Description and mapping of the coral reefs investigated during the Snellius-II Expedition in Indonesia

F.C. van Duyl

F.C. van Duyl. Description and mapping of the coral reefs investigated during the Snellius-II Expedition in Indonesia.

Zool. Med. Leiden 65 (28), 24.xii.1991: 363-392, tab. 1-3, figs. 1-16.— ISSN 0024-0672.

Key words: coral reefs; Flores Sea; Indonesia; mapping.

Macrohabitat distribution, zonation and morphology of coral reefs in the Flores Sea region were investigated. Descriptions of reefs and reef maps are presented, based on large area surveys and aerial photographs. Diving equipment, underwater scooter, depth recorder and different methods of aerial photography were employed to collect data. The aim of the surveys was to acquire synoptic views of the study areas and to attribute to a uniform classification system applicable to reef mapping throughout the archipelago.

Fleur C. van Duyl, Netherlands Institute for Sea Research, P.O. Box 59, 1790 AB Den Burg, Texel, The Netherlands.

Introduction

Mapping reefs from remotely sensed data such as aerial photographs and satellite images is a hot item at present. For the Great Barrier Reef Province and the Caribbean considerable progress is made in developing advanced mapping protocols regarding coral reef ecosystems (e.g. Done, 1977, 1982, 1983; Jupp, 1983; Jupp et al., 1981, 1983; van Duyl, 1985; Kuchler, 1985, 1987a, 1987b). In Indonesia not much has been done in this respect. Reef maps are needed for the sake of the inventory per se. Gouvernments should be aware of the extension and quality of their natural resources, for social, political and economical reasons. Reef maps provide base-line data, which subsequently allow assessment of changes in the environment. Monitoring is required in order to detect the nature of the processes responsible for changes. On the other hand assessment of negative changes caused by man-induced disturbances can result in profitable damage claims. This will make polluters more conscious of the value and vulnerability of the natural resources.

Reef maps present a starting point and a framework for the evaluation of natural resources. How much are they worth? To arrive at a balanced management between exploitation (fisheries, extraction of building materials, tourism, aquarium fish trade etc.) and conservation (natural break waters, land reclamation) more information is required of the ecosystem to which reef maps can attribute. The need for management of the marine environment is acknowledged in Indonesia (Soegiarto & Polunin, 1982; Polunin, 1983) and proposals for the development of a marine park system has been put forward (Robinson et al., 1981; Soegiarto, 1981). The achievement of plans is difficult especially with regard to the limited information particularly of reef systems with respect to their distribution and biota in Indonesia (Wijsman-Best, 1977).

The aim of this study is to describe and map coral reefs with respect to biological and geomorphological characteristics and attribute to the development and stan-

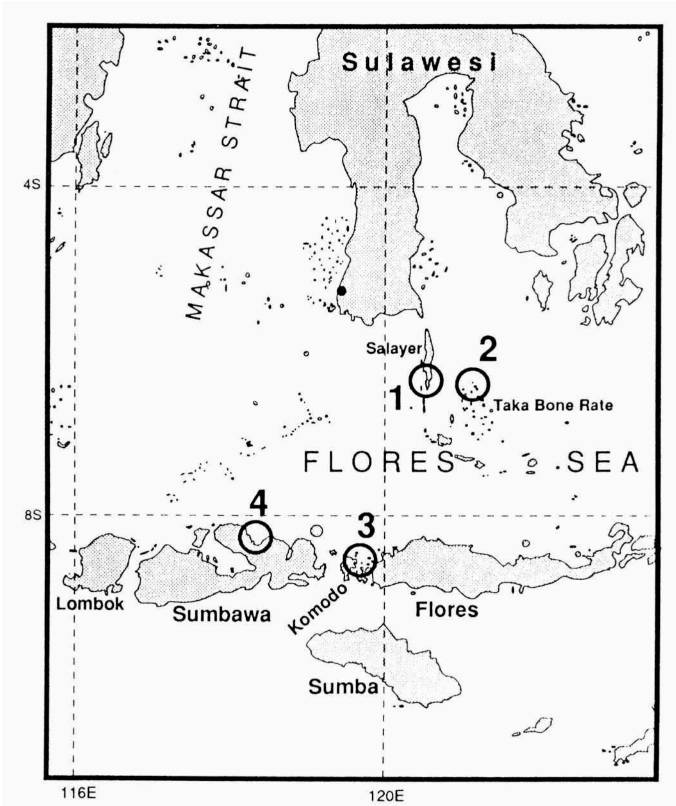


Fig. 1. Snellius-II research areas in Indonesia visited during the survey described in this paper.

dardization of a reefal classification system, a system which covers aspects, reef characteristics sufficiently informative for the verification of remotely sensed data on scales ranging from 1 : 250.000 to 1 : 2.500.

Material and methods

Reef observations were made in October 1984 in the areas indicated in fig. 1.

Position-finding and depth recording.— Hydrographic charts were used for orientation in the study area. Cross-bearings were carried out for position-finding in the field with a prismatic surveying compass in combination with an prismatic rangefinder. Survey locations were indicated on maps. Whenever position-finding in this way was not possible due to absence of (reliable) verification points our position was taken by the staff of the research vessel MS 'Tyro', which is equipped with satellite navigation. We operated in the field with rubber dingies from which we also made depth recordings with an echo sounder. The sensor was connected to the stern of the dingy. While sailing with a constant speed at right angle or parallel to the reef trend, reef profiles and reef features such as spur and groove systems were recorded.

Aerial photography.— Vertical aerial photographs were made with a remotely controlled 6 by 6 camera with a 80 mm objective connected to a He-inflated kite balloon with a payload of 6000 g. With two tether lines the kite was situated above the reef section to be photographed. Colour transparencies were made from altitudes of 60-125 m. The camera was mounted at one end of a 2 m long aluminium tube to dampen the transfer of abrupt movements of the kite balloon to the camera. A brightly orange painted wooden cross of 2 by 2 m flooting on the water was portrayed on each picture for scale verification. One side of the cross was white and was orientated to the north to help the orientation of photographs in the photomosaic, which was constructed afterwards.

In the Komodo study area pictures were taken from a manned helicopter on an altitude of 1000 m. Series of predominantly high oblique 6 by 6 colour transparencies were obtained with a hand-held camera directed through the window. For construction of reef maps from these oblique pictures vertical black and white photographs (1 : 50.000) (placed at our disposal by the Indonesian mapping center) were used for scale correction. The outlines of reefs of interest in this study area were traced from these black and whites and enlarged. Subsequently the oblique colour transparencies were projected in such a way (under different angles) that they matched the enlargements. Reef patterns of the colour slides were then copied and reduced to scales of 1 : 10.000. Synoptic views of the extensive reef platforms were thus obtained.

Groundtruth.— Subsurface surveys were carried out with viewing box, snorkeling equipment and SCUBA usually in combination with underwaterscooters, but SCUBA bounce dives were also frequently made. When scooters were employed compass or depth contours were followed. I used waterproof data sheets to record information. Sheets were adapted during the expedition to cover the major characteristics and features of the heterogenous array of reefs investigated. As primary categorizing structures I used morphology/features, community structure and condition/damage covering together about 15 specified entries (such as slope angle, conspicuous geomorphological features, substratum, live coral cover, dominant/prominent species, growth form, size, indications of dynamite fishing). When during scooter surveys conspicuous changes occurred in one of the entries this was noted together with the time elapsed after the initial survey of the studied transect.

