THE SPECIES COMPOSITION AND DISTRIBUTION OF THE ASTEROIDEA OF THE GULF OF MEXICO AND THE CARIBBEAN

A Thesis

by

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ABSTRACT

The Species Composition and Distribution of the Asteroidea of the Gulf of Mexico and the Caribbean. (May 1974)

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An examination of the asteroids collected by the R/V *Alaminos* in the Gulf of Mexico and the Caribbean shows 1,793 specimens belonging to 55 species. The exclusively deep-sea family Porcellanasteridae, which was not previously recorded from the Gulf of Mexico and the Caribbean, is treated in more detail with the description of three species, one new, representing a probable new genus. Two new species of the family Goniasteridae are also described. The new taxa are not named here. A taxonomic key is constructed for the species present. The distribution of the asteroids is analyzed in view of previous ideas on vertical zonation and zoogeography. A critique and other ideas are then presented.

TO MOM AND DAD

ACKNOWLEDGMENTS

The time that I have spent at Texas A&M has been most rewarding. I have worked toward my degree as well as learned much about so much else. I wish to thank all those who have helped make my stay here enjoyable. My thanks to Mrs. Minnette McFarland for providing a scholarship which I was fortunate enough to receive. My thanks also to members of my committee and Maureen Downey for their assistance.

Although far from home, I was never long out of contact with home. My thanks to loved ones. I especially wish to thank my fiancee Ce for her love and patience and my mom and dad for their love and support.

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INTRODUCTION

Prior to 1973 the taxonomic investigations on asteroids of the Gulf of Mexico and the Caribbean were fragmentary and in many cases outdated. Major works were done by Perrier (1884), Sladen (1889), Verrill (1915), and Clark (1933, 1941). Recently Halpern (1970a, b) has done much on one of the largest families of asteroids of this area, the Goniasteridae. Downey (1973) published the most comprehensive study of the starfish in this area.

The idea of vertical zonation in the sea has been primarily concerned with the plankton (Wood, 1965; Banse, 1964; Vinogradova, 1970; and others) but the benthos have also been considered by many workers, especially Vinogradova (1962) and Menzies, George, and Rowe (1973). General schemes were presented by Bruun (1957) and Hedgpeth (1957a). Almost all of these investigations delimited zones by temperature, light, or depth. Menzies, George, and Rowe (1973) examined the distribution of the fauna itself to determine vertical "faunal units."

Zoogeographic studies have a long history. Woodward

The format and style follow <u>Limnology and Oceanography</u>.

(1856) defined a province as an area in which fifty percent of the species are endemic. Savage (1960) determined provinces by examining the fauna and calculating a "Coefficient of Difference" between the faunas of adjacent areas. Provinces in the sea were described by Ekman (1953) in his famous book, Zoogeography of the Sea. Hedgpeth (1957b) criticized the determination of zoogeographic regions when he stated that "they have been determined by the subjective appraisal of the specialist." Vinogradova (1959) proposed a scheme for the zoogeography of the deep sea benthos and Madsen (1961a) discussed the same topic. Menzies, George, and Rowe (1973) considered both bottom topography and temperature when they proposed a zoogeographic scheme for the deep sea.

There are three objectives for this thesis. The report of the taxa present and the artificial key serve to supplement taxonomic investigations of the asteroids from this area. The data collected are then used as a basis for a study on vertical zonation and zoogeography.

METHODS

Sampling

Each year from 1964 through 1973 at least one cruise of the R/V Alaminos has been for the purpose of sampling the marine benthos. Over ninety percent of the starfish collected during that time have been taken either in the benthic skimmer or otter trawls.

The benthic skimmer has been described by Pequegnat, Bright, and James (1970). It has a 3 meter gape and is towed at speeds of 2-4 knots.

The otter trawls used have been mainly the 57 feet or 20 meter trawls. Both were towed at speeds of 2-4 knots. The opening width is not known but sixty percent has been suggested by Pequegnat (1973) and so a 12 meter gape is postulated.

Collected specimens were either frozen or preserved in ten percent buffered formalin or seventy percent alcohol.

Identification

Several taxonomic studies were used for identification. A monograph on the Porcellanasteridae by Madsen (1961a), the general work by Spencer and Wright

(1966), and most of all the work of Downey (1973) were used. It was also sometimes necessary to refer to other literature by Sladen (1889), Verrill (1915), and Clark (1933, 1941). Finally, a number of specimens were sent to Maureen Downey for confirmation.

RESULTS

Data

Fifty-five species of starfish were identified from the collection of 1,793 specimens. Table 1 is a list of the species. Tables 2 and 3 present the number of samples, species, and specimens found in 100 fathom depth intervals in the Gulf of Mexico and the Caribbean.

General distributional patterns of starfishes in the Gulf of Mexico can be given because of the relatively extensive sampling there in comparison with the Caribbean, but the only thing clearly evident from tables 2 and 3 is that the Caribbean fauna is notably richer than that of the Gulf of Mexico.

The vertical distribution of species and number of specimens in the Gulf of Mexico appears to have maxima at 0-200 fathoms, 300-600 fathoms, 1200-1300 fathoms, and possibly 1600-1800 fathoms. These maxima, however, follow the general trend of a decrease in species and population with increasing depth (table 2).

The geographic distribution of species within the Gulf of Mexico shows little regional variation. Of the species taken at more than two locations five appear to be restricted to the West Gulf, but a literature review

Table 1. Species list of asteroids caught in the Gulf of Mexico and the Caribbean. Following the station number, in parentheses, are the number of specimens caught at that station.

	Station(s)
Order Platyasterida	
Family Luidiidae	
Luidia alternata	70-A-10-39(1)
L. barbadensis	65-A-9-20(1), 70-A-10-39(2)
L. barimae	71-A-8-41(2)
L. clathrata	72-A-4(1)
L. elegans	70-A-10-39(1), 71-A-8-65(90)
Order Paxillosida	
Family Astropectinidae	
Astropecten americanus	68-A-13-7(6), 68-A-13-19(1), 69-A-11-77(1), 69-A-13-41(3), 71-A-8-71(1)
A. antillensis	72-A-4(4)
A. cingulatus	72-A-13-12(14)
A. comptus	70-A-10-20(63)
A. nitidus	65-A-9-20(9), 69-A-11-76(1), 70-A-10-14(6), 70-A-10-39(2), 71-A-8-22(28), 71-A-8-65(15)
Dytaster insignis	67-A-5-15F(1), 67-A-5-16E(2), 68-A-3-3B(3), 68-A-3-7D(1), 68-A-7-3C(3), 68-A-7-4A(2), 68-A-13-9(1), 69-A-11-48(2), 69-A-13-28(1), 69-A-13-37(2), 70-A-10-9(1), 70-A-10-13(2), 70-A-10-28(1), 70-A-10-42(1), 70-A-10-48(5), 70-A-10-58(14),

Table 1. (Continued)

	Station(s)
Dytaster insignis	71-A-8-8(1), 71-A-8-10(2), 71-A-8-13(9), 71-A-8-36(3), 71-A-8-57(5)
Persephonaster echinulatus	68-A-13-1(1), 68-A-13-4(2), 68-A-13-8(1), 69-A-11-58(2), 70-A-10-15(6), 70-A-10-25(7), 70-A-10-27(1), 71-A-7-11(1), 71-A-8-29(22), 72-A-13-17(4)
Plutonaster intermedius	68-A-7-13B(3), 68-A-7-13D(4), 68-A-13-1(2), 68-A-13-15(1), 68-A-13-24(1), 68-A-13-27(4), 69-A-13-44(3), 71-A-7-43(1), 71-A-8-29(24)
Psilaster cassiope	68-A-13-15(2), 70-A-10-16(1), 70-A-10-29(20), 70-A-10-40(3)
P. patagiatus	70-A-10-9(5), 70-A-10-16(9), 70-A-10-20(1), 70-A-10-29(7),
Tethyaster grandis	68-A-13-5(8), 72-A-13-12(1)
Family Benthopectinidae	
Benthopecten simplex	69-A-11-44(22), 70-A-10-28(7), 71-A-8-8(1), 71-A-8-57(32)
Cheiraster echinulatus	65-A-9-15A(2), 65-A-9-20(30), 70-A-10-24(1), 70-A-10-26(7)
C. enoplus	68-A-7-10A(1), 72-A-13-17(21)
C. mirabilis	68-A-13-15(12), 68-A-13-23(5), 70-A-10-9(1), 70-A-10-15(4), 70-A-10-25(12), 70-A-10-31(9), 70-A-10-42(1), 71-A-7-11(2), 71-A-~~8~~7-10-(13)

Table 1. (Continued)

	Station(s)
Pectinaster gracilis	70-A-10-14(34), 70-A-10-15(1)
Family Goniopectinidae	
Goniopecten demonstrans	68-A-3-10B(3), 68-A-13-15(2), 70-A-10-16(1), 71-A-7-10(2), 71-A-7-11(1), 71-A-7-43(3), 71-A-8-29(2), 73-A-10-20(1)
Prionaster elegans	70-A-10-26(4)
Family Porcellanasteridae	
Styracaster elongatus	70-A-10-48(14), 70-A-10-54(86)
Thoracaster cylindratus	70-A-10-43(1), 70-A-10-48(31), 70-A-10-54(20)
Species A	70-A-10-50(2)
Order Valvatida	
Family Goniasteridae	
Goniaster tesselatus	72-A-13-12(1)
Anthenoides piercei	68-A-13-17(2), 69-A-11-76(4), 69-A-13-42(8), 70-A-10-14(1), 70-A-10-15(4), 70-A-10-26(3), 70-A-10-39(30), 71-A-7-65(1), 71-A-8-22(8), 71-A-8-41(6)
Ceramaster grenadensis	70-A-10-27(2), 70-A-10-42(1)
Ceramaster sp.	70-A-10-28(196), 70-A-10-50 (11), 71-A-7-11(3), 71-A-8-8 (1)
Circeaster americanus	70-A-10-9(1)
Litonotaster intermedius	68-A-7-4E(4), 68-A-13-9(1) 69-A-11-14(1), 69-A-11-89(1),

Table 1. (Continued)

