

Late Paleocene-Early Eocene sedimentary history in western Cuba: Implications for the LPTM and for regional tectonic history

Marie-Pierre Aubry¹
Appendix 1 by Annika Sanfilippo²

¹*Institut des Sciences de l'Evolution, Université Montpellier II, 34095 Montpellier cedex 05, France*
email: aubry@isem.univ-montp2.fr

²*Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0220*
email: asanfilippo@ucsd.edu

ABSTRACT: The San Agustine and San Francisco de Paula sections constitute two complementary, albeit incomplete, records of late Paleocene-early Eocene history of western Cuba (Bahía Honda tectonic unit).

The San Agustine section is of exceptional value because it is the only definitive known record of the Late Paleocene Thermal Maximum (LPTM) in the Caribbean. This extends the geographic distribution of the LPTM calcareous nannofossil assemblage from the western Indian Ocean to the Caribbean through the Tethys and North Atlantic Ocean. The fact that this assemblage has not yet been documented outside this area may reflect provincialism or, alternatively, broadly distributed unconformities.

The San Francisco de Paula section, sampled with the hope that it would constitute a suitable reference section for the Paleocene/Eocene boundary, yields a valuable record of successive latest Paleocene-earliest Eocene erosional events, that may reflect regional tectonic in the Caribbean or may be part of a global pattern of sedimentary history.

INTRODUCTION

The upper Paleocene-lower Eocene stratigraphic record of western Cuba is among those investigated as part of the activities of IGCP Project 308, "Paleocene/Eocene Events in Space and Time", in a sustained effort to identify stratigraphic sections continuous through the Paleocene-Eocene boundary interval. Our two main objectives were 1) to document in a Caribbean land setting the late Paleocene changes already reported elsewhere (see Aubry et al. 1998), and 2) to evaluate the potential of Cuban sections to serve as a Global Stratotype Section and Point (GSSP) for the Paleocene/Eocene boundary. Our interest in the Cuban record stemmed from early micropaleontologic studies conducted in the sixties around Habana (Brönnimann and Stradner 1960; Brönnimann and Rigassi 1963) that suggested to us that the events associated with the Late Paleocene Thermal Maximum (LPTM; Zachos et al. 1993) might be recorded in the Alcazar Formation (see Brönnimann and Rigassi 1963, Plate 1).

Several sections were visited during the field trip of January 1993 among which three were systematically collected for integrated magneto-, bio- and isotope stratigraphic analyses (see introduction). Because of restriction as to the weight of material that could be collected and exported, collecting was guided by preliminary micropaleontologic studies by our Cuban colleagues, Gena Fernández-Rodríguez and Emilio Flores Albin, so that only the intervals that appeared to be most relevant to the theme of the field trip were densely sampled. Whereas these sections have yielded good micropaleontologic data (Blanco-Bustamente et al. 1999, this volume; Fernández-Rodríguez et al. 1999, this volume; Fluegeman et al. 1999, this

volume; Sanfilippo et al. 1999, this volume; this paper), they have yielded non interpretable magnetostratigraphic results (M. von Fossen, pers. commun.) and the isotopic records are strongly affected by diagenesis. Isotopic analyses have been conducted only on one section (San Agustine). Because of the poor biostratigraphic control and/or discontinuous nature of the other two sections, isotopic analysis would not have yielded much useful information.

In this paper I report on the calcareous nannofossil stratigraphy of the upper Paleocene interval of the San Agustine section and the upper Paleocene-lower Eocene interval of the San Francisco de Paula section and discuss the implications for upper Paleocene-lower Eocene stratigraphy. I do not consider the Moncada section because it consists of extremely indurated shallow water limestones that were found to be barren of calcareous nannofossils (Bralower and Iturralde-Vinent 1997) and that do not lend themselves to a confident stratigraphic interpretation, the planktonic foraminifera, identified from thin sections, being restricted to a few levels (see Fernández-Rodríguez et al. 1999, this volume).

MATERIAL AND METHODS

Material

This investigation is based on the detailed sampling of two sections (text-figure 1) located in western Cuba, and belonging to the Bahía tectonic unit that was formed on the extinct Great Antillean Cretaceous Arc (Iturralde-Vinent 1994). For the purpose of this paper, and for simplification, I follow here the

lithostratigraphic framework established by Brönnimann and Rigassi (1963).

The San Agustine section (coordinates on the map of Cuba are X=347.850, Y= 348.00), near Cabañas, ~40km west of the capital city, is a newly discovered section that exposes the marls, limestones, shales and sandstones of the Alkázar Formation (see Fernández-Rodríguez et al. 1999, this volume). Sampling, at regular 25cm intervals, was restricted to the upper 5m of the section. Measurements were taken from a prominent hard layer located at ~ 2.5m (level of sample AU 1B; text-figure 2) from the top of the section. This layer is a light to tan, thin to medium bedded calcarenite easily identified in the field.

The San Francisco de Paula section, located south south-east in the vicinity of La Habana, was described by Brönnimann and Rigassi (1963) because it provides a good exposure of typical Alkázar Beds and of their contact with the overlying Capdevila Formation. The 56m-thick section (coordinates 360.45N and 368.30E) is located at ~1.4 km east to east-northeast from the village of San Francisco de Paula and primarily consists of marls and turbiditic sandstones and silstones (text-figure 2). A prominent marker bed consisting of a hard sandstone occurs at 44.2m above the base of the outcrop, and marks the contact between the Alkázar Formation and the lower Capdevila Formation. The section was measured from this prominent marker bed. Detailed sampling was conducted on both sides of it. Samples SFE 1 to 9 above were taken at 50 cm interval whereas samples SFP 1 through 20 below were taken 10 cm apart, and samples SFP21 to 37 were taken at irregular intervals of up to several meters (see further details in Sanfilippo and Hull 1999, this volume).

Micropaleontologic analysis

Calcareous nannofossil analysis was conducted on smear slides directly prepared from chips of rock samples, examined with a photomicroscope Zeiss III at magnifications of X500, X1250 and X2500. Because of the essentially poor preservation of the calcareous nannofossils in all samples, quantitative counts of specimens would have been meaningless. Instead, the search for the marker species has been as thorough as possible, the entire slides (660mm²) being scanned in natural light at magnification X650 (except slides with very rare nannofossils). The reason for this was to accurately establish the stratigraphic distribution in the sections of species of *Discoaster*, *Rhombaster* and *Tribrachiatus*, taxa that are non birefringent but are essential markers for the NP9-NP10 zonal interval (uppermost Paleocene-lowermost Eocene). In slides with abundant nannofossils, this was completed by a scan in each slide of 8 rows at magnification X650, using cross polarized light.

Biozonal scheme

Biozonal interpretation is based on the zonal scheme of Martini (1971) complemented by the subzonal scheme introduced by Aubry (1996) for Zone NP10 based on DSDP Site 550, and found to be broadly applicable to upper Paleocene-lower Eocene sections (e.g., Bybell and Self-Trail 1997; Faris and Strougo 1998; Aubry 1998a). This subzonal scheme uses the total range of *Tribrachiatus digitalis* and *T. contortus* (Subzones NP10b and d) and the partial range of *T. bramlettei* (Subzone NP10a and c).

Whereas the completeness of stratigraphic sections through Zone NP10 is now easily established based on these subzonal divisions, two problematic areas exist in the NP9-NP10 zonal

interval, due to the multiple unconformities that occur in the sedimentary record of Chron C24r (Aubry et al. 1996, Aubry 1998a, b). First, to this date the only sections that have provided a satisfactory record of the NP9/NP10 zonal boundary are ODP Site 690 (Aubry et al. 1996) and the Gebel Awaina section, Egypt (Schmitz et al. 1996). In other sections, the NP9/NP10 zonal contact is unconformable (as in DSDP Holes 550 and 577, Aubry et al. 1996, Aubry 1998a, respectively). Second, and more serious, is the difficulty in establishing a sequence of calcareous nannofossil events in mid-Zone NP9 and to select a reliable criterion to subdivide Zone NP9. Bukry (1973a) subdivided his *Discoaster multiradiatus* Zone (subsequently Zone CP8 of Okada and Bukry 1980; essentially correlative with Martini's Zone NP9) based on the lowest occurrence (LO) in the zone of *Cruciplacolithus eodelus* and/or *Rhombaster cuspis*. Bralower and Mutterlose (1995) reported the LO of *C. eodelus* well below the base of Zone NP9 in the Paleocene section recovered from ODP Site 865. I have similarly observed the LO of *C. eodelus* well below that of *R. cuspis* (e.g., at Site 1051, Aubry, unpublished data).

