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臺灣南部海域水深35至120公尺間底質和大型底棲生物的分布

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ABSTRACT

Direct underwater observations, using a remote operated vehicle, on substrate types and distributions of macrobenthos were made at depths between 35 and 120 m in southern Taiwan. Three substrate types were classified, i. e. blocks and boulders, rubbles and gravels, and sandy bottom. No existing coral reefs were found below 40 m and the majority of the substrates were covered by sand. The rocky substrate with scattered blocks and boulders supports the richest fauna and flora including many forms of gorgonaceans, antipatharians, hydroids, sponges, bryozoans, ascidians and crustose coralline algae. The most dominant macrobenthos on rocky substrates are fan and whip-shaped gorgonaceans and antipatharians. The soft coral, *Dendronephthya* spp., was dominant on the substrate of rubbles and gravels. The sandy bottom was depauperate in fauna and flora. Hydroid colonies including large plumularid hydroids were often found on sandy bottom. The depth limit of hermatypic corals and algae in southern Taiwan were at depths between 70 and 80 m. The distribution of corals and algae in deep water habitat is likely restricted by low light intensity, heavy sedimentation, the deficiency of firm substrates and high benthic hydraulic energy of the environment.

INTRODUCTION

The study area, Hengchun Peninsula, is located on the southern tip of Taiwan (Lat. 21°55′-22°00′N., Long. 120°40′-120°52′E.). The Peninsula comprises the major part of Kenting National Park and is famous for its well-developed Pleistocene and Holocene reefs. The coastal area of the Peninsula is surrounded by fringing reefs inhabited by a relatively rich coral fauna and other reef organisms (Jones *et al.* 1972; Dai, 1991).

The reef ecosystem of southern Taiwan is of particular importance since it constitutes the major recreational resources of Kenting National Park and also supports fishery resources for local people. The basis of this ecosystem is the primary productivity of benthic macroalgae and symbiotic reef-building corals. To assess the potential resources and productivity of the marine ecosystem in the coastal areas of southern Taiwan, we need to know the distribution and depth limits of benthic macroalgae and corals in that area. A detailed knowledge on distributions of fauna and flora in deep waters of southern Taiwan will not only provide the basic information for recreation and resource management of Kenting National Park but also extend our understanding on the marine environment and resources of Taiwan.

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Underwater studies of reef communities in southern Taiwan were initiated by Jones *et al.* (1972). They introduced scuba survey techniques to Taiwan and provided qualitative descriptions on reef environment and biotic communities down to a depth of 20 m. Subsequent studies by several anthors further described the fauna and the distribution of reef organisms (e.g. Yang, 1985; Chen *et al.* 1988; Chao and Chang, 1989; Chen and Chang, 1991) but all confined to the depth of 30 m mainly due to the physiological restriction of scuba diving. Dai (1988) reported that coral communities in southern Taiwan often ended at the depths between 20 and 30 m. But judging from the studies on distribution limits of reef-building corals (Yamazato, 1972; Fricke and Schuhmacher, 1983), he suggested that deep water coral communities may exist below the depth of 40 m.

By the use of SCUBA, manned submersibles and remote video devices in the past two decades, several studies have investigated deep water benthic communities and our knowledge of depth maxima of algal and coral communities have been extended in significant ways (Kühlmann, 1983; Littler *et al.* 1985; Sarano and Pichon, 1988; Vadas and Steneck, 1988). A record depth for living marine macrophytes has been reported to a depth of 268 m (Littler *et al.* 1985, 1986). Reef-building corals have frequently been reported to the depth below 100 m (Yamazato, 1972; Lang, 1974; Fricke and Schuhmacher, 1983). However, the depth limits of algal and coral distributions in the coastal areas of Taiwan have hardly been investigated.

Here we describe the substrate types and distribution of macrobenthos at depths between 35 and 120 m in the coastal waters of southern Taiwan based on surveys conducted by a remote operated vehicle. This report provides the first direct observations on substrates and benthic organisms to a depth of 120 m in the coastal waters of Taiwan.

MATERIAL AND METHODS

A remote operated vehicle (ROV), MiniRover MK-II, from the National Undersea Research Center, The University of Connecticut at Avery Point (NURC-UCAP) was used for investigation on a cruise conducted from 10 to 14 May, 1991. Eighteen stations, 12 in Nanwan Bay and 4 on the west coast of Hengchun Peninsula, were surveyed (Fig. 1). At each station, the support ship, R/V Hai-Hung of the Taiwan Fishery Research Institute, was at anchor for all ROV dives and an area of 30-50 m in radius from the downweight was surveyed. The video camera in the ROV was used to record the bottom topography and macrobenthos of the study sites. A dual lens system on the ROV permitted the camera viewing perspective to be changed from wide angle (3 mm), used in normal reconnaissance, to macro range (8 mm) for close inspection and identification of organism/substrate features under observation. In addition, a camera mounted on the ROV was applied to take still photographs. The 35 mm still camera and strobe were aligned in order to photograph selected video fields-of-view on demand by ROV investigators. High resolution 35 mm still photos were obtained with horizontal axis dimensions of 0.5-1.0 m (Figs. 3-14). Color video recording and still photography were taken continuously throughout each dive. Qualitative descriptions of the substrate types and distribution of macrobenthos were based on observations conducted on board the R/V Hai-Hung and by analysis of the recorded tapes and photographs.

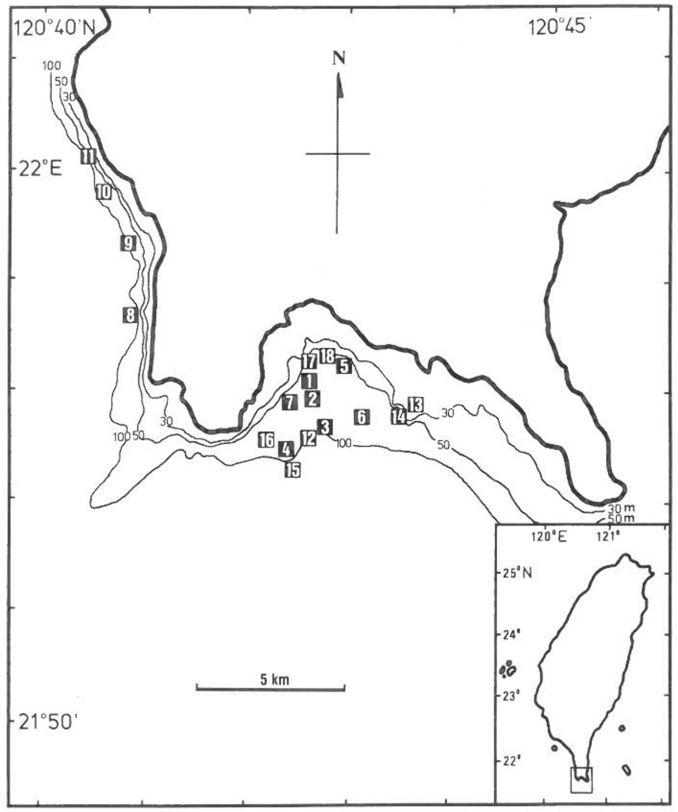

Fig. 1. Map of the study area showing the survey stations. Depth contour adopted from Chen *et al.* (1974).