	Station(s)
Litonotaster intermedius	69-A-13-37(1), 70-A-10-28(5), 70-A-10-43(1), 70-A-10-50(1), 70-A-10-58(7), 71-A-7-43(5), 71-A-8-10(3), 71-A-8-36(1), 71-A-8-57(12)
Nymphaster arenatus	65-A-9-15(4), 67-A-5-2H(1), 67-A-5-8(1), 68-A-13-1(6), 68-A-13-11(1), 68-A-13-12A(1), 68-A-13-15(3), 69-A-11-86(2), 69-A-13-44(2), 70-A-10-9(20), 70-A-10-13(6), 70-A-10-15(1), 70-A-10-20(3), 70-A-10-24(2), 70-A-10-25(23), 70-A-10-27(2), 70-A-10-29(55), 70-A-10-31(117), 70-A-10-42(10), 70-A-10-51(7), 71-A-7-49(2), 71-A-8-8(2), 71-A-8-10(3), 71-A-8-29(5), 71-A-8-40(57), 71-A-8-73(1), 72-A-13-23(3)
Paragonaster subtilis	69-A-13-37(2), 70-A-10-58(2)
Plinthaster dentatus	68-A-13-4(3), 69-A-11-86(2), 70-A-10-9(3), 70-A-10-16(6), 70-A-10-20(1), 70-A-10-27(1), 70-A-10-29(4), 70-A-10-31(3), 70-A-10-42(1), 70-A-10-51(5), 71-A-7-10(1), 71-A-7-11(1), 71-A-8-29(1), 71-A-8-40(30), 72-A-13-17(2)
Pseudarchaster sp.	65-A-9-15(1), 70-A-10-14(10), 70-A-10-16(2), 70-A-10-26(5), 70-A-10-31(6), 70-A-10-40(8), 71-A-7-43(1)
Rosaster alexandri	65-A-9-15A(1), 65-A-9-20(12), 70-A-10-14(29), 70-A-10-39(13)

Table 1. (Continued)

Species	Station(s)
Tosia parva	70-A-10-39(1)
Species B	70-A-10-6(1)
Family Odontasteridae	
Odontaster hispidus	68-A-7-13A(1)
Order Spinulosida	
Family Echinasteridae	
Henricia antillarum	70-A-10-27(6)
H. species	70-A-10-16(1)
Family Pterasteridae	
Pteraster acicula	68-A-7-13D(3)
P. militaroides	65-A-9-15(1), 70-A-10-27(3)
P. personatus	71-A-8-57(3)
Calyptraster coa	71-A-8-36(1)
C. personatus	70-A-10-28(2), 70-A-10-50(1)
Hymenaster modestus	70-A-10-28(11), 70-A-10-50(2), 71-A-8-36(3)
H. rex	71-A-8-57(1)
Order Forcipulatida	
Family Asteriidae	
Ampheraster alaminos	67-A-5-15F(2), 67-A-5-16E(4), 68-A-7-4E(9), 69-A-11-52(1), 69-A-13-28(2), 69-A-13-37(2)

Table 1. (Continued)

	Station(s)
Coronaster briareus	65-A-9-20(1)
Order Zorocallida	
Family Zoroasteridae	
Zoroaster fulgens	68-A-13-1(1), 69-A-11-44(2), 69-A-13-44(1), 70-A-10-9(1), 70-A-10-12(1), 70-A-10-13(5), 70-A-10-16(1), 70-A-10-29 (20), 70-A-10-28(1), 70-A-10-31(3), 70-A-10-40(27), 70-A-10-42(5), 70-A-10-51(2), 71-A-7-11(2), 71-A-8-24(1), 71-A-8-29(5), 71-A-8-57(8)
Doraster constellatus	68-A-7-1A(16), 69-A-13-44(2), 70-A-10-15(17), 70-A-10-14 (2), 71-A-7-11(2), 72-A-13-17(5)
Order Euclasterida	
Family Brisingidae	
Brisingella verticellata	68-A-13-8(2)
Midgardia xandaros	68-A-13-4(1), 68-A-13-15(1), 70-A-10-31(1), 71-A-7-11(1), 71-A-8-60(1)

Table 2. Number of samples, species, and specimens in 100 fathom depth intervals in the Gulf of Mexico

Depth interval	Number of samples	Number of species	Number of specimens
0-100	14	12	232
100-200	26	5	47
200-300	15	3	8
300-400	14	13	136
400-500	19	10	48
500-600	21	7	76
600-700	12	3	10
700-800	14	1	3
800-900	4	3	17
900-1000	2	0	0
1000-1100	4	2	2
1100-1200	8	7	58
1200-1300	2	7	61
1300-1400	2	1	1
1400-1500	5	2	3
1500-1600	1	1	3
1600-1700	4	4	10
1700-1800	10	4	53
1800-1900	3	2	2
1900-2000	6	0	0
2000-2100	7	1	4
Total	194	28	774

Table 3. Number of samples, species, and specimens in 100 fathom depth intervals in the Caribbean

Depth interval	Number of samples	Number of species	Number of specimens
0-100	0	0	0
100-200	5	13	133
200-300	4	9	90
300-400	1	3	37
400-500	3	10	173
500-600	2	3	1
600-700	6	8	154
700-800	1	4	19
800-900	0	0	0
900-1000	0	0	0
1000-1100	2	3	14
1100-1200	0	0	0
1200-1300	1	7	223
1300-1400	0	0	0
1400-1500	1	5	17
1500-1600	0	0	0
1600-1700	1	2	2
1700-1800	0	0	0
1800-1900	0	0	0
1900-2000	1	0	0
2000-2100	0	0	0
2100-2200	1	0	0

Table 3. (Continued)

Depth interval	Number of samples	Number of species	Number of specimens
2200-2300	1	3	50
2300-2400	2	0	0
2400-2500	1	2	106
Total	33	72	1019

reveals that only one of these, *Midgardia xandaros*, is actually so restricted (Downey, 1973). The East Gulf has been less sampled than the West Gulf and it is probable that future investigations will discover *M. xandaros* throughout the Gulf. There appears to be no marked latitudinal variation of species in the Gulf.

The Porcellanasteridae and possible new species

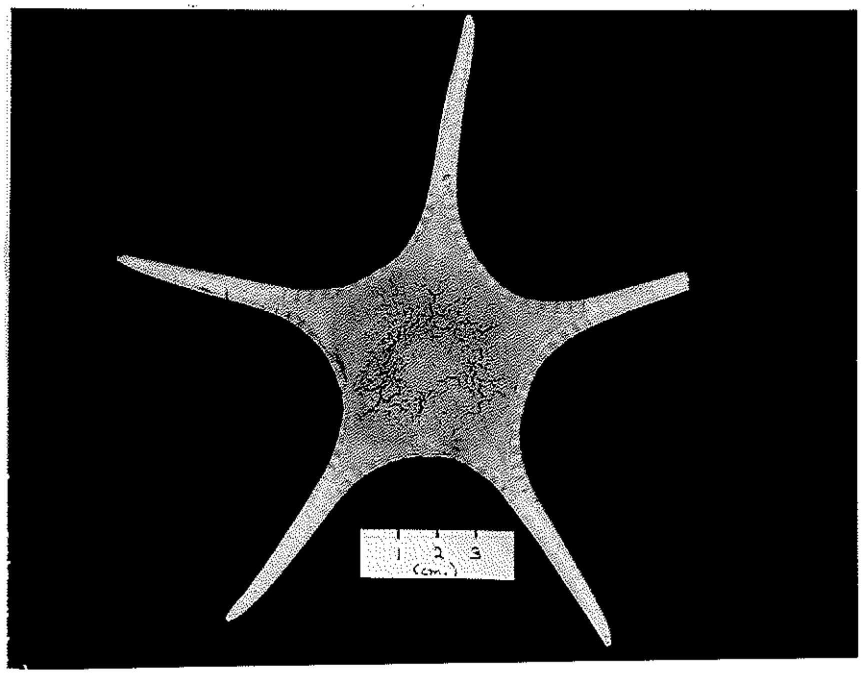
The Porcellanasteridae are an exclusively deep sea family that have been previously unreported in the Gulf of Mexico and the Caribbean. Two species of two genera were taken during cruise 70-A-10 in the deep waters of the Caribbean. Both species are described below.

Thoracaster cylindratus Sladen, 1883

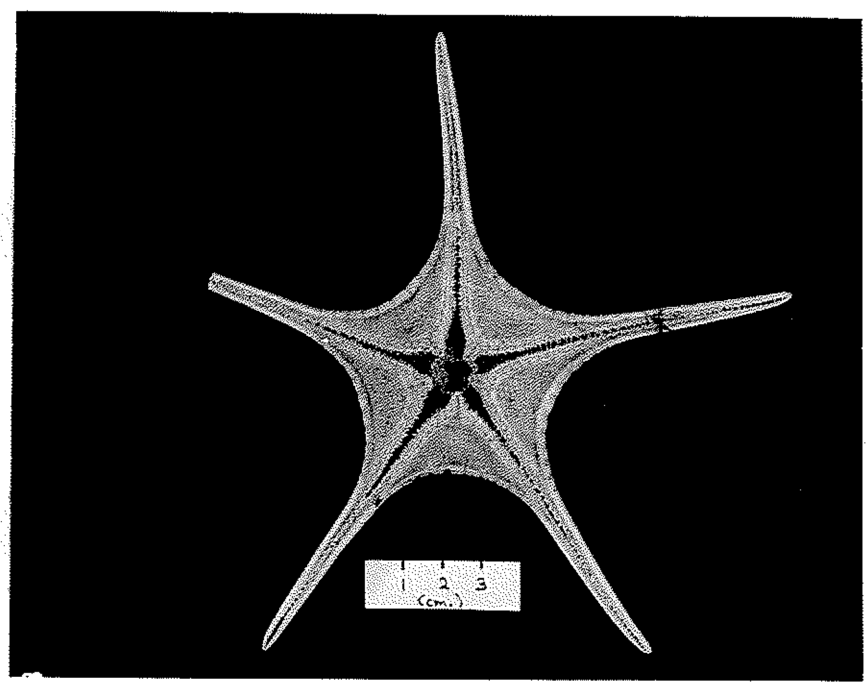
Figure 1: A, B

Diagnosis.--This species is unique in the family in having an odd marginal plate interradially and having the superomarginal plates in contact along the dorsal midline of the arms.

Description.--The dorsal surface contains the madreporite, which is separated from the odd marginal plate by 2-4 rows of paxillae. The madreporite is flat, roughly ovular, and approximately 6 mm. wide in the largest



A



B

Figure 1: A. Aboral view of Thoracaster cylindratus

B. Oral view of same

specimen. The superomarginal plates are bare except for scattered spinules. The low crowded dorsal paxillae consist of a pedicel equal in height to its cover of 10-15 uniform spinules.

The ventral surface contains no paxillae. The irregularly shaped actinal intermediate plates are covered by 8-12 scattered spinules. The adambulacral plates each bear 4-5 slightly scattered furrow spines. Behind these spines are an irregular row of spinules similar to those of the adjacent plates. The convex mouth plates have 2 large spines at their apex and smaller spines and spinules scattered on the surface of the plates. Seven spines similar to the furrow spines of the adambulacral plate are present along each furrow edge of the mouth plates. Fourteen cribriform organs are present in the larger specimens.

