Cainozoic Research, 3(1-2), pp. 143-156, December 2004
In: Donovan, S.K. (ed.). *The Mid-Cainozoic White Limestone Group of Jamaica*

Echinoderms of the Mid-Cainozoic White Limestone Group of Jamaica

Stephen K. Donovan

Nationaal Natuurhistorisch Museum, Department of Palaeontology, P.O. Box 9517, NL-2300 RA Leiden, the Netherlands; e-mail: Donovan@naturalis.nnm.nl

Received 15 September 2001; revised version accepted 22 April 2003

Echinoids are locally common in certain units of the White Limestone Group, Jamaica. The upper Middle to Upper Eocene Troy Formation (lagoonal palaeoenvironment) includes common clypeasteroids, particularly neolaganids. In contrast, the dominant echinoids of the coeval Swanswick Formation (shelf edge setting) are oligopygoids and spatangoids. In deeper water, an upper Middle Eocene horizon low in the Montpelier Formation includes clypeasteroids and cidaroid spines, although these may have been derived by downslope transport. Nominal echinoid taxa are almost unknown from the Upper Eocene and Lower Oligocene of the island. The Oligocene *Lepidocyclina*-dominated biofacies of the Moneague Formation (shelf edge) includes a fauna in which the spatangoids are reminiscent of similar Middle Eocene settings, although not as diverse, but the oligopygoids are replaced by *Clypeaster* spp. The shallow-water Miocene *Amphisorites matleyi*-yielding limestones of the Moneague Formation has yielded few echinoid remains apart from clypeasteroids, particularly *Clypeaster* spp., but a reef fauna preserved in deeper-water chalks (Montpelier Formation) after downslope transport retained a greater diversity of species. Faunas of the Oligocene and Miocene units have a distinct modern aspect. However, the well-lithified limestones of the White Limestone Group do not favour collecting techniques that would enable accurate determinations of diversity of echinoderms.

Key words: Eocene, Oligocene, Miocene, Crinoidea, Asteroidea, Ophiuroidea, Echinoidea.

Introduction

The rock record of Jamaica spans the interval Cretaceous to Quaternary. The fossil echinoids of the island were initially described by Arnold & Clark (1927, 1934) and Hawkins (1923, 1924, 1927). The monographic studies of Arnold & Clark were made outside a biostratigraphic framework and it was not until Donovan's (1988) study that most Jamaican Cainozoic echinoid taxa were even related to series. This study emphasised that the majority of well-known fossil echinoids from the island were from either the Eocene Yellow Limestone Group or, to a much lesser extent, the fossiliferous units of the Upper Cretaceous. This original study was refined and expanded by Donovan (1993, table 2), in which a summary of the known echinoids of the White Limestone Group was included, supplementing the original analysis with data gleaned from new collections and the specimens of McFarlane (1974, 1977a) in the UWIGM. With the notable exception of the Eocene Swanswick Formation (Donovan *et al.*, 1989), even so recently as the early 1990s the record remained sparse and patchy, based on relatively few specimens and fewer localities.

I took up an appointment as part of the teaching staff in the Department of Geology, University of the West Indies (UWI), Mona, in January 1986, and within six months had examined many of the principal Cretaceous and Cainozoic fossiliferous units exposed in eastern and central Jamaica. At this time I was persuaded by what I had seen that the White Limestone Group offered little encouragement for echinoderm studies; I had seen few spines, no tests and considered the case hardened limestones to be unpromising for most aspects of macropalaeontology. As Fortey (2000, p. 189) has noted regarding lithologically similar, albeit Palaeozoic, deposits, 'Collecting fossils from great cliffs of former tropical limestones can be a dispiriting experience, as your hammer bounces helplessly off the intransigent surfaces. .... You curse the fact that the limestone and [fossils] are made of the same material, calcite, as you try to lever out a block with your precious specimen somewhere in the middle.'

That my preliminary opinion was proved erroneous, at least in part, is principally due to the collecting efforts of three notable individuals, each of whom has made an important contribution to our knowledge of echinoids from

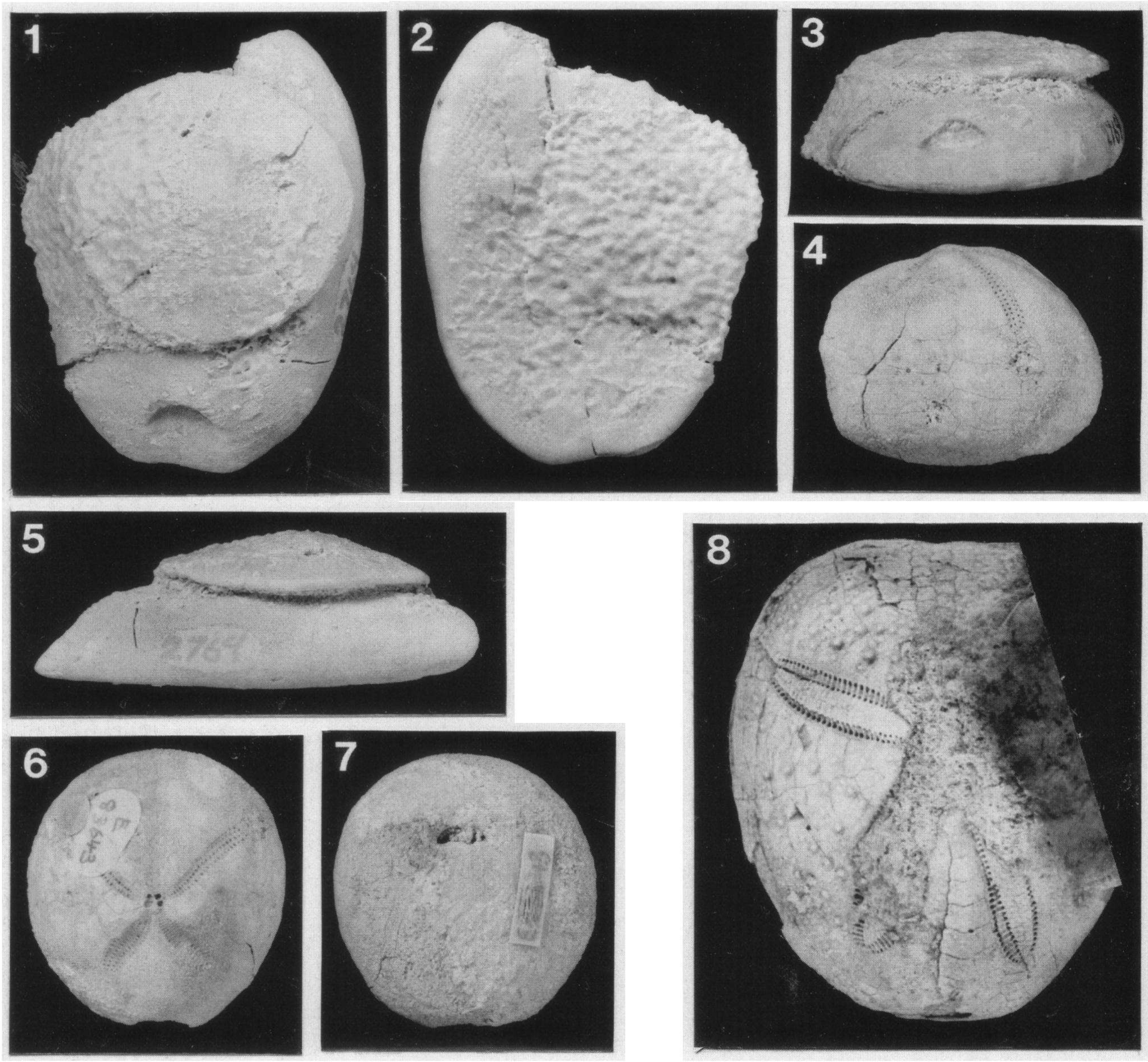


Figure 1 (above). Selected Eocene echinoids of the White Limestone Group, Jamaica.

1-3, 5 - *Eurhodia* sp. cf. *E. rugosa* (Ravenel, 1848) (with unidentified neolaganid clypeasteroid cemented to apical surface), UWIGM 2764, Troy Formation, in apical (1), oral (2), posterior (3) and right lateral views (5).

4, 6, 7 - *Agassizia inflata* Jackson, 1922, BMNH E83643, Swanswick Formation, in right lateral (4), apical (6) and oral (7) views.

8 - *Eupatagus* sp. cf. *E. antillarum* (Cotteau, 1875), BMNH EE 6341, Troy Formation, apical view (after Donovan & Rowe, 2000, fig. 4.1), x 1.3.

All x 1.5 unless stated otherwise. Specimens whitened with ammonium chloride sublimate.

