

Three new records of deep-water goniasterids (Echinodermata: Asteroidea: Goniasteridae) from China seas*

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Received Dec. 26, 2012; accepted in principle Feb. 19, 2013; accepted for publication May 8, 2013

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Abstract In this paper, three deep-water species of the family Goniasteridae, *Ceramaster misakiensis* (Goto, 1914), *Nymphaster arthrocnemis* Fisher, 1913 and *Pontioceramus grandis* Fisher, 1911, are recorded for the first time from Chinese waters based on collections deposited in the Marine Biological Museum, Chinese Academy of Sciences. The specimens examined were collected during the period 1956 to 1978 from the East China and South China Seas at depths of 184 to 472 m. Diagnosis, detailed figures, and the geographic distributions are provided. A revised list of Goniasteridae recorded from Chinese waters is proposed.

Keyword: Echinodermata; Asteroidea; Valvatida; deep-water goniasterids; new records; China seas

1 INTRODUCTION

The Goniasteridae is a large, widespread family within the Valvatida, consisting of 65 genera and 256 species worldwide to date (Mah and Blake, 2012). They are found in all of the world's oceans from shallow to abyssal depths mainly distributed in coldwater environments, including high-latitude and deep-water habitats (Mah, 2011). Goniasterids may play an important ecological role in the benthic fauna. For example, hippasterine asteroids are prominent members of deep-sea coral communities (Mah et al., 2010). Primarily characterized by conspicuous marginal plates and relatively well-developed calcium carbonate skeletons, goniasterids exhibit extraordinary diversity in form and size. Heavily calcified endoskeletons suggest they are severely affected by ocean acidification (Wood et al., 2008; Gooding et al., 2009).

Recent phylogenetic efforts have provided additional insights into understanding the Goniasteridae taxa. *Paragonaster* Sladen, 1889 has historically been included with the Goniasteridae (Clark and Downey, 1992; Clark, 1993). However, new phylogenetic data by Mah and Foltz (2011) placed *Paragonaster* within the Paxillosida. Several goniasterid-like ophiasterids, such as *Fromia* Gray,

1840 and *Neoferdina* Livingstone, 1931 were considered members of the Goniasteridae rather than the Ophiasteridae. We follow the scheme of Mah and Foltz (2011) herein, which is the omission of *Paragonaster* and inclusion of *Fromia* and *Neoferdina* within the Goniasteridae.

There have been very few systematic studies on the Goniasteridae in Chinese waters. Liao (1984, 1989) described two new species, *Rosaster attenuatus* and *Calliaster quadrispinus*. *Anthenoides laevigatus* and *Anthenoides tenuis* were subsequently recorded (Liao and Clark, 1989). Liao and Clark (1995) studied the echinoderms of southern China, including nine goniasterid taxa and published a taxonomic key to the Goniasteridae of this region. Liao (2008) provided the first checklist of echinoderms from Chinese waters, which included 10 goniasterid taxa. Chao and Su (2009) reviewed the sea stars of Taiwan Island, including eight goniasterid taxa. Among these goniasterid species, all were recorded from the East China and South China Seas. To date, 19 species of

* Supported by the Funding Program of Institute of Oceanology, Chinese Academy of Sciences (No. 2012IO060104)

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Table 1 Checklist of Goniasteridae recorded from Chinese waters and their world distributions