Smaller specimens (R = 50 mm.) are easily identifiable. The notable difference is a general reduction in the quantity of particular features. Paxillar spinules number 4-10, cribriform organs are as few as 6, superomarginal plates are as few as 6 and are very bare except for isolated spinules.

Distribution.--This species was caught at three different stations in the Caribbean. Specimens range in size from R/r = 87/24 to R/r = 12/7. It has been taken previously in 20 dredgings from the East and Tropical Atlantic, North Indian Ocean, Eastern Tropical Pacific, and Western North Pacific (Madsen, 1961a). The present recorded depths fall within the range previously recorded (2600-5000 m), but the temperature, about 4°C, is above that previously recorded (1.3-2.8°C).

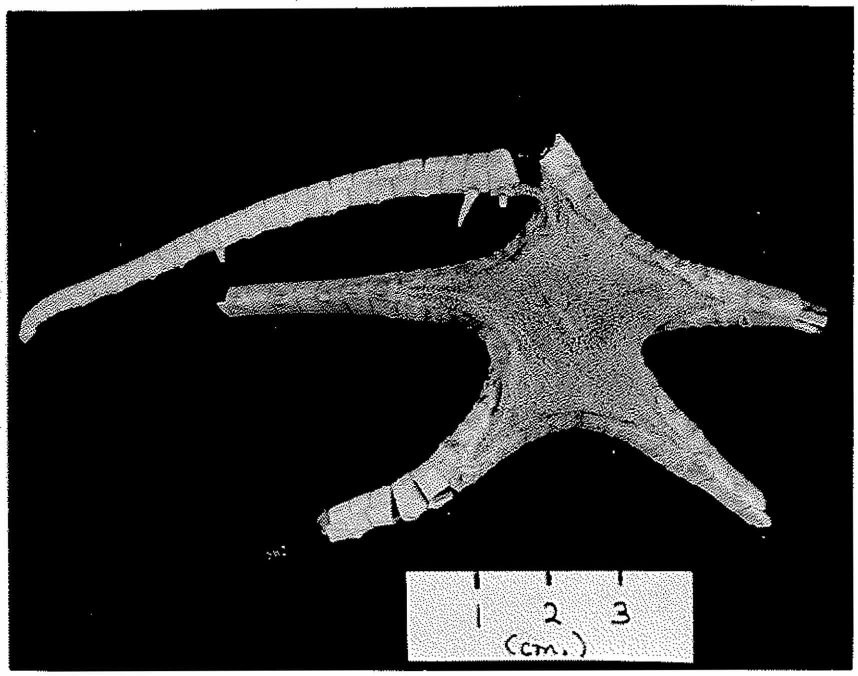
Material examined.--Station 70-A-10-43 R/r = 63/18. Station 70-A-10-48 R/r = 81/20, 78/20, 87/21, 82/21, 72/21, 65/19, 76/17, 80/20, 75/21, 72/17, 72/17, 79/21, 40/14, 86/21, 86/26, 87/24, 68/23, 78/19, 84/23, 78/22, 73/20, 77/20, 23/10, 20/10, 22/11, 18/9, 18/10, 19/10, 12/7. Station 70-A-10-54 R/r = 40/20, 45/23, 38/20, 35/18, 31/16, 38/18, 32/15, 36/19, 32/16, 32/17, 34/19, 28/12, 21/10, 23/13, 20/10, 20/11, 18/9, 18/9, 18/9, 18/8.

Styracaster elongatus Koehler, 1907

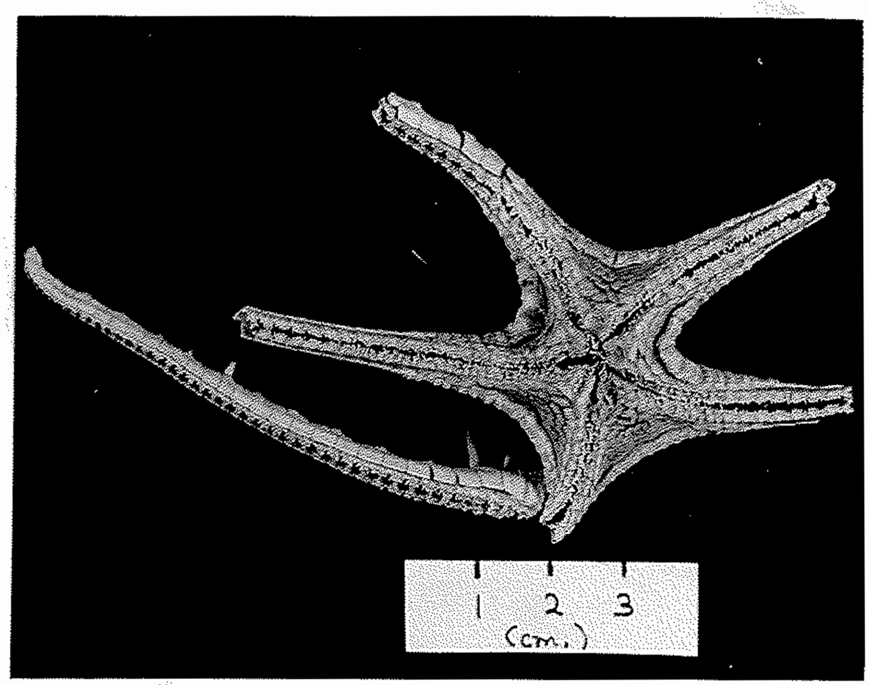
Figure 2: A, B

Diagnosis.--*Styracaster* is recognized by the presence of long spines dorsally along the midline of the arms.

Description.--The dorsal surface has short paxillae topped by 4-6 spinules. The madreporite is roughly circular, 5 mm. wide, and tends to bulge beyond the margin. The superomarginal plates are bare except for



A



B

Figure 2: A. Aboral view of Styracaster elongatus

B. Oral view of same

9-12 hyaline tipped spines along the midline of the arms. These spines are up to 9 mm. long.

The ventral surface is covered by bare imbricate plates that do not extend onto the arms. The spinulation on the adambulacral plates varies. Generally, 4-5 lanceolate furrow spines are present. Behind these spines, a spinule is generally present distally on each plate, however, spinules may be proximal, proximal and distal, or not present. Since Madsen distinguishes the 3 species S. elongatus, S. caroli and S. horridus primarily on the basis of the subambulacral spinulation, it is questionable whether the 3 species are valid. Present specimens need be compared with type material. The tumid oral plates have a cluster of 4 large spines at the apex and 7-8 lateral spines like the adambulacral furrow spines. Seven to 9 cribriform organs are present.

Smaller specimens have 1-3 superomarginal spines, 3-5 cribriform organs, oculars with 3 spines, and variable adambulacral armature.

Distribution.--This species was taken at 2 stations where the previous species was also taken. R/r range from 94/16 to 12/5. It also has been taken 7 times previously in the Eastern North Atlantic, the Bay of Biscay, off the Azores, and in the Indian Ocean (Madsen, 1961a). Its occurrence in the Caribbean is within the previously recorded range of 3310-4870 m, but again the temperature of 4°C exceeds previous recorded temperatures of 1.8°C.

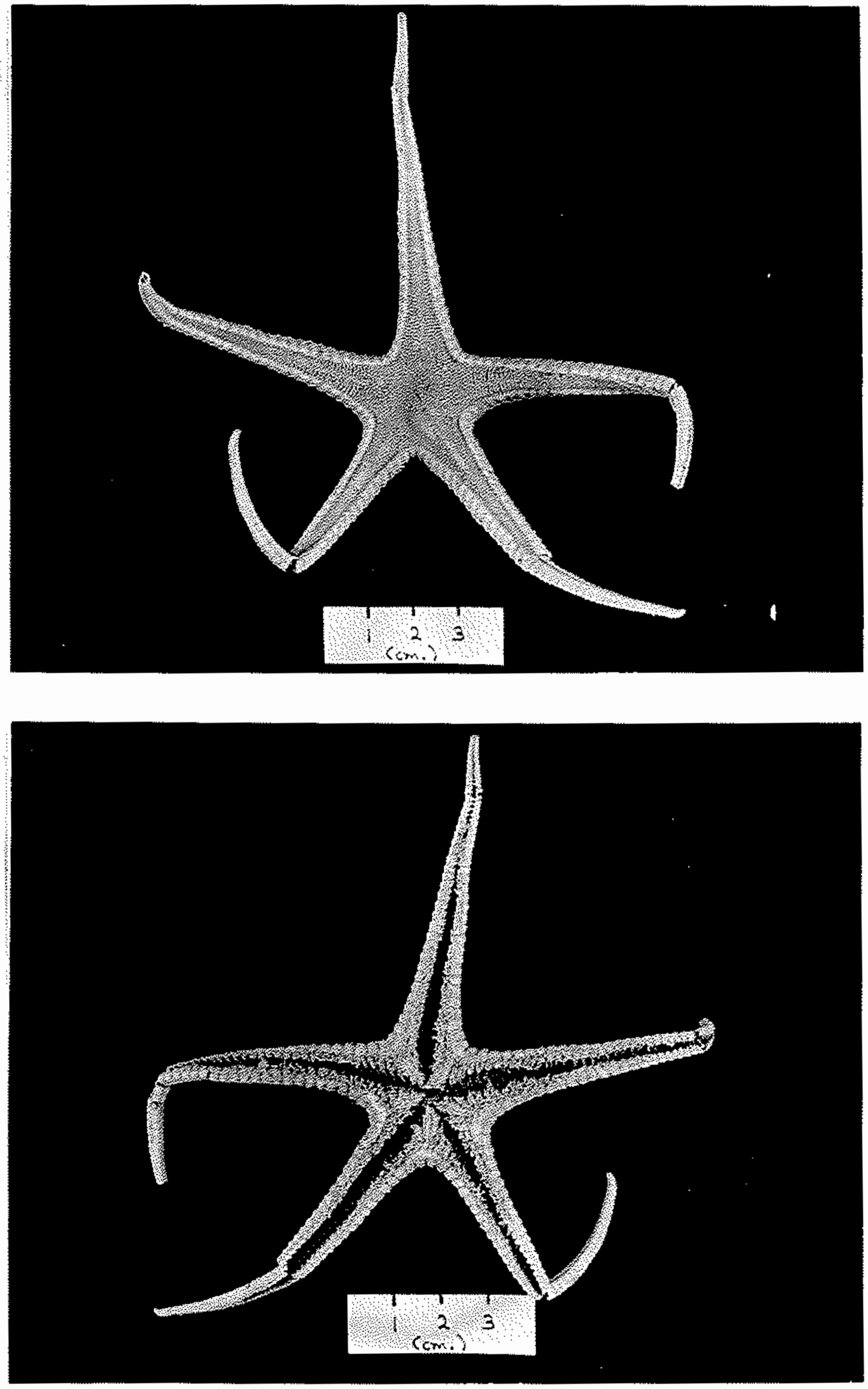
Material examined.--Station 70-A-10-48 R/r = 81/17, 94/16, 75/18, 71/19, 91/16. Station 70-A-10-54 R/r = 24/12, 25/11, 26/10, 29/12, 21/10, 24/11, 33/11, 29/14, 20/8, 24/10, 21/8, 23/9, 24/10, 20/10, 18/8, 29/14, 22/9, 21/7, 19/8, 28/11, 26/11, 20/9, 17/7, 19/10, 24/10, 24/10, 26/11, 28/11, 22/10, 24/6, 12/5, 23/12, 25/9, 26/11, 25/9, 26/8, 28/11, 19/8, 24/9, 24/9, 24/1, 22/9, 23/10, 30/9, 24/11, 24/7, 22/7, 26/13, 21/8, 22/6, 23/8, 24/8, 22/9, 27/10, 28/13, 27/11, 27/13, 26/11, 25/8, 23/13, 23/10, 23/11, 22/10, 23/9, 23/11, 24/11, 28/10, 20/9, 15/9, 19/11, 20/8, 21/9, 19/9.

