ATOLL RESEARCH BULLETIN
NO. 346

SEDIMENTARY CHARACTERISTICS OF CORAL REEFS IN THE NORTHERN PART OF THE SOUTH CHINA SEA

BY

WANG GUOZHONG, LU BINGQUAN AND QUAN SONGQING

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D. C., U. S. A.
SEPTEMBER 1990

SEDIMENTARY CHARACTERISTICS OF CORAL REEFS IN THE NORTHERN PART OF THE SOUTH CHINA SEA*

BY

WANG GUOZHONG, LU BINGQUAN AND QUAN SONGQING**

In the northern part of the South China Sea there is a complete range of modern coral-reef types, including fringing reefs, barrier reefs, table reefs and atolls (Fig. 1). The distribution of these coral reefs is controlled either by the terrigenous sedimentation, or by climatic and hydrodynamic conditions. Because of the interference of terrigenous sediments from the Pearl River and other small rivers, fringing and barrier reefs are mainly limited to the Guangdong shelf around Hainan and Weizhou Islands and in some estuaries, such as the estuary Daya near Hong Kong (Wang Guozhong et al 1979, Lu Bingquan et al 1983, 1984). Fringing reefs are absent along most of the coastlines of this continental shelf. Table reefs and atolls are developing off the Xisha Islands area, consisting of more than 30 shoals, banks, islets and islands which cap a submarine platform on the continental slope. Over 1251 m of reef-derived carbonate sediments have accumulated in this area since the Miocene epoch (Fig. 2, Wang Congyou 1979).

The northern area of the South China Sea falls within the tropical biogeographic zone, which extends from about 15° N to 23° N, and for most of the year is dominated by the northeasterly monsoons; in summer, however, typhoons and hurricanes strike from the southwest (Fig. 3). The climate is humid with moderate evaporation. The average water temperatures range seasonally from 20℃ to 30℃, but locally the minimum water temperatures fall appreciably to 18℃ in winter. Salinities over the reefs range from 33.5‰ to 34.0‰. During most of the year the surface water currents flow from northeast to southwest with a complete reversal during the summer months. The tidal range is about 1-2 m.

---

*The Project Supported by National Natural Science Foundation of China

**Department of Marine Geology, Tongji University, Shanghai, China

Manuscript received 13 March 1989; revised 9 February 1990

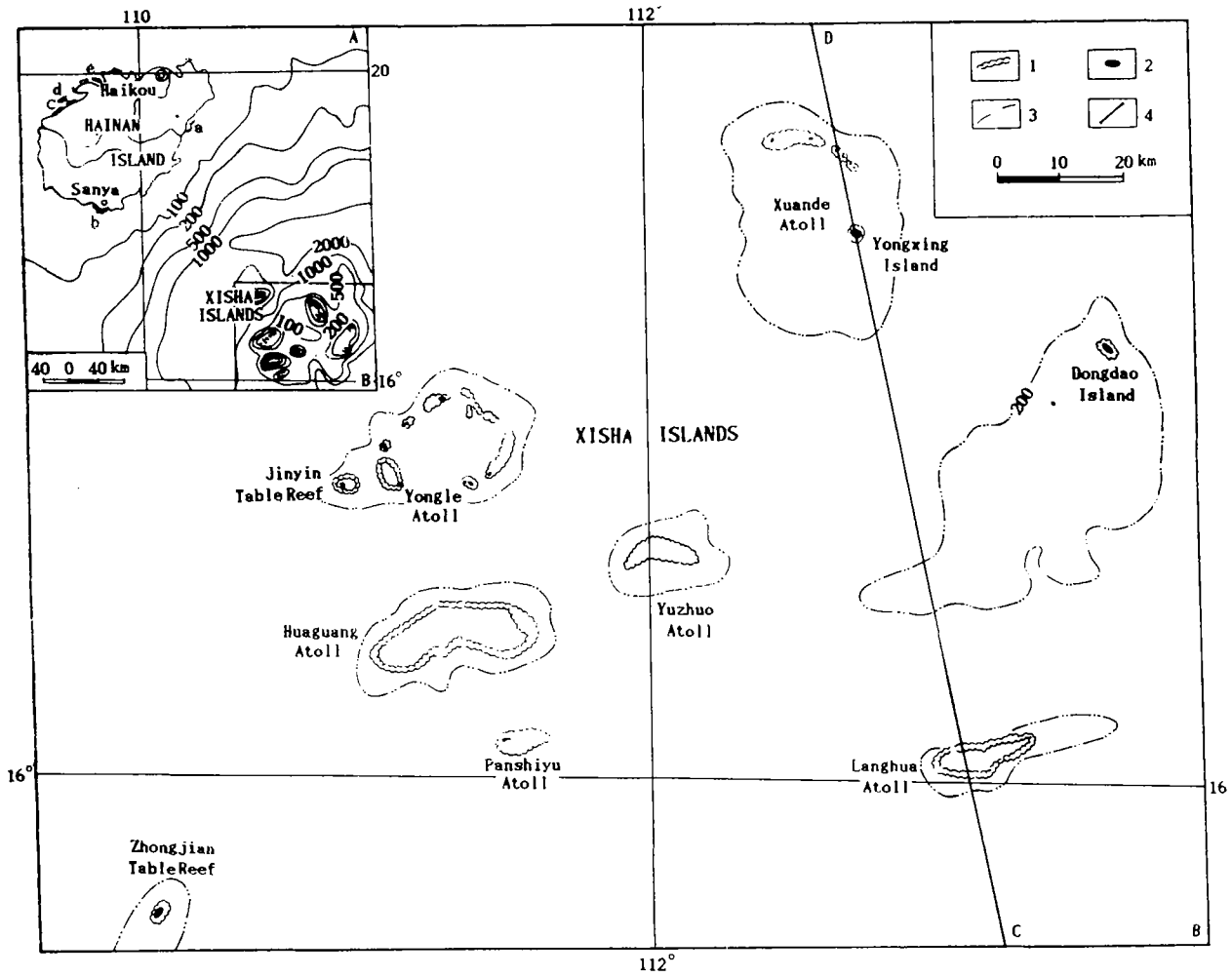

Fig. 1. Distribution of modern coral reefs in the northern part of the South China Sea. Contour depths in meters.

