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The Echinoids of the Middle Eocene Warley Hill Formation, Santee Limestone, and Castle Hayne Limestone of North and South Carolina

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ABSTRACT

Kier, Porter M. The Echinoids of the Middle Eocene Warley Hill Formation, Santee Limestone, and Castle Hayne Limestone of North and South Carolina. *Smithsonian Contributions to Paleobiology*, number 39, 102 pages, 1980.—The echinoids are described from the middle Eocene Warley Hill Formation, Santee Limestone, and Castle Hayne Limestone of North and South Carolina. Twenty-seven species are present including the following new taxa: *Eurhodia baumi*, *Eurhodia rugosa ideali*, *Eurhodia rugosa depressa*, *Eupatagus wilsoni*, *Eupatagus lawsonae*, *Linthia harmatuki*, *Agassizia wilmingtonica* Cooke *inflata*, and *Protoscutella mississippiensis* (Twitchell) *rosehillensis*. Three zones are identified: the earliest characterized by *Protoscutella mississippiensis* (Twitchell) and *Santeelampas oviformis* (Conrad), a "middle zone" with *Linthia harmatuki* and the youngest species of *Protoscutella*, and a "late zone" with large numbers of *Periarchus lyelli* (Conrad) and *Echinolampas appendiculata* Emmons. The "early zone" is considered early middle Eocene, the "middle zone" middle Eocene and the "late zone" probably late middle Eocene. The three species of *Protoscutella* appear to represent an evolutionary series—*P. mississippiensis* (Twitchell) to *P. conradi* (Cotteau) to *P. plana* (Conrad)—characterized by the shifting of the periproct nearer to the peristome.

The echinoids lived in well-aerated sediments in a tropical sea.

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Contents

The Echinoids of the Middle Eocene Warley Hill Formation, Santee Limestone, and Castle Hayne Limestone of North and South Carolina

Porter M. Kier

Introduction

Many new quarries have been opened in southeastern United States since Cooke (1959) completed his monograph on the Cenozoic echinoids of eastern United States. New species have been found, and it is likely that further search will yield many more. In the past twenty years much research has been published on the living habits and functional morphology of echinoids, and it is possible to make paleoecological determinations on the fossil echinoids that were not possible before. Also we have a better understanding of the stratigraphy of the region. Therefore, it now seems worthwhile to undertake a restudy of these echinoids. I am particularly interested in discerning evolutionary trends and in determining the rate of evolution in echinoids. Paleontologists are now embroiled in controversy over gradualism or punctuated equilibria, and I am hopeful that research in the Tertiary echinoids will produce data relevant to these problems.

CASTLE HAYNE LIMESTONE.—The Castle Hayne Limestone was named by Miller (1912); and its fauna was described in detail by Kellum (1926) who referred it with some reservations to Jacksonian stage. Cooke and MacNeil (1952) proposed that most of the fossils attributed by Kellum to the Castle Hayne Limestone are restricted to late Claibornian, and are equivalent to the Gosport Sand of Alabama.

Baum, Harris, and Zullo (1978) selected a type-section 2.3 miles northeast of Castle Hayne, New Hanover County (my locality 34). They described three facies in ascending stratigraphic order: phosphate pebble biomicrudite, bryozoan biosparrudite, and bryozoan biomicrudite.

Ward, Lawrence, and Blackwelder (1978) divided the Castle Hayne into three members. The lowest, the New Hanover Member, lies unconformably on the Cretaceous or Paleocene and is the phosphate pebble biomicrudite facies of Baum, Harris, and Zullo. Their second member, the Comfort Member, includes the bryozoan biosparrudite and bryozoan biomicrudite facies of Baum, Harris, and Zullo. Their top member, the Spring Garden Member, is considered a separate formation, the New Bern Formation, by Baum, Harris, and Zullo. No echinoids have been collected from this member. The Ideal Cement Company quarry (my locality 12) was selected by

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Ward, Lawrence, and Blackwelder as the type-locality of the Castle Hayne Limestone.

Baum, Harris, and Zullo considered the Castle Hayne Limestone to be Claibornian, although portions may extend into the Jacksonian (Zullo and Baum, in press); whereas, Ward, Lawrence, and Blackwelder considered their New Hanover Member as equivalent to the Lisbon Formation (middle middle Eocene), and their Comfort Member as equivalent to the Gosport Sand (late middle Eocene).

A list of the echinoids occurring in the Castle Hayne Limestone is given in Table 1, the localities on Figure 1.

SANTEE LIMESTONE.—The Santee Limestone was informally named by Tuomey (1848:156, 190, 211). It was considered Jacksonian by Canu and Bassler (1920); but now because of the presence of *Ostrea sellaeformis* Conrad, it is placed in the middle or middle and late Calibornian (Stenzel, 1949; Cooke and MacNeil, 1952; and Pooser, 1965).

Banks (1978) made a detailed study of the lithology and fauna of the Santee Limestone in three quarries and divided the formation into lithozones and biozones. He concluded that the lowermost Santee Limestone, his zone I, correlated with the lower Lisbon Formation on the basis of his reported occurrence in this zone of *Cubitostrea lisbonensis* Harris. He correlated his zone II with the upper Lisbon Formation on the basis of the presence of *Cubitostrea sellaeformis*. He could

TABLE 1.—Stratigraphic occurrence of echinoids

Species	Warley Hill Formation*	Santee Limestone	Castle Hayne Limestone
Agassizia wilmingtonica inflata, new subspecies	–	X	
Agassizia wilmingtonica wilmingtonica Cooke		–	X
Cidaris pratti Clark		X	X
Coelopleurus carolinensis Cooke		–	X
Coelopleurus infulatus (Morton)		X	X
Dixieus cf. *Dixieus dixie* (Cooke)		–	X
Echinocyamus bisexus Kier		–	X
Echinocyamus parvus (Emmons)			X
Echinolampas appendiculata Emmons			X
Eupatagus carolinensis Clark			X
Eupatagus lawsonae, new species			X
Eupatgus wilsoni, new species			X
Eurhodia baumi, new species			X
Eurhodia holmesi (Twitchell)		X	X
Eurhodia rugosa depressa, new subspecies		–	X
Eurhodia rugosa ideali, new subspecies		–	X
Eurhodia rugosa rugosa (Ravenel)		X	–
Linthia hanoverensis Kellum		X	X
Linthia harmatuki, new species		X	X
Linthia wilmingtonensis Clark		X	X
Maretia subrostrata (Clark)		–	X
Periarchus lyelli (Conrad)		X	X
Phyllacanthus carolinensis (Emmons)		–	X(?)
Phyllacanthus mitchellii (Emmons)			X(?)
Protoscutella conradi (Cotteau)		X	X
Protoscutella mississippiensis (Twitchell)	X		–
Protoscutella mississippiensis rosehillensis, new subspecies	–	–	X
Protoscutella plana (Conrad)		X	X
Rhyncholampas carolinensis (Twitchell)			X
Santeelampas oviformis (Conrad)	X	?	X
Unifascia carolinensis (Clark)		X	X

* Basal Santee Limestone of some workers

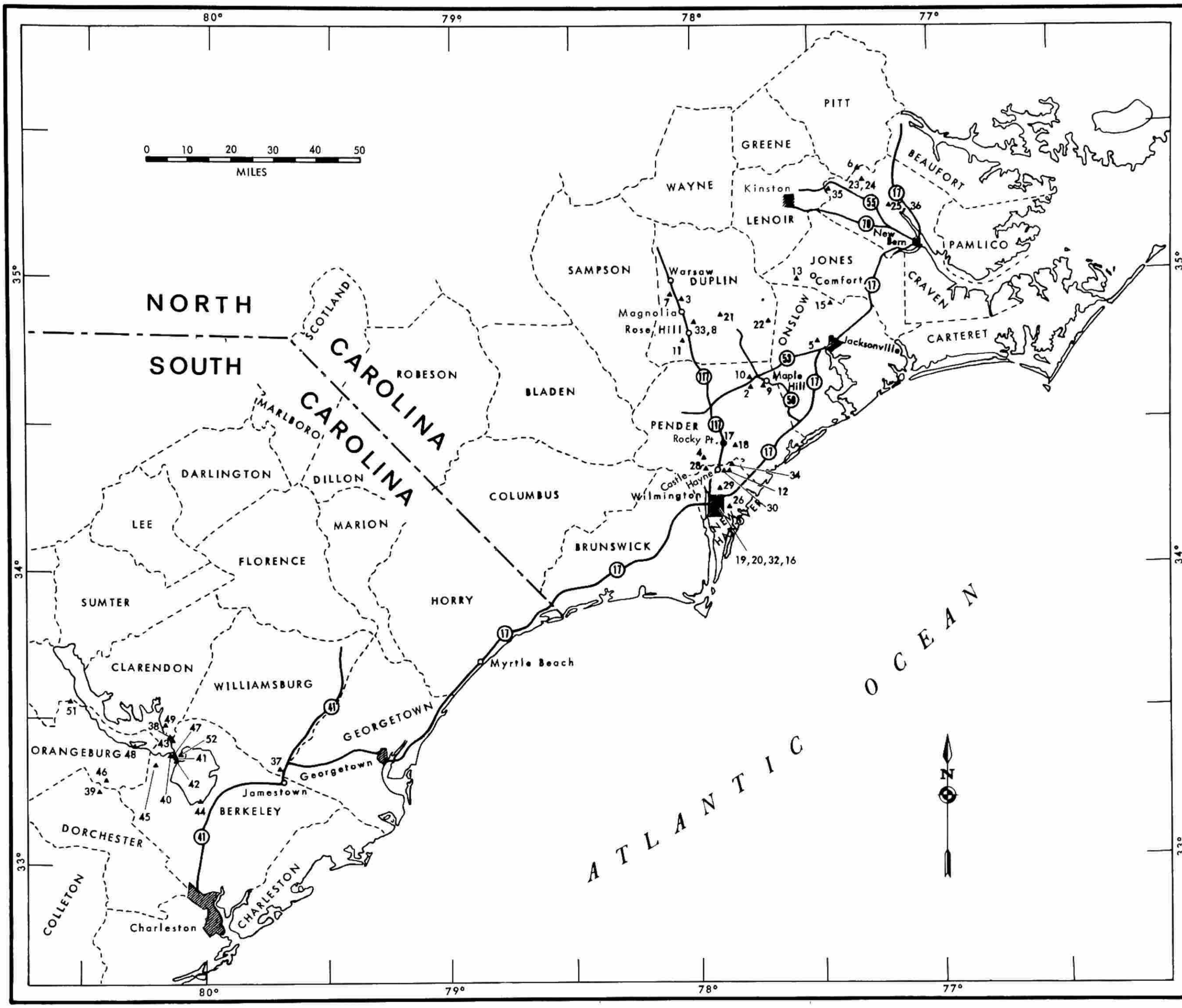

FIGURE 1.—Location of echinoid localities.

not date his zone III, but his zone IV he correlated with the Gosport Sand because of the occurrence in it of *Periarchus lyelli* (Conrad) and *Crassatella alta* Conrad.

Ward, Blackwelder, Gohn, and Poore (1979) restudied two of these quarries and a third one not studied by Banks and divided the Santee Limestone into two members. The lower, the Moultrie Member, includes Banks' zones I and II. This member they consider middle Claibornian and equivalent to the Lisbon Formation in Alabama and the New Hanover Member of the Castle Hayne Limestone of North Carolina. Their upper member, the Cross Member, includes Banks' zones III and IV. They consider this member late Claibornian and equivalent to the Gosport Sand of Alabama and the Comfort and Spring Garden Members of the Castle Hayne Limestone in North Carolina.

Baum, et al. (in press) divide the Santee Limestone into two faunal zones: the lower *Cubitostrea lisbonensis* zone and the upper *C. sellaeformis* zone.

They exclude the Cross Member from the Santee Limestone, raise it to a formation, and consider it equivalent to the New Bern Formation in North Carolina. They suggest that it is late Eocene. Finally, they propose that the Moultrie Member be abandoned.

A list of the echinoids in the Santee Limestone is given in Table 1 and their stratigraphic distribution within the limestone in Table 2.

WARLEY HILL FORMATION.—The "Warley Hill phase" was described by Sloan (1908:458) and included in the McBean Formation by Cooke in 1936. Later Cooke and MacNeil (1952:23) considered it to include the dominantly glauconitic beds that intervene between the Congaree and McBean Formations. Pooser (1965:15) considered that the Congaree and Warley Hill Formations, and basal portions of the Santee Limestone were deposited penecontemporaneously as lithofacies of a transgressive middle Eocene sea. The echinoids described here in (Table 1) came from localities in the Warley Hill Formation where, according to Pooser (1965:16), this formation underlies beds low in the Santee Limestone. Pooser, on the basis of ostracods, considers the Warley Hill Formation at these localities to be lower middle Eocene or lower Claibornian.

AGE.—Although these formations share some of the same echinoid species, three assemblages (Table 3) seem to be represented. The oldest or "early zone" occurs in the western portion of the outcrop area of the Castle Hayne Limestone and in the Warley Hill Formation (considered by some workers to be basal Santee, i.e. Banks, 1978; Baum, et al., in press) at Wilson's Landing (locality 38) in South Carolina. This fauna is characterized by *Santeelampas oviformis* (Conrad) and *Protoscutella mississippiensis* (Twitchell) and is herein considered to be lower middle Eocene (lower middle Claibornian). This age determination is based on the occurrence of *Protoscutella mississippiensis* (Twitchell) elsewhere in the lower Claibornian, Mount Selman Formation in Texas; basal Lisbon Formation (middle Claibornian) and top of the Tallahatta Formation (lower Claibornian) in Alabama and middle Claibornian Winona Sand of Mississippi. Furthermore, Cooke and MacNeil (1952:23) report that Sloan found *Cubitostrea lisbonensis* (Harris) in the Warley Hill Formation. Banks (1978), Baum, et al. (in press),

Table 2.—Stratigraphic occurrence of echinoids within the Santee Limestone

Ward, et al. (1979) members	Banks' (1978) zones	Echinoid species	
Cross Member	Zone IV	*Periarchus lyelli* (Conrad) (occurs throughout Zone IV) *Maretia subrostrata* (Clark)[1] *Protoscutella plana* (Conrad)[1]	
	Zone III—position uncertain according to Banks	*Coelopleurus infulatus* (Morton)	Georgetown Quarry[2] (?) *Agassizia wilmingtonica inflata*, new subspecies *Cidaris pratti* Clark *Eurhodia holmesi* (Twitchell) *Eurhodia rugosa rugosa* (Ravenel) *Linthia hanoverensis* Kellum *Linthia harmatuki*, new species *Linthia wilmingtonensis* Clark *Protoscutella conradi* (Cotteau) *Unifascia carolinensis* (Clark)
Moultrie Member	Zone II	*Cidaris pratti* Clark *Eurhodia holmesi* (Twitchell) *Eurhodia rugosa rugosa* (Ravenel) *Protoscutella conradi* (Cotteau)	
	Zone I	No echinoids; zone may be equivalent to Warley Hill Marl at Wilson's Landing	

[1] Appear to be confined to lower Zone IV.

[2] All from beds Ward (1979, pers. comm.) considers low in Cross Member; however, Baum, et al. (in press) believe these beds are older and are equivalent to Banks' Zone II.

TABLE 3.—Characteristic species, lithology, and localities of the three faunal zones in the Castle Hayne Limestone (note that both *Periarchus lyelli* (Conrad) and *Echinolampas appendiculata* Emmons occur rarely in the "middle zone," as opposed to their great abundance in the "late zone"; *Linthia harmatuki*, new species, is never found in the "late zone")

Formation	Faunal zone	Echinoid species	Lithology	Localities
Santee Limestone	"Late Zone"	*Periarchus lyelli* (Conrad) and *Echinolampas appendiculata* Emmons	Bryozoan biomicrudite	Ideal (locality 12), Maple Hill (Lanier) (locality 9), Comfort (locality 13), and Martin Marietta Castle Hayne quarry (locality 34)
	"Middle Zone"	*Linthia harmatuki*, new species	Bryozoan biosparrudite	Maple Hill (East Coast) (locality 10), Martin Marietta Castle Hayne quarry (locality 34), and Georgetown (locality 37)
Warley Hill Formation*	"Early Zone"	*Protoscutella mississippiensis* (Twitchell), and *Santeelampas oviformis* (Conrad)	Bryozoan biosparrudite or glauconitic limestone	Rose Hill (locality 11), Mosleys Creek (locality 35), and Wilson's Landing (locality 38)

* Some workers consider the Warley Hill Formation to be a part of the Santee Limestone.

consider *C. lisbonensis* to represent a zone within the Santee Limestone. This oyster is found elsewhere in the middle Claibornian basal Lisbon Formation of Alabama and the Winona Formation of Mississippi (Stenzel, 1949:45; Pooser, 1965:16; Toulmin, 1969:472, 1977:112).

Protoscutella mississippiensis (Twitchell) has been found at only two localities in South Carolina, both of which are in the Warley Hill Formation (locality 38, 43). *Santeelampas oviformis* (Conrad) is found at these two localities and near Eadytown (locality 47) in float dredged from the Santee-Cooper diversion canal. Here it occurs with echinoids typical of higher beds in the Santee Limestone. However, the matrix on and in the tests of the specimens of *S. oviformis* is similar to the Warley Hill Formation at Wilson's Landing (containing many glauconite and arenaceous grains—Pooser, 1965:67); whereas, the other echinoids have a matrix lacking these grains and typical to that found in higher beds in the Santee Limestone. Presumably this float is a mixture of both formations. This locality is very near an outcrop of the Warley Hill Formation at Wilson's Landing, and it is expected that it would be encountered by the dredge.

The Rose Hill (locality 11) fauna in the Castle Hayne Limestone of North Carolina contains *P. mississippiensis* and *S. oviformis* and is considered here equivalent in age to the fauna found in the Warley Hill Formation at Wilson's Landing in South Carolina. This fauna is strikingly different from that found in the Castle Hayne Limestone at Comfort (locality 13), Ideal (locality 12), Maple Hill, Lanier (locality 9), and at the Wilmington localities. The most abundant species at Rose Hill, *Protoscutella mississippiensis* (Twitchell), *P. conradi* (Cotteau), *Eurhodia baumi*, new species, and *Santeelampas oviformis* (Conrad), are absent in the Castle Hayne Limestone at these other localities. The two species most abundant at these localities, *Periarchus lyelli* (Conrad) and *Echinolampas appendiculata* Emmons, are absent at Rose Hill. This older Warley Hill-Rose Hill fauna is also found at Mosleys Creek (locality 35). It is restricted to the western, more updip, portions of the Castle Hayne Limestone.

Further east in North Carolina and South Carolina occur exposures of the Castle Hayne Limestone and Santee Limestone with an echinoid fauna that appears to be younger than the Rose Hill and Warley Hill faunas. This fauna lacks *Protoscutella mississippiensis* (Twitchell) and *Santeelampas oviformis* (Conrad) and is typified by a large spatangoid, *Linthia harmatuki*, new species. It is considered herein as the "middle zone." In South

Carolina this fauna is associated with *Cubitostrea sellaeformis* Conrad considered to be middle Claibornian in age. In North Carolina the fauna is best displayed at the East Coast Construction Company quarry at Maple Hill (locality 10) where it occurs in a bryozoan biosparrudite that Baum, Harris, and Zullo (1978:7) consider as underlying a bryozoan biomicrudite that occurs a few miles away at the Lanier pit (locality 9). The fauna at Lanier is easily distinguished from the "middle zone" fauna by the absence of *Linthia harmatuki* and *Protoscutella* and the presence in large numbers of *Periarchus lyelli* Conrad and *Echinolampas appendiculata* Emmons (species only rarely found in the "middle zone"). Furthermore, at Lanier occur the following species or subspecies not found in the "middle zone": *Agassizia wilmingtonica wilmingtonica* Cooke, *Dixeus* cf. *Dixeus dixie* (Cooke), *Echinocyamus bisexus* Kier, and *E. parvus* (Emmons). This zone at Lanier is considered the "late zone" and is exposed in the eastern portion of the outcrop zone of the Castle Hayne Limestone in North Carolina and highest beds of the Santee Limestone. It is probably upper Claibornian in age.

The relative ages of the biomicrudite fauna found at Ideal and the biosparrudite at Maple Hill (East Coast) are confirmed at the Martin Marietta Superior Stone quarry (locality 34) near Castle Hayne where both faunas were collected in place. Species common at Maple Hill (East Coast)—*Linthia harmatuki*, new species, *Protoscutella plana* (Conrad), *Rhyncholampas carolinensis* (Twitchell), and *Eurhodia rugosa depressa*, new subspecies—were found in place in a bed 2 meters thick of glauconitic bryozoan coarse calcarenite (Baum's biosparrudite). Overlying this bed are 2.5 meters of a bryozoan fine to coarse calcarenite with a microsucrosic matrix (Baum's biomicrudite) containing slightly less glauconite. This bed lacks *L. harmatuki* and contains an abundance of *Periarchus lyelli* (Conrad) and *Echinolampas appendiculata* Emmons. The "middle zone" thins southward in the quarry and pinches out, resulting in the "late zone" lying directly on the New Hanover Member in the western part of the quarry (see Plate 22: figure 4).

Although Ward, Lawrence, and Blackwelder (1978, figs. 1, 2) consider their New Hanover Member to be the oldest unit of the Castle Hayne Limestone, it contains here at the type-locality an echinoid restricted to the "middle" and "late" zones, *Echinolampas appendiculata* Emmons. The "early zone" is absent at this locality. Therefore, the New Hanover Member cannot be considered older than all the beds that have been referred to the Comfort Member. The sediments exposed at Rose Hill (locality 11) are older, on the basis of the echinoids they contain, than the New Hanover Member at the Martin Marietta quarry. Ward, et al. (1978:F8) refer these sediments to the Comfort Member. The New Hanover Member is not present at Rose Hill. The Comfort Member there rests directly on the Late Cretaceous Peedee Formation.

Protoscutella and *Periarchus* are considered to be very useful for age determination. In the Santee Limestone (Table 2), *Protoscutella* is found in the lower Moultrie Member of Ward, et al. (1979), zones II, III and in the lower part of zone IV of Banks (1978). It is absent in the upper beds in the higher Cross Member of Ward, et al., and in the upper part of Banks' zone IV. *Periarchus* is absent in the Moultrie Member and zones II and III of Banks, and present only high in the Santee Limestone in the higher beds in the Cross Member or zone IV. In the Castle Hayne Limestone, *Protoscutella* occurs in the "early" and "middle" zones but is absent in the "late." *Periarchus* is absent in the "early," and present in the "middle" and "late" zones.

Protoscutella is restricted to the middle and lower upper Claibornian. Three of the five species are found in the middle Claibornian: *P. mississippiensis* (Twitchell), *P. tuomeyi* (Twitchell), and *P. pentagonium* Cooke. *P plana* (Conrad) and *P. conradi* (Cotteau) occur in the lower upper Claibornian. The earliest *Periarchus* occurs with the latest *Protoscutella*, *P. plana*, and the genus is well represented in the late Eocene.

Protoscutella appears to be ancestral to *Periarchus*. The two genera differ only in the position of the periproct, being nearer the peristome in *Periarchus*. Previous workers considered *Protoscutella* distinct from *Periarchus* because of the discontinuous interambulacra in *Protoscutella.* However, this character is not consistent in any species of *Protoscutella*—some specimens of each species have continuous interambulacra.

Protoscutella mississippiensis rosehillensis, P. conradi, and *P plana* appear to represent an evolutionary series. In the oldest species, *P. mississippiensis rosehillensis*, the periproct is marginal. In *P. conradi*, which occurs above it in the "early zone" at Rose Hill (locality 11), the periproct is more anterior. Finally, in *P. plana*, whose first occurrence is in the "middle zone," the periproct is even more anteriorly situated.

In summary, three echinoid faunas are present. The "early zone" typified by *Santeelampas oviformis* (Conrad) and *Protoscutella mississippiensis* (Twitchell); the "middle zone" by *Linthia harmatuki* and the youngest species of *Protoscutella*; and the "late zone" with large numbers of *Periarchus lyelli* (Conrad) and *Echinolampas appendiculata* Emmons. The ranges of all the species are given in Table 4.

ECOLOGY.—These Eocene echinoids are similar enough to living species that it is possible to predict their living habits. The echinoids from the "early zone" at Rose Hill occur in a bryozoan biosparrudite as described by Baum, Harris, and Zullo (1978:7). The following species are present.

TABLE 4.—Distribution of species at major echinoid localities where faunal "zones" have been identified

Species	"Early Zone" Rose Hill (locality 11) Mosleys Creek (locality 35) Wilson's Landing (locality 38)	"Middle Zone" Maple Hill (East Coast) (locality 10) Georgetown (locality 37) Martin Marietta (locality 34)	"Late Zone" Maple Hill (Lanier) (locality 9) Ideal (locality 12) Comfort (locality 13) Martin Marietta (locality 34)
Agassizia wilmingtonica inflata, new subspecies		X	
Agassizia wilmingtonica wilmingtonica Cooke			X
Cidaris pratti Clark	X	X	X
Coelopleurus carolinensis Cooke			X
Coelopleurus infulatus (Morton)		X	X
Dixieus cf. *Dixieus dixie* (Cooke)			X
Echinocyamus bisexus Kier			X
Echinocyamus parvus (Emmons)			X
Echinolampas appendiculata Emmons		X	X
Eupatagus carolinensis Clark		–	X
Eupatagus lawsonae, new species		–	X
Eupatagus wilsoni, new species		–	X
Eurhodia baumi, new species	X	–	
Eurhodia holmesi (Twitchell)		X	
Eurhodia rugosa depressa, new subspecies		X	
Eurhodia rugosa ideali, new subspecies	X		X
Eurhodia rugosa rugosa (Ravenel)		X	
Linthia hanoverensis Kellum		X	X
Linthia harmatuki, new species	–	X	
Linthia wilmingtonensis Clark		X	X
Maretia subrostrata (Clark)	X		X
Periarchus lyelli (Conrad)		X	X
Protoscutella conradi (Cotteau)	X	X	
Protoscutella mississippiensis rosehillensis, new subspecies	X	–	
Protoscutella plana (Conrad)	–	X	
Rhyncholampas carolinensis (Twitchell)	–	X	X
Santeelampas oviformis (Conrad)	X	–	
Unifascia carolinensis (Clark)	–	X	X

Regular echinoid
Cidaris pratti Clark
Cassiduloids
Santeelampas oviformis (Conrad)
Eurhodia rugosa (Ravenel) *ideali*, new subspecies
Eurhodia baumi, new species
Sand dollars
Protoscutella conradi (Cotteau)
P. mississippiensis (Twitchell) *rosehillensis*, new subspecies
Spatangoids
Maretia subrostrata (Clark)

Cidaris pratti Clark would have fed on vegetation, including algae and probably turtle grass. The cassiduloids no doubt lived like the present *Cassidulus cariboearum* Lamarck. They would have burrowed in the sediment; but because they were unable to maintain a tube to the surface (water-sediment interface), the sediment would have had to be well aerated. The sand dollars would have lived covered by the sediment, at a depth in the sediment shallower than the cassiduloids. The spatangoid *Maretia subrostrata* (Clark) probably lived within a burrow with a tube leading posterior for a drainoff as indicated by the presence of a subanal fasciole in this species. The lack of a deep anterior groove and lack of crowding of the porepairs in ambulacrum III indicate a limited funnel-building ability.

The "middle zone" echinoids are best represented at the East Coast Construction Company pit at Maple Hill (locality 10). Here they occur in a bryozoan biosparrudite similar to the lithology at Rose Hill. The following species are present.

Cassiduloids
Rhyncholampas carolinensis (Twitchell)
Eurhodia rugosa (Ravenel) *depressa*, new subspecies
Echinolampas appendiculata Emmons
Sand dollars
Protoscutella plana (Conrad)
Periarchus lyelli (Conrad)
Spatangoid
Linthia harmatuki, new species

This fauna is what one would expect to find living in a well-aerated sand. The fauna is dominated by clypeasteroids and cassiduloids, echinoids preferring this environment. The spatangoid *Linthia harmatuki* is strikingly similar to the *Meoma ventricosa* (Lamarck) that lives today in the Caribbean partially covered with sand. It does not maintain a funnel and lives only shallowly buried.

The "late zone" fauna is best represented at the Ideal Cement Company quarry near Castle Hayne (locality 12). The sediment is a bryozoan biomicrudite (Baum, Harris, and Zullo, 1978:7).

Regular echinoids
Cidaris pratti (Clark)
Coelopleurus infulatus (Morton)
Coelopleurus carolinensis Cooke
Cassiduloids
Echinolampas appendiculata Emmons
Eurhodia rugosa (Ravenel) *ideali*, new subspecies
Clypeasteroids
Echinocyamus parvus Emmons
Periarchus lyelli (Conrad)
Spatangoids
Maretia subrostrata Clark
Eupatagus lawsonae, new species
Eupatagus wilsoni, new species
Eupatagus carolinensis Clark
Unifascia carolinensis (Clark)
Linthia hanoverensis Kellum

The echinoid fauna is similar to those previously described in having many cassiduloids and clypeasteroids. These echinoids indicate well-aerated sediment. Furthermore, the spatangoids lack deep anterior grooves and crowded porepairs in ambulacrum III, suggesting a limited ability to construct funnels.

In summary, the echinoid fauna in the three zones is dominated by species that would have been partially or completely buried in the sediment. All the cassiduloids, clypeasteroids, and most of the spatangoids could not have lived in this sediment unless it was well aerated.

Little can be deduced from the echinoids concerning the depth of the water. All the species and eight of the sixteen genera are extinct. The extant genera have the following bathymetric (in meters) and climatic distribution according to Mortensen (1928–51).

Echinocyamus	10–2286	widespread
Echinolampas	8–500	widespread
Coelopleurus	55–2380	widespread
Eupatagus	10–425	Tasmania, Philippines, Hawaii

Maretia	50–108	Fiji, Philippines, Korean Strait
Agassizia	ebb zone–900	confined to tropical ports of American seas
Rhyncholampas	one species *R. pacificus* (A. Agassiz), which Agassiz (1873:555) reports being in 5–6 foot depth; Ziesenhenne (pers. comm.) has dredged specimens of this species from 20 meters; Lower California to Panama	
Cidaris	32–2000	widespread

Most of these genera occur in shallow to moderately deep water. Only one, *Rhyncholampas*, has not been found in depths over 20 meters but only one species of this genus is now living so the genus may not be significant as an indicator of shallow water.

All the genera, except *Agassizia*, have wide distribution today and, therefore, are of no use in determining the temperature of the seas. *Agassizia* has two extant species, both of which are found only in tropical waters. Furthermore, the fossil species of this genus are generally found in beds considered to have been deposited in tropical seas. Likewise, the great diversity of the fauna with 13 species from one locality (Ideal, locality 12) supports this evidence that these echinoids lived in warm waters. Modern echinoid faunas are more diversified in warmer waters (Durham, 1966; Pawson, 1979, pers. comm.).

Warm water is also indicated by non-echinoid elements of the fauna. Baum (in press) reports a possible occurrence in the Castle Hayne Limestone of green algae (*Penicillus*) which suggests tropical waters; and Copeland (1964:224), on the basis of the foraminifera, believed that the waters were warmer than are now common at this latitude. Finally, Druid Wilson (1979, pers. comm.) reports the Tethyan bivalve *Exputens* in the Castle Hayne Limestone.

I had hoped that the cidaroid echinoids might be useful as temperature indicators. Smith (1978: 778) reports that all cidaroids presently living in shallow-water coral reef environments have conjugate porepairs; whereas, cidaroids from colder water shelf areas or from deeper waters have nonconjugate pores. *Cidaris pratti* Clark has nonconjugate pores that would indicate that it lived in colder waters. However, this correlation between temperature of water and nature of the porepairs does not appear to be consistent among fossil echinoids. *Phyllacanthus carolinensis* (Emmons) and *Phyllacanthus mitchellii* (Emmons) occur together. In the former the porepairs are nonconjugate; whereas, in the latter they are strongly conjugate. Smith (1979, pers. comm.) now reports a similar situation with some Jurassic cidaroids in the Pea Grit fauna.

AFFINITIES OF FAUNA.—Only three of the twenty-seven echinoid species from the Castle Hayne and Santee Limestones and Warley Hill Formation are found elsewhere. *Periarchus lyelli* (Conrad) is known from the upper Claibornian Gosport Sand and equivalents and the lower Jacksonian Moodys Branch Marl, Inglis Formation, and Williston Limestone of Florida, Georgia, Alabama, and Mississippi. *Echinocyamus bisexus* Kier has been found in the middle Eocene Lake City Formation in Georgia. Although Cooke (1959:31) reports *Echinocyamus parvus* Emmons from Alabama, I have studied this specimen and it is too poorly preserved to be referred with certainty to this species.

Protoscutella mississippiensis (Twitchell) is known from the Mount Selman, basal Lisbon, top of the Tallahatta, and Winona Formations of Texas, Alabama, and Mississippi.

LONGEVITY OF SPECIES.—It is too early in this long-range study to reach any firm conclusions on the longevity of echinoid species. A few observations are possible, although they are based on very tentative evidence. Berggren (1972:203) estimates that the middle Eocene lasted approximately six million years. The Warley Hill and Rose Hill faunas lived during the early middle Eocene, the "middle zone" during the middle middle and the "late zone" probably during the late middle Eocene. Eight echinoid species are confined to the "late" zone, one to the "middle," and three to the "early." Therefore, 12 are confined to one zone; and if one zone represents one-third of the time, these species lived less than two million years. Eight of the species occur in two zones living perhaps four million years, and only five (including two differentiated into subspecies) are found in all three zones. Therefore, over one-half of the species may have lived two million years or less, 32 percent four million, and 20 percent six million.

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Occurrences

(Localities cited on Figure 1 when exact location is known)

NORTH CAROLINA: CASTLE HAYNE LIMESTONE

Locality 1

Trask Farm, Rocky Point, Pender Co.

1. *Echinolampas appendiculata* Emmons
2. *Periarchus lyelli* (Conrad)

Locality 2

USGS 22389, Pender Co. Pit, 0.3 mi (0.5 km) S of NC Rte 53, 8.1 mi (13 km) E of NE Cape Fear River bridge, Pender Co.

1. *Cidaris pratti* Clark
2. *Echinolampas appendiculata* Emmons
3. *Eurhodia rugosa* (Ravenel) *ideali*, new subspecies
4. *Linthia wilmingtonensis* Clark
5. *Periarchus lyelli* (Conrad)

Locality 3

Stewarts Creek, 4.5 mi (7.2 km) N of Magnolia, Duplin Co.

1. *Coelopleurus carolinensis* Cooke
2. *Echinolampas appendiculata* Emmons
3. *Periarchus lyelli* (Conrad)
4. *Rhyncholampas carolinensis* (Twitchell)

Locality 4

USGS 22329, spoil bank of irrigation pit about 0.1 mi (0.2 km) S on W side of first dirt road turning off NC Rte 210 (Lane Ferry Road) at a point about 0.1 mi (0.2 km) W of NE Cape Fear River, Pender Co.

1. *Cidaris pratti* Clark
2. *Echinolampas appendiculata* Emmons
3. *Periarchus lyelli* (Conrad)

Locality 5

Marvin Rhode's pit, W bank of New River above Jacksonville, Onslow Co.

1. *Echinolampas appendiculata* Emmons
2. *Eurhodia rugosa* (Ravenel) *ideali*, new subspecies
3. *Periarchus lyelli* (Conrad)

Locality 6

USGS 10627, T. J. Faulkner farm, 2 mi (3.2 km) N of Neuse River and 3 mi (4.8 km) E of Quinerly, Pitt-Craven Co.

1. *Eurhodia holmesi* (Twitchell)

Locality 7

2 mi (3.2 km) S of Warsaw (probably same as locality 3), Duplin Co.

1. *Echinolampas appendiculata* Emmons
2. *Periarchus lyelli* (Conrad)
3. *Rhyncholampas carolinensis* (Twitchell)

Locality 8

Atlantic Limestone Company quarry, 2.4 mi (3.8 km) SSE of Magnolia, just E of US Rte 117, Duplin Co.

1. *Eurhodia rugosa* (Ravenel) *ideali*, new subspecies
2. *Protoscutella conradi* (Cotteau)
3. *Santeelampas oviformis* (Conrad)

Locality 9

Maple Hill (Lanier Pit), 3.5 mi (5.6 km) from intersection of NC Rtes 50 and 53 on S side of NC Rte 50, approximately 2.5 mi (4.0 km) SE of Maple Hill, Pender Co. A bryozoan biomicrudite 1.9 m thick according to Baum (1979, pers. comm.).

1. *Agassizia wilmingtonica wilmingtonica* Cooke
2. *Cidaris pratti* Clark
3. *Echinocyamus bisexus* Kier
4. *Echinocyamus parvus* Emmons
5. *Echinolampas appendiculata* Emmons
6. *Dixieus* cf. *D. dixie* (Cooke)
7. *Linthia hanoverensis* Kellum
8. *Linthia wilmingtonensis* Clark
9. *Maretia subrostrata* (Clark)
10. *Periarchus lyelli* (Conrad)
11. *Unifascia carolinensis* (Clark)

Locality 10

Maple Hill (East Coast Construction Company quarry), 0.9 mi (1.4 km) SW of intersection of NC Rtes 50 and 53 on N side of NC Rte 53, approximately 2 mi (3.2 km) W of Maple Hill, Pender Co. A bryozoan biosparrudite 4.4 m thick according to Baum (1978, pers. comm.).

1. *Echinolampas appendiculata* Emmons
2. *Eurhodia rugosa* (Ravenel) *depressa*, new subspecies
3. *Linthia harmatuki*, new species—collected in place one meter below top of quarry
4. *Periarchus lyelli* (Conrad)
5. *Plagiobrissus* species
6. *Protoscutella plana* (Conrad)
7. *Rhyncholampas carolinensis* (Twitchell)

Locality 11

Rose Hill (Billy B. Fussel Company, Inc. quarry), 0.75 mi (1.2 km) W of US Rte 117 and NC Rte 1148, 1.5 mi (2.4 km) S of Rose Hill, Duplin Co. A bryozoan biosparrudite, approximately 17 m thick exposed in quarry in June, 1979. *Protoscutella mississippiensis* (Twitchell) *rosehillensis*, new subspecies, was found in beds 2.5 m to 6.3 m above base of the Castle Hayne Limestone. *Protoscutella conradi* (Cotteau) occurs from 6.8 m above the base to the top of the quarry. *Santeelampas oviformis* (Conrad) was found within 3 meters of the base and is present throughout the rest of the section.

1. *Cidaris pratti* Clark
2. *Eurhodia baumi*, new species
3. *Eurhodia rugosa* (Ravenel) *ideali*, new subspecies
4. *Maretia subrostrata* (Clark)
5. *Plagiobrissus* species
6. *Protoscutella conradi* (Cotteau)
7. *Protoscutella mississippiensis* (Twitchell) *rosehillensis*, new subspecies
8. *Santeelampas oviformis* (Conrad)

Locality 12

Ideal Cement Company quarry, S of junction of Island Creek with NE Cape Fear, N of NC Rte 1002 at end of NC Rte 2023, 4.5 mi (7.2 km) NE of Castle Hayne, New Hanover Co.

1. *Cidaris pratti* Clark
2. *Coelopleurus carolinensis* Cooke
3. *Coelopleurus infulatus* (Morton)
4. *Echinocyamus parvus* Emmons
5. *Echinolampas appendiculata* Emmons
6. *Eupatagus carolinensis* Clark
7. *Eupatagus lawsonae*, new species
8. *Eupatagus wilsoni*, new species
9. *Eurhodia rugosa* (Ravenel) *ideali*, new subspecies
10. *Linthia hanoverensis* Kellum
11. *Maretia subrostrata* (Clark)
12. *Periarchus lyelli* (Conrad)
13. *Unifascia carolinensis* (Clark)

Locality 13

Comfort, North Carolina Lime Company pit, adjacent to Tuckahoe Church, 3.8 mi (6.1 km) W of Comfort, Jones Co. A bryozoan biomicrudite 2.5 m thick according to Baum (1978, pers. comm.).

