

Zoning the White Limestone Group of Jamaica using larger foraminiferal genera: a review and proposal

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A scheme of biozones, with at least local application, is proposed for strata of the White Limestone Group of Jamaica, based on larger benthic foraminiferal genera. Four zones, the *Asterocyclina*, *Eulepidina*, *Miogypsina* and *Amphistegina* zones, extend through the Eocene, Oligocene, Lower Miocene, and Middle Miocene and higher horizons, respectively. The *Asterocyclina* Zone is divided into four subzones, three of Middle Eocene and one of Late Eocene age. The lowest of these includes strata of the Yellow Limestone Group, but only doubtfully of the White Limestone Group in central Jamaica. The *Eulepidina* Zone is divided into three subzones, the *Miogypsina* Zone into two. The *Amphistegina* Zone contains one subzone, the *Nummulites* Subzone, which extends through the upper part of the White Limestone Group. The higher part of the *Amphistegina* Zone is not divided. Further subdivision within some subzones is indicated, but not formalised. Correlation of the zones and subzones with larger foraminiferal genera of the platform interior still presents problems for Oligocene and Miocene horizons. Assemblages containing *Praerhapydionina delicata* are assigned to the Oligocene. Those with archaiaasinids, resembling *A. kirkukensis*, are found near the Oligo-Miocene boundary, and may span the stratigraphic interval marked by the occurrence of *Heterostegina* (*Vlerkina*) *antillea*. The '*Amphisorus matleyi*' fauna of earlier workers appears to be wholly of Miocene age.

KEY WORDS: Biozone, foraminifera, Eocene, Oligocene, Miocene.

'The white limestone of Jamaica appears to have been deposited slowly and steadily in the bed of a tranquil sea, during the period known to geologists as the miocene' (Arthur Lennox, in Sawkins, 1869, p. 149).

Introduction

More or less pure carbonates of the White Limestone Group outcrop over greater than half the surface of the Caribbean island of Jamaica (Figure 1). The name was first used by De la Beche (1827) to describe all the Tertiary limestones of the island. Later workers (Sawkins, 1869; Hill, 1899) have generally restricted the term to include the nearly pure, Middle Tertiary carbonates which, over most of Jamaica, overlie the Middle Eocene Yellow Limestone Group. In the John Crow Mountains of eastern Jamaica (Figure 2), carbonates lithologically indistinguishable from much of the White Limestone elsewhere include horizons dated as early as Late Paleocene (Robinson, 1997b).

Matley (1925) was the first to attempt to zone the White Limestone, using larger foraminifera (Table 1). He suggested an age range for the unit extending from the Late Eocene to Miocene, based on material identified by Vaughan (1928a, b, 1929). Matley sent additional samples from the Kingston district to Davies, who established, beyond doubt, a Middle Eocene age for much of the lowest part of the White Limestone (Davies, 1952). Hose & Versey (1957) developed a more com-

prehensive zonal scheme (Table 1), and also attempted a subdivision of the White Limestone into a number of smaller lithological units, based on microfacies analyses of the limestones (Figure 3). Although these, and others later erected by Robinson (1969) and Steineck (1974, 1981) as members of the White Limestone Formation, have frequently been given formational status (e.g., Wright, 1974; Robinson, 1988), their recognition is mainly based on a combination of lithostratigraphic and biostratigraphic criteria. They are not lithostratigraphic units in the strict sense of the definition (North American Commission on Stratigraphic Nomenclature, 1983). Until the lithostratigraphic and cyclostratigraphic relationships of these units have been investigated in more detail, the names are here used informally. Nevertheless, the names are well entrenched in the literature (Zans *et al.*, 1963; Wright, 1974; Eva & McFarlane, 1985) and mapping of some of the units has been successful over parts of central Jamaica (McFarlane, 1977b).

The proposal in this paper to define a new series of biozones based on larger benthic foraminifera, accompanies a proposed revision of the lithostratigraphy of the White Limestone Group by Mitchell (2004).

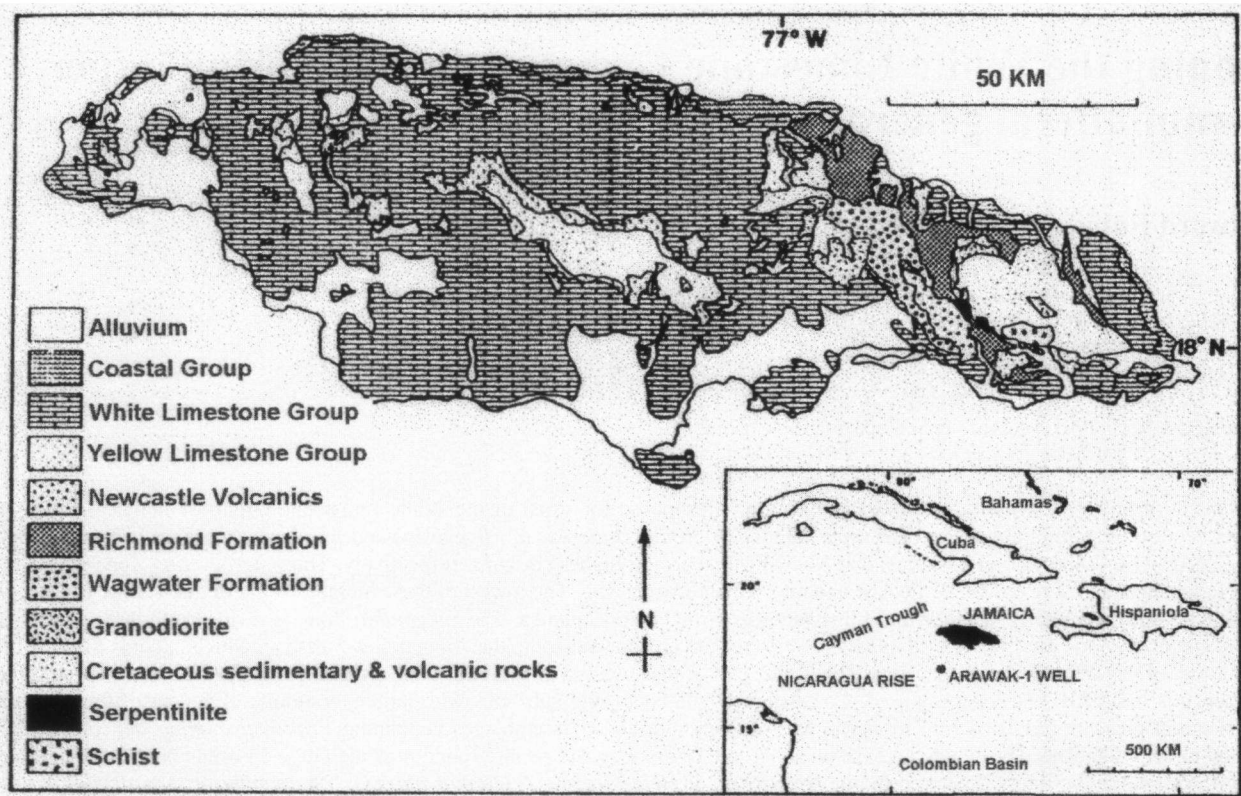


Figure 1. Simplified geological map of Jamaica, modified from Robinson (1994).

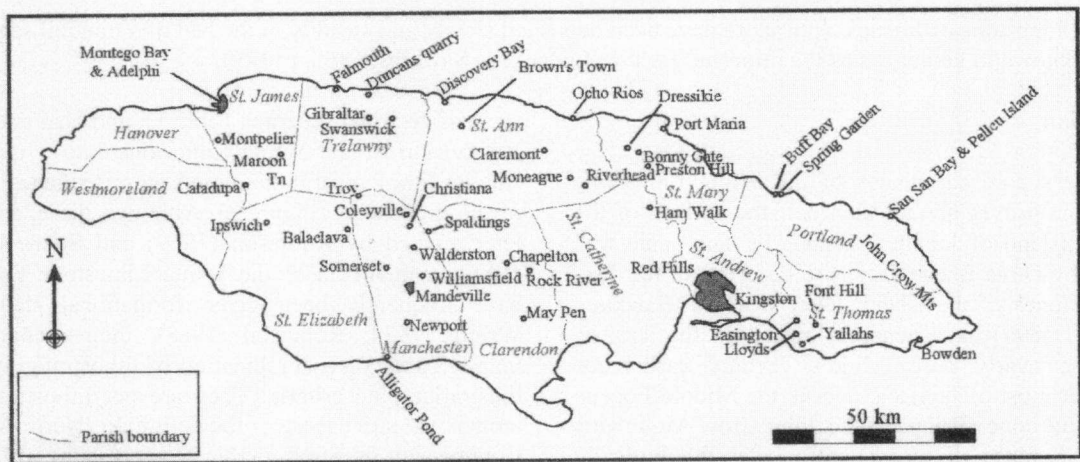


Figure 2. Location map of Jamaica, modified from Mitchell (2004).

The zonation is a revision of Robinson & Wright (1993) and modification of previous proposals (Table 1) that extended into the Neogene. A zonation based primarily on foraminiferal genera is used because, while specific characters are frequently difficult to distinguish in accidental thin sections of hard limestone (with important exceptions), generic traits are more readily recognised. The zones as proposed herein are defined as interval

zones, but, because they are not tied securely to a large number of measured sections, they are not true biozones and they share many conceptual properties with the East Indian Letter Stages (Adams, 1970, 1984). They lack the precision of the European Shallow Benthic Zones (SBZs) of Serra-Kiel *et al.* (1998) as they are not tied to a cyclostratigraphy and are relatively firmly based on evolving species groups only for the Eocene.

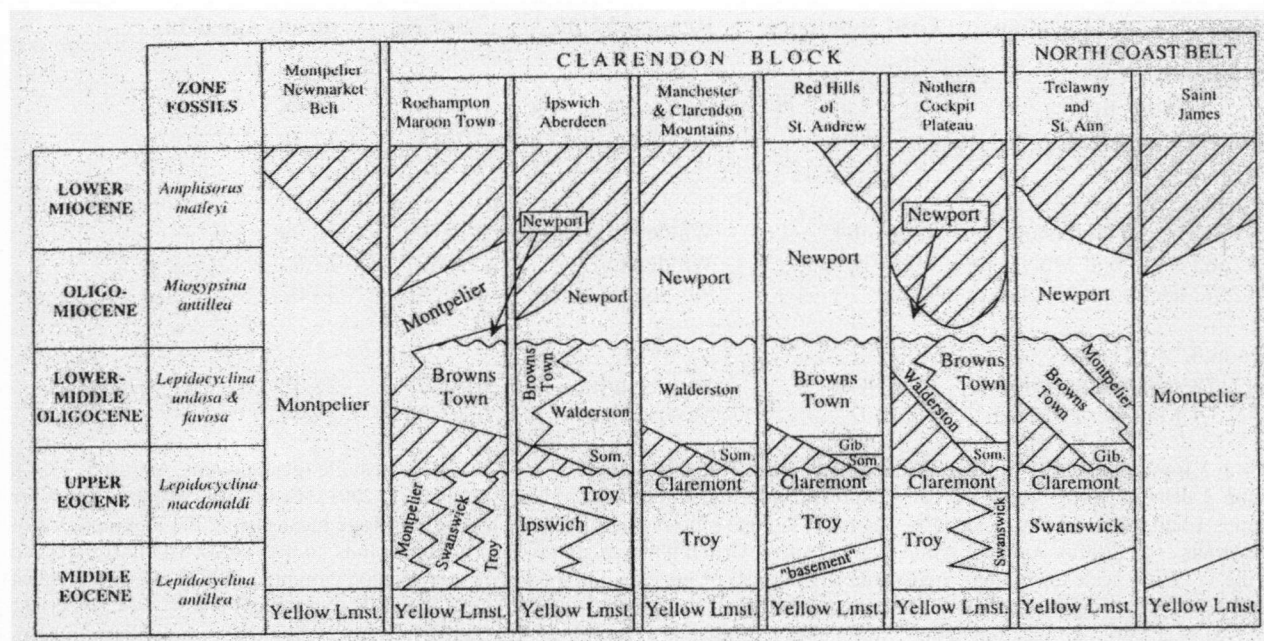


Figure 3. White Limestone stratigraphy and larger benthic foraminiferal zonation of Versey (in Zans *et al.*, 1963) [from Robinson & Mitchell (1999)].

Lower Miocene	M2 - M4, M5?		Miogypsina	Lepidocyclus	Miogypsina antillea	Beds with Amphisorus Archais Sorites Peneroplis Heterostegina Miogypsina	Amphisorus zone
Lower Miocene	M1 - M2			Heterostegina (Vierkina)			
Upper Oligocene	P21-P22	NP24 - NP25	Eulepidina	Heterostegina (Vierkina)- Miogypsina	L. undosa - L. favosa	Beds with Lepidocyclus Coskinolina Fabularia	Lepidocyclus zone large species subzone
Upper Oligocene	P21	NP24		Heterostegina (Vierkina)- Neorotalia			
Lower Oligocene	P18 - P20			Nephrolepidina-Neorotalia			
Upper Eocene		NP21 - NP18	Asterocyclus	Lepidocyclus-Heterostegina ocalana	Lepidocyclus macdonaldi		Lepidocyclus zone small species subzone
Middle Eocene		NP17 - NP16?		Lepidocyclus-Yaberinella			
	P12	NP16		Eulinderina-Polyepidina	Lepidocyclus antillea	Beds with Dictyoconus Borelis Yaberinella	Dictyoconus zone
	P11 - P10	NP15 - NP14B		Helicostegina-Nummulites			

Table 1. Zonation of the White Limestone Group, based on larger shallow benthic foraminifera and comparison with previous Jamaican zonal schemes.

Sample No. and Location	Grid Reference	Reported Unit	⁸⁷ Sr/ ⁸⁶ Sr	means Age (Ma)
Group 1.				
Reef block in chalk	39855550	Browns Town Ls	0.70831	22.86
<i>In situ</i> reef at Tobolski	41855344	Browns Town Ls	0.70833	22.30
Group 2.				
ER2566 near Walderston	38064464	Walderston Ls	0.70790	32.09
ER2585 section at Mocho	43154189	Walderston Ls	0.70807	27.84
ER2572 section at Mocho	42944238	top Somerset Ls	0.70785	33.02
Group 3.				
ER3128 near Walderston	38124472	Walderston Ls	0.70805	28.32
TSN 3.1 Manchester Parish	38644012	Newport Ls	0.70823	24.44

Group 1 from Land (1991); group 2 determined by P.A. Mueller, University of Florida, Gainesville (pers. comm., August 5, 1997); group 3 determined by Adina Paytan, Stanford University, California (comm., October 31, 2001). Error limits were reported for groups 1 and 3 but are not included in this table. Isotope ratio means have been converted to age means using the look-up table of McArthur *et al.* (2001). Ages for group 2 are tentative. Grid references are given in Imperial Units, to the nearest 100 ft. (referenced to the 1: 12,500 scale topographic map series of Jamaica). Conversion to the metric grid used on current 1: 50,000 maps of Jamaica can be derived, using the formulas X (Eastings) metric = $(X \text{ imperial} \cdot 0.3048) + 82,360$; Y (Northings) metric = $(Y \text{ imperial} \cdot 0.3048) + 28,080$. No biostratigraphic information is available for group 1. Associated faunas for group 2 were published in Robinson & Mitchell (1999, figs 7, 8). Sr isotope determinations for group 3 were carried out on *Kuphus* linings. Associated larger foraminiferal faunas are given in the text.

Table 2. ⁸⁷Sr/⁸⁶Sr determinations for some White Limestone samples from Jamaica

They are also subject to the limitations imposed by facies variations within the White Limestone Group (Versey in Zans *et al.*, 1963). Over wide areas of the island rocks assigned to a proposed zone may lack the index taxa, but contain taxa that elsewhere are associated with the indices. These variations in assemblages are comparatively well understood for the Eocene, but less so for the Oligocene and Miocene.

The larger foraminiferal biostratigraphy of the White Limestone Group cannot be considered in isolation from that of the Yellow Limestone Group. The assemblages of the lowest two subzones of Table 1 are found in strata assigned, in different places, to both the Yellow Limestone and the White Limestone, indicating contemporaneous deposition of these lithic units during the lower Middle Eocene (Versey in Zans *et al.*, 1963; Wright, 1966).

Some of the white limestones of the John Crow Mountains (Figure 2) have yielded planktonic foraminifera indicative of the Upper Palaeocene (Robinson, 1997b). Larger foraminifera have been identified at several localities, but the stratigraphy is still obscure, as the region is difficult of access and has not been mapped. Available data have accumulated slowly from spot sampling on a reconnaissance basis. Larger benthic assemblages recovered include samples with *Ranikothalia catenula* Cushman & Jarvis, *Neodiscocyclina* sp. cf. *N. weaveri* Vaughan, *Hexagonocyclina* spp. and dictyocoids, suggesting a Late Palaeocene to possibly Early Eocene age (Jiang & Robinson, 1987). The present paper excludes consideration of the stratigraphy of the limestones of the John Crow Mountains as well as that of post-White Limestone Group formations.

A section containing definitions (or redefinitions) and a review of some index taxa (Appendix 1) as used in the present paper is included at the end of the paper. The names of the various species mentioned in the text and in Figure 4 are listed alphabetically by species in Appendix 1, with authors and year of publication, together with one or more useful figured references.

While the main emphasis in this paper is on the biostratigraphic utility of the larger foraminifera, the status of work on planktonic foraminiferal and calcareous nannofossil biostratigraphy is summarised below.

Planktonic and smaller benthic foraminifera

Robinson (1967, 1969) outlined a partial correlation of the larger foraminiferal assemblages and the limestone units erected by Hose & Versey (1957) with the standard planktonic foraminiferal zonation of that time (Bolli, 1966; Banner & Blow, 1965). Correlation of the White Limestone with the standard planktonic zones was further elaborated by Steineck (1974, 1981), who showed that, in the deeper-water marine units of the Montpelier Formation and its divisions, the entire sequence of planktonic foraminiferal zones was probably represented. No attempt was made by him to correlate the planktonic foraminiferal zonation with the larger shallow benthic foraminiferal assemblages. Berggren (1993) provided planktonic foraminiferal data indicating the top of the White Limestone Group at Buff Bay to be at approximately 11.5 Ma, correlating with the N14 zone of Blow (1969; latest Middle Miocene).