Porcellanasteridae, new genus, new species

Figure 3: A, B

Diagnosis.--Superomarginal plates not joined along midline of arms. The cribriform organs not as distinct as in the two preceding species.

Description.--The dorsal surface is covered by small ovular paxillae. The paxillae have a short base equal in height to its cover of 10-20 small spinules. They extend to the tip of the arm. The superomarginals are confined mostly to the sides of the arms and are



A

B

Figure 3: A. Aboral view of Species A

B. Oral view of same

covered by short, fine spinules. The cribriform organs appear to be very rudimentary, almost resembling fascioles. The madreporite is roughly circular and covers an area of 5-6 paxillae. It lies 1/3 of the way from the margin to the center of the disc.

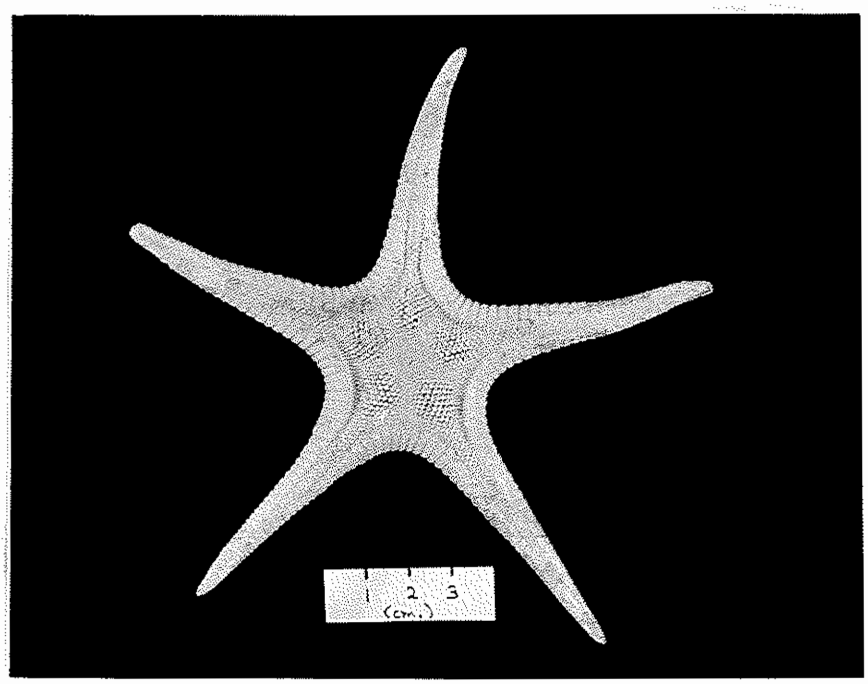
The ventral surface has a small interradial area that extends to the third or fourth inferomarginal plate. Most of the inferomarginals on the proximal half of each arm have 2 or more long, thin spines directed dorsally. The adambulacral plates have a palmate furrow series of 6 long spines which are followed by 2 or 3 irregular rows of spines. The mouth plates are small, tumid and very distinctive. Two broad, flat spines are at its apex. A group of 4-5 similar but smaller spines lie below and adjacent to each side of these spines. The surface of the mouth plate also has several of these flat spines as well as regular spinules.

Material examined.--Station 70-A-10-50 R/r = 86/13, 65/10.

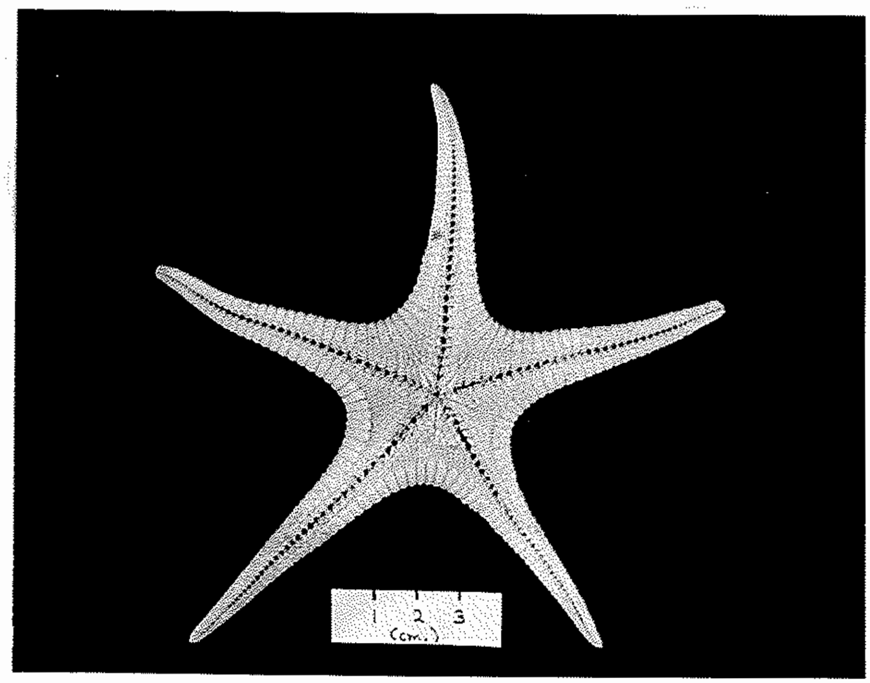
Pseudarchaster, new species

Figure 4: A, B

Diagnosis.--_Pseudarchaster_ has an unpaired spine at the apex of each mouth plate, and has several rows of paxillae extending dorsally along the entire length



A



B

Figure 4: A. Aboral view of <u>Pseudarchaster</u> sp.

B. Oral view of same

of the arm.

Description.--The dorsal surface is covered by paxillae very crowded except for the region extending from the base of the arms almost to the disc center. The paxillae have 12-20 granules forming a circular compact top half as high as its circular base. The madreporite is round and covers an area approximately equal to 3 or 4 paxillae. The superomarginals are over half as wide as the paxillar area on the arms. Each is densely covered with short granules stouter than those of the paxillae.

The ventral surface is heavy spined. The large interradial area is covered by many square shaped plates covered by numerous spinules. Each plate generally bears 1 spinule larger than the rest. The adambulacral plates have a row of 8 furrow spines which are followed by 2 irregular rows of spines. There is a single stout spine at the apex of each mouth plate which is flanked on both sides by a slightly smaller spine and then 8 spines similar to the furrow spines. The surface of the mouth plate is covered by 4 irregular rows of spinules.

Thirty-three specimens of <u>Pseudarchaster</u> were taken from the Gulf of Mexico and the Caribbean. Sizes ranged from R/r = 153/44 to R/r = 11/5. The large range in size makes it difficult to determine if more than one species is involved. The characters given were for specimens with R greater than 30 mm.

Material examined.--Station 71-A-7-43 R/r = 153/44. Station 70-A-10-16 R/r = 90/23, 70/20. Station 70-A-10-14 R/r = 15/7, 14/6, 13/5, 17/7, 16/7, 14/6, 12/5, 12/7, 11/5, 13/6. Station 70-A-10-31 R/r = 62/20, 42/17, 38/13, 33/11, 36/13, 24/8. Station 65-A-9-14 R/r = 14/6. Station 70-A-10-40 R/r = 26/9, 21/11, 16/6, 17/7, 19/6, 13/5, 13/6, 12/5.

