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FORAMINIFERA AND BIOSTRATIGRAPHY OF THE BOWDEN SHELL BED, JAMAICA, WEST INDIES

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The type Woodring shell bed locality of the Bowden Formation is located on the eastern side of Port Morant Harbour on the southeast coast of Jamaica, parish of St Thomas. Eight samples were studied from a measured section which included the Bowden shell bed. A total of 182 species and 105 genera of benthic foraminifera are identified and charted from this late Pliocene measured section.

The Bowden Formation is represented at the shell bed locality by interbedded sands and clays. There is an upward deepening of the palaeo-water depths at this locality ranging from shallow-outer neritic to deep-outer neritic (100-200 m). Additional localities used as reference sections contain rare upper bathyal species. The measured section is equivalent to Zone N21 of Blow (late Pliocene). All samples are below the Last Appearance Datum (LAD) of *Globorotalia miocenica* and *Gl. exilis* and above the LAD of *Dentoglobigerina altispira* and *Globorotalia multicamerata*. The shell bed is dominated by highly-abraded shallow water (inner neritic, less than 20 m) foraminifera which represent a downslope transport of inner neritic sediments and fossils into an outer neritic environment.

Key words — Bowden Formation, Bowden shell bed, Pliocene, Foraminifera, biostratigraphy, palaeoenvironment.

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CONTENTS

INTRODUCTION

Since its discovery by Lucas Barrett in 1859, many studies have utilised collections from the Bowden shell bed (Figs 1-3). The most notable of these are the classic monographs on the molluscs by Wendell P. Woodring (1925, 1928), who assigned a Miocene age to the bed, based on molluscan data.

The purpose of the present study is to document the occurrence of larger and smaller benthic foraminifera in the Bowden shell bed and enclosing sedimentary rocks, in order to determine the age and environment of deposition. Planktonic foraminifera are primarily used herein for dating along with calcareous nannofossils. Additionally, the palaeoenvironments are documented and the relationship of the Bowden shell bed to other Bowden Formation sedimentary rocks is discussed.

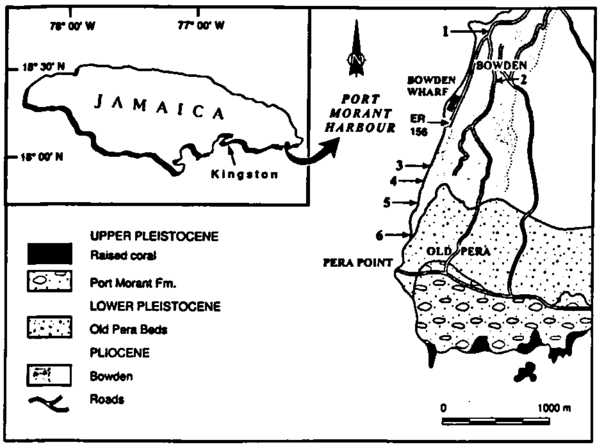
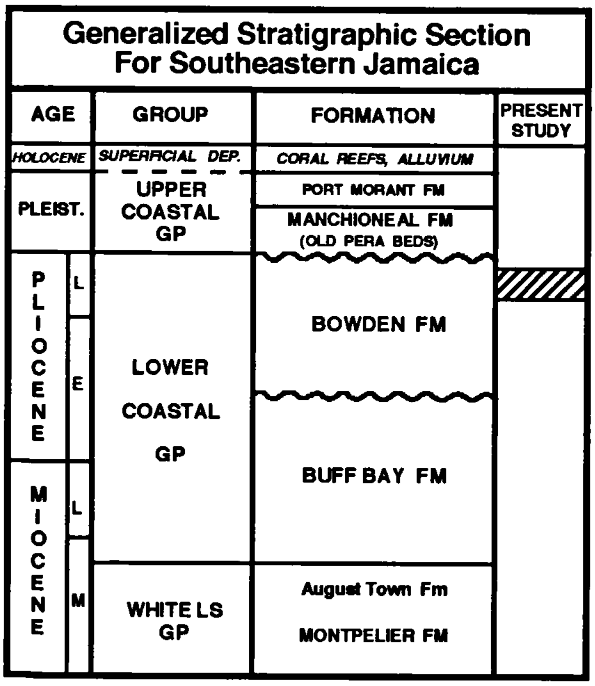


Fig. 1. Locality and geologic map of the east side of Port Morant Harbour, southeastern Jamaica, showing the outcrops of the Bowden Formation and Manchioneal Formation (Old Pera beds) used for this study. The numbers 1 through 6 refer to measured sections. The location of ER 156 (Blow's N-20 type locality) is also shown. Section 1 is the location of Woodring's Bowden shell bed. See Figs 3 and 4 for stratigraphic columns of Sections 1, 3-6 (modified after Pickerill *et al.*, 1998).



Generalized Stratigraphic Section For Southeastern Jamaica

AGE		GROUP	FORMATION	PRESENT STUDY
HOLOCENE		SUPERFICIAL DEP.	CORAL REEFS, ALLUVIUM	
PLEIST.		UPPER COASTAL GP	PORT MORANT FM	
			MANCHIONEAL FM (OLD PERA BEDS)	
PLIOCENE	L	LOWER COASTAL GP	BOWDEN FM	▨
	E			
MIOCENE	L		BUFF BAY FM	
	M	WHITE LS GP	August Town Fm MONTPELIER FM	

Fig. 2. Generalised stratigraphic column for the late Neogene and Quaternary of southeastern Jamaica (after Robinson, 1969a, 1994).

Previous work — The collections made by Barrett from the Bowden shell bed included foraminifera. These were examined by Jones & Parker (1863; see also Jones & Parker, 1876), who described two species for which the Bowden shell bed was probably the type locality. Additional studies by Bagg (*in* Hill, 1899) and Cushman (1919) increased the number of species known from the Bowden shell bed to thirty-six. This earlier work was reviewed by Palmer (1945), who discussed the significance of the benthic and planktonic foraminiferal assemblages. Palmer examined samples from the Bowden shell bed collected by herself in 1934 and from supplemental samples collected by others. She reported 171 species and 88 genera of foraminifera from that study.

There have not been any comprehensive benthic foraminiferal studies published from the Bowden Formation at Bowden or the shell bed since 1945. Other benthic foraminiferal studies from the Bowden Formation at Buff Bay, on the northeast coast, include Cushman & Todd (1945), Cushman & Jarvis (1930, 1936) and Katz & Miller (1993).

GENERAL GEOLOGY

Jamaica is situated on the Nicaraguan Rise and is separated from Cuba by the Cayman Trough, which reaches depths of 4-7 km. The close proximity of the trough to the northern coast of Jamaica creates a very narrow shelf, usually less than 2 km wide. The shelf on the southeastern coast near Bowden is also narrow being less than 5 km wide and, at Bowden itself, about 2.5 km wide. That Jamaica has been and still is tectonically active is shown by the present day seismicity, the numerous faults cutting the Pliocene and later sedimentary rocks, and the presence of a series of raised Quaternary marine terraces (Cant, 1972; Horsfield, 1973; Wadge & Dixon, 1987; Land, 1991; Wiggins-Grandison, 1996).

The late Miocene to Quaternary Coastal Group includes the Manchioneal (Trechmann, 1930; Robinson, 1969a; Kohl, 1992) and Bowden Formations, further described herein (Fig. 2). The Coastal Group crops out as a narrow, discontinuous band along the northeastern, eastern, and southeastern coasts of Jamaica. Inland, a core of igneous, sedimentary and metamorphic rocks of Cretaceous age (Blue Mountain Inlier) is surrounded by early Tertiary siliciclastic rocks and Paleocene to middle Miocene limestones of the Yellow and White Limestone Groups (Robinson, 1994; Donovan *et al.*, 1995).

Bowden Formation — The name of this unit, as the Bowden beds, was formalised by Hill (1899, p. 82) following Guppy & Dall's (1896) restudy of the stratigraphic relationship of these rocks. However, the name had been used much earlier by the Jamaican Geological Survey (Sawkins, 1869, p. 44) in mentioning 'beds of marl, sand, and conglomerate of the Bowden series at Port Morant.' Sawkins (1869, p. 46) also indicated the stratigraphic relationships of the Bowden shell bed when he reported that, ' ... below the pteropod marl [at Bowden] there are beds of the most perfect tertiary shells yet known on the Island...'. These comments are under Sawkins' signature, but as Chubb (1962) has remarked, the style is that of Lucas Barrett, who as the first Director of the Jamaican Survey had discovered the shell bed.

Barrett was also the first person to consider the geological age of these units when he wrote in 1860 (*in* Sawkins, 1869, p. 82), concluding that the pteropod marl was Pliocene in age based on the occurrence of deep-water molluscs. He assigned a water depth of '150-200 fathoms' based on his dredge of molluscs and foraminifera from the north coast of Jamaica which had a close similarity to the faunal assemblage in the pteropod marls. He also concluded that 'the coast had been elevated by at least 1,200 ft...'.

Robert Etheridge (*in* Sawkins, 1869, p. 313) listed foraminifera identified by T.R. Jones from the pteropod marl and also quoted Jones & Parker (1863) in concluding that this fauna is indicative of depths of 100 fathoms or more. In the section published by Woodward (1862) for this part of Jamaica, the highest beds were referred to as 'Pliocene Limestone and Marls'.