EPOCHS	STAGES	ASSEMBLAGE II TAXA		ASSEMBLAGE I TAXA		Ratios
		AGE	CAUCH- RECH- MAO- ONIC FORAM ZONES	PLANT ZONES		
MID MIOCENE	SERRA- VALLAN	11	Ma	N15		6/8738
		12	N16			
		13	N17			
		14	N18			
		15	N19			
LOWER MIOCENE	BURDIGALIAN	16	N20			
		17	N21			
		18	N22			
		19	N23			
		20	N24			
OLIGOCENE	CHATTIAN	21	N25			0.80833
		22	N26			0.80833
		23	N27			0.70807
		24	N28			0.70805
		25	N29			
Eocene	RUPELIAN	26	N30			
		27	N31			
		28	N32			
		29	N33			
		30	N34			
Eocene	PRIBOLIAN	31	N35			
		32	N36			
		33	N37			
		34	N38			
		35	N39			
Eocene	BARTONIAN	36	N40			
		37	N41			
		38	N42			
		39	N43			
		40	N44			
Eocene	LUTETIAN	41	N45			
		42	N46			
		43	N47			
		44	N48			
		45	N49			
Eocene	YPRSIAN	46	N50			
		47	N51			
Eocene	YPRSIAN	48	N52			
		49	N53			

Figure 4. Stratigraphic distribution of some Middle Cainozoic, larger shallow-water benthic foraminiferal taxa from the central Caribbean region (Jamaica and the Nicaragua Rise). The taxa are divided into two assemblages. Assemblage I contains taxa that are more or less widespread over the tropical Western Hemisphere; Assemblage II includes forms restricted to carbonate platform and shelf palaeoenvironments. Many are apparently endemic to the Nicaragua Rise (Robinson, 1993). Key: solid squares = known occurrences; open squares = occurrences with poor stratigraphic control; question marks = possible occurrences; [1] = apparently endemic to the Nicaragua Rise; [2] also reported from Cuba and Hispaniola (*Pellatispirella* is also recorded from southern Mexico); [3] also reported from Panama; [4] also reported from Panama, Costa Rica and Oman (Middle East; Adams & Racey, 1992); [5] open squares in upper part of ranges based on occurrences in the Greater Antilles, but not yet recorded from Jamaica; [6] reported throughout the Tethyan-Indo Pacific region, but not from the Western Hemisphere except Jamaica; [7] reported from elsewhere in the New World, but not from the Old World. Taxa without numbers are cosmopolitan, at least at the generic level, or have not been examined in detail. Time scale (Ma) and Paleogene planktonic foraminiferal zones after Berggren *et al.* (1995). Neogene planktonic foraminiferal zones after Blow (1969) and Berggren *et al.* (1995). Calcareous nannofossil zonation after Martini (1971). $^{87}\text{Sr}/^{86}\text{Sr}$ stratigraphic positions are approximate (see Table 2 for details), as are the boundaries (broken lines) between the zones.

However, in southwestern Jamaica significantly younger ages for strata assigned to the Newport member of the White Limestone were reported by W.H. Blow (*in* Wright, 1971). Katz & Miller (1993) described the smaller benthic foraminifera from Buff Bay. Their data suggested that substantial shallowing of that region occurred between about 8 and 4 Ma, from lower bathyal (1,300-2,000 m) to upper bathyal (200-500 m) depths, in broad agreement with the conclusions of Steineck (1981) and Robertson (1998).

Calcareous nannofossils

Information on the calcareous nannofossil content of the older parts of the White Limestone is largely unpublished, except for two assemblages of NP 16 zone age, reported by Robinson & Jiang (1990) for the White Limestone of the Buff Bay area. A paper detailing calcareous nannofossil data from a number of Palaeogene localities is being published elsewhere (M. Jiang, pers. comm.). Summary data from this work have been used in the present paper in the construction of the tables and Figure 4.

Aubry (1993) included information on the calcareous nannofossil biostratigraphy of the upper part of the Montpelier Formation at Buff Bay in her discussion of the Buff Bay Formation and other formations of the Coastal Group. The top of the White Limestone there correlates with the NN8 zone of Martini (1971; latest Middle Miocene).

Strontium isotope data

Strontium isotope data are available from three sources, but there is scope for much further documentation. Land (1991) carried out an investigation of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for spot samples from the upper part of the Brown's Town limestone, Montpelier Formation and Coastal Group near Discovery Bay (Figure 2). Thirteen of his determinations were made on samples from the White Limestone Group. Unfortunately, no biostratigraphic data

were given for these localities. Three determinations were made by Paul Mueller, University of Florida (Gainesville), for samples collected from the Walderston limestone of south central Jamaica (Robinson & Mitchell, 1999; Robinson, 2003). In the present paper two more determinations, provided by Adina Paytan of Stanford University, are listed (Table 2).

Larger foraminiferal zones

Since the work of Hose & Versey (1957), zonal schemes based on larger benthic foraminifera have been proposed by Robinson (1976, 1993) for Paleogene rocks deposited on the Clarendon Block. Robinson & Mitchell (1999, p. 22) introduced a list of eleven assemblages of larger foraminifera characteristic of the interval late Early Eocene to Early Oligocene. Of these, Assemblages 4 to 11 are found in the White Limestone Group. In the present paper, ten subzones are defined within four main biozones. In some cases it is possible to distinguish smaller biostratigraphic intervals within the subzones, but these have not been formalised. The proposed zones and subzones are listed and correlated with planktonic foraminiferal and calcareous nannofossil zones in Table 1.

Although the indices used in the proposed zonation are mainly genera that are characteristic of shelf edge environments in Jamaica (Versey, 1957a; Versey *in* Zans *et al.*, 1963), there is considerable variation in assemblage composition from place to place. Most of the index genera used herein commonly occur in turbidites introduced into the deeper marine environments of the Montpelier Formation. They are more frequently associated with planktonic foraminifera and calcareous nannofossils, and they include genera that have been used elsewhere in the Caribbean (see below). However, they may be rare or absent in the back reef and platform interior. Instead, index species defined for the Eocene zonation of the platform interior of the Nicaragua Rise (Robinson, 1993) may be used. The relationship between the two zonal schemes is shown in Table 3, and is elaborated in the comments for each zone and in the section on biofacies.

AGE	CENTRAL JAMAICA ZONES (Robinson, 1993)	INNER SHELF/PLATFORM	SHELF EDGE	UPPER SLOPE	LARGER FORAMINIFERAL ZONES	LARGER FORAMINIFERAL SUBZONES
Middle Miocene	Not zoned	Archaeasainids, sortids; Misorites americanus group; Archais? of A. kirkukensis near the base and in the top of the previous zone	Nummulites cojmarensis, Amphistegina spp.	Nummulites, Amphistegina	Amphistegina	Nummulites
Lower Miocene			Miogypina, Nummulites of cojmarensis, Amphistegina spp.	Nummulites, Amphistegina	Miogypina	Lepidocyclina
Lower Miocene			Miogypina, Heterostegina (Verkina) antilles, Spirochypus bullbrooki, Lepidocyclina caneliei, Eulepidina spp. (rare), Nummulites of N. panamensis	Lepidocyclina, Spirochypus, Heterostegina		Heterostegina (Verkina)
Upper Oligocene			Miogypina bermudezi, Heterostegina (Verkina) antilles, Lepidocyclina spp., Nephrolepidina spp., Eulepidina spp.	Heterostegina, Lepidocyclina, Eulepidina	Eulepidina	Heterostegina (Verkina)-Miogypina
Upper Oligocene	ZONE 5 Peneroplis spp. - Praerhapydionina delicata	Archaeasainids, Praerhapydionina, Borelis (rare), Archais of A. americanus	Lepidocyclina spp., Nephrolepidina spp., Eulepidina spp., Heterostegina (Verkina) antilles, Neorotalia mexicana	Nephrolepidina, Eulepidina		Heterostegina (Verkina)-Neorotalia
Lower Oligocene		Fallotella cooki, peneroplis	Nephrolepidina ymaguensis, Eulepidina undosa, Haliyardia bikiniensis, Neorotalia mexicana	Nephrolepidina, Eulepidina		Nephrolepidina-Neorotalia
Upper Eocene	ZONE 4 Fabularia verseyi - Fallotella cooki ZONE 3 Fabularia verseyi - Cushmania americana	Fallotella cooki, Fabularia verseyi, Pseudochrysalidina, Cyrtobulcinoides, Peltatispirilla Cushmani (lower part)	F. verseyi, F. hanzawai, Eulepidina chaperti, Nummulites striatoreticulatus, N. spp. Nephrolepidina? subglobosa, Lepidocyclina of L. macdonaldi, Fabiania	Asterocyclina, pseudophragminids, Nummulites floridensis gr., Nephrolepidina, Eulepidina, Heterostegina	Asterocyclina	Lepidocyclina-Heterostegina ocalina
Middle Eocene	ZONE 2B Fabularia vaughani - Yaberinella jamaicensis	Cushmania spp., Fabularia gunteri gr., Yaberinella jamaicensis, Peltatispirilla	Lepidocyclina macdonaldi, Pileolepidina of panamensis (top part), Fabiania, Nummulites wilcox	Asterocyclina, pseudophragminids, Nummulites floridensis gr., lepidocyclinids		Lepidocyclina-Yaberinella
	ZONE 2A Fabularia vaughani - Peltatispirilla matveyi	Cushmania and other conicals, Fabularia gunteri gr., Yaberinella hottingeri/ trelawmensis and spp., Peltatispirilla	Polyepidina chiapensis (top part), Eulindina subplana, E. antilles, Nummulites of vanderstoki, Lepidocyclina peruviana gr., Fabiania	Asterocyclina, pseudophragminids, Nummulites floridensis gr.		Eulindina-Polyepidina
	ZONE 1?	The Stettin Fm. Fauna: Helicolepidinoides gyralls, Verseyella, Cokinolina zansli, (may be slightly older)	Helicostegina dimorpha, Nummulites guayabalensis, Pseudolepidina	Asterocyclina, pseudophragminids, Nummulites floridensis gr.		Helicostegina-Nummulites

Table 3. Typical facies assemblages of larger foraminifera for each larger foraminiferal zone and subzone of the White Limestone Group.

Thus, for the Eocene, the zones of this paper may be regarded as composite or concurrent range zones (Serra-Kiel *et al.*, 1998), using both mutually exclusive and co-occurring assemblages, based on evolving species groups, particularly the lepidocyclines, *Yaberinella* and *Fabularia*. This relationship is shown in a preliminary distribution chart of some larger benthic foraminiferal species for the interval embracing the White Limestone Group (Figure 4). This is based on occurrences in Jamaica, together with unpublished data from offshore wells on the Nicaragua Rise, and correlation with selected areas in adjacent parts of the north and central Caribbean region, as discussed in the text.

Previous larger foraminiferal zonal schemes proposed in the Caribbean region include those of Cole (1964, 1967), Cole & Applin (1964) and Butterlin (1981) for the Caribbean generally, Gravell & Hanna (1938) and Applin & Jordan (1945) for the Gulf Coast of the United States, and Blanco-Bustamante *et al.* (1987) for Cuba. Larger foraminiferal range charts have been published for the Americas generally (Butterlin, 1981), Cuba (e.g., Beckmann, 1958; Seiglie, 1965), Trinidad (Caudri, 1975, 1996), Jamaica (Robinson, 1969; Robinson & Wright, 1993) and southern Mexico (Frost & Langenheim, 1974). Differences between the schemes, especially in the Eocene, are partly a reflection of the different larger foraminiferal provinces represented. Jamaica belongs to a distinct province, centred on the Nicaragua Rise, and a number of species are endemic to that region

(Robinson, 1993). This is the only accessible province in the Americas where extensive platform carbonate assemblages evolved in the Eocene and Oligocene in a truly tropical setting (Acton *et al.*, 2000; Robinson, 2003). The Aves Ridge may also fall into this category, but has been probed only superficially (Bouysse *et al.*, 1985; Holcombe *et al.*, 1990).

Asterocyclina Zone

Definition — The zone is defined by the total range of *Asterocyclina*. The base of the zone lies below the base of the White Limestone Group as discussed here, probably within the Lower Eocene. The top of the zone coincides with the last occurrence of *Asterocyclina*. Other orthophragmine genera, notably species of pseudophragmines (*sensu lato*; see Appendix 1) are common companions of *Asterocyclina*, and may dominate assemblages of the shelf edge and upper slope (e.g., Eva, 1976). Four subzones are recognized within this zone (Table 1). In addition, there is an as yet undefined interval below the base of the lowest of these subzones, containing assemblages of orthophragmines, *Amphistegina* spp. and *Eoconuloides* spp., but lacking nummulitids. This lies below the base of the White Limestone Group and is not further considered herein. Zones C and D of Butterlin (1981) are equivalent to the *Asterocyclina* Zone.

Comments — Other genera occurring throughout rocks of this zone include the imperforate conical dictyocoids, such as *Fallotella*, and species of *Fabularia* and *Fabiania*. *Pellatispirella* is abundant in some biofacies of the platform, above the *Helicostegina*-*Nummulites* Subzone.

Age — In Cuba, the first appearance of *Asterocyclina* lies in strata of Early Eocene age (Beckmann, 1958). In Jamaica, the lower range of the index genus is poorly defined, but extends, at least, to the base of the Middle Eocene. The lowest occurrences associated with planktonics are with P9 zone (and, perhaps, P8 zone) planktic foraminiferal assemblages and with calcareous nanofossils of the NP14 zone (Robinson & Mitchell, 1999), but strata below this horizon have not been investigated in any detail. The top of the zone is taken here as corresponding to the top of the Eocene, Priabonian stage (Setiawan, 1983; Brinkhuis & Visscher, 1995). The highest assemblages with *Asterocyclina* seen in the Jamaican section are in sedimentary rocks of the Montpelier Formation containing lower NP 21 calcareous nanofossil assemblages (M. Jiang, pers. comm.). *Asterocyclina* and *Pseudophragmina*, as well as many other common Eocene genera, become extinct globally at this horizon (Adams *et al.*, 1986).

***Helicostegina*-*Nummulites* Subzone**

Definition — This subzone is defined as the interval between the first appearance of *Nummulites* (*sensu lato*) in the Jamaican succession (see Appendix 1) and the first appearance of *Eulinderina* spp., which more or less coincides with the disappearance of *Helicostegina dimorpha* and *Helicolepidinoides gyralis* (Caudri, 1975, p. 567). *Gunteria floridana* extends up into this zone from lower strata, but has not been recorded from higher horizons.

Typical localities — The lower part of the Preston Hill marls (Font Hill Formation of the Yellow Limestone Group; Figures 1, 2), e.g. at ER3080 (M. Jiang, pers. comm.), in marls overlying the Rio Sambre exposures (Robinson & Mitchell, 1999), representative of the shelf edge and upper slope assemblages. ER1315, the type locality for the imperforate foraminiferal zone 1 of Robinson (1976; Robinson & Mitchell, 1999, p. 5), may be taken as typical of the platform. Both localities are in the Yellow Limestone Group. Other localities are in the quarry at the foot of Swanswick Hill (Cole, 1956a; Robinson & Mitchell, 1999, stop 3, p. 31), and along the lowest part of the driveway leading up to Swanswick House (e.g., at ER3022; see Figure 5a).

Comments — The overlap in the ranges of *Helicostegina* and *Nummulites*, exemplified by *H. dimorpha*, *Helicolepidinoides gyralis* and *Nummulites guayabalensis*, is

typical for this subzone. This association is seen in strata belonging to the Yellow Limestone Group in central and eastern Jamaica, together with such forms as *Gunteria floridana*, *Nummulites* sp. cf. *N. floridensis* and *Pseudophragmina* spp. In central Jamaica, *H. gyralis* is associated with imperforate taxa such as *Coskinolina zansi*, *Verseyella jamaicensis* and peneroplids in the Stettin Limestone (Robinson, 1993). Nummulitids are lacking in the Stettin Limestone. This may be due to facies differences or this unit may be somewhat older than the nummulitic facies further east and north. The assemblage has not been recorded from the White Limestone, except from the disused quarry at the foot of Swanswick Hill, where rare *H. sp.* cf. *H. gyralis* is associated with abundant *N. guayabalensis* and common *Pseudolepidina trimera* (Figure 5a). The strata at this location have been included in the lower part of the Swanswick limestone, at least by inference, by Hose & Versey (1957), who mentioned *Linderina floridensis*, a foraminifer occurring in the quarry, as being characteristic of their lower Swanswick Limestone. Here the Swanswick quarry rocks are regarded as part of the Yellow Limestone Group. Wright (1966) regarded strata of the lower Swanswick limestone as correlative of the Chapelton Formation of the Yellow Limestone Group.

Age — Assemblages containing the index genera are associated, in the Preston Hill marls, with calcareous nanofossils belonging to the NP 14b and NP 15 zones, early Middle Eocene (M. Jiang, pers. comm.).

***Eulinderina*-*Polylepidina* Subzone**

Definition — The subzone is defined as the interval between the first appearance of *Eulinderina* spp. and the first appearance of *Lepidocyclina* of the *L. ariana*-*L. macdonaldi* group (Y *Lepidocyclina* lineage of Grimsdale, 1959; see section on definitions of taxa below). It corresponds to the *Lepidocyclina antillea* zone of Hose & Versey (1957) and to the Larger Benthic Assemblages 3 and 4 of Robinson & Mitchell (1999). In random thin sections it is commonly difficult to separate *Eulinderina* from *Polylepidina*, but with equatorially and axially oriented sections passing through the nucleus, and with free specimens, it is possible to recognise two divisions in this subzone, an upper one characterised by *Polylepidina chiapasensis* and/or *P. gardnerae*, and a lower division distinguished by species of *Eulinderina* (Robinson & Jiang, 1995).

Typical localities — Most records of the subzonal markers in Jamaica are from rocks belonging to the Yellow Limestone Group. Key localities containing shelf edge assemblages are in the upper part of the Preston Hill marls (Figure 2), as at ER161 at Preston Hill (Robinson, 1996b) and Grants Town (Robinson & Mitchell, 1999, stop 1, p. 35).

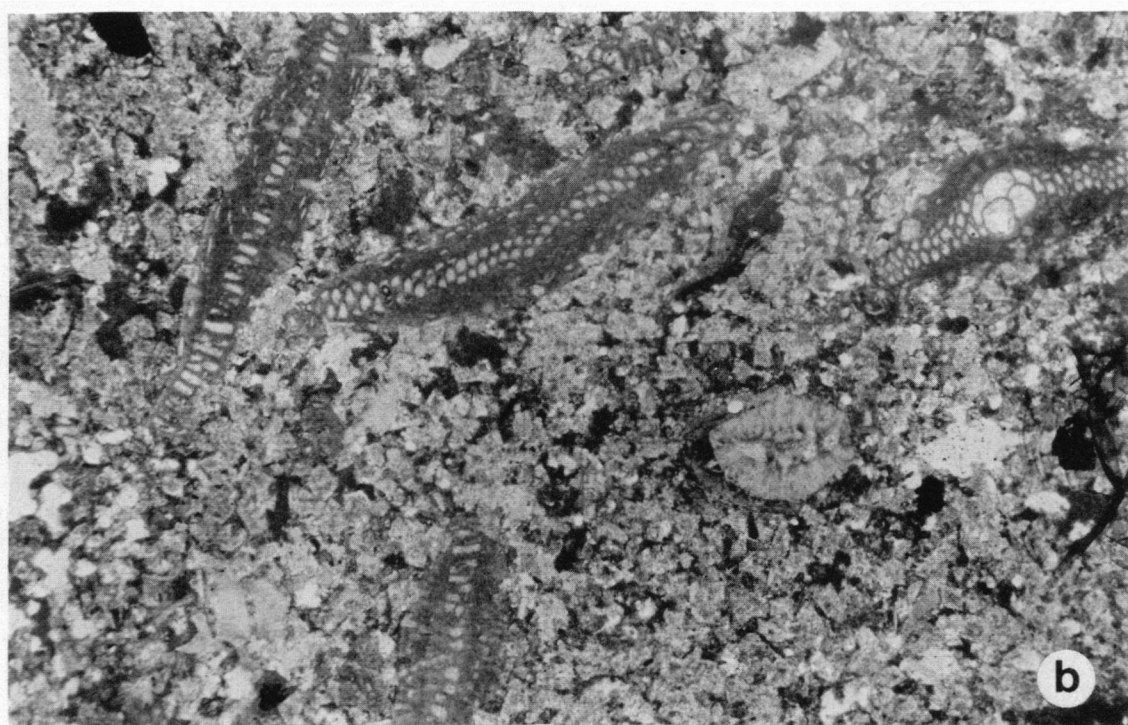


Figure 5.

