Lower Miocene echinoderms of Jamaica, West Indies

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Despite being diverse globally, Miocene echinoids are poorly known from Jamaica. Moderately diverse echinoids and other echinoderms have been identified mainly from fragmentary specimens collected from chalks and mass-flow deposits of the Lower Miocene Montpelier Formation, White Limestone Group, near Duncans, parish of Trelawny. This locality has yielded the most diverse association of fossil echinoderms known from the Miocene of Jamaica, including at least ten species in four classes. This fauna is comprised of the isocrinid crinoids *Neocrinus* sp. cf. *N. decorus* (Wyville Thomson) and *Isocrinus* sp.; the ophiuroid *Ophiomusium*? sp.; the asteroids *Astropecten*? spp.; and the echinoids *Prionocidaris*? sp., *Histocidaris* sp., *Echinometra* sp. cf. *E. lucunter* (Linné), *Echinoneus cyclostomus* Leske, *Clypeaster*? sp. and spatangoid sp. Some echinoids are preserved as "crystal apples". The deep water echinoderm taxa in this death assemblage suggest the depth of deposition to have been at least 200 m. At the level of genus, the echinoids of Duncans Quarry show strong similarities with coeval associations from Anguilla and Puerto Rico, although no consistent biostratigraphic marker(s) emerge from this comparison.

Contents

Introduction

Perhaps the most unexpected 'gap' in our knowledge of the Cenozoic fossil echinoids of the Antillean region is their poor record from the Miocene of Jamaica (Donovan, 2001). Global data show that Miocene echinoids were diverse, recovering from their decline following the Eocene-Oligocene extinctions (Kier, 1977; McKinney *et al.*, 1992, fig. 17.1); indeed, at least one author has referred to the Miocene as 'the age of echinoids' (Ager, 1993, p. 27). Although an alternative explanation for the global paucity of Oligocene echinoids postulates that our knowledge is limited by sampling artefact

(Smith & Jeffery, 2000, p. 182), in Jamaica even the best known Oligocene (Dixon & Donovan, 1998) and Miocene sites that yield echinoderms have fewer complete specimens and a reduced diversity compared with the Lower and Middle Eocene of the island (Donovan, 1993).

Miocene echinoids are known to attain at least a moderate diversity elsewhere in the Antillean region, such as in Anguilla (Cotteau, 1875; Poddubiuk & Rose, 1985). The Cuban Miocene echinoids were probably even more diverse, but there is some confusion and uncertainty concerning the precise correlation of the Cuban Oligo-Miocene taxa (Kier, 1984, p. 6). A previous attempt to document the echinoids from the Miocene of the Jamaican sedimentary succession on the basis of published records (Donovan, 1988, table 1) has been shown to be largely erroneous (Donovan, 1993, table 2) (see below). New finds during the past 15 years necessitate a revision of the echinoderms, including the echinoids, from this part of the island's fossil record.

Although the diversity of fossil echinoids in the Miocene of Jamaica is low, they are common fossils, at least locally. For example, some localities in the shallow water *Amphisorites matleyi*-yielding limestones of the Moneague Formation *sensu* Mitchell (2004) (formerly Newport Formation) yield numerous tests of *Clypeaster* spp., albeit limited locally to one species (Donovan, 1991). As with the Oligocene (Dixon & Donovan, 1998), two principal factors have probably combined to influence our (limited) knowledge of the Miocene echinoids of Jamaica. There is a reduction in diversity of facies between the Yellow Limestone Group (mid Lower to mid Middle Eocene) and the overlying White Limestone Group (mid Middle Eocene to lowermost Upper Miocene; Robinson, 1988, 1994) in Jamaica (Donovan, 1994a, 1995a; Dixon & Donovan, 1994). The reduction of lithofacies was apparently mirrored by a reduction in echinoid diversity (but see Donovan *et al.*, in press, for an alternative interpretation), a pattern noted in analogous situations by Carter & Azab (1993) and Carter (1995). Further, earlier systematic investigations of the Jamaican fauna concentrated largely on the more obviously fossiliferous parts of the succession, that is, the Upper Cretaceous and Eocene (Arnold & Clark, 1927, 1934; Hawkins, 1923, 1924, 1927; reviewed in Donovan, 1988), and largely ignored those units that were perceived to lack easily collectable faunas. It is only now that these mid Cenozoic formations have been investigated (Donovan, 2004b).

The present contribution is a study of the Miocene fossil echinoderms of a particularly productive site in Jamaica, which goes some way to rectifying the deficiencies in our knowledge recognised above. While echinoids are moderately diverse, six species being identified from complete tests and/or fragments, they are supplemented by disarticulated ossicles derived from ophiuroids, isocrinid crinoids and astropectinid asteroids. Thus, this locality has yielded one of the most diverse accumulations of Miocene echinoderms known from the region, despite previous misconceptions. However, unlike most other analyses of Caribbean Miocene echinoderms, the present study leans heavily on the information provided by disarticulated ossicles. This work is based on new collections made by S.K.D., R.W.P. and co-workers since 1987.

The terminology of the echinoid endoskeleton used herein follows Melville & Durham (1966), Durham & Wagner (1966) and Smith (1984). The classification of echinoids is that of Smith (1981, 1984) and Smith & Wright (1989-in progress). Terminology of the isocrinine crinoid stem follows Moore *et al.* (1968), Roux (1977) and Ubaghs (1978). Classification of the articulate crinoids follows Simms & Sevastopulo (1993) and Simms *et al.*

(1993). Descriptive terminology of the asteroid test follows Gale (1987a). The philosophy of open nomenclature follows Bengtson (1988). Synonymy lists are limited to fossil occurrences in Jamaica. The material described and illustrated herein is deposited in the Florida Museum of Natural History, Gainesville (UF) and the Nationaal Natuur-historisch Museum, Leiden (RGM).

History of research

Donovan (1988) published the first stratigraphic analysis of the Jamaican fossil echinoids. In this original compilation, the following taxa were considered to be Miocene or uncertainly Miocene, based mainly on the available information presented in earlier publications, particularly Arnold & Clark (1927, 1934) and Hawkins (1924): ??*Tretocidaris anguillensis* Cutress, 1980; *Pedina* sp.; *Echinometra lucunter* (Linné, 1758); *Clypeaster concavus* Cotteau, 1875; *Clypeaster* sp.; *Scutella* sp.; *Cassidulus punctatus* (Arnold & Clark, 1927); *Echinolampas alta* (Arnold & Clark, 1927); *Agassizia inflata* Jackson, 1922; *Brissus* sp. indet.; and *Eupatagus clevei* (Cotteau, 1875). This preliminary group of 'Miocene' echinoids has not fared well in the intervening interval and most have been confidently redated. ??*Tretocidaris anguillensis* was regarded by Cutress (1980, p. 61) to be a 'lost' specimen; it was subsequently rediscovered in the Museum of Comparative Zoology, Harvard, by Donovan (1994b) and reclassified as *Cidaris* (*Tretocidaris*) sp. of probable Eocene age. Other taxa now considered to be Eocene (Donovan, 1993) include *Pedina* sp., *Rhyncholampas*? *punctatus*, *Ec. alta*, *A. inflata* and *Eu. clevei*. *Clypeaster* sp. and *Scutella* sp., both referred to by Chubb (1958), are probably *Clypeaster rosaceus* (Linné, 1758) (see Donovan, 1993, p. 388) and *Encope homala* Arnold & Clark, 1934 (see Donovan *et al.* 1994b), respectively, both from the Plio-Pleistocene August Town Formation. The specimen of *Echinometra lucunter* referred to by Arnold & Clark (1934) is probably Pleistocene (Sangamonian) (Donovan, 1994b). Thus, from the putative Miocene fauna of 1988, the sorrowful remnants following further research (Donovan, 1993, table 2) were *Clypeaster concavus* and *Brissus* sp. indet. The latter taxon was reassessed by Donovan & Harper (2000) and has been classified as *Brissus* sp. cf. *B. unicolor* (Leske).

Before 1988, the only utilisation of Jamaican Miocene echinoids in a biostratigraphic context was by Hose & Versey (1957, text-fig. 1), who recognised an *Echinolampas* marker band in the Newport Formation (= part of the Moneague Formation of modern usage; Mitchell, 2004). Unfortunately, no locality at which this band could be examined was indicated and subsequent attempts to identify it have failed. Donovan (1991) suggested that such a marker band, composed of abundant cassiduloids, which remains the only report of this group of echinoids from the Miocene of Jamaica, was improbable and it is more likely that Hose & Versey misidentified a clypeasteroid horizon. Of these, Donovan (1991) identified at least three locally abundant taxa in the Newport Formation, including two species of *Clypeaster* (later referred to as *Clypeaster* spp. 1 and 2; Donovan & Portell, 1996) and a scutelline. One of the species of *Clypeaster* was considered closely similar to *C. concavus* (Donovan, 1991), although Chalmers (2001) placed this taxon in *Clypeaster duchassaingi* Michelin, 1861.

Some echinoderms from Duncans Quarry have already been mentioned elsewhere. Donovan & Portell (2000) published a note on the taphonomy of the echinoids, particu-
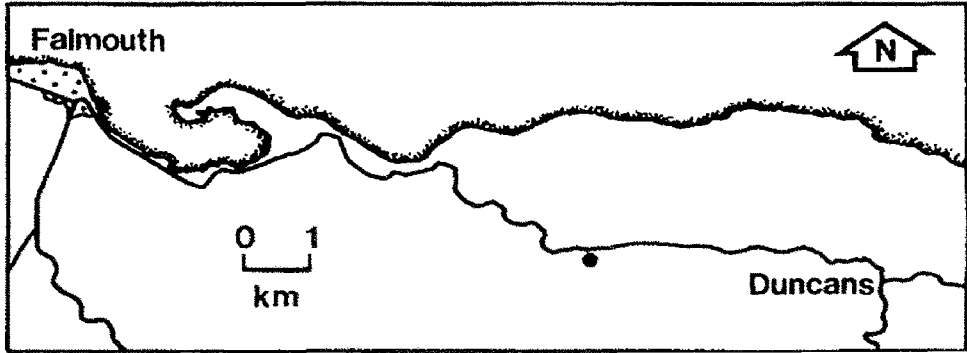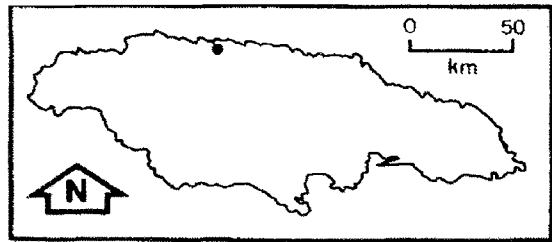
Fig. 1. Locality map of the Duncans to Falmouth area, central north Jamaica, showing the position of Duncans Quarry (after Harper *et al.*, 1997, fig. 1).
Key: • = Duncans Quarry; stippled line = coast; thick line = main road. The inset map of Jamaica shows the approximate position of Duncans Quarry (•).

larly the unusual preservation of some tests as incipient 'crystal apples.' Rare isocrinid columnals from the Lower Miocene of Duncans (see below) have been recorded. Hitherto, these have been variously classified, erroneously, as *Diplocrinus* sp. (Donovan *et al.*, 1993) or *Teliocrinus*? sp. (Donovan, 1995b). Asteroid ossicles from the same locality were listed in Donovan (2001, table 5).

Stratigraphy

The lithostratigraphy (Mitchell, 2004) and biostratigraphy (Robinson, 2004) of the White Limestone Group of Jamaica have been reviewed and revised in a recent monographic study of this unit (Donovan, 2004a). Duncans Quarry forms part of the sequence of the Montpelier Formation which, at this locality, is correlated on foraminiferal evidence with the Lower Miocene.