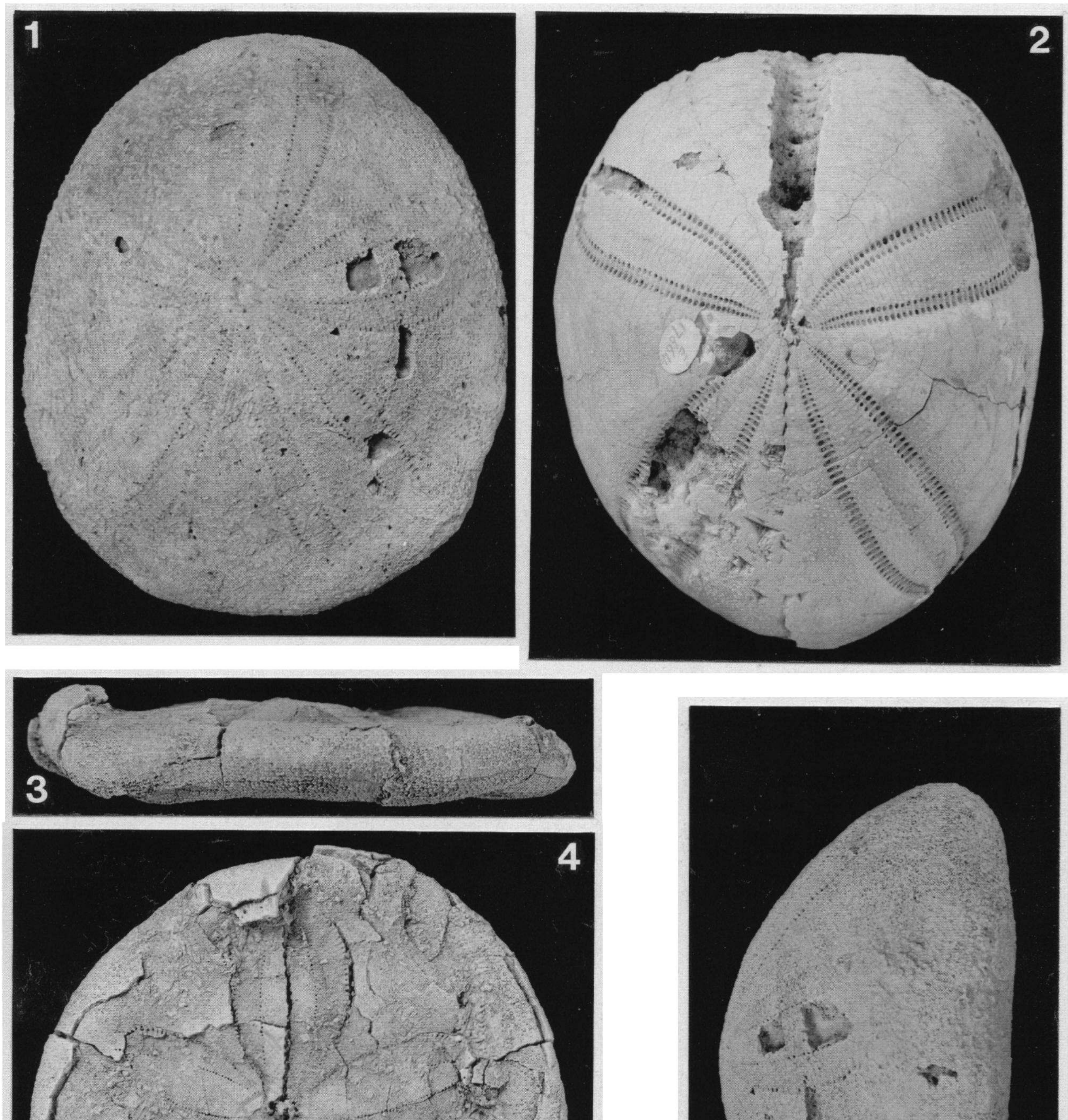
Figure 2 (opposite). Selected Oligocene echinoids of the *Lepidocyclina*-dominated biofacies of the Moneague Formation (ex-Browns Town Formation), White Limestone Group, Jamaica.

1, 5 - *Clypeaster* sp. cf. *C. julii* Roman, 1952, BMNH EE 5698, in apical (1) and right lateral (5, anterior towards top of page) views.

2 - *Eupatagus hildae* Hawkins, 1927, holotype, BMNH E17664, apical view.

3, 4 - *Clypeaster oxybaphon* Jackson, 1922, BMNH EE 5690, in left lateral (3, anterior to left) and apical (4) views.

All x 1. Specimens whitened with ammonium chloride sublimate.


1
2
3
4
5

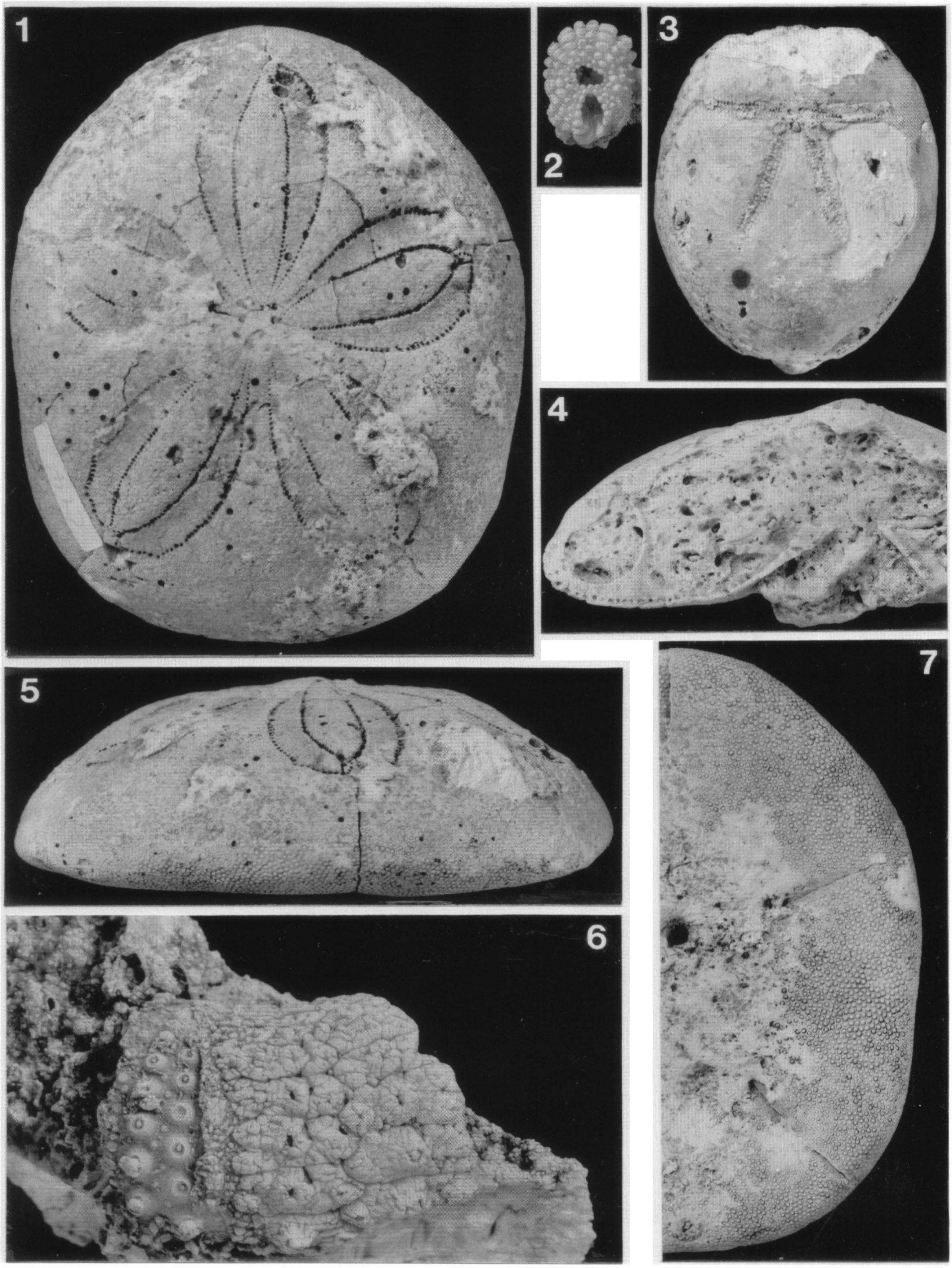

1
2
3
4
5
6
7

Figure 3. Selected Miocene echinoids of the White Limestone Group, Jamaica. All Montpelier Formation unless stated otherwise.