A - Locality ER3022, bottom of driveway up to Swanswick House, parish of Trelawny, limestone with *Helicolepidinoides?* sp. and *Pseudolepidina trimera* (arrowed), x 20.

B - Locality ER670, Sherwood Content, parish of Trelawny, from lower part of the Swanswick limestone, with *Polylepidina* sp. and *Amphistegina parvula*, x 20.

Assemblages representative of the back-reef and platform interior with mixed eulinderine and imperforate species occur in the Yellow Limestone Group at Albert Town (Robinson, 1996b; Robinson & Mitchell, 1999, stops 2A and 2B, p. 30, fig. 7) and Dump (Robinson & Mitchell, 1999, stop 5, p. 27), and the lower part of the Swanswick limestone (White Limestone Group) as at Sherwood Content (type locality for *Lepidocyclina sherwoodensis* and *Yaberinella trelawniensis*; Vaughan, 1928a, 1929). The Sherwood Content assemblages also contain *Polylepidina chiapasensis* and *Amphistegina parvula* (Figure 5b). Many other localities have been recorded (e.g., Hose & Versey, 1957; Robinson, 1969; Wright, 1974; Eva, 1976; Eva & McFarlane, 1985). They have also been reported from the lower part of the Ipswich limestone by Versey (1957b) and personal observation.

Comments — Other taxa in this subzone include *Fabiania cubensis* (Cole & Bermudez), *Nummulites vanderstoki*, pseudophragmines, *Cushmania americana*, and lepidocyclines of the *L. peruviana* and *L. pustulosa* groups (see section on definitions of taxa below). In the more interior regions of the shelf, *Yaberinella* spp. with relatively small proloculi (such as *Y. hottingeri*, *Y. trelawniensis*), *Pellatispirella matleyi*, *Coskinolina christianaensis* and the *Fabularia gunteri* group, may be common to abundant.

Age — Both divisions are associated with NP16 calcareous nannofossil assemblages in the Gulf Coastal states of North America and in Jamaica, and *Eulinderina antillea* occurs with the P12 planktonic foraminiferal assemblage in Jamaica (Robinson, 1996b).

***Lepidocyclina-Yaberinella* Subzone**

Definition — The base of this subzone is marked by the first appearance of *Lepidocyclina* of the *L. ariana/L. macdonaldi* group. The top of the interval is defined by the last appearance of the genus *Yaberinella*. In this subzone *Yaberinella* normally possesses a relatively large proloculus (*Y. jamaicensis*). Assemblages 5 to 7 of Robinson & Mitchell (1999) correspond to this subzone.

Typical localities — Assemblages belonging to this subzone are characteristic of the upper part of the Ipswich and Swanswick limestones of Hose & Versey (1957) and Versey (1957b); in the upper part of the Ipswich limestone at Ipswich (e.g., ER647; Figure 6a) and Maggoty (Robinson & Mitchell, 1999, p. 29, stop 1); in the Swanswick limestone (Figure 2) in the upper part of the driveway to Swanswick House. The more interior parts of the platform contain assemblages rich in *Fabularia*, *Cushmania* and *Yaberinella jamaicensis* represented by the type locality for Zone 2 of Robinson (1976), Matley J503M, Gentle Hill at 1100 ft. descent, St

Elizabeth-Manchester parish boundary. Probably the highest part of the Chapelton Formation at the western end of the Central Inlier also belongs to this subzone (Robinson & Mitchell, 1999, stops 6A, 6B, p. 28).

Comments — Although the top of this subzone is defined by the disappearance of *Yaberinella*, the occurrence of this genus is strongly controlled by facies variations. At the shelf edge, *Yaberinella* is rare or absent. In orbitoidal assemblages the uppermost part of the zone contains specimens of a relatively large variety of the *Lepidocyclina pustulosa* group, showing features transitional to *Pliolepidina* sp. cf. *P. panamensis*. In miliolid-rich assemblages, *Fabularia gunterii* is replaced at about the top of the zone by *F. hanzawai*. *Fabiania* and *Cushmania* continue through this interval into the overlying subzone. Lepidocycline species in this subzone include *L. ariana* and *L. macdonaldi*, characterised by the possession of a nucleus in which the deuteroconch is distinctly less than, or subequal in width to, the protoconch (Figure 6a).

Age — In Alabama, *L. ariana* is associated with calcareous nannofossils belonging to the NP17 zone (Robinson & Jiang, 1995) and, in Jamaica, with calcareous nannofossils assignable to the NP16-17 zones (M. Jiang, pers. comm.).

***Lepidocyclina-Heterostegina ocalana* Subzone**

Definition — The base of this subzone is defined by the last appearance of *Yaberinella*, the top by the disappearance of the Eocene orthophragmine genus *Asterocyclina*. Assemblages 8 and 9 of Robinson & Mitchell (1999) correspond to this interval. The earliest *Heterostegina*, of the *H. ocalana* group, and the earliest *Eulepidina*, as *E. chaperi*, make their initial appearances in this subzone in the Jamaican succession. *Nephrolepidina? subglobosa* may be common in orbitoidal-rich assemblages, including samples containing specimens transitional to *N. yurnagunensis*. In assemblages containing a miliolid component, the subzone may be divided into a lower division, with *Fabularia hanzawai*, characterised by a thickened basal layer, and an upper division, with *F. verseyi*, distinguished by the possession of tubular passages in the basal layer in addition to the marginal chamberlets.

Typical localities — In the orbitoidal-rich Gibraltar limestone (Figure 7b; stop 4 of Robinson & Mitchell, 1999, p. 32), and in turbiditic accumulations in the lower part of the Montpelier Formation in the parish of St Mary and the Montpelier-Newmarket Belt (Figures 7a, 15, 16); in the miliolid-rich Somerset limestone of Hose & Versey (1957; see Figures 2, 6b, 8a, b here), at Red Gal Ring (Robinson, 1974a), Philadelphia and near Riverhead, parish of St Ann (Stops 2, 3A, 3B of Robinson & Mitchell, 1999, p. 33).

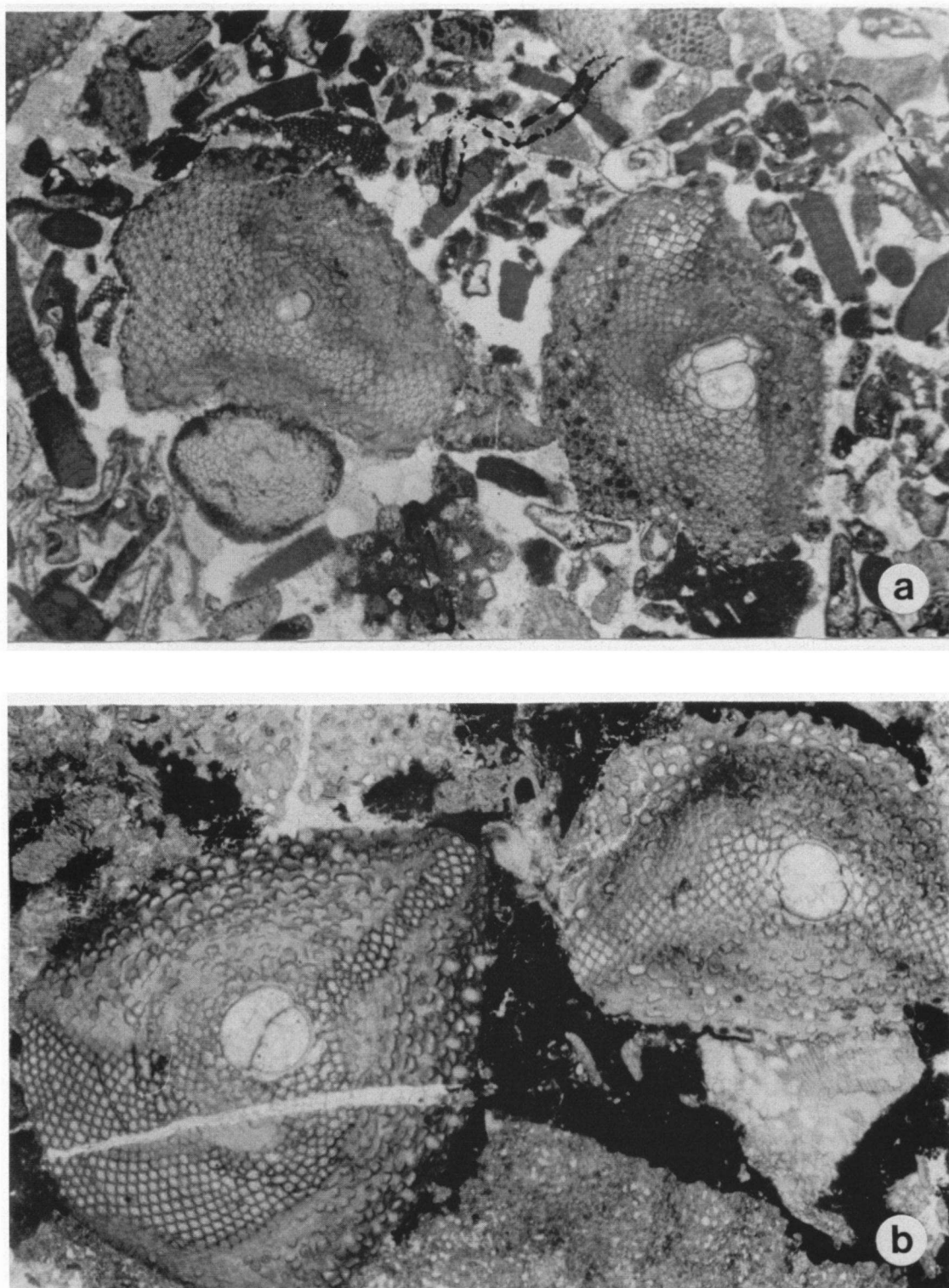


Figure 6.

- A - Locality ER647, 1 km west of Ipswich railway station; upper part of the Ipswich limestone, with *Lepidocyclina macdonaldi*, *L. pustulosa* and *Pellatispirella*, x 20.
- B - Locality ER2647, Natural Bridge, parish of St Catherine, Somerset limestone, *Eulepidina chaperi* with *Fabularia verseyi* (not figured), x 20; note large 'nephrolepidine' nucleus, arcuate to short spatulate equatorial chambers, and lateral chambers similar to those of *Lepidocyclina macdonaldi*.

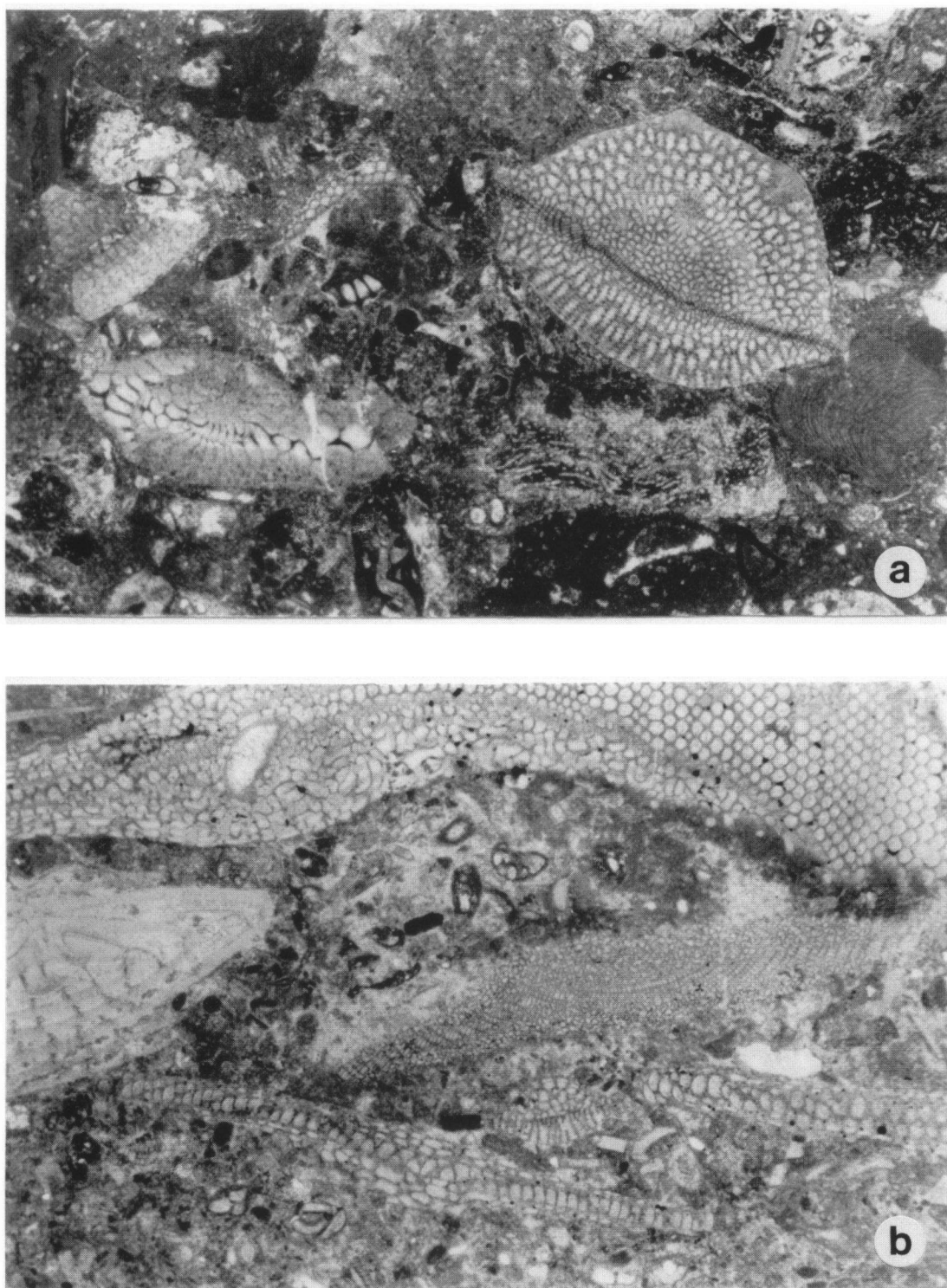


Figure 7.

A - Locality ER2849, Montpelier-Newmarket Belt, with *Heterostegina* sp. and *Asterocyclina minima*?, x 20.

B - Locality ER3021, type locality of the Gibraltar limestone, 1 km west of Clarks Town, parish of Trelawny, with *Eulepidina chaperi*, *Nephrolepidina*? *subglobosa*, *Pseudophragmina* and *Nummulites striatoreticulatus*, x 20.

The type localities of the imperforate benthic foraminiferal zones 3 and 4 of Robinson (1976) lie within the *Lepidocyclina-Heterostegina ocalana* subzone (localities

ER289 and ER355, respectively; Red Gal Ring section, Robinson, 1974a).

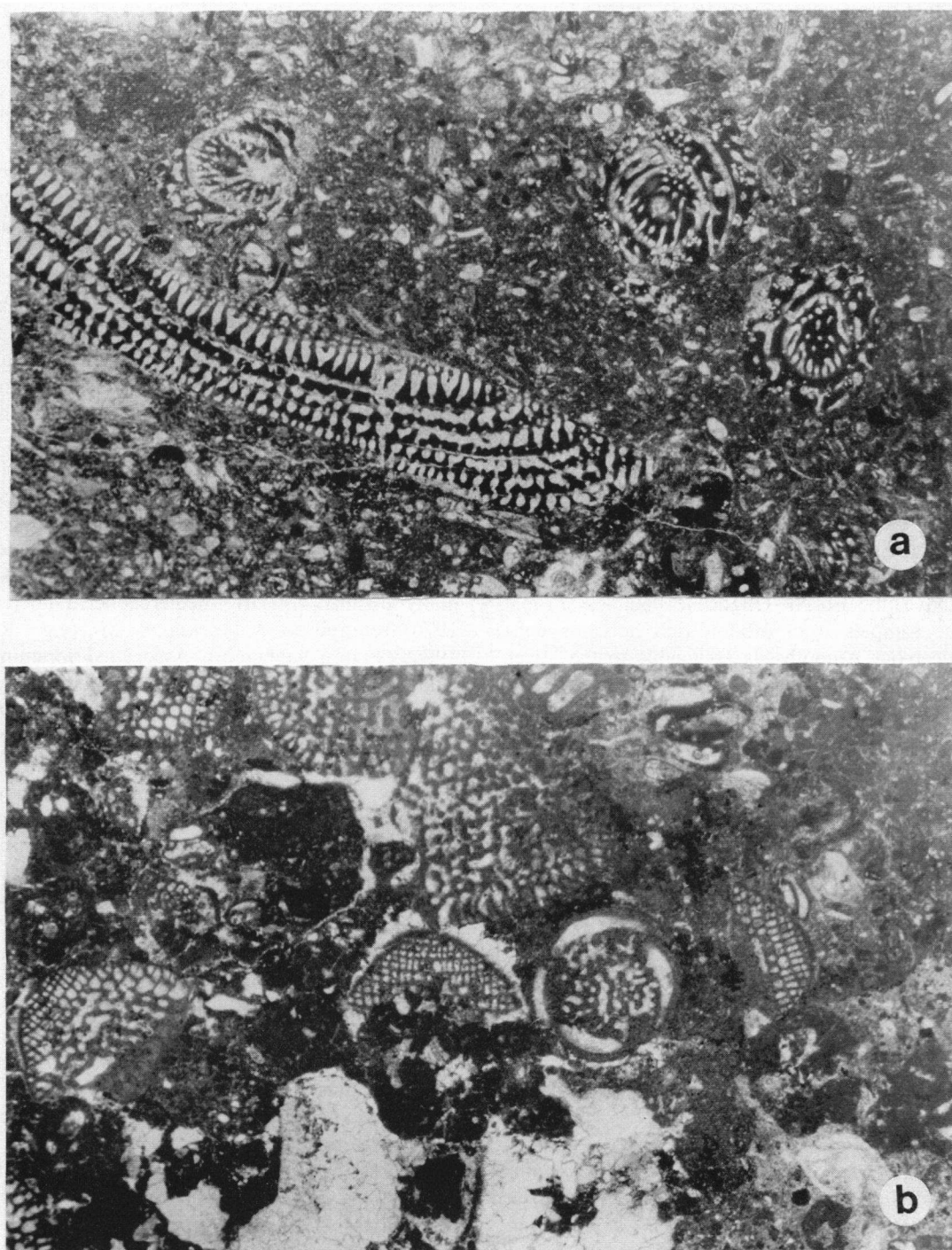


Figure 8.