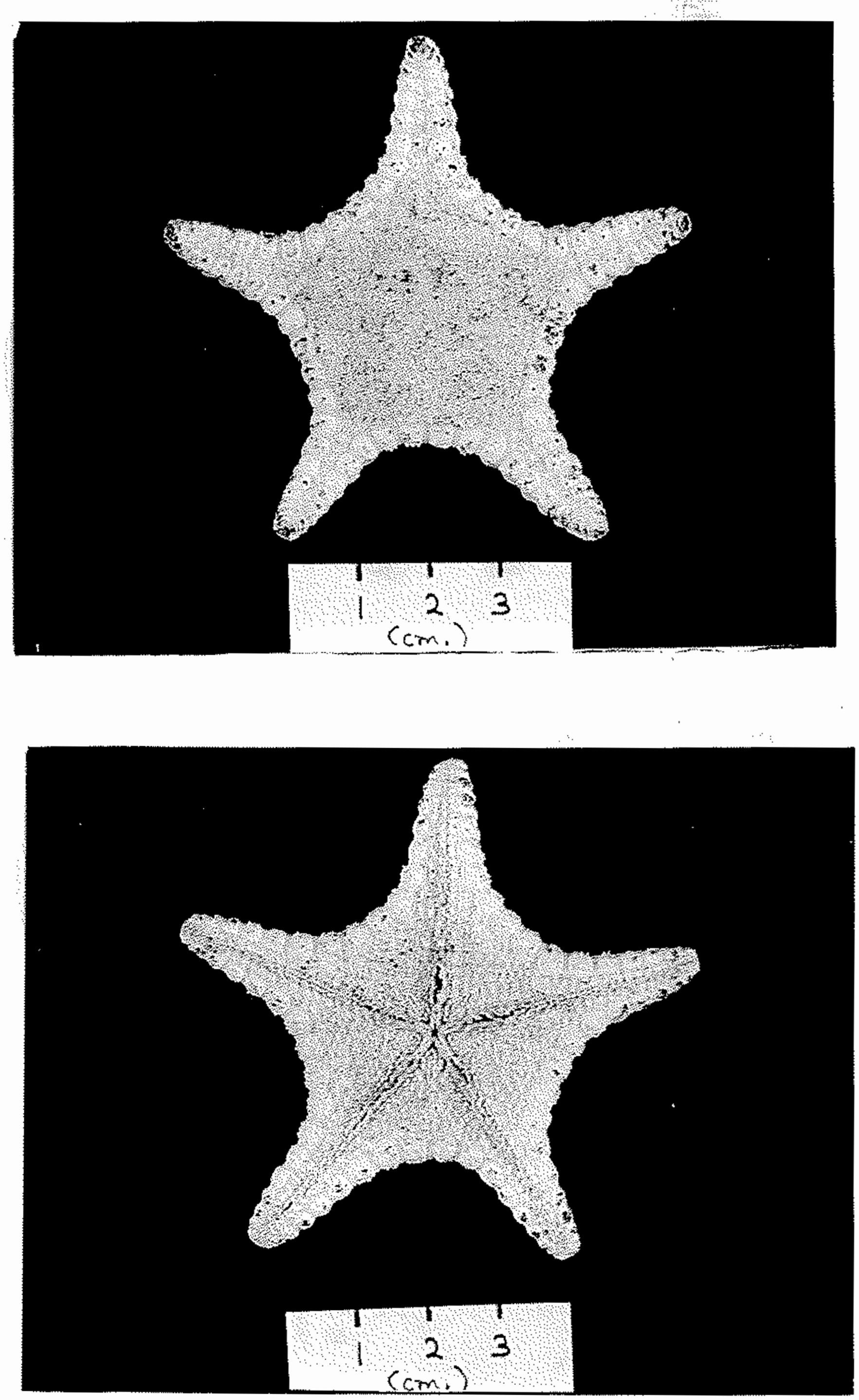
Goniasteridae, new genus, new species

Figure 5: A, B

Diagnosis.--This species has dorsal plates surrounded by groups of pedicellaria-like granules and bearing a single granule in its center.

Description.--The dorsal surface appears very crowded because of the granules surrounding the plates. Four granules form each of the 10-16 groups that surround each plate. Two rows of these granules separate the superomarginals from each other. The superomarginals are bare except for scattered granules similar to the central granules of the dorsal plates. The madreporite is rounded and is of similar height and size as the dorsal plates.

The ventral surface appears crowded also. The



A

B

Figure 5: A. Aboral view of Species B

B. Oral view of same

actinal interradial area has plates similar to the dorsal plates except that the central portion contains a group of 8-12 granules. The adambulacral plates contain 8 furrow spines and a ventral pedicellaria similar in size to the furrow spines. The mouth plates are flat and bear 2 spines at their apex and 9 lateral spines on each side. These spines of the mouth plates are similar to the adambulacral furrow spines.

Material examined.--Station 70-A-10-16 R/r = 41/18.

Artificial key

The artificial key that follows contains only species from the collection before me. Originally, it was hoped that a key could be constructed for all of the species from this area. This proved futile when working only with descriptions of approximately 100 other species. This key is adapted from Downey (1973) but includes 9 species not keyed out by Downey. It is hoped that this key will be especially useful to any who may wish to use the collection at Texas A&M, and will serve as an adjunct to Downey's work. For definitions of unusual morphological terms see the glossary.

1. Margin of body lined either by 2 distinct series of plates abactinally and actinally

or only 1 row of plates actinally; abactinal surface paxillate or tessellate.................. 2

Margin not lined by distinct series of plates; abactinal surface not tesselate or paxillate...41

2. Only 1 series of marginal plates present, the inferomarginals, which are elongate and extend from the adambulacral plates to the margin; spinous fascioles extend from the furrow to the margin................................... 3

Two series of marginals present; spinous fascioles, if present, do not extend from the furrow to the margin........................ 7

3. Ten arms............................*Luidia* *barimae*

Five or 6 arms................................... 4

4. Paxillae square or rectangular; body very firm.................................*L. clathrata*

Paxillae rounded; body fragile.................. 5

5. Arms with large dark colored blotches.*L. alternata*

Arms without blotches........................... 6

6. Six arms; inferomarginals with 1 long spine..............................*L. barbadensis*

Five arms; inferomarginals with 3 long spines.................................*L. elegans*

7. Specialized fascioles or cribriform organs present; abactinal surface paxillate............ 8

No fascioles or cribriform organs; abactinal surface not usually paxillate...................23

8. Cribriform organs present....................... 9

Marginal fascioles present......................13

9. Cribriform organs bordered by webbed spinelets..10

Cribriform organs not bordered by webbed spinelets.....................................11

10. Unpaired plates present interradially in both marginal series; madreporite much smaller than marginal plates...*Prionaster elegans*

No unpaired marginals; madreporite larger than marginals............*Goniopecten demonstrans*

11. Superomarginals separated along entire midline of arms.........................Species A

Superomarginals joined along entire midline of arms.......................................12

12. Large spines present along intersection of superomarginals; actinal interradial plates imbricate..................*Styracaster elongatus*

No large spines on superomarginals; actinal interradial plates not imbricate.................*Thoracaster cylindratus*

13. Actinal interradial area with few or no plates; inferomarginals often project beyond superomarginals................................14

Actinal interradial area with many plates; inferomarginals do not project beyond superomarginals................................18

14. Marginals covered with spinules; superomarginals slightly concave...........*Astropecten americanus*

Marginals covered with granules; superomarginals convex.................................15

15. Single large spines present on some superomarginals........................*A. antillensis*

No spines present on superomarginals...........16

16. More than 35 superomarginals...........*A. comptus*

Less than 30 superomarginals...................17

17. A few actinal interradial plates present; no spines on actinal surface of the adambulacral plates of comparable size to the furrow spines..............*A. niditus*

No actinal interradial plates present: 1 spine on actinal surface of the adambulacral plates larger than or comparable in size to the furrow spines..............................*A. cingulatus*

18. Madreporite large and with a few enlarged paxillae on its surface........................19

Madreporite small, or large and bare...........20

19. Superomarginals confined to sides of arm; paxillae topped with long thorny spinules........................*Dytaster insignis*

Superomarginals extend to abactinal surface; paxillae flat topped...................*Plutonaster intermedius*

20. Madreporite much larger than superomarginals, flat, bare.....................*Tethyaster grandis*

Madreporite not as above......................21

21. Apex of mouth plate with no flat spines; superomarginals are wider than the paxillar area on arms.................*Psilaster patagiatus*

Apex of mouth plates with flat spines; superomarginals not as wide as paxillar area on arms.................................22

22. Superomarginals with spines; paxillae topped with long spinules.....*Persephonaster echinulatus*

No superomarginal spines; paxillae flat topped........................*Psilaster cassiope*

23. Superomarginal and inferomarginal plates not exactly opposite each other; marginals with spines..................................24

Superomarginal and inferomarginal plates exactly opposite each other; marginals generally without spines........................28

24. Unpaired interradial marginals present which possess a very long spine; no papularia....................*Benthopecten simplex*

No unpaired marginals; papularia present.......25

25. Papular region with tumid plates; adambulacral plates triangular, almost touching the plate on the opposite side.........*Pectinaster gracilis*

Papular region without tumid plates; adambulacral plates triangular or rectangular, not generally extending close to the opposite plates......................................26

26. More than 50 papular pores per papularium; truncate spines at apex of mouth plate.........................*Cheiraster enoplus*

Fewer than 50 papular pores per papularium; spines at apex of mouth plate sharp............27

27. Fewer than 25 marginal plates along 1 side of each arm; superomarginals rectangular..........................*C. echinulatus*

More than 30 marginals along 1 side of each arm; superomarginals ovular..........*C. mirabilis*

28. Single enlarged hyaline spine at apex of mouth plate; inferomarginals extend beyond superomarginals...............*Odontaster hispidus*

No enlarged hyaline spine at apex of mouth plates; inferomarginals do not extend beyond superomarginals................................29

29. Unpaired interradial marginals present.........30

Paired interradial marginals present...........31

30. Superomarginals extend onto dorsal surface, covered with granules......*Ceramaster grenadensis*

Superomarginals mostly lateral, bare....*C.* species

31. Abactinal plates surrounded by grouped granules, large granule in plate center..Species B

Abactinal plates not as above...................32

32. Abactinal surface with large conspicuous spines......................*Goniaster tessellatus*

Abactinal surface without large spines..........33

33. Body covered by skin which obscures the underlying plates..............*Anthenoides piercei*

Body not covered by skin........................34

34. Arms long and with superomarginals joined along the midline for its entire length.........35

Arms short, or if long, with superomarginals joined for less than half its length............36

35. R/r less than 3; abactinal plates covered by thorny spinules..............*Rosaster alexandri*

R/r greater than 3; abactinal plates covered by granules....................*Nymphaster arenatus*

36. Abactinal arm plates larger than those on disc........................*Circeaster americanus*

Abactinal arm plates not larger than those on disc....................................37

37. Single median spine present at apex of each mouth plate.................................38

Two median spines at apex of each mouth plate...39

38. One row of plates on abactinal surface separating superomarginals; proximal pair of tube feet several times larger than normal.....................*Paragonaster subtilis*

Several rows of plates separating superomarginals; no enlarged tube feet...*Pseudarchaster* sp.