Thus, from an early date, the pteropod marl was dated as Pliocene. It was recognised to be a relatively deep-water deposit, and to overlie the shell horizon at Bowden. This stratigraphic relationship is best seen in the section exposed along the road going uphill to the old Captain Baker house from the shell bed locality (for example, Section 2 of Pickerill *et al.*, 1998). The Bowden Formation sections of Robinson (1969a, pp. 15, 16) include the Bowden shell bed and the overlying pteropod marl of Barrett and Sawkins.

When Hill (1899, p. 12) restudied the Bowden section from collections he made in 1896 from the Bowden shell bed, he relied on foraminiferal determinations made by Bagg to suggest a Miocene age for the bed. He also interpreted a depositional environment of less than 300 fathoms of water. Guppy & Dall (1896) had previously referred the molluscan fauna of Bowden to 'the Oligocene of Jamaica'. Hill also reported pteropods from his Bowden beds (1899, p. 151), but later in the publication confused the pteropod marls of Barrett with his Manchioneal beds (1899, p. 154).

The Bowden Formation, part of the Coastal Group, is represented at its type locality (= the Bowden shell bed locality) by several coarse-grained sandy and conglomeratic layers occurring as lenses within a sequence of silty planktonic foraminiferal marls (Figs 3, 4).

'At intervals, allochthonous material was introduced from shallower water areas by sliding and sand flow mechanisms. The material included rounded beach pebbles, rare massive hermatypic coral heads and a rich assemblage of shallow and deeper marine organisms, together with freshwater molluscs and fragments of wood' (Robinson, 1969a, p. 15). The Bowden Formation is overlain unconformably by the Manchioneal Formation at Port Antonio, San San Bay, Innes Bay, and Bowden (Aubry, 1993).

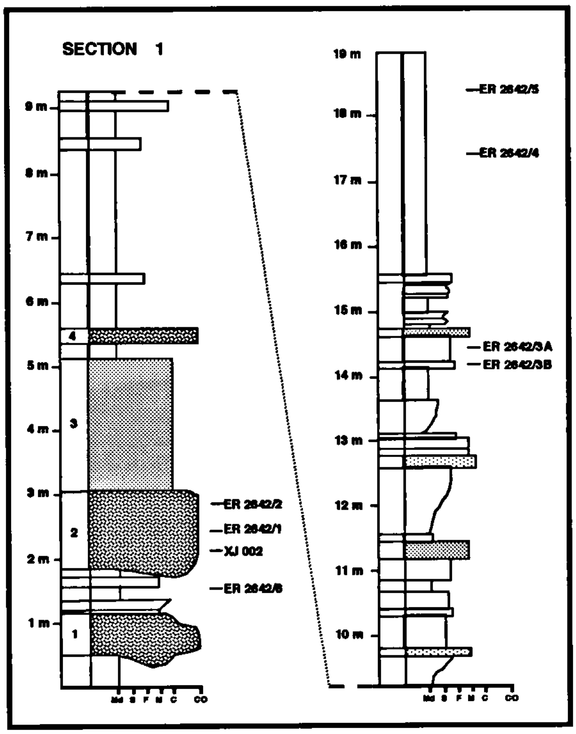


Fig. 3. Lithologic section which includes the Bowden shell bed of Woodring (1928). There are two shell beds located at Section 1. The thicker bed (Unit 2 of Pickerill *et al.*, 1998) is the one which has been sampled extensively for molluscs. The samples used in this study are indicated by ER and XJ prefixes (modified after Pickerill *et al.*, 1998).

At Buff Bay, on the northeastern coast, the Bowden Formation is early Pliocene to early late Pliocene (PL2-PL3 of Berggren, 1973) and lies unconformably on the late Miocene Buff Bay Formation (N17 of Blow, 1969) (Berggren, 1993; Aubry, 1993).

Manchioneal Formation — The Manchioneal Formation, part of the Coastal Group, is represented by forereef detritus with interbedded calcareous clays, rubbly coral, limestone and calcareous algae (Robinson, 1969a). Kohl (1992) reported that the palaeo-water depth of the Manchioneal Formation was generally middle to outer neritic. Samples included in that study are early Pleistocene in age (see Fig. 5). The Manchioneal Formation in the study area (as the Old Pera beds) lies unconformably on the Bowden Formation. Robinson & Lamb (1970) documented that there is a major unconformity between the Manchioneal and Bowden Formations. Aubry (1993, p. 156) placed the duration of the unconformity between the Navy Island member of the Manchioneal Formation and the Bowden Formation at Folly Point as 1.1 Ma.

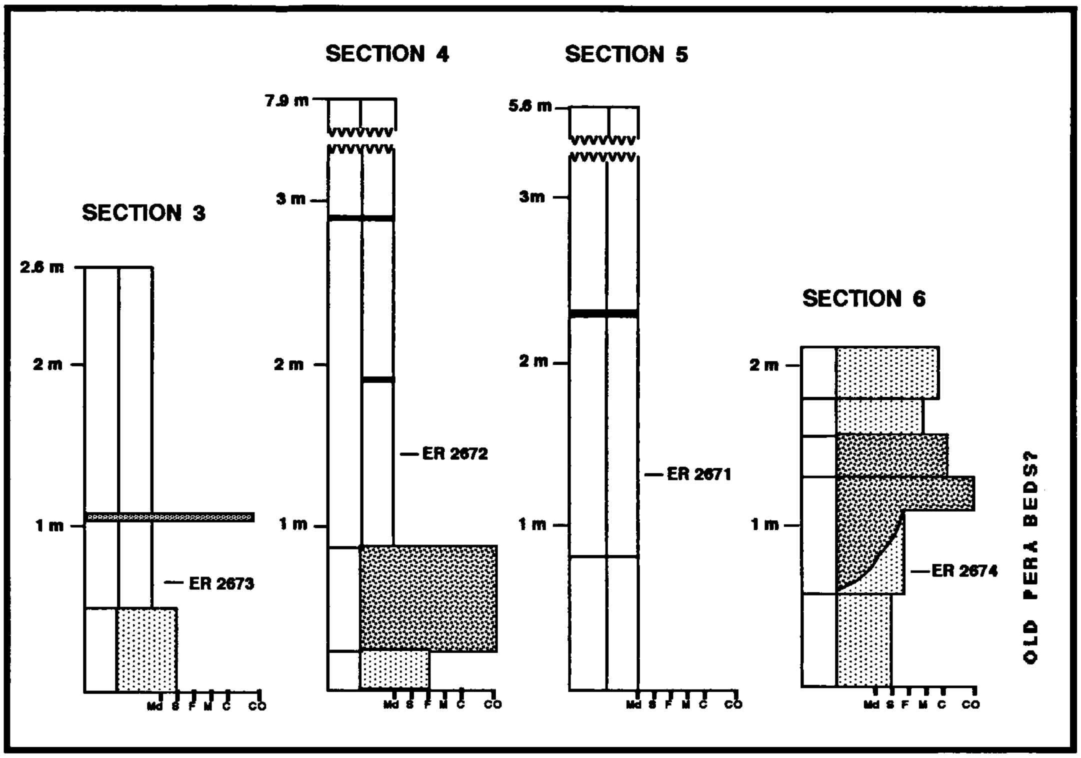


Fig. 4. Supplemental sections between Bowden and Pera Point used in this paper. The samples used for this study are indicated by ER prefixes. The stratigraphic relationships of Sections 3 and 4 are uncertain. In Section 6, the boundary between the Bowden Formation and Manchioneal Formation is provisional (modified after Pickerill *et al.*, 1998).

Kohl (1992) reported that there had been reworking of shallow-water assemblages within the Manchioneal Formation. Shallow-water benthic faunas, dominated by *Amphistegina gibbosa* d'Orbigny, were probably transported from an inner neritic environment across the narrow shelf and redeposited into outer neritic sediments along with Palaeogene foraminifera and calcareous nannoplankton. Some Manchioneal Formation samples from Port Maria contained common Eocene and Oligocene planktonic foraminifera. Those occurrences were interpreted by Kohl (1992) to be the result of erosion and redeposition from older outcrops inland.

The overall shallowing trend of the Manchioneal Formation coincides with the uplift of Jamaica during the late Pliocene and Pleistocene at Buff Bay. The palaeowater depth ranges from 600 m in the underlying Bowden Formation (Katz & Miller, 1993) to 90 m for the shallowest sample examined from the Manchioneal Formation (Kohl, 1992).

MATERIALS AND METHODS

Seven samples including the Bowden shell bed were collected by E. Robinson on February 23, 1996, from a measured section (Section 1 of Pickerill *et al.*, 1998) shown in Figs 1 and 3. Seven bulk samples (ER 2642/1-5) were collected from this section which is 19 m thick. An additional sample collected by the Florida Museum of Natural History (XJ 002) in 1990, from the main Bowden shell bed, was used for additional control.

Four additional samples were collected on June 9, 1996, from localities between Bowden and Old Pera (Sections 3-6) to be used for palaeoenvironmental control (see Figs 1, 4). Since Blow's N-20 holotype sample (ER 156) fell within the study area, we reviewed the planktonic and benthic foraminifera from reference samples collected previously from this important location. Detailed locality data can be found at the end of this paper.

All samples were disaggregated by drying, soaking in a petroleum distillate and boiling in a weak solution of sodium carbonate. The disaggregated samples were washed through 10 mesh (2 mm) and 230 mesh (0.063 mm) sieves. The fossils caught on a 10 mesh sieve were picked and the residue discarded. Each sample less than 10 mesh was dry sieved on a 100 mesh (0.149 mm) sieve and fractions greater than 100 mesh split on a microsplitter. An aliquot was selected which included 300 specimens of benthic and at least 300 specimens of planktonic foraminifers. The residue greater than 100 mesh was used for the foraminiferal counts. These counts were used to calculate the planktonic percent of the total fauna and benthic foraminiferal percentages for each sample. Abundance and occurrence data of benthic and planktonic foraminifera are shown in Tables 1a-d, 2 and 3.