1, 4, 5, 7 - *Clypeaster* sp., *Amphisorites matleyi*-yielding limestones of the Moneague Formation (ex-Newport Formation), BMNH EE 5718, in apical (1), right lateral (5) and partial oral (5) views; BMNH EE 5719, anteroposterior section of test (4, anterior to right) showing depressed peristomial region and raised apex.
2 - *Echinoneus cyclostomus* Leske, 1778, Montpelier Formation, UF 38953, oral view of 'crystal apple' (Donovan & Portell, 2000), x 4.
3 - *Brissus* sp. aff. *B. unicolor* (Leske, 1778), Montpelier Formation(?) (probably Miocene), BMNH E17226, internal mould, apical view (after Donovan & Harper, 2000, fig. 1A).
6 - *Echinometra* sp. aff. *E. lucunter* (Linné, 1758), Montpelier Formation, UF 68450, ambulacrum and interambulacrum, the latter showing a well-developed coating of calcite crystals (Donovan & Portell, 2000), x 2.

All x 1 unless stated otherwise. Specimens whitened with ammonium chloride sublimate.

the White Limestone Group. The late Mr William F. Schickler (Donovan, 2002), a retired engineer from Cleveland, Ohio, was intrigued by small spherical fossils that were common in the soil of his extensive property at Pimento Hill, Beecher Town, parish of St Ann. Dr Jeremy Woodley, then head of the Discovery Bay Marine Laboratory, UWI, on Jamaica's north coast, was approached and redirected Mr Schickler's enquiries to the author. The echinoid fauna collected from Pimento Hill, now numbering over 900 specimens (including cidaroid spines), is undoubtedly Eocene as indicated by the very numerous tests of the oligopygoid *Haimea ovumserpentis* gr. (Guppy, 1866) (see Kier, 1967) and coeval spatangoids (Figure 1/4, 6, 7), and forms part of the outcrop of the Swanswick Formation. The initial report of the Pimento Hill echinoids was of local stratigraphic importance (Donovan *et al.*, 1989), as this area had most recently been mapped as part of the Miocene outcrop of the Montpelier Formation (Henry & McFarlane, 1978). Mr Schickler's contribution to the study of Jamaica Eocene echinoids is recorded by a species named in his honour, *Aguayoaster schickleri* Donovan & Rowe, 2000. This fauna is the subject of Ms Deborah-Ann Rowe's ongoing research at UWI.

Up until the early 1990s, only one echinoid, the holotype of the spatangoid *Eupatagus hildae* Hawkins, 1927 (see Figure 2/2), had been adequately described and documented from the Jamaican Oligocene. Mr Hal L. Dixon, then Head Technician in the Department of Geology, UWI, commenced research in 1991 to examine the diversity and systematics of the Jamaican Upper Oligocene echinoids of the Browns Town Formation (= *Lepidocyclina*-dominated biofacies of the Moneague Formation *sensu* Mitchell, 2004). The success of this investigation is recorded in his M.Phil. thesis (Dixon, 1995) and related publications (Dixon & Donovan, 1994, 1998). Adding to the one specimen already known, Hal collected over a thousand more echinoid tests, test fragments and spines; he also found disarticulated asteroid marginal ossicles (Donovan *et al.*, 1993), ophiuroid arm ossicles picked from sediment removed from the surfaces of echinoids during mechanical cleaning, and a solitary comatulid brachial ossicle (Dixon *et al.*, 1994).

The Miocene echinoids of Jamaica, from the stratigraphic interval that Ager called 'the age of echinoids' (Ager, 1993, p. 27), nevertheless have proved to be particularly intractable to the collector. Records of echinoids from the Miocene of the White Limestone Group have mainly been concerned with various clypeasteroids - *Clypeaster* spp. and scutellids - which are apparent locally in rock faces (Donovan, 1991), but which are only collectable in instances where they have weathered out on grassy hillsides. Mr Roger W. Portell of the Florida Museum of Natural History, Gainesville, has found reef slideblocks at the Duncans Quarry in Trelawny (see below) that had dropped down into Lower Miocene chalk deposits of the Montpelier Formation. Although dominantly composed of scleractinian corals, these blocks have yielded a fascinating fauna including brachyuran crabs (Portell & Collins, 2004), nautiloids (Portell *et al.*, 2004) and echinoid tests and test fragments preserved as 'crystal apples' (Donovan & Portell, 2000) (see Figure 3/2, 6). These remain the only complete or near- complete, non-clypeasteroid echinoids known from the Jamaican Miocene.

Specimens used in the present study are deposited in the collections of The Natural History Museum, London (BMNH), the Florida Museum of Natural History, University of Florida, Gainesville (UF) and the Geology Museum, University of the West Indies, Jamaica (UWIGM). The protocol of open nomenclature follows Matthews (1973) and Bengtson (1988). All illustrated specimens are from the White Limestone Group of Jamaica. Although not comprehensive, figured specimens were chosen to illustrate the range of preservational styles shown by echinoid tests in the White Limestone Group. Except where specifically stated, taxa discussed in this paper are echinoids.

Stratigraphic distribution

Eocene

The greatest diversity of fossil echinoids known from any stratigraphic unit of Jamaica is from the mid Lower to mid

	Tr	Sk	BG	St	Wn	BT	Nt	Mr
Order CIDAROIDA								
Eucidaris sp.			X					
Fellius? *foveatus*? (Jackson, 1922)		X						
Histocidaris sp.								X
Prionocidaris cojimarensis (Lambert & Sánchez Roig *in* Sánchez Roig, 1926)								X
Prionocidaris loveni (Cotteau, 1875)		X						
Prionocidaris spinidentatus (Palmer *in* Sánchez Roig, 1949)						X		
Order ECHINOIDA								
Echinometra sp. aff. *E. lucunter* (Linné, 1758)								X
Suborder CAMARODONTA, incerti ordinis								
Gagaria? sp.					X			
Incerti ordinis[1]								
regular echinoid sp. or spp. indet.	X	XX	X			XX		
Order HOLECTYPOIDA								
Echinoneus sp. cf. *E. cyclostomus* Leske, 1778						X		X
Order OLIGOPYGOIDA								
Haimea ovumserpentis gr. (Guppy, 1866)		X						
Haimea sp.	X							
Oligopygus wetherbyi? de Loriol, 1887		X						
Order CLYPEASTEROIDA								
Clypeaster batheri Lambert, 1915						X		
Clypeaster concavus? Cotteau, 1875 *							X	
Clypeaster sp. cf. *C. julii* Roman, 1952						X		
Clypeaster oxybaphon Jackson, 1922						X		
Clypeaster sp. or spp.*							X	X
Cubanaster sp. cf. *C. acunai* (Lambert & Sánchez *in* Sánchez Roig, 1926)	X							
cf. *Durhamella* cf. *floridanum* (Twitchell *in* Clark & Twitchell, 1915)	X							
Fibularia jacksoni Hawkins, 1927	X							
Fibularia sp.			X					
Tarphygus sp. cf. *T. ellipticus* Arnold & Clark, 1927		X						
Wythella sp.	X							
neolaganid sp. indet.	X							
clypeasteroid sp. or spp. indet.	X		XX					
scutelline clypeasteroid sp. indet.							X	
Order CASSIDULOIDA								
Echinolampas altissima? Arnold & Clark, 1927		X						
Echinolampas clevei Cotteau, 1875		X						
Echinolampas lycopersicus? Guppy, 1866						X		
Echinolampas sp. indet.		X						
Eurhodia matleyi (Hawkins, 1927)	X			?[2]				
Eurhodia sp. cf. *E. rugosa* (Ravenel, 1848)	X							
Rhyncholampas? *alabamensis*? (Twitchell *in* Clark & Twitchell, 1915)†		X						
cassiduloid? sp. nov.		X						
cassiduloid sp. indet.		X						

Order SPATANGOIDA								
Agassizia inflata Jackson, 1922		X						
Agassizia sp.						X		
Aguayoaster schickleri Donovan & Rowe, 2000		X						
Brissus sp. aff. *B. unicolor* (Leske, 1778)								X
Caribbaster loveni (Cotteau, 1875)		X						
Eupatagus alatus Arnold & Clark, 1927		X						
Eupatagus sp. cf. *E. antillarum* (Cotteau, 1875)	X							
Eupatagus? sp. aff. *E. attenuatus* Arnold & Clark, 1927		X						
Eupatagus hildae Hawkins, 1927						X		
Schizaster subcylindricus Cotteau, 1875		X						
spatangoid sp. or spp. indet.		X				XX		X
Incerti ordinis[1]								
irregular echinoid sp. or spp. indet.		X						
TOTALS	**11**	**22**	**5**	**1?**	**1**	**12**	**3**	**7**