39. Actinal plates with bare center.......Tosia parva

Actinal plates usually granule covered.........40

40. Abactinal plates surrounded by single row of granules..................Plinthaster dentatus

Abactinal plates surrounded by more than 1 row of granules Litonotaster intermedius

41. Supradorsal membrane raised above abactinal surface and supported by spines; no actinal plates..42

Supradorsal membrane not raised; actinal plates usually present.........................48

42. Adambulacral spines not webbed, not in transverse series..............................43

Adambulacral spines partially or completely webbed, in transverse or oblique series........44

43. Body pentagonal; 2 suboral spines on each mouth plate.......................Hymenaster rex

Body substellate; 1 suboral spine on each mouth plate..........................H. modestus

44. Adambulacral furrow spines webbed to actinolateral spines; paxillar spines setose...45

Adambulacral furrow spines not webbed to actinolateral spines; paxillar spines not setose.......................................47

45. Suboral spines absent........Pteraster personatus

Suboral spines present.........................46

46. Dorsal membrane with calcareous deposits, translucent......................P. militaroides

Dorsal membrane without deposits, transparent.................................P. acicula

47. Entire dorsal surface convex; supradorsal membrane thin.............Calyptraster coa

Dorsal surface convex only around disc center; supradorsal membrane thin..............................*C. personatus*

48. No pedicellariae present........................49

Pedicellariae abundant.........................50

49. Inner furrow spines lined one above the other, forming a single series.......................*Henricia antillarum*

Inner furrow spines generally form 2 series...............................*H.* species

50. Five arms; adambulacral plates alternately carinate and noncarinate........................51

Six or more arms; adambulacral plates not as above..................................52

51. Dorsal disc plates convex, stellate; no spinules on dorsal surface..*Doraster constellatus*

Dorsal disc plates flat, not stellate; spinules present on dorsal surface.......*Zoroaster fulgens*

52. Six arms; base of each arm with a clear patch of thin membrane.............*Ampheraster alaminos*

Eight to 12 arms; no patch of clear membrane...53

53. Disc with plates bearing large spines; adambulacral plates with large pedicellariae in the furrow................*Coronaster briareus*

Disc plane; adambulacral plates without pedicellariae in the furrow...................54

54. Twelve arms; adambulacral plates with 2 fine spines in the furrow..........*Midgardia xandaros*

Eight arms; adambulacral plates without 2 fine spines in the furrow.....................*Brisingella verticellata*

Geographic distribution

Ekman (1953) stated that the northern boundary of the American Atlantic warm water shelf region is approximately at Cape Hatteras. He was reluctant to pinpoint a southern boundary because of the poor sampling off Brazil but postulated that the region near Rio, where the mangroves and coral reefs end, is likely. Regrettably, little sampling has been done off Brazil, but the present data for species of asteroids support his view that Cape Hatteras is the northern boundary.

The region extending from Cape Hatteras to Brazil includes the Gulf of Mexico and the Caribbean. Present data should reveal many species which range north and south of the area of this study.

One way of looking at the range of the fauna is to determine its endemism. Woodward (1856) defined a province as an area in which fifty percent of the species are endemic. The Gulf alone has only one endemic species, <u>Ampheraster alaminos</u>, out of a total of thirty-nine species. This is two and a half percent. Three species previously reported only from the Gulf, Midgardia xandaros, Doraster constellatus, and <u>Prionaster elegans</u> have now been taken in the

Caribbean. The Caribbean data contain three endemic species out of thirty-six, or eight percent. These species are Henricia antillarum, and the two new species which were earlier described. Seventeen of the fifty-six species for the entire area appear to be endemic. This is only thirty percent.

Savage (1960) used a "Coefficient of Difference" to compare two faunas. The equation is as follows:

$$C.D. = (1 - C/N)\ 100\%$$

C.D. is the "Coefficient of Difference"; C is the number of species common to two areas; and N is the number of species in the larger fauna. A C.D. greater than fifty percent indicates that the faunas belong to separate provinces.

The C.D. may be used to compare the species from the Gulf of Mexico with those found off North Carolina by Gray, Downey, and Cerame-Vivas (1968). A low C.D. value is expected.

Table 4 lists the species off North Carolina. Eight species are common to species of the Gulf of Mexico. The calculated C.D. is eighty-one percent. Such a value is unexpectedly high because many of the species of this area are reported to extend northward. In addition, Gray, Downey, and Cerame-Vivas point out in their

Table 4. Species from off North Carolina

Species	Common to Gulf and Caribbean	Distribution
Coronaster briareus	+	Northern and Southern
Odontaster hispidus	+	Northern and Southern
Asterias forbesii		Northern and Southern
Astropecten articulatus		Northern and Southern
Luidia clathrata	+	Northern and Southern
Tethyaster vestitus		Northern
Asterias vulgaris		Northern
Ctenodiscus crispatus		Northern
Henricia sanguinolenta		Northern
Leptasterias tenera		Northern
Peltaster planus		Northern
Porania insignis		Northern
Astropecten americanus	+	Northern
Asterias tanneri		Northern
Mediaster bairdii		Northern
Echinaster sentus		Southern
E. spinulosus		Southern
Thyraster serpentarius		Southern

Table 4. (Continued)

Species	Common to Gulf and Caribbean	Distribution
Astropecten duplicatus		Southern
Coscinasterias tenuispina		Southern
Luidia alternata		Southern
Astropecten niditus	+	Southern
A. nuttingi		Southern
Echinaster brasiliensis		Southern
Goniaster tessellatus	+	Southern
Linckia bouvieri		Southern
Luidia bernasconiae		Southern
L. elegans	+	Southern
Narcissia trigonaria		Southern
Oreaster reticulatus		Southern
Plinthaster dentatus	+	Southern
Solaster caribbaeus		Southern
Stephanasterias gracilis		Southern

report that eighteen species extend their range southward, nine species extend northward, and only six are common both north and south of Cape Hatteras. This is strong evidence that a distict change in the fauna occurs in the Cape Hatteras region. This has been shown for the benthos in general and is the basis for Cerame-Vivas and Gray (1966) proposing a Virginian Shelf Province north of Cape Hatteras which is influenced primarily by the cold south flowing Virginian current and the Caribbean Shelf Province south of Cape Hatteras which is influenced primarily by the warm north flowing Florida current. At Cape Hatteras the two currents meet and move offshore, providing a distinct temperature and current boundary.

The high C.D. value may be due to three factors: 1) the two faunas compared were not similar in size; 2) the North Carolina fauna was shallow water and the Gulf and Caribbean fauna was primarily deep water; and (3) the marine environment is responsible for a high C.D.

Two faunas should be similar in size for best results. For example, if one fauna has X number of species and if the second fauna has 2X species, the maximum number for C is X. Consequently, the maximum value for C/N is X/2X or 1/2. This will result in a minimum value of C.D. equal to fifty percent. Any value for C less than X will result in a higher C.D.

The comparison of shallow water fauna with primarily deep water fauna will obviously result in a high C.D. Unfortunately, no data was found for deep water asteroids off North Carolina.

The high C.D. value in the marine environment is puzzling. Savage's considerations were for terrestrial herpetofauna, and it was thought that current movements and the relative homogeneity of the marine environment would result in fewer barriers for distribution of species and therefore should necessitate a lower significant C.D.

It seems necessary to have more complete data for the North Carolinian fauna before any conclusive statements can be made on using this C.D. method.

The range of the distributions changes for the fauna beyond the shelf. Vinogradova (1958) in a discussion of the fauna of depths below 2000 meters considered deep water species to be stenographic, but Madsen (1961b) suggests that species in the abyssal region (below 3000 meters) tend to be most widely distributed. Menzies, George, and Rowe (1973) observed the shelf fauna to be eurygraphic but divided into latitudinal zones while the archibenthal fauna has the highest proportion of eurygraphic species. They agreed with Vinogradova that the distribution of the species of the abyssal zone becoming less eurygraphic as depth increases.

The problem of defining vertical zones in the ocean now presents itself when confronted with the examination of the geographical range of each zone. This problem will be considered in the next chapter and for now it is assumed that the archibenthal zone begins at 200 fathoms and the abyssal zone begins at 1000 fathoms.

The present data suggest that the archibenthal zone consists of fairly stenographic species. Many of the species endemic to the Gulf and Caribbean are from this zone. These species are *Cheiraster enoplus*, *Persephonaster echinulatus*, *Midgardia xandaros*, *Doraster constellatus*, *Goniopecten demonstrans*, and *Prionaster elegans*.

The abyssal zone appears to have more widespread species. Of the eleven species found almost exclusively in this zone only one, *Ampheraster alaminos*, appears to be endemic to this region. Eight species, *Calyptraster personatus*, *Hymenaster modestus*, *H. rex*, *Pteraster personatus*, *Paragonaster subtilis*, *Litonotaster intermedius*, *Benthopecten simplex*, and *Dytaster insignis*, are confined to the Atlantic Ocean, primarily the western or northern portions. The final two species, which have the deepest depth distribution, *Styracaster elongatus* and *Thoracaster cylindratus*, are the most widely distributed. *S. elongatus* has been found in the North Atlantic and the Indian Ocean. *T. cylindratus* has been found in the Atlantic, Indian, and Pacific Oceans.

It appears then that the asteroids show a general tendency for an increase in geographic range with an increase in depth which would therefore support Madsen's hypothesis.

Two of the most intriguing problems of the distribution of the asteroids in the Gulf of Mexico involve the apparent restriction in the Gulf of *Ampheraster alaminos*. and the apparent exclusion of *Styracaster elongatus* and *Thoracaster cylindratus* from the Gulf. There seems to be no physical barrier that can explain this.

All five of the other species of *Ampheraster* are from the Pacific (Fisher, 1928). Four species range from the Tres Marias Islands off Mexico (22°N) to Washington and the other species is from the Straits of Macassar in the Indonesian region. The bathymetric range for these species is 266-676 fathoms. It is possible that A. alaminos is related to the East Pacific Ampheraster species and that some migration occurred when the central American region was submerged during periods before the lower Pliocene. The depth range of the genus and its exclusion from the Caribbean do not support this idea. The width of the Pacific Ocean seems to be an even more imposing barrier for the spreading of Ampheraster from one side to the other. Perhaps extinct species may fill some of the gaps in the distribution of this genus or further sampling may accomplish this. For now it is a stimulating problem which should first be approached by a careful review of the genus.

Hydrographic and topographic conditions seem conducive to the extension of S. elongatus and T. cylindratus into the Gulf of Mexico. The deepest sill depths connecting the Caribbean with the Atlantic are a little over 2000 meters (Gordon, 1966). The sill depth connecting the Gulf of Mexico and the Caribbean has been estimated at 1600-2000 meters (McLellan and Nowlin, 1963). Temperature and salinity below 1500 meters vary little between all basins of the Gulf and Caribbean (Gordon, 1966).

It is unlikely that the two species have been missed by trawling in the Gulf of Mexico. Depths exceeding

1600 fathoms have been sampled thirty times without success. In contrast, these depths in the Caribbean have been sampled seven times and one or both species were taken three times.

The absence of the two species may possibly be explained by conditions in the Gulf of Mexico which support a depauperate asteroid population. The Caribbean asteroid fauna is notably richer, making it possible that conditions in the Gulf of Mexico are not sufficient for establishment of the two species. A second possibility is that the Gulf of Mexico is too shallow for these species. It may be significant that only one of the one hundred fifty-two specimens of these species was taken from 1600-1720 fathoms. All of the others were from 2270 and 2490 fathoms, depths not found in the Gulf of Mexico.

Vertical zonation

One of the most definitive works on vertical zonation is the recent book Abyssal Environment and Ecology of the World Oceans by Menzies, George, and Rowe (1973). In it, long standing ideas of particular isobaths or isotherms serving as boundaries for vertical zones in the ocean have been discarded, and the criterion used in determining zones is the change in the fauna. Ekman (1953) earlier stated the importance of such an approach.