1. *Cidaris pratti* Clark
2. *Eupatagus carolinensis* Clark
3. *Linthia hanoverensis* Kellum
4. *Periarchus lyelli* (Conrad)

Locality 14

Craven Co. Druid Wilson (1979, pers. comm.) stated: "The only specific Emmons locality associated with the Eocene of Craven County, North Carolina, is the Wadsworth plantation said to be on Core Creek (Emmons, 1858:103–105) now known as Cove Creek. On Emmons' pages 87, 102, 241, 308, and 309, the Wadsworth plantation and "eocene of Craven County" are synonymous. In as much as no other Eocene locality in Craven County is given in Emmons, it seems certain that the two expressions are always synonymous."

1. *Echinocyamus parvus* Emmons—locality for holotype.

Locality 15

Farm of J. M. Thomas, 10 mi (16.0 km) N of Jacksonville, Onslow Co.

1. *Echinocyamus parvus* Emmons

Locality 16

USGS 3602, 7302, 10340, city rock quarry near cemetery, Wilmington, New Hanover Co.

1. *Agassizia wilmingtonica wilmingtonica* Cooke
2. *Echinolampas appendiculata* Emmons
3. *Eupatagus carolinensis* Clark
4. *Eupatagus wilsoni*, new species
5. *Linthia hanoverensis* Kellum
6. *Rhyncholampas carolinensis* (Twitchell)

Locality 17

USGS 779, Rocky Point, Pender Co.

1. *Echinolampas appendiculata* Emmons
2. *Linthia wilmingtonensis* Clark
3. *Rhyncholampas carolinensis* (Twitchell)

Locality 18

Lanes Ferry, 3 mi (4.8 km) E of Rocky Point, Pender Co.

1. *Echinolampas appendiculata* Emmons

Locality 19

Castle Hayne Phosphate Works, 20 mi (32.0 km) from Wilmington.

1. *Echinolampas appendiculata* Emmons

Locality 20

R. G. Ross farm (near small branch stream—opposite from a strong spring), 1 mi (1.6 km) NW of Lanes Ferry over NE Cape Fear River, Pender Co.

1. *Echinolampas appendiculata* Emmons

Locality 21

USGS 11816, 2–2.5 mi (3.2–4.0 km) SW of Charity, Duplin Co.

1. *Echinolampas appendiculata* Emmons

Locality 22

USGS 19020, Cedar Fork Swamp, 5 mi (8.0 km) SE of Beulaville, Duplin Co.

1. *Echinolampas appendiculata* Emmons
2. *Rhyncholampas carolinensis* (Twitchell)

Locality 23

USGS 8165, J. A. Stokes farm, from Marl pits, 2 mi (3.2 km) N of creek near Maple Cypress, Craven Co.

1. *Eurhodia holmesi* (Twitchell)
2. *Protoscutella conradi* (Cotteau)

Locality 24

USGS 12007, Marl pits on Douglass Green Farm, about 1 mi (1.6 km) W of Maple Cypress, Craven Co.

1. *Eurhodia holmesi* (Twitchell)
2. *Protoscutella conradi* (Cotteau)

Locality 25

Biddle Landing, right bank of Neuse River, 1.9 mi (3.0 km) N of Ft. Barnwell, Craven Co.

1. *Eurhodia holmesi* (Twitchell)

Locality 26

County rock quarry near Wilmington, New Hanover Co.

1. *Agassizia wilmingtonica wilmingtonica* Cooke
2. *Coelopleurus carolinensis* Cooke
3. *Eurhodia rugosa* (Ravenel) *ideali*, new subspecies

Locality 27

Emmons (1858:305, 306) states that the following species came from "eocene, and accompanies the remains of the zeuglodon." According to Druid Wilson (1979, pers. comm.), Emmons reports finding remains of *Zeuglodon* in North Carolina only at "Washington" near the line of the Wilmington Railroad. Wilson believes that this is apparently "South Washington," Pender County, said to be near the town of Watha (Stephenson, 1923:158). The other Washington, Beaufort County of Emmons (1858:198) is outside the known Eocene outcrops. There is no evidence to indicate whether or not this locality is in the Castle Hayne Limestone. No specimens of these species have been found in the Castle Hayne or Santee Limestones.

1. *Phyllacanthus carolinensis* (Emmons)—locality for holotype
2. *Phyllacanthus mitchellii* (Emmons)—locality for holotype

Locality 28

Castle Hayne, 1 mi (1.6 km) NW of Lanes Ferry, NE Cape Fear River, New Hanover Co.

1. *Eurhodia rugosa* (Ravenel) *ideali*, new subspecies
2. *Rhyncholampas carolinensis* (Twitchell)

Locality 29

Wilmington, New county rock quarry near old city rock quarry, New Hanover Co.

1. *Maretia subrostrata* (Clark)

Locality 30

NE Cape Fear River, 0.75 mi (1.2 km) above Castle Hayne Bridge, New Hanover Co.

1. *Eupatagus carolinensis* Clark

Locality 31

Smith Creek near Wilmington, New Hanover Co.

1. *Rhyncholampas carolinensis* (Twitchell)

Locality 32

Wilmington, New Hanover Co.

1. *Cidaris pratti* Clark
2. *Linthia wilmingtonensis* Clark
3. *Maretia subrostrata* (Clark)

Locality 33

USGS 10621, A. R. Bland farm, 1.5 mi (2.4 km) NE of Rose Hill, Duplin Co.

1. *Protoscutella conradi* (Cotteau)

Locality 34

Martin Marietta (Formerly Superior Stone Company) Castle Hayne quarry (Superior Pit), 0.5 mi (0.8 km) N of NC Rte 1002, 2.3 mi (3.7 km) NE of Castle Hayne, New Hanover Co. The Castle Hayne Limestone rests on the Upper Cretaceous Rocky Point Member of the Peedee Formation. A phosphatic pebble layer occurs at the bottom of the Castle Hayne. In the eastern end of the quarry, directly above this layer is a biomicrudite containing abundant *Periarchus lyelli* (Conrad) and *Echinolampas appendiculata* Emmons and lacking *Linthia harmatuki* new species. The following taxa were found in float assumed, because of its location in the quarry, to be from this zone: *Eurhodia rugosa* (Ravenel) *ideali* new subspecies, *Linthia wilmingtonensis* Clark, *Linthia hanoverensis* Kellum, *Maretia subrostrata* (Clark), and *Agassizia wilmingtonica wilmingtonica* Cooke. In the southern end of the quarry, a glauconitic biosparrudite occurs on the phosphatic pebble zone and contains echinoids of the "middle zone" including four species found in place: *Linthia harmatuki*, new species, *Protoscutella plana* (Conrad), *Rhyncholampas carolinensis* (Twitchell), and *Eurhodia rugosa* (Ravenel) *depressa*, new subspecies. This layer is 2.2 m thick and overlying it is 2.5 m of a biomicrudite containing echinoids of the "late zone" including *Echinolampas appendiculata* Emmons, *Periarchus lyelli* (Conrad), and *Linthia hanoverensis* Kellum. The lower layer with "middle zone" echinoids thins easterly and wedges out towards the middle of the quarry (Plate 22: figure 4). From this point to the eastern edge of the quarry, the "late zone" rests directly on the phosphatic pebble zone.

Locality 35

Mosleys Creek on Lenoir-Craven Co. lines at NC Rte 55.

1. *Maretia subrostrata* (Clark)
2. *Protoscutella mississippiensis* (Twitchell) *rosehillensis*, new subspecies
3. *Santeelampas oviformis* (Conrad)

Locality 36

E of Neuse River at Ft. Barnwell, Craven Co.

1. *Paraster* sp.
2. *Periarchus lyelli* (Conrad)

SOUTH CAROLINA: SANTEE LIMESTONE

(Except where indicated)

Locality 37

Georgetown, Martin Marietta Company quarry, 2.8 mi (4.5 km) WNW of Jamestown, on W side of US Rte 17A, Georgetown Co.

1. *Agassizia wilmingtonica* Cooke *inflata*, new subspecies
2. *Cidaris pratti* Clark
3. *Eurhodia holmesi* (Twitchell)
4. *Eurhodia rugosa rugosa* (Ravenel)
5. *Linthia hanoverensis* Kellum
6. *Linthia harmatuki*, new species
7. *Linthia wilmingtonensis* Clark
8. *Protoscutella conradi* (Cotteau)
9. *Unifascia carolinensis* (Clark)

These echinoids were collected from high in the quarry. According to Ward (1979, pers. comm.), they came from beds in the Cross Member, zone H (Ward, et al., 1979: fig. 4). Baum (1979, pers. comm.) considers these beds to be from Ward's Moultrie Member. Ward also collected *Protoscutella conradi* (Cotteau) from the Moultrie Member, zone F.

Locality 38

(Warley Hill Formation)

Wilson's Landing, about 3 mi (4.8 km) N of Eadytown, Berkeley Co. (For description of this locality see Pooser, 1965:67)

1. *Cidaris* cf. *C. pratti* Clark
2. *Eupatagus* species
3. *Protoscutella mississippiensis* (Twitchell)
4. *Santeelampas oviformis* (Conrad)

Locality 39

USGS 18078, Giant Portland Cement Company quarry (Giant Dorchester Quarry in Banks, 1978; formerly Carolina Cement and Lime Company), approximately 2 mi (3.2 km) N of Harleyville, just E of SC Rte 453, Dorchester Co.

1. *Periarchus lyelli* (Conrad)

Banks (1978:117) found this species throughout the Santee Limestone (his zone IV) at this quarry. He reports *Mortonella quinquefarius* (Say) from his zone IVd. I have seen some of his specimens and do not believe that they belong to this species. In *M. quinquefarius* the interporiferous zones of the petals are narrow; whereas, in his specimens these zones are much wider. They appear to be small individuals of *Periarchus lyelli* (Conrad). The margin is relatively thicker in some small specimens of this species causing them to superficially resemble *M. quinquefarius*. Ward, et al. (1979:31) record *Periarchus* from their zones A and B. I have collected *Periarchus lyelli* from their zone B.

Locality 40

Just off SC Rte 45, canal spoils between Lake Marion and Lake Moultrie, Berkeley Co.

1. *Eurhodia rugosa rugosa* (Ravenel)
2. *Protoscutella conradi* (Cotteau)

Locality 41

USGS 25867, spoil bank just E of hwy bridge over Santee-Cooper diversion canal between Lake Moultrie and Lake Marion, Berkeley Co.

1. *Eurhodia rugosa rugosa* (Ravenel)

Locality 42

Santee canal at bridge, Berkeley Co.

1. *Cidaris pratti* Clark
2. *Eurhodia rugosa rugosa* (Ravenel)
3. *Protoscutella conradi* (Cotteau)

Locality 43

(Warley Hill Formation)

USGS 19018, south bank Santee River, 0.25 mi (0.4 km) below dam, fossils from 10–12 ft above water and near top of glauconitic zone, Berkeley Co.

1. *Protoscutella mississippiensis* (Twitchell)
2. *Santeelampas oviformis* (Conrad)

Locality 44

USGS 25868, Pinopolis dam, Santee-Cooper project, Berkeley Co.

1. *Agassizia wilmingtonica* Cooke *inflata*, new subspecies
2. *Periarchus lyelli* (Conrad)

Locality 45

USGS 25169, 25170, 25859, Martin Marietta Company, Berkeley quarry, approximately 1.5 mi (2.4 km) S of intersection of SC Rtes. 6 and 59 off 59 near Cross, Berkeley Co.

1. *Coelopleurus infulatus* (Morton)
2. *Eurhodia holmesi* (Twitchell)
3. *Eurhodia rugosa rugosa* (Ravenel)
4. *Linthia hanoverensis* Kellum
5. *Protoscutella conradi* (Cotteau)

These species were collected from a bryozoan biosparrudite from Ward (1979, fig. 3) bed B in the Moultrie Member or Banks' (1978, fig. 4) zones IIa-1 and II-1. *Santeelampas oviformis* (Conrad) occurs in float in this quarry. Immature specimens of *Protoscutella* cf. *P. plana* (Conrad) and immature and adults of *Coelopleurus infulatus* (Morton) occur high in the quarry in Ward (1979, fig. 3) zone E Cross Member or Banks' (1978, fig. 4) zone III. Fragments of *Cidaris* cf. *C. pratti* Clark and *Linthia harmatuki*, new species, are also present.

Locality 46

Santee Portland Cement Company (Orangeburg of Banks, 1978:107), 2.8 mi (4.5 km) S of Holly Hill, along SC Rte 453, Orangeburg Co.

1. *Maretia subrostrata* (Clark)
2. *Periarchus lyelli* (Conrad)
3. *Protoscutella plana* (Conrad)
4. *Rhyncholampas* species

Periarchus lyelli occurs throughout the section but is not abundant near the top of the quarry. The other species were found in float derived from beds low in the quarry—shown by its location near basal beds and the large amount of phosphate and bone fragments in the float. This phosphatic material is common in basal beds but rare higher in the quarry.

Locality 47

(Warley Hill Formation and Santee Limestone, mixed)

USGS 18353, dredged from Santee-Cooper diversion canal near Eadytown, Berkeley Co.

1. *Cidaris pratti* Clark
2. *Eurhodia rugosa rugosa* (Ravenel)
3. *Protoscutella conradi* (Cotteau)
4. *Santeelampas oviformis* (Conrad)—Warley Hill Formation

Locality 48

USGS 7968, 13391, Eutaw Springs, 2 mi (3.2 km) E of Eutawville, Orangeburg Co.

1. *Eurhodia rugosa rugosa* (Ravenel)
2. *Protoscutella plana* (Conrad)

Locality 49

Santee River at Santee-Cooper dam, Clarendon Co. (May be Warley Hill Formation).

1. *Santeelampas oviformis* (Conrad)

Locality 50

Santee River.

1. *Eurhodia holmesi* (Twitchell)—locality of holotype

Locality 51

USGS 4586, Cave Hall, 4 mi (6.4 km) NE of Elloree, Orangeburg Co.

1. *Eurhodia holmesi* (Twitchell)

Locality 52

Near diversion canal between two lakes of Santee-Cooper, Berkeley Co.

1. *Coelopleurus infulatus* (Morton)

Family CIDARIDAE Gray

Subfamily RHABDOCIDARINAE Lambert

Genus *Phyllacanthus* Brandt

Phyllacanthus mitchellii (Emmons)

PLATE 1: FIGURES 1–4

Cidaris mitchellii Emmons, 1858:305, fig. 237.—Clark and Twitchell, 1915:113, pl. 55: figs. 1a–c.—Cooke, 1941:3, 4; 1959:11, 12.

Leiocidaris mitchelli (Emmons).—Lambert and Thiéry, 1909–1925:560.

MATERIAL.—One specimen. No specimens or fragments have been found at any locality in the Castle Hayne Limestone. The holotype is well preserved although the apical system is missing.

SHAPE AND SIZE.—Sides steep, adapical and adoral surfaces flattened. Horizontal diameter 58 mm, height 35 mm.

APICAL SYSTEM.—Diameter 21 mm, 37 percent horizontal diameter (D) of test. No plates preserved.

AMBULACRA.—Narrow (Plate 1: figure 2), width at midzone 7.4 mm (12.7 percent D). Interporiferous zone at midzone wider than single poriferous zone; six equal-sized secondary tubercles in horizontal row between porepairs; 140 plates in ambulacrum; 11–11.5 plates adjacent to single interambulacral plate at midzone; pores strongly conjugate.

INTERAMBULACRA.—16 to 17 plates in each interambulacrum. Primary tubercles perforate, not crenulate (Plate 1: figure 4). Scrobicules separate above ambitus, but confluent at and below ambitus; 17 to 19 tubercles in each scrobicular ring at midzone. Granular zone broad at midzone, 37 percent width of interambulacrum; transversed by ridges (Plate 1: figure 4).

PERISTOME.—Small, diameter 35 percent D.

TYPE-SPECIMEN.—Holotype USNM 498883.

OCCURRENCE.—North Carolina: locality 27. Uncertain whether from Castle Hayne Limestone.

COMPARISON WITH OTHER SPECIES.—Cooke (1959:11, 12) considered this species conspecific with *Phyllacanthus carolinensis* (Emmons) and *Phyllacanthus mortoni* (Conrad). However, *P. mitchellii* differs from *P. carolinensis*, which occurs with it, in having larger scrobicules, finer granules, fewer ambulacral and interambulacral plates, and conjugate pores. *P. mitchellii* differs from *P. mortoni* from the Ocala Limestone in having its peristome smaller than its apical system. Furthermore, the interambulacral granular zone is wider in *P. mitchellii* and there are 11 to 11.5 ambulacral plates adjacent to each interambulacral plate at the midzone; whereas, there are only 7 to 8 in *P. mortoni.*

Phyllacanthus carolinensis (Emmons)

PLATE 1: FIGURES 5–8

Cidaris carolinensis Emmons, 1858:305, fig. 238.—Clark and Twitchell, 1915:113, pl. 55: figs. 2a–c.—Cooke, 1941:3, 4; 1959:11, 12.

Leiocidaris carolinensis (Emmons).—Lambert and Thiéry, 1909–1925:560.

MATERIAL.—One specimen. No specimens or fragments have been found at any locality in the Castle Hayne Limestone. The holotype is well preserved although slightly crushed and lacking the apical system.

SHAPE AND SIZE.—Sides steep, adapical and adoral surfaces flattened. Horizontal diameter 59 mm, height 37 mm.

Apical System.—Not possible to estimate size.

Ambulacra.—Narrow (Plate 1: figure 7), width at midzone 7.7 mm (13 percent D). Interporiferous zone at midzone wider than single poriferous zone, 4–6 equal-sized secondary tubercles in horizontal row between porepairs; 202 plates in ambulacrum; 11.5 to 12 plates adjacent to single interambulacral plate at midzone; pores not conjugate.

Interambulacra.—19 to 20 plates in each interambulacrum. Primary tubercles perforate, not crenulate (Plate 1: figure 5). Scrobicules separate above and at ambitus, but nearly confluent adorally; 17 tubercles in each scrobicular ring at midzone. Granular zone broad, at midzone 39 percent width of interambulacrum; transversed by ridges (Plate 1: figure 5).

Peristome.—Not possible to estimate width.

Type-Specimen.—Holotype USNM 498882.

Occurrence.—North Carolina: locality 27. Uncertain whether from Castle Hayne Limestone.

Comparison with Other Species.—*P. carolinensis* differs from *P. mitchellii* (Emmons)—which was collected with it according to Emmons (1858: 305)—in having smaller scrobicules, coarser granules, more ambulacral and interambulacral plates, and nonconjugate pores. The two holotypes are of approximately the same size; but *P. carolinensis* has 19 to 20 plates in each interambulacrum versus 16 to 17 in *P. mitchellii*, and 202 plates in each ambulacrum as opposed to only 140 in *P. mitchellii.*

Subfamily Cidarinae Gray

Genus *Cidaris* Leske

Cidaris pratti Clark

Plate 2: figures 1–5

Cidaris pratti Clark, in Clark and Twitchell, 1915:114, pl. 55: fig. 3.—Kellum, 1926:14.—Cooke, 1941:6; 1959:10.—Banks, 1978:122, 143, 149.

Material.—Description based on nine nearly complete specimens (all lacking the apical system) and 17 fragments. Too few specimens are available from just one locality to provide significant dimensions. Therefore, the statistics included below are based on all the nine nearly complete specimens even though they come from four different localities. No difference is apparent in any character between specimens from these different localities.

Shape and Size.—Horizontal diameter 11.5 to 30.0 mm ($\bar{x}$=19.67 mm); height 52.17 to 67.90 ($\bar{x}$=61.02) percent horizontal diameter (D).

Apical System.—No plate preserved; diameter 36.0 to 53.91 ($\bar{x}$=41.53) percent D.

Ambulacra.—Narrow, (Plate 2: figure 2) width at midzone 11.33 to 17.97 ($\bar{x}$=14.55) percent D. Interporiferous zone at midzone slightly wider than single poriferous zone (Plate 2: figure 5); bordered by a row of secondary tubercles with two rows of smaller tubercles between; specimen 11.5 mm in diameter with 62 plates in ambulacrum, specimen 16.2 mm with 90, specimen 30.0 mm with 138; in specimen 11.5 mm in diameter 6.5 ambulacral plates adjacent to interambulacral plate at midzone, 8 in specimen 17.5 mm, 10.5 in specimen 30.0 mm in diameter; pores not conjugate.

Interambulacra.—Plates high, 13 in interambulacrum of specimen 11.5 mm in diameter, 15 in specimen 17.5 mm and 17 in specimen 30.0 mm. Primary tubercles perforate, crenulate (Plate 2: figure 4) on all plates from apical system to below midzone, first 2 or 3 plates of each interambulacral columns not crenulate. On same specimens the crenulations present only on adapical side of tubercles on plates below ambitus; some specimens have deeper crenulations than others; on one specimen crenulations slightly developed, absent on first four plates of each column. Tubercles large, occupying most of each plate, scrobicular rings confluent, 17–20 tubercles in each ring on plates near midzone on larger specimens. Granular zone between tubercles along midzone with transverse ridges crossing interradial suture (Plate 2: figure 4).

Peristome.—Slightly smaller in diameter than apical system, 39.39 to 54.69 ($\bar{x}$=44.84) percent D.

TYPE-SPECIMENS.—Holotype USNM 164663; figured specimen USNM 264035.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: localities 2, 4, Maple Hill (Lanier pit) locality 9, Rose Hill locality 11, Ideal Cement Company quarry locality 12, Comfort localities 13, 32. Santee Limestone, South Carolina: Georgetown localities 37, 42, 47 ("early, middle, and late zones").

REMARKS.—Cooke (1941:5; 1959:10) considered *Cidaris smithi* from Alabama (probably from the Ocala Limestone) a synonym of *C. pratti*. However, the holotype and only known specimen of *C. smithi* has fewer ambulacral plates opposite each interambulacral plate at the midzone: 9 plates in the holotype 34.9 mm in diameter. The two largest specimens of *C. pratti*, 25.2 and 30.0 mm in diameter, have 10.5 to 11 plates. With only one specimen available of *C. pratti*, it is not possible to know the significance of this difference.

Family ARBACIIDAE Gray

Genus *Coelopleurus* L. Agassiz

Coelopleurus carolinensis Cooke

FIGURE 2; PLATE 2: FIGURES 6–8; PLATE 3: FIGURES 1–3

Coelopleurus carolinensis Cooke, 1941:9, pl. 2: figs. 1–3; 1959: 22, 23, pl. 3: figs. 5, 6.

MATERIAL.—Description based on 30 specimens from the Ideal quarry (locality 12). Measurements taken from 27 specimens.

SHAPE AND SIZE.—Test 10.1 to 28.7 mm in horizontal diameter (D) ($\bar{x}$=20.98 mm), height 48.48 percent D (SD=2.29, CV=22.62, N=24).

APICAL SYSTEM.—Preserved in 18 specimens; all oculars pentagonal and exsert; genital plates large, each perforated, genital 2 only slightly larger than other genital plates; fine striations on apical system forming star with five points at ocular plates (Plate 2: figure 7, plate 3: figure 1). One large, highly elevated secondary tubercle on each genital plate near edge of periproct. Periproct slightly elongated, greatest width 17.51 percent D (SD=0.78, CV=21.24, N=25).

AMBULACRA.—Greatest width adapical to ambitus, narrowing steadily to peristome, greatest width 22.39 percent D (SD=0.89, CV=19.14, N=27). Poriferous zone arcuate (Plate 3: figure 3); ambulacral plates compound, trigeminate; in each poriferous zone 42 porepairs in specimen 10.1 mm in diameter, 80 in specimen 28.7 mm in diameter (Figure 2A); the number of primary tubercles in each ambulacrum varies from 11 in a specimen 10.1 mm in diameter to 25 in a specimen 28.7 mm in diameter (Figure 2B). Each ambulacrum with 3–7 sphaeridia, most specimens with 5–7 (Figure 2C). Ambulacra flush with test or slightly inflated.

INTERAMBULACRA.—Plates low, 15 in interambulacrum of specimen 10.1 mm in diameter, 25 in interambulacrum of specimen 28.7 mm in diameter (Figure 2D); greatest width adapical to ambitus, 37.05 percent D (SD=1.97, CV=25.12, N=27). Interambulacrum medially naked of tubercles adapical from apical system to midway to ambitus; first primary tubercle occurs on fourth to sixth plate from apical system, four rows of primary tubercles in each interambulacrum at ambitus. Tubercles imperforate, not crenulate. Two rows of nodes in each interambulacrum edge the naked medial zone and extend adorally to ambitus.

PERISTOME.—Diameter 43.69 percent D (SD=1.71, CV=19.17, N=24), gill slits wide with long tags for attachment of gills.

TYPE-SPECIMENS.—Holotype USNM 166500; figured specimen USNM 264036.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: locality 3, Ideal Cement Company quarry localities 12, 26 ("late zone").

COMPARISON WITH OTHER SPECIES.—This species is very similar to *Coelopleurus infulatus* (Morton) that occurs with it at the Ideal quarry. It differs from *C. infulatus* in having a less domed test (in smaller specimens) with its ambulacra not inflated adapically and in having fewer primary tubercles with a larger adapical naked area. Its plates are higher, resulting in fewer interambulacral and ambulacral plates. Its periproct is larger; its peristome smaller; and its sphaeridia fewer in number. These differences are clearly

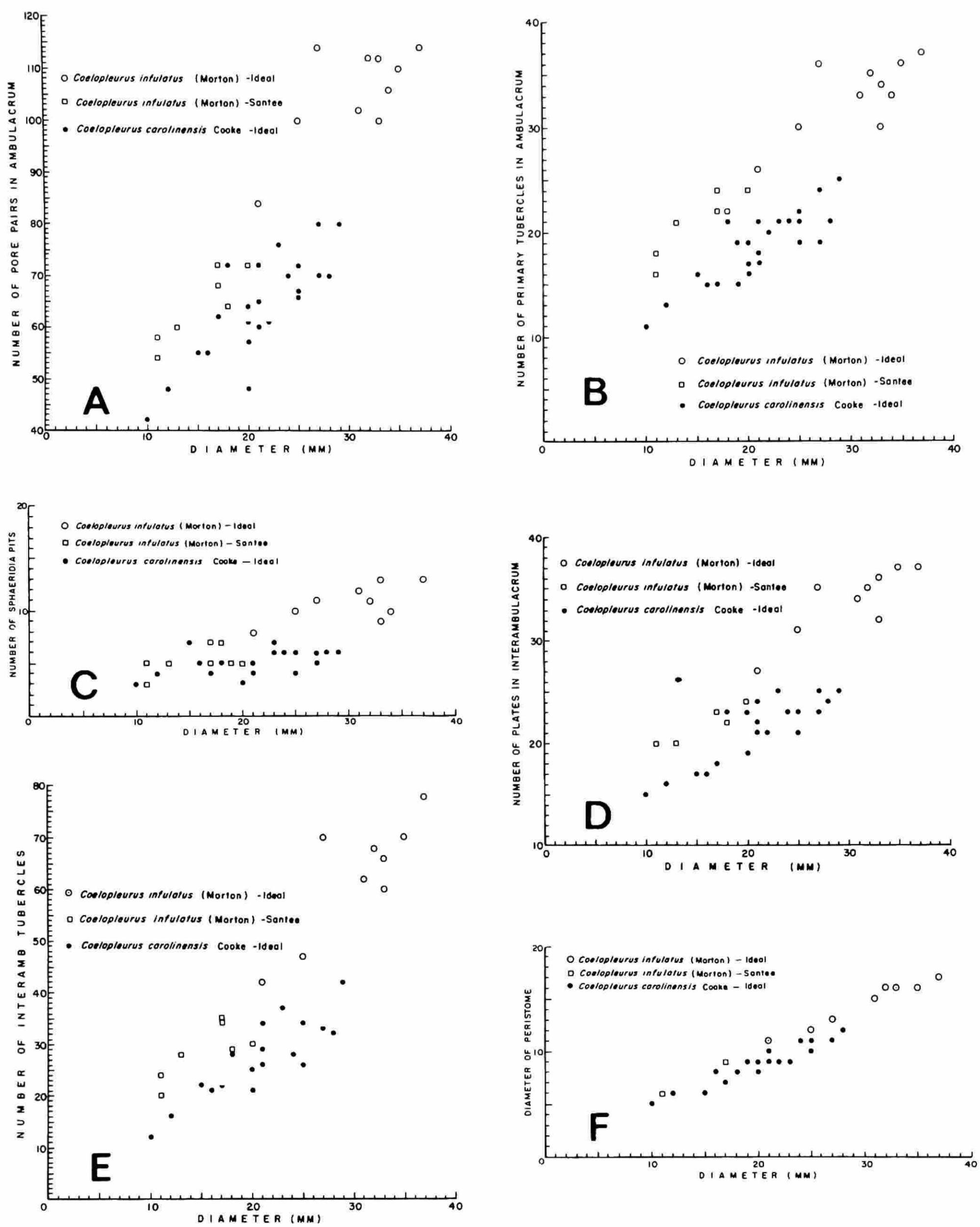


FIGURE 2.—*Coelopleurus infulatus* (Morton) and *Coelopleurus carolinensis* Cooke: A, scattergram showing difference in number of porepairs between the two species; B, scattergram showing difference in number of primary tubercles in an ambulacrum of *C. infulatus* (Morton) and *C. carolinensis* Cooke; C, scattergram showing difference in number of sphaeridia pits in *C. infulatus* (Morton) and *C. carolinensis* Cooke; D, scattergram showing difference in number of interambulacral plates in *C. infulatus* (Morton) and *C. carolinensis* Cooke; E, scattergram showing difference in number of primary tubercles in an interambulacrum of *C. infulatus* (Morton) and *C. carolinensis* Cooke; F, scattergram showing difference in the diameter of the peristome in *C. infulatus* (Morton) and *C. carolinensis* Cooke.

evident in the scattergrams (Figures 2A-F), and are described in more detail in the description of *C. infulatus* below.

REMARKS.—Cooke (1959: explanation to Plate 3: figures 5, 6) states in error that the holotype of *C. carolinensis* came from the Santee Limestone in South Carolina. As noted in his original description (Cooke, 1941:9) and on the label with the holotype, it was collected in the Castle Hayne Limestone at the County rock quarry near Wilmington, North Carolina.

Coelopleurus infulatus (Morton)

FIGURES 2, 3; PLATE 3: FIGURES 4–7; PLATE 4

Echinus infulatus Morton, 1833:131, pl. 10: fig. 7; 1834:75, pl. 10: fig. 7.

Coelopleurus infulatus (Morton).—Desor, 1855–1858:98.—Clark and Twitchell, 1915:117, pl. 56: figs. la-i.—Cooke, 1941:9; 1959:22–23.—Banks, 1978:101.

MATERIAL.—Description based on 11 specimens from the Ideal quarry (locality 12). Measurements taken from 10 specimens.

SHAPE AND SIZE.—Test 20.9 to 36.8 mm in horizontal diameter (D) ($\bar{x}$=30.82 mm), height 54.26 percent D (SD=3.41, CV=20.28, N=10). Adapically ambulacra strongly inflated; interambulacra slightly depressed along midline. Test domed, with steep sides.

APICAL SYSTEM.—Preserved in five specimens; all oculars pentagonal and exsert (Figure 3) in all specimens (Plate 4: figure 1); genital plates large, each perforated, genital 2 larger than others; system small, greatest width 24.50 percent D; periproct elongated diagonally from interambulacra 3 to 1, at greatest width 15.19 percent D (SD=0.92, CV=20.11, N=6).

AMBULACRA.—Greatest width adapical to ambitus, narrowing steadily to peristome, greatest width 20.65 percent D (SD=0.91, CV=14.37, N=10). Poriferous zones straight (Plate 3: figure 7) except near peristome where arcuate (Plate 4: figure 4); ambulacral plates compound, trigeminate; in each ambulacrum 84 porepairs in specimen 20.9 mm in diameter, 110 in specimen 35.3 mm in diameter (Figure 2A). Two rows of primary imperforate, noncrenulate tubercles in each ambulacrum extending almost to apical system; the number of tubercles in each ambulacrum varies from 26 in specimen 20.9 mm in diameter to 37 in specimen 36.8 mm in diameter (Figure 2B). Each ambulacrum with 8–13 sphaeridia in single row (Plate 4: figure 4).

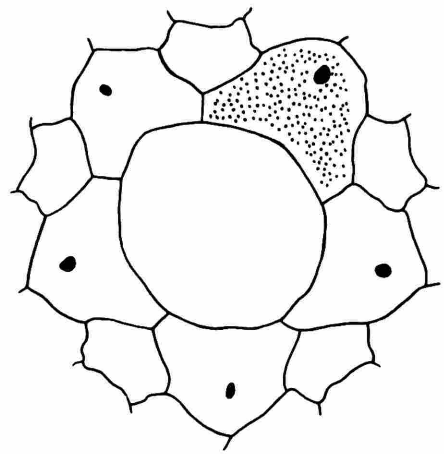


FIGURE 3.—*Coelopleurus infulatus* (Morton), apical system showing exsert ocular plates in USNM 264038, from the Castle Hayne Limestone at locality 12, × 6.

INTERAMBULACRA.—Plates low, 27 in interambulacrum of specimen 20.9 mm in diameter, 37 in interambulacrum of specimen 36.8 mm in diameter (Figure 2D); greatest width adapical to ambitus, 40.19 percent D (SD=2.19, CV=17.74, N=10). Interambulacra medially naked of tubercles adapically from apical system to midway to ambitus, with single row of tubercles along each outer edge in each interambulacrum; at point midway between apical system and ambitus two more rows of tubercles appear; the fifth and sixth rows appear at the ambitus; six rows continue from the ambitus to near peristome. Primary tubercles imperforate, noncrenulate.

PERISTOME.—Diameter 48.35 percent D (SD=2.29, CV=15.88, N=8), gill slits wide with long tags for attachment of gills.

TYPE-SPECIMENS.—The holotype is probably the specimen figured by Clark and Twitchell (1915:pl. 56: fig. 1a-i), Academy of Natural Sciences Philadelphia 1076; figured specimens USNM 264037, 264038.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Ideal Cement Company quarry locality 12. Santee Limestone, South Carolina: localities 45, 52 ("early, middle, and late zones").

REMARKS.—The probable holotype of this species (Plate 3: figures 6, 7) and all the other specimens (7) I have seen from the Santee Limestone of South Carolina are smaller than the specimens from the Castle Hayne Limestone in North Carolina. However, except for this difference in size, I can see no other differences. On the scattergrams (Figures 2A-F) the coordinates for the smaller South Carolina specimens fall in the path where you would expect to find smaller North Carolinian specimens if they had been found.

COMPARISON WITH OTHER SPECIES.—Cooke (1959:22–23) considered *C. carolinensis* a junior subjective synonym of *C. infulatus*, but his holotype and the many additional specimens collected lately from the Castle Hayne Limestone can be clearly differentiated from the holotype of *C. infulatus* and other specimens of this species that occur with *C. carolinensis* in the Castle Hayne Limestone. *C. infulatus* differs in having a more domed test in the larger specimens with steeper sides (cf. Plate 3: figure 3 to Plate 4: figure 3), and ambulacra, which are inflated adapically. More primary tubercles are present in both the ambulacra and interambulacra (Figures 2B, E) particularly adapically. In *C. carolinensis* much more of the adapical area is naked of tubercles. A double row of tubercles extends almost to the apical system in *C. infulatus*; whereas, in *C. carolinensis* the first tubercle occurs on the third or fourth plate. More interambulacral and ambulacral plates (and porepairs) are present in *C. infulatus* (Figures 2A, D). Finally in *C. infulatus* the peristome is larger (Figure 2F) and the sphaeridia pits more numerous (Figure 2C).

Most of the specimens of *C. infulatus* from the Castle Hayne Limestone are larger than those of *C. carolinensis*, but enough specimens are present of the same size to show that these morphological differences are not age related. The differentiation of the two species are clearly evident in the scattergrams and in the regression curves.

Family PHYMOSOMATIDAE Pomel

Genus *Dixieus* Cooke

Dixieus cf. *Dixieus dixie* (Cooke)

PLATE 5: FIGURES 1–3

Phymosoma dixie Cooke, 1941:17, pl. 2: fig. 15.
Dixieus dixie (Cooke).—Cooke, 1948:607.—Mortensen, 1951: 558, fig. 281.—Cooke, 1959:24, pl. 5: figs. 8–10.

MATERIAL.—Fragment of one specimen that includes one complete ambulacrum and interambulacrum and approximately one-third of the test lacking the apical system and peristome. The specimen certainly belongs to the genus *Dixieus* or *Phymosoma* having biserial porepairs, equal size ambulacral, and interambulacral crenulate tubercles. It appears very similar to *Dixieus dixie* from the late Eocene Ocala Limestone in Florida but differs in having fewer plates. The Castle Hayne specimen has 208 porepairs in an ambulacrum; the holotype, which is smaller, has 234. The holotype is 43 mm in diameter; whereas, the Castle Hayne specimen is estimated to have been 48 mm in diameter.

Although this specimen probably represents a new species, more specimens are needed before its specific characters can be determined.

TYPE-SPECIMEN.—Figured specimen USNM 264039.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (Lanier pit) locality 9 ("late zone").

Family ECHINOLAMPADIDAE Gray

Genus *Echinolampas* Gray

Echinolampas appendiculata Emmons

FIGURES 4, 5; PLATE 5: FIGURES 4–9; PLATE 6: FIGURES 1–4

Echinolampas appendiculatus Emmons, 1858:307, figs. 240, 241.—Clark and Twitchell, 1915:149, pl. 68: figs. 2a-h.—Cooke, 1942:38; 1959:56, pl. 22: figs. 5, 6.

MATERIAL.—Hundreds of specimens, many extremely well preserved and covering a wide range of size, smallest only 2.3 mm long. The description and dimensions are based on 29 specimens from Maple Hill (Lanier pit) locality 9.

SHAPE AND SIZE.—Length 2.3 to 47.33 mm ($\bar{x}$=21.17 mm), width 88.81 percent L (SD=9.88, CV=41.24, N=29), greatest width at midlength or slightly posterior to center; greatest height at apical system, height 53.69 percent L (SD=5.49, CV=36.75, N=29). Margins smoothly curving. Adorally, depressed around peristome. Margin prolonged posteriorly. Smaller specimen higher and rounder (Plate 5: figure 8).

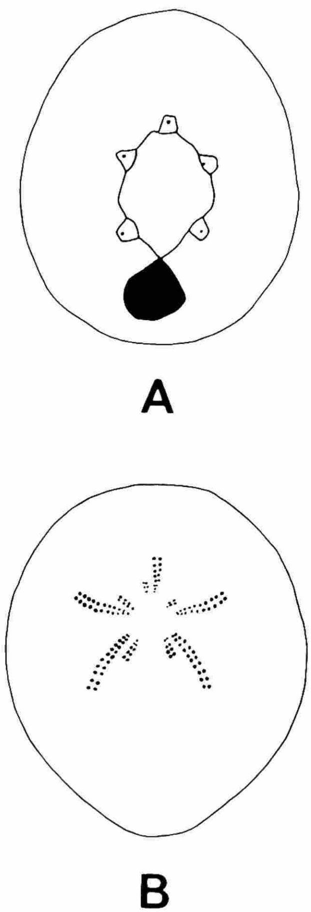


FIGURE 4.—*Echinolampas appendiculata* Emmons: A, adapical view of specimen only 2.3 mm long (note position of periproct in contact with apical system, lack of petaloid pores, and lack of genital pores), USNM 264586, from the Castle Hayne Limestone, locality 9, × 20; B, adapical view of specimen 8 mm long, USNM 264587, Castle Hayne Limestone, locality 9, × 6.