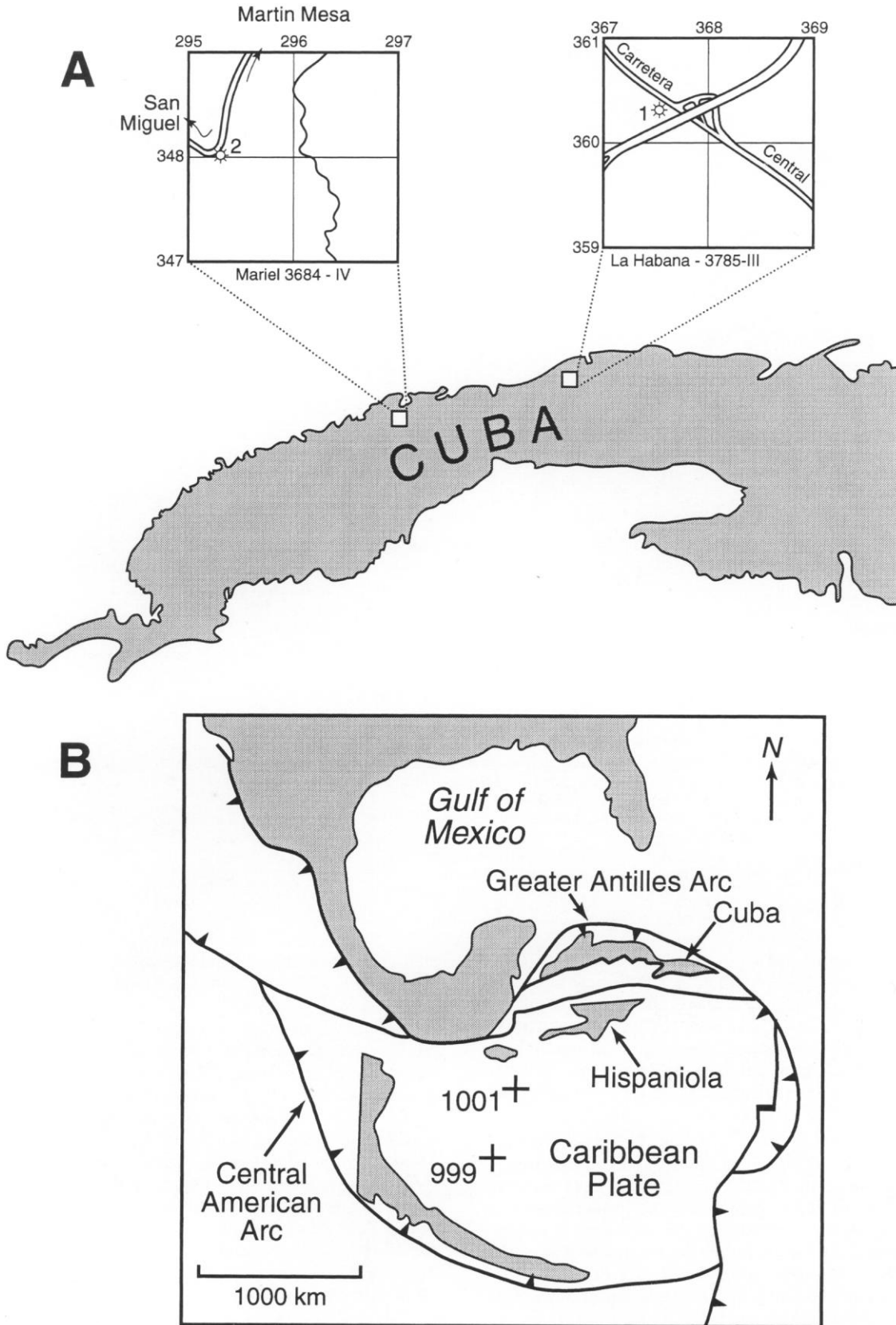
A major change in the composition of calcareous nannofossil assemblages occurs in ~mid Zone NP9 in several deep sea and land sections, that is coincident with the carbon isotope excursion. This change has been described in the Bass River section, N.J. (Cramer et al., in press), the Alamedilla section, Spain (Aubry et al., in prep.), and recorded in the Clayton Corehole (Bybell and Self-Trail 1995), the Qeriya section, Egypt, ODP Site 1051 and DSDP Site 213 (Aubry et al., in press a, and unpublished). The change involves the apparent sudden occurrences of several short-lived taxa among which *Discoaster araneus* and *Rhombaster calcitrapa* are conspicuous by their disymmetry, a singular character among calcareous nannofossils that is characteristic of the LPTM and a short subsequent interval of time of as yet unestablished duration. Indeed, the LO of this assemblage can be used to predict the exact location of the carbon isotope excursion (or of the benthic foraminiferal event, BFE). However, this is insufficient to determine whether a section yields a complete record of the isotopic event as explained in Aubry (1998a). To establish that a section is continuous across a certain interval, it is necessary to observe a sequence of events that precedes the main event. Due mainly to poor preservation in the relevant sections, this sequence of events (among which the HOs of *F. alanii*, *D. megastypus*, and LO of *R. cuspis*) is difficult to establish firmly. For the purpose of this paper, Subzones NP9a and b are differentiated based on the occurrences in the latter of *D. araneus* and *R. calcitrapa*.

CALCAREOUS NANNOFOSSIL STRATIGRAPHY

San Agustine section

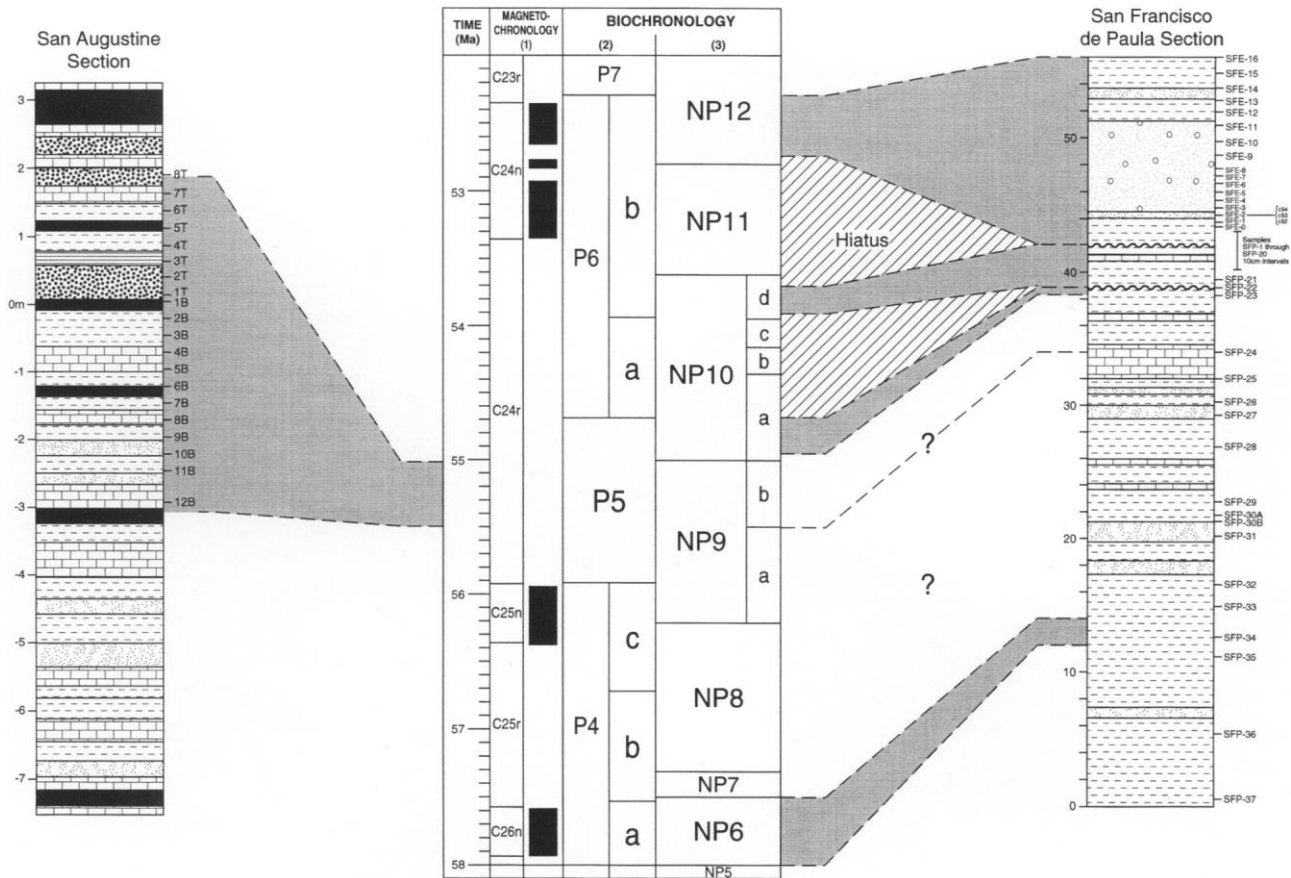
The calcareous nannofossils are poorly preserved at most levels in the San Agustine section and their abundance varies greatly (text-figure 3). Levels rich in silica, almost barren, alternate with levels with abundant calcareous nannofossils that would seem to represent diagenetically altered (recrystallized) calcareous nannofossil oozes. The cyclic alternance of silica-rich and carbonate-rich beds may be linked to the intense late Paleocene-early Eocene Caribbean volcanism (Bralower et al. 1997), although diagenetic silicification of the carbonate oozes cannot be excluded.

Among the levels with abundant nannofossils, only the uppermost sample (AU8t) has relatively good preservation. As a consequence, it was difficult to establish firmly the presence of



TEXT-FIGURE 1

Location map of the sections studied herein (A) and late Paleocene tectonic reconstruction of the Caribbean area (B), showing the Cuban Arc and the location of ODP sites 999 and 1001 (from Pindell and Barrett 1990 and Bralower et al. 1997).



TEXT-FIGURE 2

Correlation of the San Agustine and San Francisco de Paula sections to the integrated magnetobiochronologic scale (Berggren et al. 1995).

gray pattern: maximum temporal representation of various stratigraphic intervals in the two sections

hatched pattern: minimum hiatuses in the San Francisco de Paula section

Note that it is not known whether the NP9a/NP9b subzonal boundary was recovered in the San Francisco de Paula section, and consequently whether the BFE and the LPTM are represented in the section.