RESULTS

Table 1 listed the locations and substrate types of the study sites of ROV operations in southern Taiwan. A generalized picture of the bottom configuration may be drawn out of the information obtained from the observations made at 18 stations. The available data on topography, sediment types, and associated organisms allow us to classify the substrates of the study area into three types, i.e., blocks and boulders, rubbles and gravels, and sandy bottom (Fig. 2).

Blocks and Boulders

This substrate includes stations 1, 2, 3 and 12 and ranges from 40 to 100 m deep. Its location near the west side of Nanwan Bay extends from north to southwest. The substrate is characterized by blocks or boulders of various sizes scattered on rocky bottom. The surface of blocks and boulders supports the richest fauna and flora including representatives of Porifera, Gorgonacea, Antipatharia, Bryozoa, Ascidiacea, Crinoidea and Ophiuroidea.

The most dominant animals on rock surface are Gorgonacea and Antipatharia, both groups are represented by many forms, most of them assuming fan-like or whip-like shapes (Figs. 3, 4). Fan-shaped gorgonaceans such as *Subergorgia* spp.,

Table 1. Location and substrate type of the 18 survey stations in southern Taiwan

Station	Depth (m)	Location		Substrate Type
		Lat. (N)	Long. (E)	
1	53-57	21°56′06″	120°45′12″	blocks or boulders
2	58-60	21°55′48″	120°45′24″	blocks or boulders
3	96-104	21°55′06″	120°45′30″	blocks or boulders
4	68-72	21°54′42″	120°44′48″	gravels
5	43-45	21°56′22″	120°45′51″	rubbles
6	88-93	21°55′22″	120°46′12″	sand
7	43-45	21°55′39″	120°44′32″	gravels
8	90-100	21°57′12″	120°41′48″	sand
9	75-78	21°58′30″	120°41′42″	fine sand
10	42-54	21°59′36″	120°41′06″	sand with few rocks
11	42-48	22°01′00″	120°41′06″	sand
12	73-76	21°55′00″	120°45′12″	blocks or boulders
13	34-37	21°57′30″	120°47′09″	rubbles
14	86-89	21°55′09″	120°47′06″	sand
15	115-118	21°54′15″	120°44′54″	sand
16	54-56	21°54′48″	120°44′00″	blocks or boulders
17	42-44	21°56′15″	120°42′20″	rubbles
18	52-55	21°56′20″	120°42′45″	sand

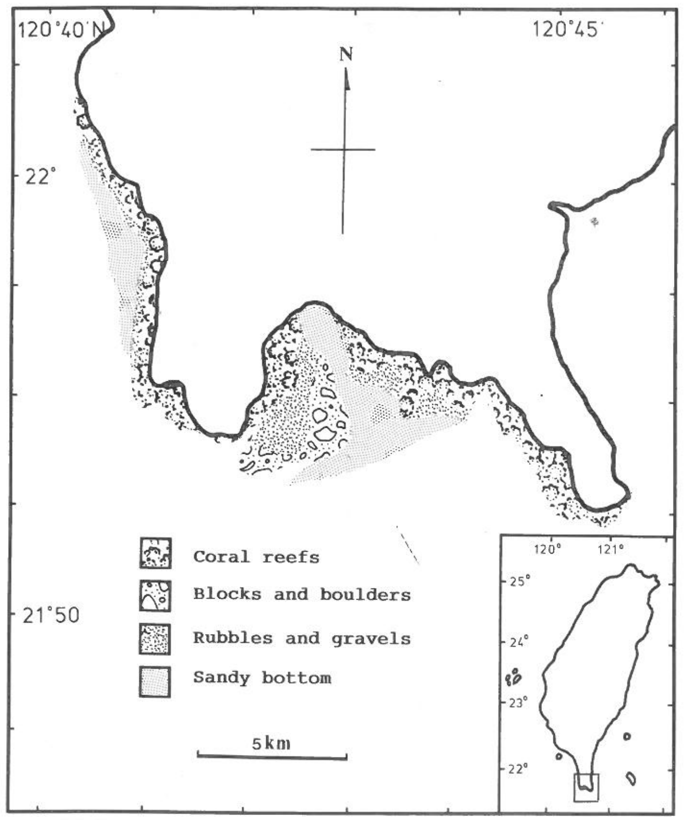

Fig. 2. Distribution of the three substrate types and living coral reefs in the study area.

Melithaea spp. are more common at depths between 50 and 70 m, while whip-like gorgonaceans and antipatharians such as *Junceella fragilis*, *J. juncea*, *Ellisella maculate*, *E. robusta*, and *Cirripathes* spp. are more common below 80 m. The red sea whip, *J. juncea* and *E. maculate* are the most abundant benthic organisms at depths below 80 m where their density may reach 10 colonies/m^2 and the length of colonies may reach 10 m with whorls near the tips. Colonies of branching or spherical alcyonacean corals, *Dendronephthya* spp., are also common on the surface of blocks. Feather-like hydroids (Plumulariidae), *Aglaophenia* spp. and *Lytocarpus* spp., and sponges including branching and encrusting forms and massive sclerosponges are also common on block surfaces (Fig. 5). Few scleractinian colonies including *Merulina ampliata*, *Echinophyllia aspera*, *Montipora foveolata*, and *Porites* spp. were found on the upper surface of blocks down to 76 m deep (Figs. 6, 7). They are encrusting or flat laminar colonies. Crinoids and a yellow holothurian, *Cucumaria* sp. were frequently found clinging to the branches of gorgonaceans (Fig. 6). Sclerosponges were also found on red crustose coralline algae are common on block surface, they are more abundant at depths between 40 to 70 m (Figs. 6, 7) and become less below 70 m. The substrate between blocks is often covered by sediment. Relatively few organisms were found on the sandy surface.

At the deep part of this substrate (100 m, Station 3), the blocks are smaller and more widely scattered. Sedimentation is relatively high and most of the surface is covered by sand of various thickness. Fan-shaped gorgonaceans, hydroids, ascidians and tube-shaped sponges are common on top of the blocks (Fig. 8) while whip-like gorgonaceans and encrusting sponges are dominant on the lower edge of the blocks. Those whip-like gorgonacean colonies are often shorter (<5 m long) but their density remains high. On the surface covered by sand, hydroids are the major epibenthos, other organisms occupying this habitat are branching sponges and the octocoral, *Siphonogorgia* sp.

Rubbles and Gravels

This substrate often borders the lower edges of living coral reefs and locates at depths between 35 and 45 m. The submarine topography of this habitat is remarkably uniform. The surface is usually flat and covered by rubbles or gravels intermingled with sand. Visibility of this environment is high, often reach 10-20 m. The most characteristic animals on this habitat are the Alcyonacea, *Dendronephthya* spp. (Fig. 9, 10). The colony is comprised of polyp-bearing anthocodia and a spicule-reinforced supporting stalk. These soft corals often display a variety of bright colors including white, yellow, or red. They are uniformly distributed over the substrate with their stalks planted in rubbles. Their density is about 1-2 colonies/m^2. Other animals on this substrate are crinoids, hydroids, bryozoans and ascidians. Filamentous green algae, often in the form of algal tufts, and foliose red algae are also common on the surface of rubbles. The brown algae, *Sargassum* spp., and the red algae, *Galaxaura* spp., are also found on top of rubbles at depths between 40 and 45 m.