Species name and author	Geographical distribution	References
<i>Anthenooides laevigatus</i> Liao and Clark, 1989	South and SE of Hainan Island; Taiwan Island	Liao and Clark, 1989; Liao and Clark, 1995; Chao and Su, 2009
<i>Anthenooides tenuis</i> Liao and Clark, 1989	East of Hainan Island; Taiwan Island	Liao and Clark, 1989; Liao and Clark, 1995; Chao and Su, 2009
<i>Astrothauma euphyllacteum</i> Fisher, 1913	Off Hainan Island; Taiwan Island; SW Japan; Philippines	Fisher, 1913; Liao and Clark, 1995; Chao and Su, 2009; Kogure et al., 2011
<i>Calliaster childreni</i> Gray, 1840	East China Sea; Japan; Australia	Gray, 1840; Liao and Clark, 1995; Rowe and Gate, 1995; Chao and Su, 2009; Xiao, 2012
<i>Calliaster quadrispinus</i> Liao, 1989	South China Sea	Liao, 1989; Liao and Clark, 1995
<i>Calliderma emma</i> Gray, 1847	South China Sea; Hawaiian Islands; Australia	Gray, 1847; Fisher, 1906; Liao and Clark, 1995; Rowe and Gate, 1995
<i>Ceramaster misakiensis</i> (Goto, 1914)	South and East China Sea; Japan	Goto, 1914; Hayashi, 1973; this research
<i>Fromia milleporella</i> (Lamarck, 1816)	Xisha Islands; Indo-west-central Pacific Ocean	Fisher, 1919; Hayashi, 1938; Clark and Rowe, 1971; Rowe and Gate, 1995; Liao and Clark, 1995; Clark and McKnight, 2001
<i>Fromia monilis</i> (Perrier, 1869)	Taiwan Island; Japan; Indonesia; Australia; New Zealand	Perrier, 1869; Hayashi, 1973; Chao and Su, 2009; Rowe and Gate, 1995; Clark and McKnight, 2001
<i>Mediaster arcuatus</i> (Sladen, 1889)	Taiwan Island; Japan; Australia; New Zealand	Sladen, 1889; Goto, 1914; Chao and Su, 2009; Rowe and Gate, 1995; Clark and McKnight, 2001
<i>Mediaster brachiatus</i> Goto, 1914	Taiwan Island; Japan	Goto, 1914; Chao and Su, 2009
<i>Neoferdina cumingi</i> (Gray, 1840)	Xisha Islands; Philippines; Australia; New Zealand	Liao and Clark, 1995; Rowe and Gate, 1995; Clark and McKnight, 2001
<i>Nymphaster arthrocnemis</i> Fisher, 1913	South China Sea; Celebes Sea; Philippines	Fisher, 1913; Clark, 1993; this research
<i>Ogmaster capella</i> (Müller and Troschel, 1842)	Red Sea; Bay of Bengal; South and East China Sea to northern Australia	Clark and Rowe, 1971; Liao and Clark, 1995; Rowe and Gate, 1995
<i>Pontioceramus grandis</i> Fisher, 1911	South China Sea; Philippines	Fisher, 1911b; 1919; this research
<i>Rosaster attenuatus</i> Liao, 1984	East China Sea	Liao, 1984
<i>Rosaster symbolicus</i> (Sladen, 1889)	South and East China Sea; Philippines; Australia	Sladen, 1889; Liao and Clark, 1995; Rowe and Gate, 1995
<i>Stellaster equestris</i> (Retzius, 1805)	South and East China Sea, Indo-west Pacific Ocean	Goto, 1914; Liao and Clark, 1995; Rowe and Gate, 1995; Chao and Su, 2009
<i>Stellasteropsis colubrinus</i> Macan, 1938	Taiwan Island; NE Africa; SE Arabia	Macan, 1938; Clark and Rowe, 1971; Chao and Su, 2009

Goniasteridae have been recorded from Chinese waters (see Table 1). However, this is the first record of the three goniasterid taxa described below.

2 MATERIAL AND METHOD

All specimens examined were deposited in the Marine Biological Museum, Chinese Academy of Sciences (MBMCAS, or MBM) in Qingdao, China. The distributions of *Ceramaster misakiensis*, *Nymphaster arthrocnemis* and *Pontioceramus grandis*, based on the collection data, in Chinese waters are shown in Fig. 1.

Observations were carried out with a Zeiss Stemi 2000-C microscope. Some specimens were bleached in sodium hypochlorite to observe the denuded plates. Specimens were photographed with a Canon EOS

30D digital camera.

The following abbreviations are used in the text: CN: collection number; Stn.: station; spm(s): specimen(s); AT: Agassiz trawl; coll.: collector; R: major radius from the center of the disc to the tip of the arm, and r: minor radius from the center of the disc to the inter-radial edge. Terminology follows that defined by Clark and Downey (1992).