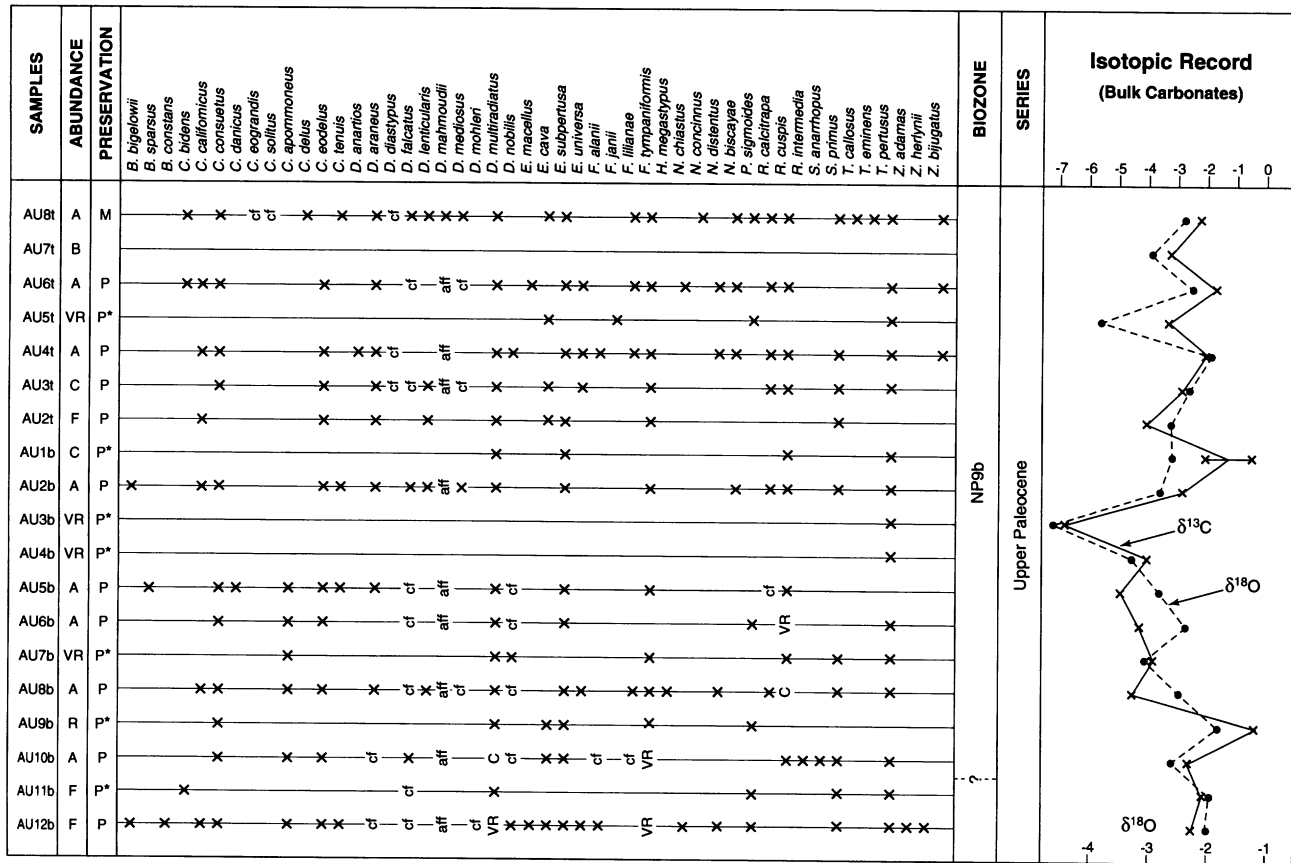
some discoaster taxa at most levels. For instance, due to a combination of overgrowth and dissolution, it was generally difficult to differentiate confidently between *Discoaster nobilis* and *D. falcaus*. In such cases, I have used “cf” to indicate that the presence of a taxon is suspected. Despite the generally poor preservation, there is strong indication that the assemblages were originally well diversified, as can be expected from their tropical setting.

Most of the section (from sample AU8b to AU8t) belongs to Subzone NP9b, as indicated by the co-occurrence of *D. araneus*, *Rhombaster cuspid* and *R. calcitrata*. No nannolith with an hexaradiate symmetry assignable to *Tribrachiatus bramlettei* was encountered. The assemblages are rather uniform in this interval, with *Discoaster multiradiatus* and *Ericsonia subpertusa* very common. Of interest is the definitive occurrence of *Discoaster mahmoudii* (5- and 6-rayed specimens) in the uppermost sample available for study (AU8t). Below this level and down to the base of the section, 5-rayed discoasters similar to *D. mahmoudii* but with a small, non-stellate knob, or without knob, occur. There are referred to *D. sp. aff. D. mahmoudii*. In

addition, *Fasciculithus tympaniformis* occurs throughout the interval and *F. liliana* occurs in samples AU6t and 8t.

It is unsure whether the base (1m) of the section lies in Subzone NP9b or in Subzone NP9a. I could not establish confidently the occurrence of *D. araneus* at levels AU12b and 10b, nor that of *R. calcitrata*, although *R. cuspid* was confidently determined at level AU10b. In contrast, rare specimens of *Fasciculithus alanii* were observed in sample AU12b. The occurrence of *Morozovella velascoensis* throughout the interval sampled for calcareous nannofossil stratigraphy and the absence of *Globanomalina pseudomenardii* indicate planktonic foraminifera Zone P5 of Berggren et al. 1995 (Fernández-Rodríguez et al. 1999, this volume). Assignment to nannoplankton Subzone NP9a indicates that only the lower middle part of Zone P5 is represented.

Radiolarian assemblages indicative of the lower part of the *Bekoma bidartensis* Zone occur in the San Agustine section (Sanfilippo, Appendix 1). This zonal determination, based on the presence of the marker species *Podocyrtilis papalis*,



TEXT-FIGURE 3

Distribution of the calcareous nanofossil species in the San Agustine section. The position of samples AU has been measured from below (AUb) and above (AUt) a prominent calcarenitic marker bed that occurs at ~2.50m below the top of the section.

C: common: numerous in every field; F: Few: present in every field but in low numbers; R: rare: present in numerous fields but not in all fields; VR: occasionally present in some fields; B: Barren. M: preservation moderate; P: preservation poor; VP: preservation very poor. Zonation from Martini 1971; subzonation from Aubry 1996. Isotopic records from bulk samples.

Phormocyrtis turgida and *Giraffospyris lata*, and the absence of the marker species *Theocotylissa auctor* and *Calocycloma castum* (see Sanfilippo and Nigrini 1998), is well supported by calcareous nanofossil stratigraphy, as indicated by cross correlation with Gulf of Mexico DSDP Site 96. From their reexamination of Cores 3 to 5 taken at this site, Sanfilippo and Nigrini (1998) established that the LOs of the first three taxa is located at a level low in the *Campylosphaera dela* Subzone of the *Discoaster multiradiatus* Zone as determined by Bukry (1973a; = Zone CP8b of Okada and Bukry [1980], which is essentially correlative with Subzone NP9b herein). Of particular interest is the fact that Bukry (1973b) reported the occurrence of *Rhomboaster cuspis* in samples 10-96-3-1, 63-64 cm and -3-6, 63-64 cm and that of *Discoaster* sp. cf. *D. araneus* in the latter sample, strongly suggesting that the lower part of Core 3 and Core 4 in Hole 96 correlates with the San Agustine section. This in turn suggests that the LPTM interval is preserved in the area of Site 96 located west-northwest of Cuba but was not recovered by Leg 10.

San Francisco de Paula section

Only the upper part (16.3m ± 2.3m) of the section, from sample SFP 23, can be interpreted biostratigraphically using calcareous nanofossils (text-figure 4). In the lower 36.7m, most levels are

barren or contain extremely rare, stratigraphically insignificant taxa. The only exception is level SFP 34 (30.5m below the marker bed) which yields a moderately well preserved assemblage characteristic of Zone NP6, with *Heliolithus kleinpelli* and *Sphenolithus anarrhopus* in addition to *Fasciculithus typaniformis* and *Sphenolithus primus*.

The upper 16.3m of the section belongs to Zones NP10 and NP12 (text-figures 2, 4, Tables 1, 2). There is no record of Zone NP11. The interval between samples SFP 23 and SFP 13 belongs to Zone NP10 as indicated by the LOs of *Discoaster multiradiatus*, *Tribrachiatus bramlettei* and *Rhomboaster cuspis* in sample SFP 23 and the highest occurrence (HO) of *Tribrachiatus contortus* in sample SFP 13. The interval is further subdivided into Subzone NP10d defined by the total range of *T. contortus* (from sample SFP 21 to SFP 13) and Subzone NP10a or c below (samples SFP 23 and 22). I have not yet identified means to differentiate Subzones NP10a from NP10c based on calcareous nanofossil ranges. However, direct correlation with planktonic foraminiferal stratigraphy (Fernández-Rodríguez et al. 1999, this volume) supports assignment to Subzone NP10a, based on the overlap of the ranges of *Morozovella velascoensis* with *T. bramlettei* in samples SFP 22 and 23. Subzone NP10b was not recorded. Of particular interest is the overlap of *T.*

contortus and *T. orthostylus* in samples SFP 15 to 13, which indicates the upper part of Zone NP10d, and the absence of overlap between the ranges of *T. bramlettei* and *T. contortus* (indicative of an unconformity, see below).

The interval between sample SFP 12 and SPE 16 (top of the section) belongs to Zone NP12. Because of poor preservation and the scarcity of the nannofossils at many levels in this interval, *Discoaster lodoensis* was not recorded at all levels. However, identification of this discoaster is unambiguous in the lower (samples SFP 13, 12, 11) and upper (samples SFP 15, 16) parts of the interval. For the same reasons, it is also difficult to determine to which part of Zone NP12 the section belongs based on the calcareous nannofossil assemblages alone. As the LO of *Morozovella aragonensis* is recorded in sample SFE 15 (10.5 m above the marker bed; Fernández-Rodríguez et al. 1999, this volume), it is likely that the lower part of Zone NP12 is represented in the section.