TABLE 1a. FAUNAL CHECKLIST		SAMPLES FROM THE BOWDEN FORMATION, SECTION 1							
BENTHIC FORAMINIFERA		2642/6	XJ 002	2642/1	2642/2	2642/3b	2642/3a	2642/4	2642/5
Ammonia beccarii	(Linné)	VR							
Amphicoryna hirsuta	(d'Orbigny)							R	
Amphicoryna intercellularis	Brady								R
Amphistegina angulata	(Cushman)	C	A	VR	F	A	C	F	F
Amphistegina angulata (abr.)	(Cushman)	VA	A	VA	VA			VR	
Amphistegina gibbosa	d'Orbigny	A	F	VA	VA	F	F	VR	R
Amphistegina gibbosa (abr.)	d'Orbigny	C	C	A	C	VR			VR
Anomalinoides nucleatus	(Seguenza)							VR	
Archaias sp.			VR	VR					
Asterigerina carinata	d'Orbigny	VR	VR	VR	VR				
Baggina dominicana	Bermudez	R	VR	VR	VR	VR	VR	VR	VR
Barbourinella sp.	Bermudez					VR	VR	VR	
Bigenerina nodosaria	d'Orbigny						VR		
Bolivina sp.					VR				
Brizalina sp.					VR		VR	VR	
Brizalina alata	(Seguenza)		VR		R	VR	F	F	F
Brizalina fragilis	Phleger and Parker						VR	VR	
Brizalina multicostata	(Cushman)							VR	
Brizalina subaenariensis	(Cushman)	VR	VR		VR	VR	VR	F	F
Buccella hannai	(Phleger and Parker)	VR			VR				
Bulimina aculeata	d'Orbigny						VR	VR	VR
Bulimina marginata	d'Orbigny		VR		VR		VR	R	VR
Bulimina rostrata	Brady		VR						
Bulimina spicata	Phleger and Parker						VR	VR	VR
Burseolina palmerae	(Bermudez and Acosta)	VR				VR	VR	VR	R
Cancris sp.								VR	VR
Cancris sagra	(d'Orbigny)	VR			VR	VR	VR	VR	
Cassidulina curvata	Phleger and Parker						VR		
Cassidulina sp.							VR	VR	VR
Cassidulinoides sp.							VR		
Chilostomella czizeki	Reuss				VR		VR	R	VR
Cibicides spp.		VR	R		VR	VR	VR	VR	VR
Cibicides lobatulus	(Walker and Jacob)	F	F	VR	VR	VR	R	VR	VR
Cibicides refulgens	Montfort	F	VR	R	VR	F	F	R	R
Cibicidoides sp.			VR	VR	VR	VR	VR	VR	
Cibicidoides cf. C. floridanus	(Cushman)	VR				R	VR		VR
Cibicidoides floridanus s.l.	(Cushman)	C	C	R	R	A	C	F	C
Cibicidoides perforatus	Coryell and Rivero					VR	VR	VR	VR
Clavulina mexicana	Cushman							VR	
Compressigerina coartata	(Palmer)	VR	R		VR	VR	F	VR	R
Cribrorobulina serpens	(Seguenza)							VR	VR
Cymbaloporetta squamosa	(d'Orbigny)	VR	R		F	VR	F	F	R
Dentalina sp.								VR	VR
Dentalina communis	d'Orbigny	VR			VR		VR	VR	VR
Discorbinella floridensis	(Cushman)	VR	VR		VR	R	R	VR	
Discorbis mira	(Cushman)		VR	VR	VR	VR	VR	VR	
Discorbis rosea	(d'Oribigny)		F	R	VR	F	F		
Dorothia caribaea	Cushman						VR		
Dyocibicides biserialis	Cushman and Valentine					VR		F	VR
Eggerella bradyi	(Cushman)								VR
Ehrenbergina olmeca	Kohl								VR

TABLE 1b. FAUNAL CHECKLIST		SAMPLES FROM THE BOWDEN FORMATION, SECTION 1							
BENTHIC FORAMINIFERA		2642/6	XJ 002	2642/1	2642/2	2642/3b	2642/3a	2642/4	2642/5
Ehrenbergina spinea	Cushman						VR	VR	VR
Ehrenbergina spinosissima	Cushman and Jarvis							VR	VR
Ehrenbergina trigona	Göes						VR		VR
Elphidium sp.		C	VR	R	F	VR	R	VR	R
Elphidium advenum	(Cushman)							VR	VR
Elphidium poeyanum	d'Orbigny	R	F	VR				VR	VR
Elphidium sagrum	(d'Orbigny)	VR							VR
Elphidium discoidale	(d'Orbigny)	VR	R	VR				VR	VR
Eponides sp.		VR	VR					VR	VR
Eponides antillarum	(d'Orbigny)					VR			
Fissurina sp.							VR		VR
Fissurina flintiana	(Cushman)								VR
Fissurina marginata	(Walker and Boys)							VR	
Florilus grateloupi	(d'Orbigny)		VR		VR		R	R	VR
Frondicularia saggitula	Vanden Broeck	VR			VR	VR		VR	
Frondicularia sp.									
Fursenkoina pontoni	(Cushman)	VR			VR	VR	VR	VR	
Gaudryina sp.			VR						
Gaudryina cf. G. aequa	Cushman							VR	
Glandulina sp.								VR	
Globobulimina sp.		VR	VR		VR	VR	VR	R	VR
Globocassidulina crassa	(d'Orbigny)							VR	VR
Globocassidulina punctata	Berggren and Miller					R	VR		
Globocassidulina subglobosa	(Brady)	VR	VR	VR	VR	F	F	C	F
Globulina sp.					VR				VR
Gypsina vesicularis	(Parker and Jones)	VR					VR		
Gyroidina sp.			VR		VR	R	R	R	F
Gyroidina umbonata	(Silvestri)	VR			VR		R	F	VR
Hanzawaia cf. H. concentrica	(Cushman)							VR	VR
Hoeglundina elegans	(d'Orbigny)		VR		VR	VR	VR	VR	VR
Lagena sp.						VR	VR	VR	
Lagena crenata	Parker and Jones					VR			
Lagena inepta	McCulloch	VR							
Lagena striata basisenta	Cushman and Stainforth								VR
Lenticulina sp.		R	VR	VR	R	VR	R	F	F
Lenticulina jamaicaensis	(Cushman and Todd)						VR		
Lenticulina calcar	(Linné)		VR	VR	VR	VR		VR	VR
Lenticulina cultrata	(Montfort)							VR	
Lenticulina orbicularis	(d'Orbigny)						VR		
Lenticulina peregrina	(Schwager)						VR	VR	VR
Lernella inflata	(Leroy)	VR							VR
Liebusella soldanii	(Jones and Parker)		R	VR	VR	A	F	VR	
Loxostomum bradyi	(Asano)							VR	VR
Marginulina sp.							VR	VR	VR
Marginulina glabra	d'Orbigny						VR		VR
Marginulina obesa	Cushman							VR	
Marginulinopsis sp.					VR				
Melonis affinis	(Reuss)		VR		VR	VR	VR	R	VR
Melonis soldanii	(d'Orbigny)	VR	VR			VR	VR	F	F
Miliolids			C	A	R	C	F	F	

TABLE 1c. FAUNAL CHECKLIST — SAMPLES FROM THE BOWDEN FORMATION, SECTION 1

BENTHIC FORAMINIFERA		2642/6	XJ 002	2642/1	2642/2	2642/3b	2642/3a	2642/4	2642/5
Neoconorbina sp.			VR				VR		
Neoeponides parantillarum	(Galloway and Heminway)	R	C	VR	R	F	R	VR	VR
Nodosaria sp.					VR	VR	R	VR	VR
Nodosaria pyrula	d'Orbigny				VR	VR	VR		VR
Nodosaria sp. (six costae)								VR	
Nodosaria albatrossi	(Cushman).		VR			VR	VR		
Nodosaria longiscata	d'Orbigny							VR	VR
Oolina acuticosta	(Reuss)		VR					VR	
Oolina hexagona	(Williamson)		VR			VR			VR
Oridorsalis stellatus	(Silvestri)				VR				
Palmula longiformis	Bermudez							VR	
Paradentalina sp.									VR
Peneroplis sp. (abr.)				VR					
Planorbulinella larvata	(Parker and Jones)		VR				VR	VR	VR
Planulina sp.		VR		VR	VR				
Planulina ariminensis	d'Orbigny						VR		
Planulina exorna	Phleger and Parker	VR			VR	VR	VR	VR	VR
Planulina foveolata	(Brady)	R	R		VR	VR	F	C	A
Plectofrondicularia floridana	Cushman							VR	
Plectofrondicularia sp.					VR			VR	
Praeglobobulimina spiniscens	(Brady)				VR		VR		
Proxifrons cf P. javana	(Boomgaart)							VR	
Pseudonodosaria comatula	(Cushman)							VR	
Pseudopatellinoides sp.							VR		
Pullenia bulloides	(d'Orbigny)				VR				VR
Pullenia quadriloba	Reuss		VR						
Pullenia quinqueloba	(Reuss)							VR	VR
Pyrgo sp.			VR			VR	VR	VR	
Quadrimorphina glabra	(Cushman)		VR					VR	VR
Quinqueloculina sp.							VR	VR	
Ramulina sp.					VR			VR	R
Rectobolivina raphana	(Parker and Jones)	VR			VR			VR	
Reophax sp.									R
Reussella glabrata	(Cushman)	VR			VR				VR
Reussella miocenica	Cushman	F	VR	VR	F	R	F	F	F
Rosalina sp.		VR	VR		VR			VR	VR
Rutherfordoides sp.							VR	VR	R
Rutherfordoides erecta	(Cushman and Renz)	VR							VR
Rutherfordoides mexicana	(Cushman)		VR					VR	
Sagrina pulchella	d'Orbigny							VR	VR
Saracenaria sp.					VR		VR	VR	R
Saracenaria arcuata	d'Orbigny								VR
Saracenaria cf S. latifrons	(Brady)						VR	VR	VR
Saracenaria obesa	Cushman and Todd					VR			
Saracenaria palmerae	Cushman and Todd							VR	VR
Saracenaria toddae	Bermudez								VR
Sigmavirgulina tortuosa	(Brady)						VR		
Sigmoilinita tenuis	(Czjzek)		VR			VR	VR		VR
Sigmoilinopsis schlumbergeri	(Silvestri)			VR					
Siphonina pulchra	Cushman	R	F		VR	F	R	F	F
Siphoninella soluta	(Brady)								VR
Siphonodosaria oinomikadoi	(Ishizaki)							VR	

