Preliminary study of the benthic foraminifera of the San Francisco de Paula Section (Upper Paleocene-Lower Eocene), Ciudad de la Habana, Cuba

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ABSTRACT: Benthic foraminifera were collected from the Paleocene-Eocene San Francisco de Paula section, Ciudad de la Habana, Cuba. The benthic foraminifera comprise a small portion (<10%) of the total foraminiferal fauna. In each sample, the benthic foraminifera generally have a high species diversity but few individuals per species. The paleoecologic setting indicated by the benthic foraminifera is middle to upper bathyal.

The benthic foraminifera collected from the San Francisco de Paula section are characteristic of the bathyal "Velasco type" fauna. Three intervals of the section contain species associated with the neritic "Midway type" fauna. The fauna in these intervals is a mixed "Midway" and "Velasco" assemblage. The mixing of the two faunas in the section suggests downslope transport of the "Midway type" species.

Two important benthic foraminiferal biostratigraphic markers are recognized in the San Francisco de Paula section. The highest occurrence of *Stensioina beccariiformis* is an important biostratigraphic datum from the bathyal realm and is documented at this locality. Another marker, the highest occurrence of the abundant benthic foraminiferan *Osangularia velascoensis*, is an important datum in western Cuba and may be useful in upper bathyal Paleocene sections elsewhere in the Caribbean.

Two bathyal benthic foraminiferal biozones are recognized at San Francisco de Paula: the *Angulogavelinella avnimelechi-Anomalinoides rubinginosus* Interval Zone (BB1), and the *Anomalinoides capitatus-Hanzawaia ammophila* Partial Range Zone (BB2).

The benthic foraminiferal fauna from the San Francisco de Paula section has affinities with many upper Paleocene-lower Eocene bathyal faunas worldwide. It is most like the upper Paleocene-lower Eocene benthic foraminiferal fauna collected from the Santa Anita Group of eastern Venezuela.

INTRODUCTION

Benthic foraminifera were obtained from samples at the San Francisco de Paula section in Ciudad de la Habana, Cuba. This section was the focus of a joint United States-Cuba study in conjunction with International Geological Correlation Project #308. The section has been studied with regard to many fossil groups as a part of this project. Of particular interest to this paper are the works on planktonic foraminifera (Fernández-Rodríguez et al. 1999, this volume) and calcareous nannofossils (Aubry 1999, this volume) which establish a correlation to the global geochronologic scale. The San Francisco de Paula section consists of the Paleocene age Apolo Formation and the Eocene age Capedevila Formation. The benthic foraminifera of the Apolo Formation are of historic interest as this unit is a lateral equivalent of the Madruga Formation (Albear and Iturralde-Vinent 1985). The Madruga Formation has produced a diverse benthic foraminiferal fauna (Cushman and Bermúdez 1948a, 1948c) from outcrops in southern La Habana Province and in Pinar del Rio Province.

Numerous studies of Paleocene and Eocene smaller benthic foraminifera from Cuba have been published. Notable among them are the works of Cushman and Bermúdez (1936a, 1936b, 1937, 1948a, 1948b, 1948c). All of these studies were taxonomic in nature and did not attempt to identify specific occurrences within sections. Thus while a diverse Paleocene and lower Eocene benthic foraminiferal fauna has been described from western Cuba, virtually no information is available on the biostratigraphy and paleoecology of the fauna.

METHODS OF STUDY

A total of 54 samples (SFP and SFE series) were collected from the San Francisco de Paula section during January, 1993. These samples were processed at the Biostratigraphy Laboratory at Ball State University. Each sample was dried at 100°C for 24 hours. The samples were then soaked in water for an additional 24 hours. Following this, each sample was washed through a 75μ sieve. The residue was then dried at 100°C for an additional 24 hours. Each sample was dry-sieved through 250μ and 150μ screens. The 150μ residue was examined for foraminifera. As the volume of each sample was small, an attempt was made to pick all identifiable benthic foraminifera from the samples.

An additional 17 samples (C series) collected and picked by Gena Fernández-Rodríguez contained benthic foraminifera and were made available for this study.

Benthic foraminifera were identified using the taxonomy of Cushman and Bermúdez (1936a., 1936b., 1937, 1948a, 1948b, 1948c) with appropriate modifications and additions by Tjalsma and Lohman (1983) and Bolli et al. (1994).

Of the 54 samples collected from San Francisco de Paula, benthic foraminifera occur in 25. Combined with the 17 picked samples, the benthic foraminiferal fauna comes from 42 samples distributed throughout the section (text-figure 1). The preservation of the fauna is generaly poor but not so bad as to prohibit identification. Study of the benthic foraminifera from San Francisco de Paula was further complicated by the relative abundance of planktonic foraminifera and by clastic dilution of the samples from the turbiditic Apolo Formation. The resultant benthic foraminiferal assemblages have a high species diversity (as high as 20 species per sample) but may have individual numbers as low as one or two individuals per species. A total of 54 benthic foraminiferal species were recognized at the San Francisco de Paula section.

BIOSTRATIGRAPHY

General

The benthic foraminiferal assemblage collected from the San Francisco de Paula section bears a strong similarity to the "Velasco type" fauna defined by Berggren and Aubert (1975). The "Velasco type" fauna is characterized by *Stensioina beccariiformis* (White) (=*Rotalia beccariiformis* 1928), *Nutallides truempyi* (Nuttall) (=*Eponides truempyi* 1930), and *Osangularia velascoensis* (Cushman) (=*Truncatulina velascoensis* 1925) among others. The "Velasco type" fauna is a cosmopolitan deep water benthic foraminiferal association restricted to the Paleocene (Morkhoven et al. 1985).

Several key datums of benthic foraminifera species in the San Francisco de Paula section have regional and global biostratigraphic significance. Among these the highest occurrence of *Stensioina beccariiformis* is an important biostratigraphic datum in the bathyal realm. Another prominent biostratigraphic marker in the San Francisco de Paula section is the highest occurrence of *Osangularia velascoensis*. This datum is an important biostratigraphic horizon in the Caribbean region (Bolli et al. 1994) and in the San Francisco de Paula section it is coincident with the highest occurrence of *Stensioina beccariiformis*. In the upper part of the section, some first occurrences are of special interest. Included are the first appearances of *Osangularia mexicana* (Cole) (=*Pulvinulinella culter* var. *mexicana* 1927) and *Bulimina semicostata* Nuttall.