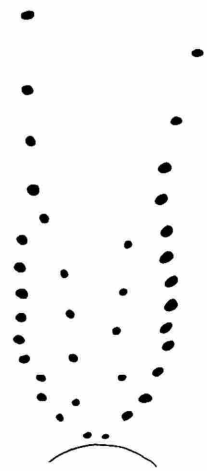


FIGURE 5.—*Echinolampas appendiculata* Emmons, phyllode in ambulacrum II of USNM 264041 from Castle Hayne Limestone at locality 9, × 10.

APICAL SYSTEM.—Located at distance from anterior margin 53.58 percent L (SD=5.91, CV=40.74, N=29); monobasal with four genital pores, no genital pores present in specimens less than 16 mm long (Figure 4A).

AMBULACRA.—Petals broad, greatest width petal III 9.49 percent L (SD=1.18, CV=43.64, N=28), petal II 9.51 percent L (SD=1.31, CV=48.51, N=29), petal I 9.42 percent L (SD=1.26, CV=47.44, N=29); closing distally; length of petal III 32.35 percent L (SD=4.76, CV=49.25, N=28), petal II 34.14 percent L (SD=5.04, CV=50.55, N=29), petal I 38.17 percent L (SD=5.53, CV=50.02, N=29); poriferous zones narrow, unequal with from 2 to 7 ($\bar{x}$=3) more porepairs in the outer zones of petals V, I, 1 to 7 ($\bar{x}$=3) more in posterior zones of petals II, IV, 1 to 4 ($\bar{x}$=2) more in right poriferous zone of petal III; no porepairs present in specimens less than 5 mm long (Figure 4A, Plate 5: figure 7), in specimen 6 mm long no porepairs in petal III, 3 in anterior, 6 in posterior zones of petals II, IV and 7 in outer and 3 inner zones of petals V, I. Additional porepairs added at consistent rate throughout growth of echinoid (Figure 4B). Pores conjugate. Ambulacral plates single pored beyond petals.

Phyllodes widening slightly (Figure 5) with 20–

24 pores in outer series, 8 to 10 in inner rows in specimen 44 mm long. Sphaeridia in two rows, 6–8 in adult specimens in single ambulacrum.

PERISTOME.—Located from anterior margin at distance 39.21 percent L (SD=4.34, CV=39.80, N=28). Width 18.44 percent L (SD=1.79, CV=35.58, N=28); height 11.29 percent L (SD=0.99, CV=32.75, N=28).

PERIPROCT.—Inframarginal, width 20.06 percent L (SD=2.22, CV=40.92, N=28). In smallest specimen 2.3 mm long periproct supramarginal in contact with apical system (Figure 4A); in specimen 3.9 mm long periproct in adult position.

TYPE-SPECIMENS.—Holotype USNM 499113; figured specimens USNM 138017, 264040, 264041, 264042, 264586, 264587.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: localities 1–5, 7, Maple Hill (Lanier pit) locality 9, Maple Hill (East Coast Construction Company quarry) locality 10, Ideal Cement Company (locality 12), localities 16–22, 34 ("middle and late zones").

Family PLIOLAMPADIDAE Kier

Genus *Eurhodia* Haime

Eurhodia baumi, new species

FIGURE 6; PLATE 6: FIGURES 5–8

DIAGNOSIS.—Species characterized by short low test, tilting posterior truncation with periproct visible from above, and low peristome.

MATERIAL.—Description based on 20 specimens from Rose Hill (locality 11). Measurements taken from 18 specimens.

SHAPE AND SIZE.—Length 26.4 to 43.2 mm ($\bar{x}$=34.33 mm), width 82.4 percent L (SD=2.51, CV=8.88, N=18) greatest width and height central to posterior to center, height 49.6 percent L (SD=1.90, CV=11.18, N=18); posterior sloping so that periproct partially visible from above.

APICAL SYSTEM.—Located at distance from anterior margin equal to 49.1 percent L (SD=2.03, CV=12.03, N=17); monobasal with four genital pores.

AMBULACRA.—Petals with interporiferous zones twice width of single poriferous zone. Length of petal III 34.0 percent L (SD=1.73, CV=14.51, N=14), petal II or IV 33.1 percent L (SD=1.85, CV=16.0, N=13), petal V or I 40.1 percent L (SD=1.84, CV=13.18, N=14); greatest width of petal III 11.6 percent L (SD=0.69, CV=16.87, N=13), petal II or IV 11.2 percent L (SD=0.69, CV=16.63, N=14), petal V or I 11.9 percent L (SD=0.76, CV=18.35, N=14). Poriferous zones of equal length in same petal. First porepair in plate 35 of ambulacrum III, 39 in II, 36 in I.

Phyllodes widening slightly, with approximately 20–22 pores in outer series in single phyllode, 8–10 in inner; 8–10 sphaeridia in each ambulacrum (Figure 6).

In specimen 26.5 mm long 60 porepairs in petal III, 58 in II, 72 in I; specimen 36 mm long 76 porepairs in III, 70 in II, 86 in I.

PERISTOME.—Located from anterior margin at distance 35.7 percent L (SD=1.49, CV=12.20, N=18). Height greater than width, height 13.7 percent L (SD=0.46, CV=9.74, N=17), width 10.4 percent L (SD=0.47, CV=13.06, N=18).

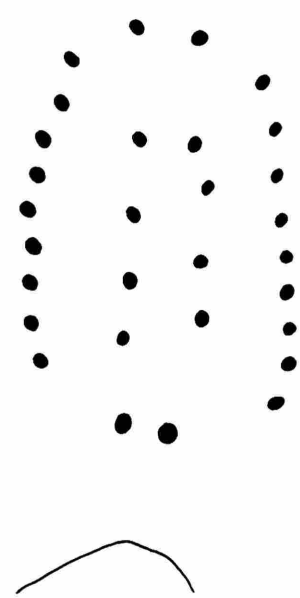


FIGURE 6.—*Eurhodia baumi*, new species, phyllode in ambulacrum V of USNM 264043 from Castle Hayne Limestone at locality 11, × 12.

Bourrelets well developed (Plate 6: figure 8). Adoral surface pitted.

PERIPROCT.—Located slightly less than midway up test, partially visible from above, width 20.1 percent L (SD=0.77, CV=11.15, N=16). Located in plates 7 or 8 through 10, 11 in interambulacrum 5.

ADORAL SURFACE.—Irregularly arranged pits in midzone of interambulacrum 5, in ambulacrum III at extremity of phyllode, and in second and third plates of interambulacra 2 and 3 alongside phyllode, and second plates of other interambulacral columns (Plate 6: figure 8).

NUMBER OF PLATES.—Specimen 36.2 mm long with 40 plates in interambulacrum 5, 34 in interambulacrum 1 and 2. Ambulacrum III with 156 plates, 136 in II, 140 in I.

TYPE-SPECIMEN.—Holotype USNM 264043.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Rose Hill locality 11 ("early zone").

COMPARISON WITH OTHER SPECIES.—*Eurhodia baumi* differs from *Eurhodia holmesi* also from the Castle Hayne but from a different locality in having a lower test with its posterior truncation tilting so that the periproct is more visible from the top. The periproct is higher on the test in *E. baumi*. It is easily distinguished from *Eurhodia rugosa rugosa* (Ravenel), which occurs with it, by its much wider test.

Eurhodia rugosa rugosa (Ravenel)

FIGURES 7, 8; PLATE 7: FIGURES 1–6

Pygorhynchus rugosus Ravenel, 1848:4, figs. 7, 8.—Clark and Twitchell, 1915:147.
Pygorhynchus crucifer (Morton).—Ravenel, 1848:4, figs. 9, 10.
Ravenelia crucifer (Morton).—McCrady, 1859:283.
Ravenelia rugosa (Ravenel).—McCrady, 1859:283.
Cassidulus (Rhynchopygus) raveneli Twitchell, in Clark and Twitchell, 1915:142, pl. 65: figs. 5a-d, pl. 66: figs. 1a-c, 2a-b.
Eurhodia rugosa (Ravenel).—Lambert and Thiéry, 1909–1925:365.—Cooke, 1959:63, pl. 22: figs. 1–4.—Kier, 1962: 214, fig. 177, pl. 41: figs. 1–5.—Banks, 1978:122, 143.
Eurhodia raveneli (Twitchell).—Cooke, 1942:35.

MATERIAL.—Description based on 70 specimens from Georgetown (locality 37). Dimensions from 38 specimens.

SHAPE AND SIZE.—Length 16.4 to 62.5 mm, $\bar{x}$=30.69 mm, test elongate, width 66.16 to 83.27 ($\bar{x}$=74.49) percent L (SD=7.52, CV=33.59, N=38), sides relatively straight, posterior margin truncated; height 29.28 to 54.27 ($\bar{x}$=44.44) percent L (SD=3.28, CV=25.35, N=38), smaller specimens higher relative to length than larger (Figure 7A). Trough extending downward from periproct; test depressed adorally along midline.

APICAL SYSTEM.—Anterior, distance from anterior margin 42.78 to 54.35 ($\bar{x}$=49.04) percent L (SD=4.93, CV=33.08, N=37); monobasal, 4 genital pores, present on smallest specimen.

AMBULACRA.—Anterior petal extending almost to anterior margin; length 27.44 to 41.03 ($\bar{x}$=35.71) percent L (SD=4.91, CV=42.63, N=32); width 9.12 to 14.33 ($\bar{x}$=11.83) percent L (SD=1.15, CV=31.34, N=31); length of petals II, IV 23.33 to 37.20 ($\bar{x}$=30.61) percent L (SD=3.60, CV=38.56, N=31); width 8.89 to 14.68 ($\bar{x}$=11.58) percent L (SD=1.23, CV=34.42, N=32); length of petals V, I 34.15 to 44.91 ($\bar{x}$=39.14) percent L (SD=5.02, CV=41.83, N=34); width 8.89 to 15.47 ($\bar{x}$=11.82) percent L (SD=1.12, CV=31.98, N=33). Petals closing distally, poriferous zones equal, interporiferous zones slightly wider than single poriferous zone. Specimen 16.6 mm long with 60 porepairs in petal III, 54 in petal IV, 66 in petal V; specimen 48.2 mm long with 109 porepairs in petal III, 92 in IV, 119 in V; specimen 62.5 mm long with 112 porepairs in petal III, 110 in IV, 128 in V.

PERISTOME.—Anterior of center, distance from anterior margin 33.71 to 40.22 ($\bar{x}$=37.15) percent L (SD=4.39, CV=38.64, N=37); elongated longitudinally, height 10.36 to 15.06 ($\bar{x}$=12.74) percent L (SD=1.38, CV=35.79, N=35); width 8.57 to 13.25 ($\bar{x}$=10.61) percent L (SD=1.19, CV=37.15, N=35). Bourrelets strongly developed (Plate 7: figure 2), peristomial opening vertically sided. Phyllodes single pored, approximately 26 pores in each phyllode, 6 in inner series in occluded plates in specimen 20.5 mm long; 30 in each phyllode, 8–9 in inner series in specimen 52.6 mm long.

PERIPROCT.—Supramarginal, transverse with

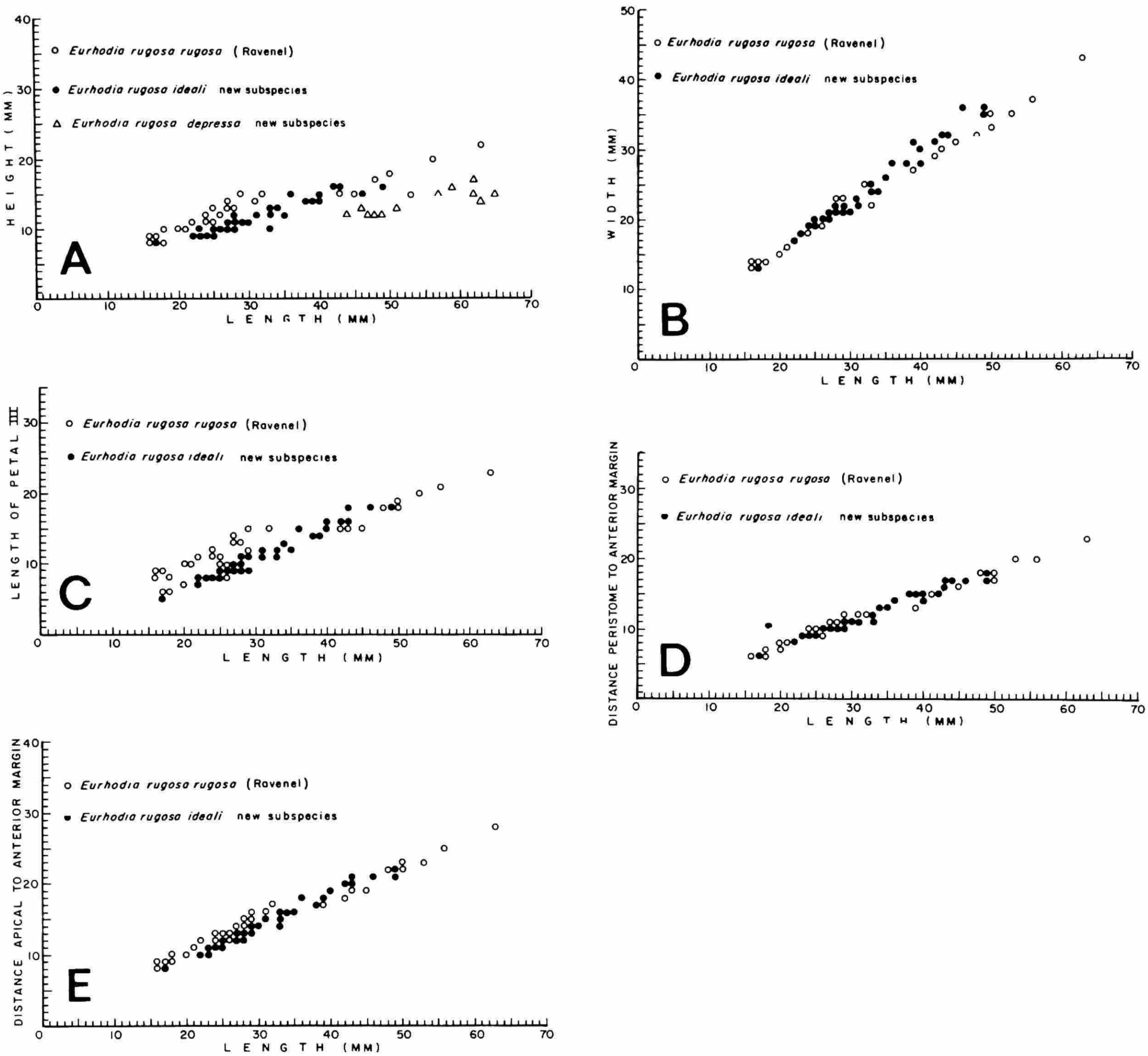


FIGURE 7.—*Eurhodia rugosa* (Ravenel): A, scattergram showing differences in height relative to length in three subspecies; B, scattergram showing difference in width relative to length in two subspecies of *E. rugosa* (Ravenel) (note that although width is similar in the smaller specimens, larger specimens of *E. rugosa ideali*, new subspecies, are narrower than large specimens of *E. rugosa rugosa* (Ravenel)); C, scattergram showing difference in length of petal III in two subspecies of *E. rugosa* (Ravenel) (note that although length of petal III is greater in small specimens of *E. rugosa ideali*, new subspecies, than in *E. rugosa rugosa* (Ravenel), this difference is absent in larger specimens); D, scattergram of subspecies of *E. rugosa* (Ravenel) showing similar position of peristome; E, scattergram of subspecies of *E. rugosa* (Ravenel) showing similar position of apical system in larger specimens.

trough extending posteriorly. Enclosed by interambulacral plates 8–12.

ADORAL SURFACE.—Large, irregularly arranged pits (Plate 7: figure 2) in midzone of interambulacrum V; two-thirds of length of ambulacrum III extending from extremity of phyllode; first and second plates of interambulacra 2, 3 and in plate 3 adjoining ambulacrum III; a few pits in plates 1 and 2 in interambulacra 4, 1. Adoral plate arrangement in Figure 8.

TYPE-SPECIMEN.—In the same paper in which he erected *Pygorhynchus rugosus*, Ravenel (1848) referred a specimen (probably of this species) to *Pygorhynchus crucifer* Morton. Twitchell, in Clark and Twitchell (1915:142), erected a new species, *Cassidulus raveneli*, for this specimen. He considered Ravenel's *P. rugosus* too poorly illustrated and, because the type-specimen was lost, not worthy of recognition. Cooke (1942:35) accepted Twitchell's species but later (1959:63) used *P. rugosus* and considered Twitchell's *C. raveneli* as a synonym. Ravenel's illustrations of *P. rugosus* are clear enough to permit reasonable certainty that his species is the form found so commonly in South Carolina in the Santee Limestone. In order to determine which name to use for this species, a neotype is herein selected for Ravenel's *P. rugosus*: USNM 562300 from the Santee Limestone at USGS 18353 (locality 47) on the Santee-Cooper diversion canal near Eadytown, Berkeley County, South Carolina (figured by Cooke, 1959: plate 22: figures 1–4).

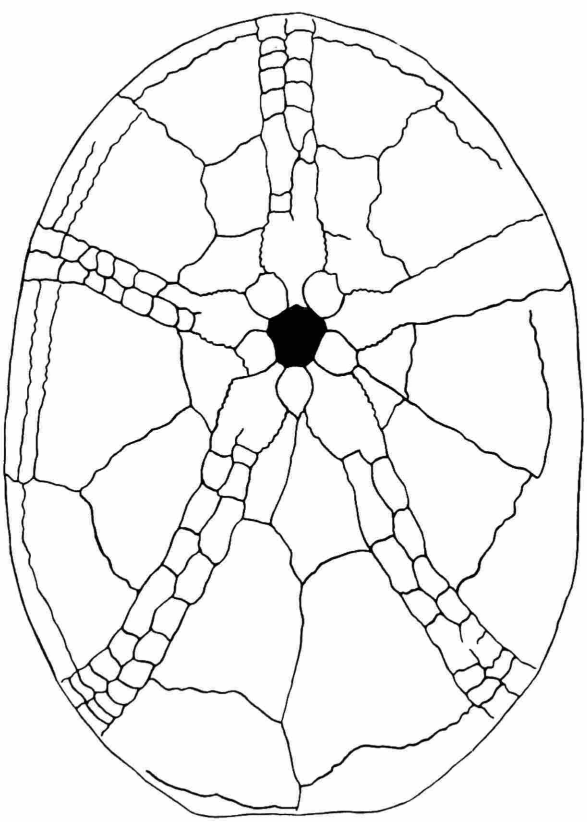


FIGURE 8.—*Eurhodia rugosa rugosa* (Ravenel), adoral plate arrangement in USNM 264588 from Santee Limestone at locality 37, × 2.

FIGURED SPECIMENS.—USNM 264044, 264045, 264588.

OCCURRENCES.—Santee Limestone, South Carolina: Georgetown localities 37, 40–42, 45, 47, 48 ("middle zone").

REMARKS.—This subspecies differs from *E. rugosa ideali* from the Castle Hayne Limestone in having far larger pits (compare Plate 7: figure 2 with Plate 7: figure 8) on its adoral surface, a narrower test in the larger specimens (Figure 7B), higher test on the smaller specimens (Figure 7A), and a longer petal III in the smaller specimens (Figure 7C). In all their other characters including position of the peristome and apical system (Figures 7D, E), the subspecies are indistinguishable. *E. rugosa rugosa* occurs only in the Santee Limestone of South Carolina.

***Eurhodia rugosa ideali*, new subspecies**

FIGURES 7, 9; PLATE 7: FIGURES 7–9

MATERIAL.—Description based on over 100 specimens from Ideal (locality 12). Dimensions from 48 specimens.

SHAPE AND SIZE.—Length 17.4 to 49.1 mm, $\bar{x}$=31.60 mm, test elongate, width 69.26 to 80.26 ($\bar{x}$=75.07) percent L (SD=5.76, CV=24.35, N=48), sides relatively straight and parallel in some specimens, in others sides widening posteriorly, posterior margin truncated; height 32.92

to 44.83 ($\bar{x}$=38.16) percent L (SD=2.34, CV=19.81, N=47). Trough extending downward from periproct; test depressed adorally along midline.

Apical System.—Anterior, distance from anterior margin 43.18 to 49.51 ($\bar{x}$=46.08) percent L (SD=3.62, CV=24.79, N=45); monobasal, 4 genital pores, present on smallest specimen.

Ambulacra.—Anterior petal extending almost to anterior margin; length 30.46 to 59.30 ($\bar{x}$=36.39) percent L (SD=4.19, CV=36.15, N=41); width 9.46 to 13.94 ($\bar{x}$=12.18) percent L (SD=0.95, CV=24.94, N=44); length of petals II, IV 25.0 to 33.81 ($\bar{x}$=29.95) percent L (SD=2.78, CV=29.13, N=40); width 9.46 to 13.94 ($\bar{x}$=11.75) percent L (SD=0.92, CV=24.85, N=41); length of petals V, I 31.89 to 43.62 ($\bar{x}$=37.82) percent L (SD=3.65, CV=30.51, N=41); width 9.12 to 13.46 ($\bar{x}$=11.41) percent L (SD=0.94, CV=25.75, N=42). Petals closing distally, poriferous zones equal, interporiferous zones slightly wider than single poriferous zone. Specimen 17.4 mm long with 40 porepairs in petal III, 40 in petal IV, 50 in petal V; specimen 48.9 mm long with 98 porepairs in petal III, 90 in IV, 110 in V.

Peristome.—Anterior of center, distance from anterior margin 34.25 to 38.46 ($\bar{x}$=36.43) percent L (SD=2.95, CV=25.61, N=48); elongated longitudinally, height 9.36 to 16.54 ($\bar{x}$=12.53) percent L (SD=0.70, CV=18.43, N=47); width 7.14 to 14.02 ($\bar{x}$=10.58) percent L (SD=0.71, CV=21.96, N=47). Bourrelets strongly developed. Phyllodes (Figure 9A) single pored, approximately 26 pores in each phyllode, 6 in inner series in occluded plates in specimen 23 mm long; 28 in each phyllode, 8–9 in inner series in specimen, 41.7 mm long.

Periproct.—Supramarginal, transverse with trough extending posteriorly. Enclosed by interambulacral plates 8–12.

Adoral Surface.—Small, irregularly arranged pits (Plate 7: figure 8) in midzone of interambulacrum V; two-thirds of length of ambulacrum III extending from extremity of phyllode; first and second plates of interambulacra 2, 3 and in plate 3 adjoining ambulacrum III; a few pits in

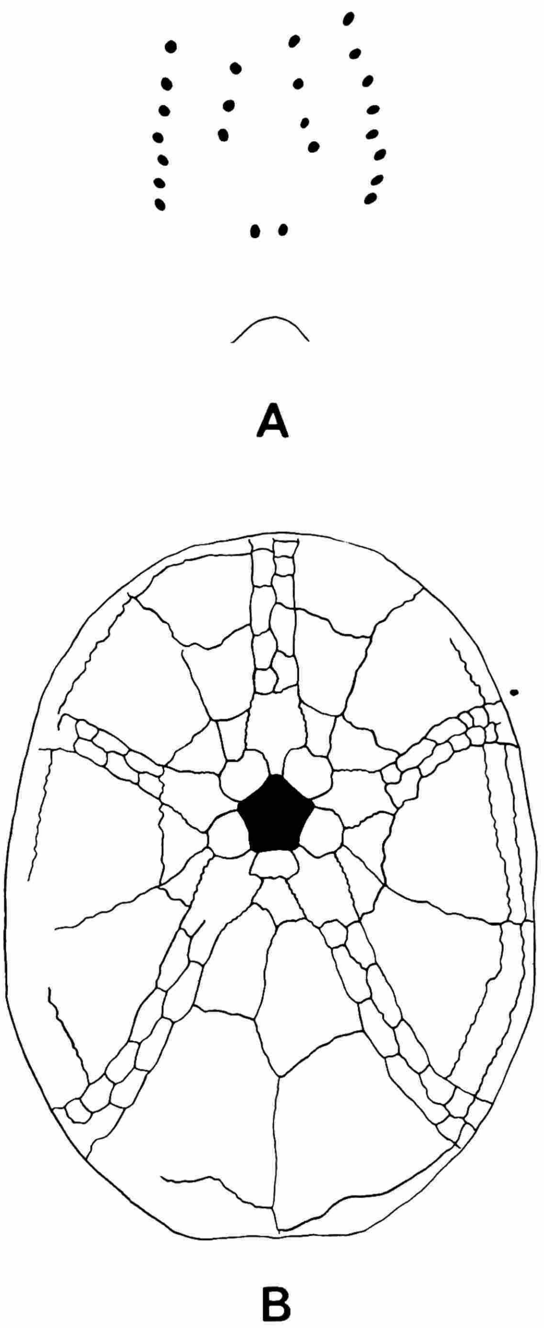


Figure 9.—*Eurhodia rugosa* (Ravenel) *ideali*, new subspecies: A, phyllode of ambulacrum III on USNM 264589 from Castle Hayne Limestone at locality 12, × 8; B, adoral plate arrangement of USNM 264589 from Castle Hayne Limestone at locality 12, × 2.

plates 1 and 2 in interambulacra 4, 1. Adoral plate arrangement in Figure 9B.

TYPE-SPECIMENS.—Holotype USNM 264046; figured specimen USNM 264589.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: localities 2, 5, 8, Rose Hill locality 11, Ideal Cement Company quarry localities 12, 26, 28 ("early and late zones").

REMARKS.—Specimens of this subspecies are distinguished from specimens of *Eurhodia rugosa rugosa* by their much smaller pits on the adoral surface (compare Plate 7: figure 2 with Plate 7: figure 8). In *Eurhodia rugosa ideali* the specimens are wider in the larger specimens, although having similar width to length ratios in the smaller specimens (Figure 7B). The width-to-length ratio decreases with increase in size in *E. rugosa rugosa.* Small specimens of *E. rugosa ideali* have lower tests than in *E. rugosa rugosa* but larger specimens have similar heights (Figure 7A). Finally, specimens of *E. rugosa ideali* commonly have petal III shorter in the smaller specimens than *E. rugosa rugosa* (Figure 7C). In all other characters the subspecies are indistinguishable including width, height, and position of the peristome (Figure 7D), location of the apical system in large specimens (Figure 7E), width of all petals and length of all petals except petal III, number of porepairs in the petals, and numbers of pores in the phyllodes. *E. rugosa ideali* occurs in the Castle Hayne of North Carolina and *E. rugosa rugosa* occurs in the Santee Limestone of South Carolina.

Eurhodia rugosa depressa, new subspecies

FIGURES 7A, 10, 21, 22; PLATE 7: FIGURES 10–12

MATERIAL.—62 specimens from Maple Hill (East Coast Company) locality 10 but only eight show adapical surface. Specimens occur in living position as shown by the filling of only the lower portion of the test with sediment—the upper part is hollow. The specimens occur at the bottom of an indurated bryozoan "hash" with the upper surface of the echinoids firmly cemented to the rock making it very difficult to clean this surface.

SHAPE AND SIZE.—Length 47.6 to 65.0 mm, $\bar{x}$=56.6 mm, test elongate, width 66.34 to 69.33 ($\bar{x}$=67.59) percent L (SD=4.69, CV=12.27, N=8), greatest width posterior to center, posterior margin truncated; height 25.38 to 28.32 ($\bar{x}$=27.43) percent L (SD=1.67, CV=11.08, N=6). Trough extending downward from periproct; test depressed adorally along midline.

APICAL SYSTEM.—Anterior, distance from anterior margin 42.62 to 43.91 ($\bar{x}$=43.07) percent L (SD=2.92, CV=12.29, N=6); monobasal, 4 genital pores, present on smallest specimen.

AMBULACRA.—Anterior petal extending almost to anterior margin; length 34.33 to 35.93 ($\bar{x}$=35.33) percent L (SD=2.65, CV=13.59, N=6); width 9.08 to 9.90 ($\bar{x}$=9.41) percent L (SD=0.66, CV=12.71, N=6); length of petals II, IV 25.92 to 30.08 ($\bar{x}$=27.91) percent L (SD=2.55, CV=16.51, N=6); width 8.92 to 9.92 ($\bar{x}$=9.45) percent L (SD=0.64, CV=12.34, N=6); length of petals V, I 36.33 to 39.40 ($\bar{x}$=37.63) percent L (SD=2.94, CV=14.16, N=6); width 8.46 to 9.76 ($\bar{x}$=9.36) percent L (SD=0.51, CV=9.69, N=5). Petals closing distally, poriferous zones equal, interporiferous zones slightly wider than single poriferous zone. Specimen 49.0 mm long with 102 porepairs in petal III, 84 in petal IV, 106 in petal V; specimen 56.9 mm long with 124 porepairs in petal III, 102 in IV, 136 in V.

PERISTOME.—Anterior of center, distance from anterior margin 34.49 to 36.13 ($\bar{x}$=35.14) percent L (SD=2.49, CV=12.66, N=7); elongated longitudinally, height 10.77 to 12.65 ($\bar{x}$=11.90) percent L (SD=0.54, CV=8.16, N=7); width 9.62 to 11.74 ($\bar{x}$=9.50) percent L (SD=1.03, CV=16.87, N=7). Bourrelets strongly developed. Phyllodes (Figure 10A) single pored, approximately 26 pores in each phyllode, 7 in inner series in occluded plates in specimen 50.4 mm long; same in specimen 63.7 mm long.

PERIPROCT.—Supramarginal, transverse with trough extending posteriorly. Enclosed by interambulacral plates 8–12.

ADORAL SURFACE.—Small, irregularly arranged pits (Plate 7: figure 11) in midzone of interambulacrum V; two-thirds of length of ambulacrum III extending from extremity of phyllode; first and second plates of interambulacra 2, 3 and in

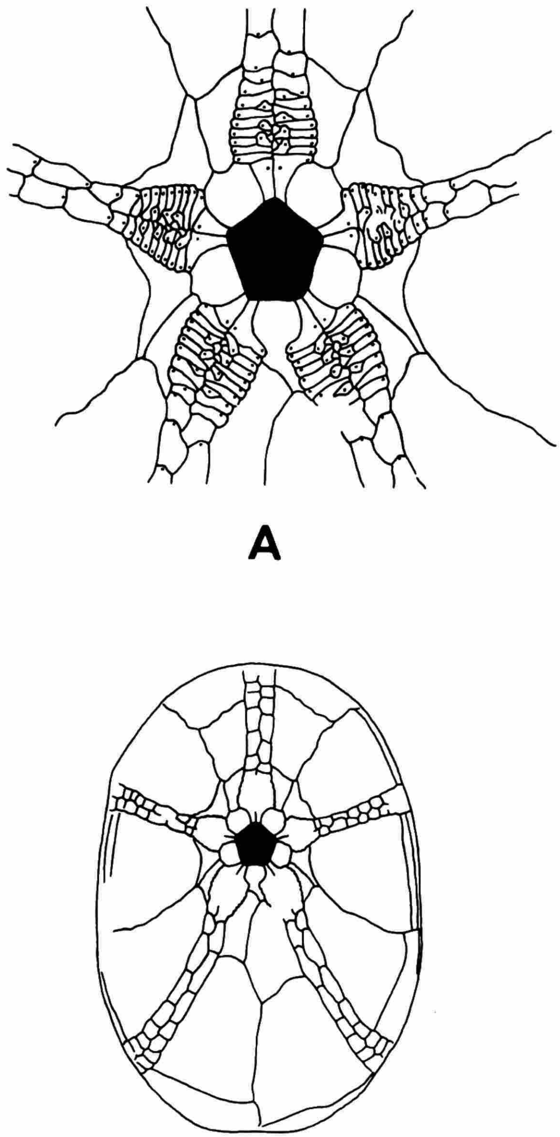


FIGURE 10.—*Eurhodia rugosa* (Ravenel) *depressa*, new subspecies: A, floscelle of USNM 264590 from Castle Hayne Limestone at locality 10, × 3; B, adoral plate arrangement of USNM 264591 from Castle Hayne Limestone, locality 10, × 1.

plate 3 adjoining ambulacrum III; a few pits in plates 1 and 2 in interambulacra 4, 1. Plate arrangement on Figure 10B.

TYPE-SPECIMENS.—Holotype USNM 264047; figured specimens USNM 264590, 264591.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (East Coast Construction Company quarry) localities 10, 34 ("middle zone").

REMARKS.—This subspecies differs from *E. rugosa rugosa* found in the Santee Limestone of South Carolina and *E. rugosa ideali* found elsewhere in the Castle Hayne Limestone of North Carolina in having a lower test (Figure 7A). The pits on the adoral side of its test are similar in size to those in *E. rugosa ideali* and smaller than those in *E. rugosa rugosa*. In all other characters, specimens of this subspecies are similar to the other subspecies, including the width of the test, length and width of the petals, position of the apical system, and position, height, and width of the peristome.

Eurhodia holmesi (Twitchell)

FIGURES 11–13; PLATE 8: FIGURES 1–7

Cassidulus (*Rhynchopygus*?) *holmesi* Twitchell, in Clark and Twitchell, 1915:140, pl. 65: figs. 3a-d.
Rhyncholampas holmesi (Twitchell).—Lambert and Thiéry, 1909–1925:370.
Eurhodia holmesi (Twitchell).—Cooke, 1942:36.
Eurhodia (*Gisopygus*) *holmesi* (Twitchell).—Cooke, 1959:65.
Cassidulus (*Pygorhynchus*) *carolinensis* var. *cravenensis* Kellum, 1926:15, pl. 1: figs. 1–3.—Cooke, 1942:36; 1959:65, pl. 23: figs. 1–5.

MATERIAL.—Description based on 99 well-preserved specimens from Georgetown (locality 37). Measurements taken from 36 specimens.

SHAPE AND SIZE.—Length 8.7 to 21.8 mm ($\bar{x}$=14.89 mm), width 79.6 to 90.3 ($\bar{x}$=85.47) percent L (SD=2.19, CV=17.19, N=36), greatest width and height posterior to center, height very variable from 55.1 to 71.8 percent L ($\bar{x}$=62.82) percent L (SD=1.51, CV=16.13, N=36). Trough extending downward from periproct; test depressed around peristome.

APICAL SYSTEM.—Located at distance from anterior margin 51.2 to 60.8 ($\bar{x}$=56.59) percent L (SD=1.27, CV=15.31, N=35); monobasal with four genital pores, pores present on smallest specimen.

AMBULACRA.—Petals with interporiferous zones wider than single poriferous zone. Length of petal III 21.7 to 37.9 ($\bar{x}$=31.17) percent L (SD=1.06, CV=22.73, N=35), petal II or IV 28.0 to 41.6 ($\bar{x}$=33.06) percent L (SD=0.95, CV=19.28, N=36), petal V or I 35.8 to 44.5 ($\bar{x}$=39.66) percent L (SD=1.22, CV=20.63, N=36); poriferous zones narrow, equal. Specimen 10.6 mm long with 24 porepairs in petal III, 26 in II, 28 in V; specimen 16.9 mm long with 28 in III, 32 in II, 38 in V; specimen 21.8 mm long with 44 in III, 46 in II, 52 in I. Pores conjugate. Ambulacral plates single pored beyond petals.

Phyllodes widening slightly, with 14 pores in outer series in single phyllode, 6 in inner in specimen 15.3 mm long; 16 in outer series, 6 in inner in specimen 21.8 mm long; 5–6 sphaeridia in ambulacrum in specimen 15.3 mm long, 8 in specimen 21.8 mm long.

PERISTOME.—Located from anterior margin at distance 36.4 to 44.7 ($\bar{x}$=38.8) percent L (SD=1.09, CV=18.82, N=36). Height greater than width, height 12.2 to 17.8 ($\bar{x}$=14.96) percent L (SD=0.48, CV=21.60, N=36), width 8.1 to 12.9 ($\bar{x}$=10.91) percent L (SD=0.36, CV=21.96, N=36). Opening vertical sided with well-developed bourrelets.

PERIPROCT.—Located on posterior truncation, width 13.5 to 21.7 ($\bar{x}$=17.21) percent L (SD=0.54, CV=21.17, N=36); enclosed within interambulacral plates 7 and 8.

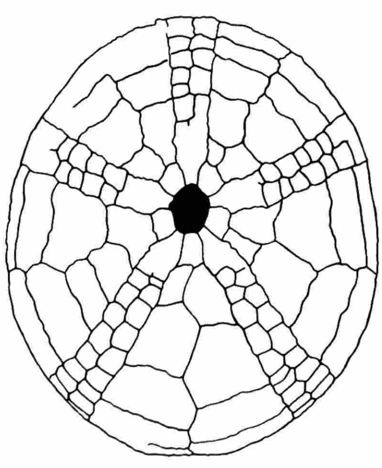


FIGURE 11.—*Eurhodia holmesi* (Twitchell), adoral plate arrangement of USNM 264592 from Santee Limestone, locality 37, × 4.

ADORAL SURFACE.—Small, irregularly arranged pits (Plate 8: figure 7) in midzone of interambulacrum 5 and in ambulacrum III at extremity of and alongside phyllode. Plate arrangement on Figure 11.

TYPE-SPECIMENS.—Holotype American Museum of Natural History 9868; figured specimens USNM 562303, 264048, 264049, 264592. Holotype *Cassidulus (Pygorhynchus) carolinensis* var. *cravenensis* Kellum USNM 353256.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: localities 6, 23–25. Santee Limestone, South Carolina: Georgetown localities 37, 45, 50, 51 ("middle zone").

REMARKS.—Cooke (1942:36; 1959:65) considered *Cassidulus carolinensis* Twitchell var. *cravenensis* Kellum from the Castle Hayne Limestone a subjective synonym of *E. holmesi.* Although the Castle Hayne specimens are slightly more angular than the Santee Limestone specimens and have slightly larger peristomes (Plate 8: figures 8–11) and wider periprocts in the smaller specimens, they are similar in all other characters. A comparison of the measurements of 31 Castle Hayne specimens and their coordinates on scattergrams shows no difference (Figures 12, 13) in the length relative to the width, height, distance of apical system and peristome from anterior margin, width and length of petals, and number of porepairs in petal III. The greater angularity of the Castle Hayne specimen reflects probably only the fact that the specimens are generally larger. Angularity in the marginal outline of an echinoid test is greater in large specimens.

Genus *Santeelampas* Cooke

Santeelampas oviformis (Conrad)

PLATE 9: FIGURES 1–8

Catopygus oviformis Conrad, 1850:39, pl. 1: fig. 15.—Clark, 1891:76; 1893:52, 64, pl. 27: figs. 2a-f.—Clark, in Clark and Twitchell, 1915:72, pl. 29: figs. 2a-f.
Nucleolites oviformis (Conrad).—Conrad, in Cook, 1868:722.
Phyllobrissus oviformis (Conrad).—Lambert, 1916:169.—Lambert and Thiéry, 1909–1925:351.
Cassidulus ?oviformis (Conrad).—Cooke, 1942:34.
Santeelampas oviformis (Conrad).—Cooke, 1959:61, pl. 26: figs.