Locality

All specimens documented herein were collected from the large, disused quarry about 5 km west of Duncans police station, on the southern side of the main A1 (north coast) road, parish of Trelawny, central north Jamaica (Fig. 1; approximate GR 887 019, new 1:50,000 series, sheet 3, "Falmouth-Browns Town"; GPS reading 18°28'30"N 77°34'46"W). Montpelier Formation, White Limestone Group; Lower Miocene (Robinson, 2004; Mitchell, 2004). Echinoderms and echinoderm fragments occur in three distinct associations within this quarry:—

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- Within interstices in massive scleractinian corals, accumulated on a high bench on the left as the quarry is entered and presumably derived from a shallower water setting (associated with a diverse fauna of well-preserved fossil brachyuran crabs; Portell & Collins, 2004).
- In the chalk and bioclastic limestone succession below this bench and below the level of the entrance road (isocrinid locality).
- At the far end of the quarry from the entrance, where blocks derived from thin beds in the face yield echinoid and asteroid remains.

The associated fauna includes benthic foraminiferans (Robinson, 2004), sponge spicules (Portell & Rigby, 2004), gastropods and bivalves (including oysters), the nautiloid cephalopod *Aturia* (Portell *et al.*, 2004), scleractinian corals (Stemann, 2004), terebratulid brachiopods (Harper *et al.*, 1997; Harper & Portell, 2002, 2004), brachyuran crabs (Portell & Collins, 2004), balanid barnacles, fishes (Underwood & Mitchell, 2004) and trace fossils (Blissett & Pickerill, 2004a, b). Faunal evidence provided by fossil fishes suggests that deposition occurred in a deeper water setting, presumably on the steep island slope and probably in more than 200 m water depth (Underwood & Mitchell, 2004).

Materials and methods

Fossil echinoderms are rare in the Duncans section and the faunal elements are the result of collecting over a 15 year period, each year involving several days of collecting by one or more of the authors and co-workers. Where present, echinoderms commonly occur as disarticulated ossicles (mainly echinoid radioles and plates) with only rare exceptions. Ossicles are most common on the surfaces of loose slabs of bioclastic debris (Pl. 1, fig. 1) that are interpreted as representing mass flow deposits derived from shallower water, a common feature of Antillean deeper water deposits (Donovan, 2002). More complete specimens, including very rare echinoid tests and larger fragments of tests, were removed from large blocks of zooxanthellate scleractinian coral by hammering. These are interpreted as being derived from shallower water as slide blocks that moved down the steep slope of the north coast of Jamaica. They seem to have acted as a trap for rare faunal elements that were living in the coral framework and were buried in these interstices when the blocks came to rest in the chalk environment. Preservation of echinoids in the setting has been marred by the surface coat of calcite crystals grown on most specimens (Donovan & Portell, 2000).

Those specimens collected in the field have been supplemented by ossicles picked in Florida Museum of Natural History (UF) from bulk samples. This methodology has yielded small, delicate plates such as ophiuroid vertebral ossicles and crinoid brachials.

Specimens illustrated by light photography were coated with a thin dusting of ammonium chloride sublimate (Pls. 1, 2). Specimens examined by scanning electron microscope (SEM) were mounted on aluminium stubs and coated with 60 % gold-palladium (Pls. 3-8).

Systematic palaeontology

Class Crinoidea J.S. Miller, 1821
Subclass Articulata von Zittel, 1879
Order Isocrinina Simms, 1988
Family Isocrinidae Gislén, 1924

Remarks — The paraphyletic family Isocrinidae awaits revision (Simms *et al.*, 1993, p. 501).

Genus *Neocrinus* Wyville Thomson, 1864

Type species — *Pentacrinus* (*Neocrinus*) *decorus* Wyville Thomson, 1864, p. 7, by monotypy (Rasmussen, 1978, p. T857).

Diagnosis of column — (After Rasmussen, 1961, p. 89) "Isocrinidae in which the articular face of the columnals has lanceolate or sub-guttiform petals surrounded by adradial and marginal crenellae. The crenellae attain their greatest length about the gradual transition from adradial to marginal position. The nodals have five outward-directed cirri. The articulation of small proximal columnals shows a combination of the pattern normal to Isocrinidae and a synarthrial ridge with different orientation in the two ends of a columnal."

Range — Lower Cretaceous to Recent (Rasmussen, 1961, p. 90).

Neocrinus sp. cf. *Neocrinus decorus* Wyville Thomson, 1864
Pl. 3, fig. 3.

2001   *Neocrinus*; Donovan, table 4.
2001   *Neocrinus* cf. *decorus*; Donovan & Veltkamp, p. 725.

Material studied — A single internodal columnal, UF 101761. One articular facet is obscured by limestone.

Description — Columnal pentagonal in outline with strongly rounded angles. Lumen small, central, rounded. Perilumen planar, narrow. Areola pentapetaloid, closed. Crenularium surrounding areola, comprised of few, moderately coarse, short, crenulae, continuing to circumference in interpetaloid zone. Latus planar, unsculptured. Columnal low.

Measurements — Columnal diameter (KD) = 3.2 mm; columnal height (KH) = 1.1 mm; lumen diameter (LD) = 0.25 mm.

Remarks — This single columnal has only one, imperfectly preserved articular facet exposed, which is close in morphology to that of *Neocrinus decorus* (compare Pl. 3, fig. 3 herein with Roux, 1977, fig. 19; Breimer, 1978, fig. 11; Donovan, 1984, pl. 74, fig. 2, text-

fig. 3). The poor preservation of the Duncans specimen precludes a definite identification, but it is considered conservative to classify it in open nomenclature close to *N. decorus*. *Neocrinus decorus* is an extant tropical western Atlantic crinoid that occurs at water depths between 154 and 1,220 m (Meyer *et al.*, 1978, p. 425). This species also occurs in the early Pleistocene Manchioneal Formation of eastern Jamaica (Donovan, 1995b), and the Miocene of Barbados and Carriacou (Donovan & Veltkamp, 2001). *Neocrinus*, other still-extant isocrinid genera and bathycrinids are unknown from the pre-Miocene of the Antillean region.

Donovan (2001) suggested that, like the echinoids, the post-Eocene crinoid genera of the region may have persisted largely unaltered to the present day. It is also significant to note the deeper-water association of the brachiopods *Tichosina*, *Terebratulina* and *Argyrotheca* (Harper & Portell, 2004) with isocrinids like *Neocrinus* and *Isocrinus*, which is known from the Lower Miocene, occurring through the Pleistocene to the present (Donovan & Harper, 1998, 2001). Although this trio of brachiopods may be found in presumed deeper water deposits without a related crinoid fauna (Harper & Donovan, 2002), their association with isocrinids is regarded as particularly strong evidence of a deeper water, island slope setting.

Three fused columnals, UF 68666, that are cemented together by pressure solution (two still articulated, the third offset) may be conspecific with UF 101761 on the basis of their rounded pentagonal outline, but they have unusual concave articular facets (again, possibly an effect of diagenesis) which preserve no diagnostic details. These columnals are tentatively referred to *Neocrinus*? sp. herein. Similarly, UF 72242 is included here for completeness, but even the class level classification of this specimen is uncertain. It is a low ossicle with raised 'facets' with a pentameral arranged, slightly reminiscent of the articular facet of an isocrinid, but with what would be the areolae preserved in positive relief.

Genus *Isocrinus* von Meyer *in* L. Agassiz, 1836

Type species — *Isocrinites pendulus* von Meyer *in* L. Agassiz, 1836, p. 57, by monotypy (Rasmussen, 1978, p. T851).

Diagnosis of column — (After Rasmussen, 1978, p. T851.) "Column rounded sub-pentagonal to pentalobate, proximal columnals pentalobate, alternating in size, and with radial pores in sutures. Internodes generally rather short, about 5 to 10 internodals. Nodals with 5 large, elliptical cirrus sockets, almost as high as nodal, facing outward. Articulation of columnals with elliptical petals and a gradual continuation of marginal and adradial crenulae reaching greatest length in radial marginal areas, there forming an oblique angle with radial axis, and diminishing toward the interradial point and toward center of articular face."

Range — Triassic to Recent (Rasmussen, 1978, p. T851).

Isocrinus sp.
Pl. 1, fig. 1; Pl. 3, figs. 2, 4.

1993   *Diplocrinus* sp.; Donovan *et al.*, pp. 126-127, fig. 4.
1995b *Teliocrinus*? sp.; Donovan, pp. 196, 197, 199, fig. 3.
2001   *Diplocrinus*; Donovan, table 4.
2001   *Isocrinus*; Donovan, p. 186.
2001   *Isocrinus* sp.; Donovan & Veltkamp, p. 725.

Material studied — Four internodal columnals, UF 38939, 67000, 101762 and 103354, and a nodal?, RGM 212432.

Description — (Revised and expanded after Donovan *et al.*, 1993; Donovan, 1995b). Columnal outline pentastellate with strongly angles. Lumen small, central, circular in outline. Perilumen small, irregularly pentastellate(?), planar. Articulation symplectial, arrayed about five slender, elongate, lensoid areola petals that correspond to the columnal angles. Areola petals elongate, deep, separate, open to open and closed on same facet. Crenulae perpendicular (more centrally) to subperpendicular (nearer circumference of articular facet) to margins of areola petals. Crenulae short, unbranched, six to seven culmina along each side of the areola petals, with crenulae of adjacent petals separate. Triangular naked zones occur adjacent to the circumference in interpetaloid zones, slightly sloping away from the columnal circumference. Latus gently convex and unsculptured.

Dimensions — See Table 1.

Remarks — These pentastellate Miocene columnals were originally described from Jamaica on the basis of UF 38939 (Donovan *et al.*, 1993), a broken internodal, and classified as *Diplocrinus* sp. Subsequent examination of the better preserved UF 67000 led to a tentative re-assignment to *Teliocrinus*? sp. (Donovan, 1995b). Two further specimens have been found subsequently. As noted by Donovan (1995b, pp. 197, 199), the columnals from Duncans, with their slender, elongate, open petals, are very similar to those of extant *Diplocrinus* (Roux, 1977; Macurda & Roux, 1981). However, extant *Diplocrinus* spp. columnals were considered to differ from these fossils in having slightly fewer culmina surrounding the petals; three extant species that were examined have only four to five culmina along each side of the areola petals, whereas the Duncans species has six to seven (that is, 12-14 per petal). While this feature was used to argue that the species from Duncans was closer to *Teliocrinus* Döderlein, this genus is otherwise only known

Table 1. Measurements of columnals of *Isocrinus* sp. (including corrections to measurements published in Donovan *et al.*, 1993). Key: KH = columnal height; KD = columnal diameter; LD = lumen diameter; FD = facet diameter. All measurements in mm.

	KH	KD	FD	LD
UF 38939	1.6	6.1	5.7	?
UF 67000	*c*. 1.5	6	5.8	0.35
UF 101762	?	6.1	5.6-5.8	0.3
UF 103354	1.3	4.4	3.9	0.2

from the Recent of the Indian Ocean and the Miocene of Japan (Roux, 1977, table 1; Rasmussen, 1978, p. T860; Oji, 1990). Herein, reassessment of the Duncans specimens and their palaeogeographic implications have led to further generic revision.

Recognition of the conservative nature of the late Cenozoic echinoderm fauna in the Antillean region (Donovan, 2001) has led to a comparison of the Duncans columnals with those of all extant species of tropical western Atlantic isocrinids in an attempt to identify similarities (Table 2). Of these, only one species, *Isocrinus blakei* (Carpenter, 1882), shares the same suite of characters as are seen in the Duncans specimens, that is, lanceolate areola; more or less open petaloid zone; more than ten crenulae; and no axial groove in the interpetaloid zone. Of these, the degree by which petals are open in the Duncans specimens is the most difficult to assess; while some petals are undoubtedly open, others may be closed (compare, for example, Pl. 3, figs. 2, 4). Therefore, it is suggested that the stellate columnals from Duncans most probably represent a species of *Isocrinus*. The Duncans specimens do not closely resemble *I. blakei* (compare Pl. 1, fig. 1, Pl. 3, figs. 2, 4, with Roux, 1977, fig. 18), although similarities with extinct species of this genus are apparent (see, for example, Rasmussen, 1978, fig. 571.1e). Tomasz K. Baumiller (written communication *in* Donovan, 1995b, p. 199) has already pointed out the similarities between the Jamaican species and Miocene *Isocrinus* from Japan (Oji, 1990). Until more and better preserved specimens have been obtained, the species from Duncans Quarry is left in open nomenclature, although it may represent a new species. The Jamaican columnals are considered conspecific with *Isocrinus* sp. from the Middle Miocene Grand Bay Formation of Carriacou (Donovan & Veltkamp, 2001).