To determine faunal changes they used the following equation:

$$D = \frac{T - Tc}{T} (100\%)$$

D is the distinctiveness; T is the total taxa at two intervals; and Tc is the taxa in common between the two intervals. A high D value indicates a change in the fauna. No significant value for D was suggested. Faunal provinces were recognized by a change in the genera. Faunal zones, subdivisions of provinces, were recognized by a change in the species.

Their work involved an extensive study of four areas off North Carolina-Georgia, Peru, the Arctic, and the Antarctic. Since it was previously noted that the North Carolinian shelf fauna is similar to the fauna of the Gulf of Mexico, a summary of their findings off North Carolina-Georgia follows.

Their data on collected isopods were used to delimit the following provinces. The intertidal province was found to coincide with the tidal range of 0-3 meters. The shelf province did not coincide with the continental shelf but was found to extend deeper, from 5-446 meters. The archibenthal zone was found to extend from 446-940 meters where principal sediments were foraminiferal and pteropod oozes and where the Florida Current was present. The abyssal province extended from 1000-5315 meters where foraminiferal oozes. clay and silt, and lutite were predominant sediments. The upper boundary for this province coincides with the 4°C isotherm. Water masses here included the Western Boundary Undercurrent and the Antarctic Bottom Water. The abyssal province was divided into upper abyssal, mesoabyssal, lower abyssal active, lower abyssal tranquil, and lower abyssal red clay zones.

Their findings from all four areas suggested several trends. The shelf province tends to extend below the depth of the continental shelf in low latitudes, but is found shallower than the shelf in high latitudes. The archibenthal zone tends to be an area of transition of temperature, sediments, and fauna between the shelf and abyssal provinces. It is usually located below the permanent thermocline. Finally, the abyssal province is not delimited by a particular isobath or isotherm but tends to be located in depths where the range in temperature is less than 2°C.

Working in areas of no large geographic extent (compared to the Gulf of Mexico), they were able to characterize depths by its predominant water masses and sediments. In this way a general correlation was shown between the faunal provinces and the environment in each of the four areas. Off North Carolina-Georgia even faunal zones were found to be correlated with water masses and sediments.

For the present data it was thought best to take the Gulf of Mexico and Caribbean separately. The data are not sufficient for a further subdivision of these areas. Unfortunately, these large areas do not have depths which are characterized by particular water masses and sediments.

Tables 5 and 6 are not significantly different and it appears that only provinces can be established with the present data. The species distribution in Table 6 best serves to illustrate provinces in the Gulf of Mexico. Since few stations were taken in the Caribbean, there is less emphasis on Table 7.

Table 6 indicates as many as four changes in the fauna. A distinct change is evident between intervals B and C. Of the eight species found in B and C none were common to both B and C. The number of samples taken, 26 in B and 15 in C, make it unlikely that many species were present but missed in these two ranges. Therefore, the depth between B and C, 200 fathoms, is defined as the boundary between the shelf province and

Table 5. Vertical distribution of asteroid genera of the Gulf of Mexico. A is 0-100 (fathoms; B is 100-200 (fathoms); K is 1000-1100 (fathoms); U is 2000-2100 (fathoms),

Genus	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Luidia	x																				
Goniaster	x																				
Coronaster	x																				
Rosaster	x																				
Astropecten	x	x																			
Anthenoides	x	x																			
Tethyaster	x	x																			
Cheiraster	x			x	x																
Persephonaster			x	x	x	x															
Plinthaster			x	x		x															
Midgardia			x	x	x		x														
Doraster				x	x																
Psilaster				x	x																
Goniopecten				x	x	x															
Brisingella					x																
Odontaster						x															
Zoroaster				x	x	x						x	x								
Pseudarchaster				x																	
Nymphaster				x	x	x	x		x		x	x									
Plutonaster					x	x	x	x	x												
Pteraster				x					x				x								
Litonotaster											x	x	x	x		x	x	x			
Ceramaster				?								x									
Benthopecten												x	x								
Calyptraster												x									
Hymenaster												x	x								
Dytaster												x	x		x	x	x	x	x		x
Ampheraster															x		x	x			
Paragonaster																	x	x			
Times Sampled	14	26	15	14	19	21	12	14	4	2	4	8	2	2	5	1	4	10	3	6	7
Distinctiveness (%)	62	100	75	44	68	75	67	75	100	100	75	44	80	100	67	50	0	75	100	100	

Table 6. Vertical distribution of asteroid species of the Gulf of Mexico. A is 0-100 (fathoms); B is 100-200 (fathoms); K is 1000-1100 (fathoms); U is 2000-2100 (fathoms).

Species	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Luidia clathrata	x																				
L. barbadensis	x																				
L. elegans	x																				
L. barimae	x																				
Astropecten cingulatus	x																				
A. antillensis	x																				
Goniaster tessellatus	x																				
Resaster alexandri	x																				
Anthenoides piercei	x	x																			
Tethyaster grandis	x	x																			
Astropecten nitidus	x	x																			
A. americanus		x																			
Cheiraster echinulatus	x	x																			
C. mirabilis				x	x																
C. enoplus				x																	
Persephonaster echinulatus			x	x	x	x															
Plinthaster dentatus			x	x		x															
Midgardia xandaros			x	x	x		x														
Pteraster militaroides				x																	
Brisingella verticellata					x																
Doraster constellatus				x	x																
Psilaster cassiope				x	x																
Coniopecten demonstrans				x	x	x															
Odontaster hispidus						x															
Zoroaster fulgens				x	x	x						x	x								
Pseudarchaster sp.				x																	
Nymphaster arenatus				x	x	x	x		x		x	x									
Plutonaster intermedius					x	x	x	x	x												
Ceramaster sp.				?								x									
Pteraster acicula									x												
P. personatus													x								
Litonotaster intermedius											x	x	x	x			x	x	x		
Benthopecten simplex												x	x								
Calyptraster personatus													x								
Dytaster insignis												x	x		x	x	x	x	x		x
Hymenaster modestus												x									
H. rex													x								
Ampheraster alaminos															x		x	x			
Paragonaster subtilis																	x	x			
Times Sampled	14	26	15	14	19	21	12	14	4	2	4	8	2	2	5	1	4	10	3	6	7
Distinctiveness (%)	70	100	77	47	58	75	67	67	100	100	71	60	76	100	50	75	0	50	100	100	

Table 7. Vertical distribution of asteroid species of the Caribbean. A is 100-200 (fathoms); B is 200-300 (fathoms); J is 1000-1100-(fathoms); O is 1500-1600 (fathoms); X is 2400-2500 (fathoms).

Species	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Luidia alternata	x																							
L. barbadensis	x																							
L. elegans	x																							
Tosia parva	x																							
Prionaster elegans	x																							
Rosaster alexandri	x																							
Astropecten nitidus	x																							
A. comptus	x																							
Pectinaster gracilis	x	x																						
Anthenoides piercei	x	x																						
Cheiraster echinulatus	x																							
C. mirabilis		x		x		x	x																	
Nymphaster arenatus	x	x		x		x				x														
Persephonaster echinulatus		x																						
Henricia antillarum		x																						
H. species				x																				
Plinthaster dentatus		x		x		x	x																	
Midgardia xandaros					x																			
Doraster constellatus		x		x	x																			
Pteraster militaroides		x																						
Psilaster cassiope			x	x		x																		
P. patagiatus				x		x																		
Pseudarchaster sp.	x		x	x																				
Goniopecten demonstrans				x																				
Zoroaster fulgens			x	x		x	x			x		x												
Species B					x																			
Circeaster americanus						x																		
Dytaster insignis						x	x			x		x										x		
Litonotaster intermedius												x		x		x								
Benthopecten simplex												x												
Calyptraster personatus												x		x										
Species A														x										
Ceramaster sp.												x		x										
Hymenaster modestus												x		x										
Thoracaster cylindratus																x						x		x
Styracaster elongatus																						x		x
Times Sampled	5	4	1	3	2	6	1	0	0	2	0	1	0	1	0	1	0	0	1	0	1	1	2	1
Distinctiveness (%)		84	100	70	91	100	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

the archibenthal province. The next change is seen at interval J, 900-1000 fathoms. Here, however, it is not possible to determine whether a change actually occurs because only two samples and no species were taken from this interval. The absence of species indicates that either too few samples were taken or the change in the environment actually restricts species from this range. If the latter is true then 900-1000 fathoms is the boundary between the archibenthal zone and the abyssal zone. The next change appears between intervals N and O at 1400 fathoms. Again there is difficulty in interpreting the data. It appears likely that two sampling trials at interval N missed Dytaster insignis. If this is so the distinctiveness between N and O drops from one hundred percent to sixty-seven percent. The final change occurs at interval T (1900-2000 fathoms). As in interval J, no species was taken in T, but here a larger number of samples (six) were taken. The data thus do not clearly indicate the beginning of the abyssal zone. The depths at which the temperature range is less than 2°C are depths exceeding 850 meters or 420 fathoms (Harding and Nowlin, 1966). This depth seems too shallow for an upper boundary to the abyssal zone and indeed no faunal change occurs here.

The advantage of using a measure of distinctiveness is that it is quasi-quantitative and non-subjective; however, problems have been shown for this set of data in ranges that were sparsely sampled or where a species was not found but should likely have been sampled. It therefore seems necessary to present a qualitative description of the species distribution in the Gulf of Mexico to aid in delimiting any vertical zones.

A distinct grouping of species is evident above 200 fathoms as was discussed above. A second grouping appears between 200-1000 fathoms. All except two of the seventeen species in this range appear to be confined here. Of these only *Nymphaster arenatus* is likely to be so eurybathic as to extend to greater depths. *Zoroaster* appears to consist of shallow water and deep water species. This will be discussed more fully in a later section. A third group of species occurs at 1000-1400 fathoms. In the upper part of this interval is *Nymphaster arenatus* while extending through the interval and below it are two species, *Litonotaster intermedius* and *Dytaster insignis*. The interval is made fairly distinct by seven species that appear to be confined to this range. The fourth and final grouping occurs below 1400 fathoms. Only four species were found here and only two of these, *Ampheraster alaminos* and *Paragonaster subtilis*, are confined to this range.

The quasi-quantitative and qualitative results indicate two well formed groups of species. The group above 200 fathoms has been designated as the shelf fauna. The group from 200-1000 fathoms represents the archibenthal fauna. The abyssal fauna begins below 1000 fathoms and consists of two less clearly demarcated groups of species. The shallower of these two groups may represent an upper abyssal fauna. The lower region may contain the mescabyssal fauna. The relatively warm temperature and shallowness of the Gulf perhaps preclude the establishment of a lower abyssal fauna.