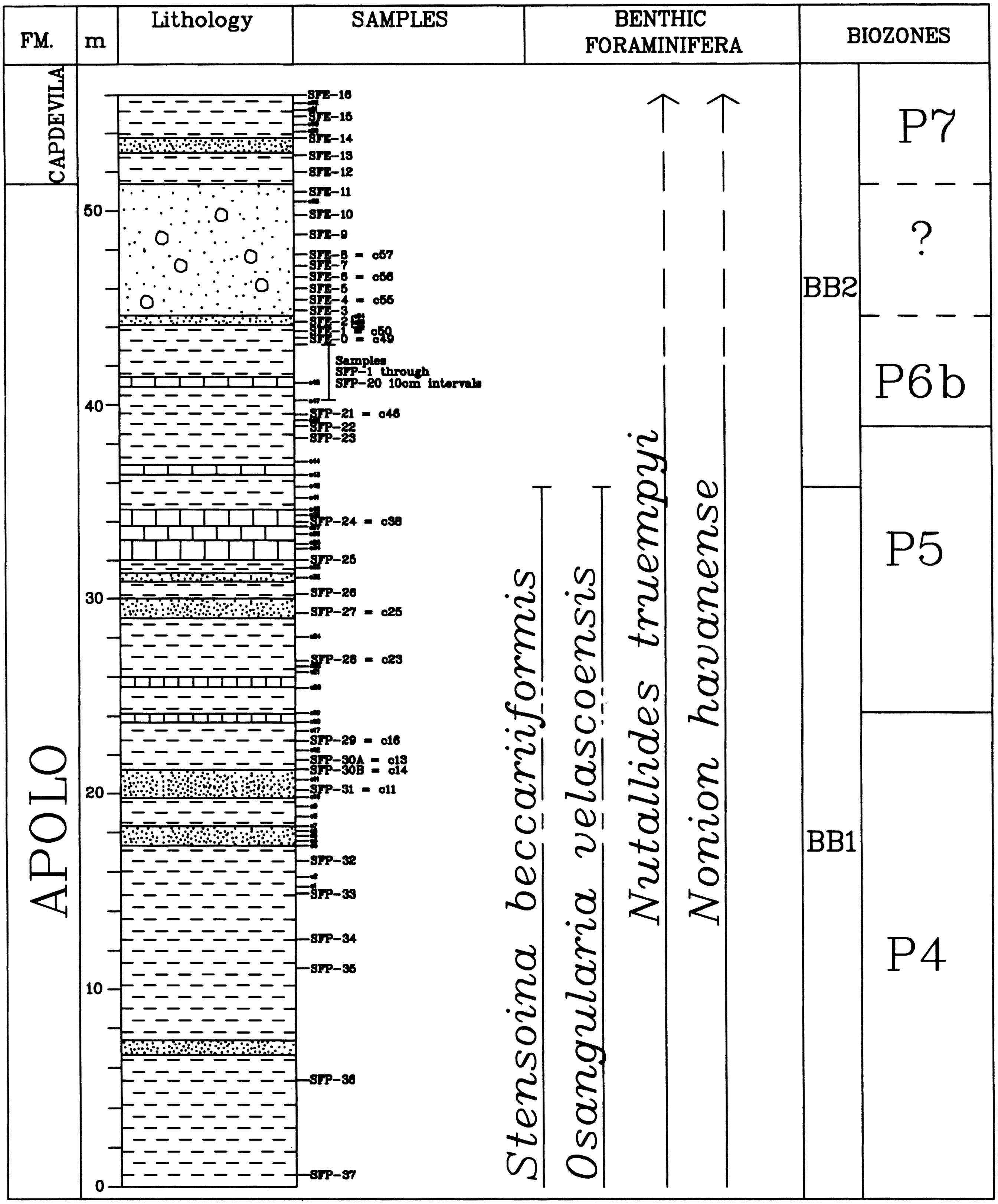
Several species of benthic foraminifera are of biostratigraphic significance but occur only sporadically in the section. Included in this group are *Lenticulina insula* (Cushman) (=*Robulus insulus* 1947), *Lenticulina velascoensis* White, *Angulogavelinella avnimelechi* (Reiss) (=*Pseudovalvulineria avnimelechi* 1952), *Anomalinoides rubiginosus* (Cushman) (=*Anomalina rubiginosus* 1926), *Pullenia coreyelli* White, and Gyroidinoides plummerae (Cushman and Bermúdez) (=*Gyroidina plummerae* 1937).

Two species of benthic foraminifera occur throughout the San Francisco de Paula section. These are *Nutallides truempyi* and *Nonion havanense* Cushman and Bermúdez. According to Tjalsma and Lohman (1983) both of these species are characteristic of the middle to outer bathyal realm during the late Paleocene and early Eocene. *Nuttalides truempyi* is the most abundant benthic foraminiferal species in the San Francisco de Paula section. The distribution of some of the biostratigraphically important species at San Francisco de Paula is shown in text-figure 1.

One of the more interesting aspects of the benthic foraminiferal fauna from the San Francisco de Paula section is the presence of "exotic" species within some of the samples. This is not unexpected as the Apolo and Capdevila Formations are interpreted as turbidites with substantial downslope transport of sediment (Albear and Ituralde-Vinent 1985). These occurrences are noteworthy as they may provide some preliminary correlations between the San Francisco de Paula section and nearby areas. Large foraminifera comprise a conspicuous part of the exotic assemblage. The larger foraminifera of the San Francisco de Paula section have been studied and illustrated by Blanco-Bustamente et al. (1999, this volume) and will not be discussed further here. Other exotic faunal elements include species typical of the Madruga Formation of western Cuba (Cushman and Bermúdez 1948a, 1948c) and of the Midway fauna (Cushman 1951; Berggren and Aubert 1975). The Madruga Formation contains a diverse assemblage of benthic foraminifera with many distinctive species. The Madruga also has many species in common with the Midway fauna of the Gulf Coastal Plain as described by Plummer (1927) and later by Cushman (1951). Enough species are common to both the Madruga and the Midway that the Madruga fauna was regarded as a part of the cosmopolitan Midway fauna by Berggren (1974). Distinct Madruga species identified in this study from the San Francisco de Paula section include *Boldia madrugaensis* Cushman and Bermúdez, *Coleites cancellatus* Cushman and Bermúdez, *Coleites pasionensis* Cushman and Bermúdez, *Rotalia havanense* Cushman and Bermúdez, and *Anomalinoides madrugaensis* (Cushman and Bermúdez) (=*Anomalina madrugaensis* 1948c). Species of the Midway fauna of Berggren and Aubert (1975) in the San Francisco de Paula section include *Anomalinoides midwayensis* (Plummer) (=*Truncatulina midwayensis* 1927), *Anomalinoides welleri* (Plummer) (=*Truncatulina welleri* 1927), *Anomalinoides clementiana* (D'Orbigny) (=*Rotalia clementiana* 1840), *Cibicidoides alleni* (Plummer) (=*Truncatulina alleni* 1927), *Cibicidoides vulgaris* (Plummer) (=*Truncatulina vulgaris* 1927), *Gyroidinoides octocameratus* (Cushman and Hanna) (=*Gyroidina octocameratus*), *Lenticulina midwayana* (Plummer) (=*Cristellaria midwayensis* 1927), *Lenticulina toddae* (Cushman) (=*Planularia toddae* 1944), *Eponides plummerae* Cushman, *Alabamina westraliensis* (Parr) (=*Pulvulinella obtusa* var. *westraliensis* 1938) and *Pulsiphonina prima* (Plummer) (=*Siphonina prima* 1927). Most of these species are general components of the cosmopolitan Midway fauna. Only the form identified as *Alabamina westraliensis* has some biostratigraphic significance in the upper Paleocene-lower Eocene interval. Fluegeman et al. (1990) have identified the first appearance of *Alabamina westraliensis* as occurring after planktonic foraminiferal Biozone P3b of Berggren et al. (1995) but before Biozone P4b. This species was identified in the eastern Gulf Coastal Plain from the Nanafalia, Tuscahoma, and Hatchetigbee Formations by Fluegeman et al. (1990) and from the Salt Mountain Limestone of Alabama by Bryan et al. (1997). At San Francisco de Paula, only one specimen was identified.