In the Guang (Salayer) and Komodo study area sketch maps based on the aerial photographs were verified in the field by means of snorkeling. Underwater photographs with a Nikonos equipped with a 15 mm objective were made to illustrate the distinguished reef communities and features. On occasions reef flat communities were surveyed on foot during emergence.

Results

Salayer

Fig. 2 shows the study sites along the W coast of Salayer. Striking geomorphological features off the west coast of Guang and Bahuluang are the undulating patterns on the shallow reef terrace (which runs from the coastline to 8-10 m depth) and seaward of the reef terrace a conspicuous relief feature (fig. 3). During the subsea surveys, features in the upper zones were recognized as spur and groove systems, which usually showed proliferating coral growth and appeared constructive in origin. Along Bahuluang seaward of such spurs unconsolidated spurs were found con-

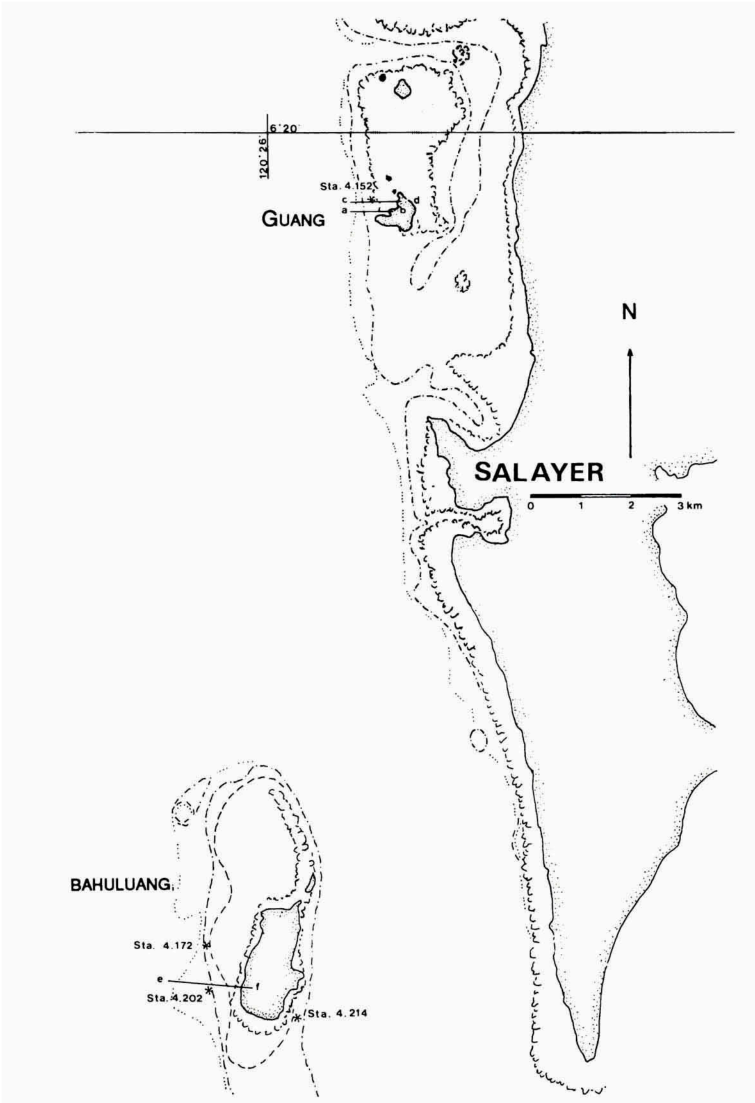


Fig. 2. Location of study sites near the islands of Guang and Bahuluang (Salayer).

sisting of elongate stacks of fine rubble, 3-4 m wide with a relief of 1.5 to 2 m. Seaward of spur zones, ridges occur parallel to the reef trend near the drop off. Occasionally, several ridges were found behind each other. Separated from the main reef by a trough with coral rubble, a more than 12 m high relief feature was found, which extends parallel to the reef tract. The feature shows the morphological characteristics of *Halimeda* bioherms as described for the northern Great Barrier reef (Orme & Salama, 1988; Marshall & Davies, 1988) and in the eastern Java sea (Phips & Roberts, 1988; Roberts et al. 1988). The feature was visited at one location (off Guang) with SCUBA, where the top of the feature was only 8-10 m below sealevel. On the top large tabular living acroporids were found. Coral cover reached 30% locally. *Halimeda* (a calcareous alga) was not a conspicuous component of the community. Unfortu-

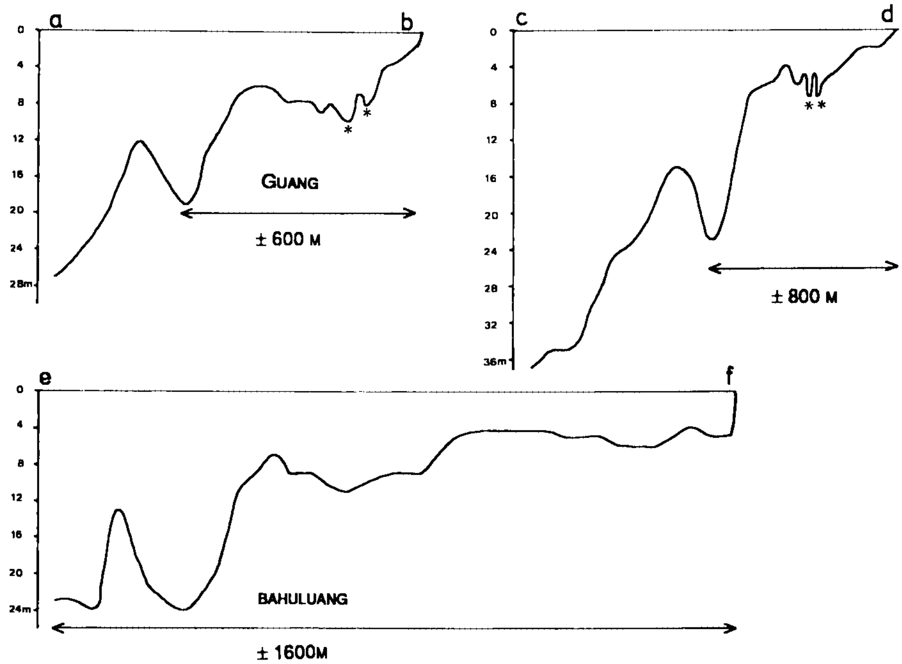


Fig. 3. Depth recordings of the reef profiles off the W-side of Guang and Bahuluang (Salayer).

nately, surface samples and cores were not obtained from these features, so they cannot be possitively confirmed as *Halimeda* bioherms.

The coral community composition and zonation of the shallow reef terrace of Guang adjacent to the shore is shown in Fig. 4. The map is based on an aerial photo mozalc of the reef compiled with aerials made from the He-kite balloon and covers the reef from the coastline to approximately 5/6 m water depth. Aerial photographs were not made of the Bahuluang study site. The zonation along the west side is quite uniform (fig. 2, stations 4.202 and 4.210). On the broad gently sloping terrace several zones were distinguished. The width of the zones was not recorded and I refer to the zones by their different mean depths.

— about 3-4 m depth: Reef zone below the steep cliff coast; irregular spur and groove pattern (E-W orientation) with 0-20% stony coral cover, patchy reef with tabular *Acropora* and massive corals; sandy bottom.

— about 5-6 m depth: Reef zone with scattered patches of massive corals and/or encrusted boulders (large specimens of *Porites*, exceeding 1.5 m in diameter); coral cover less than 10%; rubble, sand substratum.