A - Locality VL78, type locality of *Fabularia verseyi* Cole, west of Stony Hill, parish of St Andrew, with *F. verseyi* and *Cyclorbulinoides jamaicensis*, x 20.

B - Locality ER3139, highest part of the Somerset limestone, road Spaldings to Walderston, with *Fallotella cookei* and *Pseudochrysalidina floridana*, x 20.

Comments — Although *E. chaperi* is a common associate of *Fabularia verseyi*, at least in the upper part of this subzone, the range of the species is not well enough known for it to be used as a subzonal index. Wright (1966, p. 16) reported *E. chaperi* in strata considered by him to be part of the Swanswick limestone. A number of

characteristic Eocene forms, such as *Fabiania cassis*, *Fabularia*, *Pseudochrysalidina floridana*, pseudophragmines, *Heterostegina ocalana* and *Asterocyclina* disappear from the succession at the top of this subzone.

Typical shelf-edge assemblages contain species such as *Lepidocyclina* sp. cf. *L. macdonaldi* and *Eulepidina*

chaperi. Other components of the fauna include *Lepidocyclina pustulosa*, *Pliolepidina tobleri*, *L. trinitatis* and *Nephrolepidina? subglobosa*, together with *Nummulites striatoreticulatus* and *Asterocyclina minima* (Figures 6b, 7a). Away from the shelf edge common faunal components are *Fabularia verseyi*, *Cyclorbiculinoidea jamaicensis*, *Pellatispirella*, *Fallotella cookei/floridana* and *Pseudochrysalidina floridana* (Figure 8). *Cushmania* occurs in the lower part of the subzone and overlaps with *F. verseyi*, but has not been seen in the highest part of the zone.

Age — The assemblages of this zone are Late Eocene. In the Arawak-1 well, Pedro Bank, and other wells on the Nicaragua Rise, the lower part of the zone, with *F. hanzawai*, contains calcareous nannofossils referable to the NP18 zone. Intervals with *F. verseyi* correlate questionably with NP18 and with NP19/20 (M. Jiang, pers. comm.). A $^{87}\text{Sr}/^{86}\text{Sr}$ determination by P. Mueller (in Robinson & Mitchell, 1999) of 0.70785 on a limestone sample containing *F. verseyi*, *Pseudochrysalidina floridana* and *Fallotella cookei* suggests a horizon close to, but just above, the Eocene-Oligocene boundary (Table 2). Surface samples from orbitoid-rich horizons containing calcareous nannofossils assignable to the lower part of NP 21 (M. Jiang, pers. comm.) contain *H. ocalana*, *A. minima* and *E. chaperi*.

***Eulepidina* Zone**

Definition — The *Eulepidina* Zone is defined by the range of the genus *Eulepidina* between the highest occurrence of *Asterocyclina* and the lowest occurrence of *Miogypsina*. Three subzones are defined within this zone (Table 1). Zone E of Butterlin (1981) is roughly equivalent to this zone.

Comments — Species of *Lepidocyclina* and *Nephrolepidina* range throughout the zone. Away from the edge of the platform the first complex archaiaasinids appear in the upper part of this zone.

Age — The age range of the zone is taken here to coincide with the Oligocene Epoch. Age limits are discussed in more detail for each subzone.

***Nephrolepidina-Neorotalia* Subzone**

Definition — The base of the interval is defined by the disappearance of *Asterocyclina* spp. The top of the interval is marked by the first appearance of *Heterostegina* (*Vlerkina*) spp. of the *H. (V.) antillea* group. Species of *Eulepidina* and *Nephrolepidina*, and *Neorotalia mexicana* occur throughout this interval. This subzone is equivalent to the lower part of the *Eulepidina-*

Lepidocyclina sensu stricto Zone of Cole (1967).

Typical localities — In turbiditic accumulations in the lower part of the Montpelier Formation of western St Mary (Figure 9a), in the Montpelier-Newmarket Belt, and in the parish of St Thomas, eastern Jamaica (Figure 2). The Browns Town limestone type locality (Robinson & Mitchell, 1999, stop 1, p. 33). The lower horizons of the Walderston limestone of Hose & Versey (1957) are also assigned to this zone (Figure 9b).

Comments — Eocene representatives of the genus *Heterostegina* disappear at the end of the Eocene from the Jamaican section, as they have been reported to do elsewhere in the Caribbean and Gulf Coast regions (e.g., Eames *et al.*, 1962a, p. 24). They reappear as the *Heterostegina* (*Vlerkina*) *antillea* group in the upper part of the Oligocene. The lower part of the intervening biostratigraphic interval is characterised by large lepidocyclines of the *Eulepidina undosa-favosa* group, together with *Nephrolepidina* with DI (protoconch diameter) values normally less than 0.2 mm and DII/DI ratios normally less than 1.3 (DII = deuteroconch diameter; Wong, 1976) referred to *N. yurnagunensis* (e.g., Robinson, 1996a; Figure 9a herein). Associated foraminifera include *Neorotalia mexicana* and small nummulitids.

The author has not seen the genus *Heterostegina* in samples donated by H.L. Dixon from either Lee's marl quarry, the type locality of the Brown's Town limestone (Hose & Versey, 1957) or the Friendship quarry (Dixon & Donovan, 1998), and several other localities recently examined personally. The strata at these localities must, therefore, be assigned to the *Nephrolepidina-Neorotalia* subzone. The absence of *Heterostegina* may be due to ecological factors. Alternatively, these Brown's Town limestone horizons may be of Oligocene but pre-*H. (V.) antillea* age, as intimated by Versey (1957a). At Lee's quarry abundant *Eulepidina favosa* (mean of six measurements of DI = 0.80 mm; of DII = 1.19 mm) is associated with *Neorotalia mexicana*, and with *Nephrolepidina* with DI values of up to 0.30 mm and DII/DI ratios of about 1.3 to 1.4. This suggests a biostratigraphic horizon somewhat higher than the above-mentioned *N. yurnagunensis* assemblages. A strontium isotope ratio determination on *Eulepidina favosa* from the type Browns Town limestone locality gave an age of 29.59 Ma (Sr ratio of 0.70800; A. Paytan, pers. comm., 16 December 2002) suggesting a pre-*H. (Vlerkina)* horizon, high in the Lower Oligocene (Berggren *et al.*, 1995).

Away from the shelf edge, foraminiferal assemblages in rocks mapped as Walderston limestone are dominated by small benthic peneroplid and miliolid genera. Associated strata containing *Fallotella cookei/floridana* and *Praerhapidionina delicata*, but lacking *Fabularia* and *Pseudochrysalidina*, are correlated with this subzone (Figure 9b).

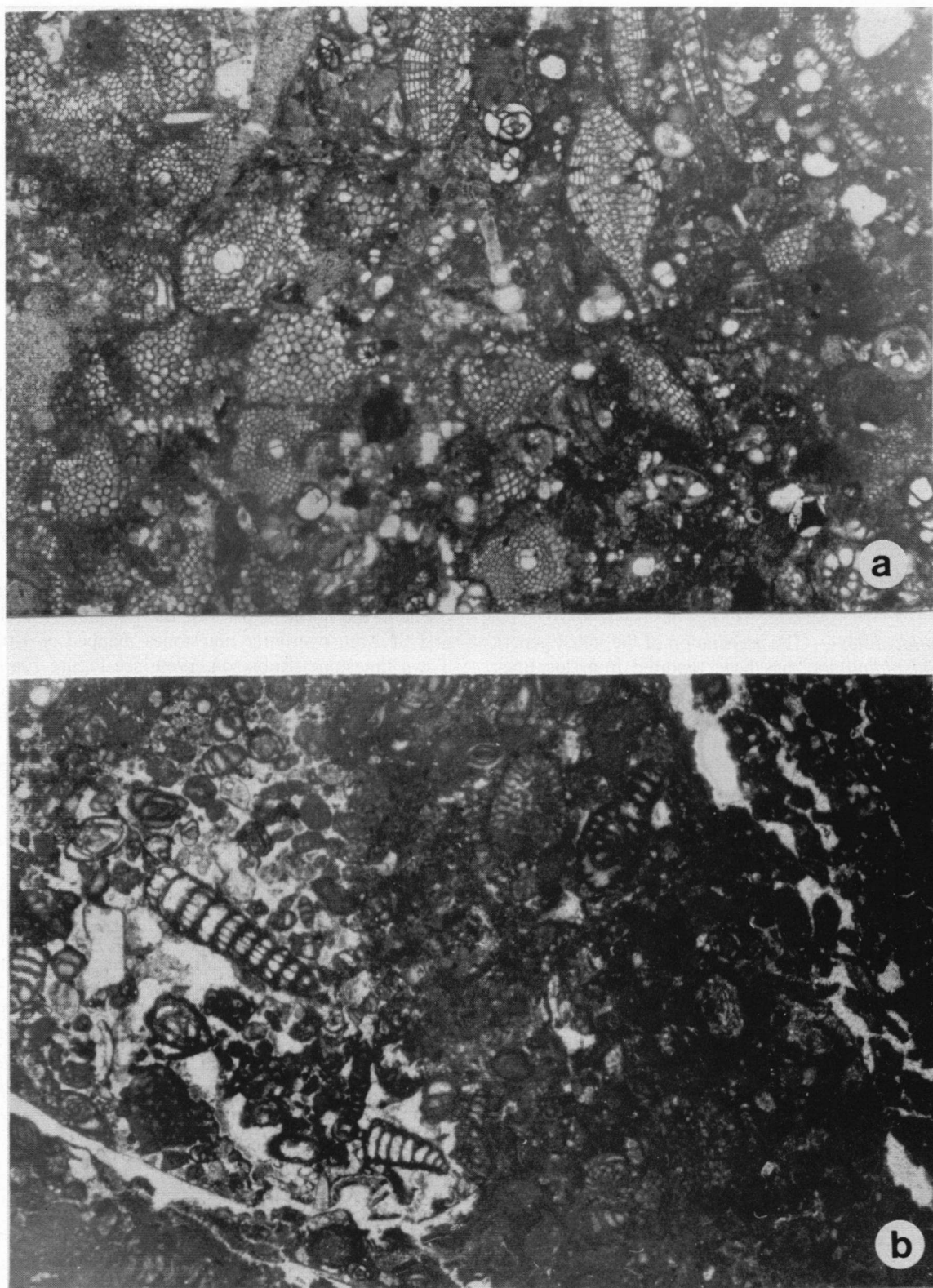


Figure 9.

- A - Locality ER621, near Bonny Gate, parish of St Mary, from a turbidite unit in the Bonny Gate limestone (= lower part of the Montpellier Formation), with *Nephrolepidina yurnagunensis* and *Neorotalia* sp., x 20 (see also Figure 14).
- B - Locality ER2895, from a section in the Walderston limestone at Sligoville, parish of St Catherine, with *Praerhapydionina delicata*, *Falotella* sp. and *Peneroplis* sp., x 20; correlated with the *Nephrolepidina-Neorotalia/Heterostegina (Vlerkina)-Neorotalia* subzones, based on the rare occurrence of small *Neorotalia* sp. cf. *N. mexicana*.

Archaias sp. cf. *A. asmaricus* also occurs high in this level or in the next subzone above (Robinson & Wright, 1993, fig. 15).

Age — Assemblages with *Eulepidina* sp., *Neorotalia mexicana* and *Nephrolepidina yurnagunensis*, in lower Montpelier Formation turbidites, have been dated by planktonic foraminifera to the earliest part of the Oligocene, P18 zone (W.H. Blow in Eames *et al.*, 1968, p. 295). The same zonal markers are found in Vicksburg-age limestones of the Gulf Coast of North America (Bryan & Huddleston, 1991).

***Heterostegina* (*Vlerkina*)-*Neorotalia* Subzone**

Definition — The base of this subzone is marked by the first appearance of *Heterostegina* (*Vlerkina*) *antillea* (*sensu* Cole, 1961a, b). The top of the interval is marked by the first appearance of *Miogypsinella* (= *Miogypsinoides* of authors; see section on definitions of taxa below). This subzone is equivalent to the middle part of the *Eulepidina*-*Lepidocyclus* *sensu stricto* Zone of Cole (1967).

Typical localities — The association of the index genera with *Eulepidina* spp. has been reported from localities e.g., on the south facing slope of Yallahs Hill, parish of St Thomas (Figure 2), regarded as belonging to the Brown's Town and/or Montpelier limestone of Hose & Versey (1957; but not the type Brown's Town).

Comments — Assemblages are typified by *Heterostegina* (*Vlerkina*) *antillea* Cushman and *Eulepidina favosa* Cushman. The classical area for this assemblage in the Caribbean is the Antigua Formation of the island of Antigua (Vaughan, 1919; Persad, 1969; Weiss, 1994). There it is possible to recognise two zones in which *Eulepidina* and *Heterostegina* (*Vlerkina*) co-occur, an upper one with *Miogypsinella* and a lower one without *Miogypsinella*, but with *Neorotalia mexicana* (Robinson & Persad, 1989). In Jamaica a similar situation appears to exist, although not confirmed from measured sections (Robinson, 1969). It should be noted that archaiasinids have also been reported from this level in Antigua (Persad, 1969; Robinson & Persad, 1989). Away from the shelf edge in Jamaica, peneroplid-miliolid-archaiasinid faunas in rocks mapped as Walderston limestone, containing *Praerhapydionina*, archaiasinids and rare *Eulepidina*, are correlated with this and the next interval. Specimens of *Fallotella* may also occur quite commonly at these horizons, but are considered to be reworked (McFarlane, 1977a).

Age — No direct correlation of this subzone with the standard planktic zones has been published from Jamaica. Two strontium isotope determinations on samples from a section near Walderston, Jamaica, containing *Fallotella* (probably reworked) and *Praerhapydionina*,

suggest ages within the middle part of the Oligocene (Table 2; ER2566, ER3128). In Antigua, the Antigua Formation correlates with the P21 planktonic foraminiferal zone and the NP24 calcareous nannofossil zone on the evidence of published microfossil lists in Robinson & Persad (1989) and Mascle & Westercamp (1983), within age limits of 29.4 to 27.5 Ma (Berggren *et al.*, 1995). A P20 zone age is not excluded (van den Bold, 1966). This age is greater than that published by Weiss (1994), who quoted a date within the P22 planktonic zone.

***Heterostegina* (*Vlerkina*)-*Miogypsinella* Subzone**

Definition — The base of the interval is marked by the first appearance of the genus *Miogypsinella*. The top is marked by the first appearance of *Miogypsina*, typically *M. gunteri* Cole. *Heterostegina* (*Vlerkina*) and *Eulepidina* persist throughout the interval. This subzone is equivalent to the *Miogypsinoides* Subzone of the *Eulepidina*-*Lepidocyclus* *sensu stricto* Zone of Cole (1967).

Typical localities — Assemblages with *Miogypsinella* occur in the northern parts of the parishes of Trelawny and St Ann, overlying limestones mapped as Brown's Town limestone (Robinson, 1969; see Figure 10a here).

Comments — In the absence of *Miogypsinella*, this interval is presently impossible to distinguish from the preceding subzone. *Neorotalia mexicana* does not seem to occur commonly with *Miogypsinella* and its presence alone may, therefore, indicate horizons in the preceding subzone. Away from the shelf edge, peneroplid-miliolid dominated assemblages with *Praerhapydionina* and archaiasinids are provisionally correlated with this subzone.

Age — In Antigua, *Miogypsinella* occurs in the upper part of the Antigua Formation in strata assigned to the NP24 calcareous nannofossil zone (see comments above). Its first occurrence at other sites in the Caribbean region is at about the same horizon (Robinson & Persad, 1989, and references therein, where it is called *Miogypsinoides*). This correlation is accepted for assemblages seen in northern Jamaica.

***Miogypsina* Zone**

Definition — The *Miogypsina* Biozone is defined by the interval containing the total range of the genus in Jamaica. This biozone is divided into two subzones (Table 1). Zone F of Butterlin (1981) is roughly equivalent to this zone.

Age — The zone effectively spans the Lower Miocene although there are records which may indicate its extension down into the highest part of the Oligocene.

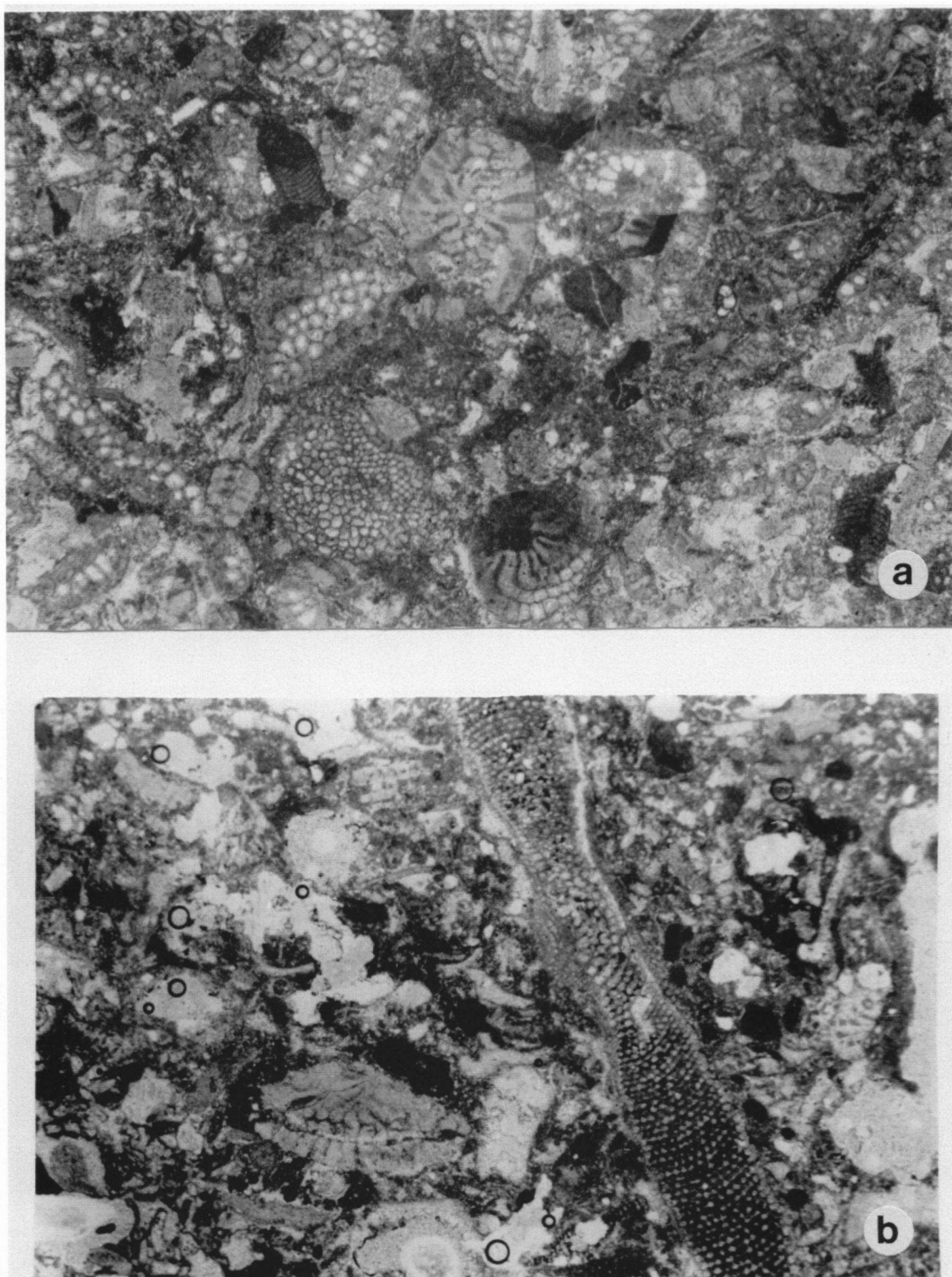


Figure 10.