The samples containing Midway-Madruga faunal elements are not evenly distributed throughout the section. These samples occur in three distinct clusters in the San Francisco de Paula section (text-figure 2).

In the upper part of the San Francisco de Paula section, Fernández-Rodríguez et al. (1999, this volume) have identified an interval of dissolution and reworking. Only a few abraded calcareous foraminifera were collected from this interval. Several samples in this interval did produce an assemblage of agglutinated foraminifera. Included within this assemblage are *Hormosinella distans* (Brady) (=*Reophax distans* 1881),



TEXT-FIGURE 1
Distribution of biostratigraphically important benthic foraminifera in the San Francisco de Paula section. Bathyal benthic foraminiferal biozones are those of Berggren and Miller (1989). Planktonic foraminiferal biozones are from Fernández-Rodríguez et al. (this volume).

Reophax elongata Grzybowski, *Saccammina complanata* (Franke) (=*Pelosina complanata* 1912), *Glomospira serpens* (Grzybowski) (=*Ammodiscus serpens* 1898), *Glomospira gaultina* (Berthelin) (=*Ammodiscus gaultinus* 1880), and *Rzehakina epigona* (Rzehak) (=*Silicina epigona* 1895). This assemblage is similar to the "Flysch-type" agglutinated fauna identified by Kaminski et al. (1988) from Trinidad. It also has a strong affinity to the fauna identified by Kaminski et al. (1996) from the Paleocene-Eocene Numidian Flysch of northern Morocco and to the Paleocene-Eocene foraminiferal fauna of the external Polish Carpathians (Morgiel and Olszewska 1981). A similar zone of dissolution occurs at approximately the same stratigraphic horizon in the Caravaca section in Spain (Molina et al. 1994).

The distribution of benthic foraminifera in the San Francisco de Paula section are listed in Table 1.

Biozones

Despite the occurrence of numerous exotic elements in the benthic foraminiferal assemblage of the San Francisco de Paula section, the most abundant species (Table 1) are all indicative of the bathyal realm (Tjalsma and Lohman 1983, Bolli et al. 1994). Berggren and Miller (1989) constructed a biozonation for bathyal and abyssal benthic foraminifera. The purpose of this biozonation was to supplement planktonic foraminiferal biostratigraphy, especially in sections lacking diagnostic planktonic foraminifera. While this is not a problem at San Francisco de Paula when the overall section is studied, some samples do not contain diagnostic planktonic foraminifera but do contain benthic foraminifera. The potential for using benthic foraminiferal biostratigraphy to correlate small discontinuous exposures and subsurface sections in Cuba which do not contain planktonics is great provided they can be referred to a section containing benthic and planktonic foraminifera such as San Francisco de Paula. Use of the San Francisco de Paula section as a reference section in Cuba can facilitate correlation with the biozonations of radiolaria (Sanfilipo and Hull 1999, this volume), calcareous nannofossils (Aubry 1999, this volume), and larger foraminifera (Blanco-Bustamente et al. 1999, this volume).

The bathyal benthic foraminiferal biozones recognized in the San Francisco de Paula section are identified below.

Angulogavelinella avnimelechi-Anomalinoides rubinginosus Interval Zone (BB1)

Original Authors: Berggren and Miller (1989)

Definition: Concurrent partial ranges of the nominate taxa between the last occurrence of *Bolivinoides draco* (Marsson) (=*Bolivina draco* 1878) and the last occurrences of *A. avnimelechi* and *Neoflabellina jarvisi* (Cushman) (=*Flabellina jarvisi* 1935).

Remarks: This zone was recognized in the San Francisco de Paula section primarily by the associated taxa. While *Angulogavelinella avnimelechi* does occur at San Francisco de Paula, it is rare. Further, *Anomalinoides rubiginosus* occurs in only one sample and *Neoflabellina jarvisi* does not occur anywhere in the section. By contrast, both *Stensioina beccariiformis* and *Osangularia velascoensis* are fairly abundant throughout the lower 22 meters of the section (see Table 1). In this sense, the benthic foraminiferal assemblage resembles that of the *Stensioina beccariiformis* Zone at Caravaca, Spain (Molina et al. 1994). The last occurrences of both *S. beccariiformis* and *O. velascoensis* occur below the last occurrence of *A. avnimelechi* (The upper boundary of Biozone BB1) in most range charts (Tjalsma and Lohman 1983). In the San Francisco de Paula section, the highest occurrence of *S. beccariiformis* and *O. velascoensis* may be at an unconformity (Fernández-Rodríguez et al. 1999, this volume; Aubry 1999, this volume). Given the scarcity of *Angulogavelinella avnimelechi* in the section and the possible unconformity, the highest occurrence of *Stensioina beccariiformis* and *Osangularia velascoensis* is used as the upper boundary of Zone BB1 at San Francisco de Paula. The base of this zone is not present in the San Francisco de Paula section. Samples were collected from an outcrop 1.1 km to the south of San Francisco de Paula at San Pedro. This section exposes the contact of the Apolo Formation with the underlying Maastrichtian age Peñalver Formation. This section was studied by Brönnimann and Rigassi (1963) who reported this as an unconformable contact. Planktonic foraminifera identified by Brönnimann and Rigassi (1963) and in this study indicate that the basal Apolo Formation at this locality should be assigned to the *Morozovella angulata-Igorina albeari* Interval Subzone (P3a) of Berggren et al. (1995).