3 TAXONOMY

Family Goniasteridae Forbes, 1841 Genus *Ceramaster* Verrill, 1899

Ceramaster Verrill, 1899: 161; Fisher, 1911a: 162, 204; Verrill, 1914: 289; Koehler, 1924: 173; Mortensen, 1927: 80; Djakonov, 1968: 38; Halpern, 1970a: 62; 1970b: 212; Downey, 1973: 49; McKnight,

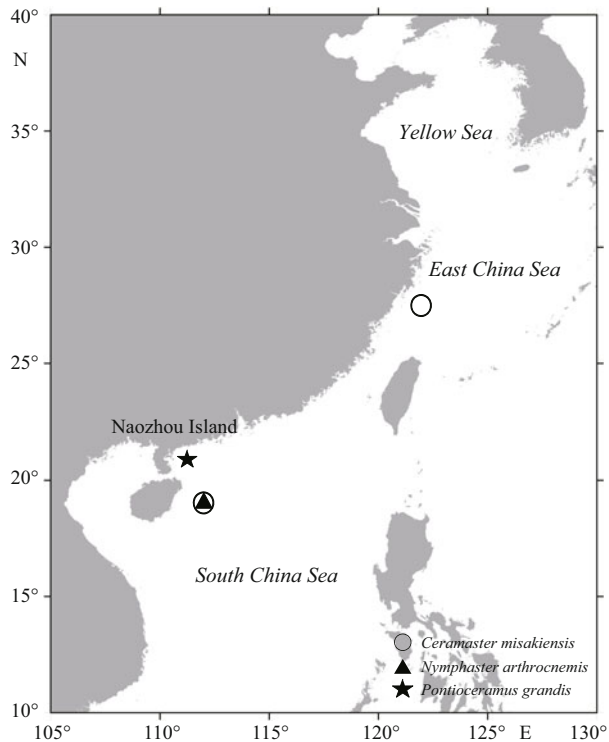


Fig.1 *Ceramaster misakiensis*, *Nymphaster arthrocnemis*, and *Pontioceramus grandis* distributions in Chinese waters

1973: 178; A. M. Clark and Courtman-Stock, 1976: 61; A. M. Clark and Downey, 1992: 231; A. M. Clark, 1993: 247 (list); Rowe and Gate, 1995: 64; H. E. S. Clark and McKnight, 2001: 32.

Philonaster Koehler, 1909: 78.

Tosia (*Ceramaster*): Fisher, 1906: 1054.

Type species: *Asterias granularis* Retzius, 1783

Diagnosis: Body flattened, generally pentagonal. Disc large, arms generally short. Abactinal plates are tabulate and covered with granules. Generally, no secondary abactinal plates, if present confined to the disc. Both series of marginal plates are large, block-like, and covered with granules; the middle ones may occasionally have a naked area. Superomarginal plates are generally separate throughout all or most of the arm. No spines of any kind on either the abactinal or the marginal plates. Actinal intermediate area is extensive, with the plates bearing only granules. Furrow margin of the adambulacral plates is straight. Pedicellariae bivalvate or tong-shaped, sometimes present on the actinal and abactinal surfaces and on the marginal plates, rarely almost or completely absent.

Remarks: The genus *Ceramaster* contains 17 species (Mah and Hansson, 2012a) and is well



Fig.2 *Ceramaster misakiensis* (Goto, 1914) MBM176427

a. Abactinal view; b. Actinal view; Scale bar=10 mm

represented in the North Pacific, South Pacific, and Atlantic Oceans. *Ceramaster* occurs mostly in cold waters (Mah and Blake, 2012). This is the first record of this genus in Chinese waters.

Ceramaster misakiensis (Goto, 1914) (Figs.2, 3)

Pentagonaster misakiensis Goto, 1914: 332, Pl. XIII, Figs.194-202.

Ceramaster misakiensis Hayashi, 1973: 13; A. M. Clark, 1993: 249 (list).

Material examined

East China Sea: MBM176427, CN V561B-18, Stn. 03, 27°30'N, 122°00'E, one spm, 184 m, AT, fine sand, coll. Fengshan XU, 30 May 1978.

South China Sea: MBM014392, CN K32B-88, Stn. 6094, 19°00'N, 112°00'E, one spm, 270 m, AT, calcareous silt, coll. Fuzeng SUN, 19 Apr 1959; MBM014396, CN K7B-22, Stn. 6094, 19°00'N, 112°00'E, one spm, 472 m, AT, granular biological remains, coll. Zhican TANG, 17 Feb 1959.