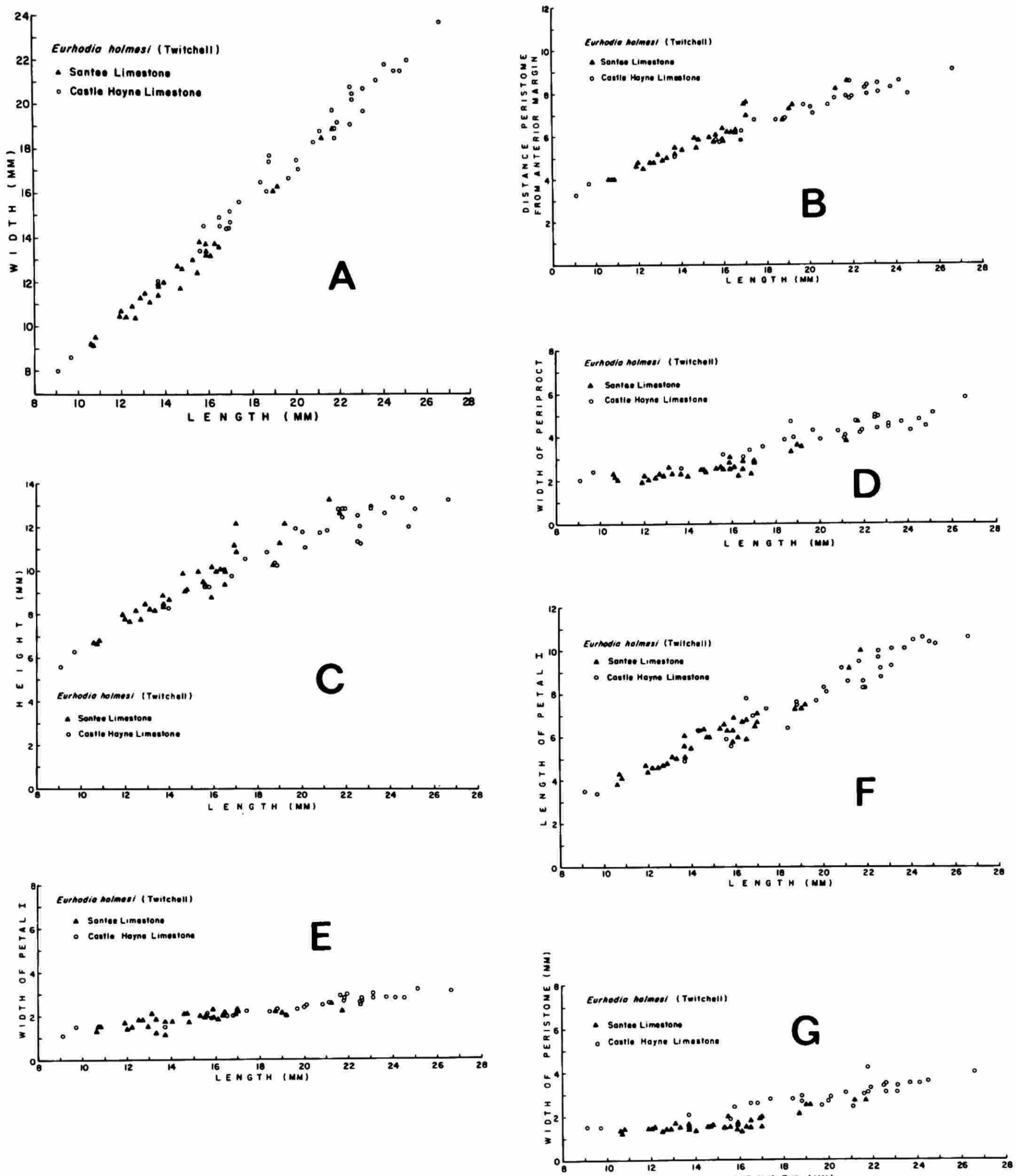


FIGURE 12.—*Eurhodia holmesi* (Twitchell): A, scattergram showing lack of difference in width between Santee Limestone and Castle Hayne Limestone specimens; B, scattergram showing lack of difference in position of peristome between Santee Limestone and Castle Hayne Limestone specimens; C, scattergram showing lack of difference in height between Santee Limestone and Castle Hayne Limestone specimens; D, scattergram showing lack of difference in width of periproct between Santee Limestone and Castle Hayne Limestone specimens; E, scattergram showing lack of difference in width of petal I between Santee Limestone and Castle Hayne Limestone specimens; F, scattergram showing lack of difference in length of petal I between Santee Limestone and Castle Hayne Limestone specimens; G, scattergram showing lack of difference in width of peristome between Santee Limestone and Castle Hayne Limestone specimens.

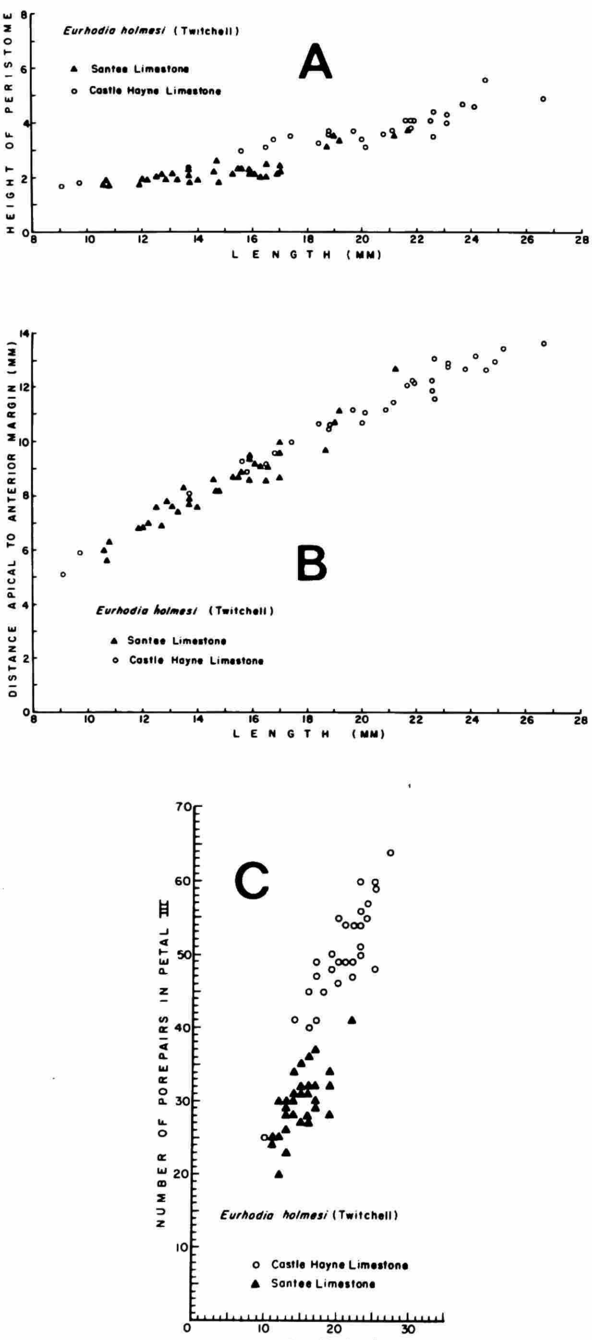


FIGURE 13.—*Eurhodia holmesi* (Twitchell): A, scattergram showing lack of difference in height of peristome between Santee Limestone and Castle Hayne Limestone specimens; B, scattergram showing lack of difference in position of apical system between Santee Limestone and Castle Hayne Limestone specimens; C, scattergram showing lack of difference (relative to size) in number of porepairs in petal III between Santee Limestone and Castle Hayne Limestone specimens.

1–8.—Kier, 1962:203, fig. 168, pl. 38: figs. 7–10.—Banks, 1978:143.

Breynella gregoryi Twitchell, in Clark and Twitchell, 1915:148, pl. 68: figs. 1a-f.—Cooke, 1959:61.

Echinanthus gregoryi (Twitchell).—Lambert and Thiéry, 1909–1925:367.

Cassidulus (*Paralampas*?) *gregoryi* (Twitchell).—Cooke, 1942: 34.

MATERIAL.—Description based on 30 specimens from Rose Hill (locality 11).

SHAPE AND SIZE.—Length 13.8 to 40.4 mm ($\bar{x}$=29.25 mm), width 83.75 percent L (SD=5.10, CV=20.83, N=30), greatest width and height posterior to center, height 52.8 percent L (SD=2.75, CV=17.96, N=30); posterior truncation sloping slightly so that portion of periproct visible from above.

APICAL SYSTEM.—Located at distance from anterior margin equal to 45.3 percent L (SD=2.78, CV=20.95, N=30); monobasal with four genital pores.

AMBULACRA.—Petals with interporiferous zones less than twice width of single poriferous zone. Length of petal III 33.26 percent L (SD=2.53, CV=25.67, N=29) extending to anterior margin; petal II or IV 33.1 percent L (SD=2.38, CV=24.39, N=30), petal V or I 41.5 percent L (SD=2.98, CV=24.39, N=30); greatest width of petal III 10.8 percent L (SD=0.70, CV=22.19, N=29), II or IV 10.9 percent L (SD=0.71, CV=22.17, N=30), V or I 10.5 percent L (SD=0.70, CV=22.76, N=30). Length of poriferous zones equal in same petal.

Phyllodes widening slightly, with 14 pores in outer series, 6 in inner. Number of sphaeridia not clear but apparently only two.

In specimen 13.8 mm long 32 porepairs in petal III, 32 in II, 46 in I; specimen 39 mm long 74 porepairs in petal III, 74 in II, 84 in I.

PERISTOME.—Located from anterior margin at distance 35.1 percent L (SD=2.14, CV=20.85, N=30). Width greater than height, width 15.4 percent L (SD=0.94, CV=20.95, N=30); height

12.1 percent L (SD=0.75, CV=21.29, N=30). Bourrelets well developed.

PERIPROCT.—Located slightly above middle of posterior, slightly visible from above, height greater than width, height 14.1 percent L (SD=0.79, CV=19.23, N=29). Located in plates 7–9 in most specimens but in 8–10 or 9–11 in several.

TYPE-SPECIMENS.—Holotype Academy of Natural Sciences Philadelphia 1477; figured specimens USNM 264050, 264051.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: locality 8, Rose Hill localities 11, 35. Warley Hill Formation, South Carolina: localities 38, 43, 45, 47, 49 (may be Santee Limestone) ("early zone").

Family CASSIDULIDAE L. Agassiz and Desor

Genus *Rhyncholampas* A. Agassiz

Rhyncholampas carolinensis (Twitchell)

PLATE 9: FIGURES 9–12; PLATE 10: FIGURES 1–4

Cassidulus (Pygorhynchus) carolinensis Twitchell, in Clark and Twitchell, 1915:146, pl. 67: figs. 2a-g.—Lambert and Thiéry, 1909–1925:370.

Cassidulus (Paralampas) carolinensis Twitchell.—Cooke, 1942: 34.

Cassidulus conradi carolinensis Twitchell.—Cooke, 1959:60, pl. 25: figs. 7–10.

MATERIAL.—Over 60 specimens. This description is based on specimens from Maple Hill (East Coast Construction Company) locality 10. Measurements taken of 24 specimens.

SHAPE AND SIZE.—Length 17.3 to 49.0 mm ($\bar{x}$=37.93 mm), width 85.6 percent L (SD=5.35, CV=16.55, N=23), greatest width posterior to center, greatest height at center, 49.2 percent L (SD=2.94, CV=15.93, N=22); posterior truncation sloping so that periproct slightly visible from above; test depressed around peristome.

APICAL SYSTEM.—Located at distance from anterior margin equal to 50.3 percent L (SD=3.93, CV=20.61, N=18); monobasal with four genital pores.

AMBULACRA.—Petals with interporiferous zones almost twice width of single poriferous zones. Length of petal III 36.3 percent L (SD=3.06, CV=21.97, N=16), petal II or IV 38.6 percent L (SD=3.12, CV=21.38, N=18) petal V or I 46.4 percent L (SD=3.78, CV=21.51, N=18); greatest width of petal III 11.9 percent L (SD=0.92, CV=20.40, N=18), petal II or IV 12.8 percent L (SD=1.06, CV=21.90, N=19), petal V or I 12.6 percent L (SD=0.93, CV=19.66, N=19). Length of poriferous zones unequal in same petal with 1–5 more porepairs in right poriferous zones of petal III, 3–6 more in posterior zone of petals II or IV, 5–9 more in anterior zone of petals V or I. Ambulacral plates single pored beyond petals.

Phyllodes widening slightly, with 14 pores in outer series in single phyllode, 7–8 in inner in specimen 39 mm long; 4–6 sphaeridia in each ambulacrum.

In specimen 26 mm long 55 porepairs in petal III, 59 in II, 76 in I; specimen 42 mm long 74 porepairs in petal III, 76 in II, 92 in I.

PERISTOME.—Located from anterior margin at distance 35.5 percent L (SD=2.33, CV=17.29, N=21). Width greater than height, width 16.0 percent L (SD=1.08, CV=17.71, N=21); height 11.9 percent L (SD=0.77, CV=16.86, N=21). Bourrelets well developed.

PERIPROCT.—Located on posterior truncation, elongated longitudinally, width 17.6 percent L (SD=1.27, CV=19.06, N=21). Located in plates 7–9 in interambulacrum 5.

TYPE-SPECIMENS.—Holotype USNM 599488; figured specimen USNM 264052.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: localities 3, 7, Maple Hill (East Coast Construction Company) localities 10, 16, 17, 22, 28, 31, 34 ("middle and late zones").

Cooke (1942:34) reports this species not only from the Castle Hayne of North Carolina but also from a quarry in Florida. On the basis of this citation, both Fischer (1951:53) and Toulmin (1977:360) record it from Jacksonian beds. Later, Cooke (1959:60) cites only North Carolinian localities in the Castle Hayne Limestone. I have found no specimens of this species from Florida in the National collections.

COMPARISON WITH OTHER SPECIES.—*Rhyncho-*

lampas carolinensis is easily distinguished from *Eurhodia baumi*, new species, which occurs with it at Rose Hill (locality 11), by its longitudinally elongate periproct.

Family FIBULARIIDAE Gray

Genus *Echinocyamus* van Phelsum

Echinocyamus parvus Emmons

PLATE 10: FIGURES 5–10

Echinocyamus parvus Emmons 1858:307, fig. 244.—Clark and Twitchell, 1915:119.—Kellum, 1926:14.—Cooke, 1942: 28, pl. 1: figs. 6–8; 1959:31, pl. 9: figs. 9–11.—Kier, 1966: figs. 10, 11, 13B.—Toulmin, 1977:360.

MATERIAL.—Description based on 67 specimens (dimension from specimens over 2.5 mm long except where indicated) from Maple Hill (Lanier pit) locality 9. Measurements based on 24 specimens.

SHAPE AND SIZE.—Length 1.3 to 4.6 mm, $\bar{x}$=3.56 mm, width 71.83 percent L (SD=0.53, CV=20.86, N=24) with greatest width posterior to center. Height 37.68 percent L (SD=0.29, CV=21.27, N=24) with greatest height at apical system in most specimens, posterior in some. Anterior margin pointed, posterior more rounded.

APICAL SYSTEM.—Located slightly anterior of center; four genital pores, not present on any specimens less than 2.5 mm in length; pores very large (Plate 10: figure 6) in some specimens, minute in others (Plate 10: figure 5) suggesting sexual dimorphism.

AMBULACRA.—Petal III slightly longer than other petals with 0–4 more porepairs than petals II or IV (average 2) and petals V and I (average 1); no porepairs present in specimens less than 2.0 mm long, specimen 2.02 mm long with two porepairs in each petal; specimens 2.8 mm long with 7 porepairs in petal III, 5 in petal IV, 6 in V; specimen 4.08 mm long with 10 in petal III, 8 in IV, 9 in V; rate of introduction of new porepairs decreasing with growth.

PERISTOME.—Posterior to center, anterior margin of opening located at distance from apical system equal to 42.52 percent L (SD=35.35, CV=23.18, N=24), diameter of opening 23.27 percent L (SD=0.08, CV=10.21, N=23).

PERIPROCT.—On adults opening inframarginal, located approximately two-thirds distance from peristome to posterior margin; on small specimen less than 2 mm long periproct marginal to slightly visible from above; opening circular and large with diameter 10.28 percent L (SD=0.06, CV=15.98, N=24).

TYPE-SPECIMEN.—Holotype lost according to Cooke (1959:31); figured specimens USNM 499002, 264053, 264054, 264055.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (Lanier pit) locality 9, Ideal Cement Company quarry localities 12, 14, 15 ("late zone").

Echinocyamus bisexus Kier

PLATE 10: FIGURE 11

Echinocyamus bisexus Kier, 1968:12, figs. 11–23, pl. 3: figs. 1–6, pl. 4: figs. 1, 2.

DISCUSSION.—Thirteen specimens were found of this species while searching with a microscope through screened sediment from Maple Hill (Lanier pit) locality 9. All are very small females 1.3 to 1.9 mm long. Only in the largest specimen are any porepairs present. These specimens are easily distinguished from the other small echinoids that occur in this sediment by their large, widely separated genital pores. I found no males, but they are indistinguishable from immature specimens of *Echinocyamus parvus* that occurs in this sediment. In spite of an extensive search, no adults were found of either male or female specimens of *E. bisexus*. If present, they would have been easily distinguished from adults of *E. parvus*: the female adults by their large, widely separated genital pores and the males by their narrower tests and longer petals made up of more porepairs (note: in Kier 1968: figure 17 the vertical axis of the scattergram should read "number of porepairs in a single poriferous zone in petals III and V").

This species is previously known from the middle Eocene Lake City Formation of Georgia.

TYPE-SPECIMENS.—Holotype USNM 650722;

figured paratypes USNM 650720 through 650723, 650745 through 650748; figured specimen USNM 264056.

OCCURRENCES.—Middle Eocene Lake City Formation, Georgia: USGS locality 34 H 337, test well number 5, near Brunswick, Glynn County. Castle Hayne Limestone, North Carolina: Maple Hill (Lanier pit) locality 9 ("late zone").

Family PROTOSCUTELLIDAE Durham

Genus *Protoscutella* Stefanini

Protoscutella conradi (Cotteau)

FIGURES 14, 15; PLATE 11: FIGURES 1-5

Sismondia conradi Cotteau, 1889-1894:300 [for a complete synonymy see Cooke (1959:39, 40)].
Protoscutella conradi (Cotteau).—Banks, 1978:99, 101, 122, 143.

MATERIAL.—This description is based on 49 specimens from Georgetown (locality 37).

SHAPE AND SIZE.—Length 7.0 to 72.0 mm long, $\bar{x}$=22.07 mm; width 94.66 percent L (SD=11.97, CV=56.45, N=48), smaller specimens more elongate, greatest width posterior to center; height 17.76 percent L (SD=1.19, CV=36.05, N=32). Margin thin, sharp with three indentations at posterior margin where posterior ambulacra and interambulacrum cross margin; indentations not present in smaller specimens. Adoral surface flat.

APICAL SYSTEM.—Slightly anterior of center, distance from anterior 47.31 percent L (SD=6.51, CV=62.08, N=35). Five genital pores, not present on specimen smaller than 9 mm in length.

AMBULACRA.—Petals extending 50-60 percent distances from apical system to margin; petals of approximately same length; length of petal III 26.22 percent L (SD=3.44, CV=61.91, N=31), petal II 25.29 percent L (SD=3.30, CV=61.87, N=31), petal I 26.83 percent L (SD=3.33, CV=58.61, N=32); width of petal III 12.68 percent L (SD=1.17, CV=45.35, N=30), petal II 12.51 percent L (SD=1.26, CV=49.09, N=32), petal I 12.54 percent L (SD=1.26, CV=48.88, N=32). Petals closing slightly with both poriferous and interporiferous zones narrowing distally. Interporiferous zones at greatest width slightly narrower, equal to, or slightly wider than single poriferous zone. All petals of same specimen with approximately same number of porepairs, specimen 7 mm long with 26 porepairs in petal III, specimen 19.6 mm long with 56, 27.0 mm long with 66, 44.3 mm long with 102, 72.0 mm with 150.

PERISTOME.—Slightly anterior of center, distance from anterior margin 44.28 percent L (SD=5.55, CV=54.35, N=46); circular, diameter 9.75 percent L (SD=0.41, CV=21.31, N=45), sides of opening vertical.

PERIPROCT.—Inframarginal, near posterior margin at distance from posterior margin 4.86 percent L (SD=1.07, CV=95.68, N=47). Situated between plates 2-3 in some specimens, 3-4 in most.

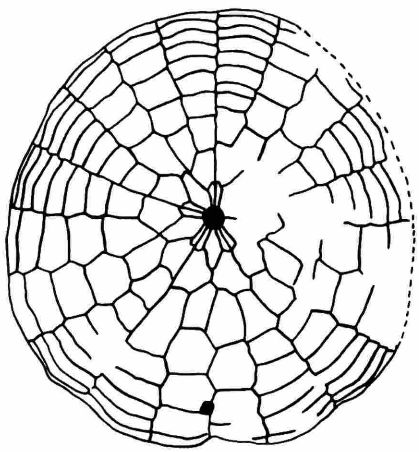
ADORAL PLATE ARRANGEMENT.—Basicoronal plates star-shaped with interambulacral plates much larger than ambulacral, almost twice as long (Figure 14A). Basicoronal interambulacral plates in contact with succeeding paired plates except in interambulacrum 5 in which basicoronal plate separated from rest of interambulacrum by pair of ambulacral plates (Figure 14A) in some specimens but not in others (Figure 14B). Eleven to twelve interambulacral plates in each column on adoral side of test; 18-19 in each ambulacrum.

FOOD GROOVES.—Appear to be simple, nonbifurcating.

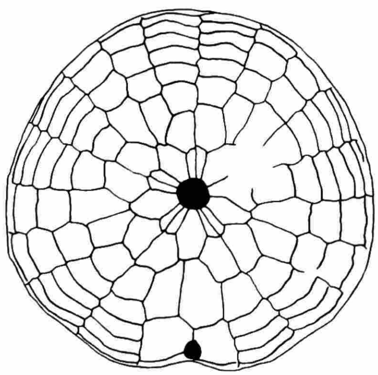
TYPE-SPECIMENS.—Holotype Academy of Natural Sciences Philadelphia 1081; figured specimens USNM 264057, 264058, 264059, 264593, 264594.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: locality 8, Rose Hill (locality 11), localities 23, 24, 33. Santee Limestone, South Carolina: Georgetown localities 37, 40, 42, 45, 47 ("early and middle zones"). At Rose Hill (locality 11) *P. conradi* was collected from beds 6.8 m above the base of the Castle Hayne Limestone to the top of the quarry. *Protoscutella mississippiensis rosehillensis* occurs below it in beds 2.5 m to 6.3 m above the base.

REMARKS.—The posterior interambulacrum is



A



B

FIGURE 14.—*Protoscutella conradi* (Cotteau): A, adoral plate arrangement of USNM 264593 from the Santee Limestone at locality 37, × 2; B, adoral plate arrangement of USNM 264594 from the Santee Limestone at locality 37 (note that basicoronal plate is in contact with the rest of interambulacrum; whereas, it is separated in specimen figured in Figure 14A, × 3).

not consistently separated by ambulacral plates from the basicoronal plate. Among the 32 specimens from Georgetown in which the plate sutures are visible, 4 of them (Figure 14A) have the basicoronal plate separated (*interrupted*), in 7 of them it is intermediate with one of the interambulacral plates not in contact with the basicoronal plates, and in 17 (Figure 14B) of the specimens both are in contact (*continuous*). In the collection from Rose Hill, 12 of the specimens have the posterior interambulacrum continuous and 18 interrupted. Likewise, among four specimens of *Protoscutella plana* (Conrad) from Maple Hill (East Coast Construction Company), three of them have a continuous posterior interambulacrum; the fourth is interrupted. Finally, I have found specimens of the type-species; *P. mississippiensis* (Twitchell), in which the posterior interambulacrum is continuous. Therefore, an interrupted posterior interambulacrum cannot be considered a generic character of *Protoscutella.*

COMPARISON WITH OTHER SPECIES.—This species is very similar to *P. plana* from the Santee and Castle Hayne Limestones. It differs in having a thinner margin, more developed indentations at the posterior margin, and in having its periproct nearer the posterior margin. They are similar in their width of test (Figure 15A) and number of porepairs in their petals (Figure 15B). These two species are so similar that they must have been closely related. The earliest occurrence of *P. conradi* in beds older than *P. plana* suggests that it is probably ancestral to *P. plana.*

P. conradi is very similar to *Protoscutella tuomeyi* (Twitchell) from the middle Eocene, Warley Hill Formation of South Carolina. It is similar to it in its length relative to width, marginal outline, and number of porepairs in the petals (Figure 15B). Although its periproct is slightly nearer to the posterior margin than in *P. tuomeyi* (Figure 15C), the two species are probably synonymous. Until more specimens from the type-locality have been found, it is not possible to be certain.

The holotype of *P. tuomeyi* is from the Warley Hill Marl at Cave Hall, Calhoun County, South Carolina, but the species does not occur in the Marl at Wilson's Landing (locality 38) where *P. mississippiensis* is present. In North Carolina *P. mississippiensis* occurs below *P. conradi*. It is, therefore, likely that the portion of the Warley Hill Marl exposed at Cave Hall is younger than the Marl at Wilson's Landing.

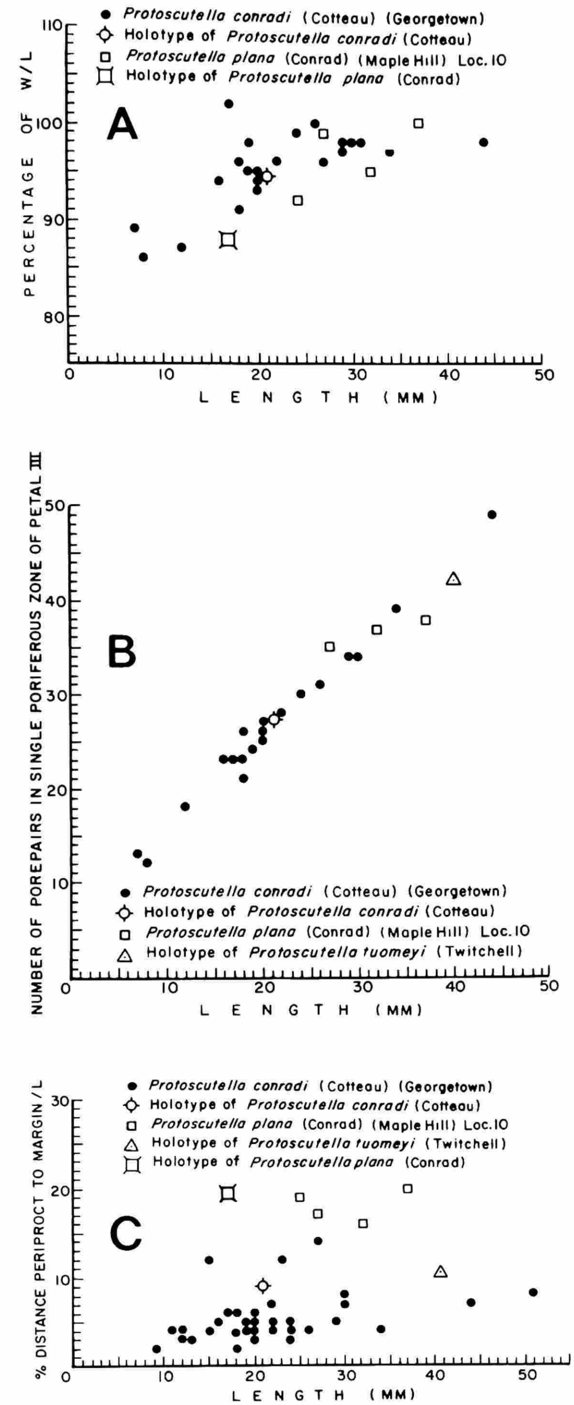


FIGURE 15.—*Protoscutella conradi* (Cotteau) and *Protoscutella plana* (Conrad): A, scattergram showing similarity of width of specimens; B, scattergram showing similarity in number of porepairs in petal III in *P. conradi* (Cotteau), *P. plana* (Conrad), and *P. tuomeyi* (Twitchell); C, scattergram showing differences in position of periproct in *P. conradi* (Cotteau), *P. plana* (Conrad), and *P. tuomeyi* (Twitchell).

P. conradi is distinguished from *Protoscutella mississippiensis* (Twitchell) *rosehillensis*, new subspecies, which occurs below it at Rose Hill, by its periproct, which is inframarginal rather than marginal, and which is situated between coronal plates 2–3 or 3–4 rather than 5–12 as in *Protoscutella mississippiensis* (Twitchell) *rosehillensis*, new subspecies.

***Protoscutella plana* (Conrad)**

FIGURE 15; PLATE 11: FIGURES 6, 7

Sismondia plana Conrad, 1865:75. [For a complete synonymy see Cooke (1959:40).]

MATERIAL.—Four specimens.

SHAPE AND SIZE.—Length 24.4 to 37.0 mm long, $\bar{x}$=30.2 mm; average width 95.6 percent L, smallest specimen more elongate than longer, with width 92.2 percent L in specimen 24.4 mm long as opposed to 95.4 percent L in largest 37.0 mm long; greatest width posterior to center or central; height 18.4 to 19.1 percent L. Margin thick with posterior margin smooth or with very slight indentations at posterior interambulacra or interambulacrum; adoral surface flat.

APICAL SYSTEM.—Slightly anterior of center, distance from anterior margin 51.4 to 49.3 percent L. Five genital pores.

AMBULACRA.—Petals extending 59.1 to 64.2 percent distances from apical system to margin; petals of approximately same length; length of petal III 31.9 to 30.1 percent L; petal II 27.6 to 29.0 percent L, petal I 28.6 to 30.5 percent L; width of petal III 11.4 to 14.7 percent L, petal II 11.6 to 14.3 percent L, petal I 11.6 to 14.3 percent L. Petals closing distally with both poriferous and interporiferous zones narrowing distally; interporiferous zones at greatest width slightly narrower, equal to, or slightly wider than single poriferous zone. All petals of same specimen with approximately same number of porepairs specimen 27.2 mm long with 68 porepairs in petal III, 66 in petal II, 70 in petal I.

PERISTOME.—Slightly anterior of center, distance from anterior margin 46.3 to 47.8 percent L; circular, diameter 6.5 to 8.1 percent L, sides of opening vertical.

PERIPROCT.—Inframarginal, located approximately two-fifths distance from posterior margin to peristome; distance from margin 15.8 to 19.5 percent L. Situated between coronal interambulacral plates 1a, 2a, and 2b.

ADORAL PLATE ARRANGEMENT.—Basicoronal plates star-shaped with interambulacral plates much larger than ambulacral, almost twice as long. Basicoronal interambulacral plates in contact with succeeding paired plates except in interambulacrum 5 in which basicoronal plate separated from rest of interambulacrum by pair of ambulacrum plates in one specimen, in other three specimens plates not interrupted. Eleven to twelve interambulacral plates in each column on adoral side of test; 16–18 in each ambulacrum.

FOOD-GROOVES.—Not visible, specimens too weathered.

TYPE-SPECIMENS.—Holotype Academy of Natural Sciences Philadelphia 1080; figured specimens USNM 562275, 264060, 264070.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (East Coast Construction Company quarry) localities 10, 34. Santee Limestone, South Carolina: localities 46, 48, near Charleston (Holotype) ("middle zone").

COMPARISON WITH OTHER SPECIES.—This species is very similar to *Protoscutella conradi* (Cotteau) also from the Santee and the Castle Hayne Limestones. The two species have tests with similar width (Figure 15A) and number of porepairs in their petals (Figure 15B). *P. plana* differs in having a thicker margin, less developed indentations at the posterior margin, and in having its periproct more distant from the posterior margin. As can be seen in the scattergram (Figure 15C), a few specimens of *P. conradi* have their periproct nearly as far distant from the margin as in *P. plana* but in most the periproct is much nearer the margin. Cooke (1959:40) considered *P. plana* to have a more elongate test. The holotype is a smaller specimen and the test is more elongate in the smaller specimens of both species. These species are alike in all other characters and must have been closely related. The earliest occurrence of *P. plana* is in beds younger than the earliest occurrence of *P. conradi* suggesting that it is descended from *P. conradi*.

P. plana is also very similar to small specimens of *Periarchus lyelli*. The periproct in *P. plana* is less anterior and is situated between the first and second pair of coronal plates; whereas, in *Periarchus lyelli* the periproct is within the first coronal plate in almost all specimens. The test of *P plana* is more blunted posteriorly and has less marked posterior indentations. However, all these differences are slight; and it is difficult to distinguish some specimens of these two species. *Protoscutella* is known from older beds than *Periarchus* and presumably is ancestral to *Periarchus*.

Protoscutella mississippiensis mississippiensis (Twitchell)

Scutella mississippiensis Twitchell, 1915:124, pl. 59: figs. 1a-f. [For a complete synonymy and list of localities, see Cooke (1959:38,39).]

Protoscutella mississippiensis (Twitchell).—Toulmin, 1969:472; 1977:306, pl. 51: figs. 1, 2.

DISCUSSION.—This subspecies is known from the middle Eocene Winona Sand in Mississippi, Mount Selman Formation in Texas, and basal Lisbon Formation. Cooke (1959:39) noted that specimens from the top of the Tallahatta Formation in Alabama had their periprocts above the margin. These specimens may represent a separate subspecies.

Protoscutella mississippiensis rosehillensis, new subspecies

FIGURE 16; PLATE 12: FIGURES 1–5

DIAGNOSIS.—Subspecies characterized by narrower test, thicker margin, and periproct which on the smaller specimens is situated above the margin.

MATERIAL.—Description based on 33 specimens from Rose Hill (locality 11).

SHAPE AND SIZE.—Length from 17.0 to 44.2 mm, $\bar{x}$=34.99 mm, (SD=6.97, CV=19.97, N=33); width 100.4 percent L (SD=7.22, CV=20.53, N=33), greatest width posterior to center; adapical surface gently inflated around apical system, height 16.85 percent L (SD=0.98, CV=17.18, N=28). Margin with two slight indentations at posterior margin where posterior ambulacra cross margin. Adoral surface flat, slightly concave.

APICAL SYSTEM.—Slightly anterior of center, distance from anterior 49.2 percent L (SD=3.74, CV=21.83, N=30). Five genital pores, present on next to smallest specimen 23.2 mm.

AMBULACRA.—Petals extending 50–60 percent distance from apical system to margin; petals approximately of same length; length of petal III 28.21 percent L (SD=2.21, CV=22.58, N=28), petal II 27.57 percent L (SD=2.16, CV=22.61, N=28), petal I 28.23 percent L (SD=2.02, CV=20.68, N=29); width of petal III 12.03 percent L (SD=0.81, CV=19.67, N=29), petal II 11.50 percent L (SD=0.75, CV=19.21, N=29), petal I 11.15 percent L (SD=0.79, CV=20.62, N=30). Petals closing slightly with both poriferous and interporiferous zones narrowing distally. Interporiferous zones slightly wider than single poriferous zone; width of interporiferous zone of petal III 4.8 percent L (SD=0.31, CV=18.80, N=30). Specimen 23.2 mm long, with 64 porepairs in petal III, 68 in II, 66 in I; specimen 42.7 mm long with 92 porepairs in petal III, 96 in II, 100 in I.

PERISTOME.—Slightly anterior of center, distance from anterior margin 46.46 percent L (SD=3.47, CV=21.03, N=29); circular, diameter 7.20 percent L (SD=0.38, CV=15.69, N=21), sides of opening vertical.

PERIPROCT.—Located on margin in slight indentation, opening small, wider than high. Situated between coronal plates 5-12 (± 1). On smaller specimens, 17–20 mm long, periproct located just above margin.

ADORAL PLATE ARRANGEMENT.—Basicoronal plates star-shaped with interambulacral plates much larger than ambulacral, almost twice as long (Figure 16). Basicoronal interambulacral plates in contact with succeeding paired coronal plates except in interambulacrum 5 in which basicoronal plates separated from succeeding by pair of ambulacral plates except in one specimen where it is continuous. Six to seven coronal interambulacral plates in each column on adoral side of test; 13–14 in each ambulacrum.

FOOD GROOVES.—Appear to be simple, nonbifurcating but most specimens too weathered to show grooves.

TYPE-SPECIMENS.—Holotype USNM 264062; figured paratypes USNM 264061, 264063; figured specimen USNM 264595.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Rose Hill locality 11 (in beds 2.5 to 6.3 m above base of Castle Hayne Limestone), locality 35 ("early zone").

REMARKS.—This subspecies differs from the holotype, figured paratype, and topotypes of *P. mississippiensis mississippiensis* in having a narrower

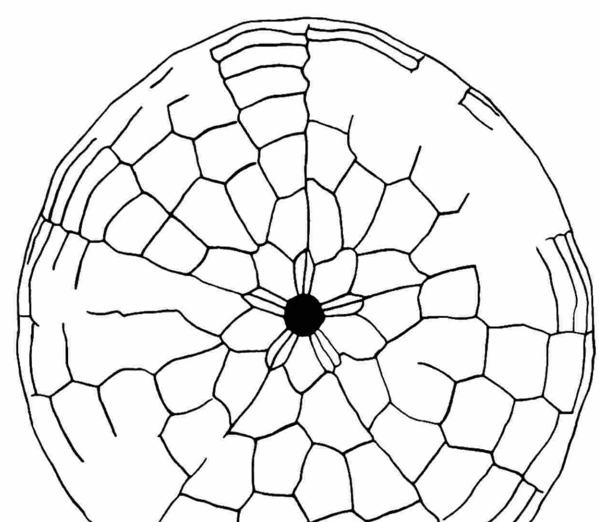


FIGURE 16.—*Protoscutella mississippiensis* (Twitchell) *rosehillensis*, new subspecies, adoral plate arrangement of figured paratype USNM 264595 from Castle Hayne Limestone at locality 11, × 2.

test, thicker margin, and the periproct on the smaller specimens above the margin. Although some of the specimens of *P. mississippiensis rosehillensis* are as wide as some of the narrower specimens of *P. mississippiensis mississippiensis*, the average width of the Rose Hill specimen is 100.4 percent L as opposed to 103.7 percent L in the Mississippian specimens. Although there is overlap in this character between the two populations, the Student t-test value of 4.50 with 68 degrees of freedom shows that the difference between the means is highly significant.

The specimens of *P. mississippiensis* from the Warley Hill Formation at Wilson's Landing (locality 38) and locality 43 in South Carolina appear to be intermediate between these two subspecies. The smaller specimens (Plate 12: figures 6, 7) are indistinguishable from *P. mississippiensis rosehillensis*, but one very large specimen has the wide test (width 115 percent L) of *P. mississippiensis mississippiensis* (approximately same width as the paratype, USNM 137655a figured in Clark and Twitchell, 1915:pl. 59: fig. 2). The three other large specimens from Wilson's Landing have an average width 107 percent L.

Genus *Periarchus* Conrad

Periarchus lyelli (Conrad)

FIGURES 17, 18; PLATE 13; PLATE 14: FIGURES 1–7

Scutella lyelli Conrad, 1834:152.

Periarchus rutriformis Paulson, 1958:362. [For a complete synonymy, see Cooke (1959:41, 42).]

Periarchus lyelli (Conrad).—Kier, 1968:40, pl. 5: figs. 4, 5.—Toulmin, 1969:474, pl. 4: figs. 5–7; 1977:344, pl. 68: figs. 4–6.—Banks, 1978:109, 146, 149.

MATERIAL.—Description based on over 100 specimens from the Ideal Cement Company quarry (locality 12). Dimensions from 31 specimens.

SHAPE AND SIZE.—Length from 16.6 to 79.2 mm, $\bar{x}$=42.12 mm, (SD=15.93, CV=37.83, N=31); width 95.32 percent L (SD=15.76, CV=39.11, N=31). Marginal outline with two indentations posteriorly where posterior ambulacra cross margin (Plate 14: figure 1); in larger specimens these indentations relatively smaller, and a third present where posterior interambulacrum crosses margin. Greatest width posterior to center, greatest height at apical system, height 17.61 percent L (SD=3.32, CV=43.34, N=30). Some specimens sharply convex at apical system, others gently domed. Adoral surface flat except where slightly depressed in food grooves. Margin thickest anteriorly where 8.20 percent L (SD=0.88, CV=26.66, N=31), thinning posteriorly where 5.39 percent L (SD=0.49, CV=22.67, N=31).

APICAL SYSTEM.—Slightly anterior of center, distance from anterior margin 47.69 percent L (SD=8.18, CV=40.47, N=31); madreporite pores covering whole apical system; five genital pores; no genital pores in specimens less than 25 mm long.