DISCUSSION

The San Augustine and San Francisco de Paula sections complement each other for a better —yet incomplete— representation of the uppermost Paleocene-lower Eocene interval. They also complement the record of lower Paleogene calcareous nannofossil biozones documented by Bralower and Iturralde (1997). Zones NP6 and NP9 and the subzones of Zone NP10 are for the first time documented in the Bahia Honda tectonic unit, and in fact perhaps in western Cuba. Zone NP6 had not yet been identified in western Cuba. Zone NP9 was tentatively identified in the Manacas Formation (Sites I-2 and I-12) of the Guaniguanico tectonic unit (Bralower and Iturralde-Vinent (1997). However, this was based on tenuous evidence from poorly diversified assemblages without primary markers, which contrasts with the diversified assemblages recovered from the San Augustine section in which *Discoaster multiradiatus* is abundant.

The presence of Zone NP10 (*Marthasterites* [vel *Tribrachiatus*] *contortus* Zone) in the area of La Habana was established (Martini 1971) based on the work of Brönnimann and Stradner (1960) who informally introduced the “*Discoaster multiradiatus*-*Marthasterites* [vel *Tribrachiatus*] *bramlettei*-*M. contortus* biostratigraphic zone” to which they assigned the Alkázar Formation, and who illustrated schematically the morpho-structural transition *Tribrachiatus bramlettei*-*T. contortus*-*T. orthostylus*, which involves a 60° rotation of two superposed triplets. Because the ranges of these taxa in the Alkázar Formation were not given by Brönnimann and Stradner (1960), it is not possible to determine which subzones of Zone NP10 occur in the sections they studied. However, recently, based on the co-occurrence of *Tribrachiatus contortus* and *T. orthostylus*, Bralower and Iturralde-Vinent (1997) reported that the Capdevila Formation (at Site I-42) exposed near the contact between the Bahia Honda and Guaniguanico tectonic units belongs to the upper part of Zone NP10. Using the subzonal scheme described above, this overlap implies that only the upper part of Subzone NP10d is present at Site I-42. Only Subzones NP10a and NP10d are present in the San Francisco de Paula section. Although it might be tempting to attribute the absence of Subzone NP10b to the absence of the marker species *Tribrachiatus digitalis* in the Caribbean, this cannot be the case because specimens of the latter species were found reworked in the upper part of the San Francisco de Paula section (samples SFE 8, SFP 3, SFP 10, text-figure 4).

The San Augustine section: a record of the LPTM

The San Augustine section corresponds to a stratigraphic interval (Subzone NP9b) that is rarely preserved in deep sea sections, but has been identified in Mediterranean (e.g., Egypt, Spain, Aubry, unpublished data), northern Indian Ocean (Site 213, Aubry, unpublished) and New Jersey (Cramer et al., in press; Aubry et al., in press a) sections. As indicated above, the interval is characterized by short-range taxa that lack symmetry or with an unusual symmetry. *Discoaster araneus*, *D. anartios* (asymmetrical discoasters) and *Rhomboaster cuspis*, *R. calcitrapa* and *R. spineus* (nannoliths with a basic rhomboidal shape; see Aubry et al., in press b), are the most characteristic components of this assemblage that evolved in association with the LPTM (Cramer et al., in press; Aubry et al., in press a).

Because of the uneven preservation and abundance of the calcareous nannofossils, the potential for reworking in a tectonically active area (as seen in the San Francisco de Paula section) and its restricted stratigraphic coverage, the San Augustine section does not help resolve the fine stratigraphic relationships between LPTM taxa. But the discovery of the “LPTM assemblage” in the San Augustine section extends its geographic distribution from the northern Indian Ocean to the Caribbean (text-figure 5). This peculiar assemblage has not been identified outside this area as yet (Aubry, in progress), and it may be that its extent was largely determined by the latest Paleocene paleogeographic configuration (see text-figure 5).

The paleoceanographic significance of this assemblage is unknown as yet. The particular morphology (with a tendency towards globular shapes and long arms) of the nannoliths suggest a possible adaptation to changes in water density (e.g., salinity) but little is known of functional morphology among the extant Coccolithophoridae. Most modern Coccolithophoridae are adapted to strongly oligotrophic conditions, and this has been used to interpret the long term Paleogene history of the calcareous nannoplankton (Aubry 1992, 1998c). It is thus also possible that the sudden occurrence of this assemblage in association with the LPTM reflects changes in fertility in the area where it occurred.

Aubry et al. (in press a) have indicated that the lowest occurrence of the “LPTM assemblage” can be used in a predictive way —to identify the stratigraphic interval where the CIE is recorded. In order to resolve the stratigraphic position of the lower part of the San Augustine section (the lower 50 cm of the section), bulk carbonate isotope measurements on powdered samples were made on a VG-prism mass spectrometer at the University of Southern California (text-figure 3). Average precision, as determined from replicate of ULTISS standard were 0.10 ‰, except for a small memory effect caused by the Cuban carbonates and that resulted in a systematic negative deviation of a few tenths of a per mil. The carbon isotopic values are very low (compared for instance with values on bulk from deep sea oozes at ODP Sites 999 and 1001 (Bralower et al. 1997, Figs. 3, 4), and the diagenetic effect on these values is apparent from the essentially parallel variations in carbon and oxygen isotopic compositions through the section. Nevertheless, no excursion occurs at the base of the section, which strongly suggest that the whole interval corresponds to the LPTM.

Correlation with the San Francisco de Paula section (text-figure 2) indicates that the CIE would occur in an unsampled (unexposed? unrepresented?) stratigraphic interval comprised between level SFP 24 and AU12b. Isotope analyses could not be

SAMPLE	ABUNDANCE	PRESERVATION	BIOZONE		DATUMS
			NP10	NP12	
16	C	M			
15	F	P			
14	C	P			
13	F	VVP			
12	VR	VVP			
11	R	F			
10	R	P			
9B	B				
9A	R	VP			
8	R	VP			
7B	B				
7A	B				
6B	B				
6A	B				
5	B				
4	VR	VVP			
3	VR	VVP			
2	B				
SFE1	VR	VP			
SFO	C	VP			
SFP1	F	VP			
2	F	VP			
3	C	M			
4	C	G			
5	F	VVP			
6	F	VVP			
7	C	VP			
8	C	P			
9	R	P			
9A	R	P			
10	C	P			
11	C	P			
12	F	P			
13	C	P			
14	C	P			
15	C	P			
16	A	VP			
16A	C	VP			
17	A	P			
18	C	P			
19	VP				
20	C	VP			
21	C	VP			
22	C	VP			
23	B				
24	B				
25	B				
26	R	VVVP			
27	B				
28	B				
29	VR				
30A	B				
30B	B				
31	B				
32	B				
33	B				
34	F	M			
35	B				
36	B				
37	VR	VP			

TEXT-FIGURE 4

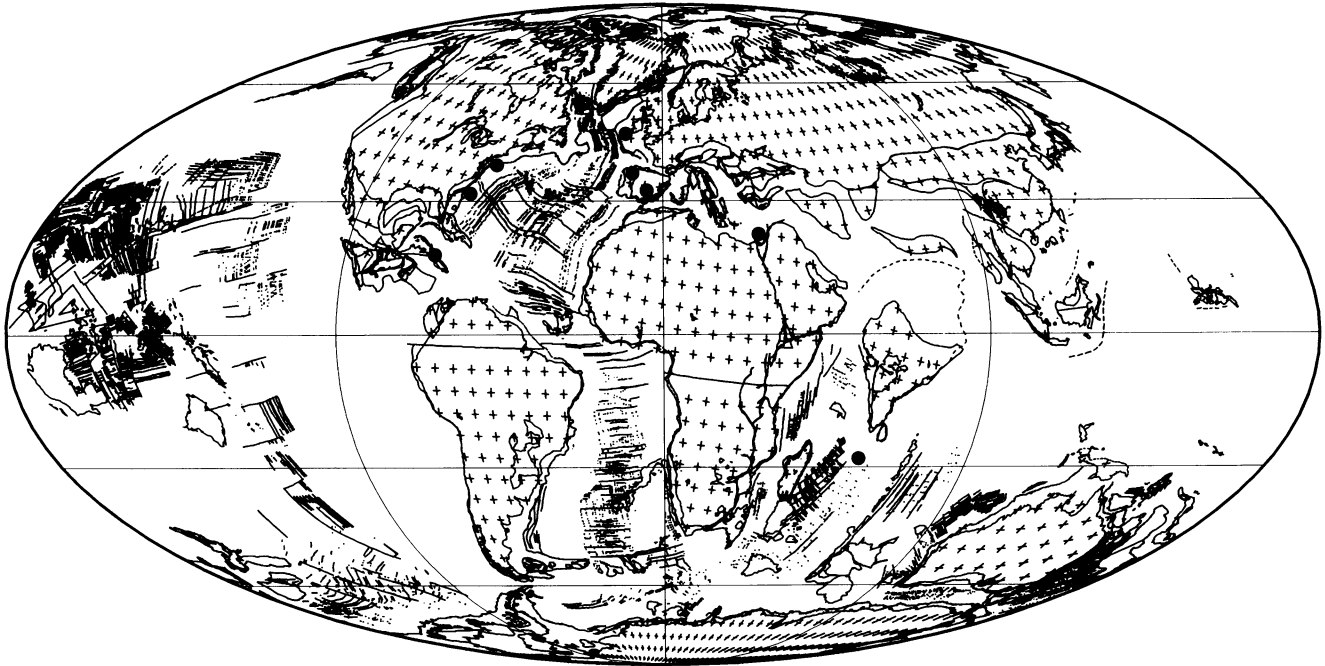
Distribution of the calcareous nannofossil species in the San Francisco de Paula section. The position of samples SFP and SFE has been measured from the prominent marker bed that occurs at ~44 m above the base of the section (see text). Symbols and explanation as for text-figure 3. This figure is not meant to provide an inventory of species in each sample, and should not be taken as indicative of the range of taxa other than the marker species. In the interval between samples SFP 23 and SFP 13, the ranges given are essentially those of the marker species. Note the large number of Paleocene-earliest Eocene species (e.g., *D. multiradiatus*, *F. alanii*, *N. biscaye*, *P. sigmoides*, *R. cuspis*, *T. bramlettei*, *T. digitalis*) that are reworked in the upper 14m of the section (Zone NP12). Noticeable amount of reworking among benthic foraminifera was also noted (Fluegeman 1999, this volume).

performed on the San Francisco de Paula section due to the unavailability of material.