Size: R varies between 35 and 43 mm, r varies

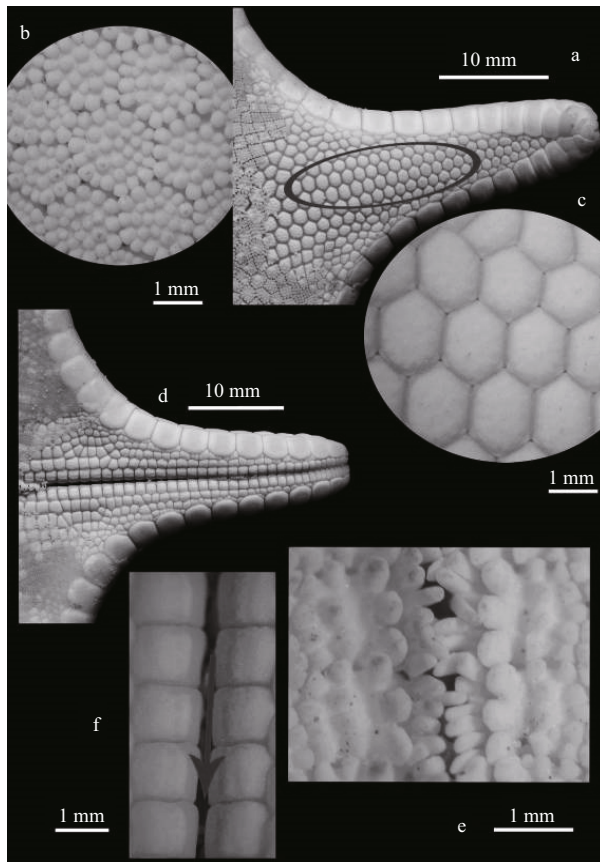


Fig.3 *Ceramaster misakiensis* (Goto, 1914) MBM176427

a. Cleared abactinal arm showing separated superomarginal plates; b. Abactinal plates covered with granules; c. Cleared abactinal plates; d. Cleared actinal arm; e. Adambulacral spines; f. Cleared adambulacral plates showing straight furrow marginal. Scale bars=1 or 10 mm.

between 15 and 20 mm. R/r varies between 2.1 and 2.3, average R/r (three specimens) = 2.2.

Diagnosis: Body flattened, disc large, normally five arms, short, tips gently upturned. Abactinal are plates rectangular to hexagonal, low-tabulate, close-set, and forming regular rows along the midline of the arms (Fig.3c). Abactinal plates covered with granules. Granules similar in size, polygonal or roundish in shape, little distinction between the central and peripheral granules (Fig.3b). Superomarginal and inferomarginal plates form a distinct edge to the disc and arms. Superomarginal plates large, rectangular, generally separate (superomarginal plates, from opposite sides of arm, do not meet in the midline) throughout all or most of the arm (Fig.3a). The surface is covered with well-spaced granules. Inferomarginal plates corresponding with superomarginal plates. The granules covering the surface are similar to those of the superomarginals. No spines of any kind on either the abactinal or the marginal plates. Adambulacral plates are rectangular to almost square, with a straight margin