These columnals differ from *Neocrinus* sp. cf. *N. decorus* in having a more pentastellate outline, more elongate areola petals and more culmina surrounding each petal. Extant *Isocrinus blakei* is found between 220 and 650 m (Meyer *et al.*, 1978, p. 425).

Other ossicles from this locality are undoubtedly crinoidal in origin, but can only be classified very broadly. Thus, two cirral ossicles (UF 72231, 103353) are typical of comatulids and isocrinids (compare Pl. 3, fig. 1 with, for example, Macurda & Roux, 1981, pl. 5, figs 3-6; Donovan, 1984, pl. 76, fig.7) and are presumably derived from one or both of the isocrinid species discussed herein. Similarly, four brachial ossicles (Pl. 3, fig. 5; Pl. 4, fig. 1), UF 72248 (two ossicles) and 101759 (two ossicles), could be derived from either isocrinid taxon. However, any of these indeterminate ossicles could alternatively be derived from an unrecognised comatulid crinoid.

Table 2. Features of the articular facet of extant tropical western Atlantic isocrinid crinoids (expanded after Donovan, 2001, table 1; based on Roux, 1977, table 2; Macurda & Roux, 1981) and *Isocrinus* sp. from Duncans. Key: * = feature of extant species shared with *Isocrinus* sp.; + = at least some petals are undoubtedly open, whereas others may be closed.

	Areola shape	Outer edge of petaloid zone	Crenulae of one petaloid zone	Interpetaloid zone
Cenocrinus asterias	lanceolate*	slightly open*	less than 10	closed axial groove
Endoxocrinus parrae	pear-shaped	closed	more than 10*	axial groove
Neocrinus decorus	pear-shaped	closed	8-11*	axial groove
Isocrinus blakei	lanceolate*	slightly open*	8-11*	no axial groove*
Diplocrinus maclearanus	lanceolate*	open	less than 10	no axial groove*
Isocrinus sp.	lanceolate	slightly open[+]	more than 10	no axial groove

Class Ophiuroidea Gray, 1840
Order Ophiurida Müller & Troschel, 1840
Suborder Ophiurina Müller & Troschel, 1840
Family Ophiolepidinae Ljungman, 1867
Genus *Ophiomusium* Lyman, 1869

Type species — *Ophiomusium eburneum* Lyman, 1869, p. 322, by original designation (Spencer & Wright, 1966, p. U96).

Diagnosis — See Spencer & Wright (1966, p. U96).

Range — Lower Jurassic (Smith *et al.*, 1995, table 2) to Recent.

***Ophiomusium*? sp.**
Pl. 4, figs. 2-4

Material studied — Twenty eight mainly vertebral ossicles; UF 72230 (two ossicles), 72245 (one ossicle), 101760 (24 ossicles) and 103355.

Remarks — The ophiuroids are a common and diverse component of the modern Antillean marine fauna. Hendler *et al.* (1995, pp. 89-195) documented over 60 extant Caribbean species from shallow water alone (0-30 m). However, their species-level classification is based mainly on features of complete individuals, not isolated ossicles (but see Irimura & Fujita, 2003). Although ophiuroid ossicles may be very abundant in some ancient deposits (Rundle, 2001, p. 17), they remain poorly studied and apparently rare in the fossil record of the Antilles (Donovan, 2001, pp. 187-188), with few published accounts. Complete fossil ophiuroids remain unknown from the region.

Although the vertebral ossicles from Duncans Quarry may represent more than one species in the light of their modern high diversity in the Caribbean, they are sufficiently similar to preclude easy differentiation and are treated herein as a single taxon, some of the variability being explained by the changing ossicle morphology along the length of the arm. Articulations between ossicles are zygospondyline (compare Pl. 4, figs. 2, 4, with Smith *et al.*, 1995, fig. A4c), widely distributed in the ophiuroids. These ossicles are dissimilar to the gorgonocephalid? ossicle figured from the Upper Pliocene Bowden Shell Bed of Jamaica, which has a streptospondyline, 'hourglass-shaped' articulation (Donovan & Paul, 1998, p. 130, pl. 1, fig. 8). The Duncans Quarry ossicles show greater similarity to those from the Upper Oligocene of Jamaica (Dixon *et al.*, 1994) than to those from the Upper Pliocene(?) of Trinidad (Berry, 1935). The closest comparison is with vertebral ossicles from the Upper Pleistocene (last interglacial, oxygen isotope stage 5e) Falmouth Formation of Jamaica (Donovan *et al.*, 1993). The specimens from Duncans Quarry are also close in morphology to vertebral ossicles classified as *Ophiura* (Rasmussen, 1950, pl. 16, fig. 5) and *Ophiomusium* (Hess, 1962, figs 128, 129). Gordon L.J. Paterson (pers. comm. to S.K.D.) emphasised this similarity to *Ophiomusium* and compared it with the figured ossicles of Recent *Ophiomusium lymani* (Paterson & Baker, 1988, fig. 3a, b).

Class Asteroidea de Blainville, 1830
Subclass Neoasteroidea Gale, 1987b
Order Paxillosida Perrier, 1884
Family Astropectinidae Gray, 1840
Genus *Astropecten* Gray, 1840

Type species — *Asterias aranciaca* Linné, 1758, by the subsequent designation of Fisher (1908) (Spencer & Wright, 1966, p. U45).

Diagnosis — (Based on Spencer & Wright, 1966, p. U45.) Disc commonly rather small with long, pointed arms with straight sides. Marginal fascioles not webbed. Intermarginal facet small, not angular; inferomarginals with irregularly distributed horseshoe-shaped tubercles, which bear long radioles of varying size.

Range — Lower Paleocene (Danian) (Rasmussen 1972) to Recent.

Astropecten? spp.
Pl. 4, fig. 5.

2001   unidentified marginal ossicles; Donovan, table 5.

Material studied — Thirteen marginal ossicles, UF 68667, 72232 (six ossicles), 101757, 101758, 101763, 101777 and 103356, and RGM 212433.

Remarks — Asteroids are a diverse component of the modern fauna of the Caribbean and Gulf of Mexico (Downey, 1973). Asteroid marginal ossicles are known from the Upper Cretaceous and Eocene-Pleistocene of Jamaica (Donovan *et al.*, 1993; Donovan, 2001), mainly derived from astropectinids and possibly goniasterids. These ossicles are mainly known from small samples and have not been identified to generic or specific level; the problems involved were discussed elsewhere (A.S. Gale pers. comm. *in* Donovan *et al.*, 1993, pp. 129-130; Donovan, 2001). Marginal ossicles from Duncans Quarry display a range of external sculptures, pitted (Pl. 4, fig. 5), tuberculated or smooth, presumably indicating the presence of more than one species. The first articulated astropectinid from the Antilles, from the Middle Miocene Grand Bay Formation of Carriacou, has tuberculated marginal ossicles that show some similarities to certain specimens from Duncans Quarry. Further discussion should wait until that specimen has been adequately documented (Donovan, Portell and co-workers, research in progress). None of the marginal ossicles from Duncans Quarry closely resemble the large oreasterid-like ossicles from the Upper Oligocene of Jamaica and Antigua (C. Mah, research in progress). They are closer in morphology to some of the ossicles, again probably representing more than one species, known from the Upper Pliocene Bowden Shell Bed of Jamaica (Donovan & Paul, 1996, 1998). Comparison with the Eocene(?) (Donovan, 2001, p. 187) asteroid ossicles described by Valette (1926), *Nymphaster miocenicus* and *Stauranderaster sanchezi*, must wait until these Cuban specimens have been adequately re-described and illustrated.

Class Echinoidea Leske, 1778
Subclass Cidaroidea Claus, 1880
Order Cidaroida Claus, 1880
Family Cidaridae Gray, 1825
Genus *Prionocidaris* A. Agassiz, 1863

Type species — *Cidarites pistillaris* Lamarck, 1816, by original designation (Fell, 1966, p. U330).

Diagnosis — See Smith & Wright (1989, p. 89).

Range — Upper Cretaceous to Recent (Fell, 1966, p. U330).

***Prionocidaris*? sp.**
Pl. 1, figs. 6-13; Pl. 5, figs. 1-7; Pl. 6, figs. 1-3.

2000   unidentified cidaroid; Donovan & Portell, pp. 168, 169, fig. 1c.

Material studied — Test, UF 68437 (most detail obscured by crystal apple preservation); test plates, UF 72214 (13 interambulacral plates), 101767, 101779, 103340 (two genital plates), 103344 (19 interambulacral plates), 103345; radioles, UF 38948, 39009 (seven radioles), 68458, 68459, 68659, 68660, 68663-68665, 68668-68671, 72218, 72219 (24 radioles), 101764-101766, 101768-101774, 101776, 101780-101784, 101786, 101787, 10338 (six radioles), 103339 (45 radioles); lantern elements, UF 103341 (rotula), 103342 (three demipyramids), 103343 (tooth). A collection of radioles in the RGM are probably conspecific, but the cortical layer is lost in most specimens; RGM 212434-212437, 212438 (cluster of radioles), 212439 (cluster of radioles), 212440 (27 loose radioles), 212441 (cluster of radioles), 212442, 212443, 212444 (three radioles), 212445, 212446.

Description — Test small, rounded in outline, ambitus at mid height. Ambulacra slightly sinuous. Genital plates rounded trapezoid in outline, narrowing adambitally, with a single circular genital pore close to centre of this side. Interambulacral plates wide and high, bearing a large primary tubercle with a broad, conical, circular, perforate, non-crenulate areola. Small, granular secondary tubercles arrayed in columns adradially.

Primary radioles robust, swollen centrally, with an external sculpture of linearly-arranged spinules along length of shaft. Acetabulum depressed, circular, about half diameter of base. Base low, unsculptured, conical. Collarette low and smooth, with a sinuous junction with the shaft. Shaft broadest centrally, tapering distally. Smaller primary radioles are more tapered and lack a central swollen region. Some spinules are pronounced and include thorn-like circlets (UF 68668), while on other radioles they become elongated and globular towards the tip. Spinules coalesce as ridges in some specimens. Maximum length 35 mm (UF 38948; cortex lost, but otherwise radiole complete).

Remarks — Donovan & Portell (2000, p. 169) considered the cidaroids from Duncans Quarry to be "... close to [*Eucidaris*] *tribuloides* or *Stylocidaris affinis* (Philippi) on the basis

of [their] spines ...” The available sample of radioles and coronal plates has increased since this initial determination and, although tentative, they are identified as *Priono-cidaris*? sp., perhaps close to *Prionocidaris cojimarensis* (Lambert & Sánchez Roig *in* Sánchez Roig, 1926) (Cutress, 1980). None of the radioles is really as thorny as the most pronounced of those of *P. cojimarensis* figured by Cutress (1980), but there is reasonable agreement with less spinose radioles and also interambulacral plates. They are unlikely to represent the thorny Mio-Pliocene *Eucidaris madrugensis* (Sánchez Roig) (see Cutress, 1980) because they lack the low, ribbed crown with a central, raised boss that is typical of this genus. There is a possibility that more than one species is represented by these robust, tubercular radioles, but variations in morphology are as likely to be due to dif-ferences in position on the test, ontogeny or various between individuals. The only complete test (Pl. 1, figs. 6, 7) has its surface detail obscured by calcite crystals (Donovan & Portell, 2000).

UF 103361 is a mixed group of poorly preserved radioles. It is most probably a mix-ture of fragments of *Prionocidaris*? sp. and *Echinometra* sp. cf. *E. lucunter*.