AMBULACRA.—Petals extending between 50–60 percent distance from apical system to margin; petals of approximately same length; length of petal III 27.58 percent L (SD=4.72, CV=40.22, N=31), length of petal II 24.94 percent L (SD=4.37, CV=41.07, N=31), length of petal I 25.36 percent L (SD=3.98, CV=37.81, N=29); petals of approximately same width: width of petal III 11.39 percent L (SD=1.54, CV=32.44, N=31), petal II 11.53 percent L (SD=1.65, CV=34.28, N=31), petal I 11.18 percent L (SD=1.63, CV=34.82, N=30). Petals closing slightly with both poriferous and interporiferous zones narrowing distally. Interporiferous zones slightly narrower than single poriferous zone, width of interporiferous zone of petal 4.78 percent L (SD=0.52, CV=26.92, N=31). Smallest specimen (16.6 mm long) with 20 porepairs in single poriferous zone of petal III, 21 porepairs in II, 22 porepairs in I; largest specimen (79.2 mm long) with 68 porepairs in III, 65 in II, 62 in I.

PERISTOME.—Anterior of center (Plate 14: figure 2) distance from anterior margin 44.16 percent L (SD=6.78, CV=35.29, N=28); circular to subpentagonal with apices in interambulacra; diameter 5.77 percent L (SD=0.54, CV=22.37, N=28); sides of opening vertical with buccal pores at top of opening.

PERIPROCT.—Located anterior of midpoint between peristome and posterior margin at distance from posterior margin 27.20 percent L (SD=5.12, CV=43.79, N=31). Opening circular to elongate longitudinally, small, width 3.37 percent L (SD=0.38, CV=27.65, N=30); located between first coronal plates and in few specimens in contact with one of second pair.

ADORAL PLATE ARRANGEMENT.—Basicoronal plates star-shaped with interambulacral plates much larger than ambulacral, over twice as long (Figure 17). Basicoronal interambulacral plates barely in contact with succeeding paired coronal plates. Six interambulacral plates in each column on adoral side of test; 9–10 in each ambulacrum.

FOOD GROOVES.—On smaller specimens less than 40 mm long, each food groove bifurcates only once at distance from peristome between one-half and two-thirds distance to ambitus (Figure 18A). Specimens longer than 60 mm may have 3 or 4 bifurcations (Figure 18B). Arrangement of food grooves is variable and their position is difficult to discern in many specimens.

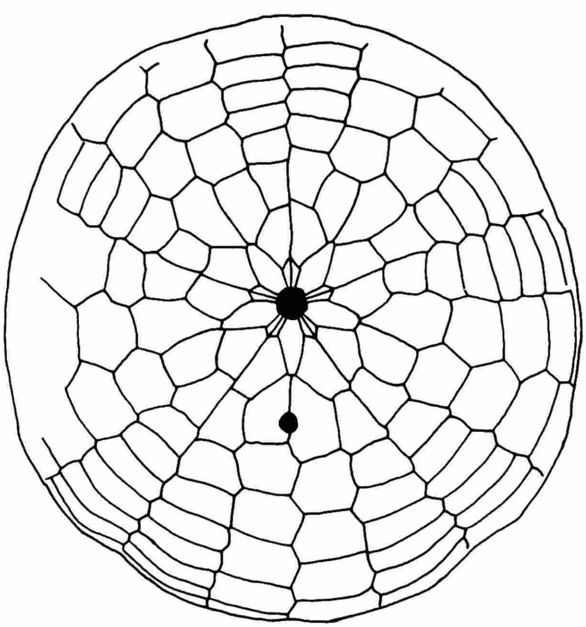


FIGURE 17.—*Periarchus lyelli* (Conrad), adoral plate arrangement in USNM 264596 from Castle Hayne Limestone at locality 12, × 2.

LANTERN SUPPORTS.—Each support composed of a single interambulacral plate as typical in a non-Clypeasterina clypeasteroid (Kier, 1970: figure I-M); supports rising from test at considerable distance from edge of peristome; each with ridge extending from peristome and extending to upper tip of support.

TYPE-SPECIMENS.—The type-specimen is lost. According to Cooke (1942:14), the type was probably at the Philadelphia Academy of Natural Sciences but later he (1959:42) considered its location unknown. One specimen (ANSP 51545) at the Academy is labelled provisionally as the holotype, but it is a poorly preserved specimen whose dimensions do not match Conrad's original description. Conrad (1834:153) states that his specimen is "nearly three inches" in diameter; whereas, the Academy specimen is more than 3.5 inches in diameter. After so many years of unsuccessful search, it now appears highly unlikely that the holotype of this species will ever be positively identified, particularly because the specimen has never been figured. Considering the stratigraphical importance of this species and its common occurrence and wide geographical distribution, it seems warranted to select a neotype. Clark and Twitchell (1915:pl. 61: figs. 2a-f) figured a specimen from the type-locality. This specimen is herein designated the neotype. It is now at the Museum of Comparative Zoology at Harvard (MCZ 3543) and is figured herein (Figure 18C, Plate 13: figures 1–3). Figured specimens are USNM 264066, 264067, 264068, 264069, 264596, 264597.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: localities 1–5, 7, Maple Hill (Lanier pit) locality 9, Maple Hill (East Coast Construction Company quarry) locality 10, Ideal Cement Company quarry locality 12, Comfort localities 13, 34, 36. Santee Limestone, South Carolina: localities 39, 44, 46. For localities outside North Carolina see Cooke (1959:42) ("middle and late zones").

REMARKS.—Some of the specimens have a sharply pointed or conical apex while in others the apex is smoothly domed. Ravenel (1844:97) erected a separate species, *Periarchus pileussinensis*, for the specimens with a sharp apex. Cooke (1942: 15) considered *P. pileussinensis* a synonym of *P. lyelli* for he found all gradations between the domed shape considered typical of *P. lyelli* and the conical form referred to *P. pileussinensis*. According to Cooke "these variations occur in the same bed and at many different places, there seems to be no reason for retaining both names, unless one wishes to distinguish as varieties the end members of the series, which are widely different in appearance." The large collection of *P. lyelli* from Ideal includes a full range of intermediates between the two extremes. Furthermore, these two forms differ in no other morphological characters including: length, width, height, distance of the periproct from the posterior margin, diameter of the peristome, lengths of petals I, II, and III, widths of petals I, II, and III, greatest width of the interporiferous zones, distance from apical system to the anterior margin, distance from the peristome to the anterior margin, height at the ambitus, width of the periproct, and height at ambitus posteriorly. I also measured these characters in all the figured specimens here in the USNM that have been referred to by others as *P. pileussinensis* and compared their statistics on scattergrams with those of the typical *P lyelli.* No significant separation of the coordinates occur on any of the scattergrams.

Because most of the specimens collected are from float, it is possible that more than one time interval is represented at those localities and that the domed form may be a different age than the sharply convex form with cline joining the two extremes. However, there is no evidence of such an age difference in the other fossils found at these localities or in the lithology of the matrix on and in specimens of both forms.

Toulmin (1969:475; 1977:344, Table 4) states that in Mississippi and Alabama *P. pileussinensis* occurs above *P. lyelli.* Banks (1978:121) reports

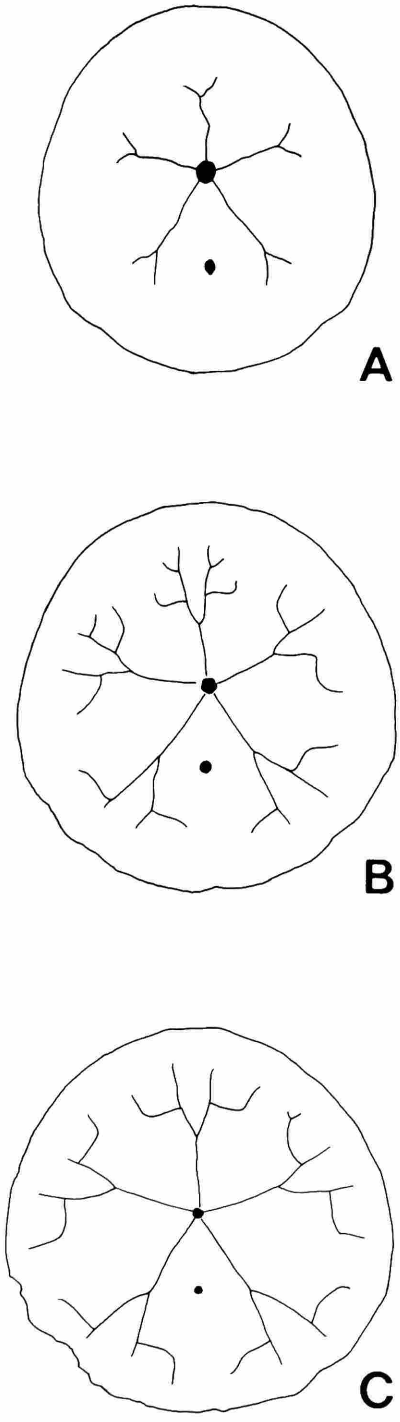


FIGURE 18.—*Periarchus lyelli* (Conrad): A, position of food groove in small specimen 25 mm long. USNM 264597 from Castle Hayne Limestone at locality 12, × 2; B, position of food grooves in specimen 70 mm long. USNM 264066 from Castle Hayne Limestone at locality 12, × 0.75; C, position of food grooves in neotype MCZ 3543 from near Claiborne, Alabama, × 0.75.

Periarchus cf. *P. pileussinensis* in beds in the Santee Limestone underlying beds containing *P. lyelli*, but he (1978:109) says that his specimens are not identical to Toulmin's Alabama specimens. I have not seen Toulmin's or Banks' specimens so cannot comment on their conclusions, neither can I determine the validity of the maintenance of *P. pileussinensis* as a separate subspecies.

Paulson (1958:362) erected a new species, *Periarchus rutriformis*, for a group of specimens from a quarry in the Castle Hayne Limestone near Carlton, Duplin County, North Carolina. Cooke (1959:41) considered this species a synonym of *P. lyelli*. I have borrowed the holotype T-6934 (figured herein on Plate 14: figures 8–10) and the paratypes of *P. rutriformis* from the Museum of Geoscience at Louisiana State University at Baton Rouge, Louisiana, and measured the following characters: length, width, height, distance of the periproct from the posterior margin, diameter of the peristome, lengths of petals I, II, and III, widths of petals I, II, and III, greatest width of the interporiferous zones, distance from apical system to the anterior margin, distance from the peristome to the anterior margin, height at the ambitus, width of the periproct, and height at ambitus posteriorly. None of these dimensions, except length, differ significantly from those for specimens considered to be typically *P. lyelli*. Scattergrams of all those measurements showed no separation of the coordinates for Paulson's specimens from those of specimens of *P. lyelli* including the neotype.

Paulson said that his species differs from *P. lyelli* in its smaller size, food grooves that bifurcate only once, unequal basicoronal ambulacral plates, and concave basicoronal interambulacral plates. The difference in size is probably a reflection of the difference in the age of the specimens. Echinoid populations commonly represent a single generation. The older, larger specimens frequently are not found associated with the smaller and younger. The difference in the food grooves is probably only the difference found between smaller and larger specimens. Specimens of *P lyelli* of the same size as Paulson's likewise have food grooves that bifurcate only once. It is only in specimens larger than Paulson's that the second and third bifurcations are present. The unequal size of the basicoronal plates and the concavity of the basicoronal interambulacral plates are characters too variable to be specifically significant. Some specimens of *P. lyelli* have unequal or equal basicoronal ambulacral plates and concave or convex basicoronal interambulacral plates. These differences are present even on a single specimen. Therefore, *P. rutriformis* is considered herein as a junior subjective synonym of *P. lyelli*. The similarity between the holotype of *P. rutriformis* and a specimen of similar size of *P. lyelli* is shown by comparison of Plate 14: figures 6, 7 with Plate 14: figures 8–10.

Family Schizasteridae Lambert

Genus *Agassizia* Agassiz and Desor

Agassizia (*Anisaster*) *wilmingtonica wilmingtonica* Cooke

Figure 19; Plate 15: figures 1–7

Agassizia (*Anisaster*) *wilmingtonica* Cooke, 1942:46, pl. 5: figs. 9–13; 1959:76, pl. 32: figs. 10–13.

Material.—The dimensions included below came from 12 specimens from Maple Hill (Lanier pit) locality 9.

Shape and Size.—Largest specimen 32.2 mm, smallest 14.2 mm, mean of 8 specimens 20.98 mm; width of test 88.76 percent L (SD=4.85, CV=25.59, N=6) with greatest width central; height 68.64 percent L (SD=3.22, CV=24.15, N=7); greatest height central or posterior to center; posterior truncation overhanging.

Apical System.—Four genital pores, first appearing in specimens approximately 21 mm long, ethmolytic; located at distance from anterior margin to center of genital pores equal to 74.81 percent L (SD=5.45, CV=35.93, N=6).

Ambulacra.—Anterior paired petals (II, IV) long extending almost to margin, length 46.84 percent L (SD=4.35, CV=44.78, N=6); greatest width 7.35 percent L (SD=0.46, CV=30.13, N=7). Porepairs in anterior half zones greatly reduced in size; extent of reduction variable between specimens and within a specimen; in five specimens all porepairs reduced, three specimens with reduced porepairs in petal IV but 2–7 enlarged porepairs in petal II, one specimen with enlarged porepairs in petal IV, all reduced in petal II. Posterior poriferous zone with 17 porepairs in specimen 14.7 mm long, 23 in specimen 24 mm long. Posterior petals (V, I) short with length 24.67 percent L (SD=2.21, CV=42.94, N=7); petals wide, greatest width 9.03 percent L (SD=0.51, CV=24.79, N=6); 10 porepairs in single poriferous zones in specimen 14.7 mm long, 15 in specimen 24 mm long.

PERISTOME.—Anterior, located at distance from anterior margin to anterior edge of peristome equal to 23.88 percent L (SD=0.82, CV=17.91, N=7), width of opening 21.57 percent L (SD=0.96, CV=22.98, N=7), height 8.51 percent L (SD=0.17, CV=12.42, N=4).

PERIPROCT.—Opening high on overhanging posterior truncation, wider than high, on specimen 24 mm long opening 5.4 mm wide; height not preserved on any specimen.

ORAL PLATE ARRANGEMENT.—Labrum low, length only 5.4 percent L in a specimen 16.5 mm long. Plastron long, sternal plates with length 55–60 percent L in five specimens.

FASCIOLES.—Peripetalous, a narrow band passing anteriorly below ambitus, curving deeply into interambulacra 1 and 4, crossing ambulacra II or IV on plates 6 or 7, ambulacrum III on plate 4, ambulacra V or I on plate 15, interambulacra 2, 3 on plate 3, position on other interambulacra not clear. Latero-anal fasciole extending from posterior of the anterior paired passing around posterior of test below periproct; crossing interambulacrum 5 on plate 5, ambulacra V or I on plate 10.

TYPE-SPECIMENS.—Holotype USNM 499004; figured specimens USNM 264071, 264072.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (Lanier pit) localities 9, 16, 26, 34 ("late zone").

COMPARISON WITH OTHER SPECIES.—This species is easily distinguished from *Agassizia* (*Anisaster*) *mossomi* Cooke from the late Oligocene by its far lower test, more posterior apical system, and overhanging posterior truncation. *A. wilmingtonica* is more similar to *A.* (*Agassizia*) *floridana* from the late Eocene Ocala and Inglis Limestone but differs in having some normal-sized porepairs in the anterior poriferous zones of the anterior petals; whereas, in *A.* (*A.*) *floridana* all the pores are microscopic in this anterior zone.

Agassizia (*Anisaster*) *wilmingtonica inflata*, new subspecies

FIGURE 19; PLATE 15: FIGURES 8–10

DISCUSSION.—Specimens (25 measured) from Georgetown have slightly more inflated tests (Figure 19) with more anteriorly situated apical systems than specimens of this species from the Castle Hayne Limestone including the holotype and eleven specimens from Maple Hill (Lanier pit) locality 9. In all other characters the specimens are indistinguishable.

TYPE-SPECIMEN.—Holotype USNM 264073.

OCCURRENCES.—Santee Limestone, South Carolina: Georgetown localities 37, 44 ("middle zone").

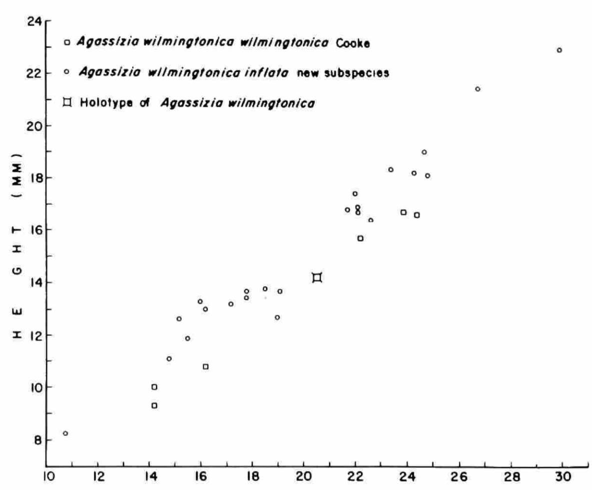


FIGURE 19.—Scattergram showing height of two subspecies of *Agassizia wilmingtonica* Cooke.

Genus *Linthia* Desor

Linthia (*Linthia*) *harmatuki*, new species

FIGURES 20, 21; PLATE 16: FIGURES 1, 2, PLATE 17: FIGURES 1, 2

DIAGNOSIS.—Species characterized by large, low test; petals narrow of equal length with posterior petals diverging, slight anterior groove.

MATERIAL.—Seven specimens, one nearly complete showing most of test; others more incomplete or covered with hard matrix but showing large parts of test. Thirteen fragments of small portions of test. Occurrence of spines still attached to their tubercles on portions of tests indicates echinoids covered by sediment soon after death. Measurements were taken of 5 specimens.

SHAPE AND SIZE.—Largest specimen 126.5 mm long, smallest 92.4, mean of five specimens 116.4 mm; test wide, width 89.99 percent L with greatest width central; height 53.77 percent L, greatest height posterior to center; posterior truncation slightly overhanging.

APICAL SYSTEM.—Four genital pores, ethmolytic with genital 2 extending far posteriorly; located at distance from anterior margin to center of genital pores equal to 37.81 percent L (measurable on five specimens.).

AMBULACRA.—Anterior ambulacrum not petaloid, in groove from apical system to peristome, groove deepest in midlength of adapical portion, shallowest at peristome; on specimen 126.5 mm long groove 4 mm deep (3.16 percent L) at midlength adapically, 2 mm (1.6 percent L) at anterior margin. Pores paired between apical system and peripetalous fasciole with inner pore more adoral to outer; pores between fasciole and phyllode are single and smaller. Anterior paired petals (II and IV) long extending almost to margin; length of each petal 48.09 percent L. Petals slightly convex anteriorly except near tips where turning anteriorly (Plate 17: figure 1). Petals depressed in groove deepest near midlength where depth equal to 4.42 percent L; petals narrow with greatest width 7.76 percent L. Pores conjugate with outer pores slit-like; 96 porepairs in specimen 92.4 mm long; 122 in specimen 126.5 mm long. Interporiferous zone narrower than a poriferous zone. Pores between end of petals of phyllodes small and single. Posterior paired petals (V and I) approximately same length as anterior petals, 46.37 percent L, extending 75 percent distance from apical system to margin. Petals concave curving away from each other distally (Plate 17: figure 1). Petals depressed in groove deepest near midlength where depth equal to 4 percent L; petals narrow with greatest width 7.66 percent L. Pores conjugate with outer pore slit-like; 96 porepairs in specimen 92.4 mm long, 104 in specimen 117.3 mm long, 130 in specimen 126.5 mm long. Interporiferous zones narrower than a poriferous zone. Pores between end of petals and phyllodes small and single.

INTERAMBULACRA.—Not possible to count number of plates in interambulacra on any specimens.

PERISTOME.—Anterior, located at distance from anterior margin to anterior edge of peristome equal to 17.45 percent L, opening wider than high, with width 15.91 percent L, height 2.48 percent L.

PERIPROCT.—Located approximately midway between top and bottom of test on slight posterior truncation; periproct not visible in top or bottom view of specimen. Opening higher than wide, height 11.3 percent L, width 9.18 percent L; occurs within plates 5–9.

ORAL PLATE ARRANGEMENT.—Labrum low (Figure 20) extending posteriorly only one-third to one-half height of first ambulacral plate; length of labrum 3.70 percent L. Labrum widest posteriorly where 10.81 percent L, narrower at peristome where 9.59 percent L. Plastron long and narrow composed of four plates: two sternal plates 51.67 to 47.42 percent L in length, combined width 28.49 to 30.19 percent L; two post-sternal plates shorter, 19.05 to 19.84 percent L, combined width 20.83 to 21.66 percent L. Sternal plates bordered by ambulacral plates 1 to 7.5; post-sternal pair by ambulacral plates 8, 9. First plate of interambulacra 1, 4 separated from peristome by coalesced ambulacra I, II, and IV and V; first plates of interambulacra 2, 3 reaching peristome.

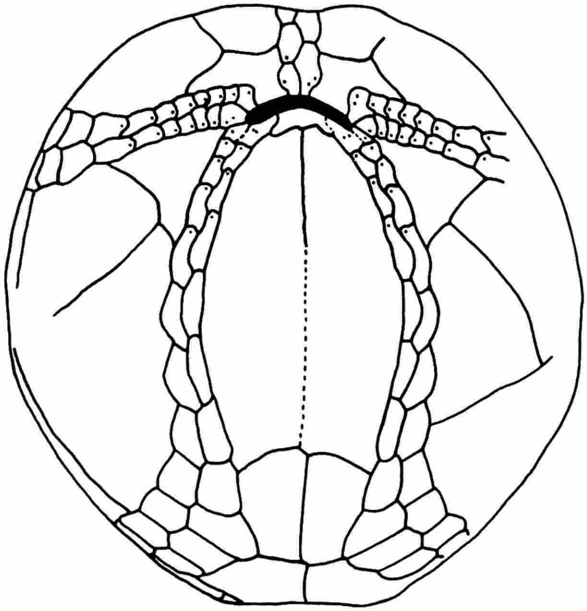


FIGURE 20.—*Linthia harmatuki*, new species, adoral plate arrangement of figured paratype USNM 264598 from Castle Hayne Limestone at locality 10, × 0.75.

Phyllodes with 4 large pores in ambulacra III, 16–17 in II or IV, 10 in V or I.

FASCIOLES.—Peripetalous fasciole (Figure 21) narrow, angular, curving sharply into interambulacra 1, 4 and in interambulacra 2, 3 just anterior of petals II, IV. Fasciole crosses ambulacra II or IV on plates 12 or 13, ambulacra V or I on plates 17 or 18, interambulacra 2 or 3 on plate 4 or 5 (not clear on any specimen which plates crossed on interambulacra 4, 5, or 1). Latero-anal fasciole passes below periproct at distance from periproct equal approximately to height of periproct; crosses ambulacra V or I on plates 13 or 14, interambulacrum 5 on plates 4, 5, 6, interambulacra 4, 1 on plate 5.

TYPE-SPECIMENS.—Holotype USNM 264076; figured paratypes USNM 264074, 264075; figured specimen USNM 264598.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (East Coast Construction Company quarry) localities 10, 34. Santee Limestone, South Carolina: Georgetown locality 37 ("middle zone").

COMPARISON WITH OTHER SPECIES.—This species is referred to the Schizasteridae because of its peripetalous and latero-anal fasciole. Its ethmolytic apical system with four genital pores, depressed anterior ambulacrum, and peripetalous fasciole curving deeply between the petals are characters of *Linthia*. Its large test, anterior apical system, and vertically elongate periproct are typical of the subgenus *Linthia* (*Linthia*). *L.* (*L.*) *harmatuki* is easily distinguished from *Linthia hanoverensis* Kellum and *Linthia wilmingtonensis* Clark both from the Castle Hayne Limestone by its far larger test, petals of nearly equal length, and divergent posterior petals. It further differs from *L. hanoverensis* in its lower test, which is not highly elevated posteriorly. From *L. wilmingtonensis* it is further distinguished by its far less depressed anterior ambulacrum with a narrower interporiferous zone, much narrower petals, and less developed posterior truncation. In general appearance *L.* (*L.*) *harmatuki* is remarkably similar to the recent *Meoma ventricosa* (Lamarck) now living off Florida and in the Caribbean. The petals are almost identical in shape, relative length, and width of their interporiferous zones. Both species have a slight anterior groove and both have a large test. However, *L.* (*L.*) *harmatuki* has a latero-anal fasciole placing it among the Schizasteridae; whereas, *M. ventricosa* has a subanal fasciole as typical in the Brissidae. Fascioles are considered of great importance in the classification of spatangoids, and the difference in the fascioles in *L.* (*L.*) *harmatuki* and *M. ventricosa* suggests that the general appearance of the two is coincidental and that *L.* (*L.*) *harmatuki* is not an ancestor of *M. ventricosa.* Chesher (1970:756) considered that *Meoma ventricosa* was probably derived from the Eocene species *M. antillarum* (Cotteau) which in turn evolved from a *Macropneustes* ancestor in the early Eocene of Europe. *Macropneustes* has the fascioles of a Brissidae, not a Schizasteridae.

Linthia wilmingtonensis Clark

PLATE 17: FIGURES 3–61

Linthia wilmingtonensis Clark, in Clark and Twitchell, 1915:

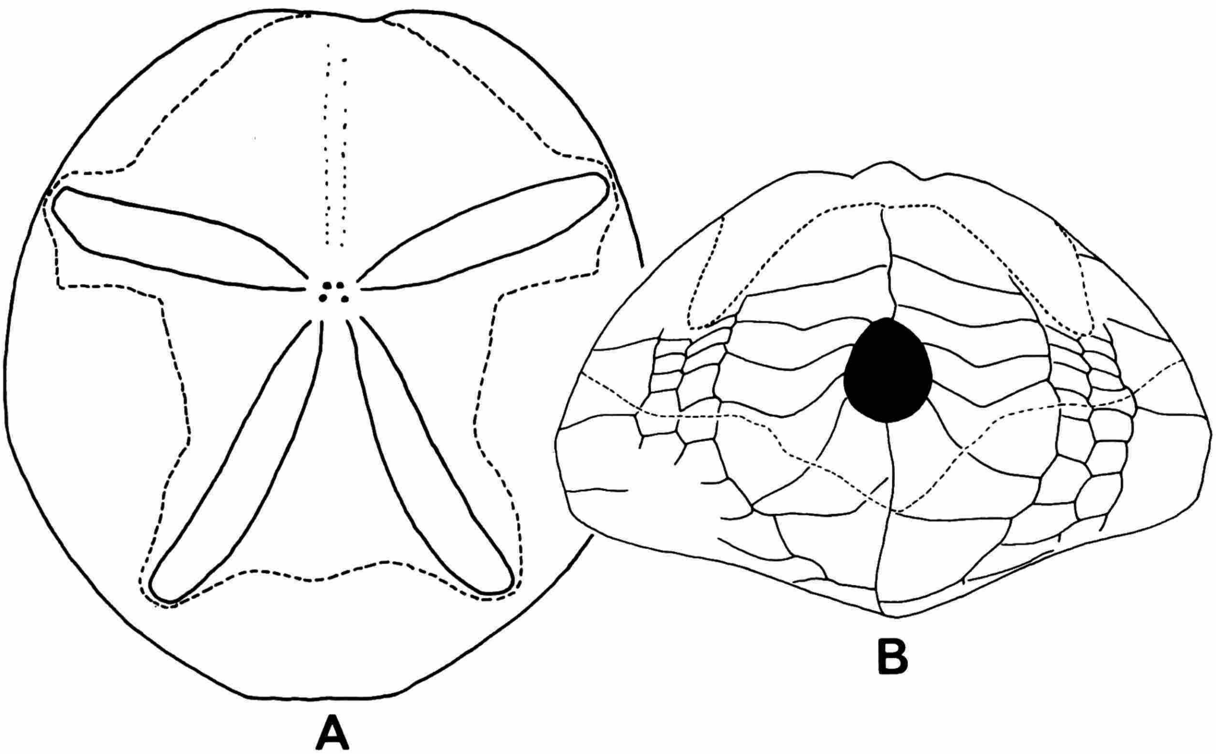


FIGURE 21.—*Linthia harmatuki*, new species: A, adapical view of holotype USNM 264076 from Castle Hayne Limestone at locality 10, × 1; B, rear view of same specimen showing position of peripetalous fasciole (dashed line), × 1.

152, pl. 70: figs. 3a-c.—Cooke, 1959:69, pl. 29: figs. 1–4.
Schizaster (*Linthia*) *wilmingtonensis* (Clark).—Cooke, 1942:41.

DISCUSSION.—Only two additional specimens have been found and, therefore, a redescription of this species is not warranted. However, because of the significance proven by Chesher (1968) for the position of the fascioles, this information is herein included. The peripetalous fasciole crosses ambulacra II or IV on plate 11, ambulacrum III on plate 6, ambulacra V or I on plate 16; interambulacra 1, 2, 3, 4 on plate 5, interambulacrum 5 on plate 10.

TYPE-SPECIMENS.—Holotype USNM 166482; figured specimens USNM 164673, 264077.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: locality 2, Maple Hill (Lanier pit) localities 9, 17, 32, 34. Santee Limestone, South Carolina: Georgetown locality 37 ("middle and late zones").

Linthia hanoverensis Kellum

FIGURE 22; PLATE 18

Linthia hanoverensis Kellum, 1926:15, pl. 1: figs. 8, 9.—Cooke, 1959: 70, pl. 29: figs. 8–12.
Schizaster (*Linthia*) *hanoverensis* (Kellum).—Cooke, 1942:42.

MATERIAL.—Fifty-one specimens; measurements of 25 specimens from Ideal Company quarry (locality 12).

SHAPE AND SIZE.—Largest specimen 65.4 mm long, smallest 27.2 mm, $\bar{x}$=39.74 mm; test wide, width 98.79 percent L (SD=8.22, CV=20.98, N=23), with greatest width central; height 72.92 percent L (SD=6.35, CV=21.87, N=24), greatest height central to posterior to center; posterior truncation high, vertical to slightly tilted resulting in portion of periproct being visible from above.

AMBULACRA.—Anterior ambulacrum not petaloid, in slight groove from apical system to peristome, depth of groove at ambitus 2.76 percent L (SD=0.33, CV=29.74, N=24). Anterior paired petals straight (II and IV) long, extending almost to margin; length of each petal 50.94 percent L (SD=4.40, CV=21.69, N=25), narrow, width 11.28 percent L (SD=0.58, CV=13.21, N=25); depth 3.36 percent L (SD=0.46, CV=33.45, N=24). Posterior petals (V and I) shorter extending over one-half distance to margin, length 38.19 percent L (SD=3.67, CV=24.06, N=25), narrow, width 9.42 percent L (SD=0.53, CV=14.35, N=25); depth 2.91 percent L (SD=0.32, CV=27.77, N=24). Pores conjugate with outer pore slit-like, 45 (in amb. I) porepairs in specimen 27.2 mm long, 55 in specimen 44.1 mm long, 58 in specimen 65.4 mm long. Interporiferous zone slightly narrower than poriferous.

INTERAMBULACRA.—In specimen 35 mm long 12 plates in single column of interambulacrum 1, 11 in interambulacrum 2, 15 in 5.

APICAL SYSTEM.—Four genital pores, ethmolytic with genital 2 extending far posteriorly; located at distance from anterior margin to center of genital pores equal to 60.81 percent L (SD=4.55, CV=18.87, N=25).

PERISTOME.—Anterior, located at distance from anterior margin to anterior edge of peristome equal to 30.32 percent L (SD=1.71, CV=14.35, N=25), opening wider than high, with width 22.79 percent L (SD=1.48, CV=16.63, N=22), height 8.92 percent L (SD=0.64, CV=18.64, N=13).

PERIPROCT.—Located high on posterior truncation, slightly visible from above on most specimens. Opening higher than wide, height 18.39 percent L (SD=0.79, CV=11.44, N=19), width 12.18 percent L (SD=0.58, CV=13.07, N=16).

ORAL PLATE ARRANGEMENT.—Labrum low (Figure 22) extending posteriorly only two-thirds height of first ambulacral plate; length of labrum 5.97 percent L (SD=0.53, CV=22.63, N=12).

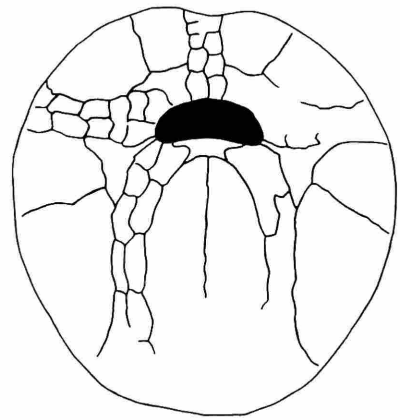


FIGURE 22.—*Linthia hanoverensis* Kellum, adoral plate arrangement of USNM 264599 from Castle Hayne Limestone at locality 12, × 2.

Plastron long and narrow, composed of four plates: two sternal plates with length 48 percent L in specimens 35 mm and 45 mm long; two post-sternal plates much shorter, length 17 percent L in specimen 45 mm long. Sternal plates bordered by ambulacral plates 1 to 4.5; post-sternal pair by ambulacral plates 5–7. First plate of interambulacra 1, 2, 3, 4 reaching peristome. Phyllodes with 4 pores in ambulacrum III, 9–10 in II or IV, and 4–6 in V or I.

FASCIOLES.—Peripetalous fasciole narrow, curving sharply into interambulacra 1, 4. Fasciole crosses ambulacra II or IV on plate 9, ambulacra V or I on plate 18, interambulacra 1, 2, 3, 4 on 3 or 4, interambulacrum 5 on plate 12. Latero-anal fasciole passes below periproct; crosses ambulacra V or I on plates 10 or 11, interambulacrum 5 on plate 5.

TYPE-SPECIMENS.—Holotype USNM 164664; figured specimens USNM 562458, 264078, 264079, 264080, 264599.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (Lanier pit) locality 9, Ideal Cement Company quarry locality 12, Comfort localities 13, 16, 34. Santee Limestone, South Carolina: Georgetown localities 37, 45 ("middle and late zones").

COMPARISON WITH OTHER SPECIES.—This species is easily differentiated from *Linthia harmatuki*, new species, and *L. wilmingtonensis* Clark, both from the Castle Hayne Limestone. It differs from *L. harmatuki* in its smaller and lower test and shorter petals. It is distinct from *L. wilmingtonensis* because of its far lower test, much less depressed and narrower petals, and anterior ambulacrum.

Family Spatangidae Gray

Genus *Maretia* Gray

Maretia subrostrata (Clark)

Figure 23; Plate 19

Hemipatagus subrostratus Clark, in Clark and Twitchell, 1915: 151, pl. 69: figs. 2a-b.—Cooke, 1942:53.
Maretia subrostrata (Clark).—Cooke, 1959:81, pl. 34: figs. 5, 6.—Banks, 1978:143.

Material.—This description is based on 10 specimens from Maple Hill (Lanier pit) locality 9. Measurements were taken of eight specimens.

Shape and Size.—Largest specimen 42.7 mm long, smallest 27.2 mm, mean of specimens 33.65 mm; width 89.23 percent L (SD=4.82, CV=16.49, N=6) with greatest width anterior; height 48.13 percent L (SD=2.02, CV=12.51, N=4), greatest height posterior; posterior truncation vertical.

Apical System.—Four genital pores (one specimen with three), ethmolytic with genital 2 extending far posteriorly; located at distance from anterior margin to center of genital pores equal to 48.09 percent L (SD=2.63, CV=15.82, N=7).

Ambulacra.—Anterior ambulacrum in groove with depth at ambitus 6.41 percent L (SD=0.53, CV=25.28, N=7). Anterior paired petals long, 35.20 percent L (SD=0.20, CV=18.03, N=7), width 10.11 percent L (SD=0.82, CV=23.96, N=8); porepairs in anterior zones reduced in size near apical system. Posterior petals with length 36.94 percent L (SD=2.02, CV=15.81, N=7), width 10.99 percent L (SD=0.98, CV=25.53, N=7). Specimen 39 mm long with 19 porepairs in single poriferous zone in anterior petal, 20 in posterior petal; same number of porepairs in specimen 29 mm long. Interporiferous zones equal to or slightly narrower than poriferous.

Peristome.—Anterior, located at distance from anterior margin to anterior edge of peristome equal to 26.45 percent L (SD=1.05, CV=12.65, N=4), opening wider than high with width 15.62 percent L on only measurable specimens, no specimens showing height.

Periproct.—Located high on posterior truncation with opening wider than high.

Oral Plate Arrangement.—Labrum very long (Figure 23) but whole length not visible on any specimen. Sternal plates, with length 30 percent L on single specimen in which length could be measured.

Fasciole.—Subanal fasciole lobed, crossing ambulacral plates 6–9, interambulacral plates 3–5 or perhaps 6.

Tubercles.—Large tubercles with sunken areoles present adapically in paired interambulacra but none in posterior interambulacrum.

Type-Specimens.—Holotype USNM 164652; figured specimens USNM 166516, 264081, 264082, 264600.

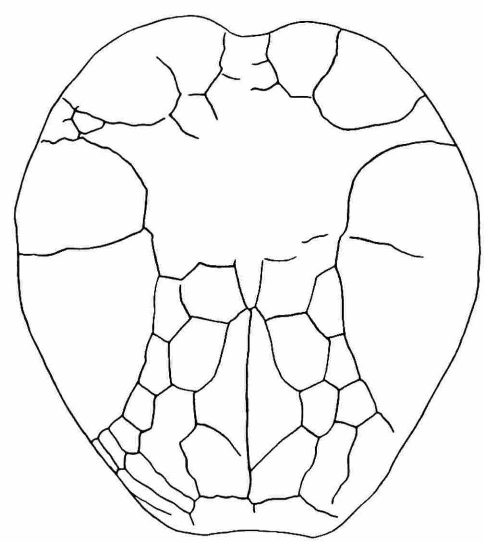


Figure 23.—*Maretia subrostrata* (Clark), adoral plate arrangement of USNM 264600 from Castle Hayne Limestone at locality 11, × 2.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (Lanier pit) locality 9, Rose Hill locality 11, Ideal Cement Company quarry localities 12, 29, 32, 34, 35, 46 ("early and late zones").

REMARKS.—This species occurs in the "lower zone" of the Castle Hayne at Rose Hill, the "upper zone" at Maple Hill (Lanier), and elsewhere but has not been found yet in the "middle zone" or in the Santee Limestone. It is rare at all the localities where it occurs. With further searching it will probably be found in the "middle zone" of the Castle Hayne and in the Santee.

This species, as noted by Cooke (1959:81) is very similar and may be conspecific with *Maretia arguta* (Clark) from the Winona Sand of lower Lisbon age of Mississippi. *M. subrostrata* has a more rounded horizontal outline and less compressed posterolateral margins. Only one specimen is known of *M. arguta*; and it is, therefore, not possible to be certain of the significance of these differences.

Family BRISSIDAE Gray

Genus *Eupatagus* L. Agassiz

Eupatagus carolinensis Clark

FIGURE 24; PLATE 20: FIGURES 1–6

Eupatagus carolinensis Clark, in Clark and Twitchell, 1915: 153, pl. 71: figs. 3a-d, 4.—Cooke, 1942:56; 1959:91, pl. 42: figs. 4–7.

MATERIAL.—Description based on 12 specimens from the Ideal quarry (locality 12). Measurements taken of 9 specimens. Most specimens lack posterior area making it impossible to measure length. On these specimens the length is estimated on the basis of the width of the test. In echinoids the width and length are so closely related with so little variation that if a few specimens show both the length and width, the percentage of width to length can be used to estimate the length on those specimens in which only the width can be measured.

SHAPE AND SIZE.—Largest specimen 56.4 mm long, smallest approximately 40 mm ($\bar{x}$=47.77 mm); test wide, width approximately 85 percent L with greatest width central; height 39.8 to 49.5 percent L, greatest height posterior, posterior truncation slightly tilted resulting in periproct being partially visible from above.