Sandy Bottom

The sandy bottom represents the areas covered by various thickness of sediment layer. On the surface of the substrate one often finds holes, funnel-shaped depressions or volcano-shaped mounds; these are the evidence of rich populations of sand-dwelling animals. Although we were unable to collect these

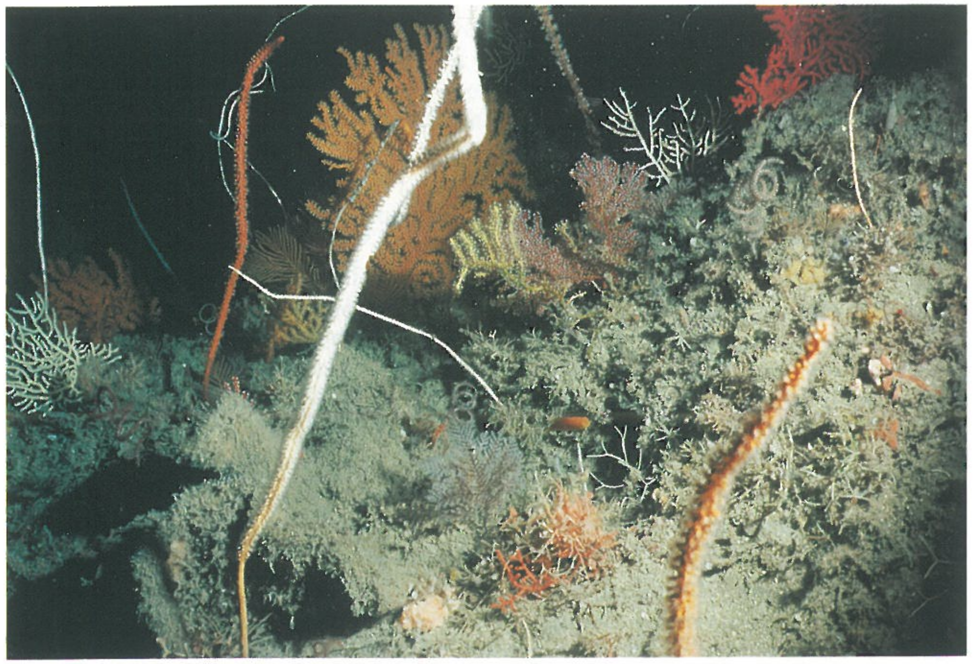

Fig. 3. A typical benthic community on the substrate of blocks and boulders dominated by fan-like and whip-like gorgonacean corals at 75 m deep of Station 12.

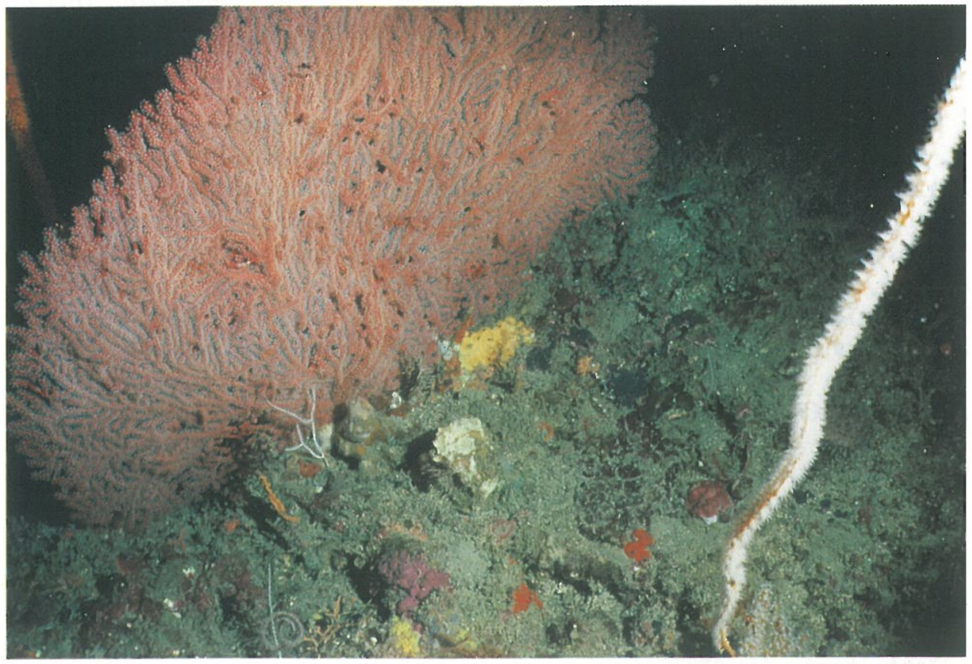

Fig. 4. A fan-shaped gorgonacean colony at 55 m deep of Station 1.

Fig. 5. Colonies of sclerosponges (black), demosponges (right), braching bryozoans and whip-like *Cirripathes* sp. at 60 m deep of Station 2.

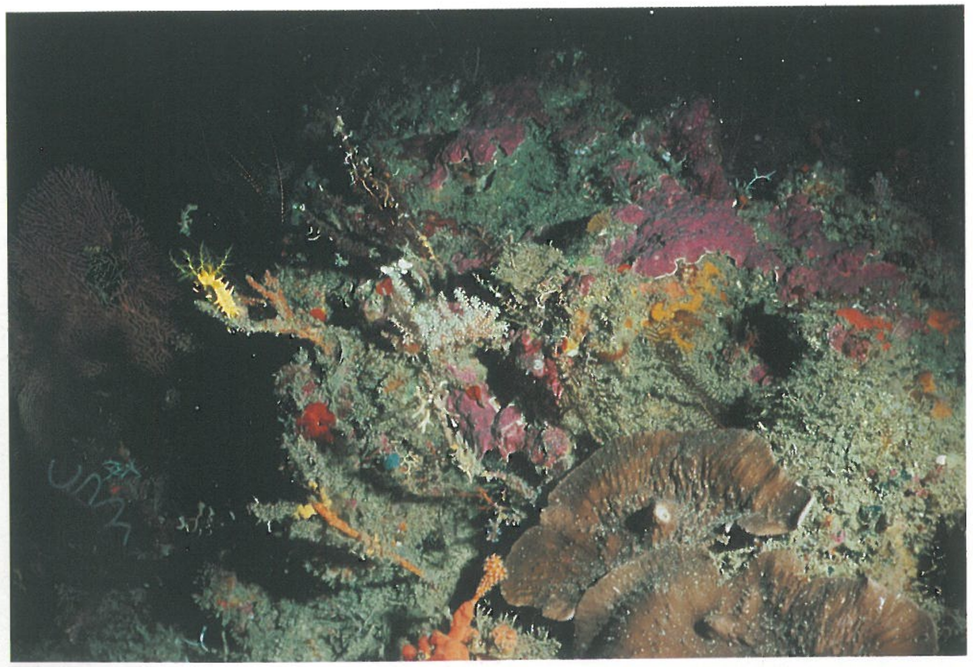

Fig. 6. A hermatypic coral clolony, *Merulina ampliata* (bottom right), crustose coralline algae (top right) and a holothurian, *Cucumaria* sp. (top left) at 55 m deep of Station 1.