Family Rhabdocidaridae Lambert, 1900
Genus *Histocidaris* Mortensen, 1903

Type species — *Porocidaris elegans* A. Agassiz, 1879, by original designation (Fell, 1966, p. U321).

Diagnosis — (Based on Fell, 1966, pp. U321-U323; Smith & Wright, 1989, pp. 8, 13, 14.) Test rigidly sutured, commonly high, flattened apically and peristomially. Test plates thin. Ambulacral plates of peristomial membrane bear internal, marginally-directed prongs. Interambulacral plates wider than high. Areoles separate on adapical interam-bulacral plates, scrobicular circles complete; above ambitus scrobicular tubercles ar-ranged in contiguous band. Tubercles perforate and crenulate. Primary radioles cylin-drical for most or all length, tip tapered or less commonly flared. Radioles with thorny spinules with sort collars, cortical hairs simple or absent. Tridactylous pedicellariae in two forms; globiferous pedicellariae absent.

Range — Eocene (Cutress, 1980, p. 41) to Recent.

Histocidaris sp.
Pl. 5, figs. 8, 9.

Material studied — Two radiole fragments, UF 103349.

Description — Short fragments of slender, cylindrical primary radioles. Shaft sculp-tured by low, parallel, raised ridges, evenly spaced. Low, triangular thorns irregularly spaced, but organised in columns, about as wide as distance between ridges.

Remarks — *Histocidaris* has not previously been reported from the fossil record of Jamaica. Phelan (1970) listed two extant species within this genus from the tropical western Atlantic; *Histocidaris nuttingi* Mortensen, distributed from Cuba to near Anti-gua (225-740 m), and *Histocidaris sharreri* (A. Agassiz) from the Leeward Islands, Nevis

and St. Kitts (200-740 m; depth ranges from Serafy, 1979, table 2). The two radiole fragments from the Miocene of Jamaica (Pl. 5, figs. 8, 9) compare well with the "large shiny thorny primary spine" of extant *Histocidaris nuttingi* Mortensen illustrated by Phelan (1970, pl. 15, figs 2, 3). The stereom microstructure of these radioles has been infilled by calcite spar, so no internal structure is apparent; the same is true of radioles of *Prionocidaris*? sp.

In her monograph of Caribbean fossil cidaroids, Cutress (1980) recorded *Histocidaris* sp. indet. from the Miocene of Cuba and *Histocidaris sanchezi* (Lambert) from the Eocene of Cuba. *Histocidaris* sp. indet. of Cutress (1980), based on disarticulated, fragmentary radioles, is approximately coeval with the Jamaican specimens and has slender radioles that are morphologically similar, whereas those of *H. sanchezi* are distinctly thornier.

Subclass Euechinoidea Bronn, 1860
Order Echinoida Claus, 1876
Family Echinometridae Gray, 1825
Genus *Echinometra* Gray, 1825

Type species — *Echinus lucunter* Linné, 1758, p. 665, by original designation (Fell & Pawson, 1966, p. U433).

Diagnosis — See Fell & Pawson (1966, p. U433).

Range — Paleocene to Recent (Fell & Pawson, 1966, p. U433).

***Echinometra* sp. cf. *E. lucunter* (Linné, 1758)**
Pl. 1, fig. 13; Pl. 2, figs. 1-7; Pl. 7, figs. 2, 3, 6.

2000   *Echinometra* sp.; Donovan & Portell, pp. 168, 169, fig. 1a, b.

Material studied — Ten fragments of test, UF 38940, 38941, 38960, 39004, 39005, 68338, 68449, 68450, 68455 and 72213. Eighteen incomplete radioles, UF 38947, 68671, 68458 (Pl. 2, fig. 7), 72247 (eleven radioles) and 103348 (four radioles), may be conspecific. UF 68458 and 68459 were incorrectly identified as *Echinometra* sp. in Donovan & Portell (2000), and are included in *Prionocidaris*? sp. herein (see above).

Description — Test outline unknown. Test moderately large; largest specimen (UF 68450) 25.5 mm high and incomplete, interambulacrum+ambulacrum 33.4 mm wide, suggesting a test diameter of *circa* 50 mm. Ambitus about mid-height of test.

Ambulacra broadest abambitally. Ambulacral plates with polygeminate echinoid compounding. Poriferous zones flush with test surface. Pore pairs arranged in short arcs around primary ambulacral tubercles, each arc being closest to the adjacent tubercle adapically. Six to eight pore pairs per arc. Pores rounded and closely spaced. Primary ambulacral tubercles moderately large, conical, imperforate and non-crenulate. Smaller ambulacral tubercles sparse.

Interambulacra about twice as broad as ambulacra ambitally. Interambulacral plates

low and broad. One primary tubercle per plate, arranged in columns. Primary tubercles large, conical, imperforate and non-crenulate with a broad areole. Smaller tubercles of two or three orders; larger secondary tubercles occur adjacent to the interradial suture as a zigzag series.

Primary radioles short to long, with the longest specimen 33.0 mm (UF 38947; Pl. 1, fig. 13). Base moderately high, tapering proximally. Milled ring low. Shaft gently convex, with sculpture of longitudinal, slightly sinuous ridges separated by narrow, shallow grooves.

Apical system, periproct, peristome and pedicellariae not preserved.

Remarks — Two extant species of *Echinometra* are widespread throughout the Caribbean. *Echinometra lucunter* (Linné) occurs in depressions in rocky substrates, generated or modified by its own boring action, while *E. viridis* A. Agassiz is a crevice dweller in coral reefs and rocky areas (Hendler *et al.*, 1995). Although only rarely preserved in the fossil record of the region as complete specimens (but, for example, see Donovan, 1994b; Donovan & Collins, 1997), living members of these species have particularly robust tests that enable them to survive in shallow water, high energy environments (Gordon, 1991; Donovan & Gordon, 1993). The more complete, albeit still fragmentary specimens of *Echinometra* from Duncans Quarry, which unfortunately are encrusted by calcite crystals (Donovan & Portell, 2000), were all collected from interstices within massive scleractinian corals and thus may be considered ecological analogues to *E. viridis*. However, as noted by Donovan (1993, p. 382), *E. viridis* typically has pore pairs arrayed in arcs of five, whereas fossil specimens from this site have at least six (UF 68450), six to seven or more (UF 39005) or eight (UF 72213; from adjacent to the peristome) pore pairs per ambulacral plate. Donovan (1993) considered pore pairs to be are arrayed in arcs of six in *E. lucunter*, but Gordon (1963, p. 632) considered arcs of seven or eight to be typical. Other diagnostic features of *Echinometra* species, such as degree of insertion of the oculars, number of coronal plates and presence or absence of tags on the auricles, are not preserved in the Duncans Quarry specimens.

Few Tertiary *Echinometra* are known from the Antilles. Gordon (1963) recorded *E. lucunter* (with pore pairs arrayed in arcs of six) from the San Sebastián Formation of Puerto Rico (Oligocene; Larue, 1994). *Echinometra prisca* Cotteau, 1875, from the Lower Miocene of Anguilla (Poddubiuk & Rose, 1985) and Oligo-Miocene of Cuba (Sánchez Roig, 1949, p. 48) has the ambulacral pore pairs arrayed in arcs of three to four (Cotteau, 1875; Jackson, 1922). Kier (1992) documented a well-preserved test of *E. lucunter* from the Lower Pliocene of the Dominican Republic. Both *E. viridis* (Donovan *et al.*, 1994a; Donovan & Collins, 1997) and *E. lucunter* (Donovan, 1993, 1994b) are well known from the Pleistocene of Jamaica (see also Gordon, 1990, 1991), and *Echinometra* sp. occurs in the Upper Pliocene Bowden Shell Bed of the island (Donovan & Paul, 1998).

The calculation of test diameter made above assumes that it is rounded. However, as the tests of *E. lucunter* are commonly elongated, this estimate must be regarded as being very approximate.

Five radiole fragments (UF 103347) are too poorly preserved to determine if they are anything more than indeterminate irregular echinoids, but they are most probably conspecific with this taxon.

Cohort Irregularia Latreille, 1825
Order Holectypoida Duncan, 1889
Family Echinoneidae Agassiz & Desor, 1847
Genus *Echinoneus* Leske, 1778

Type species — *Echinoneus cyclostomus* Leske, 1778, p. 173, by the subsequent designation of H.L. Clark (1917, p. 101) (Wagner & Durham, 1966, p. U445).

Diagnosis — See Donovan & Veale (1996, p. 633).

Range — Oligocene to Recent (Rose, 1978, p. 304: Dixon & Donovan, 1998, pp. 102, 104).

***Echinoneus cyclostomus* Leske, 1778**
Pl. 1, figs. 2-5; Pl. 7, fig. 1.

	1930	*Echinoneus cyclostomus* Leske; Hawkins *in* Trechmann: p. 216.
	1988	*Echinoneus cyclostomus* Leske; Donovan, table 1.
	1993	*Echinoneus cyclostomus* Leske; Donovan, p. 382, fig. 9.5, 9.6.
	1993	*Echinoneus cyclostomus* Leske; Donovan & Lewis, p. 189, fig. 2a-c.
?	1994	holectypoid sp. nov.; Dixon & Donovan, fig. 2, table 1.
	1996	*Echinoneus cyclostomus* Leske; Donovan & Embden, pp. 488, 489, fig. 2.6-2.8.
?	1998	*Echinoneus* cf. *cyclostomous* Leske; Dixon & Donovan, p. 104, pl. 3, figs. 1-2, text-fig. 3, table 1.
	2000	*Echinoneus cyclostomus* Leske; Donovan & Portell, p. 169, fig. 1d.

Material studied — A single test, UF 38953, encrusted by calcite crystals. Two test fragments, UF 72256 and 103346, are probably conspecific.

Description — UF 38953 is too heavily encrusted by calcite to make description efficacious (Pl. 1, figs. 2-5). See Donovan (1993, p. 382) and Dixon & Donovan (1998, p. 104) for descriptions of *E. cyclostomus* and *E.* sp. cf. *E. cylostomus* from the Recent and Oligocene of Jamaica, respectively.

Remarks — This test is heavily encrusted in calcite (Donovan & Portell, 2000), but is obviously *Echinoneus*, as indicated by overall shape and size, and the outlines and relative positions of the periproct and peristome (compare Pl. 1, figs. 2, 3, with Donovan, 1993, figs 9.5, 9.6). As discussed by Mortensen (1948, p. 74) and Donovan & Veale (1996), fossil species tend to be indistinguishable from extant *E. cyclostomus*. Although other nominal species of *Echinoneus* are known from the Antillean region (see, for example, Sánchez Roig, 1949, pp. 117-120), it is at least probable that they are junior synonyms of *E. cyclostomus*. It is therefore considered conservative to include the Duncans specimen in this geographically and temporally widely-distributed species.
The status of the genus *Echinoneus*, particularly *E. cyclostomus*, in the fossil record of the Antillean region was recently reviewed by Donovan & Veale (1996). Subsequently, Dixon & Donovan (1998) described *Echinoneus* sp. cf. *E. cyclostomus* from the Upper Oligocene of Jamaica. UF 38953 is the first *Echinoneus* from the Miocene of Jamaica, al-

though it is otherwise known from the Oligo-Miocene of Cuba (Sánchez Roig, 1949) and the Miocene of Anguilla (*E.* sp. cf. *E. cyclostomus*; Poddubiuk & Rose, 1985; Table 4 herein).

UF 38953 (Pl. 1, figs. 2-5) is one of the rare complete tests to be collected from the Duncans Quarry, where it was removed from a slide block of scleractinian coral derived from shallower water. Extant *E. cyclostomus* occurs in water depths of 5-570 m (Serafy, 1979). It is a cryptic species, clinging to the underside of rocks resting on sand and is common in reefal environments (Hendler *et al.*, 1995, pp. 227, 228).

Order Clypeasteroida A. Agassiz, 1872
Suborder Clypeasterina A. Agassiz, 1872
Family Clypeasteridae L. Agassiz, 1836
Genus *Clypeaster* Lamarck, 1801

Type species — *Echinus rosaceus* Linné, 1758, p. 665, by the subsequent designation of Desmoulins (1835, p. 183) (Durham, 1966, p. U462).