TABLE 1d. FAUNAL CHECKLIST		SAMPLES FROM THE BOWDEN FORMATION, SECTION 1							
BENTHIC FORAMINIFERA		2642/6	XJ 002	2642/1	2642/2	2642/3b	2642/3a	2642/4	2642/5
Siphotextularia affinis	(Fornasini)				VR			F	VR
Siphotextularia concava	(Karrer)		VR				VR		
Siphotextularia subplana	(Cushman)						VR		
Siphouvigerina auberiana	(d'Orbigny)								VR
Sorites sp. (abr.)			VR	VR		VR			
Sphaerogypsina globulus	(Reuss)		VR		VR		VR	VR	
Sphaeroidina bulloides	d'Orbigny	VR			VR	VR	R	R	F
Spiroloculina alveata	Cushman and Todd		VR				VR		
Spiroplectammina gramen	(d'Orbigny)					VR	VR	VR	
Spirotextularia floridana	(Cushman)						VR	VR	
Stilostomella lepidula	(Schwager)						VR	VR	VR
Textularia sp.			VR	VR	VR	R	F	F	VR
Textularia barnetti	Bermudez							VR	
Textularia conica	d'Orbigny			VR			VR		
Textularia occidentalis	Cushman						VR		
Textulariella barretti	(Jones and Parker)			VR	R	R	VR	VR	VR
Tortoplectella rhomboidalis	(Millet)								VR
Trifarina sp.							VR	VR	
Trifarina eximia	(Cushman and Jarvis)				VR				
Trifarina illingi	Cushman and Renz		VR		VR	VR	R	R	F
Trifarina jamaicensis	(Cushman and Todd)								VR
Trifarina rutila	(Cushman and Todd)	VR			VR				
Uvigerina parvula	Cushman				VR	R	VR	VR	R
Uvigerina peregrina	Cushman					VR			VR
Vaginulinopsis sp.					VR				
Valvulineria mexicana	Parker	VR	R		VR	VR	F	C	F
Vasiglobulina sp.		VR	VR	VR					
Total number of benthic specimens		284	209	222	362	298	367	417	338

Table 1a-d. Abundance lists of Pliocene benthic foraminifera in the samples from Section 1, which includes the Bowden shell bed. The list includes foraminifera in the size range >100 mesh and <10 mesh. Relative abundances are indicated on the chart as follows: VA, very abundant (>20%); A, abundant (10-20%); C, common (5-10%); F, few (2-5%); R, rare (1-2%); VR, very rare (<1%). The samples are listed in stratigraphic order with the youngest to the right.

TABLE 2. FAUNAL CHECKLIST		SAMPLES FROM THE BOWDEN FORMATION, SECTION 1						
LARGER BENTHIC FORAMINIFERA		ER 2642/6	ER 2642/1	ER 2642/2	ER 2642/3B	ER 2642/3A	ER 2642/4	ER 2642/5
Amphistegina spp.		VA	VA	VA	F	C	C	
Archaias spp.			VR		VR			
Cyclorbiculina cf. C. compressa	(d'Orbigny)				VR			
Frondicularia saggitula	Vanden Broeck	VR		VR	R	VR		R
Lenticulina spp.		VR			R	A	F	R
Liebusella soldanii	(Jones and Parker)	VR	F	C	VA	VA	A	R
Sphaerogypsina globulus	(Reuss)		F	VR	VR	R		
Textulariella barretti	(Jones and Parker)	VR	F	C	A	VA	A	R
Other *			VR	R	F	C	C	
Total number of larger benthic specimens		317	326	362	353	207	47	4

Table 2. Abundance of larger benthic genera found in the >10 mesh size fraction. Abundances are the same as those for Table 1. Sample ER 2642/5 had only four specimens of larger foraminifera and ER 2642/4 had 47. The counts for the remaining samples were approximately 300 specimens. 'Other' includes *Nodosaria longiscata* d'Orbigny.

TABLE 3. FAUNAL CHECKLIST SAMPLES FROM THE BOWDEN FORMATION, SECTION 1

PLANKTONIC FORAMINIFERA		2642/6	XJ 002	2642/1	2642/2	2642/3b	2642/3a	2642/4	2642/5
Globigerina spp.		VA	VA	VA	VA	VA	VA	VA	VA
Globigerina decoraperta	Takayanagi and Saito	VR			VR		VR		R
Globigerina incisa	Bronnimann and Resig		VR		VR		VR		VR
Globigerinella siphonifera	(d'Orbigny)	R			R		VR	VR	VR
Globigerinita glutinata	(Egger)	VR					VR		VR
Globigerinoides conglobatus	(Brady)	VR	VR			VR	VR	VR	VR
Globigerinoides extremus	Bolli and Bermudez	VR	R	A	R	F	F	R	F
Globigerinoides cf. G. fistulosus	(Schubert)		VR		VR				VR
Globigerinoides fistulosus	(Schubert)		VR						
Globigerinoides ruber	(d'Orbigny)	A	A	A	A	A	A	C	C
Globigerinoides sacculifera	(Brady)	R	R		R	R	F	R	F
Globigerinoides trilobus	(Reuss)	VA	VA	VA	VA	VA	A	A	VA
Globorotalia acostaensis	Blow						VR		VR
Globorotalia crassaformis (D)	(Galloway and Wissler)	VR	VR					VR	VR
Globorotalia crassaformis (S)	(Galloway and Wissler)	VR	VR		VR	VR	R	VR	F
Globorotalia exilis	Blow	VR	VR		VR	R	R	F	F
Globorotalia menardii (D)	(d'Orbigny)	A	C	F	C	A	A	VA	A
Globorotalia menardii (S)	(d'Orbigny)	VR	R		VR	VR	VR	VR	VR
Globorotalia miocenica	Palmer	F	F	F	F	F	C	C	C
Globorotalia scitula	(Brady)		VR				VR		VR
Globorotalia cf. Gl. viola	Blow						VR		VR
Globorotalia viola	Blow	VR					VR	VR	
Neogloboquadrina humerosa	(Takayanagi and Saito)	VR	R	F	R	VR	VR	F	F
Orbulina universa	d'Orbigny	R	VR		F	F	F	F	F
Sphaeroidinella dehiscens	(Parker and Jones)	VR	VR	F	F			VR	
REWORKED PLANKTONICS									
Dentoglobigerina cf. D. altispira	(Cushman and Jarvis)	VR					VR		
Dentoglobigerina cf. D. venezuelana	(Hedberg)		VR			VR			
Globigerinatella insueta	Cushman and Stainforth							VR	
Globoquadrina dehiscens	(Chapman, Park and Collins)		VR						
Globorotalia cf. Gl. margaritae	Bolli and Bermudez		VR						
Globorotalia fohsi s.l.	Cushman and Ellisor		R			R	VR	VR	
Globorotalia peripheroacuta	Blow and Banner		VR				VR		
Globorotalia cf. Gl. peripheroronda	Blow and Banner		VR						VR
Globorotalia peripheroronda	Blow and Banner		VR			VR	VR	VR	
Globotruncana sp.							VR		
Globoturborotalita nepenthes	(Todd)		R			VR	VR		VR
Neogloboquadrina mayeri	(Cushman and Ellisor)		VR			VR			
Praeorbulina sicana	(De Stefani)	VR				R			
Sphaeroidinellopis cf. S. subdehiscens	(Blow)	VR							
Sphaeroidinellopis subdehiscens	(Blow)	VR							
Total number of planktonic specimens		299	170	29	262	308	482	424	548

Table 3. Distribution of planktonic foraminifera from Section 1. Abundances are the same as those for the benthic foraminifera in Table 1. (D) = dextrally coiled; (S) = sinistrally coiled.