The underlying Peñalver Formation at San Pedro contains planktonic foraminifera asssignable to the *Globotruncana aegyptica* Zone of Caron (1985). Benthic foraminifera from this sample included a number of gavelinellids but not the biostratigraphically important *Bolivinoides draco.*

Anomalinoides capitatus-Hanzawaia ammophila Partial Range Zone (BB2)

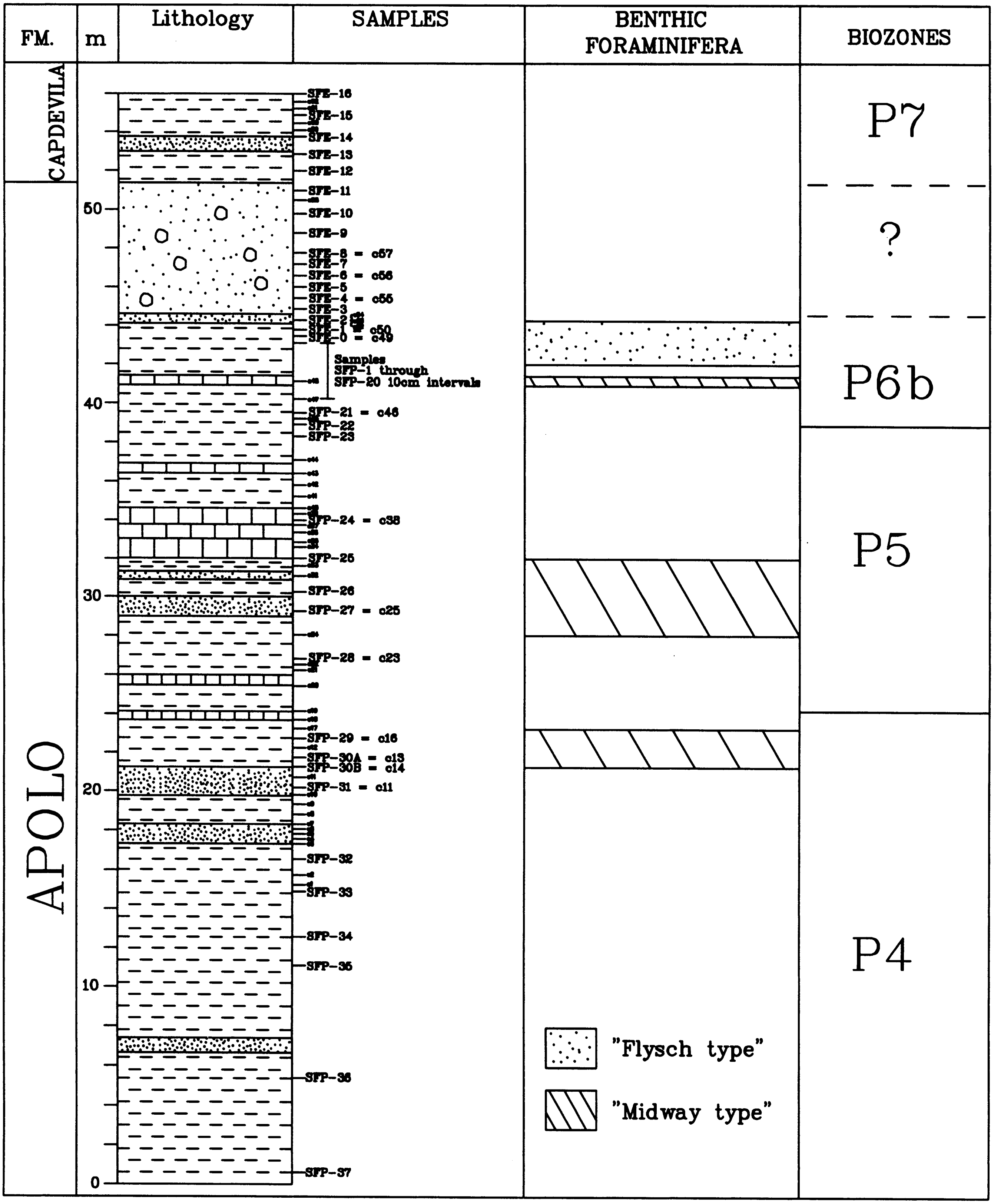
Original Authors: Berggren and Miller (1989)

Definition: Partial range of the nominate taxa between the last occurrences of *Angulogavelinella avnimelechi* and *Neoflabellina jarvisi* and the first occurrence of *Cibicidoides subspiratus* (Nuttall) (=*Cibicidides subspiratus* 1930).

Remarks: The base of this zone is somewhat problematic in the San Francisco de Paula section. While *Angulogavelinella avnimelechi* is present it is rare. *Neoflabellina jarvisi* does not occur at all in this section. The distribution of this zone at San Francisco de Paula is further complicated by the zone of reworking and dissolution above Biozone P6b (Fernández-Rodríguez et al. 1999, this volume). Additionally, neither of the nominate taxa of this zone have been identified in the San Francisco de Paula section. Given this, the joint last occurrences of *Stensioina becarriformis* and *Osangularia velascoensis* may be a better basal boundary for Zone BB2 in Cuba. The assemblage of benthic foraminifera present above the dissolution interval suggests correlation with the *Nuttallides truempyi* Zone from Caravaca, Spain (Molina et al. 1994).

The upper boundary of this zone is not present in the San Francisco de Paula section. Samples collected from the Capdevila, Toledo, and Principe Formations along Calle G in the city of Havana (Avenida de los Presidentes section of Brönnimann and Rigassi 1963) did contain the upper boundary of this zone. *Cibicidoides subspiratus* appears just above the Capdevila-Toledo contact. Sánchez-Arango et al. (1985) have reported planktonic foraminifera from this interval assignable to Biozone P9 of Berggren et al. (1995).

The distribution of the benthic foraminiferal biozones in the San Francisco de Paula section is shown in Figure 1.



TEXT-FIGURE 2
Distribution of "Midway type" and "Flysch type" assemblages in the San Francisco de Paula section.

TABLE 1
Distribution of benthic foraminifera from the San Francisco de Paula section, Ciudad de la Habana, Cuba.