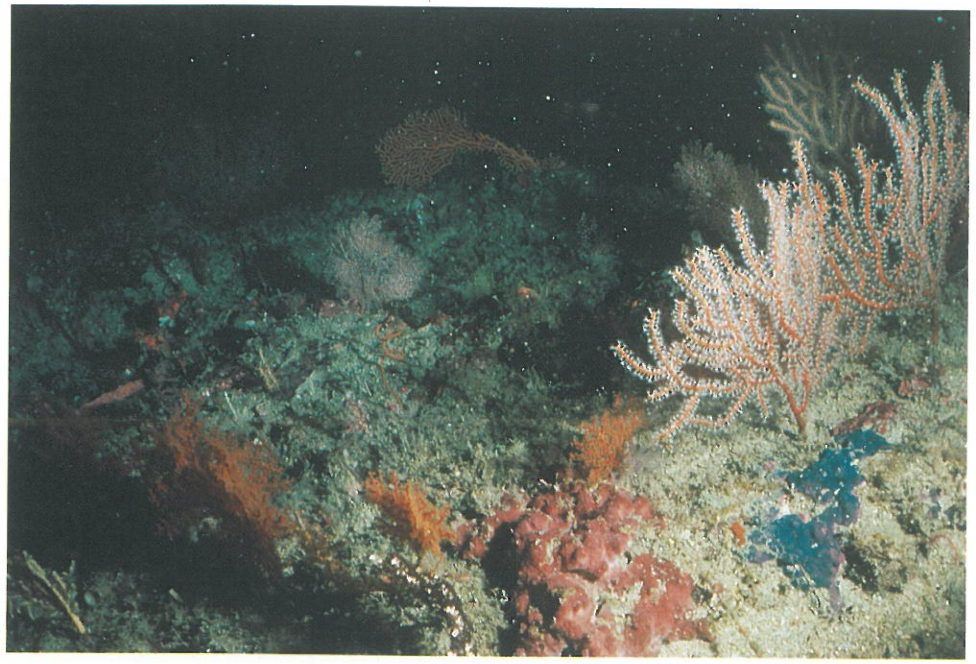

Fig. 7. Two encrusting coral colonies, *Montipora* sp. (bottom right), *Porites* sp. (bottom center), and gorgonacean colonies at 55 m deep of station 1.

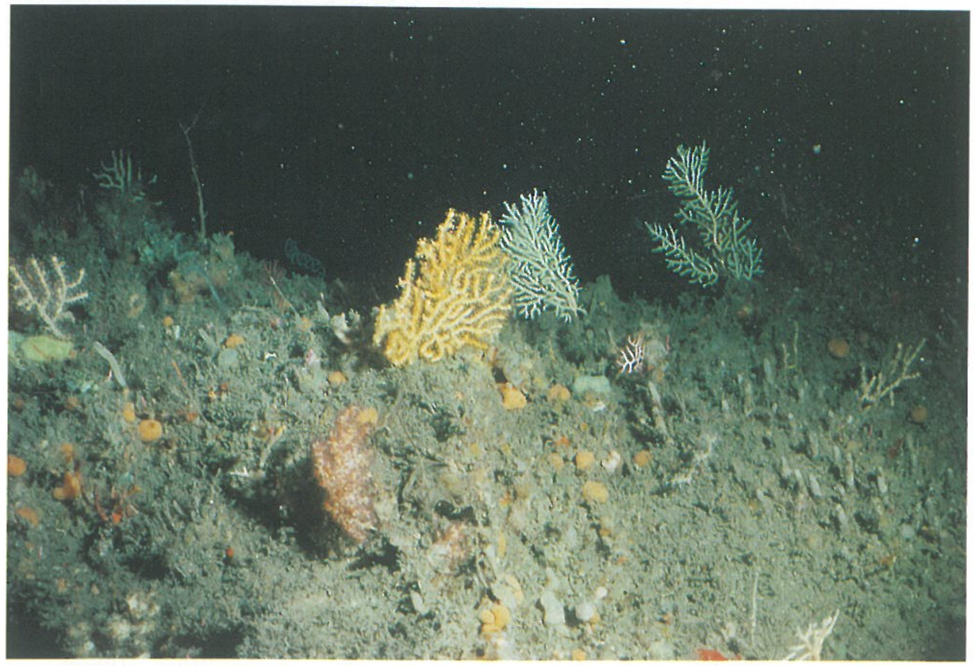

Fig. 8. Fan-shaped gorgonacean colonies and tube-shaped sponges at 101 m deep of Station 3.

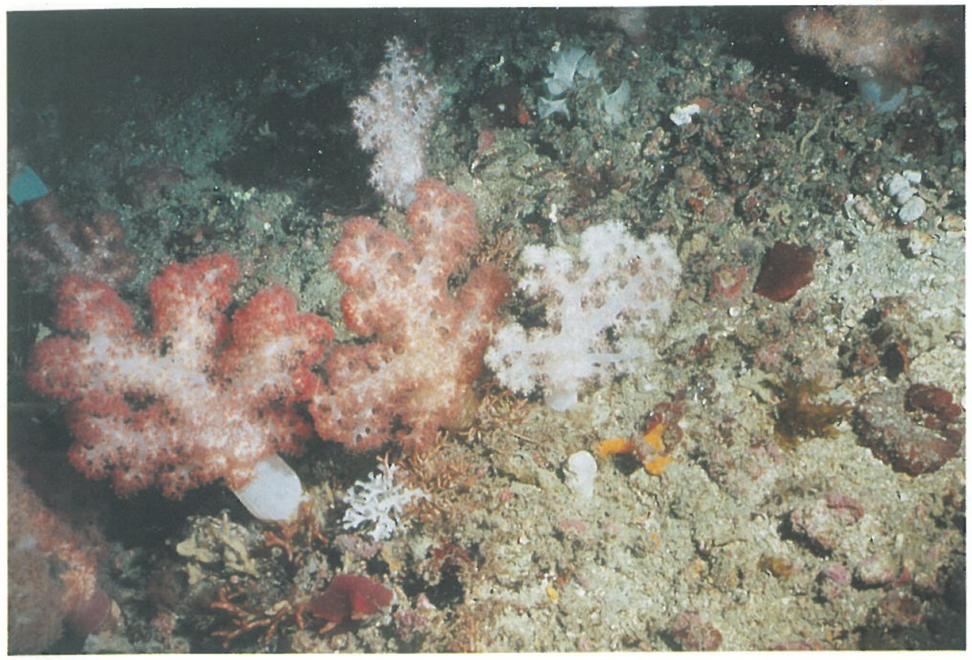

Fig. 9. A typical benthic community on substrate of rubbles and gravels containing alcyonacean colonies, *Dendronephthya* spp., and the algae, *Galaxaura* spp. at 44 m deep of Station 17.