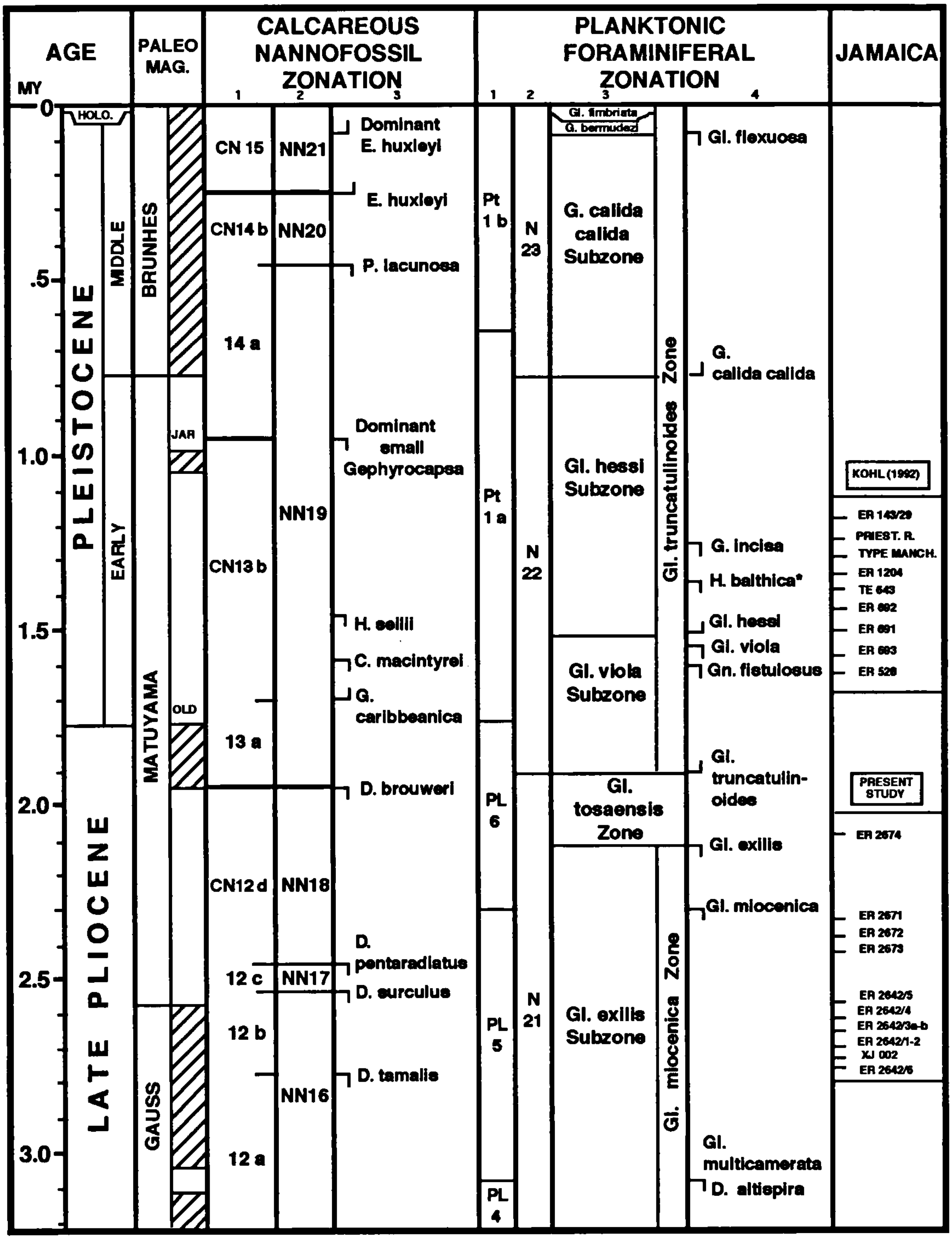


Fig. 5. Subdivision of the Pliocene and Pleistocene based on planktonic foraminifera and calcareous nannoplankton. The relative stratigraphic position of the samples (sections) used in this and a previous study are shown in the right-hand column (Jamaica). Samples from the Manchioneal Formation of northeastern Jamaica are shown as Kohl (1992). Those below are from the present Bowden study.

Age and palaeomagnetics are after Berggren (1973, 1993) and Berggren *et al.* (1985, 1995a, b). Calcareous nannoplankton zonation: column 1 after Okada & Bukry (1980); column 2 after Martini (1971); column 3 after Gartner *et al.* (1983, 1987). Planktonic foraminiferal zonation: column 1 after Berggren (1973) and Berggren *et al.* (1995b); column 2 after Blow (1969); column 3 after Bolli & Premoli-Silva (1973); column 4 after Bolli & Premoli-Silva (1973), Berggren *et al.* (1985, 1995a) and Kohl (1992).

The base of the Pleistocene conforms to the decision of the International Union of Geological Societies (IUGS) and was picked near the top of the Olduvai (C2n) Subchronozone (Berggren *et al.*, 1995a, p. 1285). The disappearance of the benthic foraminifei *Hyalinea balthica* (Schroter), as seen in the Gulf of Mexico, is included as a reference (from Kohl, 1992).

BOWDEN SHELL BED SECTION

Chronostratigraphy — Dating was accomplished by using the standard Caribbean and Gulf of Mexico planktonic foraminiferal and calcareous nannoplankton zonation shown in Fig. 5.

Additional work by Aubry (1993) and Berggren (1993) using calcareous nannoplankton and planktonic foraminifera, respectively, from the type Bowden Formation was also reviewed for our interpretation. We have used the rationale of Berggren (1993) in the naming of planktonic foraminiferal genera. Numeric ages are from Berggren *et al.* (1995a, b).

All the samples studied from Section 1, which includes the Bowden shell bed, are above the Last Appearance Datums (LAD) of *Globorotalia multicamerata* Cushman & Jarvis and *Dentoglobigerina altispira* (Cushman & Jarvis). They are below the LAD of *Globorotalia miocenica* Palmer and *Gl. exilis* Blow. The measured section is within the *Gl. exilis* Zone of Bolli *et al.* (1985), Zone N21 of Blow (1969) and the PL5 Zone of Berggren (1973). The section is equivalent to the nannofossil Zone NN 16 of Martini (1971) and CN12b of Okada & Bukry (1980) (Tab. 4). Figure 5 shows the stratigraphic position of the samples studied.

SAMPLES		Abundance	Species identified
Above Shell Bed:	ER 2642/ 5	flood	*D. asymmetricus, D. brouweri* (5 & 6 rayed), *D. pentaradiatus, D. surculus* , (Eocene, Cretaceous reworking)
	ER 2642/3a	abundant	*D. asymmetricus, D. brouweri, D. pentaradiatus, D. cf. surculus*
Ripup Clast	ER 2642/2	sparse	(Cretaceous reworking)
Shell Bed	ER 2642/1	barren	
Below Shell Bed	ER 2642/6	common	*D. asymmetricus* , (Miocene, Cretaceous reworking)

Table 4. Key calcareous nannoplankton identified from samples at Section 1 by J. Boudreaux.

SAMPLES			Benthics		Planktonics	
			Genera	Species	Plank %	RW plank
Above Shell Bed:		ER 2642/5	64	99	60	2
		ER 2642/4	74	106	49	3
		ER 2642/3a	62	90	57	6
		ER 2642/3b	44	58	49	6
Clay Clast,	Unit 2	ER 2642/2	52	66	41	0
Shell Bed,	Unit 2	ER 2642/1	19	26	9	0
Shell Bed,	Unit 2	XJ 002	45	57	47	9
Below Shell Bed		ER 2642/6	37	45	52	4

Table 5. The number of benthic foraminiferal species and genera, planktonic percent and number of reworked (RW) planktonic species identified in samples from Section 1. Unit 2 is the main Bowden shell bed (see Pickerill *et al.*, 1998).

'In-place' planktonic foraminifera — Twenty species of *in situ* planktonic foraminifera are identified from the Bowden shell bed section. The planktonic assemblages are dominated by *Globigerinoides ruber* (d'Orbigny) and *Globigerinoides trilobus* (Reuss), which together comprise 51-85% of the planktonic fauna. The planktonic ranges from 9-60% (Tab. 5).

The highest planktonic percent values are in the youngest samples (ER 2642/5). *Globigerinoides extremus* Bolli & Bermudez occurs in all samples.

According to Robinson (1969a) and Berggren (1993), the Woodring locality, studied herein, is also the type locality for *Gl. miocenica*. The designated type locality for *Gl. exilis* is 500 m southeast of Section 1 (Robinson, 1969a). *Globorotalia miocenica* is present in all the samples at Section 1.

Globigerina incisa (Brönnimann & Resig), which became extinct in the early Pleistocene, occurs in low numbers. The first record of this species in Jamaica was reported from the Manchioneal Formation by Kohl (1992).

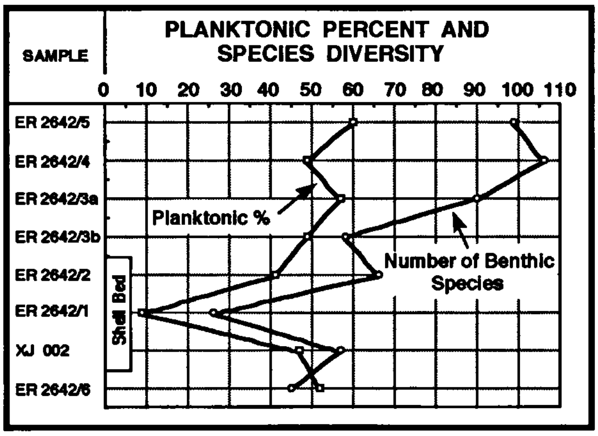


Fig. 6. Comparison of the foraminiferal planktonic percent and benthic species diversity in samples from the Bowden Formation, Section 1.