Table 1. Stratigraphic distribution of the echinoids of the White Limestone Group of Jamaica. Key: Tr = Troy Formation (mid Middle-Upper Eocene); Sk = Swanswick Formation (Middle-low Upper Eocene); BG = horizon low in the Montpelier Formation (ex-Bonny Gate Formation) (upper Middle Eocene); St = Somerset Formation (Upper Eocene); Wn = miliolid-dominated biofacies of the Moneague Formation (ex-Walderston Formation) (Oligocene); BT = *Lepidocyclina*-dominated biofacies of the Moneague Formation (ex-Browns Town Formation) (high Lower or Upper Oligocene); Nt = *Amphisorites matleyi*-yielding limestones of the Moneague Formation (ex-Newport Formation) (Miocene); Mr = Montpelier Formation (Miocene) (stratigraphic nomenclature mainly after Robinson, 1994, as modified by Mitchell, 2004); [1] = for ease of interpretation, regular and irregular echinoids *incerti ordinis* have been listed separately; [2] = the presence of *E. matleyi* in the Somerset Formation is unconfirmed (Donovan, 1994b); * = provisional identification of one of the *Clypeaster* spp. of Donovan (1991); † = *R. alabamensis* is probably a synonym of *R. gouldii* (B.D. Carter, written comm., November 2001). Data used in constructing this table derived from Dixon & Donovan (1998), Donovan (1991, 1993, 1994a, b), Donovan & Portell (2000, research in progress), Donovan & Rowe (2000), Donovan *et al.* (1991) and Rowe & Stemann (1999), and references cited therein.

Middle Eocene Yellow Limestone Group (mainly from the Chapelton Formation) (Figure 1; Donovan, 1988, 1993). Between the Yellow Limestone Group and the Eocene formations of the White Limestone Group (Robinson, 1994, fig. 6.6) there is notable drop in diversity, although continuing research has reduced this as taxa new to these formations have been discovered (contrast Figure 4 herein with McKinney *et al.*, 1992, fig. 17.5). Palaeoenvironmental and taphonomic influences on this pattern were discussed by Donovan (2001).

The Eocene echinoids of the White Limestone Group were most recently reviewed by Donovan (1994a), including determination of the broad palaeoenvironmental distribution of major taxonomic groups. The available specimens have permitted a 'transect' to be constructed from a low-energy lagoon (Troy Formation) through a high-energy shelf edge setting (Swanswick Formation) into a deeper-water island slope palaeoenvironment (Montpelier Formation). Echinoids are most diverse and numerically most common in the shelf edge Swanswick Formation (Donovan *et al.*, 1989; Donovan, 1994a; Rowe & Stemann, 1999; Donovan & Rowe, 2000), based on the large collection at the University of the West Indies made from Pimento Hill, home of the late Mr W. F. Schickler (see above). Oligopygoids, particularly *Haimea*, are common, associated with spatangoids and cidaroids (commonly as spines), with rarer cassiduloids. There is no exposure at this locality *per se*, but echinoderms have been collected loose from the soil and from dry stone walls.

Rather fewer echinoids are known from approximately coeval units (Table 1). The Troy Formation, deposited in a low-energy lagoonal palaeoenvironment, has yielded over a hundred echinoid specimens, principally clypeasteroids with rare oligopygoids, cassiduloids and indeterminate regular echinoids (McFarlane, 1974, 1977a; Donovan, 1994a). In contrast, clypeasteroids are almost unknown from the higher-energy, shelf edge limestones of the Swanswick Formation, where the closely related oligopygoids are common. Similarly, spatangoids, common in the Swanswick Formation, were unknown from the 'lagoonal' setting until Donovan & Rowe (2000) described *Eupatagus* sp. cf. *E. antillarum* (Cotteau, 1875) from the Claremont Formation. Although recorded hitherto, the cassiduloid *Eurhodia* sp. cf. *E. rugosa* (Ravenel, 1848) from Jamaica has not previously been adequately documented and is formally described herein (see below).

Donovan (1994b) described poorly preserved neolaganid clypeasteroids as cf. *Durhamella* cf. *floridana*

(Twitchell *in* Clark & Twitchell, 1915) from the Somerset Formation, but this stratigraphic assignment was erroneous (Mitchell, 2004), the specimens more accurately coming from the underlying Troy Formation. In consequence, there are no undisputed records of echinoids from the Somerset Formation (Table 1). That is, the stratigraphically highest, shallow-water units of the Jamaican Eocene have, at best, only one unverified occurrence of fossil echinoid, although some echinoids from the Troy Formation may be coeval. Thus, Figure 1 could be refined to show a moderate drop in diversity from the Yellow Limestone Group to the upper Middle Eocene of the White Limestone Group (Troy and Swanswick formations, and the horizon low in the Montpelier Formation (see below)) and a decline in the Upper Eocene (Somerset Formation) to just one occurrence. Thus, based on available evidence, the main drop in echinoid diversity in Jamaica probably occurred at about the transition from Middle to Late Eocene. The next available diverse echinoids, in the Upper Oligocene (or, at least, high in the Lower; Robinson, 2004), show notable changes in taxonomic composition from the Middle Eocene.

Donovan *et al.* (1991) described a collection of small tests and fragmentary remains of larger specimens from a horizon low in the Montpelier Formation (=ex-Bonny Gate Formation; Mitchell, 2004, appendix 2) of eastern Jamaica and conformable on the Font Hill Formation (Yellow Limestone Group), that should probably be considered a distinct lithostratigraphic unit (E. Robinson, pers. comm.). Included benthic foraminifera suggest a shallow-water environment, although, as the Montpelier and Font Hill formations are considered to be deeper-water units, derivation by downslope transport should not be ruled out. Certainly, a deeper-water setting is supported by the presence of isocrinid crinoid columnals (Donovan *et al.*, 1993, p. 127) and the occurrence of small complete tests associated with fragments of larger individuals is reminiscent of the Upper Pliocene Bowden shell bed of southeast Jamaica (Donovan & Paul, 1998), deposited by submarine mass flow in a deeper-water, island shelf setting (Pickerill *et al.*, 1998). Echinoids from this unit include *Eucidaris* sp., *Fibularia* sp. and indeterminate echinoid fragments, including both regular echinoids and clypeasteroids. This horizon is considered to be upper Middle Eocene.

Oligocene

After the relative richness of the Middle Eocene and the Upper Eocene decline, the Jamaican Lower Oligocene maintains a vanishingly small known diversity, although the degree to which taphonomic influences can be separated from the effects of Eocene-Oligocene extinctions is uncertain (Donovan, 1995a, 2001). The Lower Oligocene miliolid-dominated biofacies of the Moneague Formation (ex-Walderston Formation; Mitchell, 2004) has yielded only one identifiable echinoderm fossil, a partial test of the camarodont *Gagaria*? sp. (Donovan, 1996). Mr H. L. Dixon (pers. comm.) has noted clypeasteroids in cross section in indurated limestones and fragmentary spines of regular echinoids also occur locally. However, collecting bias may be an important contributor to our ignorance of Jamaican Early Oligocene echinoids, this part of the succession having received little attention from macropalaeontologists.

In contrast, the high Lower or Upper Oligocene (Robinson, 2004) *Lepidocyclina*-dominated biofacies of the Moneague Formation (ex-Browns Town Formation; Mitchell, 2004) is now known to contain locally abundant echinoid tests and fragmentary remains of about twelve taxa in the type area (Dixon, 1995; Dixon & Donovan, 1998). Most prominent among these are the three species of *Clypeaster*, two of which are illustrated (Figure 2/1, 3-5); all are known from complete tests and, in the example of *Clypeaster oxybaphon* Jackson, 1922, from numerous ambital test fragments. These species show some ecological(?) differentiation and *C. oxybaphon* does not occur at the same horizon as *Clypeaster* sp. cf. *C. julii* Roman, 1952; *Clypeaster batheri* Lambert, 1915, occurs in association with both of these species. However, apart from *Clypeaster* spp., complete echinoid tests are uncommon. Spatangoids show a moderate diversity (Figure 2/2), but specimens are neither as common nor as well preserved as *Clypeaster* spp. Regular echinoids are only known from fragmentary remains, particularly the robust, thorny spines of *Prionocidaris spinidentatus* (Palmer *in* Sánchez Roig, 1949).

The Moneague Formation in the Browns Town area has also yielded ossicles of other echinoderms. Prominent amongst these are unusually large marginal ossicles (up to 10+ mm maximum dimension) of an astropectinid or goniasterid asteroid (Donovan *et al.*, 1993; Mr C. Mah, research in progress); I have noted similar ossicles in the coeval Antigua Formation of Antigua. Dixon *et al.* (1994) also documented indeterminate ophiuroid vertebral ossicles and a comatulid brachial ossicle from these deposits.