1—Contour of reef crest, 2—Sand cay, 3—200 m isobath, 4—Location of the C—D cross section (see Fig. 2), a—Shalao fringing reef, b—Luhuitou fringing reef, c—Paipu fringing reef, d—Dachan barrier reef, e—Linchang barrier reef (Hainan Island)

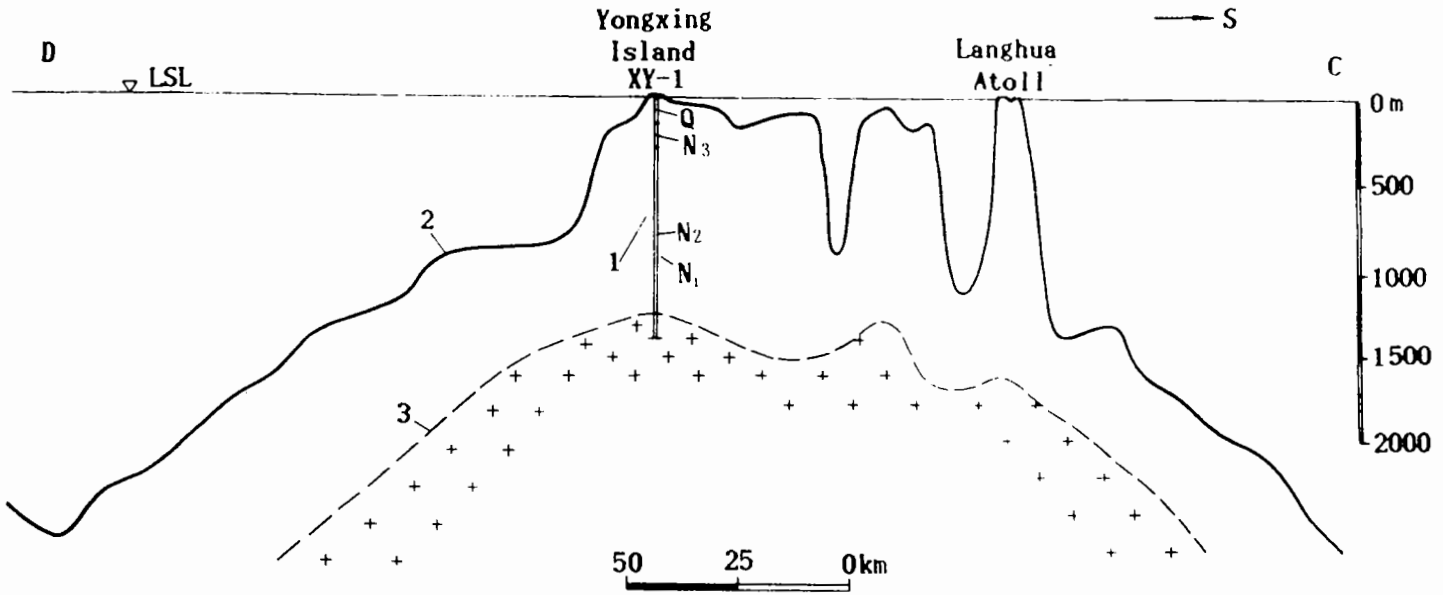

Fig.2. North-South (C-D) cross section of Xisha coral reefs (for location, see Fig.1.).
1—Well XY-1: -- N_1—Miocene(951 m), N_2—Pliocene(150 m), Q—Quaternary(150 m, included Holocene 22 m); 2—Submarine surface; 3—Residuum profile of Neogene system.

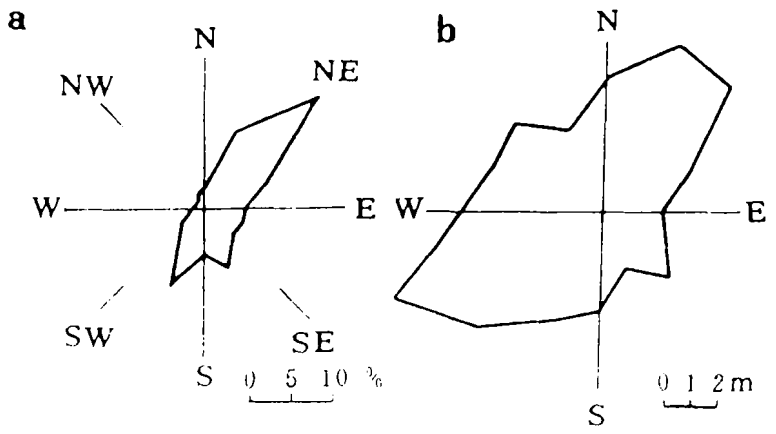

Fig. 3. The wind-rose diagram (a), and distribution of maximum mean wave heights (b) of Yongxing Island

SEDIMENTARY FACIES MODEL OF CORAL REEFS IN THE SOUTH CHINA SEA

Our investigation of the various types of modern coral reefs in the South China Sea revealed consistent zonation pattern for the reef-derived sediments, which are controlled by similar hydrological, geomorphological, biological and sedimentational parameters in this region (Wang Guozhong et al 1982, 1986). There are 7 main sedimentary facies, which are described from the fore reef shoreward as follows (Fig. 4):

The sublittoral sand-mud facies (1) is situated seaward of reefs with a smooth submarine morphology. Its upper limit starts at a depth of 10 m in the Hainan reef area and at more than 20 m in the Xisha reef area. The sediments consist mainly of clastic sand, silt, and muddy silt with patches of carbonate mud. In the Xisha reef area, this zone is almost entirely covered by white biogenic sand with scattered coral shingles, and contrasts with the Hainan and Weizhou reef areas, where the sediments consist of dark

silt and muddy silt, which contain more organic materials and terrigenous particles. The sea floor in this facies is often covered with the mounds of burrowing organisms and grasses. In this zone, there are many ostracodes and foraminifera, and the proportion of planktonic foraminifera, such as Globigerina, increases gradually seaward.

The fore-reef talus facies (2) extends from the lower limit of coral growth, which is about 5 m in the Hainan reef area and over 20 m in the Xisha area. The width of this zone ranges from 10 to 90 m. The slope is steep in the upper limits and becomes more gentle at the bases. Sediments of this facies range from boulders to sand. Living scleractinian corals are generally not found in this zone which is characterized by red algae, some gorgonians, gastropods and echinoids.

The autochthonous reef facies (3) extends from the edge of the reef flat, or low tidal level to the lower limit of coral growth as mentioned above. Its width generally ranges from 20 to 200 m and reaches a maximum of 500 m. The reef face is a slope with gradients from 6° to 30° . In this interval there are two terraces at depths of about 5 m and 10 m, which are thought to be eustatic topographic features formed during lower stands of sea level. There are 3 spur and groove (buttress) systems (Fig. 5). Two of them consist of closely-spaced, steep-sided linear highs and lows, that extend perpendicularly seaward from the reef flat; the third system with steep sides 2 m in breadth and 1-3 m in depth extends around the reef margin i.e. parallel to the reef front in ten-m lengths in water depths of about 10 m. The groove sections are both V-type and U-type and have a relief of less than 2 m. The origin of the grooves in the investigated regions is mainly erosional (Fig.9) with some constructional features.