Recovery of the LPTM assemblage in Cuba but not at nearby ODP Sites 999 and 1001 (text-figure 1; based on the description of the calcareous nannofossil assemblages in Sigurdsson et al. 1997, and in Bralower et al. 1997) requires explanation. Sigurdsson et al. (1997) observed that species of the genus *Tribracliatulus* do not occur at Sites 999 and 1001, and are also absent at equatorial Pacific Ocean ODP Site 865, indirectly suggesting that these taxa did not live in tropical oceanic waters.

The same argument could be invoked to explain the absence of the taxa characteristic of the LPTM at the two Caribbean sites. Because of their presence in Cuba this argument does not hold.

One possibility is that the LPTM assemblage was essentially restricted to shallow water depths. The assemblage is mostly known from sections deposited in neritic to upper bathyal settings such as the New Jersey and Egyptian sections (Cramer et al., in press; pers. observ.). Benthic foraminiferal assemblages in the San Agustine section indicate a mid bathyal setting (500 to 1000m water depth; Fluegeman, pers. commun.), but a lower



TEXT-FIGURE 5

Paleogeographic distribution of the LPTM assemblage. Distribution is shown on a reconstruction at 55 Ma (Late Paleocene) produced by the PLATES project, University of Texas Institute for Geophysics. Paleolocation of Site 213 from Zachos et al. (1992). Areas where the LPTM calcareous nannofossil assemblage occurs includes Cuba (this work), Blake Plateau (ODP Site 1051; pers. observ.), the New Jersey margin (Cramer et al., in press; Aubry et al., in press a), the Bay of Biscay (DSDP Site 401; Zumaya section; pers. observ.), the northwestern Tethys (Alamedilla section, Spain, Aubry et al., unpublished manuscript), the southern Tethys (e.g., Qerya section, Egypt; Aubry, in preparation), and the western Indian Ocean (DSDP Site 213; Aubry and Norris, unpublished data).

bathyal to upper abyssal paleodepth (1500-2500m) for Sites 999 and 1001 (Bralower et al. 1997). However, at North Atlantic (Bay of Biscay) DSDP Site 401 with a late Paleocene lower bathyal depth of 1800 m (Pak and Miller 1992), the LPTM assemblage occurs, and its lowest occurrence (between 202.40 and 202.60 mbsf) is at the level of the excursion (recorded between 202.60 and 202 mbsf, Pak and Miller 1992). Similarly, at DSDP Site 213, the oldest sediments above the basalt (Core 16, sections 4 to 1) belong to Subzone NP9b, have recorded the younger part of the excursion (the return from minimal $\delta^{13}C$ to more positive values), and yield the LPTM assemblage (Aubry and Norris, unpublished data). Zachos et al. (1992) have calculated a >3500 m late Paleocene-early Eocene paleodepth for the site. Thus water depth is not a direct explanation. By the same token, explaining the absence of the assemblage on the basis that it is prone to dissolution does not hold in view of its occurrence at deep water Sites 401 and 213.

The other possibility is that sections that do not yield the LPTM assemblage provide only a partial record of Subzone NP9b. Extended sections where the NP9/NP10 (chrono)zonal boundary occurs, show that the LPTM assemblage decreases upwards in abundance, and its characteristic taxa may become very rare to absent in the upper part of the subzone. It may thus be that only the uppermost part of Subzone NP9b is recorded/was recovered in sections where the LPTM assemblage does not occur. Thus I would question the temporal completeness of the upper Paleocene-lower Eocene interval at ODP Sites 999 and 1001, and in particular the full recovery of the LPTM at these sites.

While more studies are needed to explain the sudden evolution of the LPTM assemblage, the recovery/discovery of new LPTM sections will help explain its apparently differential paleogeographic distribution. In this sense, the discovery of the San Augustine section has tremendous significance despite its limited potential for high resolution studies.

THE SAN FRANCISCO DE PAULA SECTION: A COMPLEX DEPOSITIONAL HISTORY

Stratigraphic and temporal interpretation of the section

Our sampling of the lower part of the San Francisco de Paula section (below sample SFP 23; i.e., from 3.5m below our marker bed down to the base of the section) was regrettably too coarse to permit a better biostratigraphic resolution than achieved here considering the lithologies that occur. In this respect, the remark by Bralower and Iturralde Vinent (1997) that the absence of some zones in the NP5-NP9 zonal interval may be due to insufficient sampling rather than reflect major stratigraphic gaps is well taken. Close-spaced sampling is necessary to delineate zonal intervals that may be as thin as 0.50m (see Table 2). However, this study shows that depositional history at least around the Paleocene/Eocene boundary, was complex, and involved a sequence of erosional episodes.

The planktonic foraminiferal stratigraphy (Fernández-Rodríguez et al. 1999, this volume) conducted on the same samples as those studied for calcareous nannofossils provides two useful constraints. The delineation of the HO of *Globanomalina*

TABLE 1

Location of lowest and highest occurrences (LO and HO, respectively) of selected taxa in the San Francisco de Paula section. MB is marker Bed from which the section was measured upwards and downwards. Δ is the uncertainty (in cm) on the location of the datums in the section

Species	LO	HO	Sample	Distance below MB (in m)	Δ (in cm)
<i>D. lodoensis</i>	X		SFP 12	1.20 (1.25 to 1.20)	0.05
<i>T. contortus</i>		X	SFP 13	1.25 (1.25 to 1.20)	0.05
<i>T. orthostylus</i>	X		SFP 15	1.50 (1.60 to 1.50)	0.10
<i>T. contortus</i>	X		SFP 21	2.50 (3.00 to 2.50)	0.50
<i>T. bramlettei</i>		X	SFP 23	3.50 (3.50 to 3.00)	0.50
<i>T. bramlettei</i>	X		SFP 23	3.50 (3.50 to 3.00)	0.50
<i>R. cuspis</i>	X		SFP 23	3.50 (3.50 to 3.00)	0.50
<i>D. multiradiatus</i>	X		SFP 23	3.50 (3.50 to 3.00)	0.50
<i>F. tympaniformis</i>		X	SFP 34	30.50 (30.50 to 10.20)	20.30

pseudomenardii (P4/P5 zonal boundary) between samples SFP 28 and 29 indicates that level SFP 29 (18.6 m below the marker bed) cannot be younger than lowermost Zone NP9 or than the Chron C25n/C24r magnetic reversal (Table 3). The delineation of the HO of *Morozovella velascoensis* (P5/P6 zonal boundary) between samples SFP 22 and 21 indicates that level SFP 22 (3.0 m below the marker bed) cannot be younger than a level in lower Subchronozone NP10a (Table 3). Finally, the HO of the *Stensioina beccariiiformis* assemblage between samples SFP 23 and 24 (Fluegeman 1999, this volume) implies that level SFP 24 (5.8 m below the marker bed) is located in mid-biochronozone NP9 or is older (see Aubry et al. 1996; Berggren and Aubry 1998).

Level SFP 24 is barren of calcareous nannofossils, and there is a 2.3 m sampling gap between levels SFP 24 and SFP 23 (assigned to Zone NP10). Thus it is not possible to determine whether the NP9/NP10 zonal boundary is located at 5.8 m or at 3.5 m below the marker bed or somewhere in between. Its location at 3.5 m would imply that the HO of the *S. beccariiiformis* assemblage corresponds to the Benthic Foraminiferal Event (BFE; e.g., Thomas 1992), and that the 2.3 m interval between it and the LO of *T. bramlettei* represents the LPTM and correlates with the interval assigned to Subzone NP9b in the San Agustine section. Its location at 5.8 m would imply that the HO of the *S. beccariiiformis* assemblage in the section does not correspond to the BFE, but represents a pseudoevent (see Aubry 1998a). This would also mean that Subzone NP9b is not represented in the section. Any intermediate position of the NP9/NP10 zonal boundary between samples SFP 24 and 23 would imply that the BFE is represented and that a shorter or larger episode of the LPTM is represented in the section. The difference in thickness (up to a maximum of 2.3 m) of Subzone NP9b-equivalent in the San Francisco de Paula section compared with the thickness (>4 m) of the subzone in the San Agustine section may reflect different sedimentation rates at different locations, or may indicate an unconformable contact between levels SFP 23 and 24 or at either level. With the data available, this cannot be determined.

A substantial stratigraphic gap occurs between samples SFP 22 and 21 (at 3 to 2.5 m below the marker). This is clearly indicated by the juxtaposed HOs of *T. bramlettei* and *M. velascoensis* at 3 m and the LO of *T. contortus* at 2.5 m. The stratigraphic gap encompasses most of Subzone NP10a,

TABLE 2

Minimum and maximum thickness of zones and subzones delineated in the San Francisco de Paula section. The extent of Zone NP6 in this section is not known since only one level bracketed by barren intervals was assigned to it. The maximum thickness of Subzone NP10a is based on the record of the HO of the *Stensioina beccariiiformis* assemblage in sample SFP 24 (Fluegeman 1999, this volume). The LAD of the *S. beccariiiformis* assemblage has been tied to mid Biochronozone NP9 (Aubry et al. 1996).