Miocene

The Miocene echinoid fauna of Jamaica is particularly impoverished in both diversity and number of specimens. The *Amphisorites matleyi*-yielding limestones of the Moneague Formation (ex-Newport Formation; Mitchell, 2004), deposited in a shallow-water setting and areally extensive in southern central Jamaica (McFarlane, 1977b), includes at least two species of *Clypeaster* (one species, part of the *Clypeaster rosaceus* clade, is illustrated in Figure 3/1, 4, 5, 7) and a scutelline clypeasteroid (Donovan, 1991). These are commonly found in well-lithified limestones, making them difficult to study; specimens found free of the matrix, weathering out on grassy hillsides in farmland, have commonly lost much of their surface detail. Other taxa are only represented by locally common, robust spine fragments derived from regular echinoids (for example, in the southern Carpenters Mountains near the Alligator Hole River, parish of Manchester). The robust nature of the clypeasteroid test is widely appreciated (Kier, 1977; Smith, 1984), so the common occurrence of *Clypeaster* spp. in the Oligocene and Miocene of the Moneague Formation is not surprising. What is surprising is the almost complete absence of evidence for other identifiable echinoid taxa in the *A. matleyi*-yielding limestones of the Moneague Formation, in part determined by the case hardening and lack of friable horizons favouring bulk sampling within these units.

In part, the Montpelier Formation is a Miocene chalk unit exposed mainly in northern central Jamaica (McFarlane, 1977b). An internal mould of an echinoid test, presumably derived from this unit and originally discussed by Hawkins (1924, p. 322), has been described as *Brissus* sp. aff. *B. unicolor* (Leske, 1778) (Figure 3/3; Donovan & Harper, 2000); morphologically similar echinoids range from the Eocene to Recent within the region. The most diverse echinoderm assemblage from this unit comes from a large, disused quarry on the main north coast road between Duncans and Falmouth, parish of Trelawny. This fauna is currently being described by Donovan *et al.* (2005), but includes the isocrinids *Neocrinus* sp. cf. *N. decorus* Wyville Thomson, 1864, and *Isocrinus* sp. (previously referred to either *Diplocrinus* sp. or *Teliocrinus*? sp.; Donovan *et al.*, 1993; Donovan, 1995b); asteroid *Astropecten*? sp. or spp.; ophiuroid sp. indet.; and echinoids *Prionocidaris cojimarensis* (Lambert & Sánchez Roig *in* Sánchez Roig, 1926), *Histocidaris* sp., *Echinometra* sp. aff. *E. lucunter* (Linné, 1758) (Figure 3/6), *Echinoneus* sp. cf. *E. cyclostomus* Leske, 1778 (Figure 3/2), *Clypeaster* spp., and spatangoid sp. indet. All of the more complete specimens, tests or multiple plate columns from tests, are preserved as 'crystal apples' (Donovan & Portell, 2000) in slide blocks of scleractinian corals derived from a shallow-water reef, although the chalks were probably deposited in more than 200 m water depth based on the ichthyological evidence (Underwood & Mitchell, 2004). The echinoids of the Jamaican Oligocene and Miocene have a 'modern' aspect, in contrast with the Eocene of the island which includes a number of taxa (such as oligopygoids and neolaganid clypeasteroids) that went extinct before the Oligocene (Dixon & Donovan, 1994; Donovan, 1995a; for a more general account, see Prothero, 1994).

Series	**Duration (after Harland *et al.*, 1990)**	**Number of echinoid species**	**Echinoid species Myr^{-1}**
Miocene	18.1	16	0.9
Oligocene	12.1	11	0.9
Eocene	21.1	40	1.9

Table 2. Stratigraphic distribution of echinoids in the Eocene-Miocene of Florida (adapted from Oyen & Portell, fig. 2), recalculated as species Myr^{-1}/series.

Systematic palaeontology

Class Echinoidea Leske, 1778
Subclass Euechinoidea Bronn, 1860
Order Cassiduloida Claus, 1880
Family Cassidulidae L. Agassiz & Desor, 1847
Genus *Eurhodia* Haime *in* d'Archaic & Haime, 1853

Eurhodia* sp. cf. *E. rugosa (Ravenel, 1848)
Figure 1/1-3, 5

1993 *Eurhodia* sp. cf. *E. rugosa* (Ravenel)— Donovan, p. 394, table 2.
1994a *Eurhodia* sp. cf. *E. rugosa* (Ravenel)— Donovan, p. 630, table 1.
1995a *Eurhodia* sp. cf. *E. rugosa* (Ravenel) — Donovan, p. 52.

Material, locality and horizon — A single test, UWIGM 2764, from the B11 road between Browns Town and Bamboo, near Burts Run, parish of St Ann (NGR 1:50,000 (old series) 4456 5418). Mid Middle to Upper Eocene Troy Formation, White Limestone Group. Collected by N. McFarlane. In association with Mr H.L. Dixon and Dr D.T.J. Littlewood, I searched for this site in July 1993, but was unsuccessful in relocating it. However, it is close to the locality that yielded *Eupatagus* sp. cf. *E. antillarum* (see Donovan & Rowe, 2000, p. 656, fig. 1).

Description — Test broken anteriorly, poorly exposed, apex obscured by a neolaganid clypeasteroid (both echinoids preserved in same orientation). Apical system, ambulacral petals and peristome all obscured. Some cracking of the test is apparent, possibly due to crushing. Test flattened orally, low domed apically, widest anterior of mid-point, with low, rounded to more angular ambitus. Test narrow and blunt posteriorly, apparently rounded anteriorly. Periproct towards posterior, wider than high, lozenge-shaped, on apical surface and supra-ambital in position. Tuberculation preserved posteriorly, on left side of the oral surface (Figure 1/2), on posterior apical surface and on right side (Figure 1/1, 3, 5). Primary tubercles large orally, but smaller apically.

