMPANIAN/MAESTRICHTIAN BOUNDARY

The chronology of this boundary, while somewhat beyond the scope of this report, will be treated briefly because of the controversy that has surrounded it. Based on K-Ar dates of bentonites associated with various baculitid and ammonite zones. Obradovich and Cobban (1975) suggest ages of 69 Ma (about 71 Ma),<sup>7</sup> 70 to 71 Ma (about 72 to 73 Ma), and 72 to 73 Ma (about 74 to 75 Ma) for the Campanian/Maestrichtian boundary. The age estimate of 69 Ma (about 71 Ma) is based on dates in the western interior of Canada on stratigraphic levels equivalent in the United States to the Baculites grandis Zone. The Campanian/Maestrichtian boundary in the western interior of Canada was provisionally drawn by Jeletzky (1968) at a level equivalent in the United States to the boundary between the Baculites eliasi and B. baculus zones, the next two zones below the B. grandis Zone (see Obradovich and Cobban, 1975, p. 47). However, this boundary is incorrectly correlated to the stratotype Maestrichtian and is clearly too high. Jeletzky (1951) has shown that the base of the Maestrichtian Stage coincides with the bases of the Belemnella lanceolata and Acanthoscaphites tridens zones, which are correlative, in turn, with the top of the calcarata Zone (van Hinte, 1976). The base of the Maestrichtian is correlative also with the initial appearance of Rugotruncana subcircumnodifera (Berggren, 1962). Using the same criterion, Pessagno (1967, 1969) recognized this boundary in the Gulf Coast. But the boundary determined in this way corresponds approximately to the boundary between the Didymoceras nebrascense and D. stevensoni zones in the United States, some 8 zones below the boundary as correlated made by Jeletzky (1968) (Obradovich and Cobban, 1975, p. 48). Thus the correlation made by Jeletzky (1968) from the western interior to the stratotype Maestrichtian is clearly too young. That made by Pessagno (1967, 1969) is more nearly correct, and the age estimate of 72 to 73 Ma (approximately 74 to 75 Ma) is based on radiometric dates made on the D. nebrascense Zone and (two zones above) the Exiteloceros jenneyi Zone. Olsson (1964) determined the Campanian/Maestrichtian boundary in New Jersey at a level correlated with the Baculites scotti Zone, a zone below the D. nebrascense Zone. The radiometric dates on these biostratigraphic levels can serve as the basis for geochronologic estimates of the age of the Campanian/Maestrichtian boundary, not those made at the level of the Baculites grandis Zone.

A recently proposed Late Cretaceous-Cenozoic time scale (Berggren, Kent, and Flynn, in press) uses calibration points of 84 Ma (top of Anomaly 34) and 56.2 Ma (base of Anomaly 24) to determine the magnetochronology of the lower of 3 distinct segments of the scale. In terms of this scale, our magnetochronologic age estimate of the Campanian/Maestrichtian boundary would be: (1) later part of Anomaly 33 (~1085 m, ~74 Ma); or (2) early part of Anomaly 32 ( $\sim 1055$  m,  $\sim 73$  Ma). The appendix at the end of the chapter shows a revised geomagnetic polarity time scale for the Cenozoic and Late Cretaceous.

The Eiffellithus eximius Zone (Cores 114 to 116) has been equated with the Campanian-Santonian (undifferentiated) and the Marthasterites furcatus zones in the basal part of Hole 516F (Cores 116 to 124) to the Santonian-Coniacian (undifferentiated) (Čepek, personal communication, 1982). Weiss (this volume) assigns the lower part of the section of Hole 516F (Cores 114 to 122) to late to middle Santonian (undifferentiated) and draws the Santonian/Campanian boundary at the FAD of Globotruncana arca (Section 114-4; approximately 1159 m). The associated fauna (G. renzi, G. coronata, G. paraconcavata), and similar marginotruncanid elements, as well as G. fornicata, followed by the disappearance of the multiserial heterohelicid Ventilabella eggeri and the development of a more typical Globotruncana s.s. assemblage in the overlying Globotruncana ventricosa Zone (Sections 112-2 to 104-5) is a characteristic feature of early Campanian assemblages. Van Hinte (1976) shows the Campanian/Santonian boundary to be essentially correlative with the base of the Eiffellithus eximius Zone. We have thus drawn the boundary between these units in Hole 516F as a diagonal line encompassing the stratigraphic interval (less than 15 m) of these two biostratigraphic levels.

# AGE OF THE CAMPANIAN/SANTONIAN BOUNDARY

Van Hinte (1976) suggests a correlation of the base of the *Eiffellithus eximius* Zone with the reversed interval between Anomalies 33 and 34. It falls at essentially the same level in Hole 516F. The FAD of *G. arca* is located 15 m higher within the middle part of the reversed interval between Anomalies 33 and 34. In the Gubbio section, the Santonian/Campanian boundary (= *Globotruncana carinata/G. elevata* boundary) is drawn at a level near the top of the Gubbio Long Normal Zone (= Anomaly 34) (Alvarez et al., 1977).