— about 6-12 m depth: Reef zone with spurs and grooves; spurs consist predominantly of stagged rubble heaps (rubble size predominantly less than 15 cm) with an ENE-WSW orientation. Locally small branching stony corals and/or alcyonaria on spurs as well as in grooves; maximum stony coral cover 30-50% and extremely variable cover of alcyonarians; unstable rubble substratum.

— about 12-13 m depth: trough parallel to the reef trend, some small branching and folious corals, scattered massives; low stony coral cover, usually less than 10%. Alcyonarians common; rubble, sand substratum; rhodolites.

— about 13-15 m depth: smooth elongate relief features rising to depths of 12 m or less with axis parallel to the reef trend covered with corals and/or alcyonarians (mixed stony coral communities or monospecific *Acropora* staghorn stands); stony coral cover variable between 0-70%. At the seaward side a gradual drop off. Slope angle generally less than 20°.

At the SE corner of Bahuluang (station 4.214) the reef terrace adjacent to the steep drop off zone at 3-4 m harbours luxurious coral growth in a mixed assemblage. Large massive *Porites* colonies with diameters exceeding 1 m represent conspicuous components. In addition staghorn *Acropora* patches and small branching stony corals are common. The share of alcyonarians is considerable. Nearer to the coast small massive stony corals prevail with diameters up to 30-40 cm, besides alcyonarians. Stony coral cover remains quite high on the steep (45-90) fore reef slope. Fragile coral stands of *Acropora microphtalma* and *Montipora foliosa* are present in extensive more or less monospecific stands from 4-18 m depth with stony coral cover exceeding 80%. More common in this depth range, however, are mixed coral communities with massive, plating and small branching stony corals with 10-40% stony coral cover. Buttresses (van Duyl, 1985) are common on these steep slopes. Some of them have sheared off the reef front, leaving a track of destruction and deeper down a coral debris talus.

Taka Bone Rate

Geomorphology.— In the Taka Bone Rate atoll a detailed study was made of the reefs around Tinanja (fig. 5). Results are shown in figs 6 and 7. Tinanja is a sandy cay with a N-S orientation, 800 m long and a maximum width of 120 m. Beach rocks fringe the shore lines, but are better developed along the E-side. The island is surrounded by reef flats which are 200-600 m wide, with the narrowest flat at the W-side. Flats on the E-side emerge almost completely during LW from the shore to the reef rampart line (fig. 6). Reef ramparts consist of strongly cemented and lithified coral debris with a height of 1.5 m. Seaward of ramparts the reef terrace gradually slopes to 6-7 m depth where the drop off occurs. From there a steep reef slope (40-70°) continues to a sandy bottom. Locally steep cliffs are present.

At the W-side a gently sloping shallow reef terrace (from 0-2/3 m) abruptly breaks into a steep slope (40-90°). Outcrops of subrecent reefs were recognized in the steep walls. Numerous notches, spectacular dead coral overhangs and narrow terraces to depths of 40-50 m (the lagoon bottom of the Taka Bone Rate atoll) were observed along this wall.

Off the north and south tip of Tinanja conspicuous geomorphological features are present. The shallow sandy reef terrace in the north, which largely emerges during LW, gradually passes into a 10-20 fore reef slope supporting coral spurs. The consolidated spurs alternate with sandy channels locally in complex patterns. A distinct drop off is absent in the depth range covered by the survey. Some damage probably due to dynamite fishing was observed in this section.

Off the southern tip of Tinanja the reef is characterized by a sequence of reef ridges with a E-W orientation. The shallow sandy reef terrace gradually slopes to 20-25 m where the coral ridge pattern starts. Ridges rise up from depths of 20-25 m to approximately 12-15 m and are covered with folious, tabular and plating corals. Sand channels separate ridges.

Zonation.— Reef flats at the W and E sides of the island are predominantly covered by marine plants, sea grass, calcareous algae and coralline algae with the sea grasses dominating at the W-side and the coralline algae at the E-side. In a zone of approximately 60 m wide along the shore line numerous small sand hills with diameters up to 30 cm occur, which are attributed to the burrowing activities of crustaceans (such as *Calianassa*). Progressing seaward stony coral cover increases.

At the E-side micro-atolls of predominantly faviids and *Heliopora* emerging at LW are followed by acroporids. The fungiid share increases in cover nearing the reef rampart line. Seaward of ramparts coral cover rapidly increases. In the depth range of 4-8 m well developed coral communities occur with coral cover exceeding 60%. Alcyonarians usually predominate in cover but off the SE side of Tinanja stony coral cover exceeds soft coral cover. A mixed stony coral community occurs in which (sub) massive corals are most conspicuous. Massive *Porites* colonies with diameters exceeding 2 m were observed frequently. Relief in the community varies from 0.8-2.5 m which makes the reef aesthetically attractive. Below the drop off (7 m) coral cover rapidly decreases and at 10 m depth stony corals are scarce. Only locally coral growth extends to greater depths, 25 m or more.

At the W-side dense seagrass meadows with locally patches of *Halimeda* gradually pass into more coral dominated communities near the reef edge. Massive corals (faviids) and small branching corals (*Montipora* and small branching *Acropora*) occur scattered in the seagrass. Closer to the reef edge massive coral cover increases at the cost of seagrass. Below the drop off at 2-4 m live coral cover rapidly decreases. Only on the less steep slopes soft corals and stinging hydroids attain relatively high cover till 10 m depth. Locally mounds of small branching corals extend from the drop off deeper down but never deeper than 10-15 m.

Spurs in the northern part consist of predominantly large size massive stony corals and acroporids. Massive *Porites* specimens of 1.5 m high are not exceptionel. Tabular and staghorn acroporids and large folious corals are also present on spurs but occur in separate patches as well. Coral cover on the spurs and in patches amounts up to 75%.

The fore reef slope along the southern part harbours massive stony corals and tabular acroporids with a cover of 5-25%. Soft coral cover amounts to 30-50%. At 12 m depth huge massive *Porites* colonies are present on a sandy bottom together with sea whips. This zone continues until the ridges appear. The coral cover on these ridges is high, up to 75% and predominantly consists of tabular *Acropora*, large plating and folious stony corals.

Komodo

The study sites investigated in the Komodo area are indicated in fig. 8. Quick glance information was collected at the stations 1-13 of which the results are shown in table 1. The stations 4.253 and 4.257 off Gili Lawa Laut and the three reef platforms E of Sabita also covering station 4.250 were subject of more detailed studies.

Geomorphology and zonation.— Along the north side of Gili Lawa Laut (station 4.257) a well developed spur and groove system occurs. At the seaward side the relief between spurs and grooves is 3 m in waterdepths of 4 m. Seaward of spurs the bottom gradually slopes to the drop off at 6/7 m from where a 30°, fore reef slope

Table 1. Results of the quick glance surveys in the northern section of the Komodo study area (Gili Lawa Laut, Gili Lawa Darat, SW Bugis Islands).