SAMPLE	*Tritaxia havanense*	*Spiroplectammina spectabilis*	*Gaudryina pyramidata*	*Dorothia trochoides*	*Corphystoma midwayensis*	*Bulimina midwayensis*	*Bulimina trinitatensis*	*Bulimina velascoensis*	*Pullenia coreyelli*	*Gyroidinoides plummerae*	*Stensioina beccariformis*	*Angulogavel. avnimelechi*	*Nuttallides truempyi*	*Cibicidoides dayi*	*Oridosalis umbonatus*	*Lenticulina insula*	*Lenticulina velascoensis*	*Anomalinoides rubiginosus*	*Nonion havanense*
SFE-16							2	2	1				26		1				2
C-62													1						
C-61																			
SFE-15				2			3	2		1			29						1
SFE-14							1	1					22	1					
SFE-13							4	2	1				23						1
SFE-12			1	1			2	2					24						
SFP-14													19						
C-48																			
SFP-17									1				23						1
SFP-19													21						
SFP-21													17						
SFP-23													14						
C-42											1								2
C-36											1					1			
SFP-24		1				1					1		25						1
SFP-25	1										2		21						
C-31							1				1		1				1	1	1
C-30											2		1						1
C-29					1						4						1		1
SFP-26		1									2		24						
C-24																			3
SFP-27	2										2	1	14						2
SFP-28			1								4		26			2			
C-20																			
C-19																			
C-18																			
C-17									1						1				1
SFP-29		1	1		1						3		15			2	1		1
C-15																			
SFP-30A											2		8						
SFP-30B	1										1		16			1			3
SFP-31											4	1	21						2
C-10																			
C-3																			1
SFP-32											3		18			1			
C-2																			
SFP-33											5		23						2
SFP-34	1										3		27						
SFP-35		1									7	1	16			1			
SFP-36	2		1								4		25						
SFP-37	1	1									6		24						1

PALEOECOLOGY

As the focus of this study was biostratigraphic, detailed paleoecologic analysis was not conducted on the samples at this time. The benthic foraminiferal fauna that was obtained does provide some information on the paleoecology of the upper Paleocene and lower Eocene sequence of western Cuba. In general, the faunal composition of each sample indicates that middle to upper bathyal conditions persisted throughout the studied section. Especially important are the most abundant species *Nutallides truempyi, Stensioina becariiformis,* and *Nonion havanense.* These species are all components of the bathyal benthic foraminiferal fauna. They indicate paleoecologic conditions consistent with middle bathyal depths of 500-1000 meters (Tjalsma and Lohmann 1983; Berggren and Aubert 1983; Morkhoven et al. 1986).

COMPARISON WITH OTHER PALEOCENE-EOCENE BENTHIC FORAMINIFERAL FAUNAS

Gulf and Caribbean Regions

The benthic foraminiferal fauna collected from the San Francisco de Paula section is just one of many faunas collected from within the broad Gulf of Mexico and Caribbean Sea regions. The tectonic and depositional setting of the Apolo and Capdevila Formations have produced a mixed faunal assemblage in some samples.

In the Gulf Coastal Plain, the fauna which bears the closest resemblance to the one collected from the San Francisco de Paula is that of the Velasco Shale of Mexico (Cushman 1926). This fauna is dominated by *Nuttallides truempyi, Stensioina beccariiformis* and *Osangularia velascoensis* among others. This is the type area of the "Velasco type" benthic foraminiferal fauna of Berggren and Aubert (1975). The association of species in the Velasco Shale indicates middle to upper bathyal conditions. In the San Francisco de Paula section, the species which characterize the "Velasco-type" fauna are consistently present in the assemblages. Additionally, *Nuttallides truempyi* is quantitatively dominant throughout the section (Table 1).

In the Gulf Coastal Plain of the United States, Paleocene and lower Eocene benthic foraminfera have been studied by many workers. Plummer (1927), Cushman (1951), and Kellough (1959, 1965) are among the most important taxonomic studies. Plummer and Kellough both worked on lower Paleocene sections in Texas. Cushman's study included many Texas samples but also examined samples from Arkansas, Tennessee, Mississippi, and Alabama. All three studies were restricted to the Midway Group (lower Paleocene) and did not examine the fossiliferous units in the overlying Wilcox Group (upper Paleocene-lower Eocene). The fauna identified in these studies was defined as the "Midway type" fauna by Berggren and Aubert (1975). It was considered to represent the neritic realm and was considered a cosmopolitan fauna. Quantitative examinations of the benthic foraminiferal fauna of the entire

TABLE 1
continued.

SAMPLE	*Alabamina creta*	*Osangularia velascoensis*	*Boldia madrugaensis*	*Coleites cancellatus*	*Coleitus pasionensis*	*Rotalia havanense*	*Anomalinoides madrugaensis*	*Anomalinoides midwayensis*	*Anomalinoides welleri*	*Anomalinoides clementiana*	*Cibicidoides alleni*	*Cibicidoides vulgaris*	*Gyroidinoides octocameratus*	*Lenticulina midwayana*	*Lenticulina toddae*	*Eponides plummerae*	*Alabamina westraliensis*	*Pulsiphonina prima*	*Astacolus jarvisi*
SFE-16																			
C-62													2						
C-61																			
SFE-15																			
SFE-14																			
SFE-13																			
SFE-12																			
SFP-14			2			1	1		2										
C-48				1			1			1									
SFP-17									1										3
SFP-19																			
SFP-21																			
SFP-23																			
C-42		5											1						
C-36	1	1														1			
SFP-24		6										1							
SFP-25		7						4	1				2	3				5	
C-31	1	6	1								1								
C-30		4			3						2		3						
C-29		5							1		2		4	1					1
SFP-26		4																	
C-24		1										1							
SFP-27		7																	
SFP-28	2	8																	
C-20																			
C-19																			1
C-18	1	1																	
C-17									1										
SFP-29		4							1		2		2	1					1
C-15		1	2			2	2												
SFP-30A		10			3						2		2						
SFP-30B		4															1		
SFP-31	1	6																	
C-10		3																	
C-3		1																	
SFP-32		3																	
C-2	1	2					2						1						
SFP-33		6																	
SFP-34		8																	
SFP-35		5																	
SFP-36		2																	
SFP-37		4																	

Paleocene in the eastern Gulf Coastal Plain were made by Fluegeman et al. (1990) and Briskin and Fluegeman (1990). These two studies identified several important biostratigraphic and paleoecologic assemblages within the "Midway type" fauna.

Elements of the "Midway type" fauna are found in the San Francisco de Paula section. These include *Lenticulina midwayana, Cibicidoides alleni, Anomalinoides midwayensis, Gyroidinoides octocameratus,* and *Pulsiphonina prima.* The "Midway type" species are not numerically abundant and are concentrated in certain parts of the San Francisco de Paula section.