The area covered by living coral communities on the reef face may reach 70-90% , while the rest is occupied by algae and sediments. The scleractinian corals in the coral growth zone can be grouped into two broad coral communities. The shallower (upper subzone) communities are dominated by branching and encrusting corals, such as Acropora, Pocillopora, as well as Millepora (Fig. 10,11) and coralline algae, while the deeper (lower

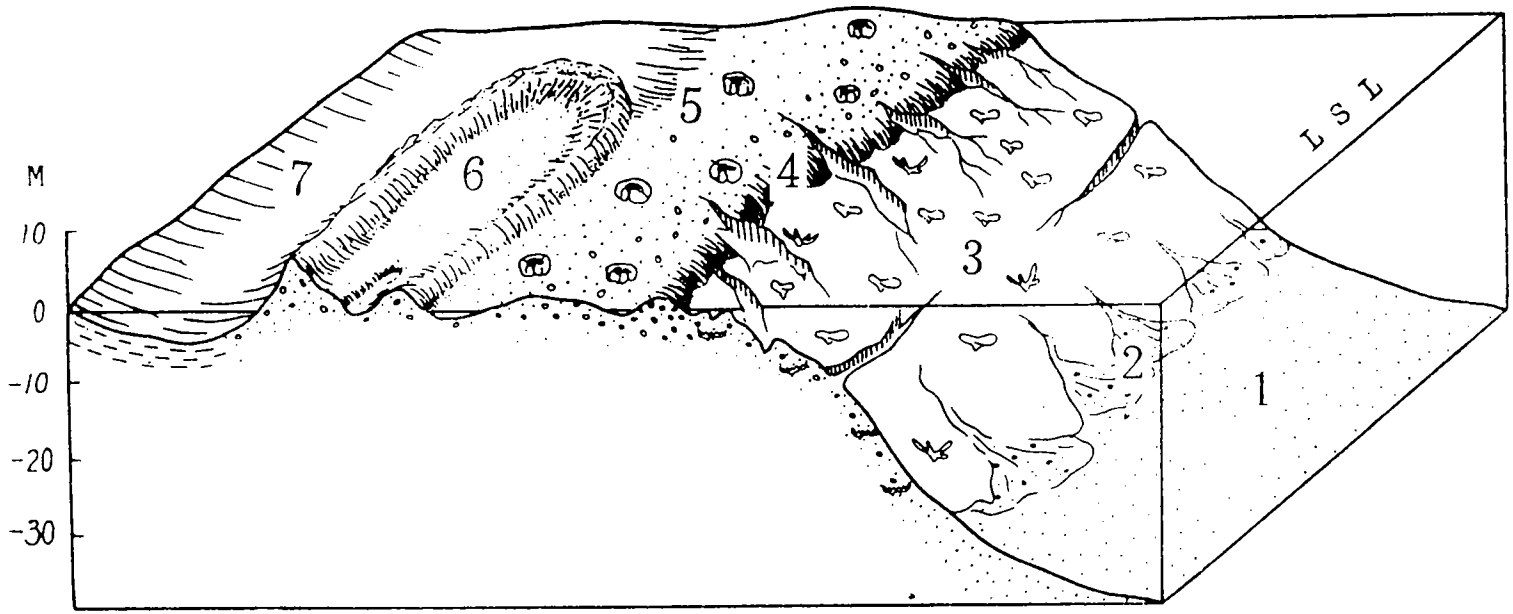

Fig.4. Sedimentary facies model of coral reefs in the northern part of the South China Sea.
1- The sublittoral sea sand-mud facies; 2- The fore-reef talus facies; 3- The autochthonous reef facies; 4- The marginal reef conglomeratic (boundstone) facies; 5- The reef flat sandy-gravel facies; 6- The sand cay gravel-sand facies; 7- The lagoonal sand-silt facies

subzone) communities contain mostly plate-like and foliose corals such as Acropora corymbosa, Acropora surcolosa and Pavona (Fig. 12). The hemispherical and massive coral species such as Porites and Favia are minor components of both subzones.

Many skeletons and shells of various organisms that grow in this facies are broken by wave action and transported mostly to the fore- and back-reef areas. Therefore, this zone becomes the source of most of the reef-derived sediments. The rigid reef framework, produced mainly by hermatypic corals, is filled with debris of various organisms and is cemented by coralline algae and by interstitially precipitated carbonate.

The marginal reef conglomeratic (boundstone) facies (4) is situated at the margin of reef flat in the form of small mounds 0.3-1 m above low tide level (Fig. 13), or rarely as gravel dams about 5 m above low tide, such as in the northwest of Hainan island, formed in response to a greater tidal range. Depending on the hydrodynamic conditions, reef margins may consist of pure gravels of reef materials or boundstones (Fig.14) and algal ridges formed by crustose coralline algae (such as Porolithon, Hydrolithon and Neogoniolithon) under conditions of very high wave energy. These algal ridges are common off the northeast margins of some islands of the Xisha Islands (as Dongdao Island, Jinyin Island etc. Zhuang Qiqian et al 1981).

The reef flat sandy-gravel facies (5). The reef flat is a broad and flat geomorphological element near low tidal level with a central prominence, which is exposed above low tidal level. Its width generally ranges from 20 to 200 m, and the maximum width reaches about 1000 m. In the Xisha Islands, because of the influence of the asymmetrical monsoons, the northeastern reef flats are wider than the southwestern, and the outer parts of atolls are wider than the inner parts (Fig. 6 and 7, Wang Guozhong et al 1986). The floors of the flats consist of sandy-gravel sediments with abundant coral patch reefs. From the reef margin shoreward the sorting and sphericity of the debris increases. Water depths on the reef flat control the development of living coral communities and other reef habitat organisms. These coral communities are sparse in some places, abundant in others, sometimes covering more than 50% of the reef flat. Heights of coral communities