A - Locality ER573, about 1.4 km south of Montpelier on the Catadupa road, parish of St James, Montpelier Formation, with *Heterostegina* (*Vlerkina*) *antillea*, *Miogypsinella* sp. cf. *M. bermudezi*, *Neorotalia*? sp. and small lepidocyclinids, x 20.

B - Locality TSN 319/01/1, bauxite pit at Windhill, near Mandeville, parish of Manchester, from strata mapped as Newport limestone, with *Heterostegina* and *Archaias*? sp. cf. *A. kirkukensis*, x 20.

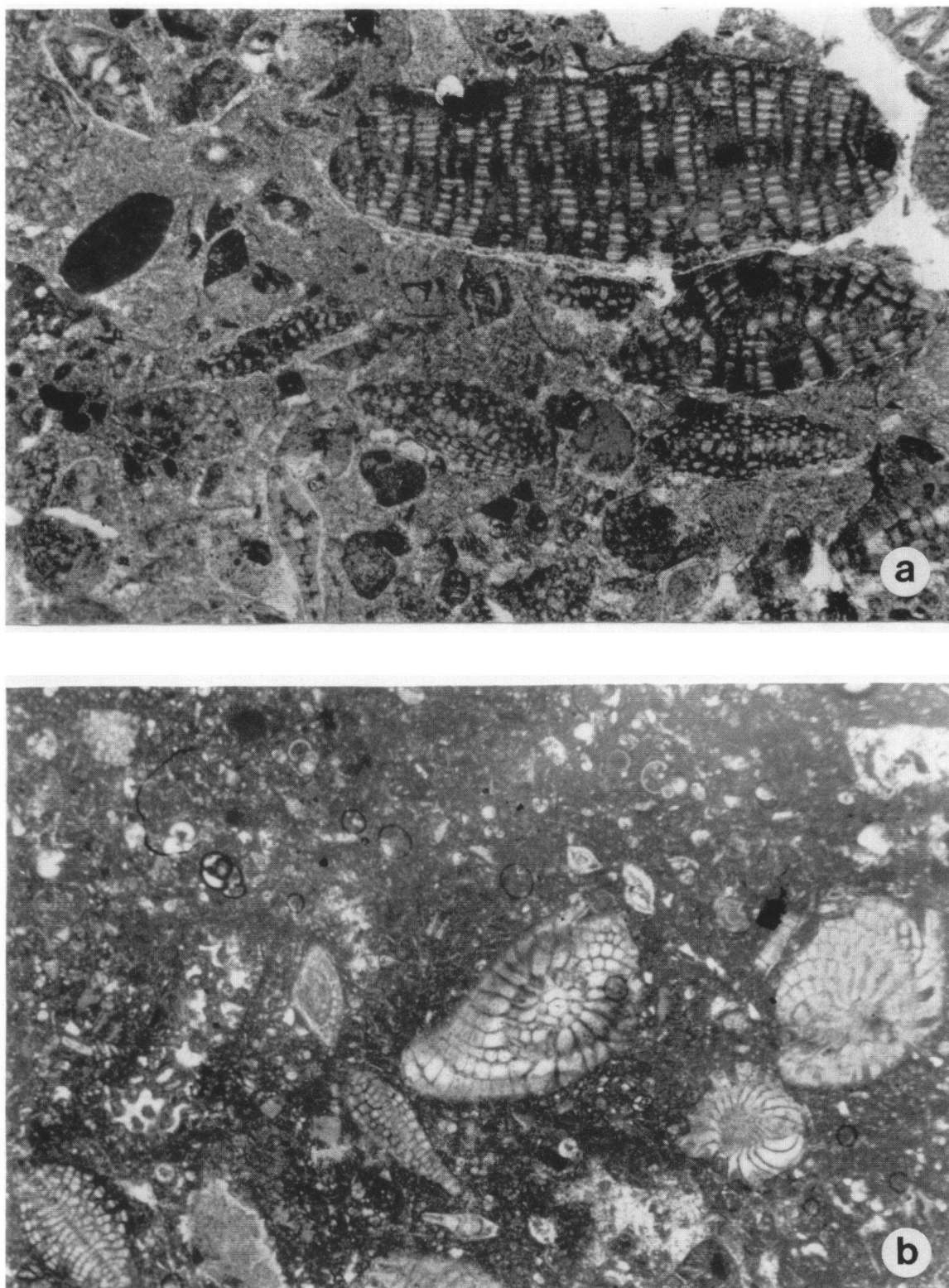


Figure 11.

A - Locality ER126A, mouth of the Swift River, parish of Portland, with *Miogypsina*, *Spiroclypeus* and *Heterostegina*, x 20.

B - Locality ER46/3, Montpelier Formation, coastal section east of Buff Bay, parish of Portland, with *Heterostegina*, *Miogypsina*, *Nummulites* and *Lepidocyclina*, x 20.

The ages of the zonal boundaries are further discussed for each subzone below.

Heterostegina (Vlerkina) Subzone

Definition — The base of this interval is defined on the first appearance of *Miogypsina* (with a single neorotaliid periembryonic spire; see section on definitions of taxa below), the top by the last appearance of *Heterostegina (Vlerkina)*. The interval corresponds to the *Miogypsina* (uniserial) Subzone of the *Eulepidina-Lepidocyclina sensu stricto* Zone of Cole (1967). In areas away from the shelf margin, limestones containing complex archaiasinids and soritids correlate, at least in part, with this subzone.

Typical localities — Assemblages typifying this subzone occur commonly in turbidite units in the Montpelier Formation (Figure 11). They are also widespread in shallow marine carbonates, appearing in rocks mapped as the lower part of the Newport limestone, in the Stony Hill district (Versey, 1957a; Robinson, 1995), parish of St Catherine (e.g., Reed, 1966, pl. 5(1), where the assemblage is listed as belonging to the Brown's Town limestone) and Manchester, just south of Mandeville.

Comments — The subzone is characterised by the presence of species of uniserial *Miogypsina* and *Heterostegina (Vlerkina) antillea*, together with *Lepidocyclina canellei*. These are usually accompanied by *Nummulites* sp. cf. *N. panamensis* and, more rarely, by *Eulepidina* sp. and *Spiroclypeus bullbrooki* (Figure 11), the latter occurring in horizons near the base of the Miocene elsewhere in the Caribbean (Trinidad and Martinique; Vaughan & Cole, 1941). This subzone has been identified over considerable areas of the carbonate platform, in rocks previously mapped as Brown's Town or lower Newport limestone (McFarlane, 1977a). The assemblages appear to mark the first Miocene transgressive system over the Jamaican region.

Age — The first appearance of *Miogypsina* in larger benthic foraminiferal assemblages is widely regarded as marking the base of the Miocene (e.g., van den Bold, 1972, for the Caribbean; Cahuzac & Poignant, 1997, for the Mediterranean region). In the older Caribbean and Jamaican literature the *Miogypsina* Subzone was assigned to the Upper Oligocene (e.g., Hose & Versey, 1957; Cole 1956a, 1967), but by Cole (1964) to the *Globorotalia kugleri* zone (= N 4 zone, basal Miocene, = M 1 zone of Berggren *et al.*, 1995, p. 142), a zone which was retained in the Upper Oligocene by Bolli & Saunders, 1985). Sample TSN 3.1, from a bauxite pit in the Newport limestone of Manchester Parish (Stemann, 2003) contained *Heterostegina (Vlerkina) antillea* and specimens of a complex archaiasinid resembling *Archaias kirkukensis* Henson (Figures 10b, 13). A ⁸⁷Sr/⁸⁶Sr determination by A. Paytan on a *Kuphus* tube from this

locality gave a value of 0.70823 (Table 2), corresponding to an age of 24.44 Ma, within the highest part of the Oligocene (Berggren *et al.*, 1995). At nearby localities at about the same stratigraphic horizon, *Heterostegina (Vlerkina)* is associated with *Miogypsina* sp. and rare, small *Lepidocyclina* sp.

The top of the subzone is placed within or near the base of planktonic foraminiferal zone N5 (Cahuzac & Poignant, 1997; van den Bold, 1972; zone M2 of Berggren *et al.*, 1995). In the Buff Bay area assemblages containing *Spiroclypeus bullbrooki*, *Heterostegina (Vlerkina) antillea* and *Eulepidina* sp. are associated with planktonic foraminifera of M1 zone age (Blow in Robinson, 1969).

Lepidocyclina Subzone

Definition — The base of this interval is marked by the last appearance of *Heterostegina (Vlerkina)*, the top by the last appearance of *Miogypsina*. Species of *Lepidocyclina* occur throughout the zone. The zone corresponds to the *Lepidocyclina sensu stricto-Miogypsina* Zone of Cole (1967).

Typical localities — This assemblage is present in turbidites in the Montpelier Formation, but rare in the Newport limestone of authors.

Comments — Species characteristic of the zone are *Nummulites* spp. (*N. cojimarensis*), biserial and multiseriate *Miogypsina* and *Lepidocyclina canellei*. Assemblages lack *Eulepidina* except rarely, as apparently reworked fragments, but *Amphistegina* spp. are a common component. In the interior parts of the platform this zone is probably typified by archaiasinids and soritids, such as *Miosorites americanus*, corresponding to the *Amphisorus* Zone of Hose & Versey (1957), but precise correlation is still obscure.

Age — As indicated above, the base of this subzone is placed within the lower part of the N5 planktonic foraminiferal zone (M2 zone of Berggren *et al.*, 1995). In the Caribbean, the top of the zone correlates with the top of the N7 (= M4) or the lower part of the N8 (= M5) planktonic foraminiferal zones (Cole, 1964; Barker, 1965; van den Bold, 1972; Robinson, 1969; Robinson & Jung, 1972). Species of *Lepidocyclina* disappear at about the same horizon as do those of *Miogypsina*.

Amphistegina Zone

Definition — The zone is defined by the presence of *Amphistegina* spp. above the disappearance of *Miogypsina* spp. Species of archaiasinids and soritids are also found throughout rocks of this interval. In the present paper one subzone is defined (Table 1).

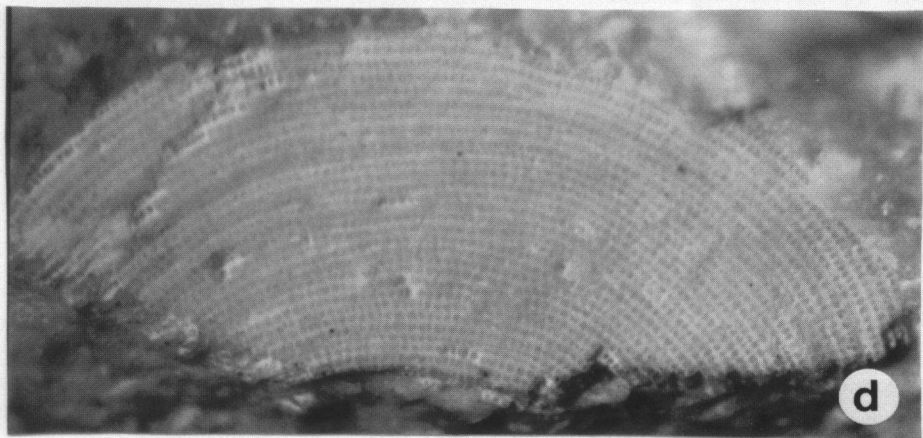
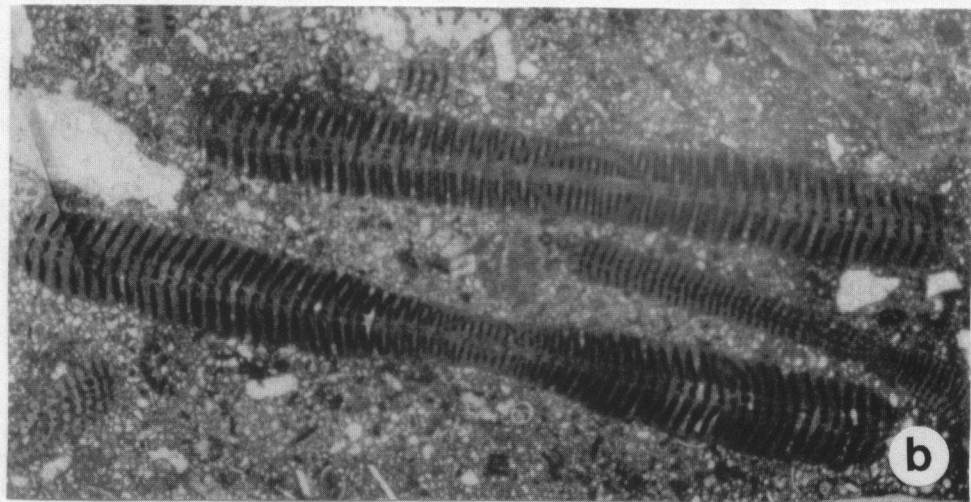


Figure 12.

- A - Locality ER535, Montpelier Formation, Easington, parish of St Thomas, with *Amphistegina*, *Nummulites* and *Sphaerogypsina*, x 20.
- B - Locality CCC 142, Newport limestone, southern part of Long Mountain, parish of St Andrew, with *Miosorites americanus*?, x 20.
- C - Locality ER1283B, near Manchioneal, parish of Portland, *Miosorites americanus*?, central part of a large microspheric specimen, x 49.
- D - Locality ER2511, road from Mandeville to Newport, below Northern Caribbean University, Mandeville, parish of Manchester, *Miosorites* sp., equatorial view of part of disc, x 18.

Age — As indicated above, the disappearance of *Miogypsina* is placed near the N7-N8 (= M4-M5) zonal boundary, at the base of the Middle Miocene. The zone extends to and includes the Holocene.

***Nummulites* Subzone**

Definition — The base of this interval is defined by the last appearance of *Miogypsina*. The top is defined by the last appearance of nummulitids. This subzone is equivalent to the *Camerina cojimarensis* (= *Nummulites cojimarensis*) zone of Cole (1967).

Typical localities — Assemblages of this kind may be seen in turbidites in the upper part of the Montpelier Formation, at localities such as Easington, parish of St Thomas (Figures 2, 12a). They have not been reported from the Moneague Formation (Newport limestone of authors).

Comments — Horizons in the White Limestone younger than the N8 (M5) zone contain shelf edge assemblages characterised by the association of *Nummulites cojimarensis* with more or less abundant *Amphistegina* spp. In the platform interior these genera are replaced by complex soritid and archaiasinid genera, but precise correlation is lacking (Figure 12b; see Hottinger, 2001).

Age — Assemblages belonging to this subzone have been noted from horizons correlating with the N10 (M7) planktonic foraminiferal zone (Robinson, 1969). They probably range higher, up to the top of the White Limestone, which, in the Buff Bay section, extends as high as the N14 (M11) zone (Robinson, 1969; Steineck, 1974; Berggren, 1993), but these horizons have been inadequately investigated. In the northeastern Caribbean and Cuba, the last Caribbean nummulitids (as *N. cojimarensis* and *Paraspiroclypeus chawneri*) occur as high as the Lower to Middle Pliocene (Andreieff, 1983). Robertson (1998) noted at least two species of *Amphistegina* from the Upper Miocene Buff Bay Formation, but did not report any nummulitids.

Age of the top of the White Limestone Group

As noted previously, the top of the White Limestone in northeastern Jamaica is found at about the level of the N14 planktonic foraminiferal zone, uppermost Middle

Miocene. In southwestern Jamaica, horizons assigned on lithological grounds by R.M. Wright to the Newport limestone contain planktonic foraminiferal assemblages belonging to the N16 and N18 zones, Upper Miocene to Pliocene (Wright, 1971). These horizons correlate with the Coastal Group elsewhere in Jamaica.

Larger foraminiferal biofacies and palaeobiogeography

The earliest reference interpreting the depositional environment of the White Limestone Group appears to be that by Arthur Lennox (*in* Sawkins, 1869, quoted above). Later interpretations include that of Hill (1899), who considered the White Limestone to be principally a deep sea deposit, and Matley (1925). However, it was Versey (1957a; *in* Zans *et al.*, 1963) who developed a modern, general biostratigraphic scheme, based on larger foraminifera, allowing for lateral variations in biofacies (his microfacies), partly following on the studies by Henson (1950) of the Middle 'Tertiary limestones of the Middle East. Versey distinguished two broad, almost mutually exclusive', larger foraminiferal facies. The first, dominated by peneropliids and/or miliolids, was interpreted to be characteristic of back-reef or shoal waters, and the second orbitoidal-nummulitid facies, characteristic of fore-reef or open-water environments. A third facies, lacking larger foraminifera, was interpreted to result from basinal deposition. Versey's observations have generally withstood the test of time, and are similar to many published subsequently for other regions (e.g., Bartholdy *et al.*, 1999; Racey, 2001). The mutually exclusive nature of the two biofacies in the Middle Eocene was demonstrated by Robinson (1969), who plotted the geographical distributions of the orthophragmines and of the peneropliiform genus *Yaberinella*. Eva (1976) indicated the probable distribution of Eocene genera over a typical carbonate platform-shelf edge profile, using generic association factors. Wright (1966, 1974) examined assemblages mainly from the northern part of the Clarendon Block and suggested a microfacies model for the White Limestone. Wallace (1969) distinguished eight facies, based on foraminiferal and coral assemblages, for the Oligocene and Miocene Browns Town and Montpelier limestones south of Discovery Bay. These range from orbitoidal-coral biosparite to planktonic foraminiferal chalk with chert, including horizons with redeposited blocks. All of these can be regarded as variations of Versey's second and third facies. Characteristic as-

semblages for the inner shelf and platform, shelf edge, and upper slope regions are indicated for each zone in Table 3. The distributions are broadly similar to those indicated by Hottinger (1997) for the Tethys.