The Campanian/Santonian boundary has been dated (K-Ar date on bentonite in the *Desmoscaphites bassleri* Zone from the western interior of the United States) at 82.5 Ma (= 84.5 Ma), which led Obradovich and Cobban (1975, p. 47) to suggest an age of about 82 Ma for the Campanian/Santonian boundary. In the magnetobiochronologic scale developed by Berggren and others (in press), the base of the *E. eximius* Zone falls at a level about one-third of the way up between the top of Anomaly 34 (84.00 Ma) and the base of *G. arca* (approximately midway between the two anomalies) is at approximately 82 Ma.

## AGE OF THE CONIACIAN/SANTONIAN BOUNDARY

Hole 516F terminated in basaltic basement overlain by sediments assigned to the *Marthasterites furcatus* Zone. The Coniacian/Santonian boundary is shown by van Hinte (1976) and Sissingh (1977) to lie within the *M*.

<sup>&</sup>lt;sup>7</sup> Ages in parentheses refer to reevaluations based on newer decay constants.

furcatus Zone. Problems with the virtually barren stratotype Coniacian preclude accurate biostratigraphic correlation (Sissingh, 1978), but there is general agreement that it is a very short time-stratigraphic unit (1-2 scaphitid zones at the most; Obradovich and Cobban, 1975). Because the lower part of the stratigraphic sequence in Hole 516F cannot be zoned with planktonic foraminifers, neither the position of the Coniacian/Santonian boundary nor the base of the Coniacian can be determined at Site 516. Van Hinte (1976) suggests correlation of the Coniacian/Santonian boundary with a level within the later part of the Long Normal Zone (Anomaly 34), about 3 Ma (82 Ma ago) below its top (79 Ma ago).

#### ACKNOWLEDGMENTS

We would like to acknowledge the kind cooperation of colleagues who have provided us with (often unpublished) magnetobiostratigraphic data, in particular R. Z. Poore (U.S. Geological Survey, Reston, VA), N. J. Shackleton (Cambridge University, England), Anne Boersma (Lamont-Doherty Geological Observatory, NY), Jan Backmann (University of Stockholm, Sweden). Discussions with these colleagues and reviews of a draft of this paper by them and by E. Vincent (Scripps Institution of Oceanography), Dennis Kent (Lamont-Doherty Geological Observatory, NY), and John Obradovich (U.S. Geological Survey, Denver, CO) are gratefully acknowledged.

Preparation of this paper has been made possible by grants from the National Science Foundation, OCE-80-19052 (to W.A.B.), and OCE-80-25208 (to D.A.J.). This is Woods Hole Oceanographic Institution Contribution No. 5266.

#### REFERENCES

- Alvarez, W., Arthur, M. A., Fischer, A. G., Lowrie, W., Napoleone, G., Premoli Silva, I., and Roggenthen, W. M., 1977. Upper Cretaceous-Paleocene magnetic stratigraphy at Gubbio, Italy. V. Type section for the Late Cretaceous-Paleocene geomagnetic reversal time scale. *Geol. Soc. Am. Bull.*, 88:383-389.
- Berggren, W. A., 1962. Some planktonic foraminifers from the Maestrichtian and type Danian stage of Southern Scandinavia. *Stockholm Contrib. Geol.*, 9(1):1–106.
- \_\_\_\_\_, 1964. The Maestrichtian, Danian and Montian Stages and the Cretaceous-Tertiary boundary. *Stockholm Contrib. Geology*, 11(5):103-176.
- Berggren, W. A., Kent, D. V., and Flynn, J. J., in press. Paleogene geochronology and chronostratigraphy, *In Snelling*, N. J. (Ed.), *Geochronology and the Geological Record:* London (Geol. Soc. London Spec. Publ.).
- Berggren, W. A., Kent, D. V., and Van Couvering, J. A., in press. Neogene geochronology and chronostratigraphy. *In Snelling*, N. J. (Ed.), *Geochronology and the Geological Record:* London (Geol. Soc. London Spec. Publ.).
- Bukry, D., 1973. Low-latitude coccolith biostratigraphic zonation. In Edgar, N. T., Saunders, J. B., et al., Init. Repts. DSDP, 15: Washington (U.S. Govt. Printing Office), 685-703.
- Channell, J. E. T., and Medizza, F., 1981. Upper Cretaceous and Paleogene magnetic stratigraphy and biostratigraphy from the Venetian (southern) Alps. *Earth Planet. Sci. Lett.* 55(1981):419-432.
- Jeletzky, J. A., 1951. Die Stratigraphie und Belemnitenfauna des Obercampan und Maestricht Westfalens, Nordwestdeutschlands und Dänemarks, sowie einige allemeine Gliederungs-Probleme der jüngeren borealen Oberkreide Eurasiens. Geol. Jahrb. Beih., 1:1-142.

\_\_\_\_\_, 1968. Macrofossil zones of the marine Cretaceous of the Western Interior of Canada and their correlation with the zones and stages of Europe and the Western Interior of the United States. *Geol. Surv. Paper Geol. Surv. Can.*, No. 67-72.