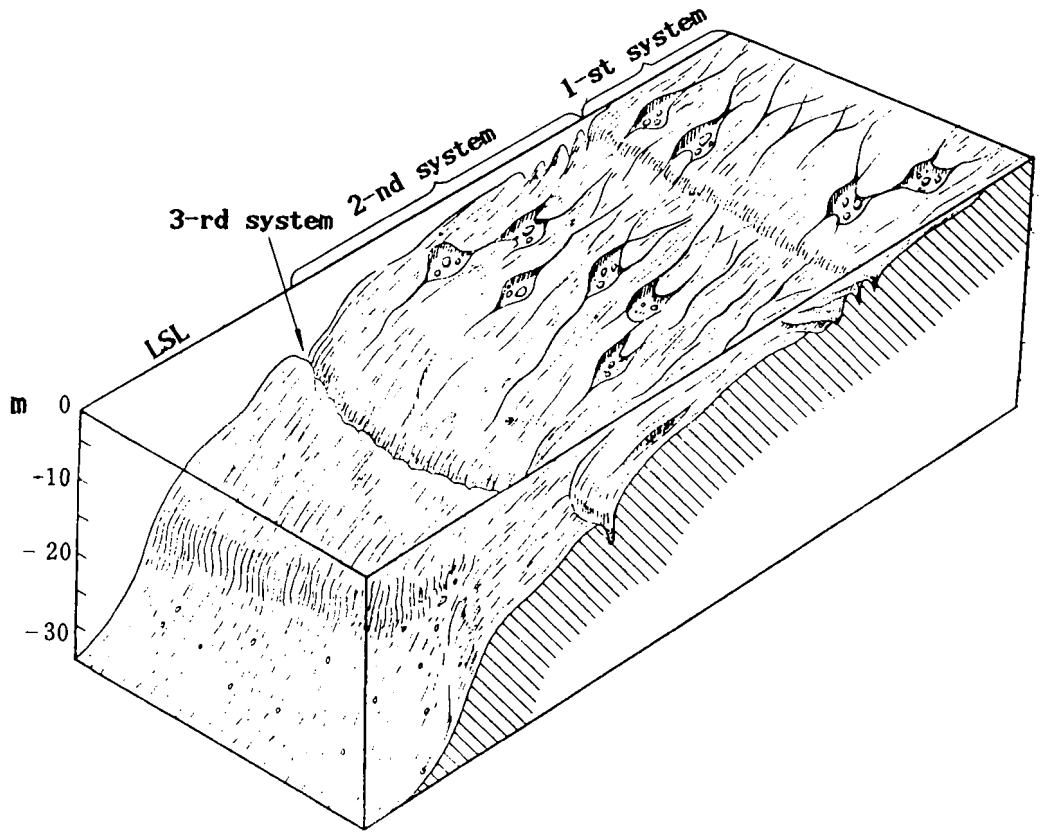

Fig. 5. The spur and groove systems of the autochthonous reef facies southwestward of Yongxing coral reef

range from 0.3 to 1 m. Coral species are dominated by encrusting, branching, plate-like (microatoll) and hemispherical corals. Scleractinian corals include Acropora (Fig.15), Montipora, Porites and Favia. In the Xisha Islands there are microatolls of Heliopora (Fig.16) and encrusting Tubipora amongst octocorals, a characteristic feature of Indo-Pacific reef flats (Milliman 1974). The variety of biota on the flats in the South China Sea is remarkable. The reef habitat organisms include mollusca, ostracoda, echinodermata, sponges, foraminifera, along with numerous algae dominated by Halimeda and Udotea. All 6 species of Tridacnidae (Fig. 17) are present, which is another characteristic feature of Indo-Pacific areas (Zhuang Qiqian, et al 1978). Benthonic foraminifera grow profusely and form 91.6-96.9% of the foraminiferal assemblage, which is dominated by Calcarina sp. and Amphistegina sp. (Wang Guozhong 1986).

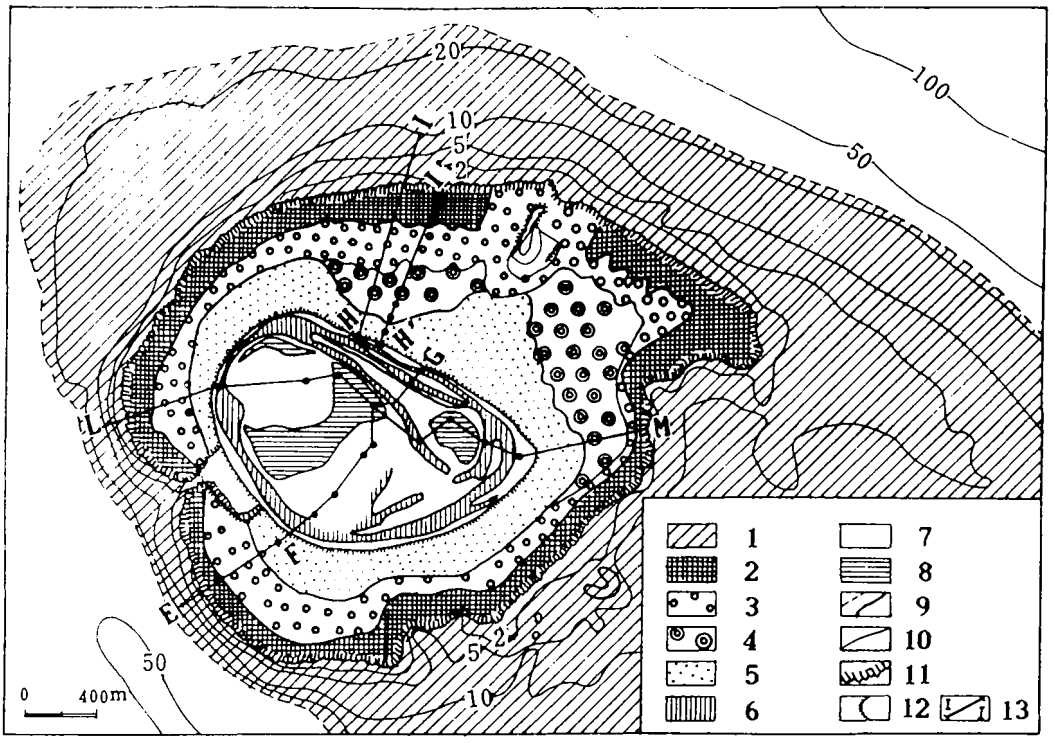

Fig. 6. Distribution of sedimentary facies of Yongxing table reef.
1- The autochthonous reef facies; 2- The marginal boundstone facies; 3-5 The reef flat facies; 6-8 The sand cay facies; 9- Boundary line of facies; 10- Isobath; 11- Reef margin; 12- Coast line; 13- Cross section.