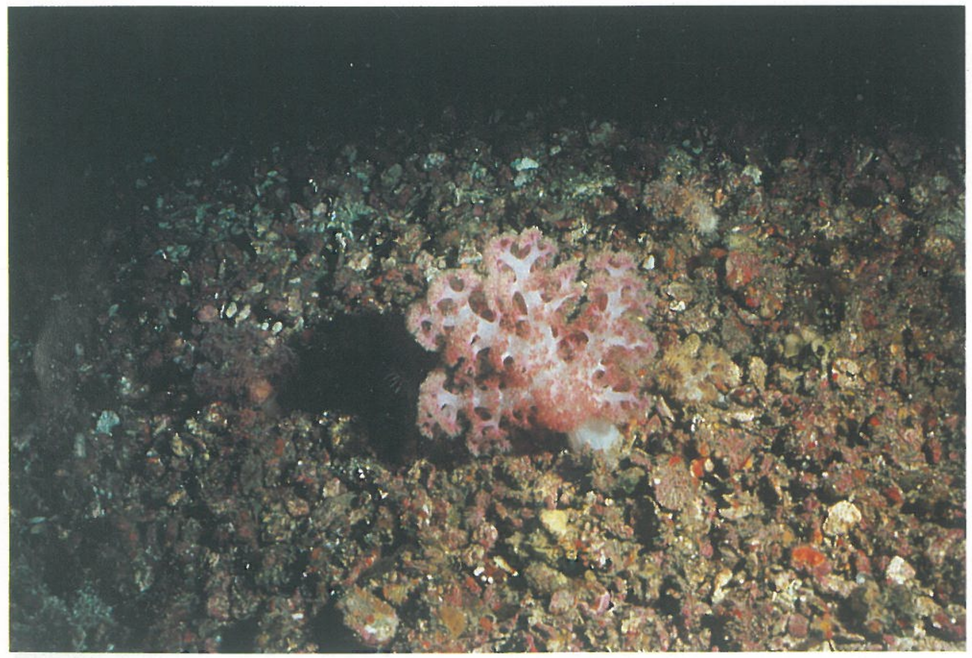

Fig. 10. The soft coral, *Dendronephthya* sp. and crustose coralline algae on the surface of rubbles.

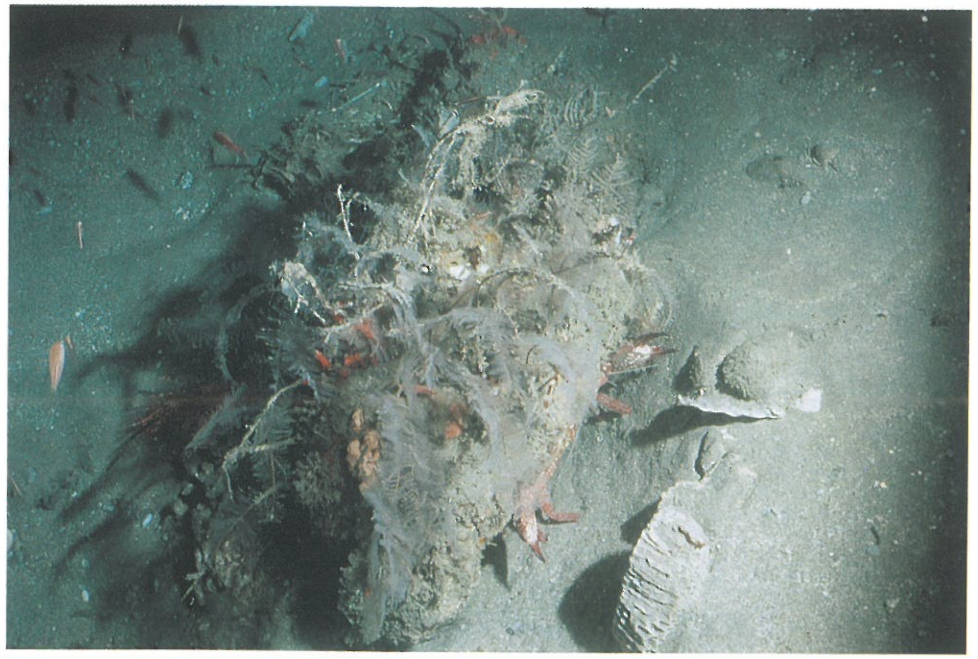

Fig. 11. A rock sitting on sandy bottom inhabited by benthic organisms including plumularid hydroids, a crab, a shrimp, and fishes at 50 m deep of Station 10.

Fig. 12. A large plumularid hydroid at 76 m deep of Station 9.

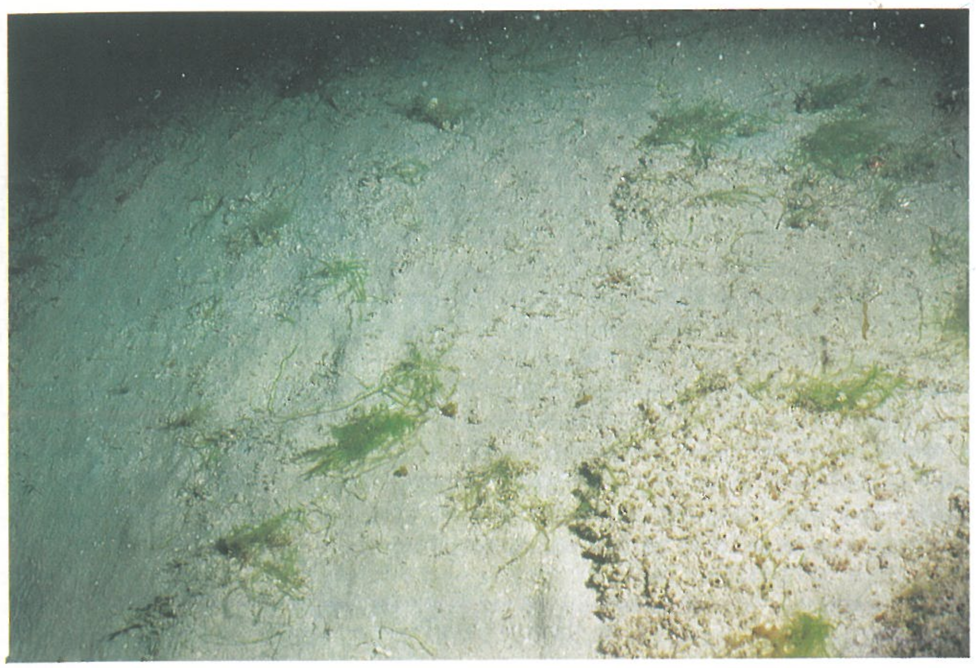

Fig. 13. Filamentous green algae on sandy bottom at 54 m deep of Station 18.

Fig. 14. A drifting brown algae, *Sargassum cristaefolium* (?) at 72 m deep of Station 4.

infaunal organisms, the shrimps, crabs, brittle stars, crinoids and small gobies were observed at the openings of some of the burrows.

On the west coast of the Peninsula (Stations 8-11), the sandy bottom is located on slopes below 40 m and is composed of fine-grained sand. The surface is usually smooth with less conspicuous sand ripples. At stations 10 and 11, few small rocks were found scattered on sandy bottom. These rocks often provide habitat for a rich fauna including hydroids, shrimps, crabs and fishes (Fig. 11). Plumularid hydroids and an ahermatypic coral, *Tubastrea micranthus*, were found on top of the rocks. Colonies of a large feather-shaped hydroid with lengths more than 1 m were commonly found standing on sandy bottom (Fig. 12). The substrate between 75 and 78 m at Station 9 was densely covered by small hydroid colonies indicating that the area may be high in productivity.