Boundaries	Interval	Distance from MB	Zone/Subzone	min. Thickness	max. Thickness
Top NP12	SFE 16	+ 12.8 m	Zone NP12	14.50 m	14.55 m
Base NP12	SFP12/ SFP13	- 1.2 m - 1.25 m			
Top NP10d	SFP 12/ SFP 13	- 1.2 m - 1.25 m	Subzone NP10d	1.25 m	1.80 m
base NP10d	SFP 21 SFP 22	- 2.5 m - 3.0 m			
Top NP10a	SFP 21 SFP 22	- 2.5 m - 3.0 m	Subzone NP10a	0.50 m	3.3 m
Base NP10a	SFP 23 SFP 24	- 3.5 m - 5.8 m			

Subzones NP10b, NP10c and the lower part of Subzone NP10d and represents a minimum hiatus of 0.8 my (Table 3). A younger unconformity occurs at the abnormal NP10/NP12 zonal contact between samples SFP 13 and 12 (between 1.4 and 1.25 m below the marker bed). It represents a hiatus of at least 0.9 my (Table 3). Intense reworking in samples SFP 12 and 11, just above the unconformity (text-figure 3) is noteworthy.

A record of tectonic events linked to the collision between the North American Plate and the Greater Antilles Arc?

The upper Paleocene-lower Eocene stratigraphic record preserved in the San Francisco de Paula section is thus highly discontinuous, and would be unsuitable as a reference for the Paleocene/Eocene boundary. Indeed, it is not possible to determine which level in the section correlates with the boundary. The base of the Ypresian Stage as delineated in northwestern Europe can be correlated quite precisely using the LO of *T. digitalis* (Aubry 1996), which defines the NP10a/b subzonal boundary. Because Subzone NP10b is unrepresented in the section, the interval spanning samples SFP23 and SFP 22 is assignable to either Subzone NP10a or NP10c. The Paleocene/Eocene contact is thus unconformable and may lie between samples SFP 24 and SFP23 or between samples SFP 22 and SFP 21.

Of the less than 2.7 my of geological time (estimated from mid Chron C24r to earliest Chron C23r) that the 14 m of section extending from level SFP 23 (LO of *Tribachiatus bramlettei*) to SFE 15 (LO of *Morozovella aragonensis*) brackets, at least 1.8 my are not represented due to unconformities (text-figure 2). Stratigraphic gaps that can be shown to be of regional extent may constitute important signals for tectonic events or for changes in sea level. To decipher such significance, a number of well chosen sections whose stratigraphic interpretations have been based on detailed sampling is necessary. There is no such database for Cuba currently, and even the data presented here would contribute little to reconstruct the Paleocene sedimentary history of the Bahia Honda unit. Nevertheless, this study of the San Francisco de Paula section shows that the potential exists to reconstruct high resolution sedimentary/tectonic history of the discrete tectonic units of western Cuba based on detailed stratigraphic analysis of densely sampled sections. It is not possible

TABLE 3

Datums and their estimated ages (from Berggren et al. 1995) used to determine the duration of hiatuses in the San Francisco de Paula section.

Event	Estimated age (Ma)
FAD <i>D. lodoensis</i>	52.85
LAD <i>T. contortus</i>	53.61
FAD <i>T. orthostylus</i>	53.64
LAD <i>T. bramlettei</i>	53.89
FAD <i>T. contortus</i>	53.93
LAD <i>M. velascoensis</i>	54.7
FAD <i>T. bramlettei</i>	55
BFE	55.5
LAD <i>G. pseudomenardii</i>	55.9
Chron C25n/C24r	55.904
FAD <i>D. multiradiatus</i>	56.2

in relation with this study to determine confidently the origin of the stratigraphic gaps in the section, although large amounts of reworking, particularly among the planktonic foraminifera (Fernández-Rodríguez et al. 1999, this volume) suggest a marked tectonic influence, possibly related to the terminal collision in western Cuba between the Greater Antillean Volcanic Arc and the continental margin of the North American Plate, dated as latest Paleocene to early Eocene (Bralower and Iturralde-Vinent 1997). It is possible that the stratigraphic gaps in the San Francisco de Paula section represent episodes of more intense tectonism whereas more continuous deposition occurred during episodes of relative tectonic quiescence. If this is the case, the ages of the unconformities in the section constrain the timing of the (3) earliest Eocene tectonic pulses associated with the collision.

The sedimentary packages delineated in the San Francisco de Paula section may also reflect, at least in part, a more global pattern of sediment distribution. We note that, as elsewhere, there are zones very poorly represented in western Cuba while others are extensively developed. For instance, Zone NP11, not represented in the San Francisco de Paula section, is known only from Site I-30 on the Los Palacios tectonic unit (Bralower and Iturralde Vinent 1997). In contrast, Zone NP12, whose lower part is well developed in the San Francisco de Paula section, is known from 5 sites on the Bahia Honda and Los Palacios tectonic unit (Bralower and Iturralde-Vinent 1997) and was recognized by Brönnimann and Stradner (1960) to correspond to the extensive Capdevila Formation. This zone is also one of the best represented of the lower middle Eocene interval in the Atlantic Ocean (Aubry 1995). Thus, it cannot be excluded that the distribution of sedimentary packages in western Cuba was also controlled by a global forcing. Similarly, it cannot be excluded that the stratigraphic gaps described in the NP10 zonal interval are part of a broad pattern of widespread unconformities in many parts of the world (Aubry 1998b). Thus perhaps these gaps record the dual effect of local tectonic and global forcing.

Whatever the origin of the unconformities, the San Francisco de Paula section constitutes a new (although isolated) test of the feasibility that the lower Paleogene sequences of western Cuba constituted a substantial source of detritic material to the upper

Neogene sequences of the Bahama Bank (Lidz and McNeill 1995, 1998). The absence of evidence for reworked lowermost Eocene rocks would be consistent with the thinness of the NP10 zonal interval and the absence of Zone NP11 in the San Francisco de Paula section. However, the absence of evidence for younger lower Eocene rocks is surprising considering the widespread development of Zone NP12 in western Cuba (see above). One section alone cannot bring a serious clue to the problem of the origin of the allochthonous Paleogene component in a Neogene sequence located hundreds of kms away. However, this study shows that at least part of the Paleogene record of western Cuba is amenable to precise temporal interpretation, and biostratigraphic study of a broader scope may eventually provide the possibility to determine whether active transport by the Florida Current from the northern coast of Cuba occurred during the late Neogene.

CONCLUSIONS

The San Augustine and San Francisco de Paula sections constitute two complementary, albeit incomplete, records of late Paleocene-early Eocene history of western Cuba (Bahia Honda tectonic unit). Together, they bring additional documentation to the stratigraphic framework established by Bralower and Iturralde-Vinent (1997) in western Cuba.

The San Augustine section is of exceptional value because it is the only definitive known record of the LPTM in the Caribbean. We were unable to derive a reliable isotopic record in this section because of strong diagenetic overprint. However, a specific calcareous nannoplankton assemblage that has its LO at the level of the CIE and is essentially restricted to the LPTM has been documented from sections in the North Atlantic Ocean and the Tethys. This assemblage occurs in the San Augustine section, implying that the section was deposited during the LPTM. In turn, this extends the geographic distribution of the LPTM calcareous nannofossil assemblage from the western Indian Ocean (Site 213) to the Caribbean through the Tethys and North Atlantic Ocean. This assemblage has not yet been documented from Pacific Ocean or South Atlantic Ocean sites, which may reflect provincialism or, alternatively, broadly distributed unconformities.

The San Francisco de Paula section was sampled with the hope that it would constitute a suitable reference section for the Paleocene/Eocene boundary. This is clearly not the case. However, it yields a valuable record of successive latest Paleocene-earliest Eocene erosional events, that may reflect the terminal collision between the Greater Antillean Volcanic Arc and the continental margin of the North American Plate, dated as latest Paleocene to early Eocene (Bralower and Iturralde-Vinent 1997). However, many uppermost Paleocene-lowermost Eocene sections outside the Caribbean yield unconformities, and it is possible that the erosional events recorded in western Cuba fit in a global rather than local pattern of sedimentary history.

APPENDIX 1

Biostratigraphic analysis of radiolarian in the San Augustine section, contributed by Annika Sanfilippo.

Radiolarians are extremely poorly preserved in most of the samples collected from the San Augustine section, and as a result they occur in extremely low abundance (text-fig. 6). However, a thin (~1m) interval in the lower half of the section (samples AU7B, 6B and 5B) and the youngest level sampled in the sec-

SERIES	NANNO ZONE (1)	RAD ZONE (2)	San Agustine Sample Number	Abundance	Preservation	Bekoma sp.	Buryella tetradica	Buryella clinata	Calocyclus castum	Dendrospyrus fragoides	Giraffospyris lata	Lamplonium pennatum	Lamplonium fab. fabaeforme	Lychnocanoma auxilla	Phormocyrtis cubensis	Phormocyrtis turgida	Phormocyrtis striata exquisita	Podocyrtis papalis	Spongodiscus cruciferus	Stylotrochus alveatus	Stylotrochus nitidus	Spongodiscus quartus quartus	Theocorys phyzella	Theocorys pre-physzella	Theocotyle spp.	Theocotylissa spp.	Thyrsoctyrtis spp.						
UPPER PALEOCENE	Subzone NP9b	Bekoma bidartensis	AU-8T	A	P-M	VR	C	-	-	R	-	R	R	R	R	VF	F	F	C	VR	VR	R	R	-	VR	-	-	-					
			AU-7T	tr	VVP	?														?													
			AU-6T	tr	VVP	VR																											
			AU-5T	tr	VVP	VR																											
			AU-4T	B	-																												
			AU-3T	C	VVP																												
			AU-2T	F	VVP																												
			AU-1T	R	P																												
			AU-1B	A	VVP																												
			AU-2B	R	VP																												
			AU-3B	tr	VP																												
			AU-4B	tr	VP																												
			AU-5B	A	P-M	-	C	-	-	R	-	R	R	R	R	R	VF	F	F	C				R									
			AU-6B	A	M	VR	C	-	-	R	-	R	R	MR	MR	MR	VF	F	F	C	R	R	R	VR	-	VR	-	-	-	-	-		
AU-7B	A	P-M	VR	C			R	VR	R	R				R	VF	F	C						-	VR	-	-	-	-					
AU-8B	R	VP																															
AU-9B	tr	VP																															
AU-10B	?A	VVP																															
AU-11B	?R	VVP																															
AU-12B	VR	VVP																															

Preservation extremely poor - tabulation of radiolarian abundances impossible

TEXT-FIGURE 6

Distribution of the radiolarian assemblages in the San Agustine section.