Diagnosis — See Durham (1966, p. U463) and Mooi (1989).

Range — Middle Eocene (Auversian) to Recent (Mooi, 1989, p. 34).

Clypeaster? sp.
Pl. 6, figs. 4, 5; Pl. 7, figs. 5, 6.

Material studied — Eleven fragments of test, UF 72216, 101775 (two fragments), 101785, 101788, 103352 (four specimens) and 103360, and RGM 212447.

Remarks — Fragments of this morphology may represent a clypeasteroid or possibly a cassiduloid (A.B. Smith, written comm.). No cassiduloids have been identified in the Jamaican Miocene and Pliocene, and only one species is known, rarely, from the Oligocene (Dixon & Donovan, 1998), but *Clypeaster* spp. are locally common in the Upper Oligocene and Miocene. Assuming that these fragments represent one species of *Clypeaster*, which is by no means certain, then they most probably were derived from either *C. concavus* Cotteau, known from coeval deposits in Anguilla and Puerto Rico (Tables 4, 5), or *C. duchassaingi* Michelin, the only nominal member of this genus known from the Miocene of Jamaica (Donovan, 1993; Chalmers, 2001). *Clypeaster duchassaingi* is otherwise considered to be limited to the Pliocene (Poddubiuk, 1985). However, there is at least one other species of *Clypeaster* in the shallow water limestones of the Jamaican Miocene (Donovan, 1991; Donovan & Portell, 1996). UF 103360, the largest fragment of *Clypeaster*?, is distinctive in having a particularly thick test, reminiscent of extant *Clypeaster rosaceus* (Linné); other specimens from Duncans Quarry have a relatively thinner test. This suggests that UF 103360 may represent a species close to *Clypeaster cubensis* Cotteau (Gordon, 1963, text-fig. 2c; Poddubiuk, 1985, p. 77). *Clypeaster cubensis sensu stricto* is limited to the Middle and lower Upper Miocene of the Antillean region (Poddubiuk, 1985). Alternately, UF 103360 may merely represent a thickened part of the test (e.g., the ambitus) that is not otherwise seen in the available specimens. While this

at least suggests that more than one species is present, we prefer to make a conservative estimate at this time, at least until the variations seen in Jamaican Miocene *Clypeaster* spp. have been fully explored on more complete specimens.

<div align="center">

Order Spatangoida Claus, 1876
Incertae familiae
Spatangoid sp.
Pl. 8.

</div>

Material studied — Only represented by fragmentary specimens, including UF 72215 (one test fragment), 72217 (one test fragment), 101788 (one test fragment), 103350 (27 broken radioles) and 103351 (eight test fragments).

Remarks — Although spatangoids are locally common and moderately diverse in the Eocene of the White Limestone Group (Donovan, 1994a), they are rare and commonly imperfectly preserved in the Oligocene and Miocene of the same unit (see, for example, Dixon & Donovan, 1998). Although only preserved as fragments, the specimens from Duncans thus take on a greater importance than at first apparent.

The incomplete preservation of these specimens makes it difficult to determine if one or more than one species of spatangoid is present at this locality. However, the range of morphologies shown by these fragments could be encompassed within the test of a single taxon, so a conservative estimate has been adhered to in placing these specimens in open nomenclature. Although fragmented, at least some specimens preserve excellent stereom microstructure (best seen in Pl. 8, figs. 4, 6, 7), although no trace of a fasciole has been detected. The test is thin. Likely candidates for a thin-tested spatangoid in the mid-Tertiary of the Antillean region might be *Schizaster* L. Agassiz, *Agassizia* Agassiz & Desor or *Brissus* Gray. *Brissus* sp. aff. *B. unicolor* (Leske, 1778) from Montego Bay, parish of St. James, may be approximately coeval (Donovan & Harper, 2000).

Table 3. Echinoids from the Miocene of Jamaica. Key: ✓ = present; ? = uncertainly derived from this unit; + = see Donovan & Harper (2000); * = see Donovan (1991, 1993).

	Montpelier Formation	*Amphisorites matleyi*-yielding limestones of the Moneague Formation (formerly Newport Formation; Mitchell 2004)*
Prionocidaris? sp.	✓	
Histocidaris sp.	✓	
Echinometra sp. cf. *E. lucunter* (Linné)	✓	
Echinoneus cyclostomus Leske	✓	
Clypeaster duchassaingi Michelin		✓
Clypeaster/*Clypeaster*? sp./spp.	✓	✓
scutellid sp. indet.		✓
Brissus sp. indet. *B. unicolor* (Leske)[+]	?	
spatangoid sp. indet.	✓	

Table 4. Echinoids of the Lower Miocene Anguilla Formation of Anguilla (simplified after Poddubiuk & Rose, 1985, table 3). Key: * = referred to ?*Psammechinus martinkayei* Cassanova, 1958, by Poddubiuk & Rose, but this is a *nomen nudum*; + = referred to *Pericosmus* ?*blanquizalensis* Sánchez Roig, 1949, by Poddubiuk & Rose, but we have been unable to recognise this taxon in the original reference.

Table 5. Echinoids of the Lower Miocene Cibao Formation of Puerto Rico (simplified after Gordon, 1963, table 1; lithostratigraphy after Larue, 1994).

Order CIDAROIDA
    Cidaris (*Tretocidaris*) *anguillensis* Cutress, 1980
    Prionocidaris clevei (Cotteau, 1875)
Order ECHINOIDA
    Echinometra prisca Cotteau, 1875
    Psammechinus? sp. *
    Tripneustes sp. nov.
Order HOLECTYPOIDA
    Echinoneus cf. *cyclostomus* Leske, 1778
Order CLYPEASTEROIDA
    Sismondia anguillae Cotteau, 1875
    Clypeaster concavus Cotteau, 1875

Order CASSIDULOIDA
    Echinolampas lycopersicus Guppy, 1866
    Echinolampas semiorbis Guppy, 1866
Order SPATANGOIDA
    Pericosmus sp. +
    Schizaster clevei Cotteau, 1875
    Schizaster loveni Cotteau, 1875
    Agassizia clevei Cotteau, 1875
    Brissus exiguus Cotteau, 1875
    Brissopis antillarum Cotteau, 1875
    Eupatagus cubensis (Cotteau, 1897)
    Meoma clevei (Cotteau, 1875)
    Meoma sp.
    Lovenia gregoryi Lambert, 1922

Order CIDAROIDA
    Cidaris spp.
    Phyllacanthus sp.

Order CLYPEASTEROIDA
    Clypeaster concavus Cotteau, 1875
    Clypeaster concavus puertoricanus Gordon, 1963
    Clypeaster oxybaphon Jackson, 1922
Order CASSIDULOIDA
    Echinolampas lycopersicus Guppy, 1866
    Echinolampas semiorbis Guppy, 1866
Order SPATANGOIDA
    Schizaster loveni (Cotteau, 1875)
    Agassizia clevei Cotteau, 187

Discussion

Fragmentary echinoderms from the Antillean islands have received little attention from systematists, so our knowledge of this group is biased towards well preserved specimens (mainly echinoids). Inclusion of fragmentary remains in such studies provides much more complete information, including examples of echinoids with a low preservation potential and rare evidence of other echinoderm classes. This paper is part of an ongoing research programme examining progressively older fragmentary echinoderm faunas from the Cenozoic of Jamaica. Successful studies have been made already of the mainly fragmentary echinoderm remains of the Upper Pleistocene Falmouth Formation (Gordon, 1990, 1991; Gordon & Donovan, 1992; Donovan & Gordon, 1993; Donovan & Collins, 1997; Simpson, 2001) and the Upper Pliocene Bowden Forma-

tion (Donovan & Paul, 1996, 1998; Donovan & Portell, 1998). Ossicles were less common at Duncans Quarry than these other two deposits, although the well-lithified limestones of that site were less easy to analyse by sieving bulk samples than most beds of the Bowden Shell Bed, Bowden Formation or the East Rio Bueno site of the Falmouth Formation.

Coeval echinoids have been documented from the Anguilla Formation of Anguilla (Table 4) and the Cibao Formation of Puerto Rico (Table 5). The Anguilla Formation includes 20 species of echinoids, that is, somewhat more diverse than Duncans Quarry, although the abundant and common taxa are cidaroids, *Echinometra prisca*, *Clypeaster concavus*, *Echinolampas* spp. and certain of the spatangoids (Poddubiuk & Rose, 1985, table 3). This association, based on specimens from multiple localities, is comparable to the echinoids from Duncans, apart from the absence of any cassiduloids at the Jamaican site. Although less diverse, the Cibao Formation has yielded a number of species also known from Anguilla. However, we question the occurrence of *Clypeaster oxybaphon* in the Cibao Formation (Table 5). This species is best known from the Upper Oligocene of the region (Jackson, 1922, p. 45; Poddubiuk, 1985; Dixon & Donovan, 1998) and its presence in the Miocene requires confirmation.

The biostratigraphic potential of the Antillean Cenozoic Echinoidea remains unfulfilled. The case for the use of echinoids in Neogene biostratigraphy was argued succinctly by Rose (1985; see also Rose & Poddubiuk, 1987). Antillean post-Oligocene echinoid taxa commonly show a patchy distribution and indifferent preservation, so the greatest potential for biostratigraphy must lie with large, distinctive, disarticulated ossicles such as cidaroid radioles and complete tests of taxa with a high preservation potential such as clypeasteroids. Use of fragmentary remains appears to be precluded in the Lower Miocene by our poor knowledge of their distribution and classification, although *Prionocidaris* or *Phyllacanthus* are recorded from Jamaica, Puerto Rico and Anguilla. Both of these cidaroid genera have large and obvious radioles. The clypeasteroid *Clypeaster* is similarly widespread and has a high potential for biostratigraphic utility (Donovan & Portell, 1996); *C. concavus* is known from the Lower Miocene of Anguilla, Puerto Rico and, uncertainly, Jamaica (Donovan, 1993, p. 388; Chalmers, 2001). Poddubiuk (1985, p. 76) considered the range of this species to be upper Lower Miocene to lower Middle Miocene.

For the first time it is possible to compare moderately diverse associations of echinoderms from the Oligocene, Miocene and Pliocene of Jamaica (Table 6). These localities represent contrasting palaeoenvironments, but the two deeper water sites (Duncans Quarry, Bowden Shell Bed) include material derived by downslope transport, so all three contain some specimens from broadly analogous shallow-water settings. Lee's Marl Crushing Plant in the Upper (or high Lower) Oligocene of the Moneague Formation (formerly Browns Town Formation; Mitchell, 2004) has been the most productive echinoderm site in the Jamaican Oligocene (Dixon *et al.*, 1994; Dixon, 1995; Dixon & Donovan, 1998). These limestones were deposited in a high energy, shelf edge setting. The Upper Pliocene Bowden Shell Bed of the Bowden Formation, Lower Coastal Group, is possibly the most famous fossiliferous deposit in the Antilles (Donovan, 1998) and has produced a moderate diversity of echinoderms, mainly fragmented and juvenile tests (Donovan & Paul, 1998). These specimens are preserved in siliciclastics laid down in deeper water by mass flows (Pickerill *et al.*, 1998). Obvious similarities are the presence

Table 6. Echinoderm associations of the Oligocene to Pliocene of Jamaica. Sources: Lee's Marl Crushing Plant (Upper Oligocene) - Dixon *et al.* (1994); Dixon & Donovan (1998); C. Mah (written comm.); Duncans Quarry (Lower Miocene) - see herein; Bowden Shell Bed (Upper Pliocene) - Donovan & Paul (1996, 1998); Donovan & Portell (1998); Donovan *et al.* (2001, table 1). Key: filled circle = present.