The sandy bottom in Nanwan Bay is composed of coarse sand. Sand ripples are very conspicuous at depths below 80 m (Stations 6, 14 and 15). Filamentous green algae are the most abundant benthic organisms on the sandy bottom between 45 and 55 m deep (Fig. 13). Several fleshy algae, including *Avrainvillea* sp., *Galaxaura* sp., and *Sargassum cristaefolium* (?) were found on drifting rocks scattered on sandy bottom at 75 m deep (Fig. 14).

DISCUSSION

Distribution of Substrates

This study reveals that the predominant substrate type below 40 m in southern Taiwan is sand. Although no sediment analysis was conducted, it was visually distinguishable that the sediments on the west coast were finer than those of Nanwan Bay. This phenomenon reflects that the west coast may have received higher proportions of sediments from terrestrial drainage. Shieh and Chen (1989) have shown that the marine sediments in Nanwan Bay are mainly composed of biogenic skeletons (>70%); these sediments are poorly sorted, medium to coarse-grained carbonate sand intermingled with various amounts of coral fragments.

The predominance of sandy substrates and biogenic sediments indicates that physical destruction and erosion by waves and currents are strong in southern Taiwan. The most destructive wave forces of the study area, although rarely occurred, are typhoon surges. The tropical location of southern Taiwan places it within the zone of typhoon disturbance. On average, the study area suffers direct hits by 1.17 typhoons per year during the past 90 years (Anonymous, 1991). The high winds, high seas and generally intense rainfall accompanying typhoons may cause considerable changes on reef morphology and benthic communities (Stoddart, 1962, 1974; Woodley *et al.* 1981). Tidal currents and wind waves may have significant effects on bottom topography and benthic communities. Wind generated waves along with tidal currents are one of the major source of benthic turbulance energy. The tidal regime of the study area is semidiurnal with spring tide alternate regularly with neap tide. In Nanwan Bay, the current flows from east to west during spring tide and from west to east during neap tide. The inshore current of the west coast of Hengchun Peninsula flows from SSE to NNW during spring tide and from NNW to SSE during neap tide. The speed of the tidal currents often reach 30-50 cm/sec (Liang *et al.* 1978; Chang and Chen, 1987). The high energy of tidal current may induce heavy abrasion on reefs and blocks and sediment deposition often occur in peripheral areas where water movement is

slowing down. In addition, Kuroshio current and monsoon drift may also have influences on bottom topography of the survey area (Chen *et al.* 1974; Liang *et al.* 1978). The flow path of Kuroshio in Nanwan Bay is paralleled to the Tapanleih Canyon which extends from the south of Oluanpi Promontory toward the Kenting offshore, then turns westward and passes the Maopitou Promontory (Shieh and Chen, 1989). The storm surges, currents and wind waves are responsible for the production and redistribution of biogenic sediments (Chen *et al.* 1974; Shieh and Chen, 1989).

This study confirms that living coral reefs in southern Taiwan is very narrow and the fore reef slope does not exist in the study area (Dai, 1988). Living coral reefs in southern Taiwan often terminate at depths between 20 and 30 m and no extensive reefs or coral communities have been found below 40 m. The poor development of underwater reefs might be attributed to the high uplifting rates and high benthic hydraulic energy of the study area. The uplift rates of the Peninsula during Holocene has been estimated from 1.5 to 4.4 mm/yr (Lin, 1989). Such uplift rates may be too high to support the extensive development of reefs. In addition, the heavy abrasion and erosion caused by tidal currents, storm surges and wind waves may also restrict the development of underwater reefs. Bottom currents were observed to be significant at deeper offshore (stations 3, 4, 12, 15, 16) and western (stations 8-11) sites. Velocities were visually estimated by particle flow to be 25-50 cm/sec and evidence of substrate scour, ripple zones and resuspensions was recorded.

Distribution of Macrobenthos

The shallow water benthic fauna and flora of southern Taiwan have been well-documented in the last two decades (Jones *et al.* 1972; Chiang, 1973; *Yang et al.* 1982; Chiang and Wang, 1986; Dai, 1988, 1992; Chen *et al.* 1988; Chao and Chang, 1989; Chen and Chang, 1991) but all restrict to the depth of 30 m. Our ROV investigations provide the first description on the distribution pattern, faunal composition and morphology of deep water benthic organisms.

Many of the deep water sessile organisms are restricted to areas that are protected from falling sediment (Lang, 1974), thus hard substrate often supports the richest fauna or flora. Although a relatively small proportion of hard substrate was found in southern Taiwan, the benthic fauna on hard substrate was rich in terms of diversity and biomass. Many species of demosponges, hydroids, gorgonaceans, antipatharians, bryozoans, and ascidians were found in high abundance. Most of them are suspension feeders; they obtain nutrition entirely through the capture of food particles suspended in fluid media. The high abundance of suspension feeders indicates that the deep water environment in southern Taiwan may be rich in food particles.

The most dominant benthic organisms on deep water hard substrate are gorgonaceans. Although they are commonly found on shallow water reefs, they rarely attain such a high abundance and diversity as in deep water habitat. The gorgonacean colonies are often planar or bushy with the plane perpendicular to the current direction. Such colony orientation minimizes the mechanical stress induced by current and maximizes the feeding rate (Wainwright and Dillon, 1969; Leversee, 1976). Others grow in a whip-like shape with whorls on top of the colony; this form is particularly resistent to strong current.

Soft corals are the most abundant benthic organisms on the substrate of rubbles and gravels where they are mainly composed of *Dendronephthya* spp. The species composition of the deep water alcyonacean fauna is different from that of shallow water reefs. The most abundant species on shallow water reefs are *Sarcophyton* spp., *Lobophytum* spp. and *Sinularia* spp. (Dai, 1988). They contain symbiotic algae and may rely on photosynthesis for their nutrition, hence their distribution is often restricted to shallow water reefs.

Other species frequently found on deep water substrates are sponges, hydroids, bryozoans, and ascidians. They are cryptic organisms on shallow water reefs where they usually occur in shaded environment, crevices, or overhangs. Since their systematics and ecology are poorly known, further studies on these groups are required for a general understanding of the deep water fauna.

Depth Limits of Hermatypic Corals

The lower limit of bathymetric distribution of hermatypic corals in southern Taiwan can be set to the depths between 70 and 80 m. The limit has been reported to be about 144 m at Bikini Atoll (Wells, 1954), at 100 m in the Ryukyu Islands (Yamazato, 1972), Jamaica (Lang, 1974) and in the Red Sea (Fricke and Schuhmacher, 1983). It seems that 100 m is the global depth limit of hermatypic corals (Sarano and Pichon, 1988). However, only few colonies of hermatypic corals were found to the depths between 70 and 80 m in southern Taiwan. The deepest record of hermatypic corals in southern Taiwan is far above the lowest depth limits of most Indo-Pacific reefs (Yamazato, 1972; Sarano and Pichon, 1988). It is unusual for the fact that the depth limit of hermatypic corals in southern Taiwan (22°N) is shallower than that of the Okinawa on higher latitude (26°N). The factors limiting coral growth in deep waters are often related to light, temperature, and the availability of hard substrates (Sheppard, 1982).