1. staghorn *Acropora* with small branching stony corals
massive *Porites* at 4m (40-50% cover)
staghorn *Acropora* stands from 8-10 m, soft coral patches deeper on the slope

2. some seagrass patches under the cliff coast
± 50m offshore small branching stony corals and *Heliopora* on rubble
seaward side of reef platform: mixed coral community (soft and stony corals) in a patchy pattern, with some tabular *Acropora*

3. mixed coral community on the reef platform, small branching corals on massive coral boulders (dead massive stony corals), patchy pattern; slight spur development

4. mixed coral community on spurs, sandy grooves

5. over the reef platform from the open reef into the bay
-staghorn *Acropora*,
-coral debris,
-small branching, some massive, some folious stony corals,
-folious-small branching stony coral assemblage

6. 1-3m: small branching-delicate folious stony coral stands, some tabular *Acropora*, spur-like features in bay

7. blocks, slabs under coastline, small branching-folious stony corals in shallow water; seaward side platform: staghorn *Acropora* predominates with soms small branching corals and a few tabular acroporids

8. submassive *Acropora*, small branching and massive stony corals, spur-like features, many tabular *Acropora* on spurs, mixed coral community; coastal side spurs: small branching corals predominate, in addition folious corals and tabular *Acropora* occur here; consolidated rubble between spurs and coast

9. fore reef slope with staghorn and tabular *Acropora* (7 m), buttresses present in drop off zone, gradual slope (high coral cover)

10. narrow passage with very strong current: massive stony corals, tabular *Acropora* and soft corals (2-4 m), hard bottom

11. massive stony corals and soft corals (3-4 m)

12. zonation from the coastline seaward
-reef flat: seagrass (3 species),
-reef edge: rubble ridge with some small branching and folious stony corals (*Heliopora*),
-upper fore reef slope: rubble,
-fore reef slope: staghorn *Acropora*

13. zonation from the coastline seaward:
-sandy bottom with scattered soft corals,
-patches small branching stony corals, some tabular *Acropora*, sandy,
-small branching stony coral, tabular *Acropora*, locally staghorn *Acropora* predominates,
-staghorn *Acropora* continues till over the drop off (4 m) to 7 m depth

proceeds which passes at about 25 m depth into a 20° sandy slope.

Fig. 9 shows the coral zonation along this northerly exposed reef stretch. The zone with small branching stony corals dominated by *Acropora* and *Heliopora* gradually merges into the spur and groove zone. Spurs possess a high coral cover up to 100% with variable stony coral composition, most common growth forms are tabular *Acropora*, massives and folious corals. Seaward of spurs an extensive staghorn *Acropora* dominated zone occurs which is locally completely flattened. Physical forces (possibly released with dynamite fishing) must have caused these devastations. Cementation of loosely piled up coral fragments now occurs as well as some regeneration of fragments. Adjacent to these damaged sections in this reef zone luxuriously developed staghorn *Acropora* stands of up to 1 m high are present, dominating an aesthetically attractive coral community with large massive stony corals, scattered tabular acroporids and alcyonarians. Stony coral cover amounts here to 50-80%. Coral growth continues on the reef slope in a mixed coral community, dominated by massive and submassive species, until 27 m depth but usually less (10-11 m) With depth coral cover decreases rapidly.

Along the south side of Gili Lawa Laut in an embayment (fig. 8, station 4.253) the reef terrace is very shallow with the drop off at 2/3 to 5/6 m depth from where a steep reef slope drops down and passes at ca 20 m in a less steep undulating relief. Double reef-like structures were observed at depths of about 30 m.

The embayment harbours an extremely delicate reef. The reef flat (1-2 m deep) is dominated by small branching corals in dense stands. Dead stands are heavily encrusted by coralline algae. On the fore reef slope fragile folia of stony corals (e.g. *Montipora, Pachyseris, Echinopora, Turbinaria*) form rose, vases and plates with axes exceeding 30/50 cm (large folious and plating growth forms). Folious corals dominate on the slope in the bay and occur here chiefly in monospecific patches of variable sizes next to each other interspersed with monospecific patches of staghorn *Acropora*. Stony coral cover exceeds 80% on the reef slope at 10 m depth. The folious corals also extend deep down the reef slope (to more than 25 m depth) in undulating patterns. Locally small fleshy erect soft corals, established on collapsed dead folia and branches on the slope, predominate cover. Leaving the enclosure of the bay the folious coral cover on the slope drops dramatically as well as the overall coral cover. Massive stony corals appear next to staghorn acroporids which remain a conspicuous component in the coral community. Fleshy alcyonarian cover slightly increases as well as the share of small branching corals in the total coral cover.

Of the three reef platforms E of Sabita in the Linta Strait (see fig. 8) reef maps were compiled on basis of aerial photographs (see figs 11, 12, and 13). The flats harbour relatively deep lagoons in their southern parts. The location and results of depth recordings are given in fig. 10. Shingle ramparts and sandy bars shield the lagoons at the E-side from the open sea. From the shingle ramparts, ridges tongues of rubble and sand are spread over the reef platforms in characteristic patterns (see legend and figs. 11 and 13). Similar features have been recognized on other reefs in the archipel by Umbgrove (1929, 1947), Verwey (1931) and Kuenen (1933). Just north of station 4.250 huge ridges of rubble and sand were found at approximately 10 m depth with a relief of several meters. Comparable features were found in the gradually NE-ward sloping northern section of Tambunan Singkala (fig. 12). Of the three platforms only Tambunan Singkala has spur patterns in the northern section orientated in NNE directions. Loose rubble slopes of 10-20° fringe the platforms at the E sides.

The different biota and substrata recorded on the reef platforms are presented in the legend of figs 11, 12 and 13. Marine plants cover considerable parts of the reef platforms. The *Ulva* bloom (which was only recorded on these reef platforms) causes considerable damage of the stony coral stands. Particularly on the platforms S of Gili Makasser extensive parts of the small branching-folious coral stands were killed only recently. The algal folia grow hooked on the coral skeleton causing coral tissue lesions and reducing illumination. These conditions result in a stress situation in which expulsion of zooxanthellae is initiated and death can follow. In addition, *Ulva* folia increase the drag of a coral to watermovement. This leads to increased instability, fragmentation and a higher susceptibility to transportation. That there is quite some transport going on on these flats was observed in situ.

Coral cover on the fore reef slopes of the reef platforms is low. Stony corals usually do not extend deeper than about 4 m depth. Station 4.250 was selected for a survey due to its relatively high coral cover. It is consequently not representative for the E-side fore reef slopes of the reef platforms but nevertheless is shortly elucidated. Small branching corals (less than 20 cm high) predominate at 10 m depth besides small folious corals. Stony coral cover locally increases here to 70%. Soft coral cover amounts to 20%. Hydroids are conspicuous at the site. Along the edge of the reef platform (about 2 m depth) patches of delicately branched staghorn *Acropora* are present, adjacent to monospecific patches of small alcyonaria. Slightly deeper an extensive patch of folious *Echinopora* was found. Large amounts of rubble of these specific corals here indicate that they have been here for a considerable period. Transitions between stands of different species or rubble chutes are extremely abrupt.

Sumbawa (N-coast)

Reefs in the Sanggar Bay and NW of this bay on the subsea slopes of the Tambora volcano were surveyed. Fig. 14 shows the study sites. Based on subsea surveys schematic maps are presented of the reef off the NW corner of Tanjung Buru (fig. 15) and of the narrow fringing reef covering the stations 4.272, 4.275 and 4.284 along the talus of the Tambora (fig. 16).

Off Tanjung Buru the fore reef slopes with 5-20° seaward and consists of a loose rubble/sandy talus locally supporting dense stands of small branching stony corals in mixed communities, occasionally interlaced with staghorn acroporids and folious corals. Separately monogeneric patches of small branching *Anacropora* are present on the slope. Deeper down patches of small soft corals were found. Coral communities interchange with rubble patches, virtually devoid of living corals. The instability of these substrata is apparently too high for reef organisms to develop. On the fore reef terrace a mixed coral community dominated by massive corals is present, separated from the reef slope by an interrupted rubble ridge parallel to the reef trend covered by small branching and folious corals. In this zone separated from the other reef zones by rubble troughs numerous *Acanthaster* were seen actively fouraging on living corals.