As has already been discussed, upper Paleocene and lower Eocene benthic foraminifera from elsewhere in Cuba are typically associated with the Madruga Formation. Outside of Cuba, Paleocene and lower Eocene benthic foraminifera are poorly known in the northern Caribbean region. Bermúdez (1949) identified 51 species of benthic foraminifera from the lower Eocene Abuillot Formation of Hispaniola. The fauna described by Bermúdez is predominantly planktonic foraminifera. The benthic foraminiferal fauna was considered to be closely related to those described from Cuba and Mexico. The fauna of the Abuillot was reported by Bermúdez from sections throughout the Dominican Republic but detailed descriptions of the foraminifera come from only three samples at the type section of the Abuillot Formation in central Haiti. Except for the presence of *Nuttallides truempyi* and *Praeglobobulimina ovata* (d'Orbigny) (=*Bulimina ovata* 1846), the Abuillot fauna has little in common with the benthic foraminifera of the San Francisco de Paula section. It is similar to the benthic foraminiferal fauna of the Universidad Group of La Habana and Pinar del Rio Provinces.

Jackson et al. (1998) list an assemblage of benthic foraminifera collected from early Paleocene age rocks in northeastern Jamaica. Although a bit older than the San Francisco de Paula section, the benthic foraminiferal fauna has some similarities. Both sections contain abundant *Nutallides truempyi* and also have in common *Alabamina creta* (Finlay) (=*Pulvinulinella creta* 1940), *Lenticulina insula,* and *Oridosalis umbonatus* (Reuss) (=Gotalina umbonata 1851). Species present in the San Francisco de Paula section which are not present in northeastern Jamaica include *Stensioina beccariformis, Angulogavelinella avnimelechi, Osangularia velascoensis,* and all "Midway type" species. Jackson et al. (1998) considered this assemblage to represent lower bathyal to upper abyssal conditions. Trace fossil assemblages collected at this site support this interpretation.

In the southern Caribbean region, a benthic foraminiferal fauna similar to that collected at San Francisco de Paula has been described from the Lizard Springs Formation of Trinidad (Cushman and Jarvis 1928; Cushman and Renz 1946; Bolli et al. 1994). All workers have noted the similarity of the Lizard

TABLE 1
continued.

SAMPLE	*Dentalina confluens*	*Anomalinoides nobilis*	*Siphonodosaria nuttalli*	*Globulina fusiformis*	*Bulimina plena*	*Nonionella robusta*	*Astacolus rectus*	*Stainforthia havarroana*	*Falsoplanulina waltonensis*	*Praeglobobulimina ovata*	*Percultazonaria tuberculata*	*Osangularia mexicana*	*Pleurostomella paleocenica*	*Clinapertina inflata*	*Karreriella chapapotensis*	*Abyssamina poagi*	*Pyramidulina latejugata*	*Vaginulina brantlyi*
SFE-16																	3	
C-62			3							1		1	1					
C-61			1															
SFE-15												1		1	2	2	4	
SFE-14												2					2	
SFE-13			1									3		1			1	
SFE-12			1									1					3	
SFP-14																		
C-48			4															
SFP-17	1	1																
SFP-19																		
SFP-21																		
SFP-23																		
C-42																		
C-36																	1	
SFP-24			1	1														
SFP-25																		
C-31																		
C-30			1															
C-29																		
SFP-26																		
C-24			1	1	1													
SFP-27								1	1	1	4							
SFP-28					1	1	1	1									2	2
C-20																		
C-19	1																	
C-18																		
C-17		1																
SFP-29																		
C-15																		
SFP-30A			1															
SFP-30B																		4
SFP-31					1	1	2	1										
C-10																		
C-3									1	1	3							
SFP-32																	1	
C-2					1	1	3	1										
SFP-33																		
SFP-34								1	1	1	4						4	
SFP-35																		
SFP-36																		
SFP-37																		

Springs fauna with the benthic foraminifera of the Velasco Shale. The presence of the "Velasco type" fauna in the Lizard Springs does demonstrate some affinity with the San Francisco de Paula benthic foraminiferal fauna but no "Midway type" foraminifera are found distributed throughout the Lizard Springs. Benthic foraminifera of the "Midway type" are found in Trinidad from Paleocene rocks but they are restricted to distinct lithofacies such as the olistostromal Soldado Rock Formation (Vaughan and Cole 1941; Kugler and Caudri 1975) and the "Rochard facies" (Bolli et al. 1994).

In the Santa Anita Group of eastern Venezuela benthic foraminifera of late Paleocene to early Eocene age have been described by Cushman (1947) and Galea (1985). This fauna contains species of both the "Velasco type" and "Midway type" faunas. The Santa Anita Group occurs in the Eastern Serranina del Interior crustal province of Case et al. (1984), a tectonically active region in northern South America. Galea (1985) regards all "Midway type" species present in the Santa Anita Group to be allochthonous. The in situ Paleocene benthic foraminiferal fauna is considered to be indicative of lower bathyal conditions.

Other Regions

Benthic foraminiferal faunas of both "Velasco type" and "Midway type" have been documented from all continents and all ocean basins. Localities containing a mixture of Midway and Velasco species are far less common, however. Berggren and Aubert (1983) document a succession of benthic foraminifera from the Paleocene and Eocene age Lodo Formation of California. Both "Velasco type" and "Midway type" foraminifera are present in the Lodo Formation. The benthic foraminifera from the Lodo represent a paleoecologic succession from the neritic realm to the bathyal realm. The assemblages are distinctly "Midway" or "Velasco" in character and not truely mixed. A similar situation is found in the Paleocene and Eocene of southern Germany (Hillebrandt 1962).

In the Tethyan region, mixed "Velasco" and "Midway" type faunas have been collected from Gebel Aweina in Egypt (Speijer et al. 1996; Speijer and Schmitz 1998). A transition exists between neritic and upper bathyal assemblages in the section. These changes in benthic foraminiferal assemblages have been related to fluctuating sea level during the late Paleocene and early Eocene (Speijer and Schmitz 1998). The Gebel Aweina section represents changes in benthic foraminiferal assemblages from the inner neritic to the upper bathyal. These fluctuations are not seen at the San Francisco de Paula section.

At Deep Sea Drilling Project (DSDP) Site 605 in the North Atlantic, Saint-Marc (1987) describes a mixed "Midway" and "Velasco" benthic foraminiferal fauna from the Paleocene. Unlike the San Francisco de Paula assemblages, Saint-Marc interprets the "Midway" elements to be in situ. The Paleocene at DSDP site 605 is considered by Saint-Marc to have accumulated under upper bathyal conditions. Thus the "Midway" species present would be at or near their maximum depth range. Could the "Midway" species in the San Francisco de Paula section similarily be in situ? Due to the abundance of such species as *Nutallides truempyi* and *Osangularia velascoensis* at San Francisco de Paula, it seems likely that the Paleocene and lower Eocene at that locality formed under middle bathyal conditions beyond the maximum depth range of "Midway" species. Given this, the "Midway" species at San Francisco de Paula must have been transported from shallower water.