Light penetration is a key to the bathymetric range of hermatypic corals (Fricke and Schuhmacher, 1983). The depth at which light is reduced to 1% of the available surface light often defines the limits of coral distribution (Fricke and Meischner, 1985). Several studies have shown that the 1% level is around 90 to 100 m deep (Yamazato, 1972; Fricke and Schuhmacher, 1983). Yang *et al.* (1982) reported that light intensity at 30 m in Nanwan Bay is often below 5% of surface value. Although we did not measure light intensity during the survey, we noticed that sedimentation below 80 m was high and a drastic decrease of light intensity to a level below 1% could be expected. Very few photoadaptive corals can survive at such twilight environment (Fricke and Knauer, 1986; Fricke *et al.* 1987).

A thermal gradient could influence the vertical distribution of corals (Sheppard, 1982; Fricke and Meischner, 1985). Hermatypic corals usually do not grow on reefs where annual temperatures are below 18°C (Wells, 1954; Yamazato, 1972; Sheppard, 1982). According to Su *et al.* (1984), even in winter, water temperatures at 70 m deep in Nanwan Bay are usually above 20°C, far above the known lethal temperatures for most of the hermatypic species. Therefore, temperature distribution seem to have a minor influence on lower depth limit of hermatypic corals in southern Taiwan.

The availability of hard substrates often plays an important role in coral colonization in deep water (Kühlmann, 1983). In this study, corals in deep water habitat were seen only on rocky substrates above 80 m in Nanwan Bay. Another type of hard substrate, rubbles and gravels, was encountered at depths between 45 and 55 m but found no corals. Rubbles and gravels are hard but unstable substrates for coral colonization. Sandy bottom and sediment scour inhibit settlement of corals. The predominance of sandy bottom and heavy sedimentation are likely the major factors restricting the distribution of corals in deep water habitat of southern Taiwan.

Depth Limit of Benthic Macroalgae

The lower depth limit or extinction depths (sensu Sears and Cooper, 1978) of macroalgal distribution in southern Taiwan is likely between 70 and 80 m. Filamentous green algae were common between 45 and 55 m, they distributed in patches or bundles on rocky outcrops or on sand flat near these outcrops. The macroalgal communities between 55 and 80 m were consisted mainly of crustose coralline algae where their distribution was patchy. Although drifting fleshy macroalgae were found at 75 m deep, they could have been swept down from shallower depths by currents. Crustose coralline algae were by far the deepest dwelling plant in southern Taiwan where they were found down to 80 m deep.

The depth limits of crustose coralline algae have been reported to 175 m at Discovery Bay, Jamaica (Lang, 1974), to 250 m at Johnson Atoll, Line Island (Agegian and Abbott, 1985), and to 268 m at San Salvador Island, Bahamas (Littler *et al.* 1985, 1986). Even on high latitude, cold-temperate continental shelves, encrusting algae have been directly observed down to 100 m (Hiscock, 1986). The recorded depth limit of macroalgal distribution in southern Taiwan is far above those recorded in other areas. This is probably due to heavy sedimentation and low light intensity of the study area.

Light is often considered to be the most important factor influencing patterns of algal depth distributions (Vadas and Steneck, 1988). Although extinction depths vary greatly with water clarity, the percent of surface illumination (SI) correlating with algal depth limits is thought to remain constant (Hiscock, 1986; Vadas and Steneck, 1988). It is generally agreed that the extinction depths are 0.02% SI for crustose algae and 0.1% SI for foliose algae (Hiscock, 1986; Vadas and Steneck, 1988). However, Littler *et al.* (1985, 1986) reported much lower light intensities for tropical algae which is 0.05% for foliose algae and 0.00005% for crustose corallines. Although no light data was available, judging from the minimum light requirement for algal growth, light may only partly account for the absence of algae at depths below 80 m in southern Taiwan. Other factors that may influence algal distribution in deep water are the availability of hard substrate and grazing of herbivores.

This study provides a first step in documenting the distribution and abundance of deep water macrobenthos in southern Taiwan. Our ROV surveys have revealed that the deep water fauna and flora are different from those of the shallow water areas. But due to scanty information of systematics and ecology of these groups, many questions remain unanswered. Further studies including (1) faunal and floral compositions based on careful species identifications, and (2) photoadaptive physiology or ecological adaptation of these organisms, are required for a general understanding of the deep water fauna and flora in southern Taiwan.

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REFERENCES CITED

AGEGIAN, C. R. and I. A. ABBOTT (1985) Deep water macroalgal communities: a comparison between Penguin Bank (Hawaii) and Johnston Atoll. Proc. 5the Int. Coral Reef Symp. **5**: 47-50.

ANONYMOUS (1991) Questions and answers on typhoons. Central Weather Bureau, Taipei, Taiwan, R. O. C., 75 p.

CHANG, K. H. and Y. M. CHEN (1987) Nutrients in coral reef waters of the Kenting National Park area. Conservation research report No. 42-1, Kenting National Park Headquarters, 61 p.

CHAO, S. M. and K. H. CHANG (1989) The shallow-water holothurians (Echinodermata: Holothuroidea) of southern Taiwan. Bull. Inst. Zool., Academia Sinica **28**: 107-137.

CHEN, C. C. and K. H. CHANG (1991) Gorgonacea (Coelenterata: Anthozoa: Octocorallia) of southern Taiwan. Bull. Inst. Zool. Academia Sinica **30**: 149-182.

CHEN, J. C., C. S. LEE, C. S. WANG, F. J. LEU and C. T. Shyu (1974) Report on the geophysical survey in Nan Wan. Institute of Oceanography, National Taiwan University, 26 p.

CHEN, J. C., K. H. CHANG and C. P. CHEN (1988) Shallow water crinoids of Kenting National Park, Taiwan. Bull. Inst. Zool., Academia Sinica **27**: 73-90.

CHIANG, Y. M. (1973) Studies on the marine flora of southern Taiwan. Bull. Jap. Soc. Phycol. **21**: 97-102.

CHIANG, Y. M. and W. L. Wang (1986) Marine algae of Kenting National Park. Spec. Publ. No. 35-1, Kenting National Park Headquarters, Ministry of Interior, R. O. C., 119 pp.

DAI, C. F. (1988) Coral communities in southern Taiwan. Proc. 6th Int. Coral Reef Symp. **2**: 647-652.

DAI, C. F. (1991) Reef environment and coral fauna of southern Taiwan. Atoll Res. Bull. **354**: 1-24.

DAI, C. F. (1992) Patterns of coral distribution and benthic space partitioning on the fringing reefs of southern Taiwan. Mar. Ecol. (in press).

FRICKE, H. W. and B. KNAUER (1986) Diversity and spatial pattern of coral communities in the Red Sea upper twilight zone. Oecologia **71**: 29-37.

FIRCKE, H. W. and D. MEISCHNER (1985) Depth limits of Bermudan scleractinian corals: a submersible survey. Mar. Biol. **88**: 175-187.