Dominant Taxa		Percent
Amphistegina gibbosa	d'Orbigny	9 - 34
Amphistegina angulata	(Cushman)	9.5 - 42.5
Cibicidoides floridanus	(Cushman) *s.l.*	6.0 - 19.5
Elphidium spp		8.0
Globocassidulina subglobosa	(Brady)	6.6
Liebusella soldanii	(Jones and Parker)	10.7
Miliolids		8.0 - 14.2
Neoeponides parantillarum	(Galloway and Heminway)	6.5
Sphaerogypsina globulus	(Reuss) *	40.0
Valvulineria mexicana	Parker	7.3

Table 6. The range of abundance of smaller benthic species in samples for Section 1 exceeding 6% of the benthic fauna. (*) indicates the % from the >10 mesh fraction in sample XJ 002.

A graph of the planktonic percentage for each sample is shown in Fig. 6. There is a general up-section increase from sample ER 2642/3b to ER 3642/5.

Reworked planktonic foraminifera — There are fifteen species of early Pliocene, middle Miocene and Cretaceous planktonic foraminifera found in Section 1 samples (Tab. 3). Rare Miocene planktonics occur in samples ER 2642 3a, 3b, 4 and 5, and include *Gl. fohsi sensu lato* and *Gl. peripheroronda* (Banner & Blow). These taxa, as well as *Neogloboquadrina mayeri* (Cushman & Ellisor) and *Globoquadrina dehiscens* (Chapman, Park & Collins), occur in sample XJ 002.

The early Pliocene index foraminifer *Globoturborotalita nepenthes* (Todd) occurs in samples ER 2642 3a, 3b, 5 and XJ 002. The occurrence of these taxa in late Pliocene sedimentary rocks supports the thesis of erosion and redeposition of Miocene and Pliocene exposures into late Pliocene sediments. Table 2 lists the occurrence of reworked species in the samples from Section 1.

Calcareous nannoplankton — Joseph Boudreaux of TBS Inc. provided calcareous nannoplankton data which are integrated into the planktonic foraminiferal data to provide an age interpretation as shown in Fig. 4. Samples ER 2642/1, 2, 3a, 5 and 6 were examined for calcareous nannofossils. The results are shown in Tab. 4. Samples are listed in order of their stratigraphic position at Section 1.

The youngest sample, ER 2642/5, is below the LAD of *Discoaster surculus* Martini & Bramlette, 1964. The discoaster assemblage is normal for the late Pliocene and is in agreement with the planktonic foraminiferal data. The oldest sample, ER 2642/6, may not be representative since the calcareous nannofossils were not as well developed. Therefore, the absence of *D. surculus* may be related to a less rich calcareous nannofossil assemblage. The base of the section is probably above the LADs of *D. variabilis* Martini & Bramlette, 1964, *Sphenolithus abies* Deflandre and *Reticulofenestra pseudoumbilicus* (Gartner), since none of these index species were encountered at Section 1.

Based on these data, the age of this section is probably equivalent to Zone NN16 of Martini (1971), and Zone CN 12b of Okada & Bukry (1980).

Smaller benthic foraminifera — The smaller benthic foraminifera are defined herein as those which pass through a 10 mesh sieve. A total of 182 benthic species and 105 genera of smaller benthic foraminifera are identified from Section 1. Table 1a-d provides a detailed listing of the occurrence and abundance of all the smaller benthic foraminifera identified in the samples from the Bowden shell bed section.

The microfauna of samples ER 2642/1, ER 2642/2 and XJ 002 are composed predominantly of the benthic foraminiferal genera *Amphistegina* and *Asterigerina*. These taxa are also dominant in sample ER 2642/6 which is located between Units 1 and 2 of Pickerill *et al.* (1998; see Fig. 3 herein). The washed residues are composed of abundant igneous rock fragments and carbonate clasts in the very coarse- to coarse-grained, sand-size fractions.

An interpretation of the environment of deposition of the Bowden shell bed, using the dominant microfauna and lithology would suggest an inner neritic environment. Low benthic foraminiferal species diversity and low planktonic percentage also support this interpretation. By recording the state of preservation (mechanical breakage or abrasion) for each taxon found in these samples, two assemblages are revealed. The first consists of attached, abraded and poorly preserved taxa representing an inner neritic environment. The second assemblage is comprised of rare, fragile, better preserved foraminifera representing an outer neritic environment. By using the second *in situ* benthic assemblage, the depositional environment for the Bowden shell bed is interpreted to be outer neritic (representing a palaeo-water depth of 100-150 m).

Main Bowden shell bed (Unit 2), Section 1 — (1) Sample ER 2642/1, near the top of the Bowden shell bed, may not be a representative sample because the foraminifera are generally poorly preserved. There are calcite overgrowths on many specimens, which may be an indication of dissolution of calcite and recrystallisation during the weathering process. The low benthic diversity of only 26 species (Tab. 5) may also be the result of poor preservation due to weathering. *Amphistegina* and *Asterigerina* comprise 76% of the benthic microfauna (Tab. 1). Abraded or broken specimens dominate, comprising over 50% of the total benthic microfauna. Miliolids make up another 14%, are generally poorly preserved and are probably displaced as well. Many of the remaining species are shallow-water attached taxa. Because of calcite overgrowths on the surface of many of the tests, it was difficult to use abrasion as a criterion to separate individual species into displaced or *in situ* categories. We interpret the palaeoenvironment as shallow outer neritic based on the rare occurrence of *Globocassidulina subglobosa* (Brady) in this sample.

(2) A second sample, XJ 002, was collected by the Florida Museum of Natural History from the lower portion of Bowden shell bed (Unit 2), approximately 0.5 m above the base. It was compared with ER 2642/1 and is similar in its microfaunal constituents (*Amphistegina* spp. = 46%), but has a higher diversity (57 *vs* 26 benthic species) and higher planktonic percent (see Tab. 5; Fig. 6). This sample was composited from the fillings of large molluscs (Roger Portell, pers. comm.) and exhibited very little of the dissolution or calcite overgrowths found in sample ER 2642/1. The *in situ* benthic species include *Globocassidulina subglobosa*, *Hoeglundina elegans* (d'Orbigny), *Melonis affinis* (Reuss), *M. soldanii*

(d'Orbigny), *Planulina foveolata* (Brady) and *Quadrimorphina glabra* (Cushman), which were all well preserved. Although the frequencies of these species are low because of dilution, a palaeo-water depth of 100-160 m (outer neritic) is interpreted for this *in situ* assemblage.

(3) The third sample, a clay clast (ER 2642/2), was collected from within the upper part of the Bowden shell bed (Unit 2) to determine whether the enclosed microfauna in the clast differed from that of the matrix of the main Bowden shell bed. The clast has a much higher species diversity than ER 2642/1 (66 *vs* 26 benthic species) as shown in Tab. 5. This increase is due to more *in situ* benthic species. The sample was dominated by broken and abraded *Amphistegina* spp. (63%), but it also included well-preserved benthic species such as rare *Chilostomella czizeki* Reuss, *Gyroidina umbonata* (Silvestri), *Hoeglundina elegans* and *Melonis soldanii*, which are all indicative of an outer neritic environment. The clay clast is interpreted as representing a palaeo-water depth of 100-150 m (outer neritic). This may represent the actual palaeo-water depths into which the Bowden shell bed was displaced.

Below Bowden shell bed, Section 1 — Sample ER 2642/6 was collected between the main Bowden shell bed (Unit 2) and the lower shell bed (Unit 1 of Pickerill *et al.*, 1998; see Fig. 3 herein). It is very similar to the samples taken from within Unit 2. The lithology, with abundant rock fragments and carbonate clasts in the coarsest fractions, is similar in character to the samples from Unit 2. The microfauna is dominated by *Amphistegina* spp., which comprise 61% of the benthic assemblage, but this sample also contains an *in situ* microfauna with rare *Sphaeroidina bulloides* d'Orbigny, *Planulina foveolata*, *Melonis affinis* and *Globocassidulina subglobosa*, indicative of an outer neritic environment.

Above Bowden shell bed, Section 1 — Samples ER 2642/3a, 3b, 4, 5 have lower abundances of *Amphistegina* spp. ranging from 18 to 3% of the fauna. The species diversity of these samples is much greater than those in or near the Bowden shell bed as shown in Tab. 4. The species diversity in samples ER 2642/3a, 4 and 5 range from 90 to 106 species and the samples have a planktonic percent ranging from 49-60%. The washed residues show a fining upward and probably represent less influx of coarser-grained, nearshore siliciclastics and associated foraminifera. There is also a shift in the three predominant genera reflecting deeper water conditions, as shown in Fig. 6, with outer neritic genera dominant. The depositional environment ranges from deep outer neritic to shallow upper bathyal.

Larger benthic foraminifera — The larger benthic foraminifera are defined, for this paper, as those greater than 10 mesh (2 mm) sieve, herein called the coarse fraction. Table 2 lists the abundances of the larger foraminifera. Sample XJ 002 is not included in this data set. The genera include *Amphistegina*, *Archaias*, *Cyclorbiculina*, *Frondicularia*, *Lenticulina*, *Liebusella*, *Nodosaria*, *Sphaerogypsina* and *Textulariella*. *Lenticulina* is represented mainly by *'Cristellaria' bowdenensis* Cushman, 1919. *Cyclorbiculina* is identical with *'Orbiculina' compressa* d'Orbigny of Cushman (1919). *Amphistegina* is the dominant taxon in samples ER 2642/1, 2 and 6, ranging from 84 to 98% of the coarse fraction. Specimens of *Amphistegina* are normally abraded in the Bowden shell bed. This is in agreement with data from the size fraction less than 10 mesh (see Tab. 1). *Liebusella soldanii* (Jones & Parker) is dominant in samples ER 2642/3a, 3b and 4 ranging from 34 to 76% of the coarse fraction. Sample 3b has the maximum value.