The sand cay (barrier) gravel-sand facies (6). In the Xisha area, sand cays are built up on southwest areas of the reef flats, in response to the dominant influence of the northeast monsoon winds. Lengths and widths of cays generally range from 20 to 200 m and the longest reaches over 1900 m. In fringing reef areas off Hainan Island the sand cays develop into sand barriers or coastal sand dams. Sand cays occur in high energy environments with sand and gravel beaches on their seaward slopes. In the supratidal zone there are 1-4 rows of barriers or dams and dunes. These storm ridges have a relief of 1-2 m and are covered with 5-6 m of vegetation (Fig.18) . The central cay areas consist of sand-gravel flats, depressions and lagoons

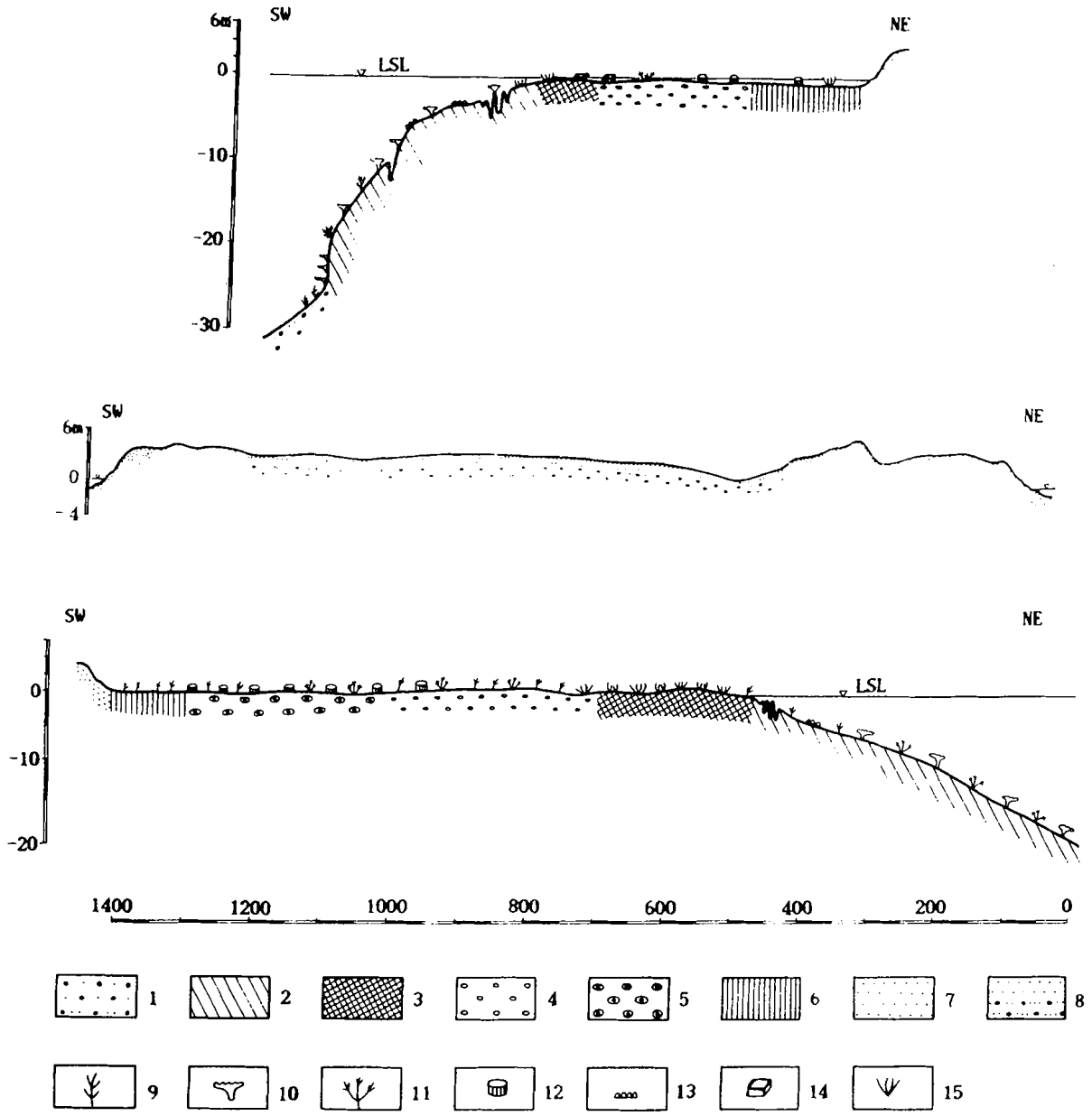

Fig.7. Cross sections of sedimentary facies across the Yongxing table reef (for location, see Fig.6).

1- The fore-reef talus facies; 2- The autochthonous reef facies; 3- The marginal reef conglomeratic (boundstone) facies; 4- The reef flat gravel facies; 5- The reef flat microatolls of Heliopora and Porites facies; 6- The reef flat sand facies; 7- The Sand Cay gravel-sand facies; 8- The Sand Cay flat and depression facies; 9- Gorgonian 10- Plate-like corals; 11- Branching corals; 12- Corals with microatoll form; 13- Short branching corals; 15- Algae.

(coastal lagoons), which are both brackish and hypersaline with salinity 7.33 to 50.76‰.

The carbonate sediments of these sand cays consist, for the most part, of debris from coral skeletons and molluscs with a marked increase in foraminifera and algae debris in the finer size fractions (Fig. 8). Some islands of Xisha area have guano deposits. Sometimes sand cay sediments are lithified which assists stabilizing sediment migration.

The lagoonal silty-sand facies (7). Lagoons are located in atolls, faros and at the back of fringing reefs. Depths of the majority of lagoons are generally less than 10 m, but some large lagoons may reach over 50 m. Sediments on the lagoonal slopes are mainly carbonate sand with coral debris or shingles. Patch reefs within the lagoons have mound-like and linear forms and, for the most part, consist of symmetrical conical coral zonation

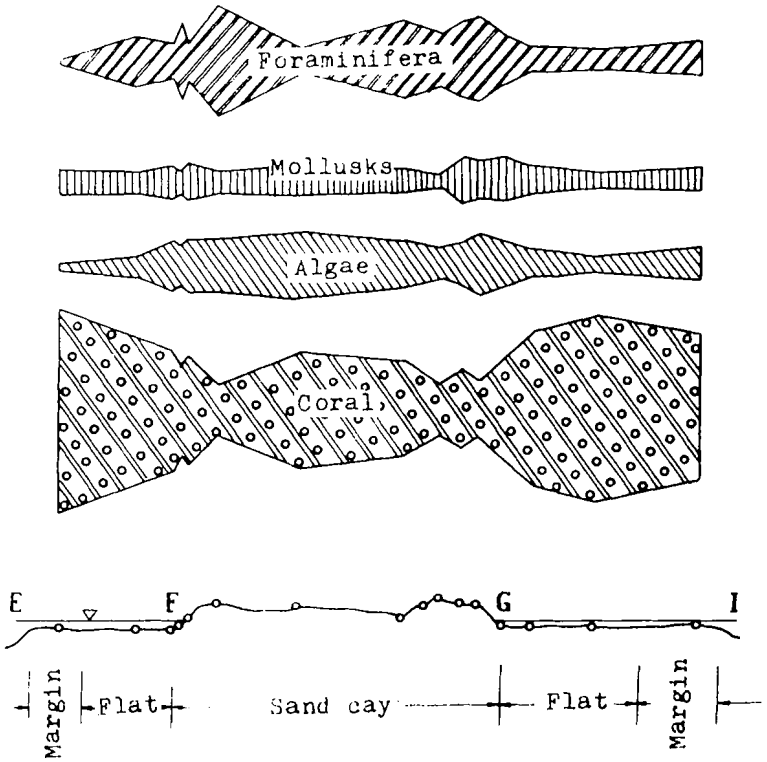

Fig. 8. Distribution of sand-size components of Yongxing coral reef along cross sections E-F-G and H-I (for location, see Fig.6)