APICAL SYSTEM.—Four genital pores, ethmolytic; located at distance from anterior margin equal to 45 to 47 percent L.

AMBULACRA.—Anterior ambulacrum not petaloid, in very broad and shallow groove; pores paired from apical system to phyllodes; anterior paired petals (II and IV) long, almost extending to margin; length of petals 30.3 to 34.75 percent L, width 8.95 to 11.69 percent L; posterior petals (V and I) extending two-thirds distance to margin, length 35.1 to 40.99 percent L, width 9.4 to 12.7 percent L. Petals slightly depressed. Interporiferous zones narrow, only slightly wider than poriferous zone; conjugation slits strongly developed. Specimen 46.1 mm long with 46 porepairs in petal II or IV, 57 in V or I; specimen 52.7 mm long with 45 porepairs in petals II or IV, 54 in V or I. First porepair in petal II in plate 12, first porepair in petal I in plate 19.

PERISTOME.—Anterior, located at distance from anterior margin to anterior edge of peristome equal to 26.0 to 32.3 percent L, opening wider than high with width 16.6 to 21.7 percent L, height 12.7 to 13.45 percent L.

PERIPROCT.—Not preserved on any specimens.

FASCIOLES.—Peripetalous fasciole narrow, 0.25 mm wide on specimen 46.1 mm long, crossing ambulacrum III on plate 6, ambulacra II or IV on plates 9 or 10, ambulacra V and I on plates 17 or 18; crossing interambulacra 2 or 3 on plates 5 or 6; interambulacra 1 or 4 on plates 5 or 6, interambulacrum on plate 10. Subanal fasciole enclosing shield-shaped area whose width in specimen 52.7 mm long is 17.3 mm or 32.8 percent L and height 12.1 or 23 percent L. Fasciole crossing plates 6–10 of ambulacra V or I, plates 3 and 4 of interambulacrum 5.

ORAL PLATE ARRANGEMENT.—Labrum long, narrow, 7.3 mm long in specimen 46.1 mm long (15.8 percent L), extending posteriorly to third ambulacral plate (Figure 24).

TUBERCULATION.—Large perforate, crenulate

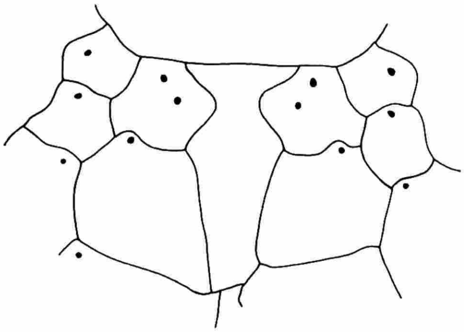


FIGURE 24.—*Eupatagus carolinensis* Clark, labrum of USNM 166484 from Castle Hayne Limestone at locality 16, × 6.

tubercles with large scrobicules confined within peripetalous fasciole, number of tubercles very variable with from 19–38 tubercles in interambulacra 1 or 4, no enlarged tubercles in interambulacra 2 or 3 except in one specimen with 2 or 3 in each area.

NUMBER OF PLATES.—A specimen 46.1 mm long has 44 plates in ambulacrum III, 96 in I or V, 64 in II or IV, 26 plates in interambulacra 2 or 4, count not possible in interambulacrum 5.

TYPE-SPECIMENS.—Holotype USNM 166484; figured paratype USNM 164674; figured specimen USNM 264083.

OCCURRENCES.—Castle Hayne Limestone, Comfort Member, North Carolina: Ideal Cement Company quarry locality 12, Comfort localities 13, 16, 30 ("late zone").

COMPARISON WITH OTHER SPECIES.—*E. carolinensis* differs from *Eupatagus wilsoni*, which occurs with it at the Ideal quarry (locality 12), and at the Wilmington city rock quarry (locality 16) in having few or no large tubercles in the anterior interambulacra, its test more inflated at the apical system and along the anterior ambulacrum, with a narrower anterior truncation, and wider poriferous and narrower interporiferous zones in the petals. In *E. carolinensis* the peripetalous fasciole crosses ambulacra V or I on plates 17 or 18 but in *E. wilsoni* it crosses plates 15 or 16. There are more plates in ambulacra V or I in *E. carolinensis* with 96 in a specimen 46.1 mm long and 57 porepairs in the petal; whereas, a specimen of *E. wilsoni* 56 mm long has only 74 plates in either ambulacrum and only 46 porepairs in the petals. Finally, in *E. carolinensis* the subanal fasciole encloses a narrower shield-shaped area whose width is 32.8 percent L as opposed to 40 percent in *E. wilsoni.*

Eupatagus wilsoni, new species

FIGURES 25, 26, PLATE 20: FIGURES 7–11

DIAGNOSIS.—Species characterized by flattening of test around apical system, broad anterior truncation, petals with broad interporiferous and narrow poriferous zones, and large tubercles in the anterior interambulacra.

MATERIAL.—Two well-preserved specimens and one with one-quarter of the test absent.

SHAPE AND SIZE.—Largest specimen 56.0 mm long, smallest 50.1 mm ($\bar{x}$=52.47 mm); test wide, width 88 to 90 percent L with greatest width central to slightly posterior; height 45 to 47 percent L, greatest height posterior, posterior truncation slightly tilted resulting in periproct being partially visible from above. Test flattened in area around apical system.

APICAL SYSTEM.—Four genital pores, ethmolytic (Figure 25, Plate 20: figure 10) located at distance from anterior margin equal to 41 to 44 percent L.

AMBULACRA.—Anterior ambulacrum not pet-

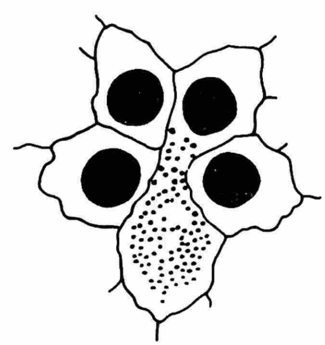


FIGURE 25.—*Eupatagus wilsoni*, new species, apical system of figured paratype USNM 264084 from Castle Hayne Limestone at locality 12, × 10.

aloid, crossing anterior margin on flat truncation, not depressed in groove; pores paired from apical system to phyllodes; anterior paired petals (II and IV) long, almost extending to margin; length of petals 34 to 35 percent L, width 10 to 12 percent L; posterior petals (V and I) extending less than two-thirds distance to margin, length 39 to 43 percent L, width 11 to 12 percent L. Petals flush, not depressed, with wide interporiferous zones, almost twice as wide as narrow poriferous zones; conjugation slits slightly developed. Specimen 56.0 mm long with 41 porepairs in petals II or IV, 47 in V and I; specimen 50.1 mm long with 43 porepairs in petals II or IV, 55 in V or I. First porepair in petal II in plate 12, first porepair in petal I in plate 16.

PERISTOME.—Anterior, located at distance from anterior margin to anterior edge of peristome equal to 29 to 30 percent L, opening wider than high with width 16 to 18 percent L, height 10 percent L.

PERIPROCT.—Preserved on one specimen located high on posterior truncation with opening higher than wide, height 14.6 percent L, width 14.3 percent L.

FASCIOLES.—Peripetalous fasciole narrow, 0.25 to 0.45 mm wide on specimen 50.1 mm long, crossing ambulacrum III on plate 7, ambulacra II or IV on plate 10, V or I on plates 15–16, interambulacrum 5 on plate 3 and 4, plate count not possible in other interambulacra. Subanal fasciole enclosing shield-shaped area whose width in specimen 56 mm long is 22.6 mm or 40 percent L and height 11.8 mm or 21 percent L. Fasciole crossing plates 6–10 of ambulacra V or I, plates 3 and 4 of interambulacrum 5.

ORAL PLATE ARRANGEMENT.—Labrum long, narrow, 1.9 mm long in specimen 56.0 mm long (3.39 percent L), extending posteriorly to second or third ambulacral plate (Figure 26).

TUBERCULATION.—Large perforate, crenulate tubercles with large scrobicules confined within peripetalous fasciole, numerous in all interambulacra.

NUMBER OF PLATES.—Specimen 56 mm long with 50 plates in ambulacrum III, 74 in I or V, 64 in II or IV; count not possible in interambulacra.

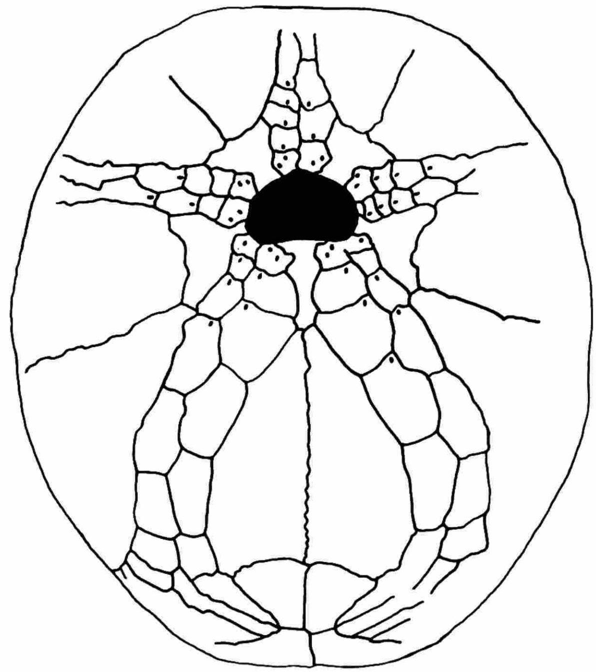


FIGURE 26.—*Eupatagus wilsoni*, new species, adoral view of holotype USNM 264084 from Castle Hayne Limestone at locality 12, × 1.5.

TYPE-SPECIMENS.—Holotype USNM 264084; figured paratype USNM 264085.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Ideal Cement Company quarry localities 12, 16 ("late zone").

COMPARISON WITH OTHER SPECIES.—*E. wilsoni* differs from *Eupatagus carolinensis* Clark, which occurs with it at the Ideal quarry (locality 12) and the Wilmington city rock quarry (locality 16), in having many large tubercles in the anterior interambulacra, its test flattened in the area around the apical system, a broader anterior truncation, and petals with narrower poriferous zones and wider interporiferous zones. In *E. wilsoni* the peripetalous fasciole crosses ambulacra V or I on plates 15 or 16 as opposed to plates 17 or 18 in *E. carolinensis*. There are fewer plates in ambulacra V or I in *E. wilsoni* with, for example, 74 in either ambulacrum (46 porepairs in the petals) in a specimen 56 mm long; whereas, a specimen of *E. carolinensis* 46.1 mm long has 96 plates and 57 porepairs in petal V or I. Finally in *E. wilsoni* the subanal fasciole encloses a broader shield-shaped area whose width is 40 percent L as opposed to 32.8 percent L in *E. carolinensis*.

Eupatagus lawsonae, new species

PLATE 21: FIGURES 1-4

DIAGNOSIS.—Species characterized by its large size, straight posterior petals, and narrow interporiferous zones.

MATERIAL.—Only one specimen known.

SHAPE AND SIZE.—Specimen large, 93.0 mm long, narrow with width 79.5 percent L, greatest width anterior to center. Height 46.2 percent L with greatest height posterior. Posterior truncation overhanging, periproct not visible from above.

APICAL SYSTEM.—Four genital pores, ethmolytic, located at distance from anterior margin equal to 39 percent L.

AMBULACRA.—Anterior ambulacrum not petaloid; anterior paired petals (II and IV) long extending more than two-thirds to margin, length 33 percent L, width 9 percent L, posterior petals straight with length 36 percent L, width 9 percent L; interporiferous zones almost twice width of poriferous zones; petals not depressed; 66 porepairs in petals II or IV, 80 in petals V or I. First porepair in petal II in plate 14, first porepair in petal I in plate 22.

PERISTOME.—Anterior, located at distance from anterior margin to anterior edge of peristome equal to 26 percent L, opening wider than high with width 10.7 percent L.

PERIPROCT.—High on posterior truncation, opening large with height greater than width, height 14.2 percent L, width 10.7 percent L.

FASCIOLES.—Peripetalous fasciole narrow but position not clear on most of specimen. Subanal fasciole enclosing shield-shaped area whose width is 29 percent L, height 21 percent L. Fasciole crossing plates 6-11 of ambulacra V or I.

TUBERCULATION.—Large, perforate, crenulate tubercles with large scrobicules confined within peripetalous fasciole, number not clear.

TYPE-SPECIMEN.—Holotype USNM 264086.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Ideal Cement Company quarry locality 12 ("late zone").

COMPARISON WITH OTHER SPECIES.—This species is easily distinguished from *Eupatagus carolinensis* Clark which occurs with it by its far larger and narrower test, straighter posterior petals, greatest width of test anterior to center, more anterior position of the apical system, and occurrence of the first porepair of petal II in plate 14 as opposed to plate 12 in *E. carolinensis*. It differs from *E. wilsoni* also occurring with it in its larger and narrower test, more inflated area around the apical system, narrower interporiferous zones, higher area circumscribed by the subanal fasciole, and overhanging posterior truncation. *E. lawsonae* is easily distinguished from *E. antillarum* (Cotteau) and *E. clevei* (Cotteau) from the late Eocene Inglis Formation by its shorter petals with far narrower interporiferous zones. It differs from *E. ocalanus* Cooke in having straighter petals which are not depressed and an overhanging posterior truncation.

Family UNIFASCIIDAE Cooke

Genus *Unifascia* Cooke

Unifascia carolinensis (Clark)

PLATE 21: FIGURE 5; PLATE 22

Macropneustes carolinensis Clark, in Clark and Twitchell, 1915: 154, pl. 71, figs. 5a-d.—Cooke, 1942:51.

Mauritanaster carolinensis (Clark).—Lambert and Thiéry, 1909-1925:493.

Unifascia carolinensis (Clark).—Cooke, 1959:80, pl. 34: figs. 7-13.

DISCUSSION.—Insufficient specimens are available to permit a more detailed description than that already present in Cooke (1959:34).

TYPE-SPECIMENS.—Holotype USNM 164651; figured specimens USNM 562447, 562448, 264087, 264088.

OCCURRENCES.—Castle Hayne Limestone, North Carolina: Maple Hill (Lanier pit) locality 9, Ideal Cement Company quarry localities 12, 34. Santee Limestone, South Carolina: Georgetown locality 37 ("middle and late zones").

Literature Cited

Banks, R.

1978. Stratigraphy of the Eocene Santee Limestone in Three Quarries of the Coastal Plain of South Carolina. *Geologic Notes*, 21(3):88–149, figures 1–15, tables 1–3, appendix 1–7.

Baum, G., W. B. Harris, and V. Zullo

1978. Stratigraphic Revision of the Exposed Middle Eocene to Lower Miocene Formations of North Carolina. *Southeastern Geology*, 20(1):1–25, figures 1–5.

Baum, G., J. Collins, R. Jones, B. Madlinger, and R. Powell

In press. Correlation of the Eocene Strata of the Carolinas. *South Carolina Geology*.

Berggren, W.

1972. A Cenozoic Time-Scale—Some Implications for Regional Geology and Paleobiogeography. *Lethaia*, 5(2):195–215, figures 1–9.

Canu, F. and R. S. Bassler

1920. North American Early Tertiary Bryozoa. *United States National Museum Bulletin*, 106: 879 pages.

Chesher, R.

1968. The Systematics of Sympatric Species in West Indian Spatangoids: A Revision of the Genera *Brissopsis*, *Plethotaenia*, *Paleopneustes*, and *Saviniaster*. *Studies in Tropical Oceanography, Institute of Marine Sciences, University of Miami*, 7: 168 pages, 25 figures, 35 plates.

1970. Evolution in the Genus *Meoma* (Echinoidea: Spatangoida) and a Description of a New Species from Panama. *Bulletin of Marine Science*, 20(3):731–761, figures 1–9.

Clark, W. B.

1891. Revision of the Cretaceous Echinoidea of North America. *Johns Hopkins University Circulars*, 86: 8 pages.

1893. The Mesozoic Echinodermata of the United States. *Bulletin of the United States Geological Survey*, 97: 207 pages, 50 plates.

Clark, W. B., and M. W. Twitchell

1915. The Mesozoic and Cenozoic Echinodermata of the United States. *Monographs of the United States Geological Survey*, 54: 341 pages, 107 plates.

Conrad, T. A.

1834. Observations on the Tertiary and More Recent Formations of a Portion of the Southern States. *Journal of the Academy of Natural Sciences of Philadelphia*, 7(1):116–154.

1850. Descriptions of One New Cretaceous and Seven New Eocene Fossils. *Proceedings of the Academy of Natural Sciences of Philadelphia*, (2)2:39–41, illustrations.

1865. Descriptions of New Species of Echinidae. *Proceedings of the Academy of Natural Sciences of Philadelphia*: 75.

1868. Synopsis of the Invertebrate Fossils of the Cretaceous Formations of New Jersey. *In* G. H. Cook, *Geology of New Jersey*, Appendix A:721–732. Newark: New Jersey Geological Survey.

Cook, G. H.

1868. *Geology of New Jersey*. 900 pages, map. Newark: New Jersey Geological Survey.

Cooke, C. W.

1936. Geology of the Coastal Plain of South Carolina. *United States Geological Survey Bulletin* 867: 196 pages, 2 figures, 18 plates.

1941. Cenozoic Regular Echinoids of Eastern United States. *Journal of Paleontology*, 15(1):1–20, plates 1–4.

1942. Cenozoic Irregular Echinoids of Eastern United States. *Journal of Paleontology*, 16(1):1–62, plates 1–8.

1948. *Arbia* and *Dixieus*, Two New Genera of Echinoids. *Journal of Paleontology*, 22(5):606–607.

1959. Cenozoic Echinoids of Eastern United States. *United States Geological Survey Professional Paper*, 321: 106 pages, 43 plates.

Cooke, C. W., and F. S. MacNeil

1952. Tertiary Stratigraphy of South Carolina. *United States Geological Survey Professional Paper*, 243-B:19–29, figure 2.

Copeland, C. W.

1964. Eocene and Miocene Foraminifera from Two Localities in Duplin County, North Carolina. *Bulletins of American Paleontology*, 47(215):209–324, plates 23–43.

Cotteau, G. H.

1889–1894. *Paleontologie française ou description des fossiles de la France, terrain Tertiaire, échinides Éocènes*. Volume 2, 788 pages, plates 200–384. Paris: G. Masson.

Desor, P.J.E.

1855–1858. *Synopsis des Échinides fossiles*. 490 pages, 44 plates. Paris: Chez Ch. Reinwald.

Emmons, E.

1858. *Report of the North Carolina Geological Survey: Agriculture of the Eastern Counties; Together with Descriptions of Fossil of Marl Beds*. 314 pages, 256 figures. Raleigh: Henry D. Turner.

Fischer, A. G.
1951. The Echinoid Fauna of the Inglis Member, Moodys Branch Formation, Part II. *Florida Geological Survey Geological Bulletin* (*Paleontologic Studies*) 34:47–101, figures 1–18, plates 1–7.

Kellum, L. B.
1926. Paleontology and Stratigraphy of Castle Hayne and Trent Marls in North Carolina. *United States Geological Survey Professional Paper*, 143: 56 pages, 1 figure, 11 plates.

Kier, P. M.
1962. Revision of the Cassiduloid Echinoids. *Smithsonian Miscellaneous Collections*, 144(3): 262 pages, 184 figures, 44 plates.
1966. Four New Eocene Echinoids from Barbados. *Smithsonian Miscellaneous Collections*, 151(9): 28 pages, 16 figures, 1 plate.
1968. Echinoids from the Middle Eocene Lake City Formation of Georgia. *Smithsonian Miscellaneous Collections*, 153(2): 45 pages, 44 figures, 10 plates.
1970. Lantern Support Structures in the Clypeasteroid Echinoids. *Journal of Paleontology*, 44(1):98–109, figures 1–8, plates 23, 24.

Lambert, J.
1916. [Untitled review.] In *Revue critique Palaeozoologie*, 20(4):168–171.

Lambert, J., and P. Thiéry
1909–1925. *Essai de nomenclature raisonnée des Échinides*. 607 pages, 15 plates. Chaumont: Librairie L. Ferriere.

Mortensen, T.
1951. Report on the Echinoidea Collected by the "Atlantide" Expedition. In *Atlantide Report*, 2:293–303, figure 1, plates 1, 2.

McCrady, J.
1859. Remarks on the Eocene Formation in the Neighborhood of Alligator, Florida. *Proceedings of the Elliott Society of Natural History* (Charleston, South Carolina), 1:282–283.

Miller, B. L.
1912. Description of the Choptank Quadrangle. *United States Geological Survey Geologic Atlas*, 182: 8 pages.

Morton, S. G.
1833. Supplement to the "Synopsis of the Organic Remains of the Ferruginous Sand Formation of the United States" Contained in Volumes 17 and 18 of this Journal. *American Journal of Science*, series 1, 23:288–294; series 1, 24:128–132, plates 5, 8–10.
1834. *Synopsis of the Organic Remains of the Cretaceous Group of the United States*. 88 pages, 19 plates. Philadelphia. [Reprinted from *American Journal of Science*, volumes 17, 18 (1830).]

Paulson, Jr., O. L.
1958. A New Species of the Eocene Echinoid *Periarchus*. *Journal of Paleontology*, 32(2):362–365, figures 1–8.

Pooser, W. K.
1965. Biostratigraphy of Cenozoic Ostracoda from South Carolina. *The University of Kansas Paleontological Contributions, Arthropoda*, 8: 80 pages, 7 figures, 22 plates.

Ravenel, E.
1844. Description of Some New Species of Fossil Organic Remains from the Eocene of South Carolina. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 2:96–98.
1848. *Echinidae, Recent and Fossil of South Carolina*. 4 pages, 2 plates. Charleston: Burges and James.

Sloan, E.
1908. Catalogue of the Mineral Localities of South Carolina. *South Carolina Geological Survey*, 4(2):1–505, figures 1–16, plates 9, 10, tables 1–8.

Smith, A.
1978. A Functional Classification of the Coronal Pores of Regular Echinoids. *Palaeontology*, 21(4):759–789, figures 1–3, plates 81–84.

Stenzel, H. B.
1949. Successional Speciation in Paleontology; the Case of the Oysters of the *sellaeformis* Stock. *Evolution*, 3(1):34–50, illustrations. [Reprinted as *Texas University Bureau of Economic Geology Report Inv.*, 3.]

Stephenson, L. W.
1923. The Cretaceous Formations of North Carolina, Part I: Invertebrate Fossils of the Upper Cretaceous Formations. *North Carolina Geological Survey*, 5(1): 604 pages, 102 plates.

Toulmin, L. D.
1969. Paleocene and Eocene Guide Fossils of the Eastern Gulf Coast Region. *Transactions of the Gulf Coast Association of Geological Societies*, 19:465–487, figures 1–5, tables 1–2, plates 1–4.
1977. Stratigraphic Distribution of Paleocene and Eocene Fossils in the Eastern Gulf Coast Region. *Geological Survey of Alabama Monograph*, 13(1, 2): 602 pages, 37 figures, 72 plates, 10 tables.

Tuomey, M.
1848. *Report on the Geology of South Carolina*. vi + 293 pages, appendix, illustration. Columbia, South Carolina.

Ward, L. W., D. R. Lawrence, and B. W. Blackwelder
1978. Stratigraphic Revision of the Middle Eocene, Oligocene, and Lower Miocene—Atlantic Coastal Plain of North Carolina. *Contributions to Stratigraphy, Geological Survey Bulletin*, 1457-F:F1-F23, figures 1–3.

Ward, L. W., B. W. Blackwelder, G. S. Gohn, and R. Z. Poore
1979. Stratigraphic Revision of Eocene, Oligocene, and Lower Miocene Formations of South Carolina. *Geologic Notes*, 23(1): 32 pages, 10 figures, appendix.

Zullo, V. A., and G. R. Baum
1979. Paleogene Barnacles from the Coastal Plain of North Carolina (Cirripedia, Thoracica). *Southeastern Geology*, 20(4):229–246, figures 1, 2, plates 1–4.

PLATE 1

Phyllacanthus mitchellii (Emmons)

1–3. Adapical, side, adoral views of holotype USNM 498883, locality 27, × 1.
4. View at ambitus of same specimen, × 4.

Phyllacanthus carolinensis (Emmons)

5. View just below ambitus of holotype USNM 498882, locality 27, × 3.
6–8. Adapical, side, adoral views of same specimen, × 1.

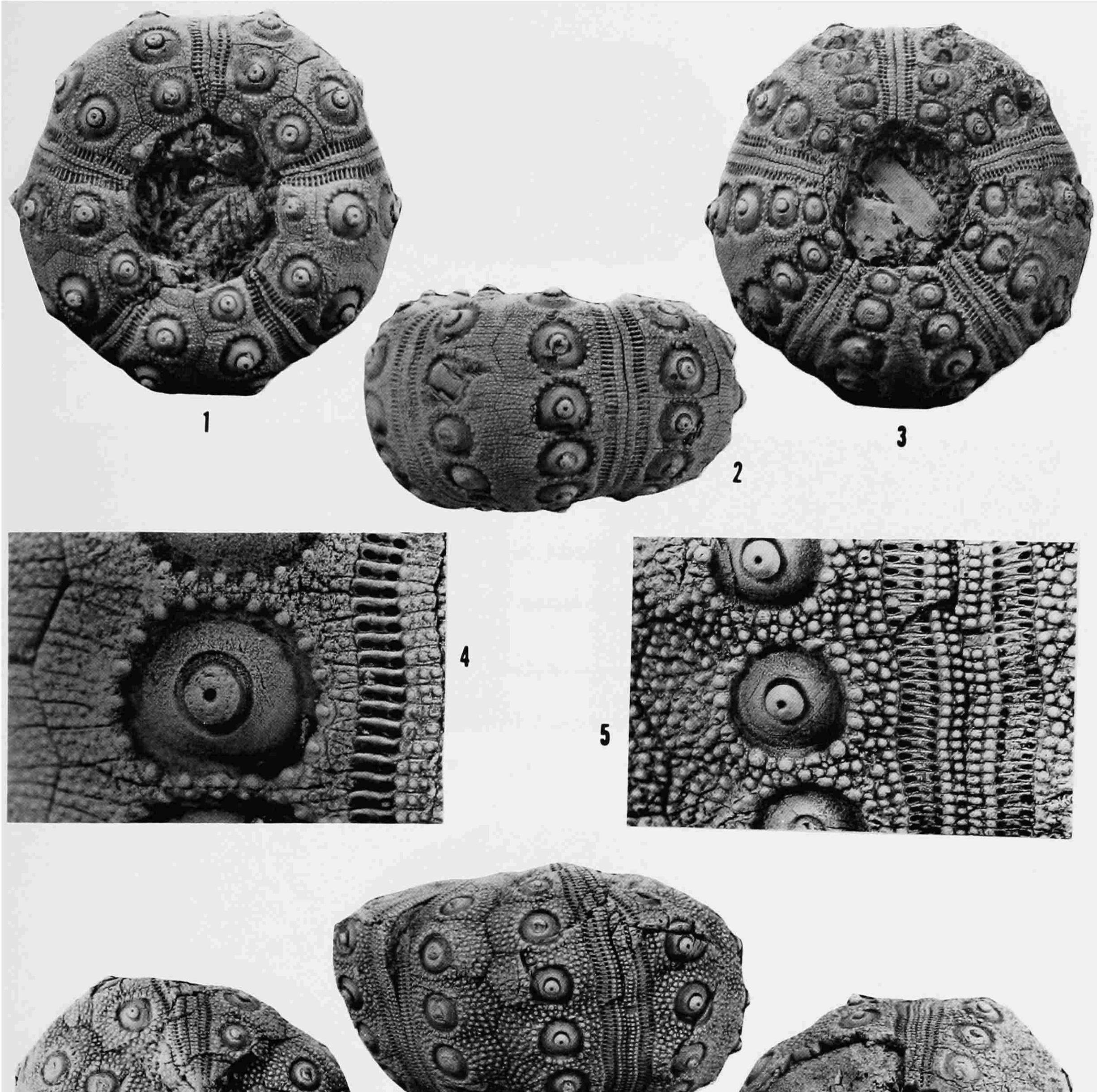

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PLATE 2

Cidaris pratti Clark

1–3. Adapical, side, adoral views of USNM 264035 from Santee Limestone, locality 37 (Georgetown), × 3.
4, 5. Views of interambulacrum and ambulacrum of same specimen, × 6.

Coelopleurus carolinensis Cooke

6–8. Side, adapical, adoral views of holotype, USNM 166500, × 4. Castle Hayne Limestone, locality 26.

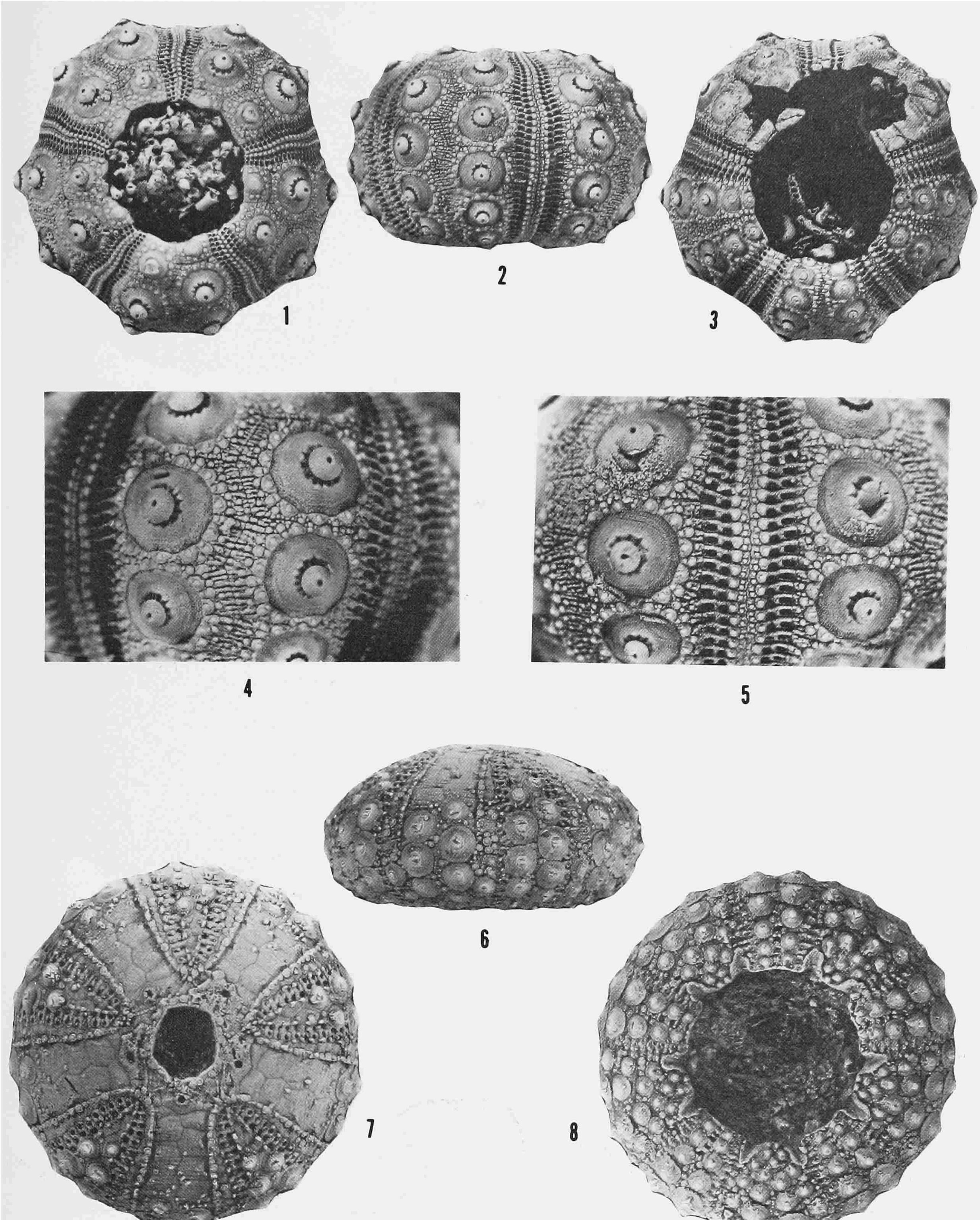
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PLATE 3

Coelopleurus carolinensis Cooke

1–3. Adapical, adoral, side views of USNM 264036 from Castle Hayne Limestone, locality 12 (Ideal), × 2.5.

Coelopleurus infulatus (Morton)

4, 5. Adapical, side views of USNM 264037 from Castle Hayne Limestone, locality 12 (Ideal), × 3.

6, 7. Side, adapical views of probable holotype, Academy of Natural Sciences, Philadelphia 1076. Santee Limestone, South Carolina, × 3.

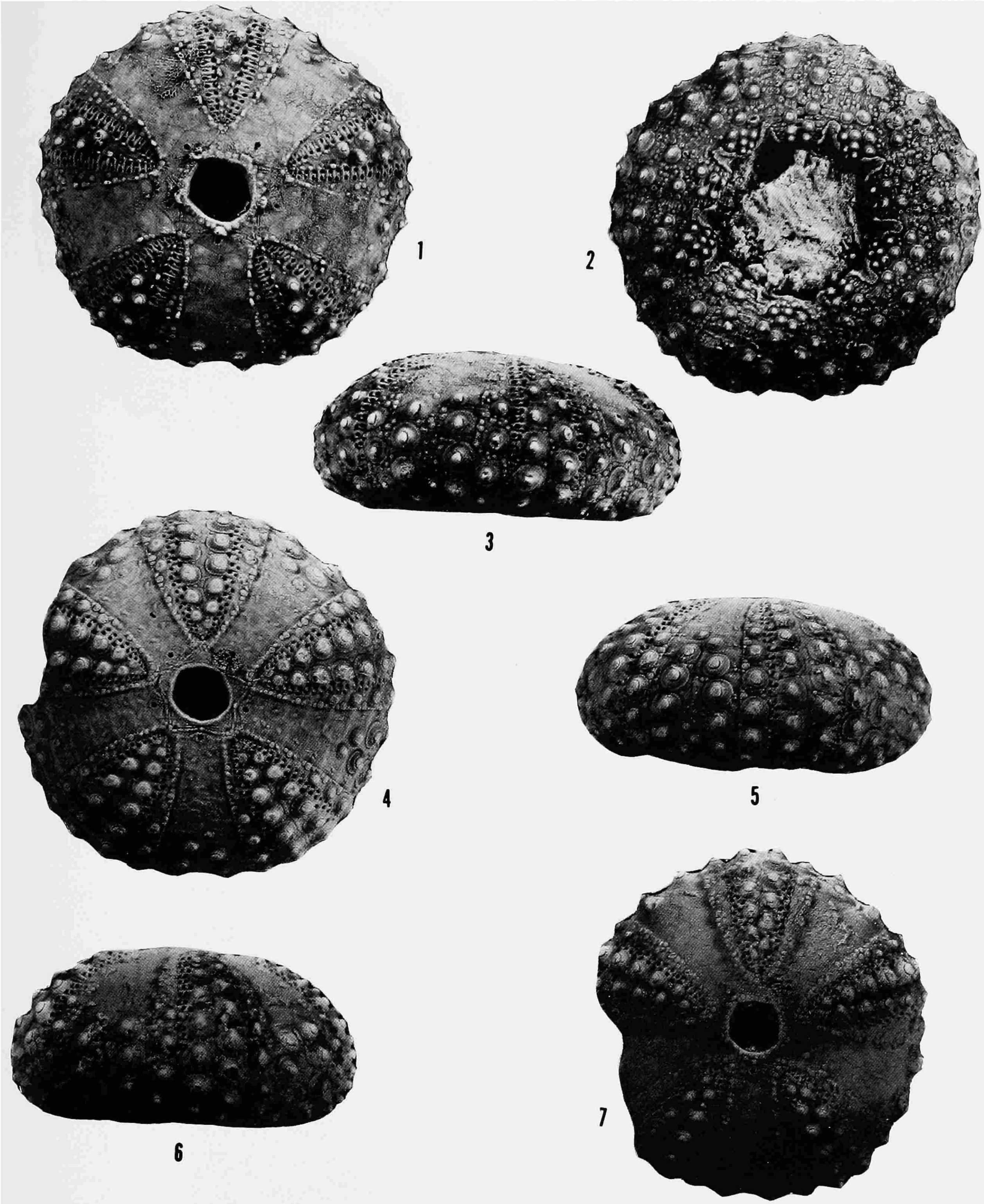
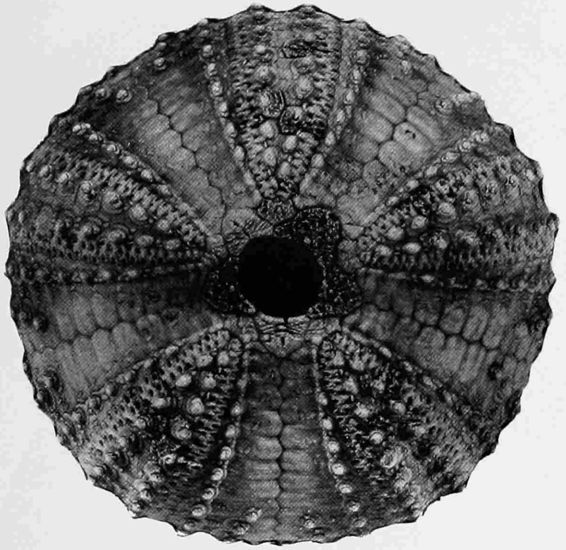


PLATE 4

Coelopleurus infulatus (Morton)

1–3. Adapical, adoral, side views of USNM 264038 from Castle Hayne Limestone, locality 12 (Ideal), × 2.

4. Ambulacrum III at peristome of same specimen, × 10.



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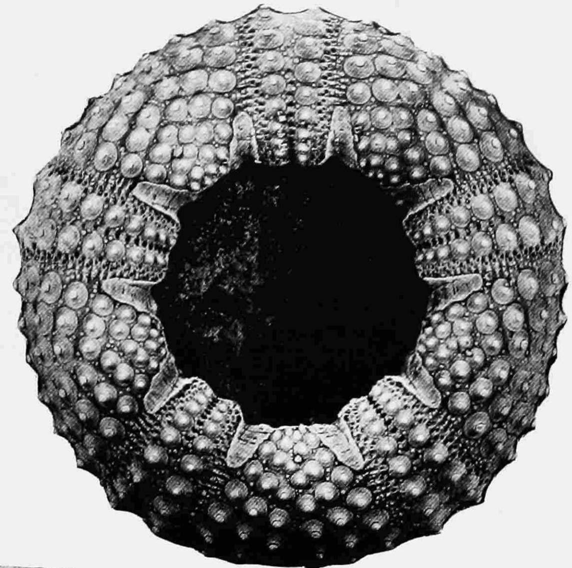

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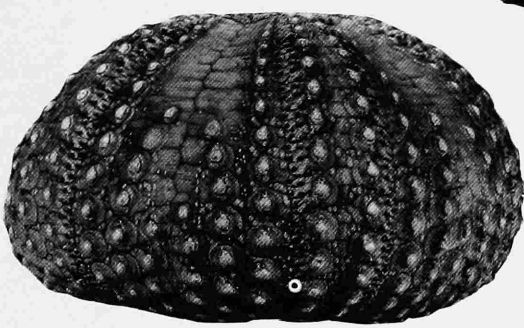

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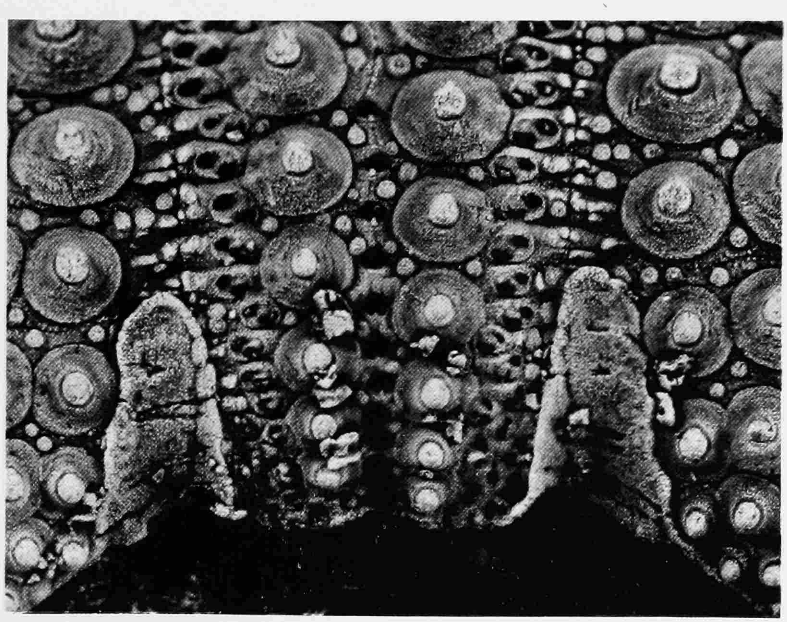

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PLATE 5

Dixieus cf. *Dixieus dixie* (Cooke)

1–3. Side, adapical, adoral views of USNM 264039, from Castle Hayne Limestone, locality 9 (Maple Hill, Lanier), × 1.25.