Notes on benthic species — (1) *Amphistegina gibbosa* d'Orbigny: *Amphistegina* has a living depth in tropical waters of 5-20 m (Murray, 1991). It attaches to sea grass, contains symbionts and prefers temperatures of 25-26°C. *Amphistegina* is dominant in samples ER 2642/1, 2, 6 and XJ 002.

(2) *Asterigerina carinata* d'Orbigny: *Asterigerina* is found living free on sand substrates and contains no symbionts. Its living depth range is 13-62 m as reported in Murray (1991). This species is restricted to samples ER 2642/1, 2, 6 and XJ 002, which are either in or just below the Bowden shell bed.

The co-occurrence of these two taxa, in the lower part of Section 1 (including the Bowden shell bed), is compelling evidence suggesting that the sediments containing this microfauna originated in water depths of less than 20 m.

(3) *Ehrenbergina olmeca* Kohl, 1985: this species was originally described from the early Pliocene of Mexico (Kohl, 1985) and occurs in sample ER 2642/5 (Section 1). *Ehrenbergina olmeca* was reported by Kohl (1985) from the Bowden Formation (early Pliocene, Zone N19) at Buff Bay, Jamaica from samples (ER 146/42-44 of Robinson, 1969a). Katz & Miller (1993, fig. 21) erroneously identified it from the Bowden Formation as *Ehrenbergina spinosissima* (Cushman & Jarvis). Their figured specimen, actually *E. olmeca*, is from sample BW244 and equivalent to ER 146/41-42 of Robinson (1969a). Berggren (1993) assigned that sample to the early Pliocene (PL2). In our sample ER 2642/5 there are rare occurrences of both *E. olmeca* and *E. spinosissima* as well as *E. spinea* Cushman.

BOWDEN FORMATION, SUPPLEMENTAL LOCALITIES

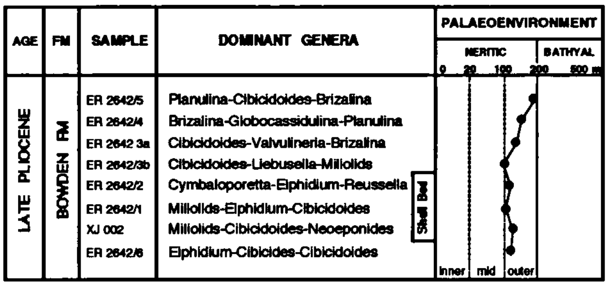
Between Sections 2 and 3 — Sample ER 156 is located between Sections 2 and 3 and offset laterally (see Fig. 1). This area is now covered and was not resampled for this study. At present, without control, it may be equivalent to ER 2642/5. Sample ER 156 was designated by Blow (1969, p. 257) as the holotype for his Zone N-20 and also the type locality for *Globorotalia exilis*. Bolli (1970, p. 596) reported that ER 156 was the only Jamaican sample that he examined where the faunal composition is in disagreement with its stratigraphic position. Bolli further commented that this sample lacked *D. altispira*, which should occur in samples with an age of N-20. Robinson (1969b) reported that his sample ER 156 did not contain *D. altispira*, but he did find rare *Gl. multicamerata*.

We examined two ER 156 equivalent samples (one collected by J.B. Dunlap in 1969 and another collected by A.N. Eva in 1974; see comments at end of paper) and they were compatible with the other samples collected for this study above the Bowden shell bed. The sample collected by Dunlap has common *Gl. miocenica*, few *Gl. exilis* and common *Gn. extremus*. We found no *Gl. multicamerata* or *D. altispira*. There were very rare, reworked *G. nepenthes*. The Eva sample was similar in lithology and microfauna, but had a higher planktonic percent.

There may be some confusion in age assignment of the Bowden Formation because there are rare early Pliocene planktonic foraminifera reworked into late Pliocene sediments at many localities (see Tab. 2). According to Blow (1969), samples from his N-20 Zone should include *D. altispira* and *Gl. multicamerata*. Bolli (1970) and Robinson (1969b) reported rare occurrences of *Gl. multicamerata* in their sample equivalents of ER 156. These may have been reworked specimens. Since our samples do not include either species, we believe that Blow's ER 156 sample may have had rare, reworked early Pliocene forms. Therefore, the age of the ER 156 sample is not Zone N-20, but fits the definition of N-21 of Blow (1969). The numeric ages for the LADs of *Gl. multicamerata* and *D. altispira* are interpreted by Berggren *et al.* (1995a) to be 3.09 Ma. The LAD of *Gl. miocenica* is 2.30 Ma. Sample ER 156 falls in between these two datums and is therefore equivalent to PL5 of Berggren (1973).

The benthic microfauna includes *Gyroidinoides altiformis* (R.E. & K.C. Stewart), *Globobulimina* sp., *Globocassidulina subglobosa*, *Chilostomella czizeki*, *Sphaeroidina bulloides*, *Pullenia bulloides* (d'Orbigny), *Planulina foveolata* and *Quadrimorphina glabra* (Cushman). The palaeoenvironment of both samples is interpreted to be deep outer neritic. This is in general agreement with the palaeoenvironment of other samples studied herein (see Fig. 7).

Sections 3-6 — Additional localities were sampled along the beach between Bowden and Pera Point. These samples are stratigraphically younger than the sediments at Section 1 and include samples ER 2671, 2672, 2673, and 2674. The section numbers coincide with those of Pickerill *et al.* (1998), and are reproduced in Figs 1 and 4. The stratigraphic relationship of sections 3 and 4 is uncertain because covered intervals lie between. The interpreted stratigraphic position of these samples are shown in Fig. 5.



AGE	FM	SAMPLE	DOMINANT GENERA
LATE PLIOCENE	BOWDEN FM	ER 2642/5	Planulina-Cibicidoides-Brizalina
		ER 2642/4	Brizalina-Globocassidulina-Planulina
		ER 2642 3a	Cibicidoides-Valvulineria-Brizalina
		ER 2642/3b	Cibicidoides-Liebusella-Miliolids
		ER 2642/2	Cymbaloporetta-Elphidium-Reussella
		ER 2642/1	Miliolids-Elphidium-Cibicidoides
		XJ 002	Miliolids-Cibicidoides-Neoeponides
		ER 2642/6	Elphidium-Cibicides-Cibicidoides

Fig. 7. Three dominant genera in each sample from the study area with interpreted water depths in the right-hand column, Bowden Formation, Section 1. The water depths are based on the occurrence of deep water species, planktonic percent, dominant genera and benthic species diversity.

Section 3 — Sample ER 2673 is an outer-neritic sample with *Hoeglundina elegans*, *Anomalinoides nucleatus* (Seguenza), *Melonis soldanii* and *Chilostomella czizeki*. Planktonic foraminifera include common *Gl. miocenica*, few *Gl. exilis* and few *Globigerinoides extremus*.

Section 4 — Sample ER 2672 is a deep outer-neritic or shallow upper bathyal sample which has rare occurrences of *Karreriella bradyi* (Cushman), *Anomalinoides nucleatus*, *Hoeglundina elegans* and *Sphaeroidina bulloides*. The planktonic assemblage includes abundant *Gl. miocenica*, rare *Gl. exilis* and *Globigerinoides extremus*. There are very rare, reworked *Globoturborotalita nepenthes* in this sample.

Section 5 — Sample ER 2671, which has a high planktonic percent, is an upper bathyal sample with rare occurrences of *Martinotiella communis* (d'Orbigny), *Alvarezina sinuata* (Akers & Dorman), *Karreriella bradyi* and *Anomalinoides nucleatus*. Planktonic index foraminifera include abundant *Gl. miocenica*, common *Globigerinoides fistulosus* and rare *Gl. exilis*.

Section 6 — Sample ER 2674 represents a middle to outer-neritic environment. Rare *Globocassidulina subglobosa*, *Melonis affinis* and common *Cibicidoides floridanus* (Cushman) are found in this sample. The benthic assemblage differs from that of the above samples in having common *Planulina exorna* (Phleger & Parker) and *Hanzawaia concentrica* (Cushman).

Although this sample was originally designated Bowden Formation, it does not contain the index planktonic foraminifera *Gl. exilis* or *Gl. miocenica* and is therefore interpreted to be much younger than the above samples. The sample contains very rare *Gl. menardii* (sinistral) and very rare, broken *Gl. truncatulinoides* (d'Orbigny). It is therefore interpreted to be equivalent to the *Gl. tosaensis* Zone of Bolli & Premoli-Silva (1973). It may be representative of the Old Pera beds (Manchioneal Formation) of latest Pliocene (see Figs 4, 5).

DOMINANT GENERIC ASSEMBLAGES

Table 6 lists taxa having abundances greater than 6% of the benthic foraminiferal assemblage for the size fraction less than 10 mesh (see Tab. 1a-d for sample occurrences and abundance).