that includes bush-like corals, such as Pavona sp., Pocillopora sp., Acropora sp., Fungia sp., Alcyonaria etc. The lagoon floors generally consist of sand and silt characterized by poor sorting, and the overlying waters are rich in suspended sediment but on some lagoon floors, even at depths of 30-50 m many encrusting corals grow, including Montipora foliosa, and Galaxea sp. Along with abundant sponges, the percentage by living coral cover may reach more than 80% (Huaguang Atoll).

Lagoon sediments contain well-preserved bivalves with thin shells, and the foraminifera are dominated by benthonic forms with porcelaneous tests.

CORAL AND SEDIMENTARY CHARACTERISTICS

Hainan and Weizhou reef areas located on the Guangdong shelf, belong to the category of shelf reefs. The table reefs and atolls in the Xisha reef are established on a submarine platform on the continental slope and may be compared with oceanic reefs, but have their own characteristics (Fig.1).

The South China Sea, as a marginal sea, is located geographically between the Pacific and Indian Oceans and represents a transitional region between them.

As a result of the weaker influence of the Pacific warm current (Kuroshio) and stronger influence of northeast and southwest monsoons, coral reefs in the South China Sea have their own specific features that can be described as follows:

Scleractinian corals of the South China Sea belong to Indo-Pacific coral reef region, but the organism diversities are relatively low. For example, 45 genera and more than 179 species of scleractinian corals are found here (Zou Renlin et al 1983), versus more than 700 species in Indo-Pacific areas and 350 species in the Great Barrier Reef area; however, only 1/3 as many (about 50 species) are found in the Caribbean (Milliman 1974, Reading 1978) (Table 1). In the Xisha area Heliopora and Tubipora (Octocorallia) are well

developed and all 6 species of tridachnidae (mollusca) are found; both are characteristic features of Indo-Pacific reefs (Zhuang Qiqian et al 1981).

Table 1. The organism diversities of coral species in various reef areas

	South China Sea	Pacific* Ocean	Great Barrier Reef*	Caribbean* Sea
Species of corals	179	700	350	50
Heliopora	+	+		-
Tubipora	+	+		-

*After Milliman 1974.

Because northeast monsoon winds are stronger than those from the southwest, coral reefs are better developed northeastward than those found southwestward. Coral reef zones in the northeastward areas are wider and have a higher production of carbonate sediments than that found in southwestward reefs (Fig. 6). On the northeast outer-reef flats of some Xisha Islands, crustose coralline algae ridges are developing, but they are weaker than those found in Pacific. In contrast, algal ridges are absent from most Indian Ocean reefs (Tracey et al 1948, Mergner et al 1974, Milliman 1974).

Most Pacific atoll sand cays are located on windward reefs (Milliman 1974) , while many cays of Xisha Islands occur on more leeward areas southwest of the reef flat or on the inner sides of the reef flat of atolls. Since most reef flats lack algal ridges, this leeward position of sand cays is more similar to that found in Indian Ocean reefs (Milliman 1974).

The composition of reef and lagoonal carbonate sediments can well reflect the environment of deposition, the distribution of populations, and productivities of the various organisms, which in turn, are influenced by the climate, current system and hydrodynamic regimes. As products of high energy environments, the shallow-water reef derived sediments of the South China Sea generally consist of coarser debris, such as sand and gravel, with an absence of lime-mud as well as oolites and cemented carbonate grains.

With respect to the total sediments, coral skeletal detritus and skeletons are the dominant component and constitute from 21 to 85% of the total sediment. Algal fragments are relatively unimportant, constituting only 3 to 27% of the sediment (Fig. 7, Tables 2, 3). This sediment distribution is more analogous to that found in the Australian Great Barrier Reef in contrast to that associated with coral reefs in the areas of Indo-Pacific and Caribbean, which are predominantly composed of algal debris ranging from 12 to 64%. Benthonic foraminifera are major contributors to both the South China Sea, or Indo-Pacific reef-flat sediments, which contrasts with their paucity in Caribbean reef sediments (Ginsburg 1965, Milliman 1974, Reading 1978) . The quantities of molluscan fragments found in various reef areas are similar but the ratio of molluscan to algal debris can be indicative of biological areas. For example, this ratio in the South China Sea is more than 0.5, but in the other reef areas it is less than 0.5 (Table 3).

To summarize, because of their location between Pacific and Indian Oceans, the sedimentology of coral reefs in the South China Sea represents a transitional pattern which has a closer similarity to sedimentary characteristics of the Great Barrier Reef.

Table 2. Composition of the sand-size components of reef flat sediments from various reef areas

	South China Sea	Pacific* Ocean	Caribbean* Sea
Coral	21-85	15-36	20-35
Algae	3-43	25-62	12-64
Foraminifera	1-21	10-23	2-13
Mollusk	5-19	12	5-22
Mollusks/Algae	0.93	0.28	0.36

*After Milliman 1974.

Table 3. Composition of the sand-size components of lagoonal sediments from various reef area

	South China Sea	Pacific* Ocean	Caribbean* Sea
Coral	40-69	15-36	25-35
Algae	7-35	33-54	41-53
Foraminifera	6-8	10-23	2-3
Mollusk	15-17	10-12	5-15
Mollusks/Algae	0.65	0.25	0.21

*After Milliman 1974.

ACKNOWLEDGEMENTS

We thank National Natural Science Foundation of China for financial support. We thank Ian G. Macintyre and Joshua Tracey very much for their interest in this project and revising the English text and Wang Xiuya for drawing figures.

REFERENCES

1. Ginsburg, R.N. 1965. Environmental relationships of grain-size and constituent particles in some south Florida carbonate sediments. Bull. Am. Assoc. Pet. Geol., 40: 2384-2427.

2. Lu Bingquan, Wang Guozhong and Quan Songqing. 1983. The recent sedimentary facies zones of the Shalao fringing reefs, Hainan Island. J. Tongji University, No. 3. 57-66.