The San Francisco de Paula benthic foraminiferal fauna has similarities with upper Paleocene-lower Eocene bathyal benthic foraminiferal faunas from around the world. The distribution of "Midway type" benthic foraminifera in a clustered rather than a sequential pattern within this section is very distinctive. With this in mind, the benthic foraminferal fauna of the San Francisco de Paula section bears the strongest resemblance to the Paleocene-Eocene benthic foraminifera of the Santa Anita Group of eastern Venezuela (Galea 1985).

DISCUSSION

The benthic foraminifera from the San Francisco de Paula section provide a biostratigraphic record generally consistent with that of Tjalsma and Lohman (1983), Berggren and Miller (1989), Thomas (1990), and Kennett and Stott (1991). Additionally, benthic foraminifera associated with the "Midway type" fauna of Berggren and Aubert (1975) also occur in the San Francisco de Paula assemblages. This association may provide some insight into the relationship between the neritic benthic foraminiferal biostratigraphy of the eastern Gulf Coastal Plain (Fluegeman et al. 1990) and the bathyal biozonation of Berggren and Miller (1989).

The "Midway" species are not uniformly distributed within the San Francisco de Paula section. Rather, they occur in three distinct intervals throughout the section. The benthic foraminifera from these intervals never comprise a "Midway" assemblage but consist of a mixed "Midway" and "Velasco" fauna. Given the middle bathyal paleoecologic interpretation for the San Francisco de Paula section and the obvious mixing of the faunas, the "Midway" species are interpreted as "exotic" components of the fauna transported basinward by turbidity currents.

The clustering of "Midway" species in the San Francisco de Paula section is interesting. Are these clusters an artifact of local tectonic activity during the late Paleocene and early Eocene? Fernández-Rodríguez et al. (1999, this volume) and Aubry (1999, this volume) have identified unconformities based on biostratigraphy. These unconformities have been related to episodes of local tectonics in western Cuba identified by Bralower and Ituralde-Vinent (1997). If the "Midway" assemblages were the result of downslope transport associated with increased tectonic activity, they might be expected to occur just below the recognized unconformities. In only one case, however, do the "Midway" species occur below a recognized unconformity. At the P4-P5 planktonic foraminifera biozone boundary, the unconformity truncates the "Midway" cluster. In the other two occurrences of the "Midway" fauna, there does not appear to be a direct relationship to a recognized unconformity.

Although the influence of local tectonics on the sedimentary and biostratigraphic framework cannot be ignored, one other explanation for the distribution of the "Midway" species must be considered. The effects of fluctuating sea level are not often observed in the bathyal realm. But during sea level lowstands, there may be significant transport of sediment to deep water (Vail and Wornardt 1990). It is possible that the tectonic activity responsible for the unconformities also produced a relative lowstand of sea level and its associated clastic shedding of sediment (including "Midway" type foraminiferal tests) to the bathyal realm. Whether these lowstands are local events or related to the global eustatic cycles identified by Haq et al. (1987) cannot be determined from the San Francisco de Paula section alone. A clearer understanding of the biostratigraphic and sedimentary framework of the northern Caribbean is necessary if the roles of tectonics, eustatic sea level fluctuations, and their interaction are to be evaluated.

SUMMARY

1. The benthic foraminifera from the San Francisco de Paula section comprise a small fraction (<10%) of the foraminiferal fauna collected.

2. Two bathyal benthic foraminiferal biozones were identified at San Francisco de Paula: the *Angulogavelinella avninelechi-Anomalinoides rubinginosus* Interval Zone (BB1) and the *Anomalinoides capitatus-Hanzawaia ammophila* Partial Range Zone (BB2).

3. The stratigraphically important *Stensioina beccariiformis* is present in the San Francisco de Paula section but it is not numerically abundant. The more common *Osangularia velascoensis* has the same stratigraphic range at San Francisco de Paula and may serve as an important proxy for the benthic extinction event (BEE) in the region.

4. The benthic foraminiferal fauna recovered from the San Francisco de Paula section indicates deposition under middle bathyal conditions. The presence of "Midway" type benthic foraminifera in distinct intervals correlate closely with unconformities identified by planktonic foraminifera (Fernández-Rodríguez et al. 1999, this volume) calcareous nannofossils (Aubry 1999, this volume), and radiolaria (Sanfilippo and Hull 1999, this volume).

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PLATE 1

Scanning electron micrographs of benthic foraminifera from the San Francisco de Paula section.

1 *Pyramidulina latejugata* (Guembel). X50

2 *Siphononodosaria nuttalli* (Cushman and Jarvis). X50.

3 *Vaginulina brantlyi* (Toulmin) X50.

4 *Pleurostomella paleocenica* Cushman. X100.

5,6 *Boldia madrugaensis* Cushman and Bermudez. X100. Figure 5, apertural view, Figure 6, umbilical view.

7,8 *Stensioina beccariiformis* (White). X100. Figure 7, umbilical view; Figure 8, apertural view.

9,10 *Nonion havanense* Cushman and Bermudez. X100. Figure 9, apical view; Figure 10, apertural view.