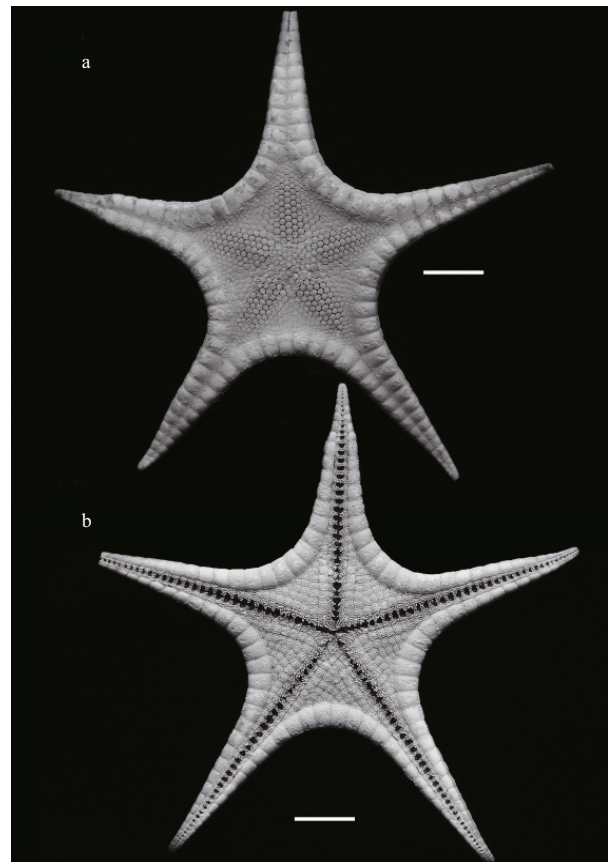


Fig.4 *Nymphaster arthrocnemis* Fisher, 1913 MBM014810

a. Abactinal view; b. Actinal view; Scale bar=10 mm

(Fig.3f). Adambulacral armature consists of three rows (Fig.3e): A series of six furrow spines on the furrow edge. Spines sub equal, flattened, and blunt tipped. Those of both sides bent towards the furrow; separated from the furrow spines by a groove, is the second series of armature consisting of three or four (commonly three), thick, short spines. The third row consists mostly of four, sometimes three or five, granules similar to those of the actinal intermediate plates. On some of the plates, the granules of this series are duplicated, forming two rows. No pedicellariae on the adambulacral plates. Oral plates relatively small and inconspicuous. Actinal areas well developed. The actual intermediate plates are very numerous, polygonal in shape, and covered with granules. No pedicellariae on the actinal intermediate plates.

Distribution: East China Sea, South China Sea; Sagami Bay area, and southeast Japan.

Depth: 184–560 m.

Remarks: This species is similar to *Ceramaster smithi* Fisher, 1913 from Philippine Island, 686–1 010 m. Both species have relatively distinct arms (not very short), and are similar in the arrangement

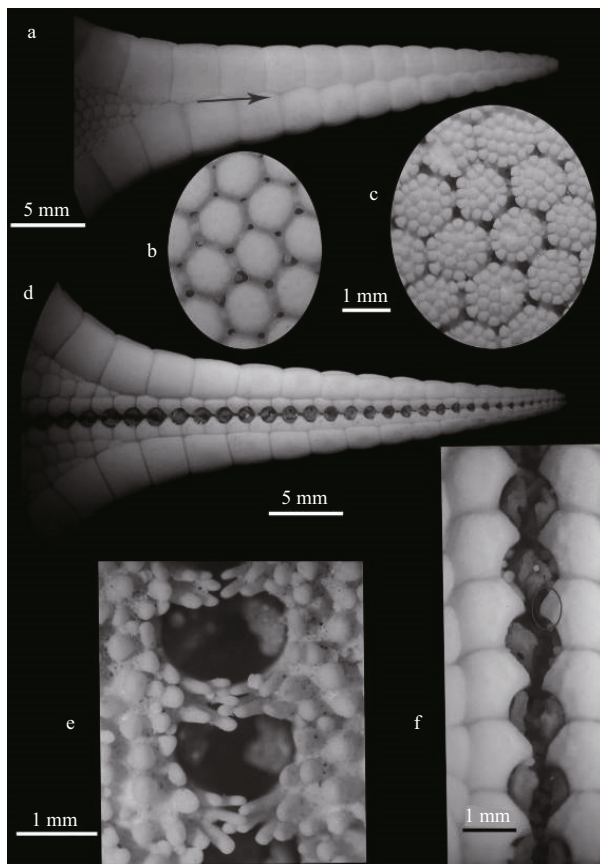


Fig.5 *Nymphaster arthrocnemis* Fisher, 1913 MBM014810

a. Cleared abactinal arm showing superomarginal plates in contact; b. Cleared abactinal plates; c. Abactinal plates covered with granules; d. Cleared actinal arm; e. Adambulacral spines; f. Cleared adambulacral plates showing angular furrow marginal. Scale bars=1 or 5 mm.

and number of granules on the abactinal plates. *C. misakiensis* differs from *C. smithi* in having more furrow spines and larger marginal plates. In *C. smithi*, marginal plates are small, forming a thin margin to the disc. The adambulacral plates have four or five furrow spines.

Our specimens from the East China and South China Seas fit well with the description of Goto (1914), except that there are no pedicellariae on the abactinal surface of the disc, arms, or marginal plates.