FRICKE, H. W. and H. SCHUHMACHER (1983) The depth limits of Red Sea stony corals: an ecophysiological problem (a deep diving survey by submersibles). P. S. Z. N. I: Mar. Ecol. **4**: 163-194.

FRICKE, H. W., E. VARESCHI and D. SCHLICHTER (1987) Photoecology of the coral *Leptoseris fragilis* in the Red Sea twilight zone (an experimental study by submersible). Oecologia **73**: 371-381.

HISCOCK, K. (1986) Aspects of the ecology of rocky sublittoral areas. In: Moore, P. G. and R. Seed (eds.), The Ecology of Rocky Coast. Columbia University Press, New York, pp. 290-328.

JONES, O. A., R. H. RANDALL, Y. M. CHENG, H. T. KAMI and S. M. MAK (1971) A marine biological survey of southern Taiwan with emphasis on corals and fishes. Inst. Oceanogr., Nat'l. Taiwan Univ., Spec. Publ. No. 1, 93 p.

KÜHLMANN, D. H. H. (1983) Composition and ecology of deep-water coral associations. Helgol. Meers. **36**: 183-204.

LANG, J. C. (1974) Biological zonation at the base of a reef. Am. Sci. **62**: 272-281.

LEVERSEE, J. G. (1976) Flow and feeding in fan-shaped colonies of the gorgonian coral, *Leptogorgia*. Biol. Bull. **151**: 344-356.

LIANG, N. K., S. L. Lien, W. C. CHEN and H. T. CHANG (1978) Oceanographic investigation in the vicinity of Ma-an-shan-Nan-wan Bay. Inst. Oceanogr., Nat'l Taiwan Univ., Special Publ. 18, 207 p.

LIN, C. F. (1989) Uranium series dating of Holocene raised corals from Hengchun Peninsula and eastern coastal area, Taiwan. M. S. Thesis, Institute of Geology, Nat'l Taiwan Univ., 119 p.

LITTLER, M. N., D. S. LITTLER, S. M. BLAIR and J. N. Norris (1985) Deepest known plant life discovered on an uncharted seamount. Science **227**: 57-59.

LITTLER, M. N., D. S. LITTLER, S. M. BLAIR and J. N. NORRIS (1986) Deep-water plant communities from an uncharted seamount off San Salvador Island, Bahamas: distribution, abundance, and primary productivity. Deep-Sea Res. **33**: 881-892.

SARANO, F. and M. PICHON (1988) Morphology and ecology of the deep fore reef slope at Osprey Reef (Coral Sea). Proc. 6th Int. Coral Reef Symp. **2**: 607-611.

SEARS, J. R. and R. A. COOPER (1978) Descriptive ecology of off-shore, deep-water, benthic algae in the temperate western North Atlantic Ocean. Mar. Biol. **44**: 309-314.

SHEPPARD, C. R. C. (1982) Coral populations on reef slopes and their major controls. Mar. Ecol. Prog. Ser. **7**: 83-115.

SHIEH, Y. T. and M. P. CHEN (1989) Marine sediments and foraminifera indicating the depositional environments around Nanwan (South Bay) Area. J. Nat. Park **1**: 107-136.

STODDART, D. R. (1962) Catastrophic storm effects on the British Honduras Reefs and Cays. Nature **196**: 512-515.

STODDART, D. R. (1974) Post-hurricane changes on the British Honduras reefs: sesurvey of 1972. Proc. 2nd Int. Coral Reef Symp. **2**: 473-483.

SU, C. C., T. C. HUNG, Y. M. CHIANG, T. H. TAN, K. H. CHANG, R. T. YANG, Y. M. CHENG, K. L. FAN and H. T. CHANG (1984) An ecological survey on the waters adjacent to the nuclear power plant in southern Taiwan. V. The progress report of the fifth year study (1983-1984) and the summary report of five years preoperational stage studies (1979-1984). Nat. Sci. Comm. Prob. Environ., Spec. publ. No. 27, 214 pp.

VADAS, R. L. and R. S. STENECK (1988) Zonation of deep water benthic algae in the Gulf of Maine. J. Phycol. **24**: 338-346.

WAINWRIGHT, S. A. and J. R. DILLON (1969) On the orientation of sea fans (Genus *Gorgonia*). Biol. Bull. **136**: 130-139.

WELLS, J. W. (1954) Recent corals of the Marshall Islands. U. S. Geol. Surv. Prof. Pap. 260-I: 285-486.

WOODLEY, J. D., E. A. CHORNESKY, P. A. CLIFFORD, J. B. C. JACKSON, L. S. KAUFMAN, N. KNOWLTON, J. C. LANG, M. P. PEARSON, J. W. PORTER, M. C. ROONEY, K. W. RYLAARSDAM, V. J. TUNICLIFFE, C. M. WAKLE, J. L. WULFF, A. S. G. CURTIS, M. D. DALLMEYER, B. P. JUPP, M. A. R. KOEHL, J. NEIGEL and E. M. SIDES (1981) Hurricane Allen's impact on Jamaican coral reefs. Science **214**: 749-755.

YAMAZATO, K. (1969) Bathymetric distribution of corals in the Ryukyu Islands. Symp. Coral and Coral Reefs, Mar. Biol. Assoc. India, p. 121-133.

YANG, R. T. (1985) Coral communities in Nanwan Bay (Taiwan). Proc. 5th Int. Coral Reef Symp., Tahiti **6**: 273-278.

YANG, R. T., C. F. DAI, S. Z. YEH, C. L. SUN, F. Y. SU, S. Y. LIAO, Y. K. HSU, C. L. CHANG and T. Y. CHOU (1982) Ecology and distribution of coral communities in Nanwan Bay, Taiwan. Inst. Oceanogr., Nat'l. Taiwan Univ., Spec. Publ. No. **40**, 74 p.

臺灣南部海域水深35至120公尺間底質和大型底棲生物的分布

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摘　要

本文報導使用水下潛航器 (ROV) 調查恆春半島沿海水深 35～120 公尺間，底質和底棲生物分布的初期成果。根據調查結果，將底質區分爲三大類型，卽：礁岩、礫石和砂底；水深40公尺以下，未見現生珊瑚礁的發育，其中砂底爲分布最廣的底質。礁岩底質分布在南灣西側水深 40～100 公尺間，其間岩塊和礁石的表面具有豐富的動物和植物相，包括各種形態的柳珊瑚、角珊瑚、水螅蟲、海綿、苔蟲類、海鞘類和殼狀珊瑚藻，緊密覆蓋在底質表面；羣體呈扇形或鞭形的柳珊瑚是其中最占優勢的種類。礫石底質分布在水深 35～45 公尺間，位於現生珊瑚礁的外緣，其上分布許多顏色鮮艷的棘穗軟珊瑚 (*Dendronephthya* spp.) 及豐富的藻類相。砂底分布在恒春半島西岸水深 45 公尺以下和南灣海域的中央及水深45公尺以下的大部分範圍，其間的生物相較貧乏，以羽枝水螅蟲和絲狀綠藻（水深 35～55 公尺間）較常見。調查結果也顯示，造礁珊瑚和藻類在臺灣南部海域的分布下限爲水深70～80公尺間，它們在深水域的分布可能受限於低光度、多沉積物、缺乏硬底質及强勁海流的影響。