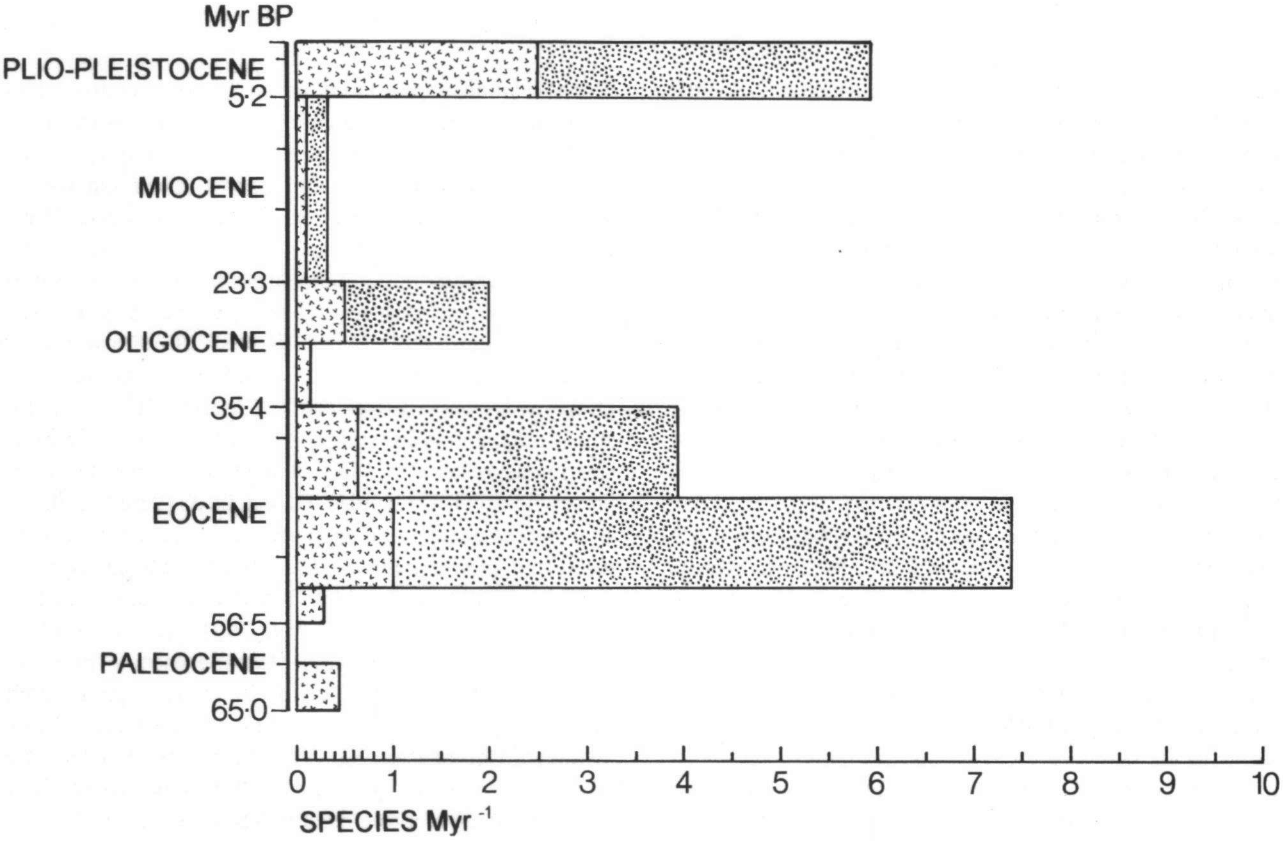


Figure 4. Temporal distribution of fossil echinoids of Jamaica, including unpublished records (after Donovan, 2001, fig. 2). The Eocene record is divided into three unequal parts: earliest (= turbidites of the Richmond Formation; at least one species of regular echinoid); mid-early to mid-middle (Yellow Limestone Group); and above (lower formations of the White Limestone Group). The Oligocene and Miocene records are entirely derived from formations of the White Limestone Group. Key: 'v'-ornament = regular echinoids; stipple = irregular echinoids. Time scale after Harland *et al.* (1990); compare with McKinney *et al.* (1992, fig. 17.5).

For a description of *E. rugosa sensu stricto*, see Cooke (1959, pp. 63, 64).

Remarks — Other echinoid taxa of the White Limestone Group have been, or will be (Rowe, research in progress), described and figured elsewhere. This specimen from the Troy Formation is the only known occurrence of this species from Jamaica, although the related *Eurhodia matleyi* (Hawkins, 1927) is known from the Eocene Troy, Somerset(?) (Donovan, 1994b) and, particularly, Chapelton formations (Miller & Donovan, 1996). It was considered desirable to illustrate UWIGM 2764 (Figure 1/1-3, 5) to show its similarities to *E. rugosa sensu stricto* while demonstrating the obscured apical and oral surfaces that preclude definite identification. Unfortunately, the well-lithified bioclastic limestone that encloses the specimen did not respond well to air abrasion. Therefore, it is considered conservative to leave this specimen in open nomenclature.

Discussion

The Jamaican Cainozoic Echinoidea — Although the echinoids of the White Limestone Group have received more attention since the mid 1980s than ever before, including the completion of one M.Phil. thesis and a second in progress, their known diversity compares poorly with that the underlying Eocene Yellow Limestone Group (Donovan, 1993) and the overlying Plio-Pleistocene units of the Coastal Group (Donovan, 2003) (Figure 4). The reasons, both taphonomic and palaeobiologic, have been discussed in detail elsewhere (Donovan, 2001), and it is sufficient to note here that the White Limestone Group is more difficult to study macropalaeontologically than the Yellow Limestone or Coastal groups. Nevertheless, it is worthwhile emphasising that the echinoids of the White Limestone Group are obviously under-represented with what might be expected from the Oligocene and Miocene intervals, based on global (Kier, 1977) and regional data (see below). In most situations, it is necessary to rely on collecting whole specimens - tests, partial tests or large, obvious spines - from the White Limestone Group, rather than developing bulk sediment samples for micropalaeontological analysis of fragments. In consequence, regular echinoids are known almost exclusively from the robust spines of cidaroids (Table 1). With the one notable exception of Pimento Hill (Swanswick Formation), where spatangoids and cassiduloids are also reasonably common (Donovan *et al.*, 1989), the tests of oligopygoids and/or neolaganid clypeasteroids (Eocene) or *Clypeaster* spp. (Oligocene and Miocene) constitute the majority of irregular echinoids known from the Mid-Cainozoic of Jamaica.

As an illustration of how the general inability to develop the well-lithified units of the White Limestone Group for micropalaeontological analysis may have influenced our knowledge of the Jamaican fossil echinoids, consider the following Jamaican example from the Coastal Group. At least eight species of echinoids are recognised from the Upper Pliocene Bowden shell bed (Donovan & Paul, 1998) based on micropalaeontological analysis of bulk samples that have yielded spines, test fragments and microscopic juveniles; the entire Pliocene was less than 4 Myr duration. Contrast this with the Miocene (duration about 14 Myr) of the island, from which the White Limestone Group may have common complete specimens of clypeasteroids locally, but which probably has a known generic diversity only equivalent to the Bowden shell bed, despite the high diversity of Miocene echinoid species within the region (see below) and globally (Kier, 1977).

Coeval Cainozoic Echinoidea of the Greater Antilles and adjacent areas — Bearing in mind the caveat's regarding perceived inadequacies in our knowledge of the White Limestone Group echinoids (see above and Donovan, 2001), worthwhile comparison with coeval deposits from the region seems at first problematic. However, similar deposits could be compared with the mid Cainozoic of some nearby islands and other land areas. Certainly, recorded echinoderm faunas from these areas are, with a few exceptions (Oyen & Portell, 2001), based entirely upon complete specimens and are numerically dominated by oligopygoids (Eocene) and clypeasteroids, that is, those groups with the most robust tests. However, this comparison indicates at least moderate similarity throughout the adjacent areas.

The diverse Oligo-Miocene echinoids of Anguilla and Antigua were most recently revised by Poddubiuk & Rose (1985) and Poddubiuk (1987). The Upper Oligocene Antigua Formation has yielded fourteen species of echinoid, including *Prionocidaris spinidentatus*, *Clypeaster batheri*, *C. julii*, *C. oxybaphon*, *Echinolampas* sp. and *Eupatagus* sp. The Antigua Formation thus has a similar specific diversity to the Oligocene of the Moneague Formation (14 *vs.* 12 species) and includes many of the same taxa. In contrast, the Lower Miocene Anguilla Formation includes twenty species, somewhat more diverse than Miocene of the Moneague and Montpelier formations together. However, there are similarities between these units, including *Prionocidaris*, *Echinometra*, *Echinoneus* sp. cf. *E. cyclostomus* and *Clypeaster concavus*. *Echinoneus cyclostomus* is also known from the Middle Miocene of Carriacou, The Grenadines (Donovan, unpublished).

The Miocene of the Cayman Islands (Donovan, Jones and Harper, research in progress) has yielded only three echinoid species, including an indeterminate regular echinoid and the spatangoid *Schizaster* sp. The third taxon is *Brissus* sp., which is locally common and is morphologically close to the species from Montpelier Formation. However, morphologically similar *Brissus* spp. range from Eocene to Recent of the region (Donovan & Veale, 1996; Donovan & Harper, 2000).

Cuba, which should provide some of the best comparative data, with extensive monographic studies available (such as Sánchez Roig, 1926, 1949). However, it remains problematic due to reassignment of much of the Oligocene of the island into the Miocene and the need for extensive systematic revision (Kier, 1984, pp. 4, 6). Brodermann (1949) listed 88 Middle-Upper Eocene, 110 Oligocene and 23 Miocene taxa from Cuba. Using a coarse estimated 'revision' factor of 0.44, derived from Kier's (1984) revision of the Cuban spatangoids (179 species revised to 79), these figures might convert to approximately 39, 48 and 10, respectively. Assuming the Oligocene total includes many Miocene taxa, the overall pattern might be regarded similar to Jamaica, apart from the larger Miocene recovery after the Oligocene. Most genera reported from the Jamaican Eocene-Miocene are also known from the same part of the Cuban succession.

Of the three Miocene taxa recorded from the Dominican Republic by Kier (1992), all are clypeasteroids and only *Clypeaster* is undoubtedly congeneric with specimens from Jamaica. However, either or both of the other taxa may be at least congeneric with indeterminate scutellines of the Newport Formation.

Gordon's (1963) account of the Oligo-Miocene echinoids of Puerto Rico included twenty-two species; no single unit (nine are considered) contains more than ten species (see Larue, 1994, for an explanation of the stratigraphic relationships of the units involved). Taxa also known from this interval in Jamaica are: Oligocene - *Echinolampas lycopersicus*, *Clypeaster* including *C. oxybaphon*, *Agassizia* and *Eupatagus*; Miocene - *Echinometra* and *Clypeaster*.