A listing of the three dominant genera for each sample at Section 1 is shown in Fig. 7. The tests of *Amphistegina gibbosa* and *Amphistegina angulata* are generally abraded suggesting that specimens have been transported from a high-energy, nearshore environment downslope. Therefore, the occurrences of *Amphistegina* have been removed and the dominance of *in situ* forms recalculated and used in Fig. 7. This approach is supported by the shallow-water fauna associated with abundant *Amphistegina*. The following taxa are some of the attached species occurring with *Amphistegina* spp.: *Cymbaloporetta squamosa*, *Dyocibicides biserialis*, *Gypsina vesicularis*, *Planorbulinella larvata* and *Sphaerogypsina globulus*. Miliolids are also present and many are abraded. These taxa were probably part of a nearshore, shallow-water assemblage which was transported downslope together with *A. gibbosa* and *A. angulata*. Most of these species are attached forms living on sea grass or rocky substrates.

The benthic foraminiferal assemblages of the Bowden Formation in the study area are very similar to Recent assemblages described by Drooger & Kaasschieter (1958) from the Orinoco-Trinidad-Paria shelf. Shelf facies off the Paria peninsula are dominated by *Cibicidoides-Globocassidulina-Planulina*. Similarly, *Amphistegina* is locally abundant on the Paria shelf and is either transported into deeper water or is a remnant of a low sea-level stand.

PALAEOENVIRONMENT

Palaeoenvironmental interpretation of the benthic fauna was aided by the published work of Murray (1973, 1991), Poag (1981), Drooger & Kaasschieter (1958), Buzas *et al.* (1977), Pflum & Frerichs (1976) and Walton (1964). The palaeoenvironment was determined using the shallow depth limit of the deepest water foraminifera, species diversity, dominant genera and planktonic foraminiferal percent following the procedure outlined by Robinson & Kohl (1978).

The Bowden Formation, which occurs below the Manchioneal Formation, has a palaeo-water depth of upper bathyal (200-600 m) at Buff Bay according to Katz & Miller (1993). In the Bowden area, the palaeoenvironment is interpreted herein to range from shallow outer-neritic to deep outer neritic/upper bathyal (100-250 m). Based on the age of the Bowden Formation in the Buff Bay area (Robinson, 1969a; Berggren, 1993), the north coast exposures are older than the type Bowden Formation in southeast Jamaica (present study). Water depth may be controlled by tectonic movement of different fault blocks and sea level changes.

The Bowden Formation at Bowden was deposited in a shallow to deep outer neritic/upper bathyal environment on a narrow shelf (a water depth of 100-250 m). There is a deepening upward at Section 1 with the uppermost sample (ER 2642/5) representing a water depth of 200-225 m - an outer neritic to upper bathyal palaeoenvironment (see Fig. 7).

The samples from Sections 4 and 5 represent an upper bathyal environment with an interpreted water depth of 225-250 m.

Down-slope transport — The results of the present study support the downslope transport interpretation of other investigators, such as Robinson (1969a) and Pickerill *et al.* (1996, 1998), and their conclusion that a shallow-water (inner neritic) fauna containing molluscs, corals and benthic foraminifera was redeposited in an outer neritic environment.

This study shows that the Bowden shell bed has a dominant, enclosed foraminiferal microfauna representative of an inner neritic palaeoenvironment. The faunal constituents are abraded and represent erosion in a high-energy (nearshore) environment. There is also a mixture of rare, outer neritic benthic foraminifera which are not abraded, indicating that they are probably *in situ*. It is interpreted herein that the sediments of Bowden shell bed, with its enclosed shallow-water (attached) inner neritic microfauna, were displaced into an outer neritic environment where they became lithified.

The dominant taxa in the shell bed are *Amphistegina* and *Asterigerina*, which live in inner neritic habitats. Other genera are attached to substrate or sea grass. Many attached or grazing species listed in Tab. 1a-d are also reported from *Thalassia* beds in water depths of less than 3 m from Discovery Bay, Jamaica by Buzas *et al.* (1977). Wood fragments and leaf impressions from the Bowden shell bed, discussed by Robinson (1969a) and Pickerill *et al.* (1998), as well as land snails (Goodfriend, 1993), support a shallow water origin for the shell bed sediments. Pickerill *et al.* (1996) suggested that the Bowden shell bed was deposited in a deep-water setting based on ichnofossils and Robinson (1969a) stated that the shell bed was deposited in water depths of over 100 m.

SUMMARY AND CONCLUSIONS

The general upward deepening of the palaeo-water depth at Section 1 may be the result of subsidence of a fault block due to tectonism during late Pliocene or sea level rise. Above the regional unconformity, in southeastern Jamaica, the Manchioneal Formation represents a shallowing of water depth (Kohl, 1992), possibly related to sea level changes or uplift of Jamaica during the Pleistocene. Berggren (1993) also recognised a regional unconformity between the Buff Bay Formation and the Bowden Formation on the north coast.

The supplemental localities (Sections 3-5) are dominated by outer neritic to upper bathyal foraminiferal faunas, similar in composition to those described by Drooger & Kaasschieter (1958) from the Trinidad-Paria shelf. Section 6 has a middle neritic fauna, and lacks the planktonic index foraminifera *Gl. miocenica* and *Gl. exilis*. It is therefore the youngest sample examined along the Bowden outcrop area and may be part of the Old Pera beds (Manchioneal Formation).

Blow's Zone N-20 holotype locality (ER 156) actually contains a planktonic foraminiferal assemblage which is representative of the younger Zone N-21 of Blow (1969). The sample lacked the occurrence of *D. altispira* and *Gl. multicamerata* indicative of that Zone. Blow may have incorrectly assigned this sample to an older time interval because he did not recognise that it contained reworked, early Pliocene planktonic foraminifera. Reworked Pliocene and Miocene planktonic foraminifera occur in many samples in the study area.

Shallow water *Amphistegina* faunas have been found displaced into deep-water Pleistocene (Kohl, 1992) and deep-water Miocene sediments (Berggren, 1993). It is generally accepted that inner neritic sediments can move downslope. Coleman (1976) documented the movement of inner neritic sands across the Louisiana shelf, near the Mississippi River Delta, by gravity flow on a slope of less than 2°.

Based on our detailed foraminiferal analysis of the Bowden shell bed and the enclosing sediments, we conclude that: (1) the Bowden shell bed was deposited in an outer neritic environment (100-125 m water depths); (2) a substantial component of the benthic foraminiferal fauna was redeposited from depths of 20 m or less; and (3) the coarse-grained Bowden shell bed was deposited by sediment gravity flows.

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LOCALITIES

The following are outcrop localities of the Bowden Formation used for this study (see Figs 3 and 4 for measured sections and relative positions of the samples).

Section #1, Bowden Formation — Samples (ER 2642/ 1, 2, 3a, 3b, 4, 5 & 6) were collected on February 23, 1996, by E. Robinson from original Bowden shell bed locality of Woodring (1928), equivalent to Unit 2 of Pickerill *et al.* (1998). This is equivalent to the ER 140 locality of Robinson (1969a). Section 1 is exposed in a bluff behind the road on the east side of Port Morant harbour, approximately 500 m northeast of the wharf at Bowden, parish of St Thomas.

Samples (ER 2642/1, 2) were collected from within the Bowden shell bed (Unit 2 of Pickerill *et al.*, 1998). ER 2642/6 was sampled approximately 0.5 m below the base of Unit 2. ER 2642/3a, 3b, are approximately 9 m above Unit 4 of Pickerill *et al.* (1998). ER 2642/4 is approximately 3 m above ER 2642/3a and ER 2642/5 is 1 m above ER 2642/4.

Sample XJ 002 was collected in 1990 by Roger W. Portell of the Florida Museum of Natural History, from the lower portion of the Bowden shell bed (Unit 2). The sample was taken approximately 0.5 m above the base of Unit 2 and is below sample ER 2642/1.

Blow's N-20 type section: between Sections #2 and #3, Bowden Formation — Two samples examined are equivalent to ER 156. One was collected by J.B. Dunlap in November 1969 during an SEPM fieldtrip to the Bowden Formation. Another sample was collected in 1974 by A.N. Eva and is designated 4 TE 208. Blow (1969) reported that ER 156 was collected approximately 10 ft (3 m) above the Bowden shell bed from brown, silty marls exposed behind the sugar store at Bowden wharf (Robinson, 1969a). This locality was not resampled as part of this study because it is presently overgrown.

Supplemental localities: Sections #3-6 — The following samples come from additional short sections collected on June 14, 1996, by E. Robinson. These sections are along the beach southwest of Bowden shell bed locality between Bowden and Old Pera, parish of St Thomas (see Figs 1, 4).

Section #3 Bowden Formation — Sample ER 2673 was taken from a section 2.6 m thick and located 1.375 km southwest of the Bowden shell bed (Section #1). The stratigraphic position of this section is uncertain.

Section #4, Bowden Formation — Sample ER 2672 is from a section 7.9 m thick located 125 m southwest of Section #3. The stratigraphic position of this section is uncertain.

Section #5, Bowden Formation — Sample ER 2671 was sampled from a 5.6 m thick section located 200 m southwest of Section #4. Section #5 is stratigraphically lower than Section #6.

Section #6, Old Pera Beds, Manchioneal Formation ? — Sample ER 2674 was sampled for us by S.F. Mitchell on June 14, 1996 near the middle of a 2 m section located 300 m southwest of Section #5. The sample does not contain *Gl. miocenica* nor *Gl. exilis* and, therefore, may be either the uppermost part of the Bowden Formation or lowermost Manchioneal Formation (equivalent to Zone PL6 of Berggren, 1973). ER 2674 could be above the Bowden Formation/Old Pera beds contact.

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