(1) Aubry, this paper; (2) Sanfilippo, this paper

A: abundant; B: Barren; C: Common; F: Few; R: Rare; Tr: Traces; VF: Very few; VR: Very rare; ?: suspected presence
M: Moderate; P: Poor; VP: Very poor; VVP: Very very poor (radiolarians are extremely corroded)

tion (sample AU8T) yield abundant and moderately preserved assemblages that permit assignment to the *Bekoma bidartensis* Zone (as applied in Sanfilippo and Nigrini 1998). These assemblages include *Podocyrtis papalis* (common), *Phormocyrtis turgida* (few) and, in sample AU7B, *Giraffospyris lata* (very rare). Of particular interest is the absence of *Theocotylissa auctor* and *Calocyclus castum*. Sanfilippo and Nigrini (1998) have established the relative sequence of upper Paleocene-lower Eocene radiolarian stratigraphic events, based on the construction of a composite section using several deep sea sites. From their reexamination of DSDP Site 96, they concluded that the lowest occurrences (LO) of *P. papalis*, *P. turgida* and *G. lata* are clustered in an unrecovered interval at the site between sections 96-4-CC and -5-1 (~321.50 and 329 mbsf) and older than the LO of *T. auctor* (in the 11m coring gap between cores 96-3 and -4 at the site). They further determined that these LOs are older than that of *C. castum* (see Sanfilippo and Nigrini, 1998, figure 13.4). The absence of *T. auctor* and *C. castum* thus indicates that the San Agustine section belongs to the lower part of the *Bekoma bidartensis* Zone below the LO of *T. auctor* and *C. castum*. It further implies that it is correlative with an unrecovered interval between Sections 4-CC and 5 in Hole 96. In Hole 96, this part of the *B. bidartensis* Zone is directly correlative with the upper Paleocene Subzone CP8b of Okada and Bukry (1980), implying an upper Paleocene age for the San Agustine section, in agreement with the determination by Aubry herein.

ACKNOWLEDGMENTS

I am grateful to Richard Fluegeman for his enthusiasm in arranging the Field Excursion to Cuba and to Manuel Iturralde-Vinent, Gena Fernández-Rodríguez and Emilio Flores-Albin for leading the field party; to Annika Sanfilippo and Richard Fluegeman for discussion on the biostratigraphy of the sections, to Lowell Stott and Miguel Rancon, University of southern California, for supervising and conducting, respectively, the isotopic analyses, and Ashish Sinha for discussion of the results; to Lisa Gahagan for providing me with a reconstruction of the world geography at 55 Ma; to W. A. Berggren and R. Norris for reviewing this manuscript, and to UNESCO and IUGS for providing the financial support for the field trip. This is ISEM Contribution 99-82.

REFERENCES

AUBRY, M-P., 1984. Handbook of Paleogene Calcareous Nannofossils. New York: Micropaleontology Press, American Museum of Natural history, 1:1-263.
 ———, 1988. Handbook of Paleogene Calcareous Nannofossils. New York: Micropaleontology Press, American Museum of Natural History, 2:1-279.
 ———, 1989. Handbook of Paleogene Calcareous Nannofossils. New York, Micropaleontology Press, American Museum of Natural History, 3:1-279.

- , 1990. Handbook of Paleogene Calcareous Nannofossils. New York: Micropaleontology Press, American Museum of Natural History, 4:1-381.
- , 1992. Late Paleogene calcareous nannoplankton evolution: A tale of climatic deterioration. In: Prothero, D. R. and Berggren, W. A., Eocene-Oligocene Climatic and Biotic Evolution, Princeton University Press, Princeton, N. J., 272-309.
- , 1995. From chronology to stratigraphy: Interpreting the lower and middle Eocene stratigraphic record in the Atlantic Ocean. In: Berggren, W. A., Kent, D. V., Aubry, M.-P. and Hardenbol, J., (Eds.), Geochronology Time Scales and Global Stratigraphic Correlation, Society of Economic Paleontologists and Mineralogists Special Publication N° 54:213-274.
- , 1996. Towards an upper Paleocene-lower Eocene high resolution stratigraphy: Israel Journal of Earth Sciences, 44:239-253.
- , 1998a. Stratigraphic (dis)continuity and temporal resolution in the upper Paleocene-lower Eocene deep sea record. In: Aubry, M.-P., Lucas, S. and Berggren, W. A. (Eds.), Late Paleocene-Early Eocene Climatic and Biotic Evolution. New York: Columbia University Press,
- , 1998b. The upper Paleocene-lower Eocene stratigraphic puzzle. *Strata*, ser. I, 9:7-9.
- , 1998c. Early Paleogene calcareous nannoplankton evolution: A tale of climatic deterioration: A tale of climatic amelioration. In: M.-P. Aubry, S. Lucas and W. A., Berggren (Eds.), Late Paleocene-Early Eocene Climatic and Biotic Evolution. New York: Columbia University Press, 158-203.
- , 1999. Handbook of Paleogene Calcareous Nannofossils. New York: Micropaleontology Press, American Museum of Natural History, 5:1-368.
- AUBRY, M.-P., BERGGREN W. A., STOTT, L. and SINHA, A., 1996. The upper Paleocene-lower Eocene stratigraphic record and the Paleocene/Eocene boundary carbon isotope excursion. In: Knox, R. O'B., Corfield, R. C., and Dunay, R. E. (Eds.), Correlation of the early Paleogene in Northwestern Europe, Special Publication of the Geological Society N° 101:353-380.
- AUBRY, M.-P., LUCAS, S., and BERGGREN, W. A. (Eds.), 1998a. Late Paleocene-Early Eocene Climatic and Biotic Events, New York, Columbia University Press, 1-513.
- AUBRY, M.-P. and BONNEMAISON, M., 1999. NannoStrat: Cenozoic calcareous nannofossils. New York: Micropaleontology Press, American Museum of Natural History, in press. (Database, in binary code).
- AUBRY, M.-P., CRAMER, B., MILLER, K. G., WRIGHT, J., KENT, D. V., and OLSSON, R. D., in press a. Late Paleocene event chronology: Unconformities not diachrony. *Geological Society of France Bulletin*.
- AUBRY, M.-P., REQUIRAND, C., and COOK, J., in press, b. The Rhomboaster *Tribrachiatus* lineage: A remarkable succession of events from 55.5 Ma to 53.2 Ma. *GFF*.
- BERGGREN, W. A., and AUBRY, M.-P., 1998. The Paleocene/Eocene Epoch/Series boundary: Chronostratigraphic framework and estimated geochronology. In: M.-P. Aubry, S. Lucas and W. A. Berggren (Eds.), Late Paleocene-Early Eocene Climatic and Biotic Evolution, Columbia University Press, New York:18-36.
- BERGGREN W. A., KENT, D. V., SWISHER, C. C., III and AUBRY, M.-P., 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W. A., Kent, D. V., Aubry, M.-P. and Hardenbol, J., (Eds.), Geochronology Time Scales and Global Stratigraphic Correlation. Society of Economic Paleontologists and Mineralogists Special Publication N° 54:129-212.
- BLANCO-BUSTAMANTE, S., FERNÁNDEZ-RODRÍGUEZ, G., and FLUEGEMAN, R. H., 1999. A note on the biostratigraphy of Paleocene-Eocene larger foraminifera from western Cuba. In: Fluegeman, R., and Aubry, M.-P., (Eds.), Lower Paleogene Biostratigraphy of Cuba. *Micropaleontology*, volume 45, supplement 2, pp. 19-26.
- BRALOWER, T. J., and MUTTERLOSE, J., 1995. Calcareous nannofossil biostratigraphy of site 865, Allison Guyot, central Pacific Ocean: A tropical Paleogene reference section. In: Winterer, E. L., Sager, W. W., Firth, J. V., and Sinton, J. M. (Eds.), Proceedings of the Ocean Drilling Program, Scientific Results, 143: College Station, TX (Ocean Drilling Program):31-74.
- BRALOWER, T. J., and ITURRALDE-VINENT, M. A., 1997. Micropaleontological dating of the collision between the North American plate and the Greater Antilles Arc in western Cuba. *Palaios*, 12:133-150.
- BRALOWER, T. J., THOMAS, D. J., ZACHOS, J. C., HIRSCHMANN, M. M., RÖHL, U., SIGURDSSON, H., THOMAS, E., and WHITNEY, D. L., 1997. High-resolution records of the late Paleocene thermal maximum and circum-Caribbean volcanism: Is there a causal link? *Geology*, 25:963-966.
- BRÖNNIMANN, P., and RIGASSI, P., 1963. Contribution to the geology of the area of the city of La Havana and its surroundings. *Eclogae Geologicae Helveticae*, 56:193-480.
- BRÖNNIMANN, P., and STRADNER, H., 1960. Die Foraminiferen- und Discoasteridenzonen von Kuba und ihre Interkontinentale Korrelation. *Erdoel Zeitschrift*, 76:364-369.
- BUKRY, D., 1973a. Low-latitude coccolith biostratigraphic zonation. In: Edgar, N. T., Saunders, J. B., et al., Initial Reports of the Deep Sea Drilling Project, 15: Washington (U.S. Government Printing Office):685-703.
- , 1973b. Coccolith stratigraphy, Leg 10 - Deep Sea Drilling Project. In: Worzel, J. L. Bryant, W. et al. (Eds.), Initial Reports of the Deep Sea Drilling Project, volume 10:385-406. Washington, D.C.: U.S. Government Printing Office.
- BYBELL, L. M. and SELF-TRAIL, J. M., 1995. Evolutionary, biostratigraphic, and taxonomic study of calcareous nannofossils from a continuous Paleocene-Eocene boundary section in New Jersey. U. S. Geological Survey Professional Paper 1554:1-36.
- , 1997. Late Paleocene and early Eocene calcareous nannofossils from three boreholes in an onshore-offshore transect from New Jersey to the Atlantic continental rise. In: Miller, K. G., and Snyder, S. W., (Eds.), Proceedings of the Ocean Drilling Program, Initial Reports, 150X: College Station, TX (Ocean Drilling Program):91-110.
- CRAMER, B., MILLER, K.G., AUBRY, M.-P., OLSSON, R. K., WRIGHT, J. D., KENT, D. V., and BROWNING, J. V., in press. The Bass River section: An exceptional record of the LPTM event in a neritic setting. *Bulletin de la Société géologique de France*.
- FARIS, M., and STROUGO, A., 1998. The lower Libyan in Farafr (Western Desert) and Luxor (Nile Valley); correlation by calcareous nannofossils. M. E. R. C., Ain Shams University, Earth Sciences Series, 12:137-156.
- FERNÁNDEZ-RODRÍGUEZ, G., BLANCO-BUSTAMANTE, S., and FLUEGEMAN, R. H., 1999. Paleocene-Eocene planktonic foraminiferal biostratigraphy of western Cuba. In: Fluegeman, R.,