Genus *Nymphaster* Sladen, 1889

Nymphaster Sladen, 1889: 294; Fisher, 1913: 633; 1917: 167; 1919: 261; A. M. Clark and Downey, 1992: 253; A. M. Clark, 1993: 264 (list); Rowe and Gate, 1995: 66.

Dorigona Perrier, 1885: 39; 1894: 365. Koehler, 1909: 54. [Non *Dorigona* Gray, 1866]

Type species: *Nymphaster protentus* Sladen, 1889

Diagnosis: Body flattened, stellate, arms long, and

narrow. Abactinal plates low tabulate completely covered with granules; Marginal plates conspicuous, forming a broad border to the disc. Superomarginal plates in contact medially throughout the length of the arms (superomarginals are not separated by other series of abactinal plates) (Fig.5a). Actinal intermediate area large, granulate. Adambulacral plates with the furrow margin strongly angular, the angular furrow series separating consecutive pairs of the tube feet.

Remarks: *Nymphaster* includes 16 species (Mah and Hansson, 2012b), the majority of which occur in the Philippine Islands and adjacent waters.

Nymphaster arthrocnemis Fisher, 1913 (Figs.4, 5)

Nymphaster arthrocnemis Fisher, 1913: 638; 1919: 277, Pl. 64, Fig. 1, Pl. 65, Fig. 4, Pl. 68. Fig. 1, Pl. 69, Fig. 1, Pl. 92, Figs. 9, 9a–b; A. M. Clark, 1993: 265 (list).

Material examined

South China Sea: MBM038070, CN K122B-26, Stn. 6094, 19°00'N, 112°00'E, two spms, 300 m, AT, coarse sand, coll. Shoupeng SHEN, 8 Feb 1960; MBM014810, CN K32B-87, Stn. 6094, 19°00'N, 112°00'E, four spms, 270 m, AT, calcareous silt, coll. Fuzeng SUN, 19 Apr 1959; MBM061292, CN K150B-94, Stn. 6094, 19°00'N, 112°00'E, two spms, 290 m, AT, muddy sand, 6 Apr 1960; MBM014818, CN K7B-21, Stn. 6094, 19°00'N, 112°00'E, two spms, 472 m, AT, granular biological remains, coll. Fuzeng SUN, 17 Feb 1959.

Size: R varies between 40 and 72 mm, r varies between 12 and 23 mm. R/r varies between 2.8 and 3.5, average R/r (ten specimens) ~3.1.

Diagnosis: Body flattened stellate, with large disc and long arms. Abactinal plates very regularly arranged, completely covered with granules. These granules are not crowded, and there is a slight space between the central group and the peripheral series (Fig.5c). Abactinal radial plates, six or seven rows, roundish or hexagonal, not conspicuously broader than long (Fig.5b). Abactinal interradiial plates squarish. Papular areas small. Both series of marginal plates large, the surface is covered with spaced granules, similar to that of the abactinal plates. Fourth superomarginal plates meeting in a median line across the arm (sometimes the third in young specimens), and, therefore, there are six superomarginal plates in each interbrachium. Superomarginal plates are wider than long, individually tumid, the fourth and fifth plates are the largest. Actinal intermediate plates