	Lee's Marl Crushing Plant	Duncans Quarry	Bowden Shell Bed
CRINOIDS			
comatulid sp.	•		
Neocrinus cf. *decorus* (Wyville Thomson, 1864)		•	
Isocrinus sp.		•	
OPHIUROIDS			
ophiuroid sp.	•		
Ophiomusium? sp.		•	
basket star			•
ASTEROIDS			
oreasterid? sp.	•		
Astropecten/Astropecten? sp. or spp.		•	•
ECHINOIDS			
Prionocidaris spinidentatus (Palmer *in* Sánchez Roig, 1949)	•		
Prionocidaris? sp.		•	
Eucidaris madrugensis (Sánchez Roig, 1949)			•
Histocidaris sp.		•	
Diadema sp.			•
Arbacia sp.			•
Echinometra cf. *lucunter* (Linné, 1758)		•	
Echinometra sp.			•
Tripneustes sp.			•
Echinoneus cyclostomus Leske, 1778	•	•	
Clypeaster batheri Lambert, 1915	•		
Clypeaster cf. *carrizoensis* Kew, 1914			•
Clypeaster oxybaphon Jackson, 1922	•		
Clypeaster? sp.		•	
scutelline sp.			•
Agassizia sp.	•		
Schizaster? sp.			•
spatangoid sp.		•	
TOTALS	**8**	**10**	**10**

of at least one species of *Clypeaster*, a cidaroid with robust radioles and a spatangoid in each of these three deposits. Asteroids and ophiuroids are recognised everywhere, but probably represent different taxa. Stalked crinoids are only known at Duncans Quarry, surprisingly being absent from the Bowden Shell Bed. Cidaroids apart, regular echinoids are rare.

Donovan & Portell (2000) have already recorded the unusual 'crystal apple' preservation of some complete and partial tests preserved within the scleractinian slide blocks (Pl. 1, fig. 2-7) (see Paul, 1980, p. 20, fig. 11C, for a fuller discussion). This is the only part of the quarry where rare complete echinoid tests have been collected. The close association with scleractinian slide blocks strongly suggests that they are derived from shallower water. Downslope transport of olistostromic blocks has been long recognised in the White Limestone Group (Robinson, 1967) and deeper water island slope deposits

in the Antillean Cenozoic have been enriched by allochthonous accumulations of shallow water fossils (Donovan, 1998, 2002). The complete echinoids from Duncans Quarry were obviously moved under unusually well-protected conditions in close association with scleractinian corals.

Sedimentological evidence from Duncans Quarry suggests it represents a deeper water palaeoenvironment, laid down off the north coast of Jamaica (Mitchell, 2004), perhaps analogous to the present-day island slope of the north coast which is steep to near-vertical. This determination is supported by palaeontological evidence provided by, for example, brachiopods (Harper & Portell, 2002, 2004) and fishes (Underwood & Mitchell, 2004). The mixture of fossil echinoderms includes taxa best regarded as primarily shallow water, although some have ranges extending into deeper water (e.g., extant *Echinoneus cyclostomus* has a depth range of 5-570 m; Serafy, 1979, table 2; Hendler *et al.*, 1995, p. 227), admixed with a number of typically deeper water species; it is the latter which obviously need to be examined for an accurate determination of minimum depth of deposition (Orr, 2001). Such disharmonious associations are typical of uplifted deeper water deposits in the Neogene of the Antilles (Donovan *et al.*, 2003) and provide strong evidence that contradicts the school of thought that shelly assemblages are commonly autochthonous or, at most, parautochthonous accumulations (Donovan, 2002).

Typical deeper water echinoderms of Duncans Quarry include the isocrinids, *Ophiomusium*? sp. and *Histocidaris* sp. In the tropical western Atlantic, extant *Neocrinus decorus* Wyville Thomson and *Isocrinus blakei* (Carpenter) have confirmed depth ranges of 154-1220 m and 220-650 m, respectively (Meyer *et al.*, 1978, p. 425). *Ophiomusium* is not known from among the numerous shallow water ophiuroids of the Caribbean, but Downey (1969, pp. 148-158) noted a number of deeper water taxa from the region, with depth ranges (converted from fathoms) from 77-183 m to 1789-4082 m. The two extant species of *Histocidaris* have depth ranges that are similar, that is, *H. nuttingi* Mortensen (225-740 m) and *H. sharreri* (A. Agassiz) (200-740 m) (Serafy, 1979). Taken together, these data suggest a minimum depth of deposition for the chalks and limestones of Duncans Quarry of *circa* 200 m and probably more.

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Plate 1

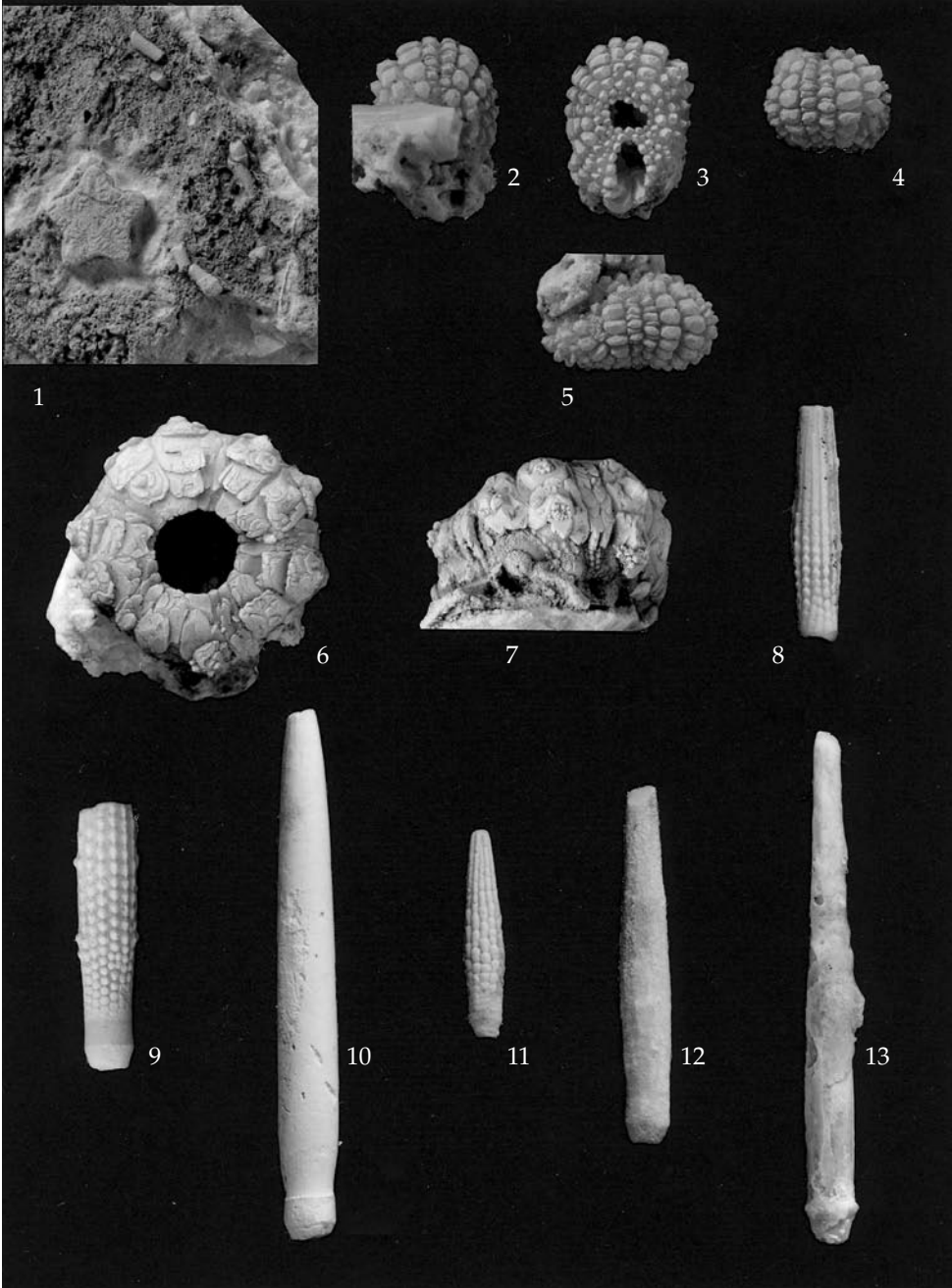Crinoid columnal, and echinoid tests and radioles from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Fig. 1. *Isocrinus* sp. with echinoid debris, UF 101762. × 2.
Figs. 2-5. *Echinoneus cyclostomus* Leske, UF 38953, test in 'crystal apple' preservation (Donovan & Portell, 2000), in apical (2), oral (3), anterior (4) and right lateral (5) views. All × 4.
Figs. 6-12. *Prionocidaris*? sp. (6, 7) UF 68437, test in 'crystal apple' preservation (Donovan & Portell, 2000), in apical? (6) and oblique lateral (7) views, both × 3. (8) UF 68669, radiole, × 4. (9) UF 68659, radiole, × 3.5. (10) UF 38948, radiole. × 2. (11) UF 68664, radiole, x 3.5. (12) UF 68670, radiole, × 3.5.
Fig. 13. *Echinometra* sp. cf. *E. lucunter* (Linné), UF 38947, radiole, × 2.

All specimens coated with ammonium chloride for photography.

Plate 2

Echinoid test fragments and radiole from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Figs. 1-7. *Echinometra* sp. cf. *E. lucunter* (Linné). (1) UF 39004, fragment of ambulacrum (left) and interambulacrum coated with calcite crystals. (2) UF 68455, fragment of interambulacrum coated with calcite crystals. (3) UF 68449, fragment of ambulacrum(?) and interambulacrum coated with calcite crystals. (4) UF 38960, ambulacrum (left) and interambulacrum. (5) UF 68338, test fragment. x 3. (6) UF 68450, fragment of ambulacrum (left) and interambulacrum, the latter coated with calcite crystals. (7) UF 68458 radiole. × 3;

All specimens coated with ammonium chloride for photography. All figures x 2 unless stated otherwise.
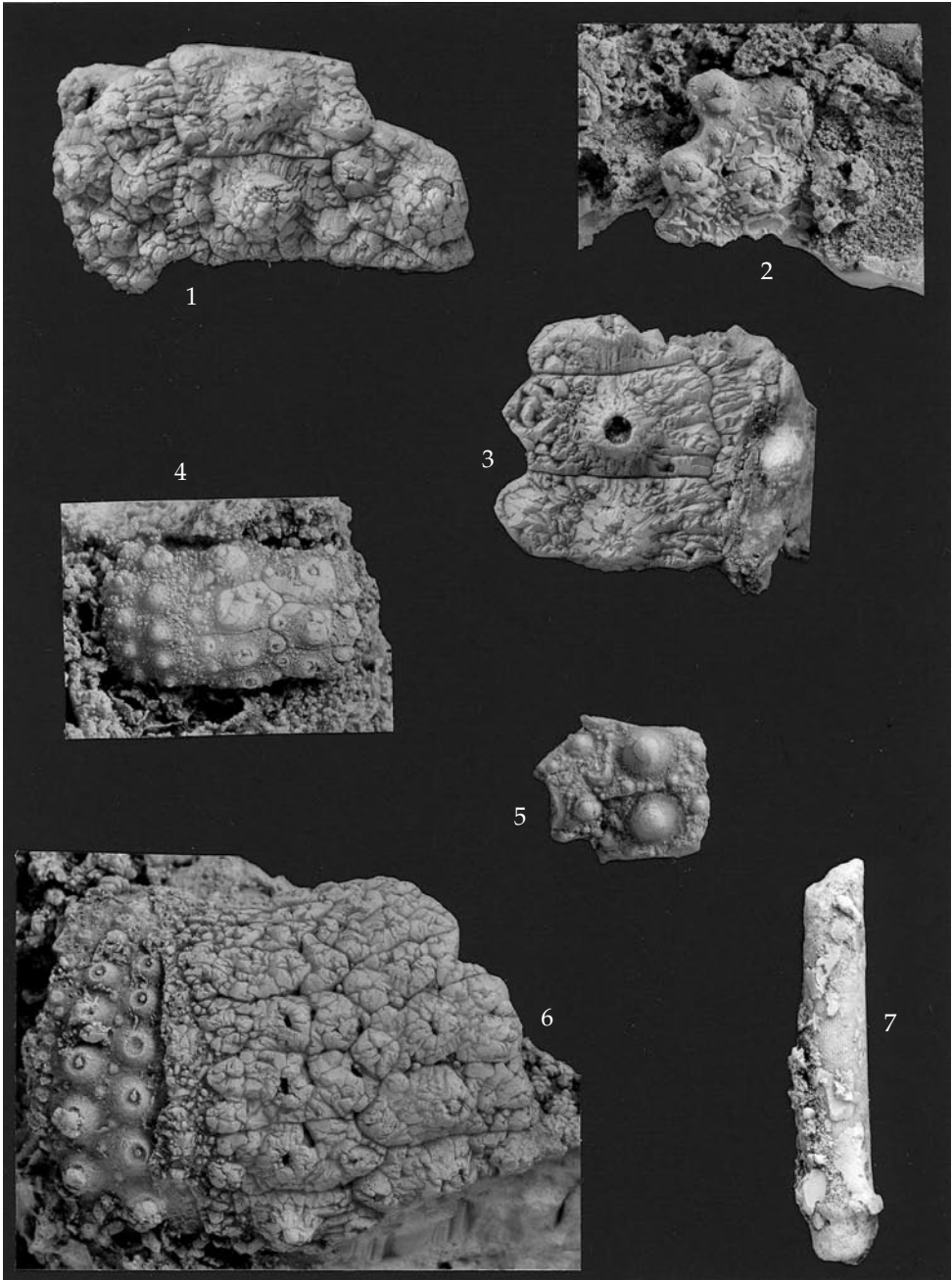
Plate 3