Seaward of subaerial capes, promontories of the Tambora talus aesthetically attractive reefs occur, forming a thin veneer over the lava formations. These formations are ascribed to volcanic eruptions which took place before the catastrophic eruption of the Tambora in 1815. Proliferous buttresses fringe the narrow subsea terraces and butt seaward. Reef slope angles of 30-90° were measured. Coral growth extends locally deep down to over 25 m depth. In the depth zone of 5-12 m mixed stony coral communities (massives, folious, staghorn *Acropora*) predominate with a coral cover varying between 20 and 70% and soft coral cover varying between 0-20%. In the shallower parts soft coral cover dominates stony coral cover on the lava substrata. Huge massive *Porites* and *Galaxea* colonies were found. Particularly slowly calcifying *Porites* specimens (8.3 + 2.74 mm.y, Bak & Laane, 1987) with diameters exceeding 1.5-2 m probably survived the Tambora eruption in 1815. Between rocky coastal promontories black sandy beaches occur passing into gradually sloping subsea sands usually devoid of corals and slope angles of 20-30°. Stony corals tend to spread vegetatively from the hard bottom substrata into these sandy spaces. Monospecific patches of *Acropora* and *Goniopora* were observed to extend in these areas. Where distances between coastal promontories are relatively small, stony corals have bridged the open spaces and now provide the solid substrata required for settlement of coral planulae.

Discussion

Geomorphology and conspicuous features

The structuring force of wave energy on reef morphology is evident on most open seaward facing reefs investigated during the Snellius-II expedition. Spur patterns occur along open seaward sides on gradually sloping relatively wide terraces. Spurs are orientated according to the prevailing direction of waves. Rubble ridges on the reef terrace or reef flat or deeper on the fore reef slope usually parallel to the reef trend are also restricted to open seaward reefs and occur at sides where huge amounts of loose rubble are produced by the growth of delicately branching corals. Rubble ridges were found on the reefs of Guang, Bahuluang, Tanjung Buru and along the edges the reef platforms in the Linta strait off Komodo. Bioherm-like features were found off the reefs of Guang and Bahuluang near the shelf margin comparably situated as the *Halimeda* bioherms west of the Kalukalukuang Bank in the eastern Java Sea (Roberts et al., 1988; Phipps & Roberts, 1988).

Seaward facing reefs tend to have deeper drop offs (7-10 m) and less steep reef slopes on the whole than the reefs in more sheltered environments. Such reefs usually show conspicuous upward growth at the reef edge until MLWS, from where the reef profile breaks into a steep fore reef slope. Buttress development was observed along restricted stretches at the SE tip of Bahuluang, NE Tinanja, in the embayment at the S-coast of Gili Lawa Laut and fringing and masking the lava outcrops of the Tambora vulcano.

Zonation

Zonation patterns are most conspicuous on seaward facing reefs. Usually more coral zones can be distinguished on these reefs than on more wave sheltered reefs. Zonation patterns are most clearly expressed when coral cover is relatively high and the coral communities occur on gradually sloping fore reef terraces passing at 7-10 m into a drop off zone. In this respect the zonations off the W-coast of Guang and N-coast of Gili Lawa Laut are comparable.

Along more wave sheltered coasts zonation is more variable and mozaic patterns are more common under such conditions. Monospecific coral and plant patches interchange (at random) with mixed coral communities and sandy patches. Good examples of such reefs are the stations at the SE tip of Bahuluang and the S-side of Gili Lawa Laut.

When coral cover is low a physiognomic zonation is usually indicated with zones characterized by conspicuous morphological features and related to depth zones. Such zonations were described for the reefs off the W-coast of Bahuluang and Tanjung Buru (Bay of Sanggar).

A striking phenomenon of practically all reefs investigated is the limited depth to which coral growth extends. Usually coral cover is extremely low below 10 m depth. Only on a few localities coral growth extends deeper, such as at the S-side of Gili Lawa Laut. On the reef slopes surrounding Tinanja (particularly W-side) and the reef platforms in the Linta Strait coral cover is usually nil below 4-5 m depth, showing bare rubble talus or rocky walls. The sealevel changes described for the area (Hopley, 1987) are possibly responsible for the erosive character of these reefs. Since 4000 y BP sea level dropped ca 4-5 m down to the present level in Australasia (Geyh et al., 1979; de Klerk, 1983). This drop probably coincided with reef erosion and redistribution of sediments, restricting the availability of suitable substrata for coral settlement in shallow water coastal zones and along platforms.

Roberts et al. (1988) forward another explanation for the restricted depth range of corals in Indonesia. They suggest that periodic upwelling of nutrient rich waters unto coastal shelfs and platforms in Indonesia may favor abundant growth of *Halimeda* over reef building corals. None of these explanations have been prooved yet.

Community composition

Community composition was determined on the basis of dominant growth form and dominant coral species or plants and size classes. The relative cover of different growth forms was also considered in relation to bottom components such as sand or rubble. These combinations are adequate to distinguish different communities in the field and map the reefs sufficiently detailed to provide data to label the different map units on aerial photographs. Bak & Povel (1988, 1989) demonstrated that such biological and physical features are even sufficient to distinguish communities with respect to wave exposition (water movement) at scales of 1:2 with principle component analysis. The coral species composition was analysed by Moll (1986), Best et al. (1989), Hoeksema & Moka (1989) during the Snellius-II expedition. These studies render too much information for mapping purposes. The coarse community descriptions of reef maps are useful in locating sites for detailed reef surveys.

Condition/damage

The most common cause of man-induced physical damage to the reef appeared to be dynamite fishing. Particularly in the Komodo study area restricted reef sections were found to be severely devastated. However, compared to the damage inflicted to reefs by natural hydrodynamic forces this damage is modest and not yet alarming. The damage to the reef caused by the extensive *Ulva* bloom on the reef platforms Tambunan Singkala and the platform south of Tambunan appears to exert a greater

Table 2. Data sheet for use in large area surveys of reefs.

Data sheet no.:	Date:	Time:	Method*: snorkeling/wading/SCUBA/Viewing box
Location:		Tidal range:	Compass reading/depth contour*:
		HW/LW*:	Tow/manta/scooter/manpower* (speed):
		Observer:	Spot reconnaissance:
Position finding method:			
Organization:			