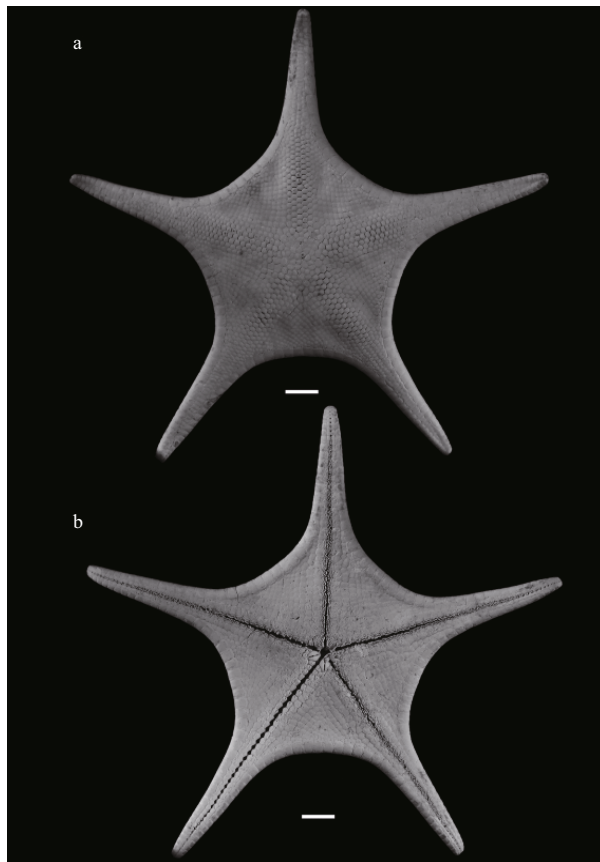


Fig.6 *Pontioceramus grandis* Fisher, 1911 MBM175193

a. Abactinal view; b. Actinal view; Scale bar=10 mm

covered with spaced hemispherical granules. Adambulacral furrow margin strongly angular (Fig.5f). Adambulacral plates with nine to eleven furrow spines at the middle of the arm, usually ten; two or three series of subadambulacral spines (seven to nine in number), and tubercular. No pedicellariae, except on the abactinal plates.

Distribution: South China Sea; Celebes Sea, and Philippine Islands.

Depth: 270–1 020 m.

Remarks: Based on the description of Fisher (1919), a few abactinal plates have a small pedicellaria. Our specimens from the South China Sea fits well with the description of Fisher (1919), except for the absence of pedicellariae on the abactinal plates and fewer furrow spines (six to eight, usually seven).

Genus *Pontioceramus* Fisher, 1911

Pontioceramus Fisher, 1911b: 420; 1919: 294; A. M. Clark, 1993: 277 (list).

Type species: *Pontioceramus grandis* Fisher, 1911

Diagnosis: Body stellate, with a large disc and relatively short arms. The surface of the abactinal

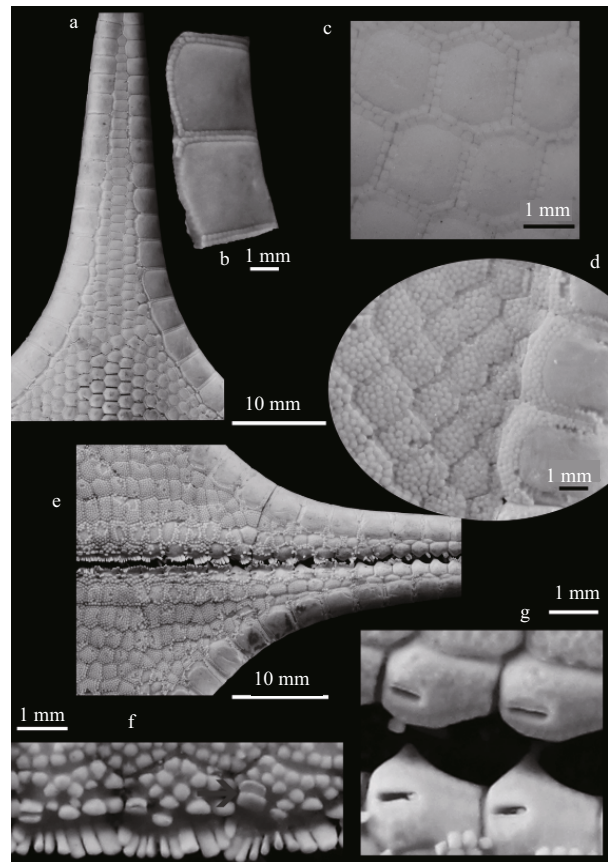


Fig.7 *Pontioceramus grandis* Fisher, 1911 MBM175193

a. Abactinal arm; b. Superomarginal plates; c. Abactinal plates; d. Actinal and inferomarginal plates; e. Actinal arm; f. Adambulacral spines showing large bivalved pedicellaria; g. Cleared adambulacral plates. Scale bars=1 or 10 mm.

plates is perfectly smooth, not covered with minute bosses. The plates of the papular areas are low tabulate. No smaller secondary abactinal plates. Abactinal and marginal plates bordered by a single series of small granules, the latter also with some on the lateral face of the arm, all flush with the level of the plate. Distalmost superomarginals in contact medially. Actinal intermediate plates reaching far along the arms, closely granulate. The adambulacral plates with an angular furrow margin; a conspicuously large subambulacral bivalved pedicellariae on the adambulacral plate (Fisher, 1919).