Echinolampas appendiculata Emmons

4–6. Adapical, right side, adoral views of holotype USNM 499113 from Castle Hayne Limestone, × 1.75.

7–9. Adapical, adoral, side views of USNM 264040 from Castle Hayne Limestone, locality 9 (Maple Hill, Lanier), × 14.

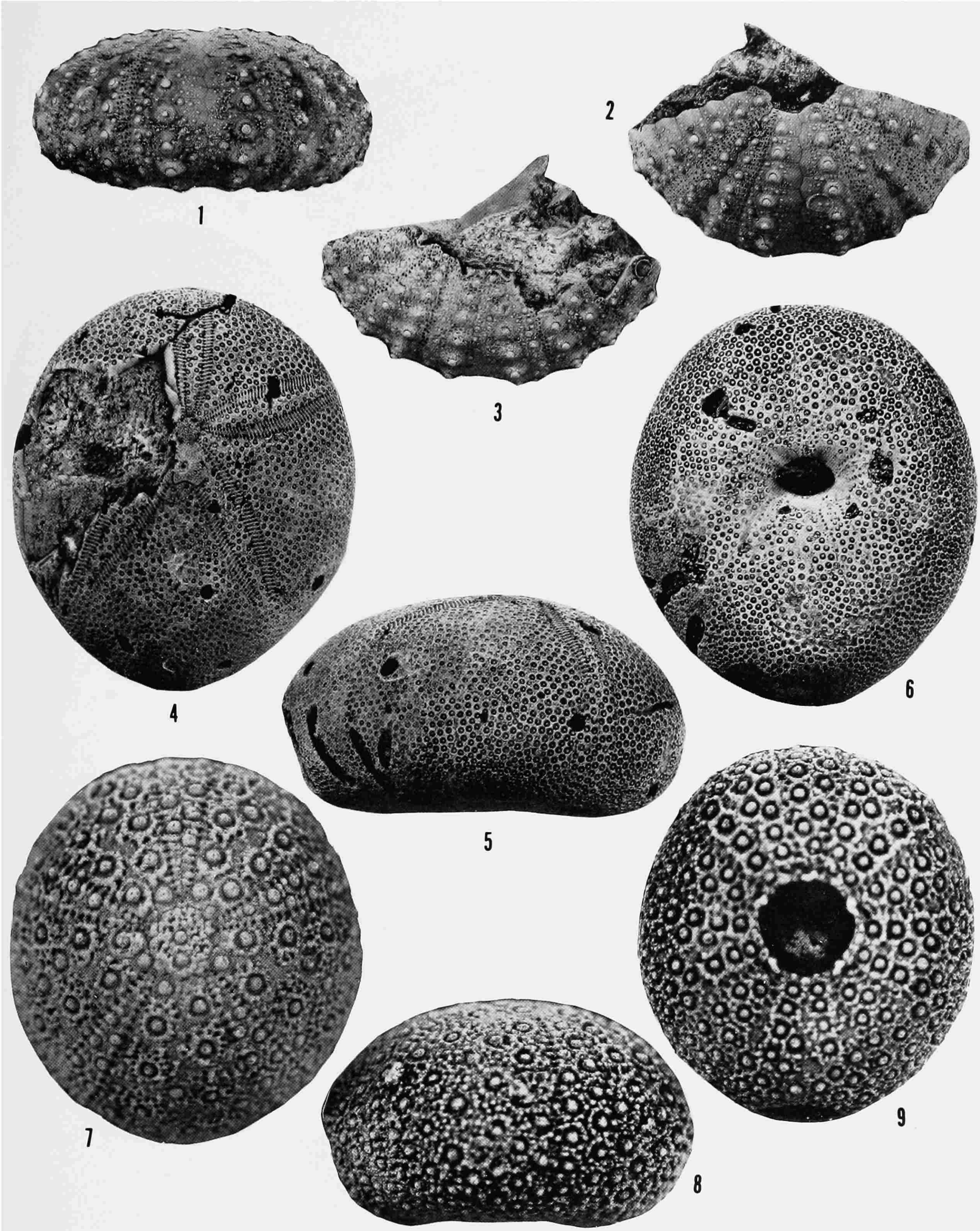
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PLATE 6

Echinolampas appendiculata Emmons

1–3. Side, adapical, adoral views of USNM 264041 from Castle Hayne Limestone, locality 9 (Maple Hill, Lanier), × 1.5.
4. Adapical view of USNM 264042 from same locality, × 6.

Eurhodia baumi, new species

5–8. Adapical, rear, right side, adoral views of holotype USNM 264043 from Castle Hayne Limestone, locality 11 (Rose Hill), × 1.75.

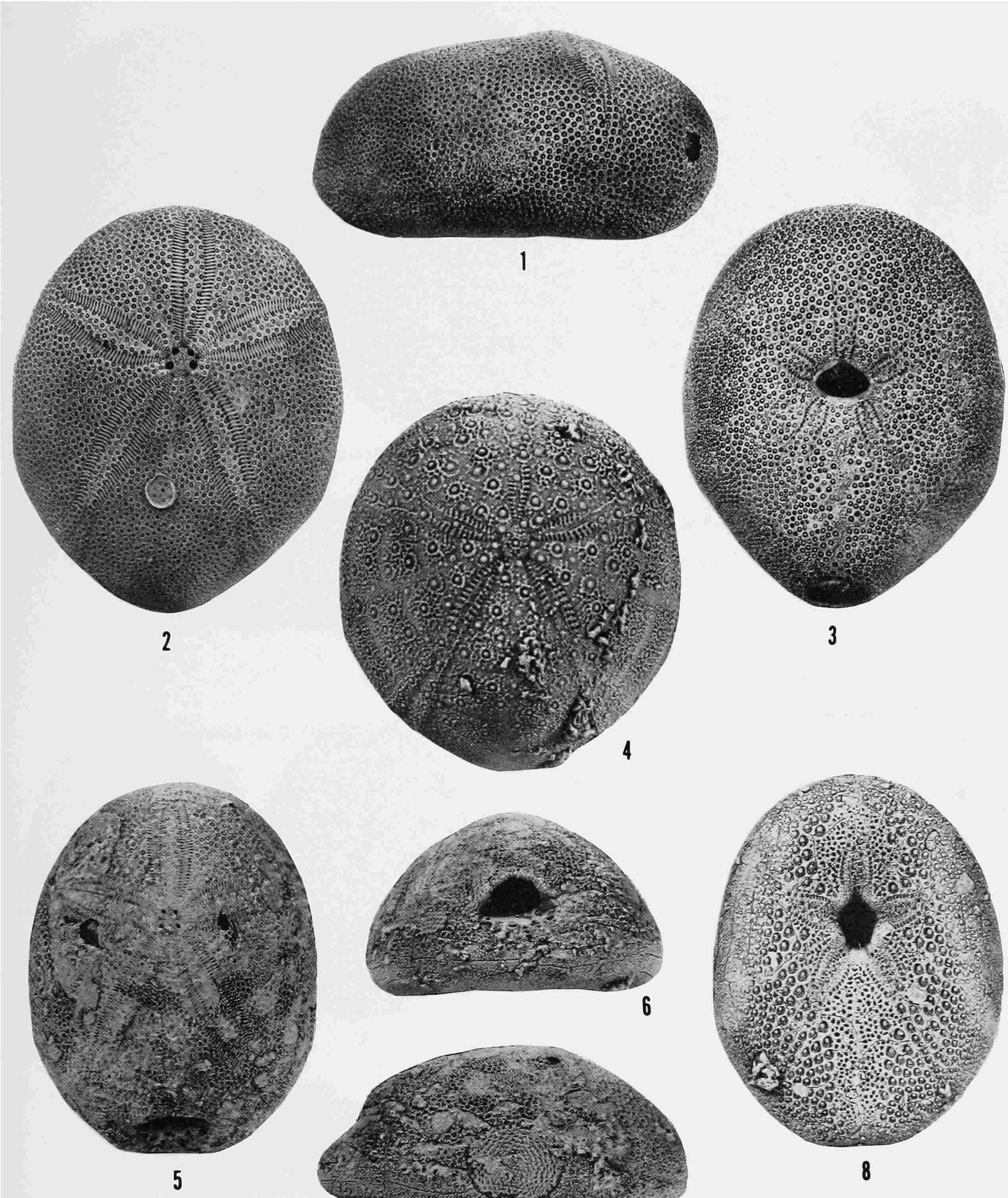

PLATE 7

Eurhodia rugosa rugosa (Ravenel)

1–3. Adapical, adoral, right side views of USNM 264044, Santee Limestone, locality 37 (Georgetown), × 1.5.
4–6. Adapical, adoral, right side views of USNM 264045, from same locality, × 1.5.

Eurhodia rugosa ideali, new subspecies

7–9. Adapical, adoral, right side views of holotype USNM 264046 from Castle Hayne Limestone, locality 12 (Ideal), × 1.

Eurhodia rugosa depressa, new subspecies

10–12. Adapical, adoral, right side views of holotype USNM 264047 from Castle Hayne Limestone, locality 10 (Maple Hill, East Coast), × 1.

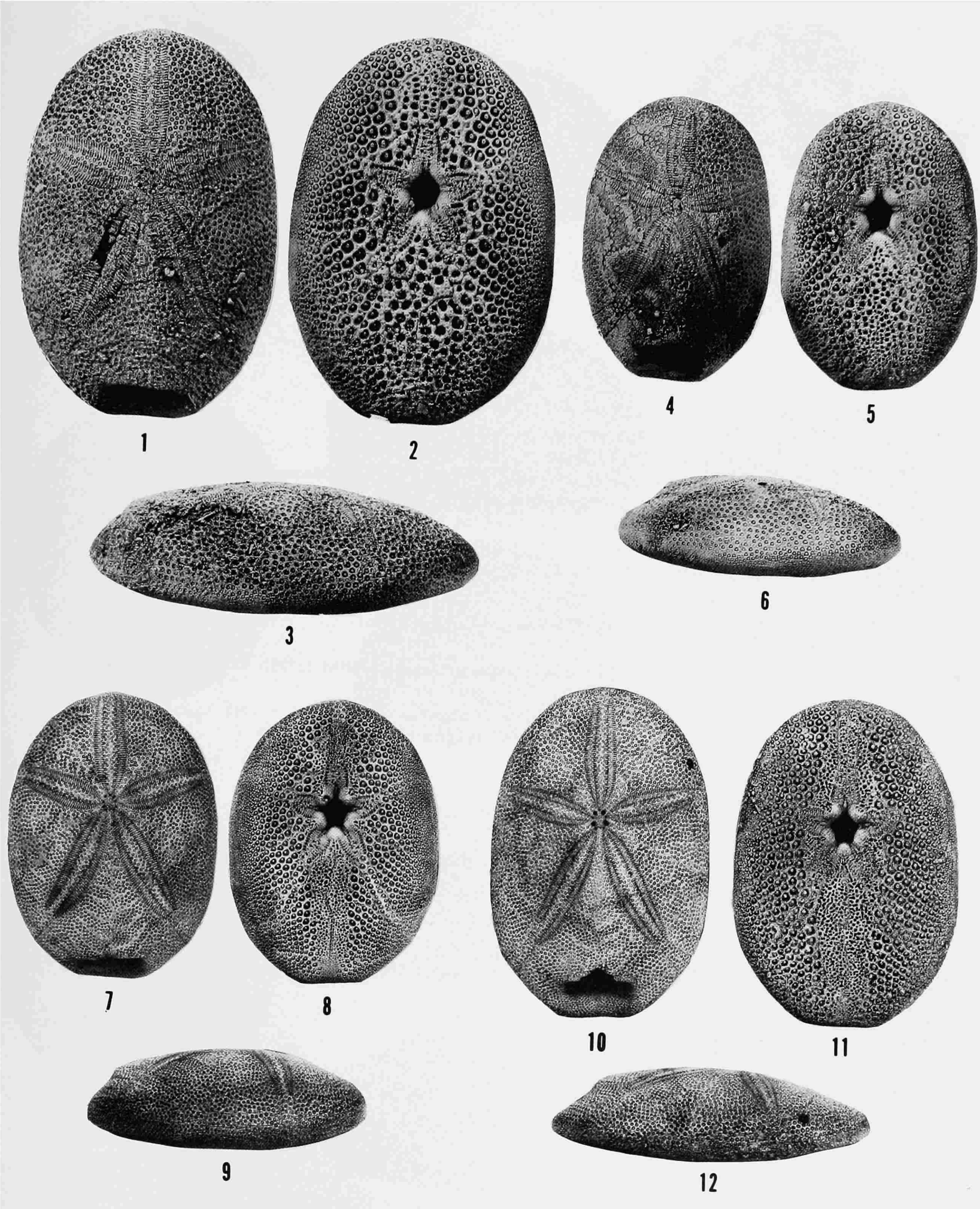
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PLATE 8

Eurhodia holmesi (Twitchell)

1–3. Adapical, right side, adoral views of holotype, American Museum of Natural History 9868 from Santee Limestone, Santee River ?, × 2.

4–6. Adapical, right side, rear views of USNM 264048, from Santee Limestone, locality 37 (Georgetown), × 3.5.

7. Adoral view of USNM 264049, from same locality, × 4.

Eurhodia cravenensis (Kellum)

8–11. Adapical, right side, rear, adoral views of holotype USNM 353256, from Castle Hayne Limestone, locality 6, × 2.25.

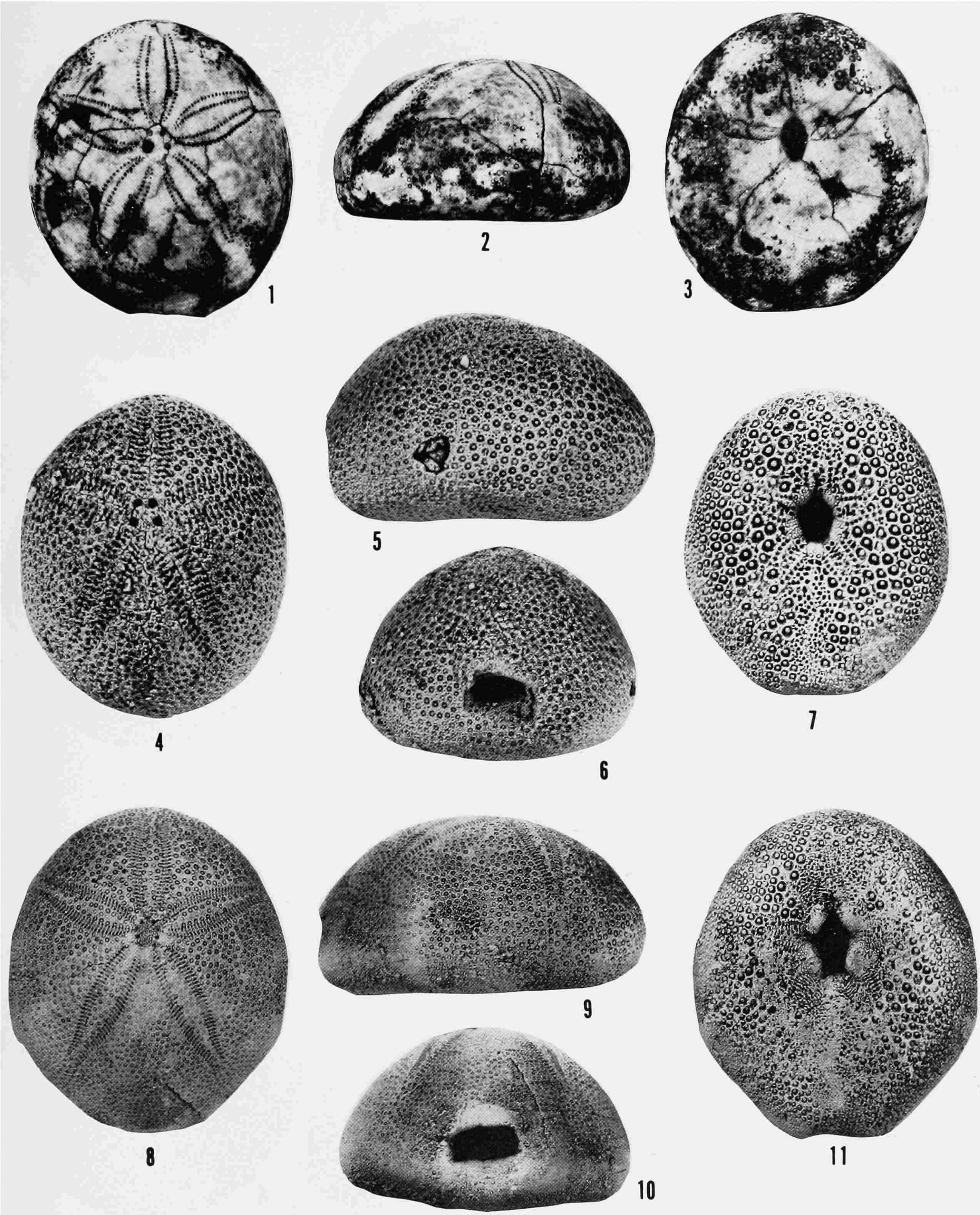
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PLATE 9

Santeelampas oviformis (Conrad)

1–4. Adapical, adoral, right side, rear views of USNM 264050, from Castle Hayne Limestone, locality 11 (Rose Hill), × 1.5.
5–8. Adapical, adoral, right side, rear views of USNM 264051, from same locality, × 2.5.

Rhyncholampas carolinensis (Twitchell)

9–12. Adapical, rear, right side, adoral views of holotype, USNM 599488, from Castle Hayne Limestone, locality 31, × 1.75.

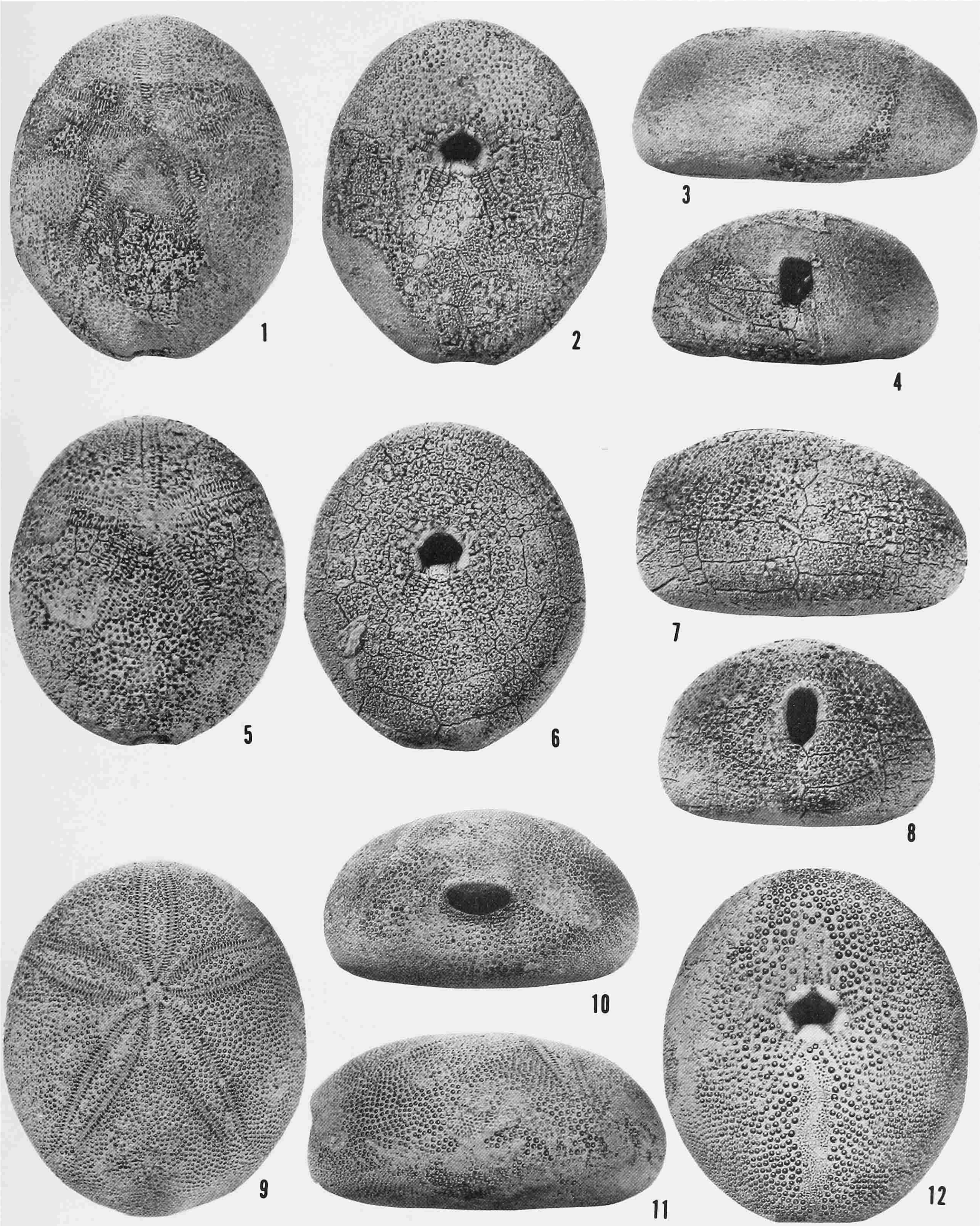
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PLATE 10

Rhyncholampas carolinensis (Twitchell)

1–4. Adapical, rear, right side, adoral views of USNM 264052 from Castle Hayne Limestone, locality 10 (Maple Hill, East Coast), × 1.25.

Echinocyamus parvus Emmons

5. Adapical view of USNM 264053 from Castle Hayne Limestone, locality 9 (Maple Hill, Lanier), × 14.

6, 7. Adapical, adoral views of USNM 264054 from same locality, × 13.

8–10. Adapical, right side, adoral views of USNM 264055 from same locality, × 10.

Echinocyamus bisexus Kier

11. Adapical view of USNM 264056 from same locality, × 30.

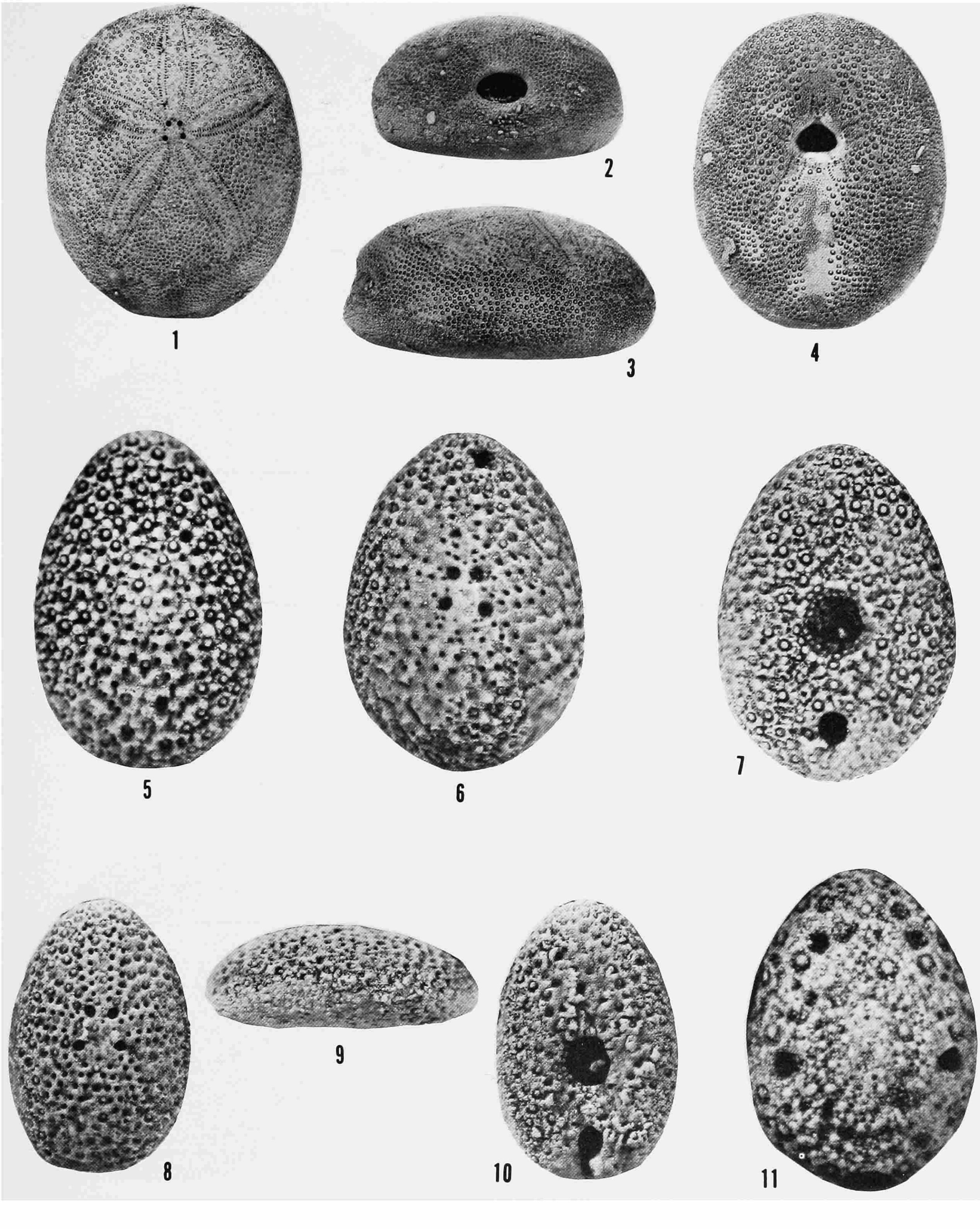
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PLATE 11

Protoscutella conradi (Cotteau)

1, 2. Adapical, adoral views of USNM 264057 from Castle Hayne Limestone at locality 11 (Rose Hill), × 1.
3, 4. Adapical, adoral views of USNM 264058 from same locality, × 1.
5. Adapical view of USNM 264059 from Santee Limestone, locality 37 (Georgetown), × 1.

Protoscutella plana (Conrad)

6. Adapical view of USNM 264060 from Castle Hayne Limestone, locality 10 (Maple Hill, East Coast), × 1.75.
7. Adoral view of USNM 264070 from same locality, × 2.

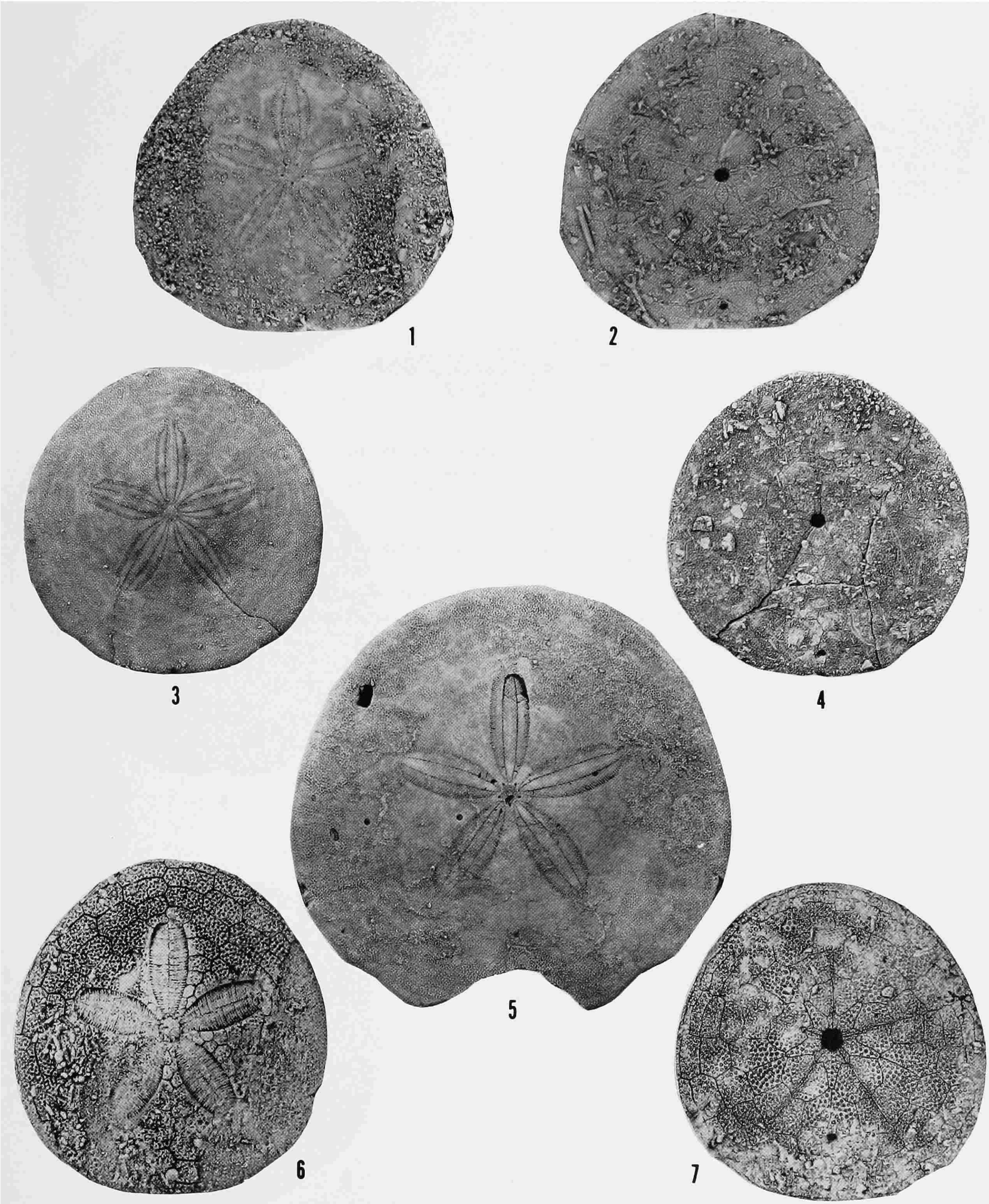
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PLATE 12

Protoscutella mississippiensis rosehillensis, new subspecies

1, 2. Adapical, right side of USNM 264061 from Castle Hayne Limestone, locality 11 (Rose Hill), × 1.5.
3, 4. Adapical view of holotype USNM 264062 from same locality, × 1.75.
5. Adoral view of USNM 264063 from Castle Hayne Limestone, locality 11 (Rose Hill), × 1.5.

Protoscutella mississippiensis subspecies uncertain

6. Adapical view of USNM 264064 from Santee Limestone, locality 38 (Wilson's Landing), × 3.
7. Adapical view of USNM 264065 from same locality, × 2.

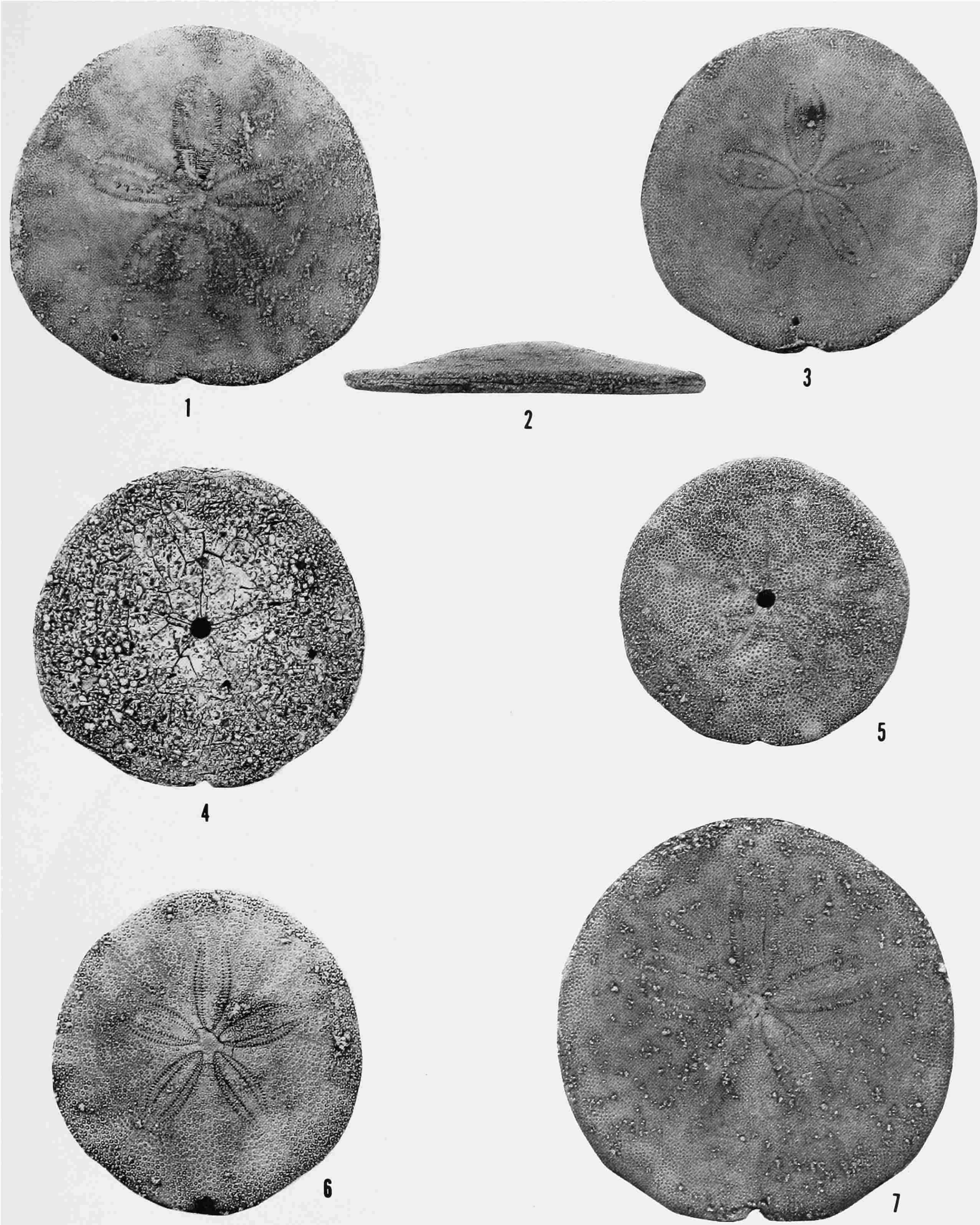
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PLATE 13

Periarchus lyelli (Conrad)

1–3. Adapical, adoral, right side of neotype, Museum of Comparative Zoology, Harvard MCZ 3543, near Claiborne, Alabama, × 1.

4–6. Adapical, right side, adoral views of USNM 264066 from Castle Hayne Limestone, locality 12 (Ideal), × 1.

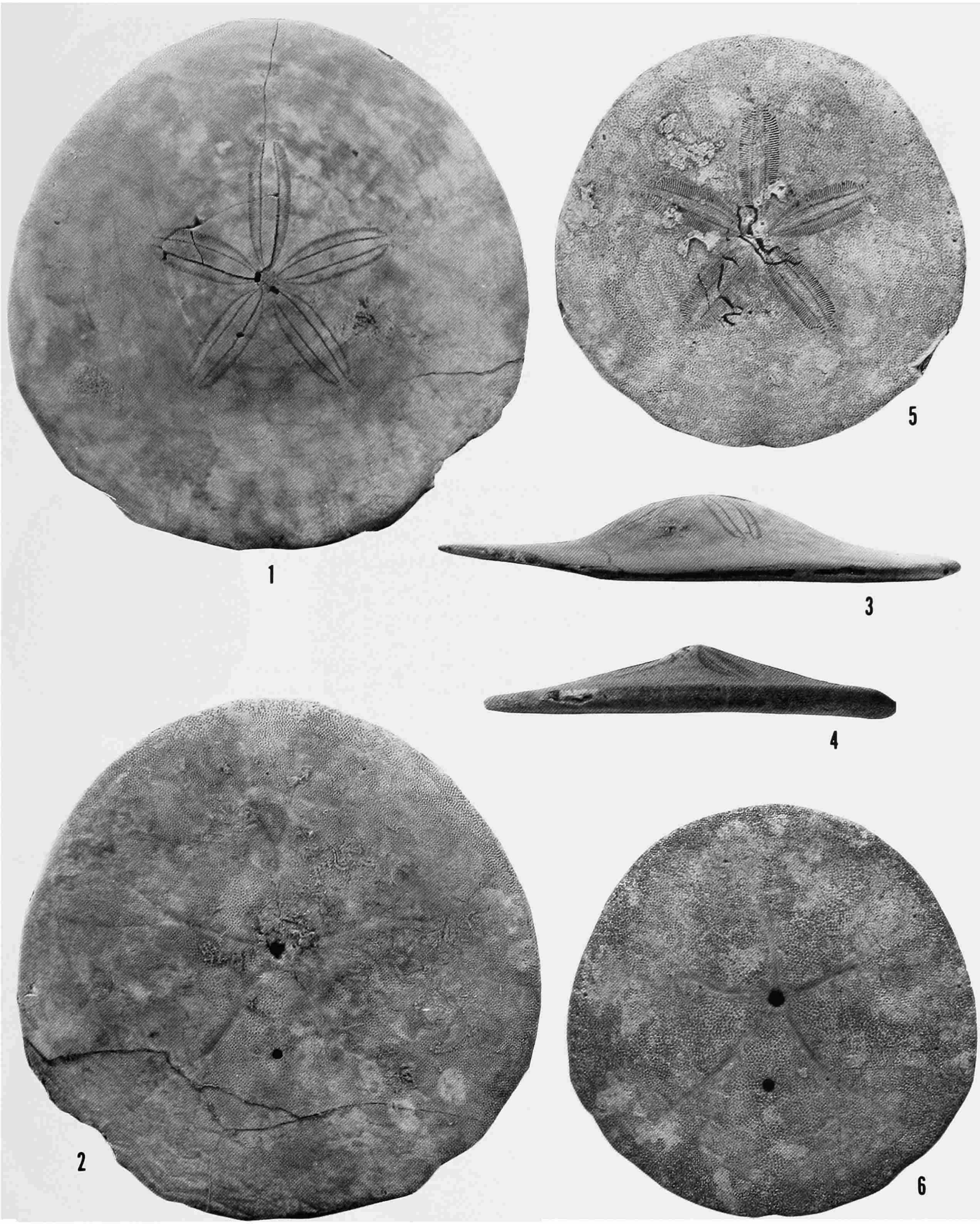
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PLATE 14

Periarchus lyelli (Conrad)

1, 2. Adapical, adoral views of USNM 264067, Castle Hayne Limestone, locality 12 (Ideal), × 1.5.
3–5. Adapical, right side, adoral views of USNM 264068 from same locality, × 1.5.
6, 7. Adapical, adoral views of USNM 264069 from same locality, × 1.5.