Robinson (1993) discussed the possible significance of the two larger foraminiferal assemblages for the recognition of faunal provinces in the Caribbean Palaeogene. His Assemblage I, characteristic of shelf edge and upper slope palaeoenvironments, contains species that are widespread in the Caribbean region. Assemblage II species are restricted mainly to back reef and interior shelf palaeoenvironments, and several species and genera appear to be endemic to the Nicaragua Rise. These assemblages are distinguished in Figure 4.

In Jamaica, the apparently sudden appearance of Grimsdale's lineage X species of *Lepidocyclina* (Robinson & Wright, 1993, fig. 24.1) within the Middle Eocene NP16 zone may indicate a dispersal event, perhaps from South America, where the most primitive forms have been recorded (Hofker, 1968; van Raadhoven, 1951; *Polylepidina nitida* Caudri, 1996, may also belong to this group, based on the well-developed tiers of lateral chambers, which are not a feature of the type species, *P. chiapasensis*). Conversely, published records suggest that the *Eulinderina*-Y *Lepidocyclina* lineage of Grimsdale (1959; *Lepidocyclinae* of Sirotti, 1983) might have evolved in the northern Caribbean (Barker & Grimsdale, 1936; Grimsdale, 1959). It should also be noted that reports of sporadic appearances of Eocene lepidocyclines in West Africa and Morocco (Freudenthal, 1972; Neumann *et al.*, 1986; Drooger & Rohling, 1988) are all of the subfamily Helicolepidininae (*sensu* Sirotti, 1983, *non* Adams, 1987).

Definitions of some generic and specific taxa

1 - Nummulitids

Nummulites Lamarck — Used in the broad sense of Loeblich & Tappan (1987) to include also species formerly placed in *Palaeonnummulites* Schubert and *Operculinoides* Hanzawa. The nummulitid genus *Ranikothalia* Caudri occurs in the Upper Palaeocene of eastern Jamaica, becoming at least locally extinct by about the beginning of the Eocene (but see Butterlin, 1977, for a review of the occurrence of *Ranikothalia* in the Caribbean). Nummulitids do not reappear in Jamaica until about the beginning of the Middle Eocene.

Heterostegina d'Orbigny — Two species (perhaps species groups) are recognised, marking distinct biostratigraphic intervals, separated by an apparent absence of the taxon:

Heterostegina ocalana Cushman: Forms referable to this species occur in samples from the Upper Eocene (Figures 7a, 16a, b). Following Banner & Hodgkinson (1991), *H. ocalana* belongs to the subgenus *Heteroste-*

gina, with an evolute final whorl and normally lacking chamberlets in the alar prolongations of the involute whorls. Measurements on twenty-two specimens in a sample from the highest part of the Eocene (lower NP21 zone) gave average values of proloculus diameter (DI) = 0.079 mm and No (number of operculine chambers, including the proloculus) = 7.45 (methodology after Chaproniere, 1980).

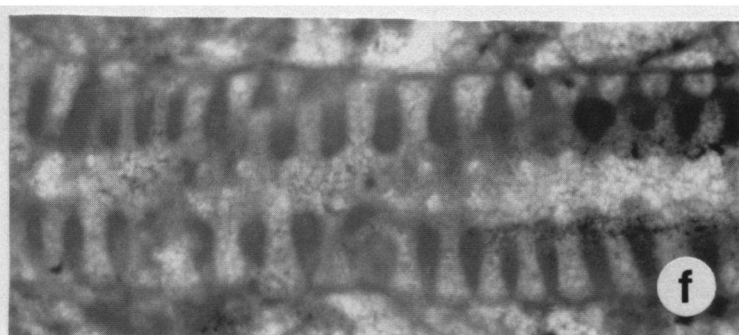
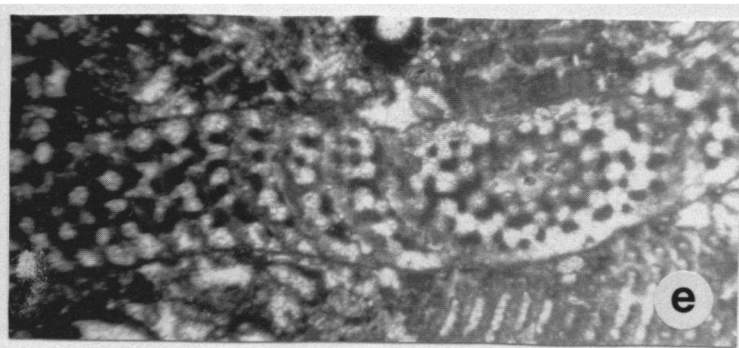
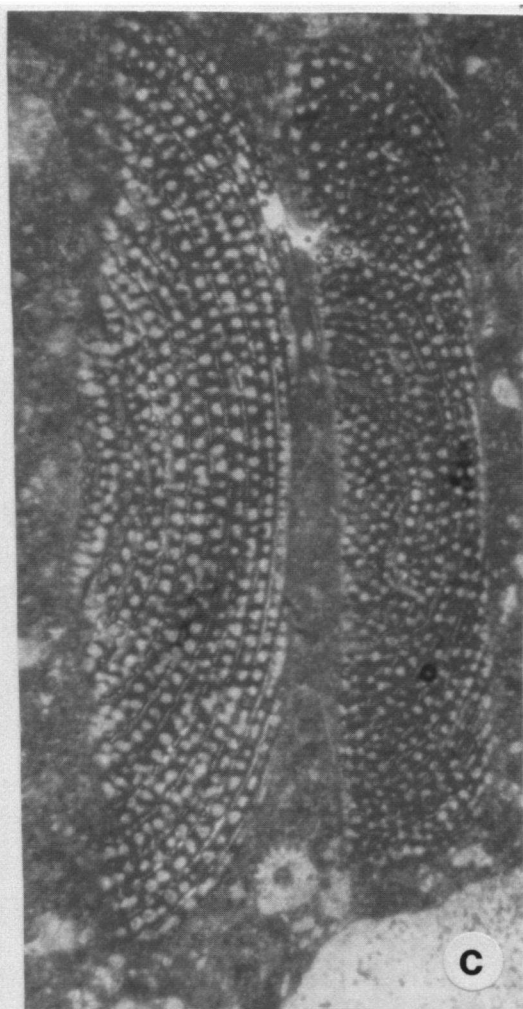
Heterostegina (Vlerkina) antillea Cushman: The opinion of Cole (1957, 1961a, b) is accepted in regarding as synonymous the species formerly distinguished as *H. israel-skyi* Gravell & Hanna, *H. panamensis* Gravell and *H. texana* Gravell & Hanna. Further evaluation of the group in Jamaica may modify this conclusion, but this has not yet been attempted (see Banner & Hodgkinson, 1991, for discussion of subgenera, where they include *H. texana* in both subgenera *Heterostegina sensu stricto* and *Vlerkina*!). Thirteen specimens of *H. (V.) antillea* in a sample from the base of the Montpelier Formation, west of Brown's Town, measured average proloculus diameter (DI) of 0.19 mm, No = 2.86, and S4+5 = 8.92 (methodology follows Chaproniere, 1980). In assemblages where the final whorl is broken off, as is frequently the case, it may be difficult to separate the subgenus *Vlerkina* from *Heterostegina sensu stricto*. A redefinition of the subgenera to include parameters such as proloculus size and number of operculine chambers might be more appropriate than that based primarily on the degree of involution.

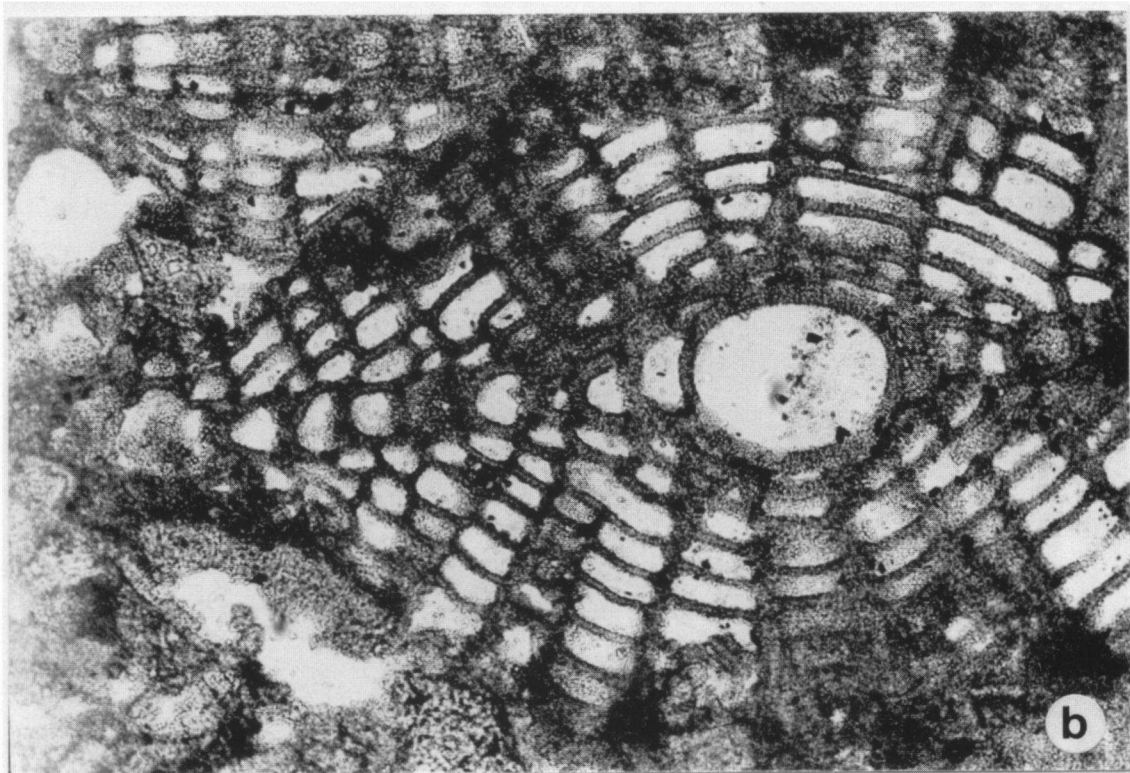
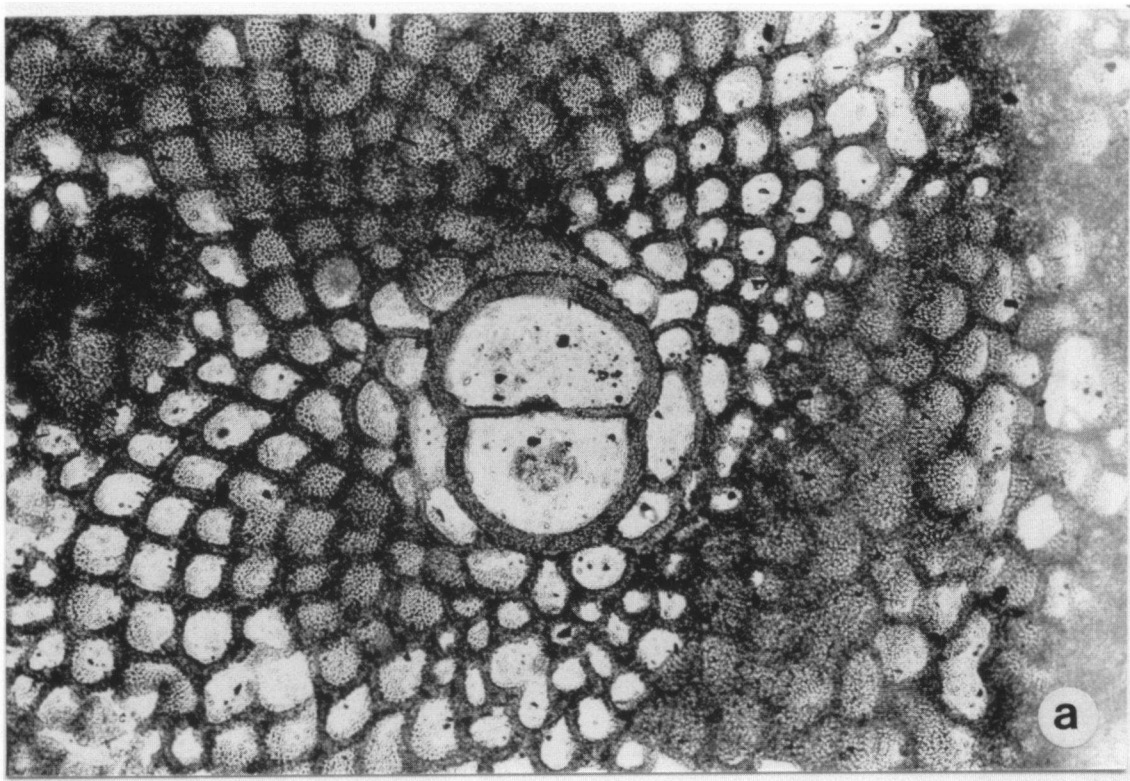
2 - Lepidocyclines

Lepidocyclina Gümbel — Used here in a broad generic sense, as defined by BouDagher-Fadel & Banner (1997), for microspheric forms, and for lepidocyclines recorded from Jamaica, but not otherwise placed in the generic taxa listed here. These taxa are *Eulinderina*, *Polylepidina*, *Pliolepidina*, *Nephrolepidina* and *Eulepidina*. The name *Lepidocyclina* is provisionally retained for Eocene megalospheric species as further noted below.

Eulinderina Barker & Grimsdale — Used in the sense of Robinson (1996b). Distinguished from *Polylepidina* Vaughan by the lack of principal auxiliary chambers.

Polylepidina Vaughan — Used in the sense of Robinson & Jiang (1995) and Robinson (1997a). Distinguished from *Eulinderina* by possessing either one or two principal auxiliary chambers. Distinguished from *Lepidocyclina sensu lato* by possessing less than four primary nepionic spires. Forms with four primary nepionic spires, such as *Lepidocyclina proteiformis*, which were included by Vaughan (1924) in his concept of *Polylepidina*, are therefore excluded from the genus, following Cole (1956a) and are removed to *Lepidocyclina sensu lato*. Like these early species of *Lepidocyclina*, *Polylepidina* possesses a subisolepidine nucleuconch (deuteroconch smaller than protoconch).





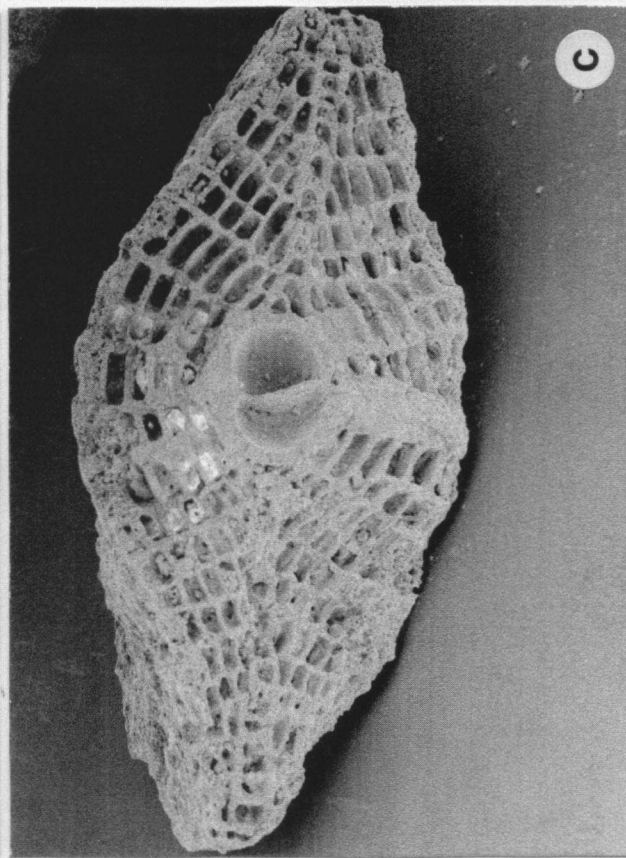
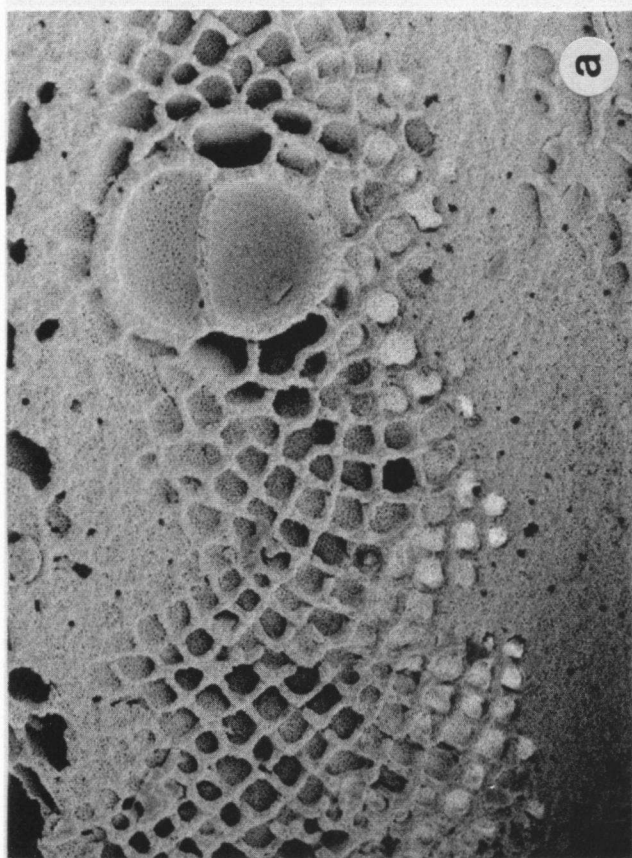
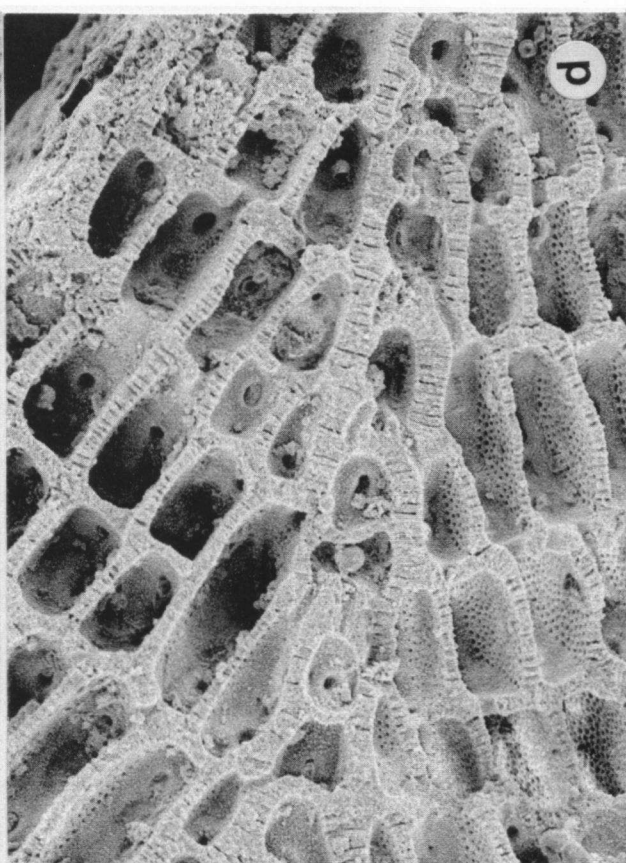
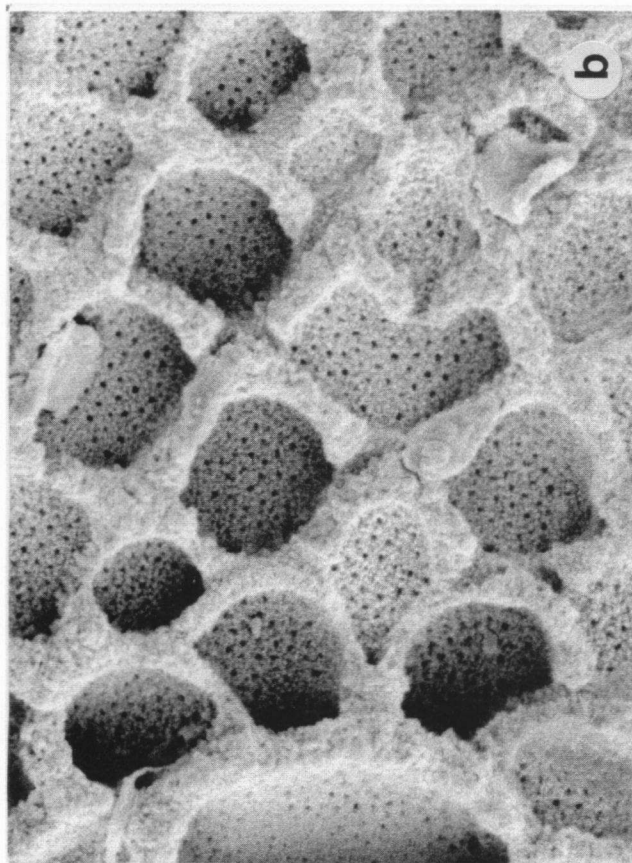


Figure 13.