- Lowrie, W., Alvarez, W., Napoleone, G., Perch-Nielsen, K. P., Premoli Silva, I., and Toumarkine, M., 1982. Paleogene magnetic stratigraphy in Umbrian pelagic carbonate rocks: the Contessa sections, Gubbio. Geol. Soc. Am. Bull., 93:414-432.
- Mörner, N. A., 1982. The Cretaceous/Tertiary boundary: chronostratigraphic position and sequence of events. J. Geol., 90: 564-573.

- Obradovich, J. D., and Cobban, W. A., 1975. A time-scale for the Late Cretaceous of the Western Interior of North America. *Geol.* Soc. Can. Spec. Pap., 13:31-54.
- Olsson, R. K., 1964. Late Cretaceous planktonic foraminifera from New Jersey and Delaware. *Micropaleontology*, 10(2):157-188.
- Pessagno, E. A., Jr., 1967. Upper Cretaceous planktonic Foraminifera from the western Gulf Coastal Plain. Paleontographica Americana, 5(37):245-445.
- , 1969. Upper Cretaceous stratigraphy of the western Gulf Coast area of Mexico, Texas, and Arkansas: Boulder, CO (Geol. Soc. Mem.), 111.
- Poore, R. Z., Tauxe, L., Percival, S. F., Jr., LaBrecque, J. L., Wright, R., Petersen, N. P., Smith, C. C., Tucker, P., and Hsü, K. J., in press. Late Cretaceous-Cenozoic magnetostratigraphy and biostratigraphy correlations of the South Atlantic Ocean: DSDP Leg 73. In Hsü, K. J., LaBrecque, J. L., et al., Init. Repts. DSDP, 73: Washington (U.S. Govt. Printing Office).
- Premoli Silva, I., and Boersma, A., 1977. Cretaceous planktonic foraminifers—DSDP Leg 39 (South Atlantic). In Supko, P. R., Perch-Nielsen, K., et al., Init. Repts. DSDP, 39: Washington (U.S. Govt. Printing Office), 615-641.
- Sissingh, W., 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. Geol. Mijnbouw, 56(1):37-65.
- \_\_\_\_\_, 1978. Microfossil biostratigraphy and stage-stratotypes of the Cretaceous. Geol. Mijnbouw, 57(3):433-440.
- Thierstein, H. R., 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. Mar. Micropaleontol., 1:325-362.
- van Hinte, J. E., 1976. A Cretaceous time scale. Am. Assoc. Pet. Geol. Bull., 60(4):498-516.

# Date of Initial Receipt: October 28, 1982

APPENDIX Revised Geomagnetic Polarity Time-Scale for the Cenozoic and Late Cretaceous

Normal polarity interval (Ma)	Anomaly
0.00-0.73	1
0.91-0.98	120
1.66-1.88	2
2.47-2.92	2A
2.99-3.08	2A
3.18-3.40	2A
3.88-3.97	3
4.10-4.24	3
4.40-4.47	3
4.57-4.77	3
5.35-5.53	3A
5.68-5.89	3A
6.37-6.50	
6.70-6.78	4
6.85-7.28	4
7.35-7.41	4
7.90-8.21	4A
8.41-8.50	4A
8.71-8.80	
8.92-10.42	5
10.54-10.59	
11.03-11.09	
11.55-11.73	5A
11.86-12.12	5A
12.46-12.49	
12.58-12.62	
12.83-13.01	
13.20-13.46	
13.69-14.08	
14.20-14.66	
14.87-14.96	5B
15.13-15.27	5B
16.22-16.52	5C
16.56-16.73	5C
16.80-16.98	5C

Appendix. (Continued).

Normal polarity interval (Ma)	Anomaly
17.57-17.90	5D
18.12-18.14	5D
18.56-19.09	5E
19.35-20.45	6
20.88-21.16	6A
21.38-21.71	6A
21.90-22.06	
22.25-22.35	
22.57-22.97	6B
23.27-23.44	6C
23.55-23.79	6C
24.04-24.21	6C
25.50-25.60	7
25.67-25.97	7
26.38-26.56	7A
26.86-26.93	8
27.01-27.74	8
28.15-28.74	9
28.80-29.21	9
29.73-30.03	10
30.09-30.33	10
31.23-31.58	11
31.64-32.06	11
32.46-32.90	12
35.29-35.47	13
35.54-35.87	13
37.24-37.46	15
37.48-37.68	15
38.10-38.34	16
38.50-38.79	16

Appendix. (Continued).

Normal polarity interval (Ma)	Anomaly
28 82-30 24	16
30 53 40 43	17
40 50-40 70	17
40.77-41.11	17
41 29-41 73	18
41 80-42 23	18
47 30 42.23	18
43 60-44 06	10
44.66-46.17	20
48 75-50 34	20
51 95-52 62	22
53 88-54 03	23
54 09-54 70	23
55 14-55 37	24
55 66-56 14	24
58 64-59 24	25
60 21-60 75	26
63 03-63 54	27
64 29-65 12	28
65 50-66 17	29
66 74-68 42	30
68 52-69 40	31
71 37-71 65	32
71 91-73 55	32
73 96-74 01	52
74 30-80 17	33
84 00	34

Note: After Berggren, Kent, and Flynn, in press. Blanks indicate "not assigned."