Crinoid ossicles from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Fig. 1. Cirral ossicle, UF 72231. × 35.
Figs. 2, 4. *Isocrinus* sp. (2) UF 103354, articular facet of broken columnal. × 16. (4) UF 67000, articular facet. × 9.
Fig. 3. *Neocrinus* sp. cf. *N. decorus* Wyville Thomson, UF 101761. × 17.
Fig. 5. Brachial ossicles, UF 101759. × 35.

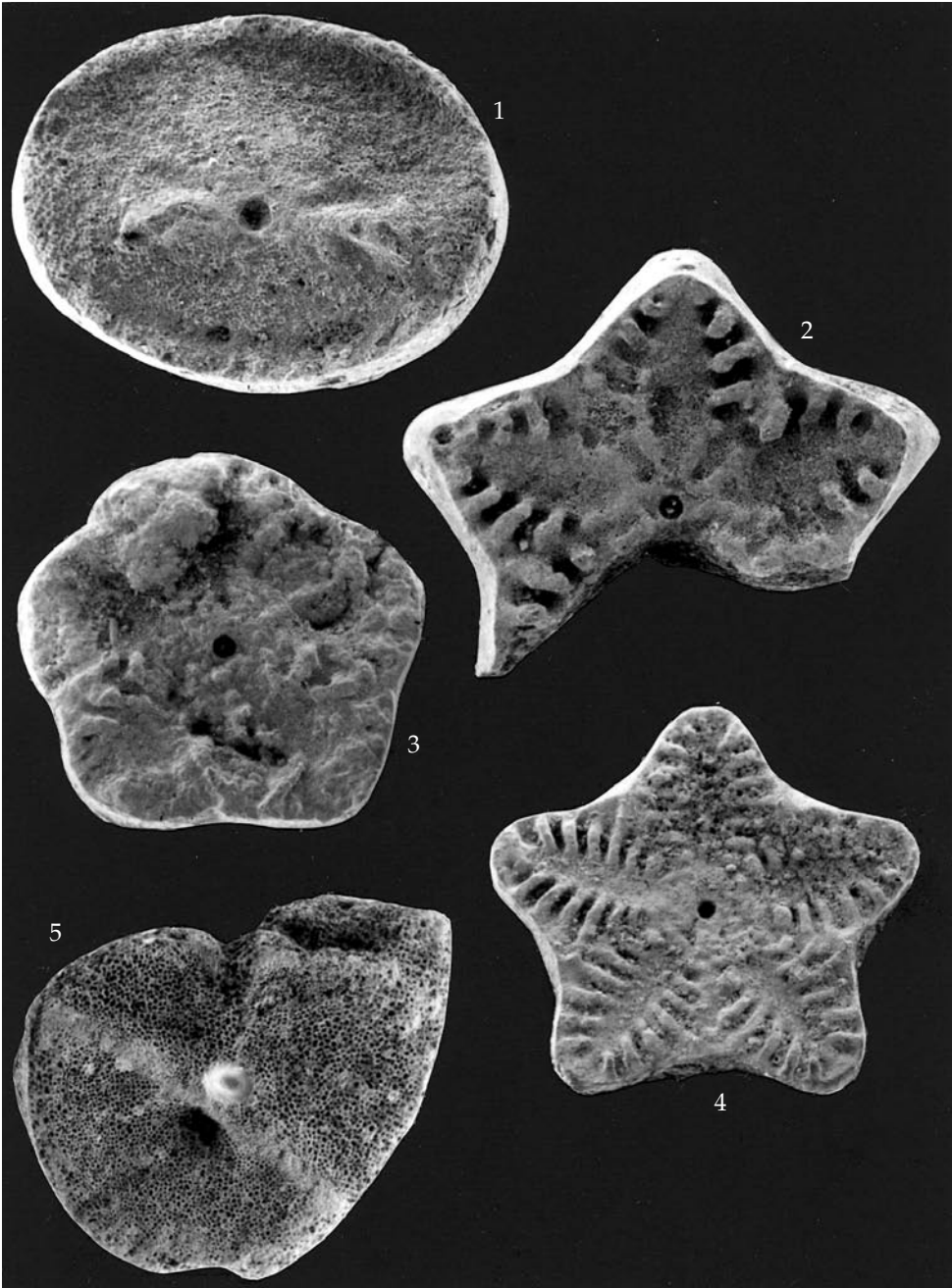SE micrographs of specimens coated with 60% gold/palladium.

Plate 4

Crinoid brachial ossicle, ophiuroid vertebral ossicle and an asteroid marginal ossicle from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Fig. 1. Brachial ossicle, UF 101759. × 44.
Figs. 2-4. *Ophiomusium*? sp., UF 101760, vertebral ossicle. × 39 (2); × 41 (3); × 43 (4).
Fig. 5. *Astropecten*? sp., UF 101763, marginal ossicle. × 14.

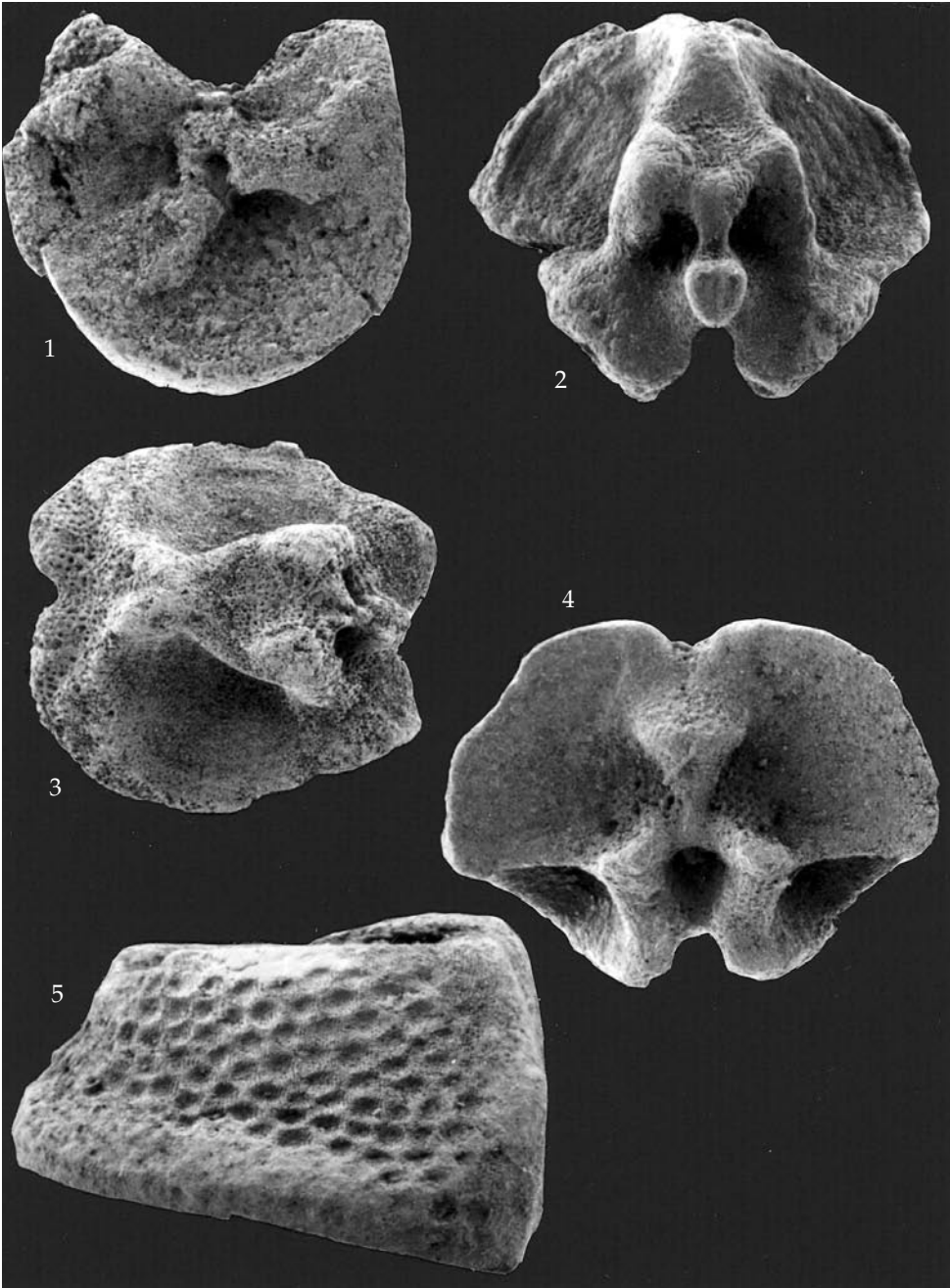SE micrographs of specimens coated with 60% gold/palladium.

Plate 5

Cidaroid radioles from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Figs. 1-7. *Prionocidaris*? (1) UF 103339. × 26. (2) UF 103339. × 9. (3) UF 103339. × 11. (4) UF 103338. × 28. (5) UF 103338. × 18. (6) UF 39009. × 7.5. (7) UF 101769. × 7.5.
Figs. 8, 9. *Histocidaris* sp., UF 103349, two radiole fragments. (8) × 24. (9) × 28.