Periarchus rutriformis Paulson

8–10. Adapical, right side, adoral views of holotype, Museum of Geoscience, Louisiana State University, T-6934, from Castle Hayne Limestone, near Carlton, Duplin County, North Carolina, × 1.5.

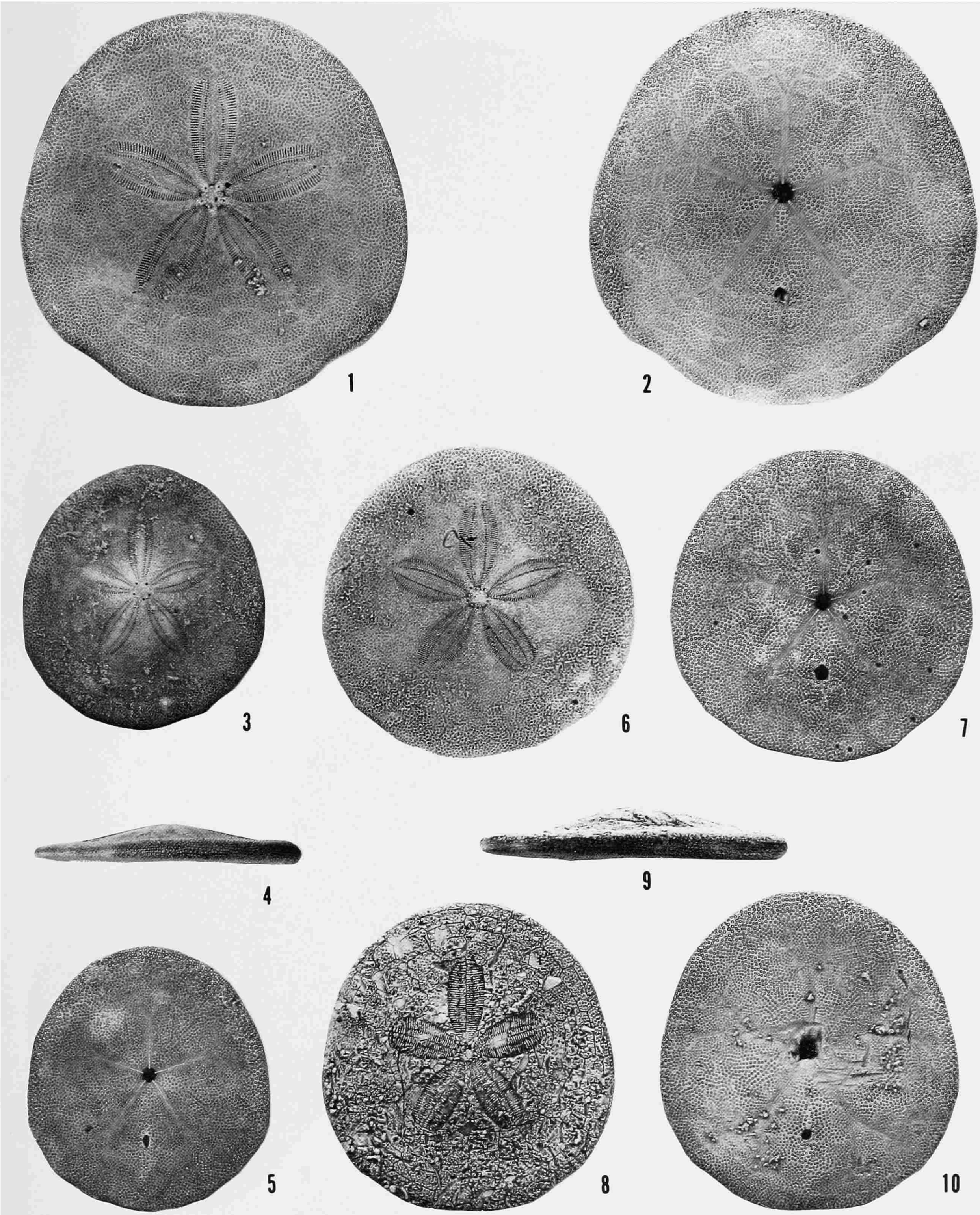
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PLATE 15

Agassizia wilmingtonica wilmingtonica Cooke

1–3. Adapical, right side, adoral views of holotype USNM 499004 from Castle Hayne Limestone, locality 26, × 2.5.
4, 5. Adapical, adoral views of USNM 264071, Castle Hayne Limestone, locality 12, × 2.5.
6, 7. Adoral, side views of USNM 264072, same locality, × 4.

Agassizia wilmingtonica inflata, new subspecies

8–10. Adapical, adoral, right side views of holotype, USNM 264073 from Santee Limestone, locality 37 (Georgetown), × 2.5.

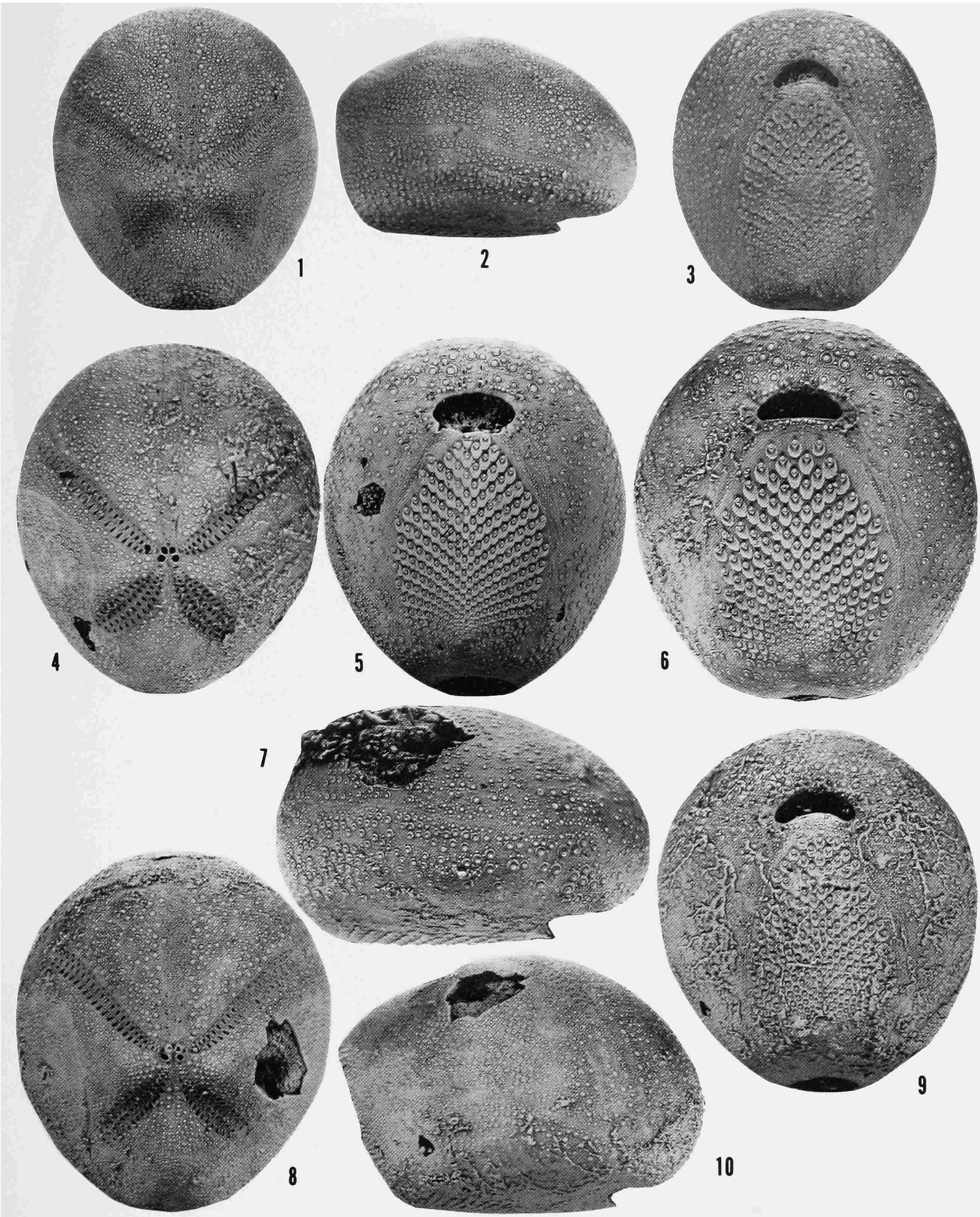
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PLATE 16

Linthia harmatuki, new species

1. Adapical view of USNM 264074 from Castle Hayne Limestone, locality 10 (Maple Hill, East Coast), × 1.
2. Adoral view of USNM 264075 from same locality, × 1.

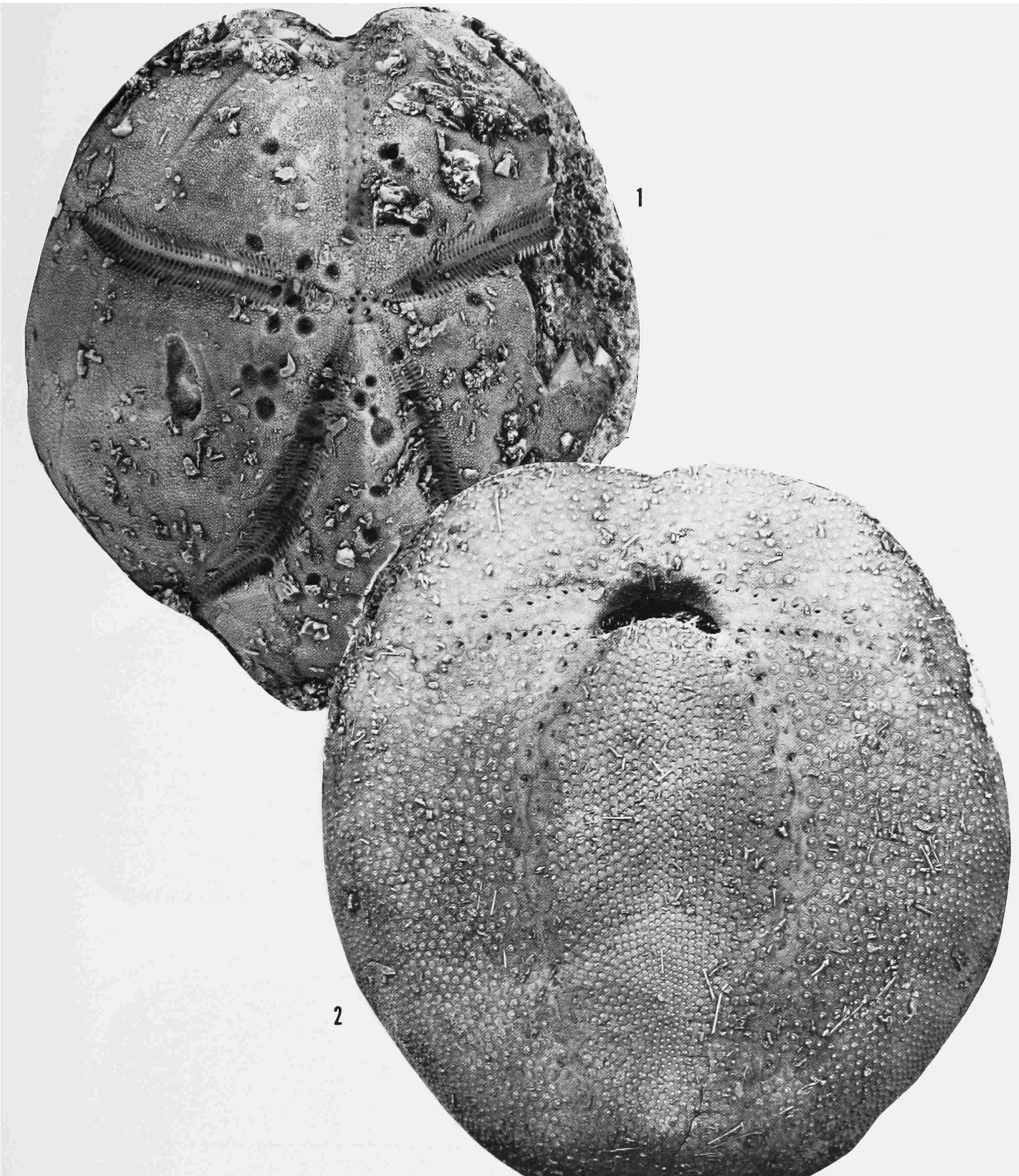
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PLATE 17

Linthia harmatuki, new species

1, 2. Adapical, right side views of holotype USNM 264076 from Castle Hayne Limestone, locality 10 (Maple Hill, East Coast), × 1.

Linthia wilmingtonensis Clark

3–6. Adapical, adoral, right side, rear views of USNM 264077 from Castle Hayne Limestone, locality 9 (Maple Hill, Lanier), × 1.25.

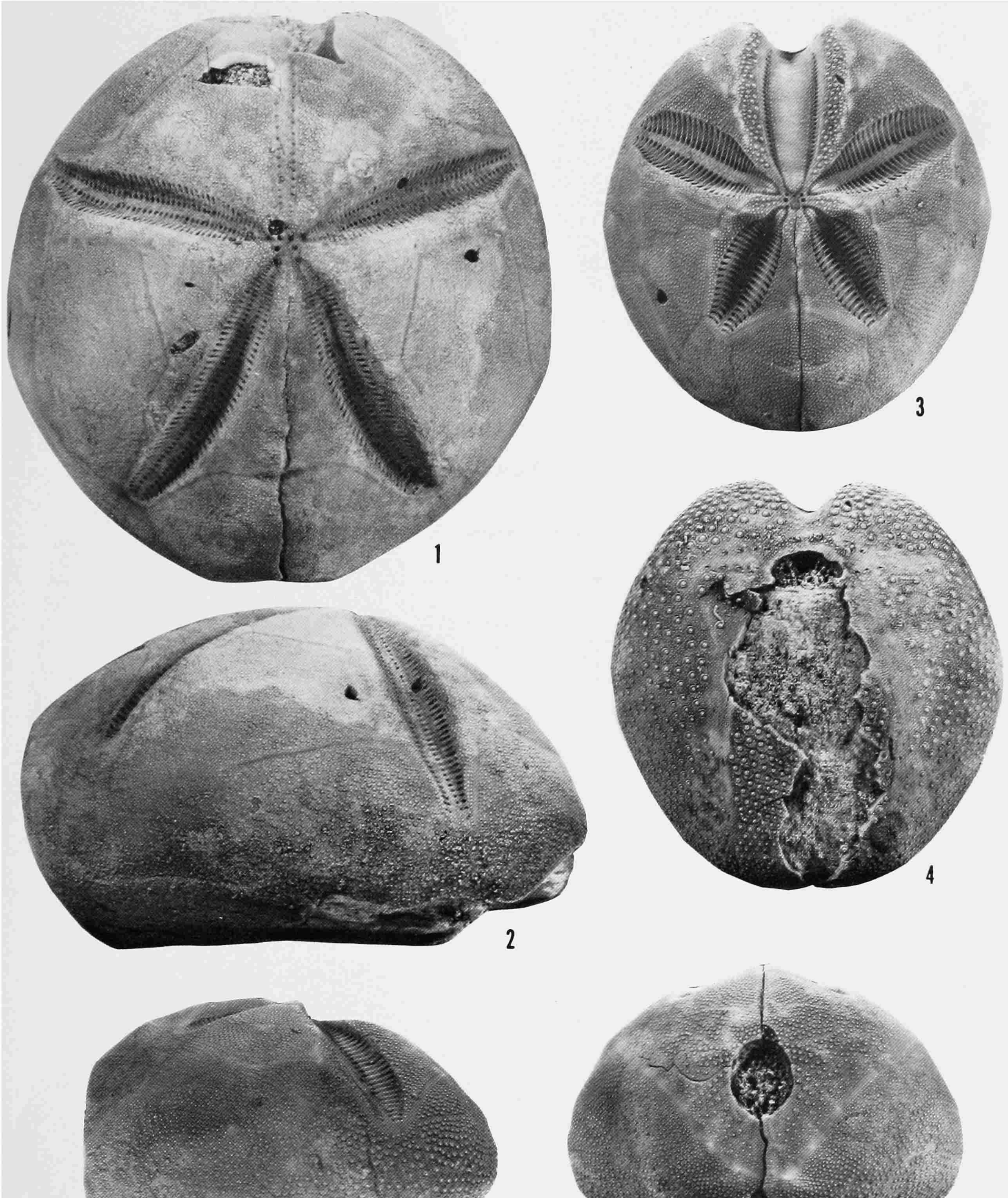
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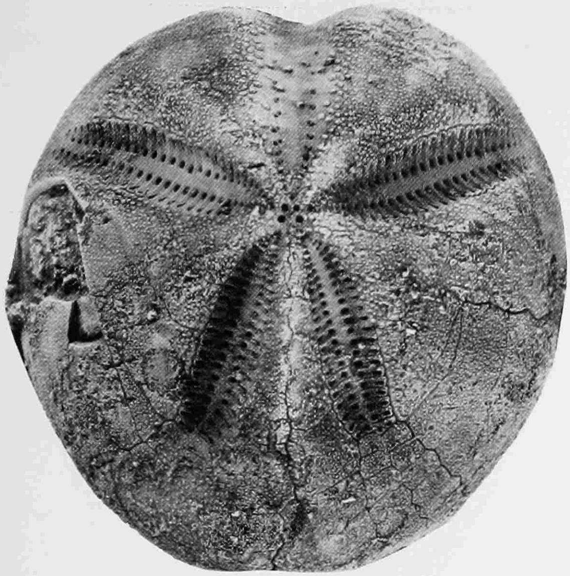
PLATE 18

Linthia hanoverensis Kellum

1–3. Adapical, right side, rear views of USNM 264078, Castle Hayne Limestone, locality 12 (Ideal), × 2.
4, 5. Adapical, right side views of USNM 264079 from same locality, × 1.25.
6. Adoral view of USNM 264080 from same locality, × 2.



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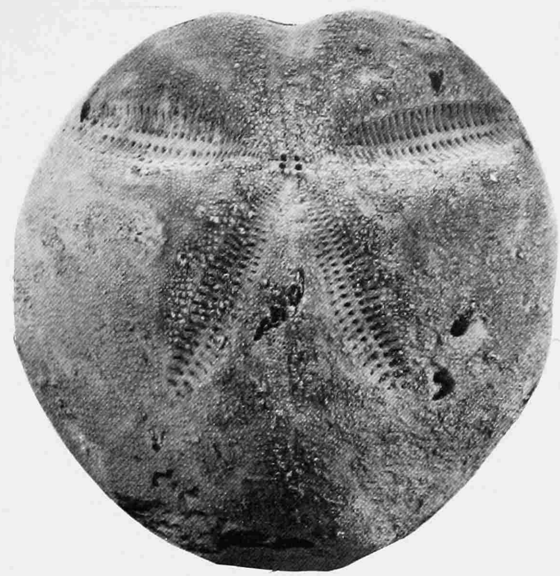

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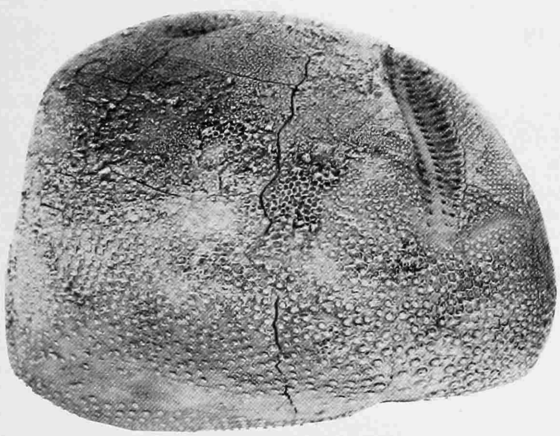

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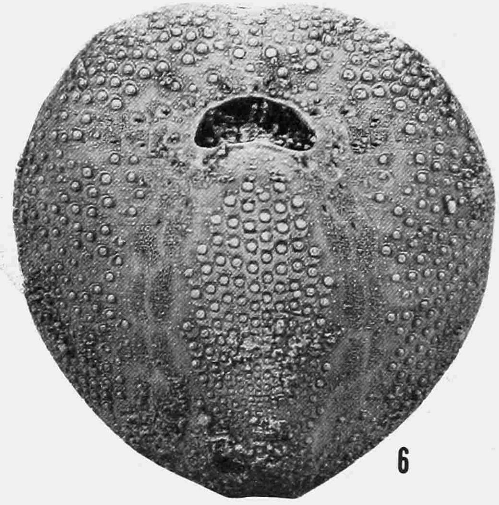

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PLATE 19

Maretia subrostrata (Clark)

1, 2. Adapical, adoral views of USNM 264081, Castle Hayne Limestone, locality 9 (Maple Hill, Lanier), × 1.75.

3–5. Adapical, right side, adoral views of USNM 264082, same locality, × 2.5.

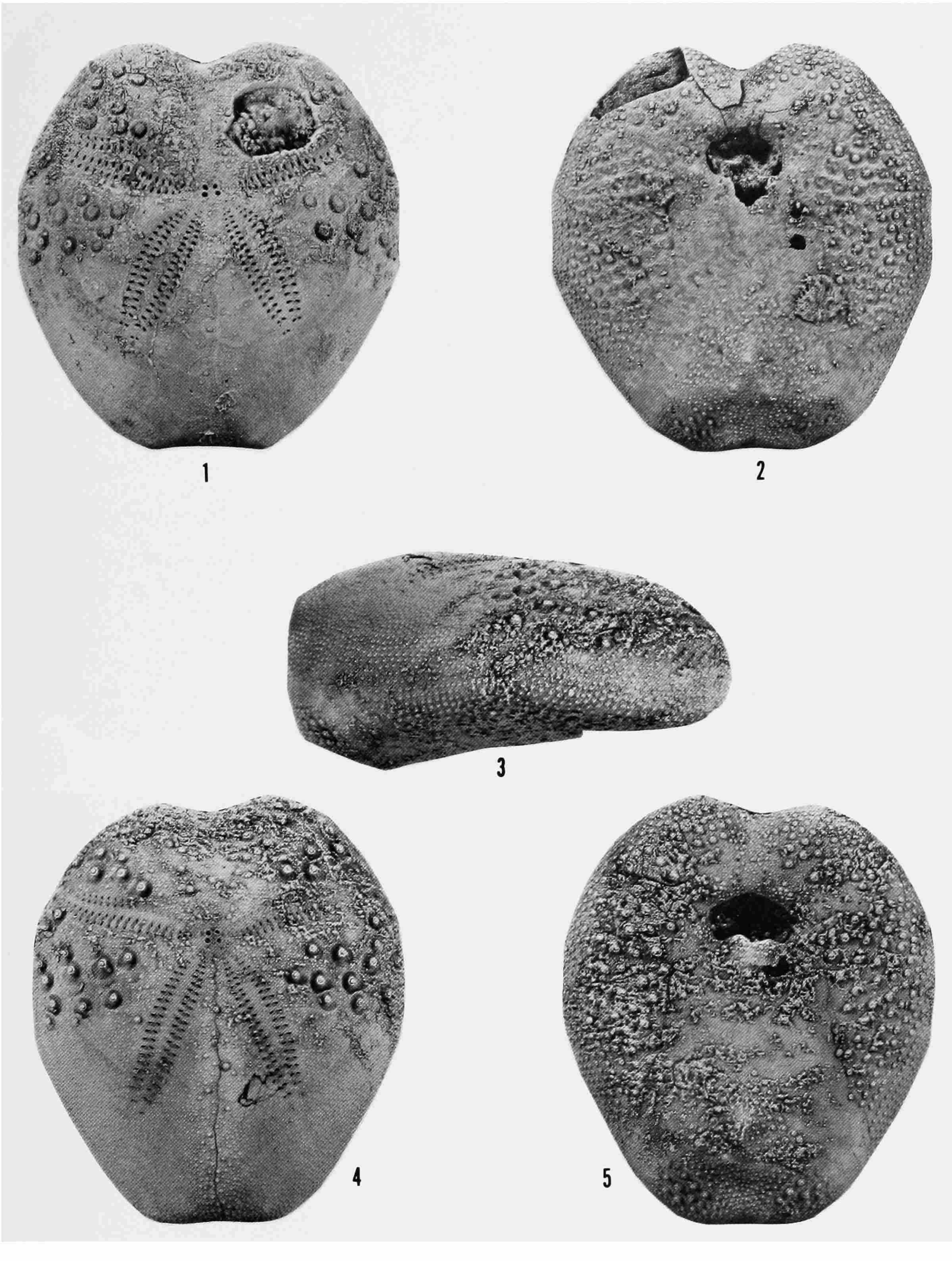
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PLATE 20

Eupatagus carolinensis Clark

1–3. Adapical, right side, adoral views of holotype USNM 166484, Castle Hayne Limestone, Wilmington, North Carolina, × 1.25.
4–6. Adapical, right side, adoral views of USNM 264083, Castle Hayne Limestone, locality 12 (Ideal), × 1.25.

Eupatagus wilsoni, new species

7–9. Adapical, right side, adoral views of holotype USNM 264084, Castle Hayne Limestone, locality 12 (Ideal), × 1.
10. Apical view of same specimen, × 8.
11. Adoral view of USNM 264085, from same locality, × 1.

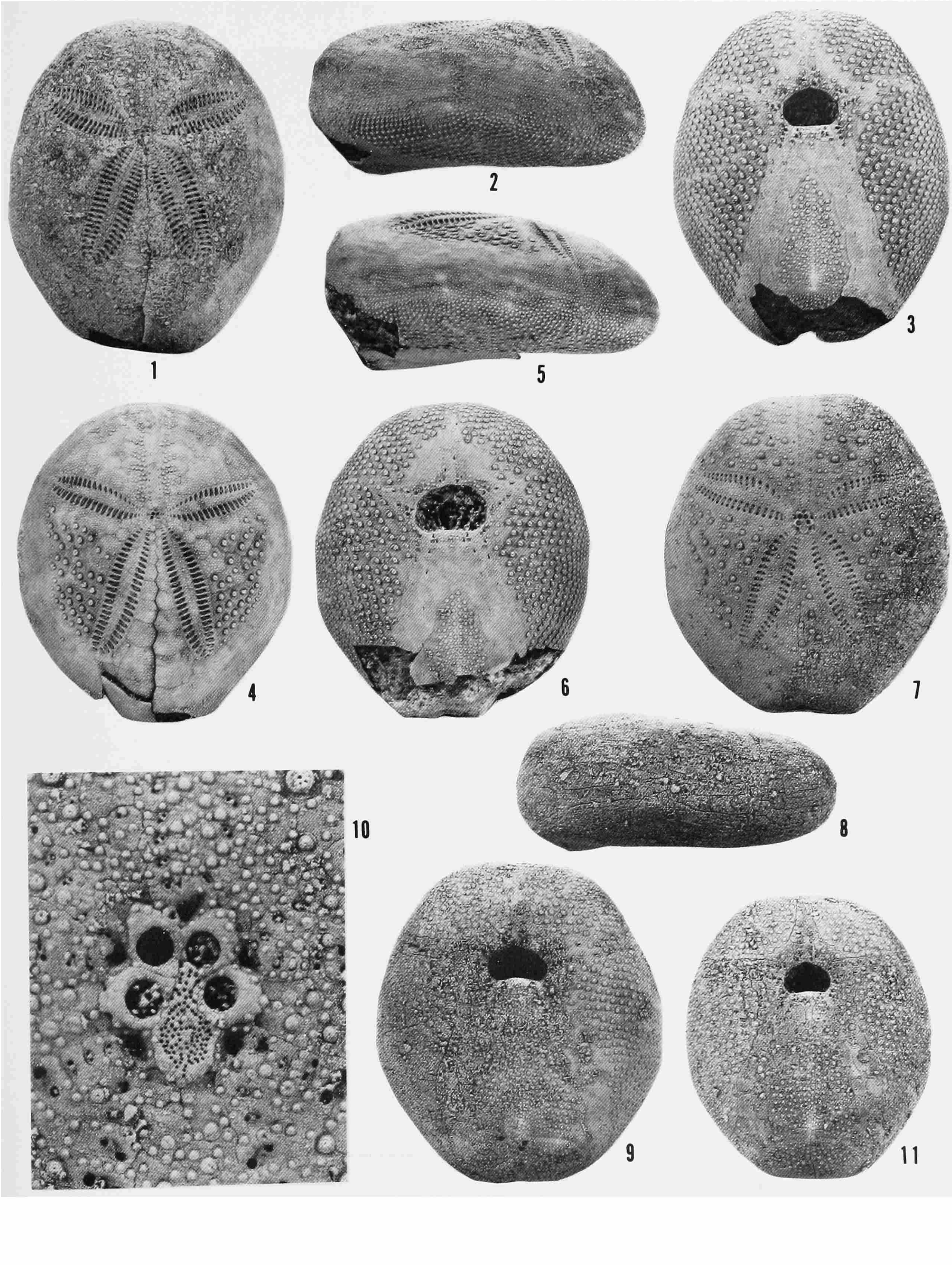
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PLATE 21

Eupatagus lawsonae, new species

1–4. Adapical, adoral, right side, rear views of holotype USNM 264086, Castle Hayne Limestone, locality 12 (Ideal), × 1.

Unifascia carolinensis (Clark)

5. Adoral view of USNM 264087, Castle Hayne Limestone, locality 9 (Maple Hill, Lanier), × 1.5.

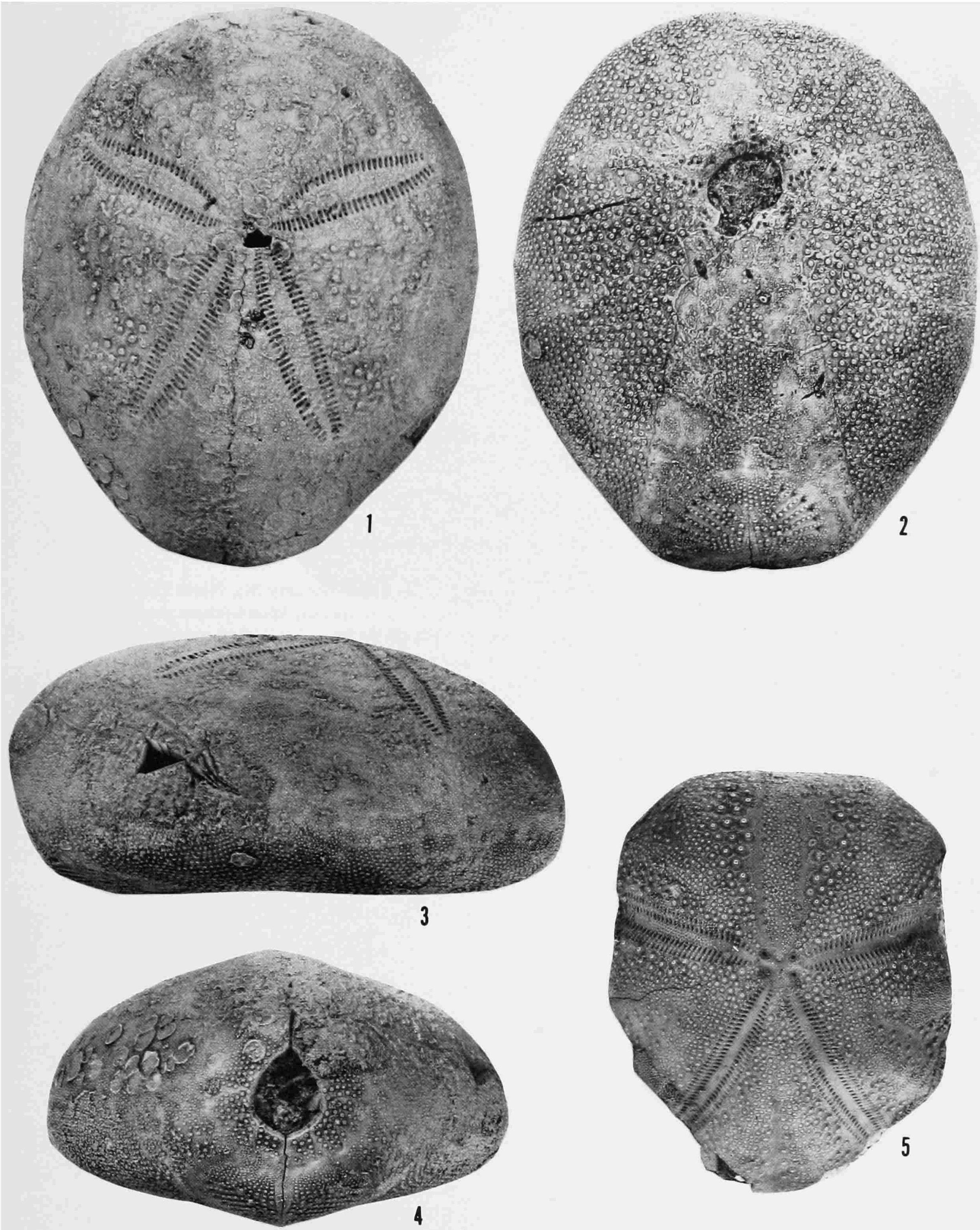
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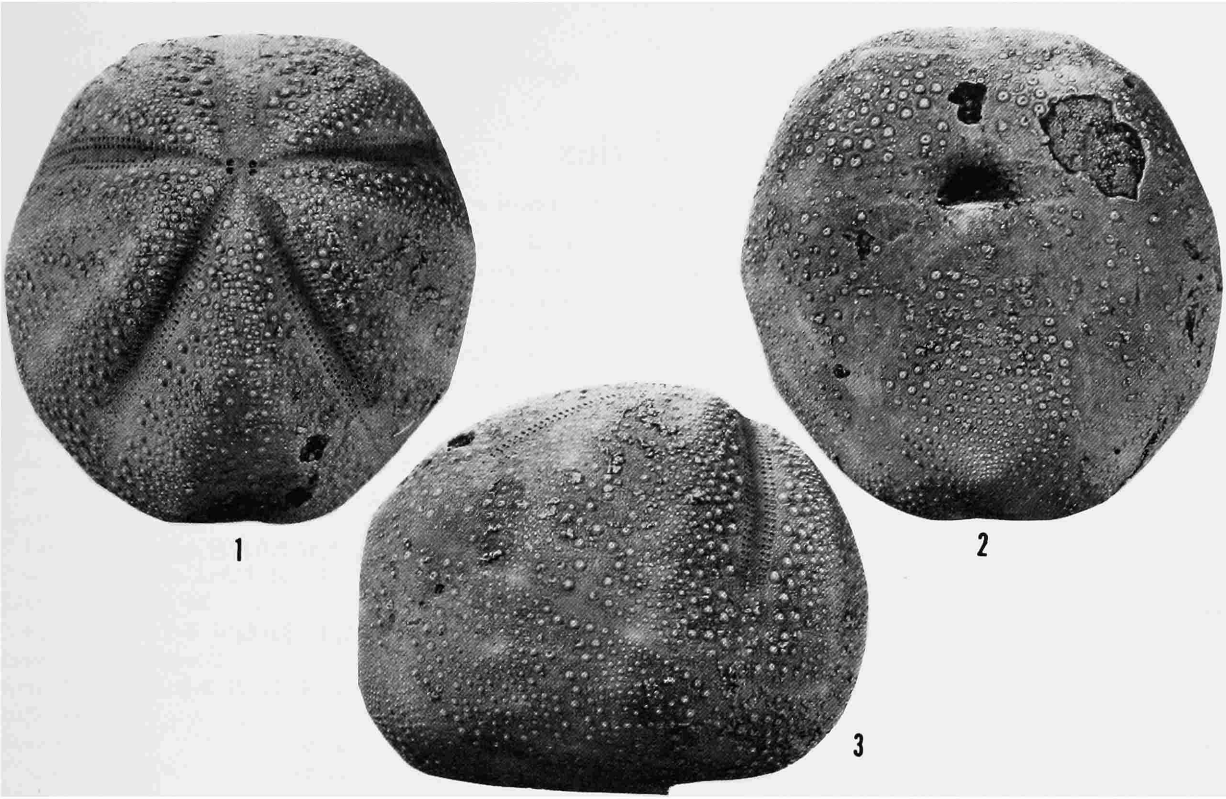
PLATE 22

Unifascia carolinensis (Clark)

1–3. Adapical, adoral, right side views of USNM 264088, Castle Hayne Limestone, locality 12 (Ideal), × 1.5.

4. Quarry of Martin Marietta Company near Castle Hayne (locality 34), North Carolina. The "middle zone" containing *Linthia harmatuki*, new species, *Rhyncholampas carolinensis* (Twitchell), *Eurhodia rugosa* (Ravenel) *depressa*, new subspecies, and *Protoscutella plana* (Conrad) can be seen pinching out between the basal member of the Castle Hayne Limestone, the New Hanover Member, and the "late zone." December, 1978.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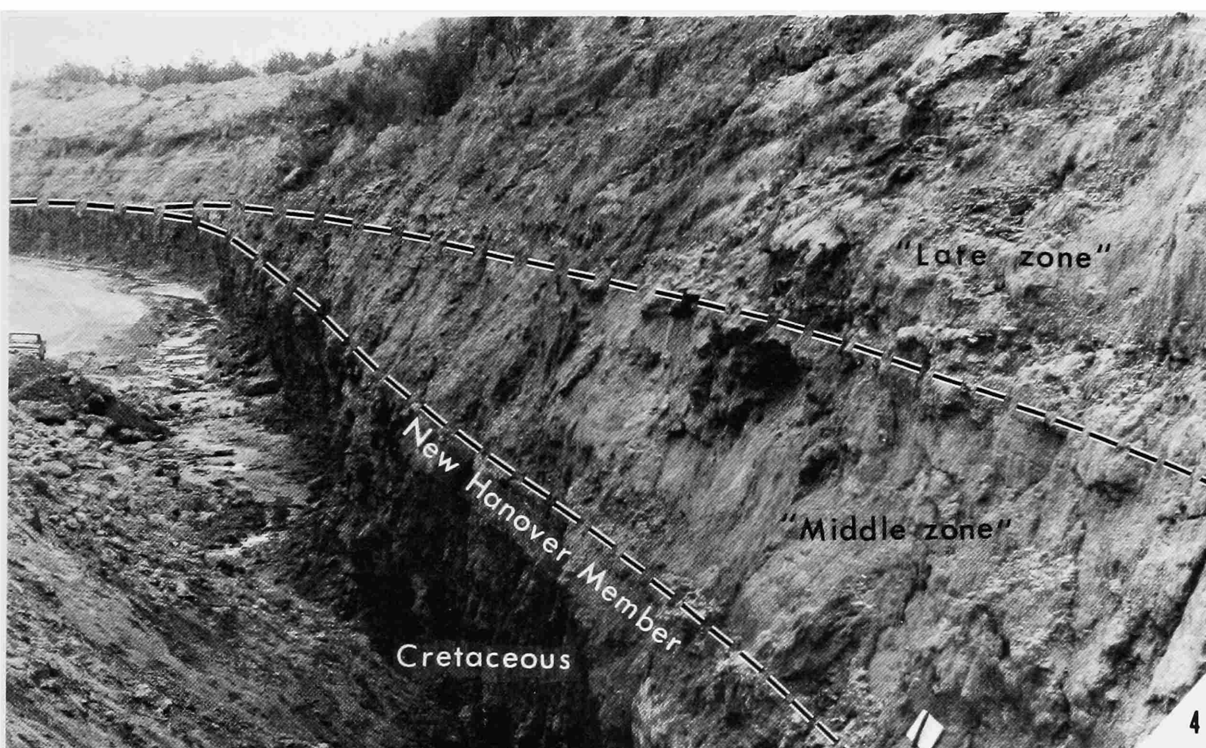
"Late zone"
"Middle zone"
New Hanover Member
Cretaceous
4

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(Synonyms and page numbers of principal accounts in italics)