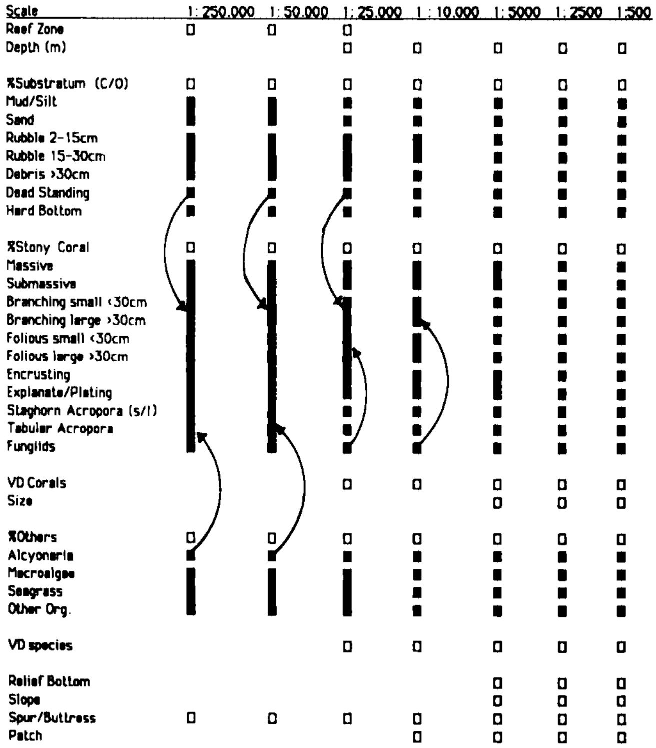
Survey spot	1	2	3	4	5	6	7	8	
Position									
Reef zone									
• Depth (m)									
%Substratum (C/O									
Mud/Silt									
Sand									
Rubble 2-15 cm									
Rubble 15-30 cm									
Debris > 30 cm									
Dead Standing									
Hard Bottom									
% Stony coral									
Massive									
Submassive									
Branching small < 30 cm									
Branching larege > 30 cm									
Folious small < 30 cm									
Folious large > 30 cm									
Encrusting									
Explanate/Plating									
Staghorn *Acropora*									
Tabular *Acropora*									
Fungiids									
VD Corals									
• Size									
% Other									
Alcyonaria									
Macroalgae									
Seagrass									
Other organisms									
VD species									
• Relief bottom									
• Slope									
Spur/Buttress									
Patch									
Radius of vision									
Photograph									
Toppled corals									
Blow holes									
Scars									
White spots									
Acanthaster									
Remarks									

negative influence on the reef condition. At several sites *Acanthaster* aggregations were observed predating on live coral tissue. Small branching corals and acroporids appear to be the favourite species for consumption by this starfish.

Standardization of classification

Based on geomorphological and biological characteristics as observed at the stations investigated in 1984 during the Snellius-II expedition a data sheet was developed to cover all aspects of importance for distinction between map units at scales of

Table 3. Groupings of different entries of data sheet (Table 2) for labelling of map units distinguishable on reef aerials of different scales.



1 : 2.500 and smaller (table 2). Sheets are meant to be used for large area surveys. An extensive knowledge of species is not required for filling in the sheet. Only some insight is needed with regard to the dominant coral and plant species and the definitions of the different entries on the sheet should be known). Data collected on sheets provide sufficient information for the verification of aerial photographs and images of scales of 1 : 2.500 and smaller. In proportion as the scale of images decreases, groupings of entries are proposed in order to bring information together in distinguishable map units on the remote pictures of the reef (table 3). Discussion with other researchers and end users of the resultant data is required before the sheet could be recommended and/or adopted as a universal data recording standard for the archipelago. The system is simple enough in concept to be used by relatively shortly trained surveyers.

Acknowledgements

The data were collected during theme 4, Coral Reefs, of the Snellius-II Expedition, which was jointly organized by the Indonesian Institute of Sciences (LIPI) and the Netherlands Council of Oceanic Research (NRZ). Thanks are due to Dr J. van der Land for reading the manuscript.

References

Bak, R.P.M. & R.W.P.M. Laane, 1987. Annual black bands in skeletons of reef corals (Scleractinia).— Mar. Ecol. Prog. Ser. 38: 169-175.

Bak, R.P.M. & G.D.E. Povel, 1988. Ecological structure and variation in a range of Indonesian fore-reef slope coral communities.— Proc. Sixth Int. Coral Reef Symp. August 1988, Townsville, Australia 3: 191-196.

Bak, R.P.M. & G.D.E. Povel, 1989. Ecological variables, including physiognomic-structural attributes, and classification of Indonesian coral reefs.— Neth. J. Sea Res. 23: 95-106.

Best, M.B., B.W. Hoeksema, W. Moka, H. Moll, Suharsono, I Nyoman Sutarna, 1989. Recent scleractinian coral species collected during the Snellius-II expedition in eastern Indonesia.— Neth. J. Sea Res. 23: 107-115.

Done, T.J., 1977. A comparison of units of cover in ecological classifications of coral communities.— Proc. 3rd Int. Coral Reef Symp. 1, Miami: 9-14.

Done, T.J., 1982. Patterns in the distribution of coral communities across the central Great Barrier Reef.— Coral Reefs 1: 95-107.

Done, T.J., 1983. Coral zonation, its nature and significance. In: Barnes, D.J. (ed.). Perspectives on coral reefs: 107-147. — Australian Institute of Marine Science, Townsville.

Duyl, F.C. van, 1985. Atlas of the living reefs of Curacao and Bonaire (Netherlands Antilles).— Studies of the flora and fauna of Surinam and the Netherlands Antilles 117.

Geyh, M.A., H.-R. Kudrass and H. Streif, 1979. Sea-level changes during the late Pleistocene and Holocene in the Strait of Malacca.— Nature 278: 441-443.

Hoeksema, B.W. & W. Moka, 1989. Species assemblages and phenotypes of mushroom corals (Fungiidae) related to coral reef habitats in the Flores Sea.— Neth. J. Sea Res. 23: 149-160.

Hopley, D., 1987. Holocene sea-level changes in Australasia and the southern Pacific. In: Devoy, R.J.N. (ed.), Sea surface studies. A global view. — Croom Helm, London, p. 375-408.

Jupp, D.L.B., 1983. Remote sensing application and potential for management of the Great Barrier Reef. In: Baker, J.T. Carter, R.M., Sammarco, P.W., Stark, K.P. (eds.). Proc. of the Inaugural Great Barrier Reef Conference: 509-515 — James Cook Univ. North Queensland, Townsville, Australia.

Jupp, D.L.B., Mayo, K.K., Kuchler, D.A., Heggen, S.J., Kendall, S.W,. 1981. Remote sensing by Landsat as support for management of the Great Barrier Reef.— Proc. Australasian Landsat Conference, Canberra, Australia: 9.5.1-6.

Jupp, D.L.B., Heggen, S.J., Mayo, K.K. Kendall, S.W.,1983. The BRIAN-handbook. An introduction to Landsat and the BRIAN (Barrier Reef Image Analysis) System for users.— CSIRO, Div. Wat. & Land Res., Canberra, ACT.

Klerk, L.G. de, 1983. Zeespiegels, riffen en kustvlakten in zuidwest Sulawesi, Indonesia, een morfogenetisch-bodemkundige studie.— Thesis, Univ. Utrecht, The Netherlands.

Kuchler, D.A., 1985. Shallow water mapping using remote sensing techniques: Research applicable to the South Pacific Region. Great Barrier Reef Marine Park Authority Technical Memorandum. Workshop, Handout no. 6.

Kuchler, D.A,. 1987a. Reef cover and zonation classification system for usepith remotely sensed Great Barrier Reef Data: user guide and handbook. Great Barrier Reef Marine Park Authority. Technical Memorandum 9.

Kuchler, D.A., 1987b. Geomorphological separability, Landsat MSS and aerial photographic data: Heron Island, Great Barrier Reef. Great Barrier Reef Marine Park Authority, Technical Memorandum 10.

Kuenen, Ph. H., 1933. The Snellius expedition. Geological results. Vol. V (2): 1-125.— Kemink, Utrecht.

Marshall, J.F. & P.J. Davies, 1988. *Halimeda* bioherms of the northern Great Barrier Reef.— Coral Reefs 6: 139-148.

Moll, H., 1986. The coral community structure on the reefs visited during the Snellius-II expedition in eastern Indonesia.— Zool. Med. Leiden 60: 1-25.

Orme, G.R. & M.S. Salama, 1988. Form and seismic stratigraphy of *Halimeda* banks in part of the northern Great Barrier Province.— Coral Reefs 6: 131-138.