A recent review of the Cainozoic echinoids of Florida (Oyen & Portell, 2001) enables broad comparison. Although the data are plotted in the form number of taxa/series (Oyen & Portell, 2001, fig. 2), it is easily recalculated as species Myr-1/series (Table 2) for broad comparison with the Jamaica data. Both the Oligocene and Miocene show low diversities; the Oligocene figure is similar to that for the Jamaican if the entire interval is considered (that is, not divided in lower and upper), whereas the Miocene of Florida is somewhat more diverse than that of Jamaica. The Eocene shows the greatest diversity, but it is much less than that seen in the entire Eocene of Jamaica (although the Middle Eocene is almost inaccessible in Florida; B.D. Carter, written comm., November 2001). Considering the much wider outcrop area than that of Jamaica, it is hard not to conclude that the Florida Cainozoic echinoids remain understudied. Similarities between the Jamaican White Limestone Group and coeval units in Florida at the generic level include: Eocene - *Oligopygus*, *Fibularia*, *Durhamella*, *Wythella*, *Eurhodia*, *Echinolampas*, *Schizaster*, *Agassizia* and *Eupatagus*; Oligocene - *Gagaria*, *Clypeaster* and *Agassizia*; Miocene - *Prionocidaris* and *Clypeaster*. At the generic level, the Oligocene is the most similar between the two areas, with three out of seven genera known in Florida in common.

Acknowledgements

I thank Phil Crabb (Photographic Unit, BMNH) for taking many of the photographs used here and Ms Xenia M. Ventikou (formerly Palaeontology Conservation Unit, BMNH) for her attempts to clean *Eurhodia* sp. cf. *E. rugosa* from the Claremont Formation. David N. Lewis (BMNH), Ian Brown (UWIGM) and Roger W. Portell (UF) are thanked for arranging access to and/or loan of specimens in their care. Special thanks to my many colleagues and students who have helped in the search for echinoderms in the White Limestone Group, particularly Ms Carla Gordon, Hal Dixon and Deborah-Ann Rowe (all currently or formerly Department of Geology, University of the West Indies), the late Bill Schickler (Beecher Town) and Roger Portell (Florida Museum of Natural History, Gainesville), amongst many others. This paper was completed during the period of National Geographic Society grant 6625-99 to SKD, which is gratefully acknowledged. I thank my three external reviewers, Professor Burt Carter (Georgia Southwestern College), David Lewis (BMNH) and Roger Portell (UF), for their constructive reviews. This is a contribution to my Nationaal Natuurhistorisch Museum, Leiden, projects 'Echinoderm studies' and 'Caribbean palaeontology'.

References

Agassiz, L. & Desor, E. 1846-1847. Catalogue raisonné des espèces, des genres et des familles d'échinides. *Annales des Sciences Naturelles* (Zoologie) (3)6, 305-374; 7, 129-168; 8, 5-35, 355-380 [not seen].

Ager, D.V. 1993. *The nature of the stratigraphic record* (3rd edition), xiv + 151 pp. Chichester (John Wiley & Sons).

Archaic, E.J.A.D. de St.S. d' & Haime, J. 1853. *Description des animaux fossiles du groupe nummulitique de l'Inde: les échinodermes*, 373 pp. Paris. [Not seen].

Arnold, B.W. & Clark, H.L. 1927. Jamaican fossil echini. *Memoirs of the Museum of Comparative Zoology, Harvard* 50, 1-75.

Arnold, B.W. & Clark, H.L. 1934. Some additional fossil echini from Jamaica. *Memoirs of the Museum of Comparative Zoology, Harvard* 54, 139-156.

Bengtson, P. 1988. Open nomenclature. *Palaeontology* 31, 223-227.

Brodermann, J. 1949. Significacion estratigrafica de los equinodermos fosiles de Cuba. *Paleontologia Cubana* 1, 305-330.

Bronn, H.G. 1860. *Klassen und Ordnungen des Thier-Reiches, 1. Amorphozoen*, 434 pp. Leipzig/Heidelberg. [Not seen].

Clark, W.B. & Twitchell, M.W. 1915. The Mesozoic and Cenozoic Echinodermata of the United States. *United States Geological Survey Monograph* 54, 1-341.

Claus, C.F.W. 1880. *Grundzüge der Zoologie (4th edition)*, vii + 821 pp. Marburg/Leipzig. [Not seen].

Cooke, C.W. 1959. Cenozoic echinoids of eastern United States. *United States Geological Survey, Professional Paper* 321, iii + 1-106.

Cotteau, G.H. 1875. Description des Echinides Tertiaires des Îles St. Barthélemy et Anguilla. *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 13(6), 1-48.

Dixon, H.L. 1995. *Upper Oligocene echinoids of Jamaica*, v + 115 pp. Mona (Department of Geology, University of the West Indies) (unpublished M.Phil. thesis).

Dixon, H.L. & Donovan, S.K. 1994. Local extinction patterns and the decline of the Jamaican Paleogene echinoid fauna. *Palaios* 9, 506-511.

Dixon, H.L. & Donovan, S.K. 1998. Oligocene echinoids of Jamaica. *Tertiary Research* 18, 95-124.

Dixon, H.L., Donovan, S.K. & Veltkamp, C.J. 1994. Crinoid and ophiuroid ossicles from the Oligocene of Jamaica. *Caribbean Journal of Science* 30, 143-145.

Donovan, S.K. 1988. A preliminary biostratigraphy of the Jamaican fossil Echinoidea. *In*: Burke, R.D., Mladenov, P.V., Lambert, P. & Parsley , R.L. (eds). *Echinoderm Biology: Proceedings of the 6th International Echinoderm Conference, Victoria, British Columbia, 23-28 August, 1987*, 125-131. Rotterdam/Brookfield (A.A. Balkema).

Donovan, S.K. 1991. An *Echinolampas* (Echinoidea: Cassiduloida) marker band in the Newport Formation? *Journal of the Geological Society of Jamaica* 28, 43, 44.

Donovan, S.K. 1993. Jamaican Cenozoic Echinoidea. *In*: Wright, R.M. & Robinson, E. (eds). Biostratigraphy of Jamaica. *Geological Society of America Memoir* 182, 371-412.

Donovan, S.K. 1994a. Middle and Upper Eocene echinoids of Jamaica. *In*: David, B., Guille, A., Féral, J.-P. & Roux, M. (eds). *Echinoderms through Time: Proceedings of the 8th International Echinoderm Conference*, Dijon, 6-10 September 1993, 629-635. Rotterdam/Brookfield (A.A. Balkema).

Donovan, S.K. 1994b. Echinoids of the Upper Eocene Somerset Formation of Jamaica. *Tertiary Research* 15, 43-48.

Donovan, S.K. 1995a. Evolution of the Jamaican echinoid fauna during the Eocene-Oligocene extinction crisis. *Jamaican Journal of Science and Technology* 5, 49-62.

Donovan, S.K. 1995b. Isocrinid crinoids from the late Cenozoic of Jamaica. *Atlantic Geology* 30, 195-203.

Donovan, S.K. 1996. A regular echinoid from the Walderston Formation (Lower Oligocene) of Jamaica. *Caribbean Journal of Science* 32, 78-82.

Donovan, S.K. 2001. Evolution of Caribbean echinoderms during the Cenozoic: moving towards a complete picture using all of the fossils. *Palaeogeography, Palaeoclimatology, Palaeoecology* 166, 177-192.

Donovan, S.K. 2002. Tribute to William F. Schickler. *Jamaican Geode* 11(1), 5.

Donovan, S.K. 2003. Completeness of a fossil record: the Pleistocene echinoids of the Antilles. *Lethaia* 36, 1-7.

Donovan, S.K., Gordon, C.M., Schickler, W.F. & Dixon, H.L. 1989. An Eocene age for an outcrop of the 'Montpelier Formation' at Beecher Town, St Ann, Jamaica, using echinoids for correlation. *Journal of the Geological Society of Jamaica* 26, 5-9.

Donovan, S.K., Gordon, C.M., Veltkamp, C.J. & Scott, A.D. 1993. Crinoids, asteroids and ophiuroids in the Jamaican fossil record. *In*: Wright, R.M. & Robinson, E. (eds). Biostratigraphy of Jamaica. *Geological Society of America Memoir* 182, 125-130.

Donovan, S.K. & Harper, D.A.T. 2000. The irregular echinoid *Brissus* Gray from the Tertiary of Jamaica. *Caribbean Journal of Science* 36, 332-335.

Donovan, S.K. & Paul, C.R.C. 1998. Echinoderms of the Pliocene Bowden shell bed, southeast Jamaica. *Contributions to Tertiary and Quaternary Geology* 35, 129-146.

Donovan, S.K. & Portell, R.W. 2000. Incipient 'crystal apples' from the Miocene of Jamaica. *Caribbean Journal of Science* 36, 168-170.

Donovan, S.K., Portell, R.W. & Veltkamp, C.J. 2005 (in press). Lower Miocene echinoderms of Jamaica, West Indies. *Scripta Geologica* 129.