- A - Locality ER2511 (see Figure 12d for locality data), *Archaias?* sp. cf. *A. kirkukensis*, two axial sections, x 31.
- B - Locality ER2511, *Archaias?* sp. cf. *A. kirkukensis*, axial section, x 31.
- C - Locality ER2511, *Archaias?* sp. cf. *A. kirkukensis* (right) and *Miosorites americanus?* (left), portions of discs, x 31.
- D - Locality ER2511, *Archaias?* sp. cf. *A. kirkukensis*, three accidental sections on a broken slab of limestone, x 18.
- E - Locality ER1283, near Manchioneal, parish of Portland, *Miarchaias floridanus?*, tangential portion of flange showing the radial wave mentioned by Smout & Eames (1958), x 49.
- F - Locality ER1283B, near Manchioneal, parish of Portland, *Miosorites americanus?*, tangential section, x 120.

Figure 14.

- A - Locality ER 621, lower Montpelier Formation, near Bonny Gate, *Nephrolepidina yurnagunensis*, equatorial section showing slightly nephrolepidine nucleus with adauxiliary chambers, x 135; note the almost straight wall dividing the protoconch from the deutoconch, seen in many specimens from this sample. These are virtually identical with *Lepiaocyclina (Nephrolepidina)* sp. cf. *L. (N.) yurnagunensis* of Adams (1987, pl. 3, figs 7-9).
- B - Locality ER621, *Nephrolepidina yurnagunensis* (Cushman), axial section showing single layer of equatorial stolons and regularly stacked cubacula, x 135.
- C - Locality ER1283B, near Manchioneal, parish of Portland, *Miosorites americanus?*, axial section of a megalospheric specimen, x 49.

Figure 15.

- A - Locality ER176, lower Montpelier Formation, Dressikie, parish of St Mary, *Nephrolepidina?* sp. cf. *N.? subglobosa*, slightly oblique section through the nucleus. Note diagonal stolons in the equatorial layer and passages through the lateral walls of the equatorial chambers connecting these with lateral chambers (cubacula), x 112; these specimens are larger than typical *N.? subglobosa* and close to specimens referred herein to *N. yurnagunensis* (see Figure 14);
- B - Locality ER176, *Nephrolepidina?* sp. cf. *N.? subglobosa*, enlargement of the right-hand part of Figure 15a to show the diagonal stolon system, x 450.
- C - Locality ER176, *Nephrolepidina?* sp. cf. *N.? subglobosa*, axial section showing well-developed vertical stacking of cubacula, x 65.
- D - Locality ER176, *Nephrolepidina?* sp. cf. *N.? subglobosa*, enlargement of right-hand part of Figure 15c showing stolons connecting equatorial chambers to cubacula and the single layer of stolons connecting equatorial chambers with one another, x 250.

Pliolepidina H. Douvillé — Although many, perhaps most, specialists consider *Pliolepidina tobleri* H. Douvillé, to be a teratologic form of *L. (Isolepidina) pustulosa* H. Douvillé (= *Neolepidina pustulosa* of Butterlin, 1990; *Pliolepidina pustulosa* of Cole, 1962; and *Nephrolepidina pustulosa* of Sirotti, 1983), the fact remains that the multilocular nuclear morphology of *P. tobleri* is strikingly different from that of *L. pustulosa*, and examples of *P. tobleri* occupy a distinct stratigraphic horizon, in Jamaica, at or near the base of the Upper Eocene. For this practical reason it is maintained as a separate genus, following Eames *et al.* (1962b), although the concept of the genus is restricted here to the Eocene type species, *P. tobleri*, and its close relative, *P. panamensis* (Cushman).

Nephrolepidina H. Douvillé — *Nephrolepidina* is regarded as a genus distinct from *Lepidocyclina sensu stricto*, following Hanzawa (1962), Sirotti (1983, in part) and Loeblich & Tappan (1987, in part). Nucleus nephrolepidine, the deutoconch broader than the protoconch, with adauxiliary chambers (Figure 14a); lateral chambers normally open, vertically stacked in regular tiers (Figures 14b, 15c, d), resembling the cubacula of Banner & Hodgkinson (1991); equatorial chambers normally with the four-stolon system of Vaughan & Cole (1941; see Figure 14), arranged in a single plane, at least in the more proximal chambers, as viewed in axial section (Figure 14b). In stratigraphically lower species, the nucleus is relatively small, and may lack adauxiliary chambers (Figure 15a). The equatorial chambers are

rhombic or diamond-shaped, giving a characteristic 'engine-turned' appearance to the equatorial chamber layer. The stratigraphically lowest species showing most of the features considered here to be characteristic of this genus is *Nephrolepidina? subglobosa* (Nuttall), morphologically very close, and probably ancestral, to *N. yurnagunensis* (Cushman) near the Eocene-Oligocene boundary (Figure 15; see also Caudri, 1996, where both species are called *Lepidocyclina*, and Adams, 1987, pl. 3, figs 7-9). *Nephrolepidina? subglobosa* is distinguished from *N. yurnagunensis* in apparently lacking adauxiliary chambers, although mixed populations occur, and in its normally smaller size. Species such as *Lepidocyclina pustulosa* and *L. peruviana* which were also included in *Nephrolepidina* by Sirotti, are here excluded, as they do not normally develop nephrolepidine nuclei and appear to lack adauxiliary chambers.

In stratigraphically higher species of *Nephrolepidina*, the nucleus is relatively larger and the deutoconch embraces the protoconch to a greater degree, usually displaying prominent adauxiliary chambers (e.g., Wong, 1976, pl. 6, figs 1-3; Robinson & Wright, 1993, fig. 24.2). The equatorial chambers may become spatulate, even hexagonal.

Although BouDagher-Fadel & Banner (1997) stated that *Nephrolepidina* does not appear until the Late Oligocene, this may be true only in the Indo-Pacific region. *Nephrolepidina isolepidinoides* van der Vlerk is regarded here as a *Nephrolepidina* (as it was by van der Vlerk, 1929).

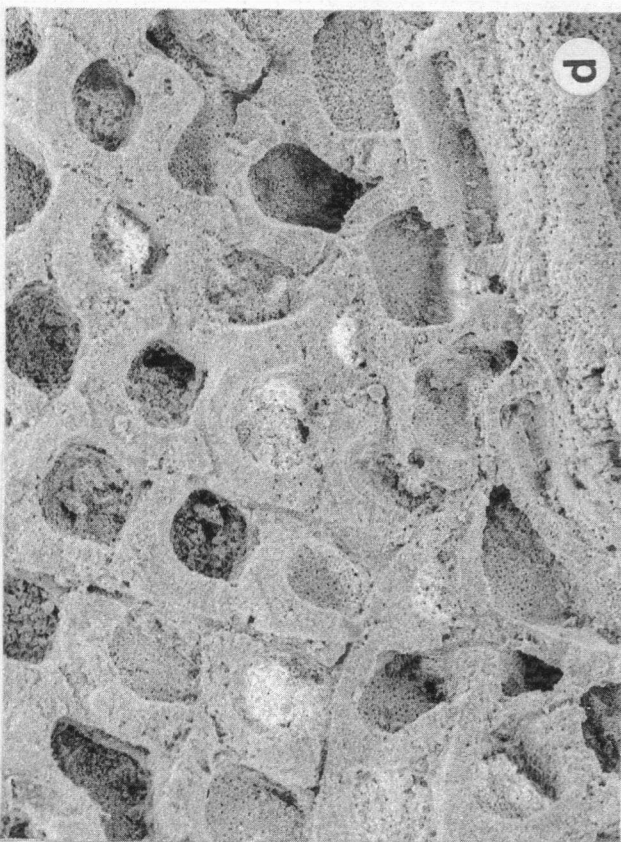
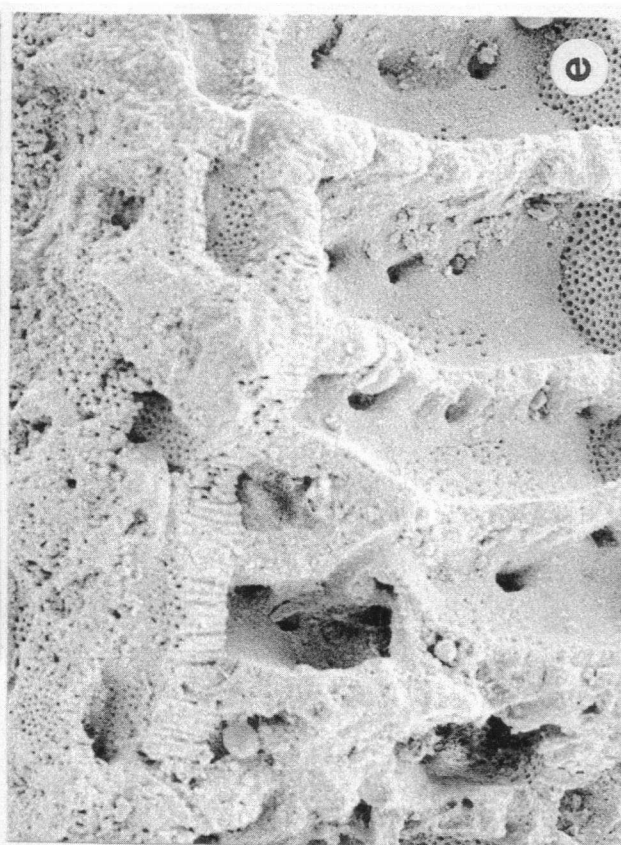
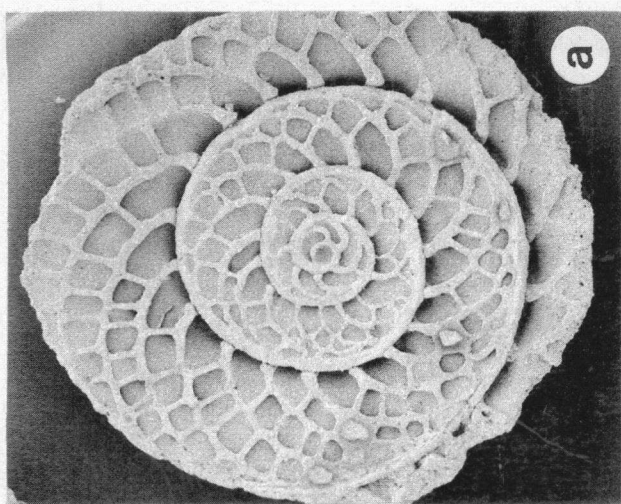
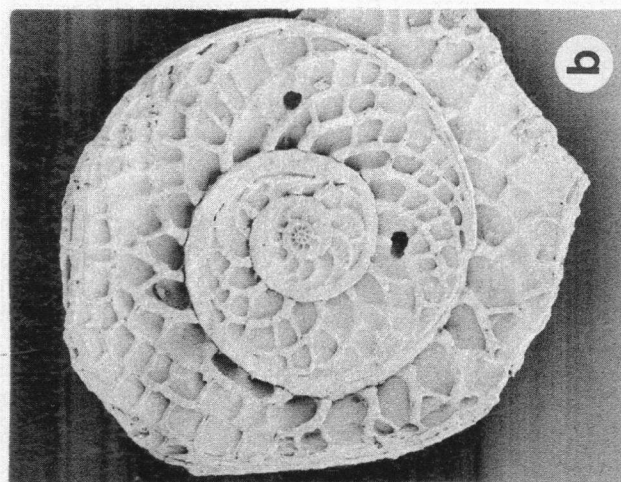
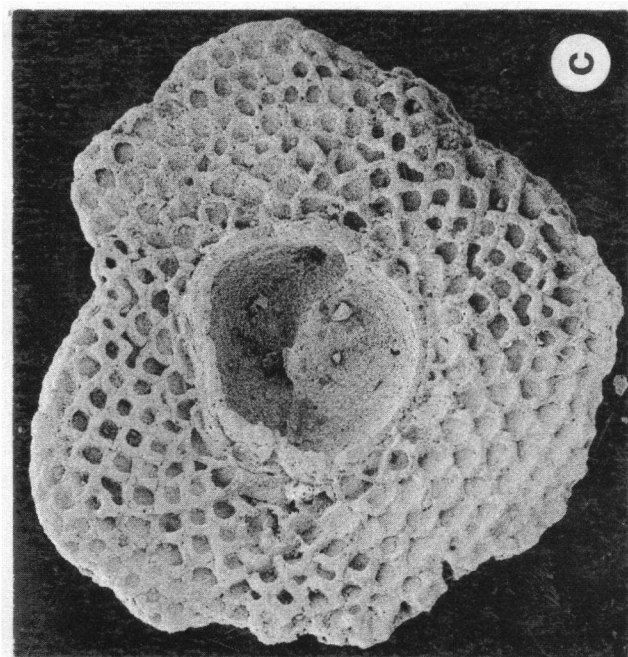


Figure 16.

- A - Locality ER176, lower Montpelier Formation, Dressikie, parish of St Mary, *Heterostegina ocalana*, megalospheric specimen, x 35; note lack of chamber subdivisions in the alar prolongations.
 B - Locality ER176, *Heterostegina ocalana*, microspheric specimen, x 35.
 C - Locality ER176, *Eulepidina chaperi*, megalospheric specimen broken equatorially, x 37.
 D - Locality ER176, enlargement of part of Figure 16C showing the diagonal and annular stolons, x 180.
 E - Locality ER176, *Eulepidina chaperi*, part of the equatorial layer to show stacking of equatorial chamber stolons in several layers, x 250.

The nephrolepidine characteristics of *N. isolepidinoides* are somewhat more advanced than those of specimens referred to *N. yurnagunensis* from Jamaica and the Guyana Basin (compare suggested species limits of van Vessem, 1978, p. 125, for *N. isolepidinoides* with the data for *N. yurnagunensis* in Wong, 1976, table 1). At locality ER621 (see Figures 9a, 14a, b; P18 planktonic foraminiferal zone) the values for three measured parameters are:

	Mean	Standard deviation
DI (protoconch diam.)	0.15 mm	0.15 on 15 specimens
DII (deuteroconch diam.)	0.17 mm	0.07 on 15 specimens
C (number of adauxiliary chambers)	range 0-3 on 10 specimens	

Lepidocyclina chaperi (H. Douvillé) and its close relatives (Cole, 1953) have commonly been assigned to *Nephrolepidina* (as it was, though doubtfully, by Robinson & Wright, 1993). It may be distinguished by the much larger size of the nucleus, compared with true *Nephrolepidina* at the same stratigraphic horizons; by the arrangement of the perieubryonic chambers, which become relatively small and numerous; by possessing adauxiliary chambers not in the equatorial plane; by a six-stolon system arranged in several planes in relatively large, close-arcuate to spatulate equatorial chambers (Figure 16c-e); and by the possession of commonly overlapping layers of lateral chambers with thick walls. These are features also possessed by *Eulepidina* H. Douvillé.

Eulepidina H. Douvillé — *Eulepidina* is here regarded as a distinct genus (Eames *et al.*, 1962b). The definition used by those authors is emended (Sirotti, 1983) to include species such as *L. sanfernandensis* Vaughan & Cole and *Eulepidina chaperi* (Lemoine & R. Douvillé), as discussed above, with relatively thin-walled, nephrolepidine to eulepidine nuclei that are substantially larger (deuteroconch widths of 0.6 mm or more) than those associated with species of true *Nephrolepidina* at uppermost Eocene and Lower Oligocene horizons (where deuteroconch widths seldom exceed 0.2 mm), and that have spatulate, rather than the rhombic or diamond-shaped chambers of *Nephrolepidina* at these horizons (compare Figure 6b with 9a, and Figure 14 with 16c).

Eocene lepidocyclines — A more complete discussion of taxonomic groupings within the lepidocyclines is outside

the scope of this paper. However, two Eocene groups, provisionally retained in *Lepidocyclina*, are recognised in Jamaica, in addition to the taxa listed above. These include forms referred by Butterlin (1990) to *Neolepidina*, by Cole (1962) to *Pliolepidina* and by Sirotti (1983) to *Nephrolepidina*. Adams (1987, p. 302) discussed some of the features of these forms under his *Lepidocyclina* groups A and B.

Eocene megalospheric forms, with isolepidine or subisolepidine nuclei (deuteroconch width less than protoconch width), surrounded by four perieubryonic spires, but retaining overlapping, vacuolar-like lateral chambers, similar to those of *Polylepidina* (Barker & Grimsdale, 1936), are represented by *L. proteiformis*, *L. ariana* and *L. macdonaldi* (Grimsdale, 1959, Y lineage). Eocene lepidocyclinids assigned by Grimsdale (1959) to his lineage X and placed in the subfamily Helicolepidininae by Sirotti (1983) also form a well-defined group, characterised by an isolepidine nucleus, rhombic-diamond shaped equatorial chambers and, normally, well-developed, vertically stacked lateral chambers in regular tiers. Most of these forms possess relatively small protoconchs and deuteroconchs, but species such as *L. trinitatis* and *L. pustulosa* developed somewhat larger nuclear chambers. The use of the name *Neolepidina* Brönnimann (type species *Lepidocyclina (Isolepidina) pustulosa* H. Douvillé) by Butterlin (1981, 1990) in an extended sense, to include species of *Lepidocyclina sensu lato*, such as *L. ariana* and *L. macdonaldi*, is here rejected, although the name remains available for members of the *Lepidocyclina pustulosa* group. The name *Polyorbitoina* van den Geyn & van der Vlerk (1935; type species *Lepidocyclina (Polylepidina) proteiformis* Vaughan) also remains available for the early Y-lineage lepidocyclines.