Phipps, C.V.G & H.H. Roberts, 1988. Seismic characteristics and accretion history of *Halimeda* bio-

herms on Kalukalukuang Bank, eastern Java Sea (Indonesia).— Coral Reefs 6: 149-160
Polunin, N.V.C., 1983. The marine resources of Indonesia. Oceanogr.— Mar. Biol. Ann. Rev. 21: 455-531.
Roberts, H.H. & C.V. Phipps, 1988. Proposed oceanographic controls of modern Indonesian reefs: A turn-off/turn-on mechanism in a monsoonal setting.— Proc. sixth Int. Coral Reef Symp. Townsville, Australia 3: 529-534.
Roberts, H.H., P. Aharon, C.V. Phipps (1988). Morphology and sedimentology of *Halimeda* bioherms from the eastern Java Sea (Indonesia).— Coral Reefs 6: 161-172.
Robinson, A., N.V.C. Polunin, Kvalvagnaes, K., Halim, M., 1981. Progress in creating a marine reserve system in Indonesia.— Bull. Mar. Sci. 31 (3): 777-785.
Soegiarto, A., 1981. The development of a marine park system in Indonesia.— Proc. Fourth Int. Coral Reef Symp., Manila 1: 287-291.
Soegiarto, A. & N.V.C. Polunin, 1982. The Marine environment of Indonesia. IUCN report, Cambridge: i-ix, 1-257.
Umbgrove, J.H.F., 1929. The coral reefs in the Bay of Batavia.— Fourth Pacific Science Congress, Java: 3-15.
Umbgrove, J.H.F., 1947. Coral reefs in the East Indies.— Bull. geol. Soc. Am. 58: 729-778.
Verwey, J., 1931. Coral reef studies. III. Geomorphological notes on the coral reefs of the Batavia Bay.— Treubia 13 (2): 199-215.
Wijsman-Best, M.B., 1977. Coral research in the Indonesian Archipelago, the past, the present and the future.— Mar. Res. in Indonesia 17: 1-14.

Received: 29.iii.1990
Accepted: 30.ix.1991
Edited: J. van der Land

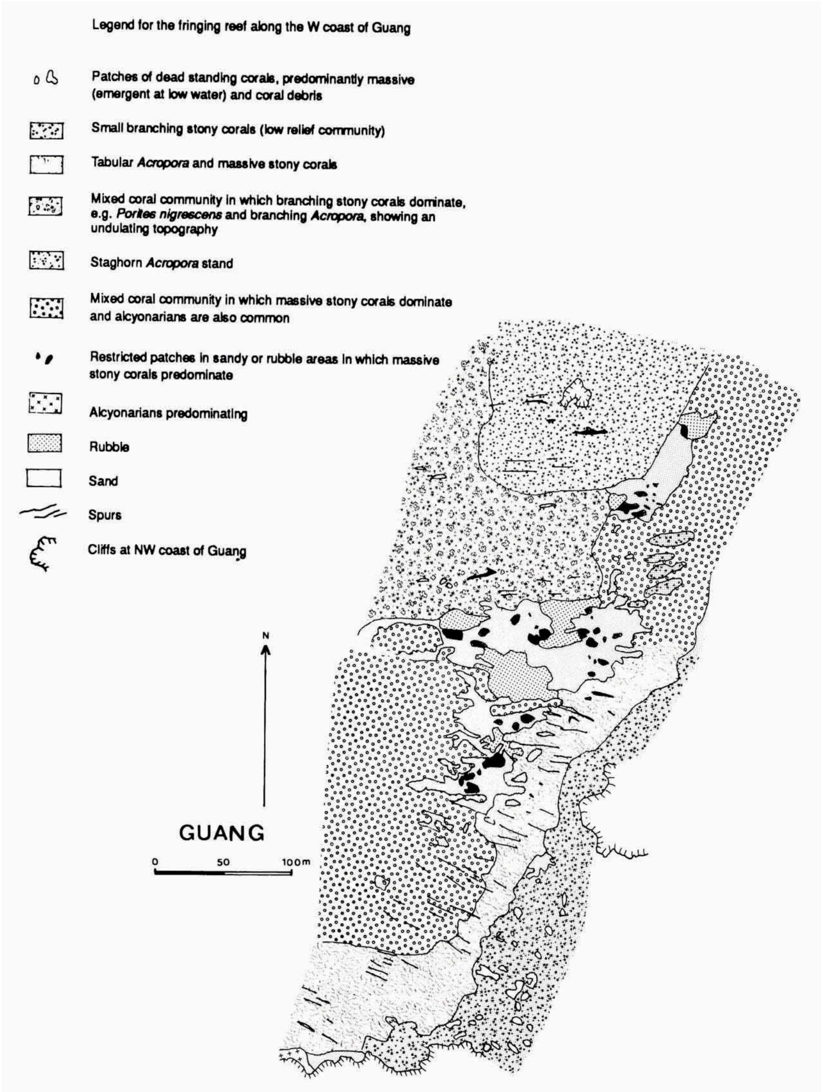


Fig. 4. Reef map of the W-side of Guang based on aerial photographs and subsurface reconnaissance.