Donovan, S.K. & Rowe, D.-A.C. 2000. Spatangoid echinoids from the Eocene of Jamaica. *Journal of Paleontology* 74, 654-661.

Donovan, S.K., Scott, A.D. & Veltkamp, C.J. 1991. A late middle Eocene echinoid fauna from Portland, northeastern Jamaica. *Journal of the Geological Society of Jamaica* 28, 1-8.

Donovan, S.K. & Veale, C. 1996. The irregular echinoids *Echinoneus* Leske and *Brissus* Gray in the Cenozoic of the Antillean region. *Journal of Paleontology* 70, 632-640.

Fortey, R.A. 2000. *Trilobite! Eyewitness to Evolution*, xv + 269 pp. London (Harper Collins).

Gordon, W.A. 1963. Middle Tertiary echinoids of Puerto Rico. *Journal of Paleontology* 37, 628-642.

Guppy, R.J.L. 1866. On Tertiary echinoderms from the West Indies. *Quarterly Journal of the Geological Society* 22, 297-301.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G. & Smith, D.G. 1990. *A geologic time scale 1990*, 263 pp. Cambridge (Cambridge University Press).

Hawkins, H.L. 1923. Some Cretaceous Echinoidea from Jamaica. *Geological Magazine* 60, 199-216.

Hawkins, H.L. 1924. Notes on a new collection of fossil Echinoidea from Jamaica. *Geological Magazine* 61, 312-324.

Hawkins, H.L. 1927. Descriptions of new species of Cainozoic Echinoidea from Jamaica. *Memoirs of the Museum of Comparative Zoology, Harvard* 50, 76-84.

Henry, L.A. & McFarlane, N. (compilers). 1978. *Provisional 1:50,000 geological sheet 18 "Ocho Rios"*. Kingston (Government of Jamaica).

Jackson, R.T. 1922. Fossil echini of the West Indies. *Carnegie Institution of Washington Publication* 306, 1-103.

Kier, P.M. 1967. Revision of the oligopygoid echinoids. *Smithsonian Miscellaneous Collections* 152(2), iii + 1-149.

Kier, P.M. 1977. The poor fossil record of the regular echinoid. *Paleobiology* 3, 168-174.

Kier, P.M. 1984. Fossil spatangoid echinoids of Cuba. *Smithsonian Contributions to Paleobiology* 55, vi + 1-336.

Kier, P.M. 1992. Neogene paleontology in the northern Dominican Republic. 13. The Class Echinoidea (Echinodermata). *Bulletins of American Paleontology* 102 (339), 13-27, 31-35.

Lambert, J.M. 1915. Échinides néogènes des Antilles Anglaises. *Mémoires de la Société académique d'Agriculture, des Sciences, Artes et Belles Lettres du Département de l'Aube* 79, 17-33.

Larue, D.K. 1994. Puerto Rico and the Virgin Islands. *In*: Donovan, S.K. & Jackson, T.A. (eds). *Caribbean geology: an introduction*, 151-165. Mona (University of the West Indies Publishers Association).

Leske, N.G. 1778. *Iacobi Theodori Klein naturalis disposito echinodermatum, edita et aucta a N.G. Leske*, 278 pp. Lipsiae. [Not seen].

Linné, C. von 1758. *Systema naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus differentis, synonymis, locis*, 824 pp. Holmiae. [Not seen].

Loriol, P. de 1887. Notes pour servir à l'étude des échinodermes. *Recueil de Zoologie Suisse* (7)2(4), 365-407. [Not seen].

Matthews, S.C. 1973. Notes on open nomenclature and on synonymy lists. *Palaeontology* 16, 713-719.

McFarlane, N. 1974. *The geology of the Dry Harbour Mountains, St. Ann, Jamaica*, 87 pp. Mona (University of the West Indies) (unpublished M.Sc. thesis).

McFarlane, N. 1977a. Some Eocene and Oligocene faunas from central Jamaica. *Memoria Segundo Congreso Latinoamericano de Geologia, Caracas, Venezuela, 11 al 16 de Noviembre de 1973*, 3, 1393-1411.

McFarlane, N. (compiler) 1977b. *1:250,000 Jamaica geological sheet*. Kingston (Ministry of Mining and Natural Resources).

McKinney, M.L., McNamara, K.J., Carter, B.D. & Donovan, S.K. 1992. Evolution of Paleogene echinoids: a global and regional view. *In*: Prothero, D.R. & Berggren, W.A. (eds). *Eocene-Oligocene climatic and biotic evolution*, 349-367. Princeton, New Jersey (Princeton University Press).

Miller, D.J. & Donovan, S.K. 1996. Geomorphology, stratigraphy and palaeontology of Wait-a-Bit Cave, central Jamaica. *Tertiary Research* 17, 33-49.

Mitchell, S.F. 2004. Lithostratigraphy and palaeogeography of the White Limestone Group. *In:* Donovan, S.K. (ed.). The Mid-Cainozoic White Limestone Group of Jamaica. *Cainozoic Research* 3, 5-29.

Oyen, C.W. & Portell, R.W. 2001. Diversity patterns and biostratigraphy of Cenozoic echinoderms from Florida. *Palaeogeography, Palaeoclimatology, Palaeoecology* 166, 193-218.

Pickerill, R.K., Mitchell, S.F., Donovan, S.K. & Keighley, D.G. 1998. Sedimentology and palaeoenvironment of the Pliocene Bowden Formation, southeast Jamaica. *Contributions to Tertiary and Quaternary Geology* 35, 9-27.

Poddubiuk, R.H. 1987. *Sedimentology, echinoid palaeoecology and palaeobiogeography of Oligo-Miocene eastern Caribbean limestones* (in 2 volumes), 419 + 148 pp. London (Royal Holloway and Bedford College, University of London) (unpublished Ph.D. thesis).

Poddubiuk, R.H. & Rose, E.P.F. 1985. Relationships between mid-Tertiary echinoid faunas from the central Mediterranean and eastern Caribbean and their palaeobiogeographic significance. *Annales géologiques des Pays Hélleniques* 32, 115-127.

Portell, R.W. & Collins, J.S.H. 2004. Decapod crustaceans of the Lower Miocene Montpelier Formation, White Limestone Group of Jamaica. *In:* Donovan, S.K. (ed.). The Mid-Cainozoic White Limestone Group of Jamaica. *Cainozoic Research* 3, 109-126.

Portell, R.W., Donovan, S.K. & Pickerill, R.K. 2004. The nautiloid *Aturia* (Mollusca, Cephalopoda) in the mid-

Cainozoic of Jamaica and Carriacou. *In:* Donovan, S.K. (ed.). The Mid-Cainozoic White Limestone Group of Jamaica. *Cainozoic Research* 3, 135-141.

Prothero, D.R. 1994. *The Eocene-Oligocene transition*, xvii + 291 pp. New York (Columbia University Press).

Ravenel, E. 1848. *Echinidae, Recent and fossil, of South Carolina*, 4 pp. Charleston, South Carolina (Burgeo & James).

Robinson, E. 1994. Jamaica. *In*: Donovan, S.K. & Jackson, T.A. (eds). *Caribbean geology: an introduction*, 111-127. Kingston (University of the West Indies Publishers Association).

Robinson, E. 2004. Zoning the White Limestone Group of Jamaica using larger foraminiferal genera: a review and proposal. *In:* Donovan, S.K. (ed.). The Mid-Cainozoic White Limestone Group of Jamaica. *Cainozoic Research* 3, 39-75.

Roman, J. 1952. Sur les structures internes des Clypéastres. *Bulletin de la Société géologique de France* (6)2, 403-416.

Rowe, D.-A.C. & Stemann, T.A. 1999. Defining species boundaries in Eocene oligopygoid echinoids: a case study from the Swanswick Formation, Jamaica. *Geological Society of America, Abstracts with Programs* 31(7), A-470.

Sánchez Roig, M. 1926. Contribución a la paleontología Cubana: los equinodermos fósiles de Cuba. *Boletin de Minas* 10, 1-179.

Sánchez Roig, M. 1949. Los equinodermos fósiles de Cuba. *Paleontología Cubana* 1, 1-302.

Smith, A.B. 1984. *Echinoid palaeobiology*, xii + 191 pp. London (George Allen and Unwin).

Underwood, C.J. & Mitchell, S.F. 2004. Sharks, bony fishes and endodental borings from the Miocene Montpelier Formation (White Limestone Group) of Jamaica. *In:* Donovan, S.K. (ed.). The Mid-Cainozoic White Limestone Group of Jamaica. *Cainozoic Research* 3, 157-165.

Wyville Thomson, C. 1864. Sea lilies. *The Intellectual Observer* 6, 1-11.