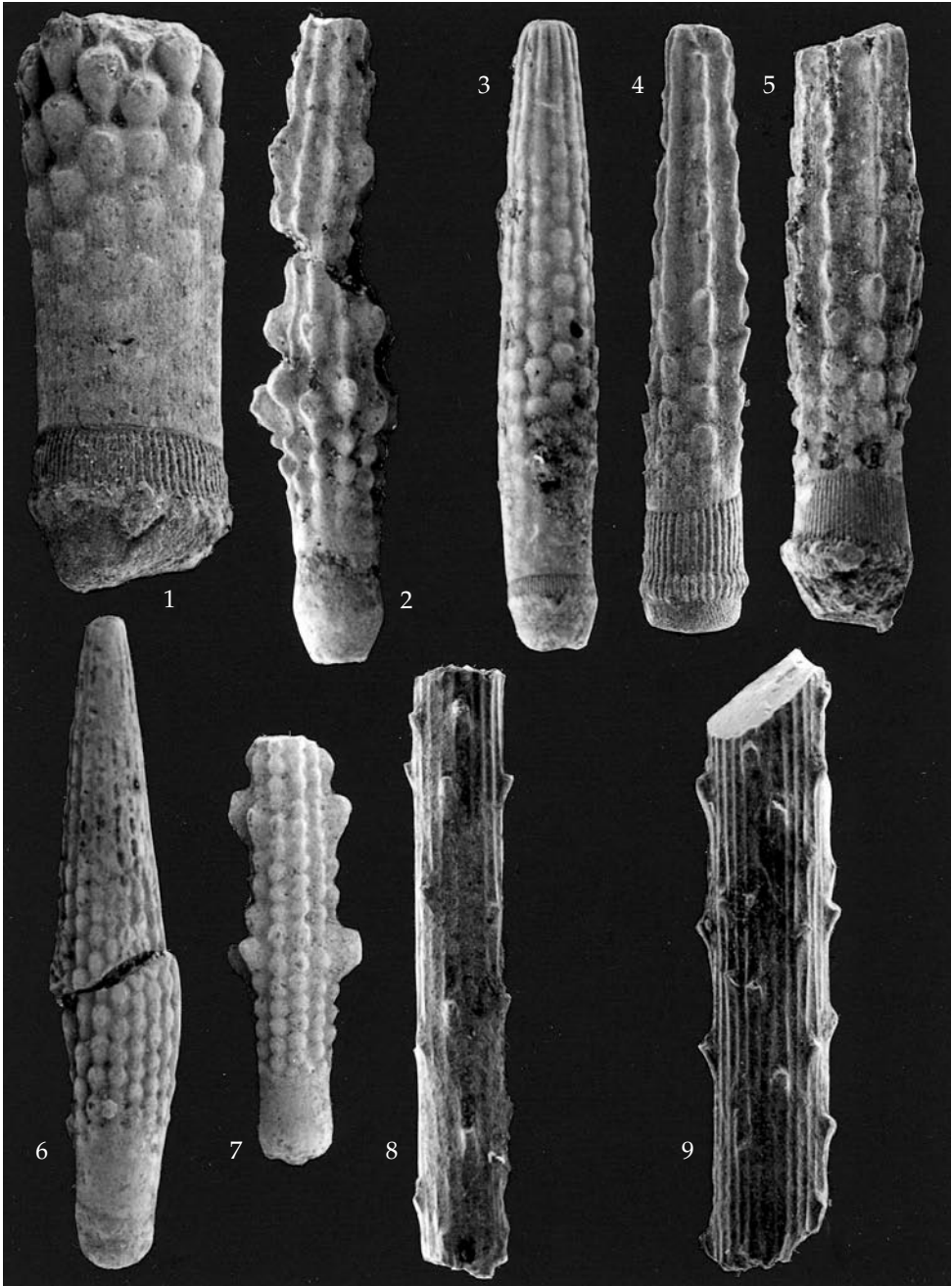SE micrographs of specimens coated with 60% gold/palladium.

Plate 6

Test fragments of cidaroids and *Clypeaster*? from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Figs. 1-3. *Prionocidaris*? sp. (1) UF 103344, interambulacral plate with ambulacral column (right). × 24. (2) UF 72212, interambulacrum flanked by ambulacral columns. × 32. (3) UF 103344, part of ambulacrum (left) and adjacent interambulacral plates. × 38.
Figs. 4, 5. *Clypeaster*? sp. (4) UF 101775. × 7. (5) UF 103352. × 14.

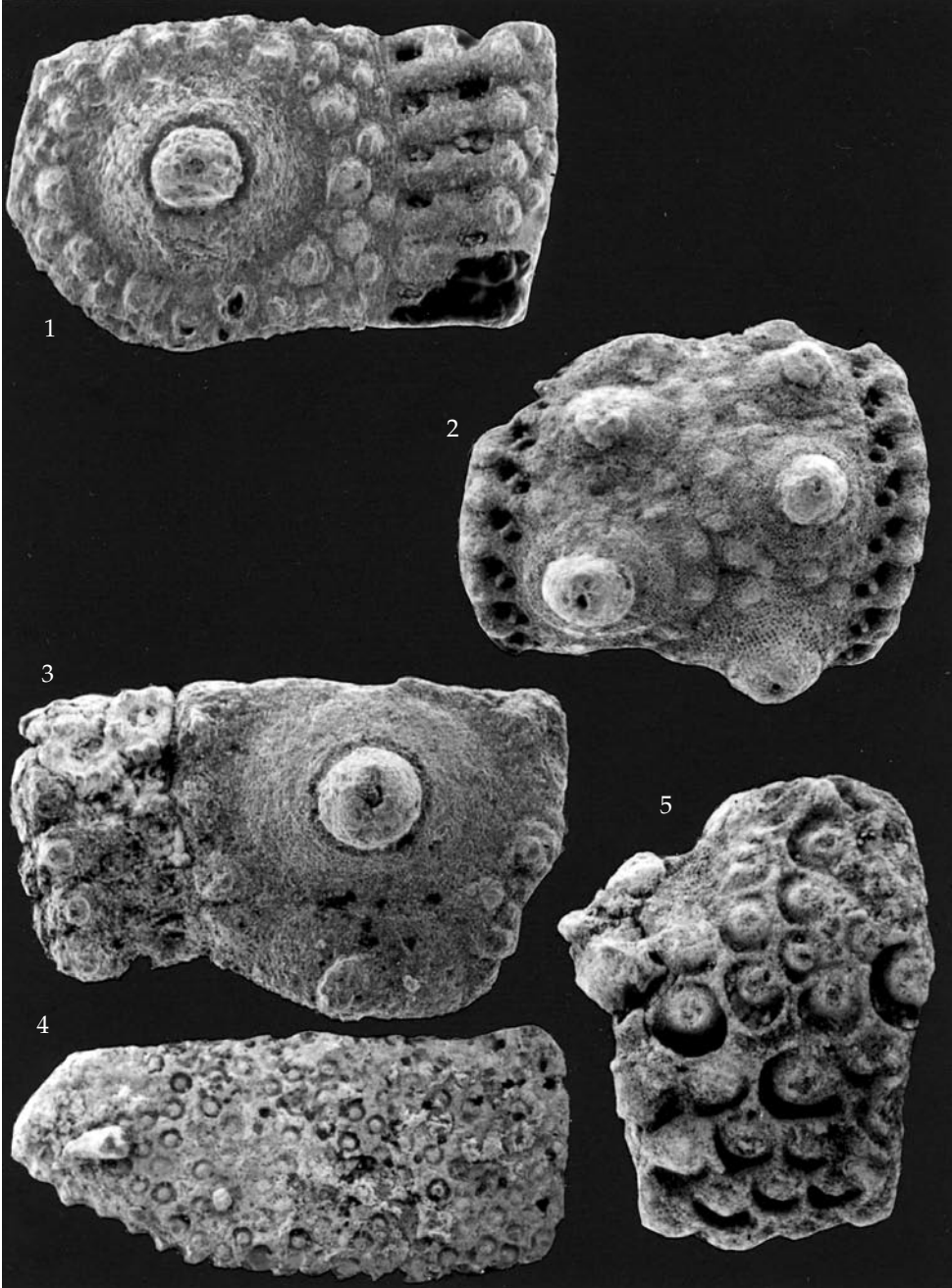SE micrographs of specimens coated with 60% gold/palladium.

Plate 7

Fragments of *Clypeaster*?, *Echinoneus*? and *Echinometra* from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Fig. 1. *Echinoneus*? sp., UF 103346. × 40.
Figs. 2-4. *Echinometra* sp. cf. *E. lucunter* (Linné). (2) UF 39005, test fragment. × 7. (3) UF 72213, test fragment. × 23, (4) UF 103348, radiole. × 14.
Figs. 5, 6. *Clypeaster*? sp., UF 103352, test fragments. (5) × 16. (6) × 22.

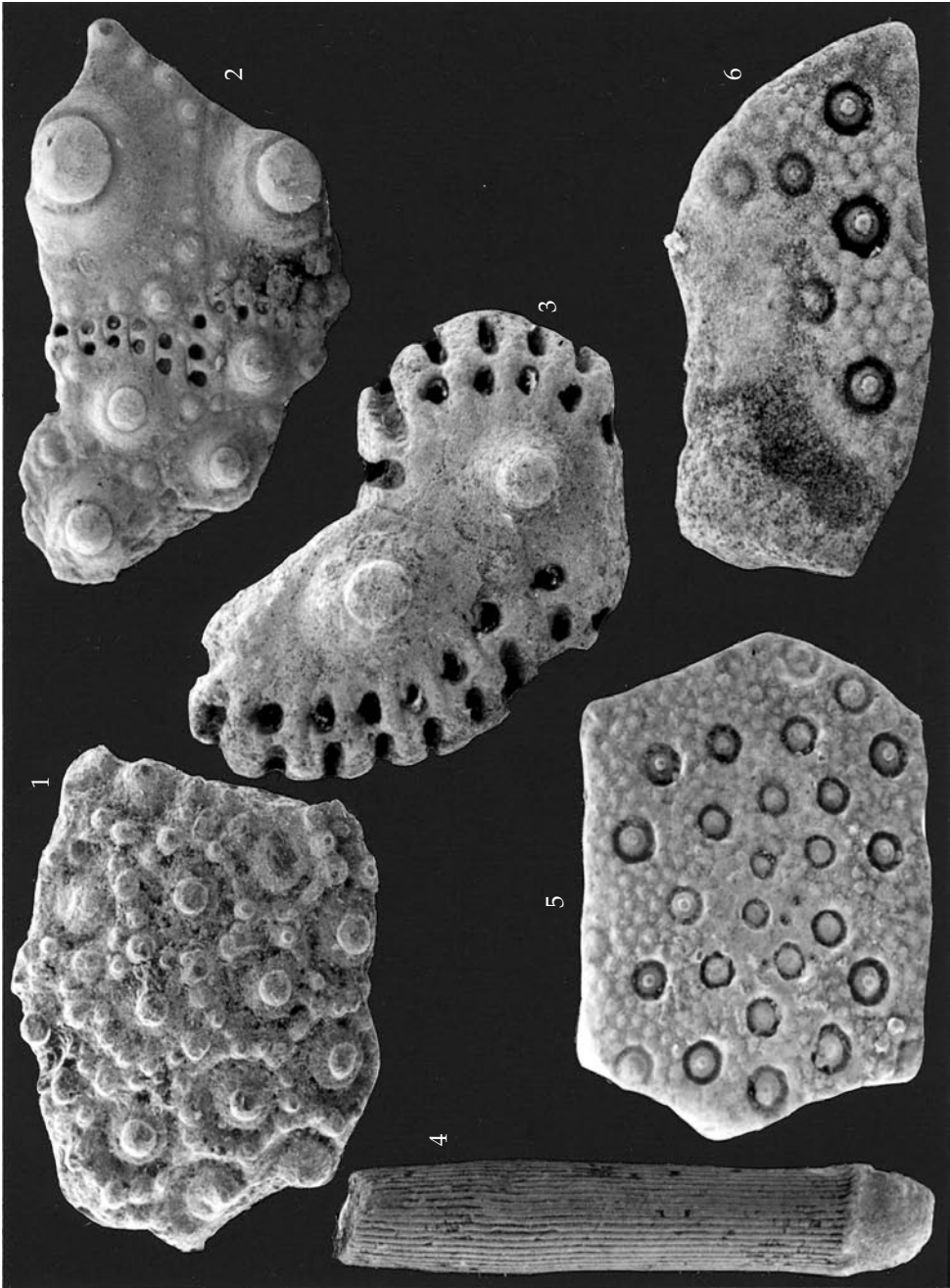SE micrographs of specimens coated with 60% gold/palladium.

Plate 8

Fragments of spatangoid from the Lower Miocene Montpelier Formation of Duncans Quarry, parish of Trelawny, Jamaica.

Figs. 1-7. Spatangoid sp. indet., test fragments unless stated otherwise. (1) UF 103350, radiole. × 18. (2) UF 103351. × 10. (3) UF 72217. × 18. (4) UF 103351. × 17. (5) UF 103350, radiole. × 22. (6) UF 103351. × 27. (7) UF 72217, enlargement of a single tubercle. × 60.

SE micrographs of specimens coated with 60% gold/palladium.