Remarks: *Pontioceramus* was previously recorded from the Philippine Islands and includes only one species *P. grandis* (See Mah, 2012). This genus differs from *Ceramaster* and *Nymphaster* in having smooth abactinal plates. *Nymphaster* is more morphologically similar to *Ceramaster* than to *Pontioceramus*. *Ceramaster* and *Nymphaster* are distinguished by the wholly granulate abactinal plates.

Table 2 Morphological differences among *Nymphaster arthrocnemis*, *Ceramaster misakiensis* and *Pontioceramus grandis*

	R/r	Abactinal armament	Furrow margin of adambulacral plates	Superomarginal plates
<i>N. arthrocnemis</i>	Approximately three, arms long	Completely covering plates	Strongly angular	Contact medially full length of arm
<i>C. misakiensis</i>	Approximately two, arms short	Completely covering plates	Straight	Separate throughout all or most of arm
<i>P. grandis</i>	Arms relatively short	Naked except for single row around plates	Curved	Distalmost superomarginals in contact medially

***Pontioceramus grandis* Fisher, 1911 (Figs.6, 7)**

Pontioceramus grandis Fisher, 1911b: 421; 1919: 294, Pl. 77, Fig. 3, Pl. 78, Fig. 3, Pl. 83, Fig. 4, Pl. 93, Figs. 4, 4a–b; Jangoux, 1981: 471; A. M. Clark, 1993: 277 (list).

Material examined

South China Sea: MBM175193, CN 56-66, Naozhou Island, seven spms, 15 Mar 1956.

Size: R varies between 50 and 87 mm, r varies between 17 and 34 mm. R/r varies between 2.4 and 2.9, average R/r (seven specimens) ~ 2.6.

Diagnosis: Size large; body stellate, with a large disc and short bluntly pointed arms, tapering from a very broad base. Abactinal plates numerous, with a very smooth and slightly convex surface, regularly hexagonal on the radial region, and low tabulate on the center of the disc and radial areas. Interradial plates flat, irregularly four- to six-sided. All abactinal plates surrounded by a single series of flat squarish granules (Fig.7c), flush with the surface of the plate, those on the radial plates are hard to see. Marginal plates conspicuous. Superomarginals surrounded by a single series of small flush granules forming an inconspicuous border (Fig.7b), in addition, on the lateral face of the arm, is a second series with a few scattered granules above. The distal five to eight superomarginals are in contact medially. The inferomarginals (Fig.7d) are surrounded by two or three series of granules similar to those of superomarginals, becoming reduced to a single series near the end of the arm. All actinal intermediate plates are closely granulate. The plates next to the adambulacrals bear one or two small, rather delicate bivalved pedicellariae, which fit into slight depressions when open. Each adambulacral plate is angular toward the furrow (Fig.7g). Most of the plates have a large bivalved subambulacral pedicellaria (Fig.7f) near the furrow; the jaws are much wider than high. The remainder of the plate is occupied by small round granules, those in line with pedicellaria being enlarged and subspinose. Nine to eleven, stout, short, round-

tipped furrow spines.

Distribution: South China Sea and Philippine Islands.

Depth: 220–300 m.

Remarks: This species is distinctive in having generally uniform abactinal plates arranged with regularity. The specimens examined here fit with the description of *P. grandis* by Fisher (1911b; 1919). The morphological characters that distinguish the three newly recorded species from each other are listed in Table 2.

4 DISCUSSION

The echinoderm fauna of the South and East China Seas is closely related to those found in Japanese waters and Indo-Malaysian regions in species composition, the latter being the richest area in the world with regard to marine biodiversity. The proportion of species shared between southern China and the Philippines is 60% (Liao and Clark, 1995). Besides these, there are a considerable number of species common to the region ranging from the South and East China Seas to the waters of southern Japan. The strong Kuroshio Current and its branches move from the southern Philippines to east-central Japan. On these currents, a great number of marine species with a pelagic larval phase are likely dispersed from their tropical center to the north, thus expanding their distribution ranges.

5 ACKNOWLEDGMENT

The first author sincerely appreciates her teacher, a great marine biologist, the late Professor Ruiyu LIU (J. Y. Liu) (Institute of Oceanology, Chinese Academy of Sciences) for his considerable guidance in marine biology research.

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