3. Lu Bingquan, Wang Guozhong and Quan Songqing. 1984. The characteristics of fringing reefs of Hainan Island. Geographical Research, 3: No. 3. 1-16.

4. Mergner, H. and Scheer, G. 1974. The physiographic zonation and the ecological conditions of some South Indian and Ceylon coral reefs. In:

Proceedings of the Second International Coral Reef Symposium. Great Barrier Reef Committee, Brisbane. 3-30.

5. Milliman, J.D. 1974. Marine carbonates. Springar-Verlag., Berlin, 375 pp.

6. Reading, H.G. 1978. Sedimentary environments and facies. Blackwell. Oxford. London. 577 pp.

7. Tracey, J.I., Ladd, J.H.S. and Hoffmeister, J.E. 1948. Reefs of Bikini, Marshall Island. Geol. Soc. Am. Bull, 59: 861-878.

8. Wang Guozhong, Chou Fougen, Lu Bingquan, Quan Songqing and Ming Qiubao. 1979. The sedimentary facies zones of the Luhuitou fringing reefs, Hainan Island. J. Tongji University. No. 70-89.

9. Wang Guozhong, Lu Bingquan and Quan Songquing. 1982. The fundamental sedimentary facies of modern coral reefs in Hainan Island and Xisha Islands. Oil and Gas Geology, 3: No.3. 211-222.

10. Wang Guozhong, Lu Bingquan and Quan Songqing. 1986. The sedimentary environments and characteristics of the coral reef of the Yongxing Island. Oceanologia et Limnologia Sinica, 17: No. 1. 36-44.

11. Wang Congyou, et al. 1979. A prime studies of limestones and micropaleontologies of Xingyong Well No. 1, Xisha Islands. Experimental Petroleum Geology No. 1. 23-38.

12. Zhuang Qiqian, et al. 1978. The Tridacnids of the Xisha Islands, Guangdong Province, China, Studia Marina Sinica, Vol. 12, 133-139.

13. Zhuang Qiqian, et al. 1981. Zonation characteristics of the reef flat of the Xisha Islands, Guangdong province, China. Oceanologia et Limnologia Sinica, 12: No. 4. 341-348.

14. Zou Renlin, et al. 1983. Preliminary study on the geographical distribution of shallow-water scleractinia corals from China. Nanhai Studia Marina Sinica, Vol. 4, 89-95.

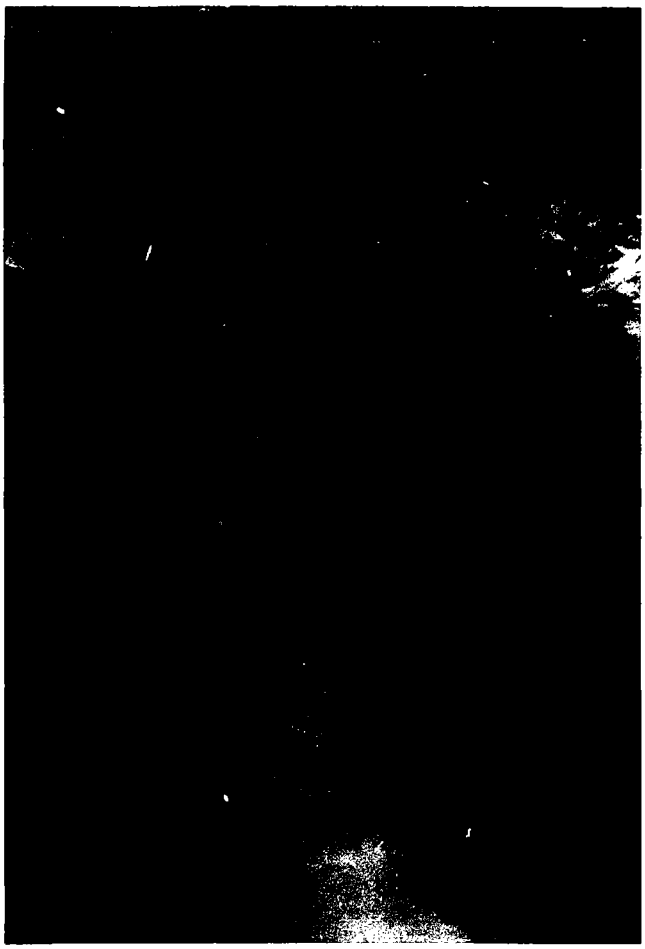

Figure 9. The groove with U-type section shows the erosional origin; bottom covered by white biogenic sand.

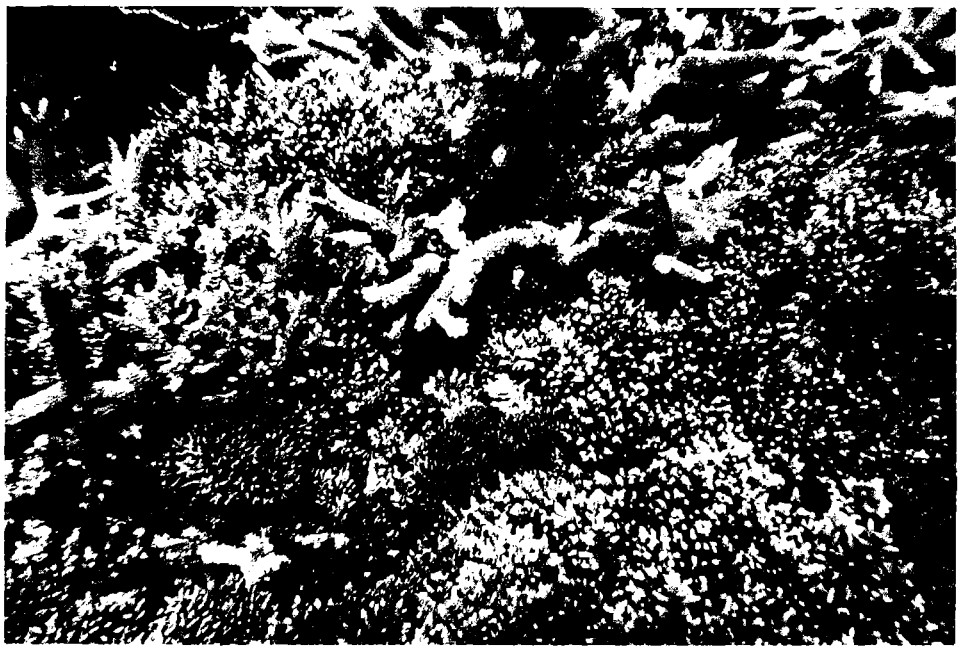

Figure 10. The shallower community consists of branching corals, dominated by Acropora sp.

Figure 11. The shallower water hermatypic organisms -Millepora, Pocillopora etc.