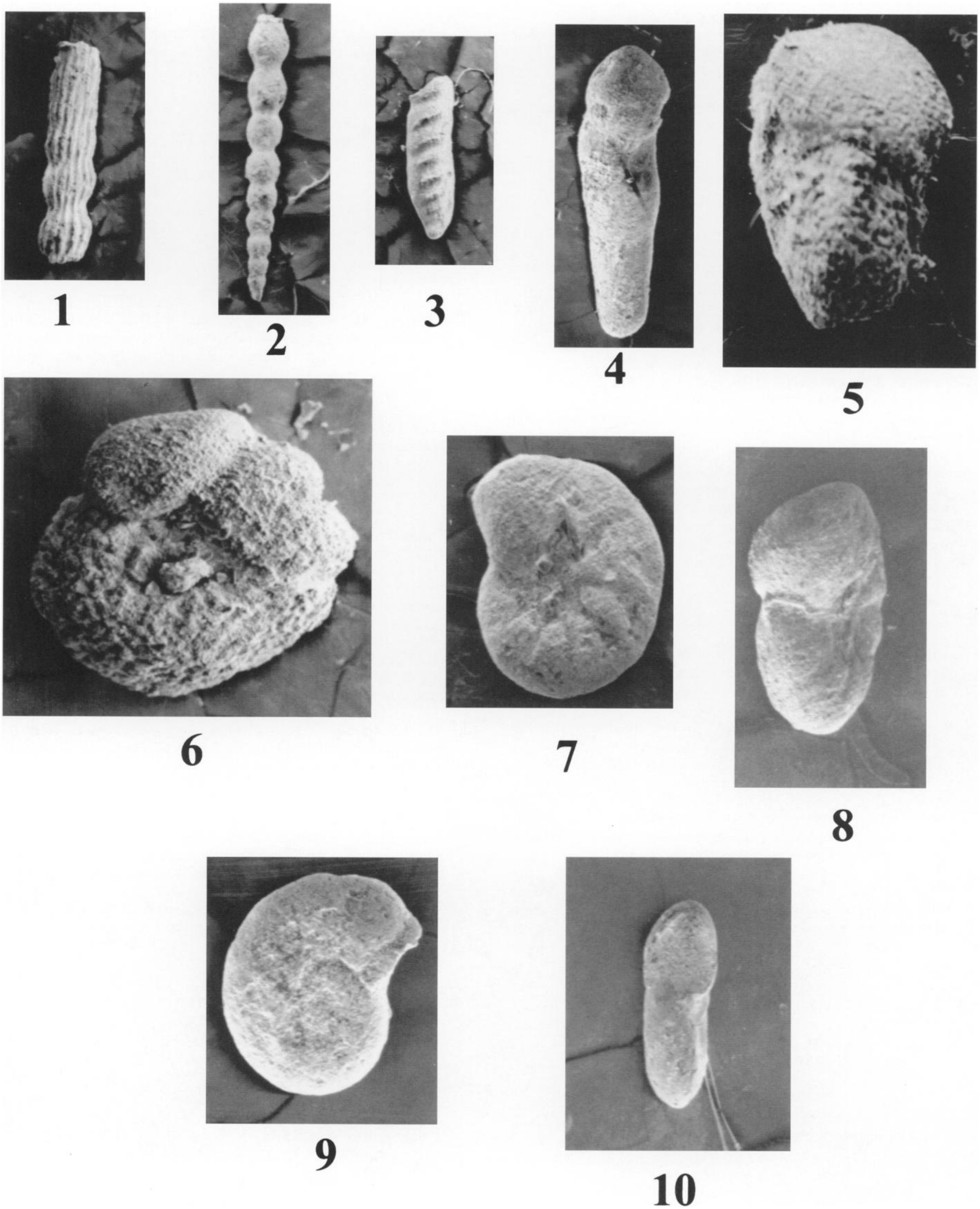
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PLATE 2

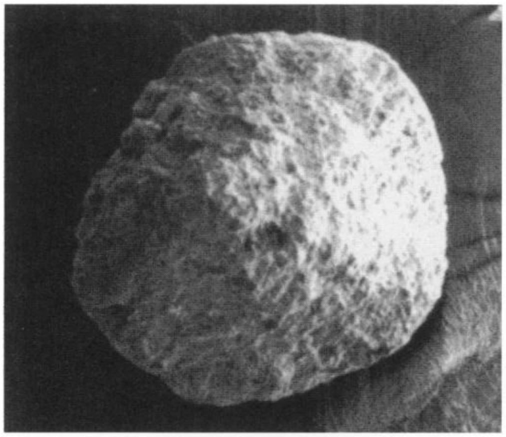
Scanning electron micrographs of benthic foraminifera from the San Francisco de Paula section.

1,2 *Nuttalides truempyi* (Nuttall) X125. Figure 1, apical view; Figure 2, lateral view.

3 *Lenticulina insula* (Cushman) X100. Apical view.

4,5 *Anomalinoides madrugaensis* (Cushman and Bermúdez). X100. Figure 4, apical view; Figure 5, apertural view.

6 *Osangularia velascoensis* (Cushman). X50. Apical view



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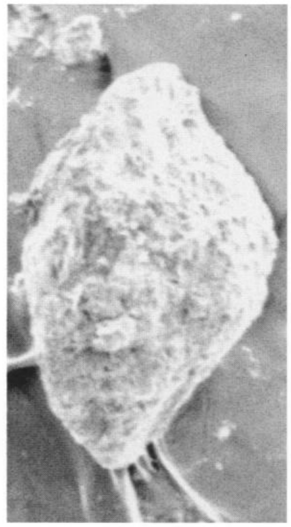

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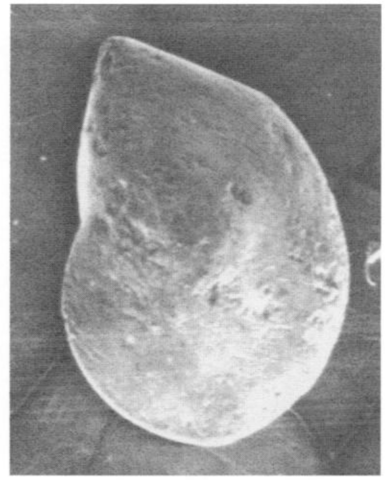

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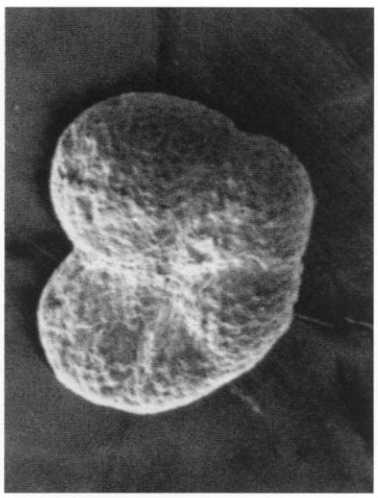

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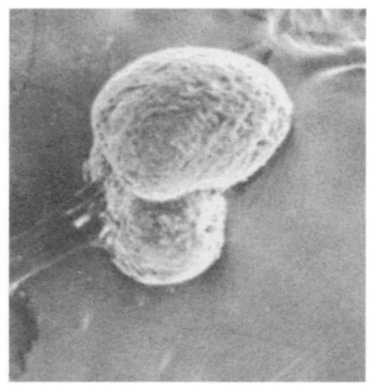

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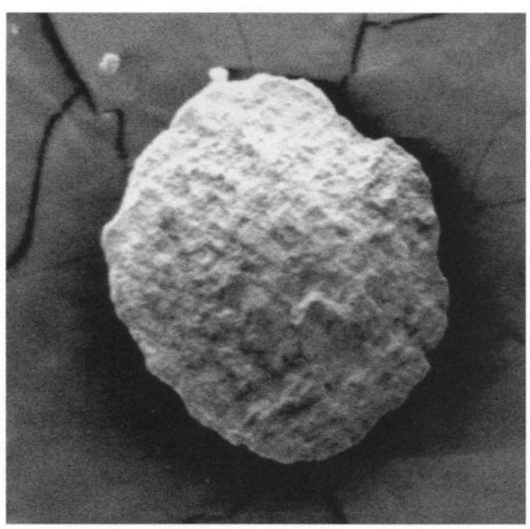

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