- and Aubry, M.-P., (Eds.), Lower Paleogene Biostratigraphy of Cuba, *Micropaleontology*, volume 45, supplement 2, pp. 27-42.
- FLUEGEMAN, R. H., 1999. Preliminary study of the benthic foraminifera of the San Francisco de Paula section (upper Paleocene-lower Eocene), Ciudad de La Habana, Cuba. In: Fluegeman, R., and Aubry, M.-P. (Eds.), Lower Paleogene Biostratigraphy of Cuba. *Micropaleontology*, volume 45, supplement 2, pp. 43-56.
- ITURRALDE-VINENT, M. A., 1994. Cuban geology: a new plate tectonic synthesis. *Journal of Petroleum Geology*, 17:39-70.
- LIDZ, B. H., and MCNEIL, D. F., 1995. Reworked Paleogene to early Neogene planktic foraminifera: implications of an intriguing distribution at a late Neogene prograding margin, Bahamas. *Marine Micropaleontology*, 25:221-268.
- , 1998. New allocyclic dimensions in a prograding carbonate bank: evidence for eustatic, tectonic, and paleoceanographic control (late Neogene, Bahamas). *Journal of Sedimentary Research*, 68:269-282.
- MARTINI, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (Ed.), Proceedings of the Second Planktonic Conference. Roma, Italy, *Tecnoscienza*, 2:739-785.
- OKADA, H., and BUKRY, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation. *Marine Micropaleontology*, 5:321-325.
- PAK, D. K. and MILLER, K. G., 1992. Paleocene to Eocene benthic foraminiferal isotopes and assemblages: Implications for deepwater circulation. *Paleoceanography*, 7:405-422.
- PINDELL, J. L., and BARRETT, S., 1990. Geologic evolution of the Caribbean region: A plate tectonic perspective. In: Dengo, G., and Case, J., (Eds.), *The Caribbean Region*. Boulder, Colorado: Geological Society of America, *Geology of North America*, H:405-432.
- SANFILIPPO, A., and HULL, D. M., 1999. Upper Paleocene-lower Eocene radiolarian biostratigraphy of the San Francisco de Paula section, western Cuba: Regional and global comparisons. In: Fluegeman, R., and Aubry, M.-P., (Eds.), Lower Paleogene Biostratigraphy of Cuba. *Micropaleontology*, volume 45, supplement 2, pp. 57-82.
- SANFILIPPO, A. and NIGRINI, C. A., 1998. Upper Paleocene - lower Eocene deep-sea radiolarian stratigraphy and the Paleocene/Eocene series boundary. In: Aubry, M.-P., Lucas, S. G. and Berggren, W. A. (Eds.), *Late Paleocene - early Eocene climatic and biotic evolution*. New York: Columbia University Press, 244-276.
- SCHMITZ, B., SPEIJER, R. P. and AUBRY, M.-P., 1996. Latest Paleocene benthic extinction event on the southern Tethyan shelf (Egypt): Foraminiferal stable isotopic ($\delta^{13}C$, $\delta^{18}O$) records. *Geology*, 24:347-350.
- SIGURDSSON, H., LECKIE, R. M., ACTON, G. D., et al., 1997. Proceedings of the Ocean Drilling Program, Initial Reports, 165. College Station, TX (Ocean Drilling Program): 131-230; 291-357.
- THOMAS, E., 1992. Cenozoic deep sea circulation: Evidence from deep sea benthic foraminifera. In: Kennett, J. P. and Warnke, D., (Eds.), *The Antarctic Paleoenvironment: A Perspective on Global Change*, American Geophysical Union Antarctic Research Series N° 56:141-165.
- ZACHOS, J. C., REA, D. K., SETO, K., NOMURA, R., and NIITSUMA, N., 1992. Paleogene and early Neogene deep water paleoceanography of the Indian Ocean as determined from benthic foraminifera stable carbon and oxygen isotope records. In: Duncan, R. A., Rea, D. K., Kidd, R. B., Rad, von U., Weissel, J. K., *Synthesis of Results from Scientific Drilling in the Indian Ocean*. Washington D. C.: American Geophysical Union, *Geophysical Monograph*, 10:351-385.
- ZACHOS, J. C., LOHMANN, K. C., WALKER, J. C. G. and WISE, S. W., 1993. Abrupt climate change and transient climates during the Paleogene: A marine perspective. *Journal of Geology*, 101:191-213.

TAXONOMIC INDEX

Original descriptions and illustrations of the species listed below can be found in Aubry (1984, 1988, 1989, 1990, 1999) and in Aubry and Bonnemaïson (1999).

-
- Biantholithus sparsus* Bramlette and Martini 1964
Biscutum constans (Gorka 1957)
Blackites herculeus (Stradner 1969)
Braarudosphaera bigelowii (Gran and Braarud 1935)
Chiasmolithus bidens (Bramlette and Sullivan 1961)
C. californicus (Sullivan 1964)
C. consuetus (Bramlette and Sullivan 1961)
C. danicus (Brotzen 1959)
C. eograndis Perch-Nielsen 1971
C. solitus (Bramlette and Sullivan 1961)
Coccolithus apommoneus Hay and Mohler 1967
C. crassus Bramlette and Sullivan 1961
Cruciplacolithus delus (Bramlette and Sullivan 1961)
C. eodelus Bukry and Percival 1971
C. tenuis (Stradner 1961)
Cyclagelosphaera alta Perch-Nielsen 1979
Discoaster anartios Bybell and Self-Trail 1995
D. araneus Bukry 1971
D. barbadiensis (Tan 1927)
D. binodosus Martini 1958
D. diastypus Bramlette and Sullivan 1961
D. falcatus Bramlette and Sullivan 1961
D. kuepperi Stradner 1959
D. lenticularis Bramlette and Sullivan 1961
D. lodoensis Bramlette and Riedel 1954
D. mahmoudii Perch-Nielsen 1981
D. mediosus Bramlette and Sullivan 1961
D. mohleri Bukry and Percival 1971
D. multiradiatus Bramlette and Riedel 1954
D. nobilis Martini 1961
D. okadai Bukry 1981
D. pacificus Haq 1969
D. praebifax Wei and Wise 1989
D. robustus Haq 1970
Ellipsolithus macellus (Bramlette and Sullivan 1961)
Ericsonia cava (Hay and Mohler 1967)
E. formosa (Kamptner 1963)
E. subpertusa Hay and Mohler 1967
E. universa Wind and Wise 1976
Fasciculithus alanii Perch-Nielsen 1971
F. janii Perch-Nielsen 1971
F. lilianae Perch-Nielsen 1971
F. tympaniformis Hay and Mohler 1967
Helolithus kleinPELLI Sullivan 1964
Lophodolithus nascens Bramlette and Sullivan 1961
Markalius inversus (Deflandre 1954)
Micrantholithus flos Deflandre 1960
Neochiastozygus chiastus (Bramlette and Sullivan 1961)
N. concinnus (Martini 1961)

- N. distentus* (Bramlette and Sullivan 1961)
Neococcolithes dubius (Deflandre 1954)
N. protenus (Bramlette and Sullivan 1961)
*Neocrepidolithus biscaya*e Perch-Nielsen 1981
Placozygus sigmoides Bramlette and Sullivan 1961
Pontosphaera fimbriata (Bramlette and Sullivan 1961)
P. multipora Kamptner ex Deflandre 1959
P. obliquipons (Deflandre 1954)
P. pulchra (Deflandre 1954)
Prinsius martinii (Perch-Nielsen 1969)
Rhomboaster calcitraba Gartner 1971
R. cuspis Bramlette and Sullivan 1961
R. intermedia Romein 1979
Sphenolithus anarrhopus Bukry and Bramlette 1969
S. conspicuus Martini 1976
- S. orphanknolli* Perch-Nielsen 1971
S. primus Perch-Nielsen 1971
S. radians Deflandre 1952
Toweius callosus Perch-Nielsen 1971
T. eminens (Bramlette and Sullivan 1961)
T. gammation (Bramlette and Sullivan 1961)
T. pertusus (Sullivan 1965)
Tibrachiatus bramlettei Brönnimann and Stradner 1960
T. contortus Stradner 1958
T. digitalis Aubry 1996
T. orthostylus Shamrai 1963
T. rotans Stradner 1958
Zygodiscus adamas Bramlette and Sullivan 1961
Z. herlynii Sullivan 1964
Zygrhablithus bijugatus (Deflandre 1954)