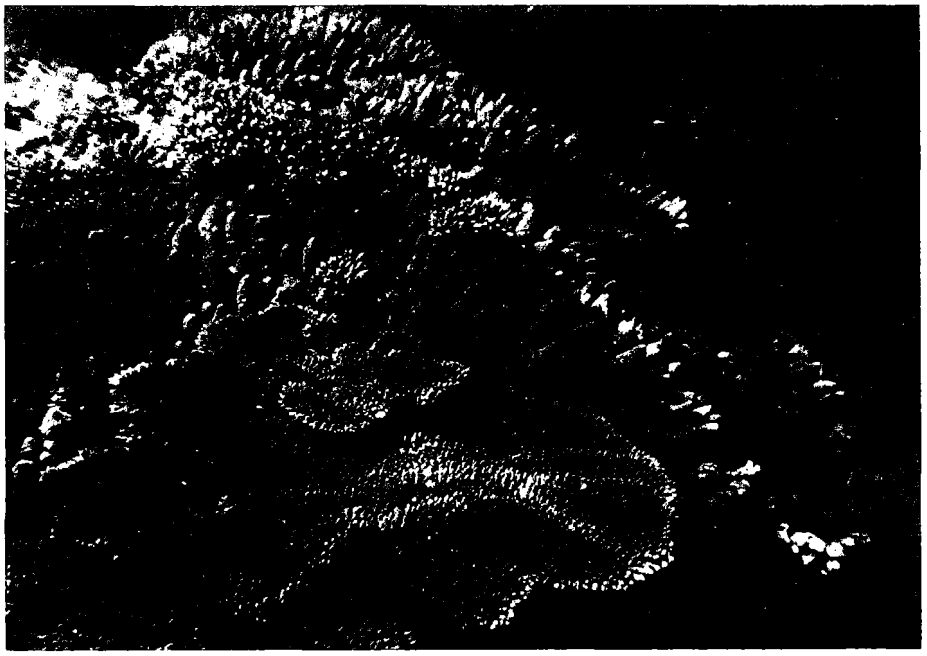

Figure 12. The scleractinian corals-Acropora corymbosa, Acropora pacifica etc.

Figure 13. The view of the reef margin.

Figure 14. The reef margin consists of reef rocks and gravels; floor consists of bound-stones.

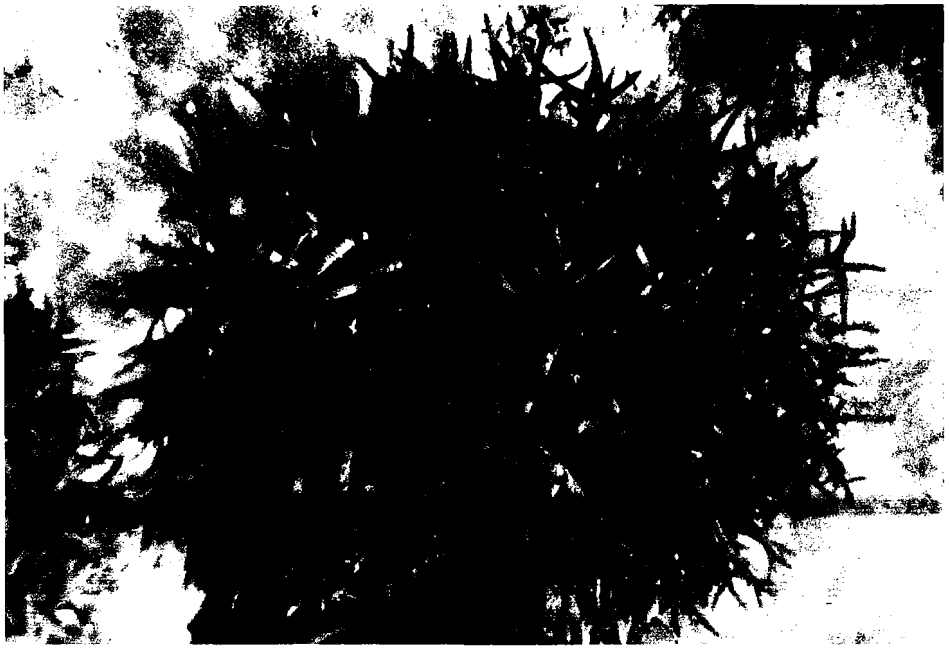

Fig. 15. The bush-like corals - Acropora sp. on the reef flat.

Fig 16. The microatoll of Heliopora - a species of octocorals on the reef flat.

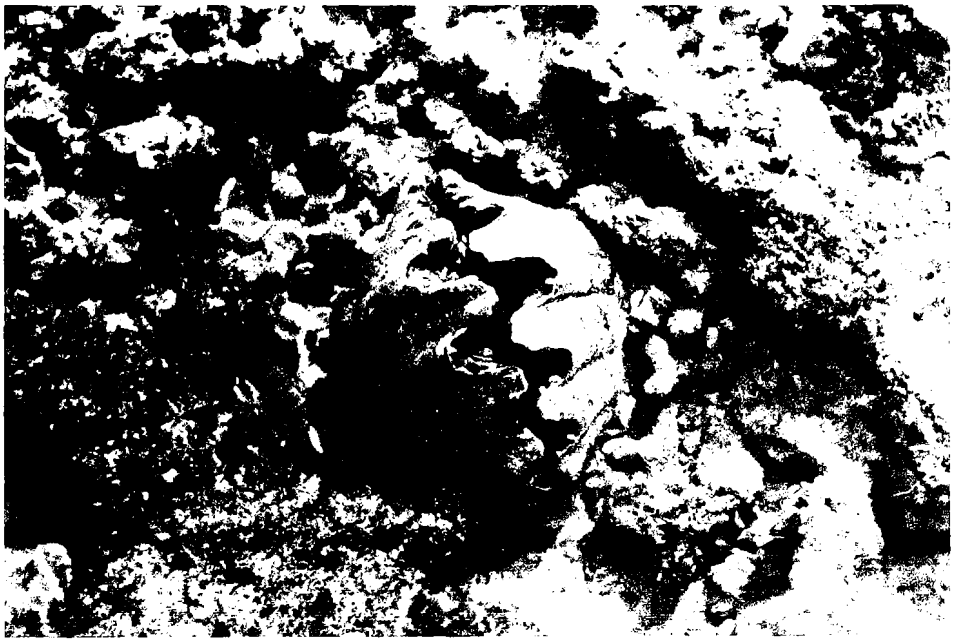

Figure 17. The tridacnid is living on the reef flat of the South China Sea.

Figure 18. The dune, with vegetation of Scaevola sericea, 5-6 m in height.