Menzies, George, and Rowe (1973) found that their results with isopods agreed with the zonation of large epifauna.

> The remarkable agreement between faunal units composed of groups of large animals and zones of species and genera of isopods suggests that the faunal provinces and zones described herein will also be of significance to other animal groups. Similarly, it can be stated that the salient features that delimit these faunal groups are those characteristics of the environment which are characteristic to life in the deep sea.

Present results using their method are encouraging, but further work needs to be done. The next step will be to define these "salient features" that delimit faunal groups. Others have worked toward this. Sokolova (1959) stated that benthic zones are influenced primarily by sedimentation. The dominant organisms of each zone are those whose mode of feeding is best suited to the characteristic sedimentation. Vinogradova (1962) suggested that ecological relationships must be examined.

DISCUSSION

Taxonomic investigations

The collection of the asteroids of the Gulf of Mexico is fairly complete. One hundred ninety-three skimmer and otter trawl samples have been taken here.

In contrast to the situation in the Gulf of Mexico, the collection of the asteroids of the Caribbean is fairly incomplete. Only thirty-three samples have been taken in this area. More attention should now be directed to the rich fauna of the Caribbean.

It is hoped that the artificial key, and the descriptions of the Porcellanasteridae and the new species have contributed to an understanding of the asteroids from this area.

Geographic distribution

The asteroid fauna of this region tends to become more eurygraphic as depth increases. The fauna in general tends to show little isolation with respect to the fifty percent endemism standard set by Woodward (1856). This isolation could not be shown using the "Coefficient of Difference" (Savage, 1960), but information is needed on the deeper water asteroids off North Carolina before this method can be better evaluated.

We seem to be at a very early stage in our knowledge of the zoogeography of the sea, especially its deeper depths. This can be realized by recalling the concluding remarks of Ekman (1953).

> . . . as a result of interactions of infinite complexity between animate and inanimate nature the present biogeographical conditions have emerged in the course of the ages. Time, which is in reality nothing more than the succession of events, that is historical happenings, is a factor of profound importance for all manifestations of life. In other words: biogeography cannot confine itself simply to describing the occurrence of living forms, analyzing them regionally, and investigating the ecological causes of distribution. It must also proceed historically.

We know little about the environment, the "inanimate nature," of the deep sea. Little has been done on historical aspects of zoogeography. Finally, the most deficient area is our knowledge of the ecology of the deep sea.

Vertical zonation

The encouraging but as yet incomplete results of the study on vertical zonation point out a need for additional research. Three possibilities appear especially appealing.

Firstly, a statistical analysis may be possible. An attempt was, in fact, made in this direction with the aid of Dr. Sielken of the Statistics Department here. The attempt pointed out a need for more proportionate sampling in the Gulf of Mexico, especially in the 900-1000, 1300-1400, and 1500-1600 fathom ranges.

Secondly, the vertical distribution of genera and species may be useful to taxonomic investigations. For instance, Zoroaster appears to have two species in the Gulf of Mexico (see Table 5, page 49), but only one has been identified. Downey (1970) synonymized *Z. diomedeae*, *Z. ackleyi*, and *Z. trispinosus* with *Z. fulgens* and reported only one species of *Zoroaster* from the Western Atlantic. Present data on the vertical distribution of the genus, and the observation of better developed carinal spines on the deeper specimens suggest the possibility of two species.

Finally, the results of a study on vertical distribution of other benthic organisms would be most informative. A synthesis of all of the benthos, studied in a localized area where hydrographic and sedimentary characteristics are known, could possibly not only define provinces and zones but also explain the biotic and abiotic interactions that result in this phenomenon of zonation.

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GLOSSARY

abactinal, the side opposite the mouth

aboral, abactinal

actinal, the side containing the mouth

adambulacral plate, the plate bordering the furrow

carina, the row of dorsal plates along the middle of the arm of some asteroids

carinate, refers to an adambulacral plate that projects into the furrow

cribriform organs, specialized structures between the marginals of some asteroids which look like many straight series of fine spinules covering a flat surface

disc, portion of the animal exclusive of the arms

distal, away from the disc center

dorsal, abactinal

fascicles, specialized spinule lined channels between the marginals of some asteroids

furrow, the channel along the oral midline of the arms

granule, a small protuberance

groove, furrow

imbricate, overlapping, like shingles

inferomarginal plates, the plates along the periphery of the oral side of some asteroids interradial, of the disc

madreporite, the dorsal plate of the water vascular system

marginals, the inferomarginal and superomarginal plates

oral, actinal

papulae, respiratory organs of soft tissue that generally project from between some dorsal plates

popularia, specialized area containing papulae

paxilla, columnar plate with spinule or granule covered top

pedicel, the paxilla exclusive of spinules or granules

pedicellaria, small external organ which serves to grasp particulate matter

proximal, toward the disc center

R, the distance from the disc center to the arm tip, measured in millimeters

r, the distance from the disc center to the disc margin, measured in millimeters

spine, a sharp protuberance

spinule, a small spine

suboral spine, spines on actinal surface of mouth plates

superomarginal plates, the plates along the periphery of the dorsal side of some asteroids

supradorsal membrane, skin raised above the abactinal surface in the Pterasteridae tessellate, a mosaic like surface formed by close fitting flat plates

unpaired marginal, the single marginal present mid-interradially (if one is present, the number of marginals from one arm tip to an adjacent one is odd)

ventral, actinal

APPENDIX

Table 1. Station list where asteroids were caught in the Gulf of Mexico and the Caribbean

Station	North latitude	West longitude	Depth (fathoms)	
65-A-9-15	23°00'	86°48'	330	604
65-A-9-15A	23°05'	87°05'	96	176
65-A-9-20	25°00'	84°00'	72	132 m
67-A-5-2H	28°23'	88°22.5'	1000	1830
67-A-5-8	28°55'	87°24'	817	1495
67-A-5-15F	27°38.4'	86°38'	1691	3095 m
67-A-5-16E	25°24.3'	86°05'	1780	3257
68-A-3-3B	25°09'	94°11'	2000	
68-A-3-7D	23°52.5'	91°02'	2030	3715
68-A-3-10B	25°09'	96°16'	530-550	988
68-A-7-1A	28°51'	88°47.5'	289-472	
68-A-7-3C	27°36'	87°41.5'	1500	2745
68-A-7-4A	25°20'	86°07'	1770	3240
68-A-7-4E	28°41.5'	87°37.8'	1294	2368
68-A-7-10A	29°15.5'	86°55'	309	565
68-A-7-13A	29°03'	87°15'	580	1061
68-A-7-13B	28°59.5'	87°21.3'	750-780	1400
68-A-7-13D	28°59'	87°23.3'	800	1464
68-A-13-1	25°38'	96°07.3'	480	878

Table 1. (Continued)

Station	North latitude	West longitude	Depth (fathoms)
68-A-13-4	25°38.4'	96°18.3'	280
68-A-13-5	26°12.5'	96°19.8'	150
68-A-13-7	26°17'	96°18'	150
68-A-13-8	26°18'	96°08'	400
68-A-13-9	25°14'	95°13'	1840
68-A-13-11	25°23'	95°57'	580-750
68-A-13-12A	25°31'	95°51'	580-720
68-A-13-15	27°34.5'	95°10.5'	360-470
68-A-13-17	27°50'	95°12.5'	100
68-A-13-19	27°44.9'	95°20.1'	185-210
68-A-13-23	27°35'	95°23'	400
68-A-13-24	27°29.5'	95°31'	480
68-A-13-27	27°17.5'	95°08.5'	600-640
69-A-11-14	26°18.5'	94°37.4'	1330
69-A-11-44	19°23'	94°50'	1160
69-A-11-48	20°02.5'	95°07'	1454
69-A-11-52	20°04'	95°07'	1475
69-A-11-58	19°02.6'	95°27.5'	260
69-A-11-76	21°16'	96°57'	100
69-A-11-77	21°24.5'	96°55'	185-205

Table 1. (Continued)

Station	North latitude	West longitude	Depth (fathoms)
69-A-11-86	21°41'	96°51'	530-590
69-A-11-89	22°25.4'	96°41.2'	1000-1150
69-A-13-28	25°27'	86°04'	1700
69-A-13-37	26°55'	86°48'	1640
69-A-13-41	29°11.5'	88°12.6'	170
69-A-13-42	29°14'	88°15'	100
69-A-13-44	28°58'	88°28'	411
70-A-10-6	20°45'	86°27.4'	510-570
70-A-10-9	18°57'	87°09'	625
70-A-10-12	16°32.8'	84°53.2'	1025
70-A-10-13	16°30.2'	84°40'	1025
70-A-10-14	16°08'	84°43.1	112
70-A-10-15	16°09'	84°37.1'	185-290
70-A-10-16	16°11.1'	84°48'	445-480
70-A-10-20	16°24'	84°37'	590-640
70-A-10-24	16°40.5'	82°40'	155
70-A-10-25	16°43'	82°38'	235-335
70-A-10-26	15°17.8'	81°21.9'	135-140
70-A-10-27	15°02'	81°05'	240-345
70-A-10-28	14°33'	79°46'	1280
70-A-10-29	11°31.8'	74°24.5'	625

Table 1. (Continued)

Station	North latitude	West longitude	Depth (fathoms)
70-A-10-31	11°33.8'	73°45.1'	400
70-A-10-39	12°13.5'	72°32.1'	112
70-A-10-40	12°40'	72°00'	340-360
70-A-10-42	12°39'	69°41'	735
70-A-10-43	13°13.2'	69°43.8'	1600-1720
70-A-10-48	14°29.5'	74°28.8'	2270
70-A-10-50	15°50'	77°24.5'	1450-1525
70-A-10-51	17°17.1'	79°50.6'	600
70-A-10-54	20°30'	85°34'	2490
70-A-10-58	25°21.3'	86°06.5'	1775
71-A-7-10	26°32.9'	96°06.4'	512
71-A-7-11	26°32.3'	96°13.2'	348
71-A-7-43	27°27.8'	92°46'	550-1010
71-A-7-49	27°26'	92°42'	512
71-A-7-65	27°57'	92°44.9'	130
71-A-8-8	26°08'	92°43.9'	1124
71-A-8-10	26°09'	92°48.3'	1135
71-A-8-13	25°52'	93°15.8'	1785
71-A-8-22	23°54.45'	97°13.73'	91
71-A-8-24	23°56.8'	97°05'	360-380
71-A-8-29	23°54.7'	96°59.9'	512