3 - Miogypsinids

The use of statistical morphometric methods of species classification, developed by Tan Sin Hok (1936, 1937) and carried to a sophisticated level by C.W. Drooger and his colleagues (Drooger, 1993 and references therein) has led to a detailed understanding of many of the evolutionary trends displayed by the miogypsinids. On the other hand, the information needed to apply his Mx, V and other scales for specific identification of miogypsinid populations (Drooger, 1963; O'Herne & van der Vlerk, 1971; Amato & Drooger, 1967) is difficult to extract from random thin sections of hard limestone. More useful is a typological approach, using generic and/or

subgeneric criteria, which can frequently be obtained from non-oriented sections.

Little systematic investigation of miogypsinids has been carried out in Jamaica. Therefore, in this paper, the Jamaican miogypsinids are divided into two categories for zonation purposes. Those species lacking lateral chambers are referred to *Miogypsinella* Hanzawa, while those with lateral chambers are placed in *Miogypsina* Sacco.

The taxon *Miogypsinella* is treated as a genus distinct from *Miogypsinoides*, following Hanzawa (1940) and Boudagher-Fadel *et al.* (2000). Apart from the differences in the structure and arrangement of the lateral tissue, the forms of *Miogypsinoides* corresponding to the type species, *Miogypsina dehaarti*, have not been seen in Jamaica, and have not been reported, so far, from the Caribbean region. It is also evident from the literature (e.g., Boudagher-Fadel *et al.*, 2000) and from personal observation of samples from Irian Jaya (Indonesia), that *Miogypsinoides sensu stricto* is essentially an Early Miocene rather than a Late Oligocene genus, whereas *Miogypsinella* occurs primarily in the Oligocene (lower Te letter stage). Placing the taxon *Miogypsinella* in synonymy with *Miogypsinoides*, as has been done by many workers in the past forty years (Barker 1965; Cole, 1964, 1967; Drooger, 1963, 1993), thus obscures useful stratigraphic and palaeobiogeographic information.

Within *Miogypsina*, distinctions in random thin sections can frequently be made between those species with a peripherally (or apically) situated proloculus (*Miogypsinopsis* Hanzawa; *Miogypsina sensu stricto*) and those with a subcentrally to centrally placed proloculus (*Miogypsinita* Drooger; *Miolepidocyclina* Silvestri). A further distinction is possible between forms with a uniserial nepiont (*Miogypsinopsis*, *Heterosteginoides* Cushman with a single neorotaliid spire of variable length, lacking a principal auxiliary chamber) and forms with a multiserial nepiont (*Miolepidocyclina*, *Miogypsinita*, *Miogypsina sensu stricto*; possessing one or two principal auxiliary chambers and two to four periembryonic spires). In the present state of investigations in Jamaica, it seems preferable to retain *Miogypsina* for all these forms, for the purposes of the zonation.

4 - Orthophragmines

Less (1987) and Ferrandez-Cañadell (1999) have taken a leading role in re-examining the phylogenetic relationships amongst the orthophragmines (discocyclines of some authors), based on examination of microspheric specimens. While the relationships among the Caribbean orthophragmine genera have yet to be investigated in detail, Caudri (1972) critically examined the evidence provided by certain microspheric examples to recognise that the genera grouped in the 'pseudophragmines' of authors (and listed as such in fig. 4) should be assigned to two different families. The Palaeocene-earliest Eocene *Athecocyclina* Vaughan & Cole and Eocene *Propocyclina* Vaughan & Cole are referred to the Discocy-

clinidae. The genera *Pseudophragmina* H. Douvillé, and *Stenocyclina* Caudri are referred to the Orbitoclypeidae, along with *Neodiscocyclina* Caudri and *Asterocyclina* Gumbel.

This grouping is acknowledged here, although, as Ferrandez-Cañadell (1999, p. 304) has remarked, further study of American species may require a modification of these views, as the microspheric characteristics of most American species are unknown. No detailed analysis of the pseudophragmines has been attempted for this paper.

5 - Archaiasins and soritines

The taxonomy of central Caribbean Oligocene and Early Miocene archaiasins and soritines is poorly known. This is partly due to poor preservation of specimens, or preservation in well lithified limestone, and partly due to the lack of detailed work on populations from these horizons. Identification of the several species evident in the author's collection is proceeding slowly.

Four species are tentatively identified here. *Archaias asmaricus* Smout & Eames was reported from Upper Oligocene limestone in eastern Jamaica (Robinson & Wright, 1993, p. 305). Herein, three more species are indicated, illustrated in Figures 12-14. *Archaias? sp. cf. A. kirkukensis* Henson is a large, biconcave discoidal species with a small spiral stage and subdued polar swelling, developing a broad annular stage, with apertures distributed more or less randomly over the entire apertural face. Identification of *Miarchaias floridanus* (Conrad) is based on the radial fold seen in one or two accidental sections (Figure 13; see Hottinger, 2001 for the description of *Miarchaias*).

Although many accidental sections of specimens called here *Miosorites americanus?* (Cushman) are available, these appear to correspond more closely to the types of *Amphisorus matleyi* Vaughan (1929) than to *M. americanus* (see Seiglie *et al.*, 1977), most showing only two or three rows of apertures in a well-marked, but poorly incised, central peripheral sulcus. The proloculus, where seen, also appears to be smaller than that of *M. americanus*. H.R. Versey (pers. comm.) has indicated that specimens called here *A. cf. A. kirkukensis* occur with *M. americanus?* in the lower of two 'Amphisorus' bands he identified in strata referred to the Newport limestone. This lower band, from which sample ER2511 was obtained (see Figures 12, 13), corresponds to the archaiasind-rich coral limestone at locality TSN 3.1, discussed above under the section on the *Heterostegina* (*Vlerkina*) Subzone of the *Miogypsina* Zone. Faunas of the upper band have not been examined, but may be represented by the spot sample of Figure 12b.

Conclusions

The zonation proposed here, while not tied securely to measured sections, is offered as a working document and a biostratigraphic basis for lithostratigraphic studies now

being undertaken (Mitchell, 2004). The fact that other Caribbean zonal schemes, such as those by Cole (1967), Butterlin (1981) and Blanco Bustamante *et al.* (1987), are closely comparable to this one suggests that the scheme will provide a reliable vehicle on which a more detailed larger shallow benthic foraminiferal biostratigraphy can be developed. The present scheme also attempts to place some poorly correlated Oligo-Miocene genera and species of the platform interior within the context of a zonation based mainly on shelf margin genera.

The larger foraminiferal zones proposed here can be correlated reasonably well with many of the standard planktonic foraminiferal and calcareous nannofossil zones of Blow (1969), Berggren *et al.* (1995) and Martini (1971; Table 1, Figure 4 herein).

A direct correlation of the Eocene larger foraminiferal zones defined here with the Tethyan shallow benthic zones (SBZs) of Serra-Kiel *et al.* (1998) and Cahuzac & Poignant (1997) is not yet possible, due to substantial transatlantic differences in genera and species (particularly for the Eocene), and the as yet inadequate matching of faunas with cyclostratigraphy in Jamaica. However, a broad, indirect comparison is accomplished through the correlation of both schemes with the standard 'Tertiary' planktonic zones.

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Appendix 1. Larger benthic foraminiferal species index

- americana* (Cushman, 1919), *Cushmania* — Cole & Applin, 1964, pl. 2, figs 3, 6
americanus (Cushman, 1918), *Miosorites* — Seiglie *et al.*, 1977, pl. 2, figs 1, 4; Vaughan, 1929, pl. 41, fig. 5
americanus? (Cushman, 1918), *Miosorites* — Vaughan, 1929, pl. 41, figs 1-4
antillea (Cushman, 1919), *Eulinderina* — Cole, 1960, pl. 10, fig. 1; pl. 11, figs 6, 13; pl. 12, figs 1-8
antillea Cushman, 1919, *Heterostegina* (*Vlerkina*) — Cole, 1953, pl. 5, figs 1-11
ariana Cole & Ponton, 1934, *Lepidocyclina* — Cole & Applin, 1964, pl. 5, figs 4, 7, 10-12
asmaricus Smout & Eames, 1958, *Archaias* — Robinson & Wright, 1993, figs 15:6-10
bermudezi Drooger, 1951, *Miogypsinoides* (*Miogypsinella*) — Drooger, 1951, text-figs 1-3; pl. 1, figs 4-6
bikiniensis Cole, 1954, *Halkyardia* — Robinson, 1996a, fig. 3a-c
bullbrookii Vaughan & Cole, 1941, *Spiroclypeus* — Vaughan & Cole, 1941, pl. 17, figs 1-8
canellei Lemoine & R. Douvillé, 1904, *Lepidocyclina* — Cole, 1953, pl. 16, figs 1, 3, 4, 11, 12, 16; pl. 17, figs 1, 3
cassis (Oppenheim, 1896), *Fabiania* — Robinson & Wright, 1993, fig. 17:1, 3-6
chaperi (Lemoine & R. Douvillé, 1904), *Eulepidina* — Cole, 1953, pl. 10, figs 3-7; pl. 12, figs 3-7
chawneri (Palmer, 1934), *Paraspiroclypeus* — Cole, 1958b, pl. 34, figs 1, 5, 8, 10, 11
chiapasensis (Vaughan, 1924), *Polylepidina* — Robinson & Mitchell, 1999, pls 9, 10
christianaensis Robinson, 1993, *Coskinolina* — Robinson, 1993, pl. 1, figs 1-7; pl. 2, fig. 1; Robinson & Wright, 1993, figs 7:8-9, 8:8
cojimarensis (Palmer, 1934), *Nummulites* — Cole, 1961b, pl. 28, figs 1-3, 5-7
colei Robinson, 1969, *Fabularia* — Cole, 1956a, pl. 26, figs 11-14
cookei (Moberg, 1928), *Fallotella* — Robinson & Wright, 1993, fig. 9:1-7
dehaarti van der Vlerk, 1924, *Miogypsinoides* (*Miogypsinoides*) — van der Vlerk, 1966, pl. 1, figs 1-3, 7
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dimorpha Barker & Grimsdale, 1936, *Helicostegina* — Barker & Grimsdale, 1936, pl. 32, figs 6, 7; pl. 34, figs 7, 9
favosa Cushman (1919), *Eulepidina* — Vaughan & Cole, 1941, pl. 40, figs 1-4
floridana Cushman & Ponton, 1933, *Gunteria* — Cole & Gravell, 1952, pl. 91, figs 1-4
floridana Cole, 1941, *Pseudochrysalidina* — Cole, 1956a, pl. 24, figs 1, 2; pl. 25, figs 1-5
floridanus (Conrad, 1846), *Miarchaias* — Smout & Eames, 1958, pl. 42, figs 1, 2
floridensis Cole, 1942, *Linderina* — Cole, 1942, pl. 11, fig. 8; pl. 15, figs 7-11
floridensis Heilprin, 1885, *Nummulites* — Cole, 1958a, pl. 19, figs 1, 10
gardnerae (Cole, 1938), *Polylepidina* — Cole, 1929, pl. 1, figs 1-6; pl. 2, figs 1, 2
guayabalensis Barker, 1939, *Nummulites* — Barker, 1939, pl. 18, fig. 4; pl. 22, fig. 3
gunteri Applin & Jordan, 1945, *Fabularia* — Cole & Applin, 1964, pl. 4, figs 3, 7, 11, 13, 17; Cole, 1956a, pl. 26, figs 7-10
gyralis (Barker & Grimsdale, 1936), *Helicolepidinoides* — Barker & Grimsdale, 1936, pl. 32, figs 4, 5; pl. 34, figs 2-6
hanzawai Robinson, 1993, *Fabularia* — Robinson, 1993, pl. 2, fig. 6; pl. 7, figs 4, 5
hottingeri Robinson, 1993, *Yaberinella* — Hottinger, 1969, pl. 5, figs 1-6
isolepidinoides (van der Vlerk, 1929), *Nephrolepidina* — van der Vlerk, 1929, figs 20, 45, 48; van Vessel, 1978, pl. 3, figs 1-6
jamaicensis Robinson, 1974a, *Cyclorbiculinoidea* — Robinson, 1974a, pl. 3, figs 3-5; pl. 4, figs 1-4, 7
jamaicensis (Cushman & Jarvis, 1931; *non* Cole, 1956a, subjective secondary homonym), *Verseyella* — Cushman & Jarvis, 1931, pl. 10, fig. 1a, b; Robinson, 1993, pl. 6, figs 1-10, 12
jamaicensis Vaughan, 1928b, *Yaberinella* — Vaughan, 1928b, pl. 4, pl. 5
kirkukensis Henson, 1950, *Archaias* — Smout & Eames, 1958, pl. 40, figs 1-15
lopeztrigoi Palmer, 1934, *Amphistegina* — Cole & Gravell, 1952, pl. 91, figs 6-8
macdonaldi Cushman, 1919, *Lepidocyclina* — Vaughan & Cole, 1941, pl. 31, fig. 2; Cole, 1956a, pl. 27, figs 3-5, 8
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matleyi Vaughan, 1929, *Amphisorus* — Vaughan, 1929, pl. 41, figs 1-4
matleyi (Vaughan, 1929), *Pellatispirella* — Cole, 1956b, pl. 32, figs 1-8; pl. 34, figs 2, 4-10
matleyi (Vaughan, 1929), *Pseudofabularia* — Vaughan, 1929, pl. 40, figs 2-12; Robinson, 1974b, pl. 1
mexicana (Nuttall, 1928a), *Neorotalia* — Poag, 1966, pl. 6, figs 11-19; Hottinger *et al.*, 1991, fig. 2
minima (Cushman, 1918), *Asterocyclina* — Cole, 1953, pl. 26, figs 6, 7, 14, 15
montgomeryensis Cole, 1949, *Lepidocyclina* — Gravell & Hanna, 1935, pl. 30, figs 1-9; pl. 31, figs 1-11; pl. 32, figs 1-4; Vaughan & Cole, 1941, pl. 32, figs 1-4
nitida Caudri, 1996, *Polylepidina* — Caudri, 1996, pl. 14, figs 3, 6-8
ocalana Cushman, 1921, *Heterostegina* — Cole, 1953, pl. 4, figs 2-18
ospinae (Caudri, 1974), *Caudriella* — Caudri, 1974, pl. 1, fig. 21; pl. 2, fig. 13; pl. 7, figs 1-9
panamensis (Cushman, 1918), *Pliolepidina* — Cole, 1956a, pl. 28, fig. 11; Robinson, 1993, pl. 8, fig. 3; Robinson &

- Mitchell, 1999, pl. 6, cover illustration
- panamensis* Robinson, 1993, *Yaberinella* — Cole, 1953, pl. 6, fig. 1, 2, 4-6; Robinson, 1993, pl. 8, fig. 2
- parvula* (Cushman, 1918), *Amphistegina* — Robinson & Wright, 1993, fig. 18:4, 5
- parvula* Cushman, 1919, *Lepidocyclina* — Vaughan & Cole, 1941, pl. 36, figs 1-5
- peruviana* Cushman, 1922, *Lepidocyclina* — Robinson & Wright, 1993, fig. 24:1
- proteiformis* Vaughan, 1924, *Lepidocyclina* — Cole, 1956a, pl. 27, fig. 6; pl. 28, figs 7, 8
- pustulosa* (H. Douvillé, 1917), *Lepidocyclina* — Caudri, 1996, pl. 15, figs 1, 2
- pygmaeus* Hanzawa, 1930, *Borelis* — Cole, 1958c, pl. 240, figs 11-13
- sanfernandensis* Vaughan & Cole, 1941, *Lepidocyclina* — Vaughan & Cole, 1941, pl. 43, figs 1-3
- seigliei* Robinson, 1993, *Twaraina* — Robinson, 1993, pl. 4, fig. 1-5
- sherwoodensis* Vaughan, 1928, *Lepidocyclina* — Vaughan, 1928a, pl. 48, figs 4-8
- striatoreticulatus* (L. Rutten, 1928), *Nummulites* — Rutten, 1928, pls H, I
- subglobosa* (Nuttall, 1928a), *Nephrolepidina*? — Vaughan & Cole, 1941, pl. 31, figs 8, 9; Caudri, 1996, pl. 17, figs 4-6, 9
- subplana* (Barker & Grimsdale, 1936), *Eulinderina* — Barker & Grimsdale, 1936, pl. 35, fig. 6
- tobleri* (H. Douvillé, 1917), *Pliolepidina* — Vaughan & Cole, 1941, pl. 24, figs 1-10; Cole, 1962, pl. 6, fig. 5; pl. 8, figs 1, 2, 4, 5, 7
- tournoueri* (Cole, 1953, *non* Lemoine & R. Douvillé, 1904), *Nephrolepidina* — Cole, 1953, pl. 19, figs 9-12
- trelawniensis* Vaughan, 1929, *Yaberinella* — Vaughan, 1929, pl. 39, fig. 1
- trimera* Barker & Grimsdale, 1937, *Pseudolepidina* — Cole, 1956a, pl. 31, figs 10-16
- trinitatis* H. Douvillé, 1924, *Lepidocyclina* — Vaughan & Cole, 1941, pl. 25, figs 6, 7, 9; pl. 26
- undosa* (Cushman, 1919), *Eulepidina* — Caudri, 1996, pl. 20, fig. 1; pl. 21, fig. 1
- vanderstoki* M.G. Rutten & Vermunt, 1932, *Nummulites* — Cole, 1958b, pl. 32, figs 10, 12-15
- vaughani* Cole & Ponton, 1934, *Fabularia* — Cole & Applin, 1964, pl. 4, fig. 12
- vaughani* (Cushman, 1919), *Nephrolepidina* — Cole, 1968, pl. 19, figs 1-3, 6; pl. 20, figs 1-3, 6, 7
- verseyi* Cole, 1956a, *Fabularia* — Robinson, 1974a, pl. 4, figs 5, 6; pl. 5, figs 1-6; pl. 6, figs 1, 3-7; pl. 7, fig. 1
- wellsi* Cole & Bermudez, 1944, *Eoconuloides* — Robinson & Wright, 1993, fig. 18:1, 2; fig. 19:1-5
- yurnagunensis* (Cushman, 1919), *Nephrolepidina* — Vaughan & Cole, 1941, pl. 38, fig. 3; Cole, 1968, pl. 23, fig. 8; pl. 24, figs 5, 8
- zansi* Robinson, 1993, *Coskinolina* — Cole, 1956a, pl. 24, figs 6-11; Robinson & Wright, 1993, fig. 7:4-7; fig. 8:10