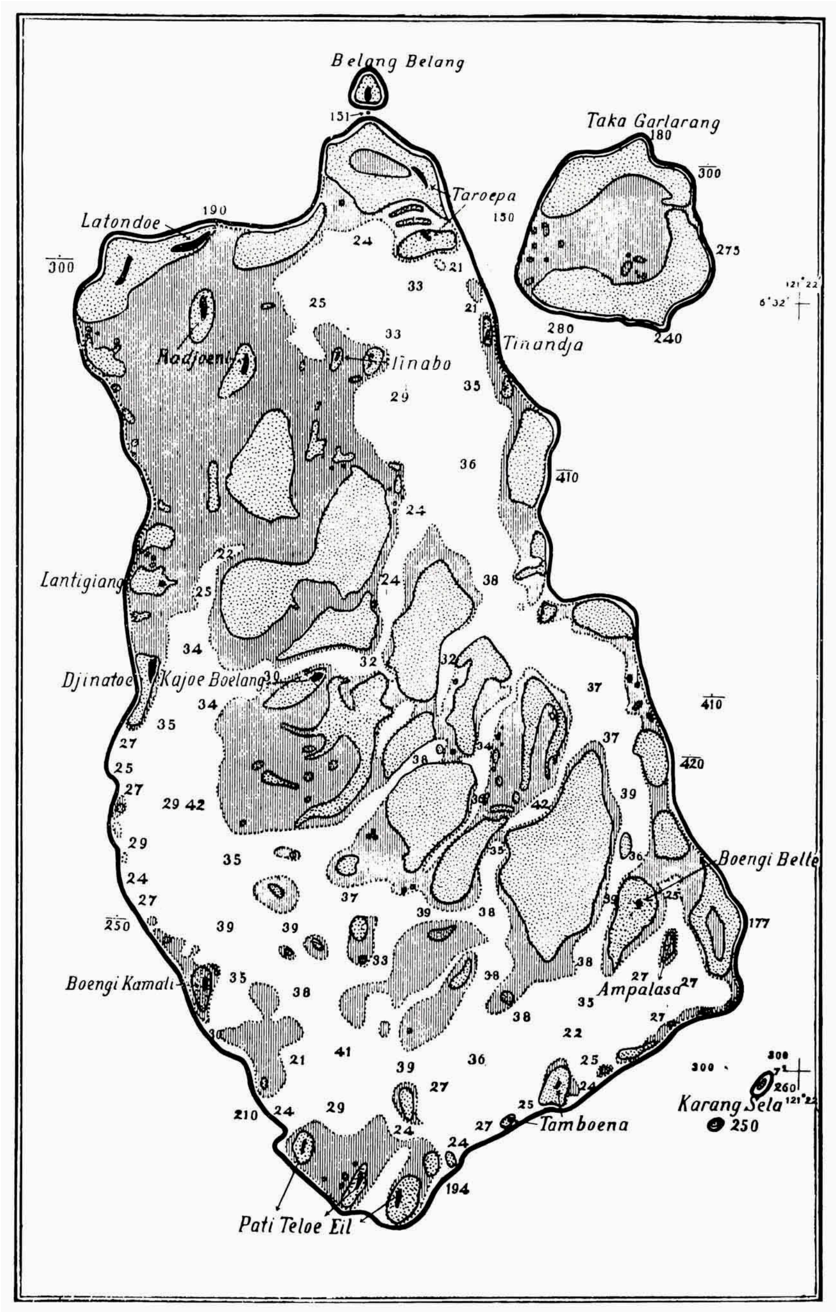


Fig. 5. Taka Bone Rate Atoll; the study site Tinanja is indicated by an arrow.

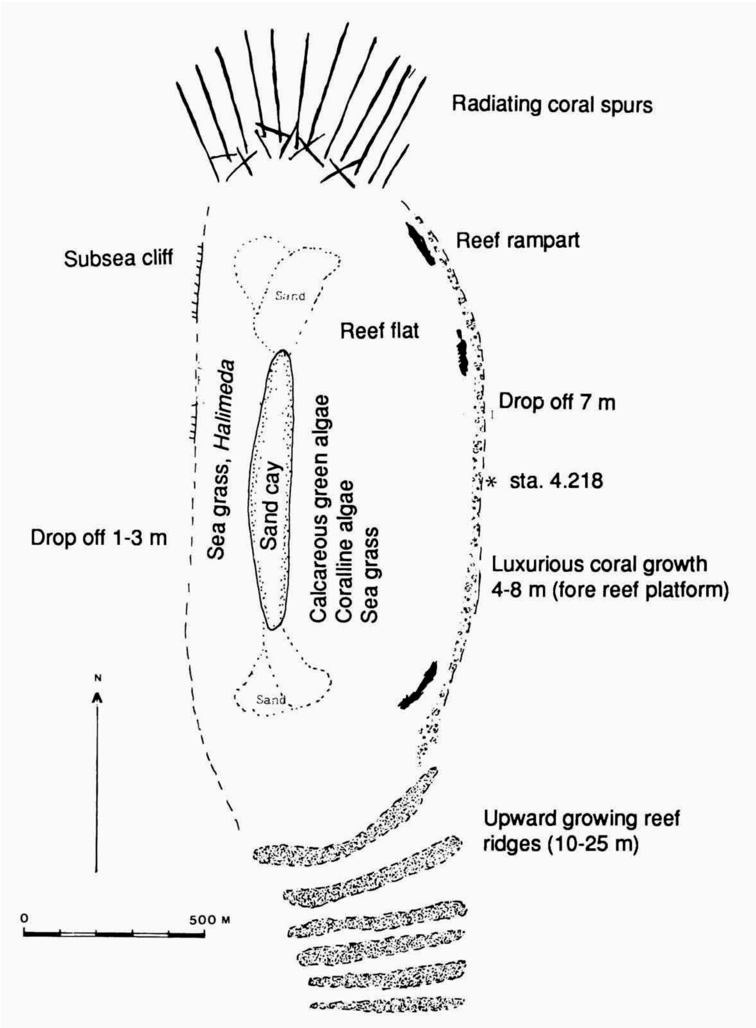


Fig. 6. Sketch map of Tinanja and surrounding reefs, solely based on ground surveys and interpretations.

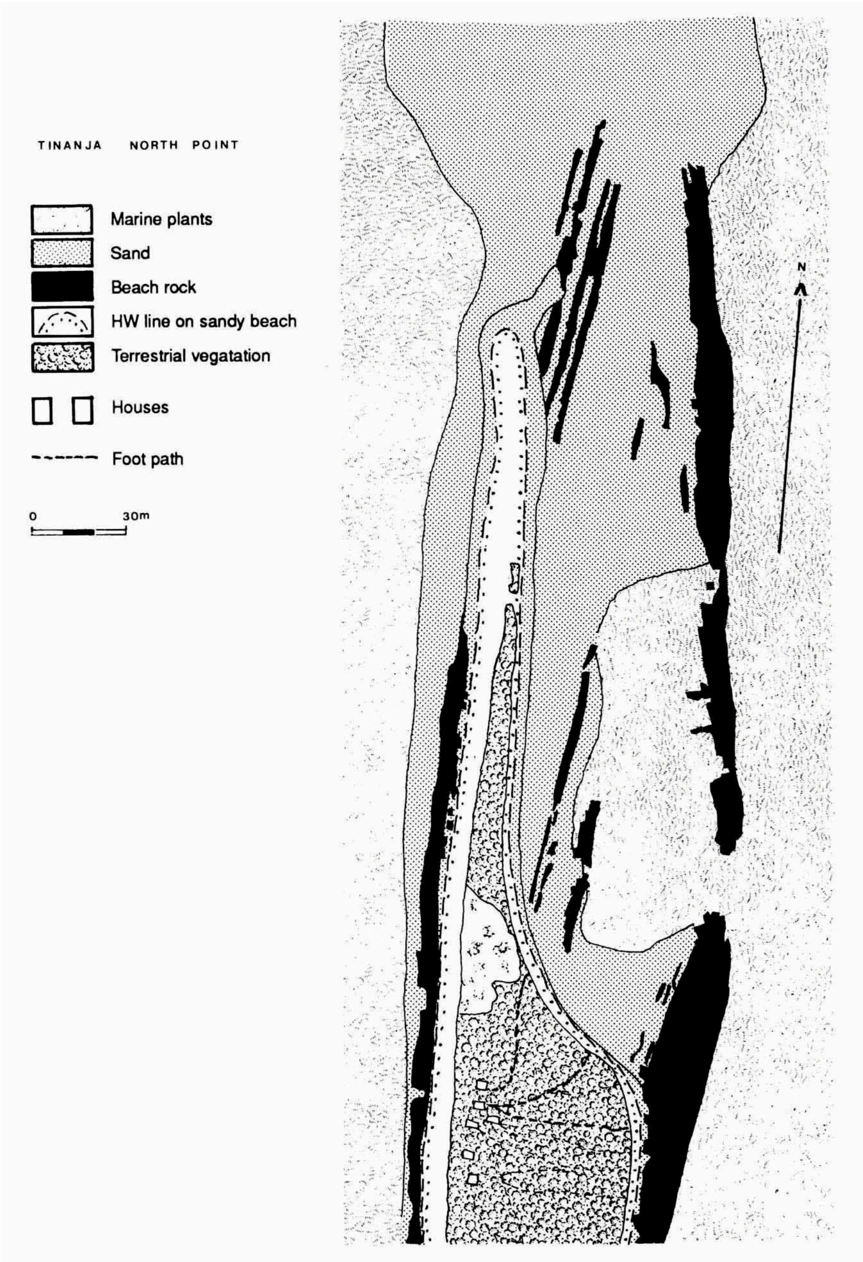


Fig. 7. Reconstruction of the N-tip of Tinanja based on aerial photographs.

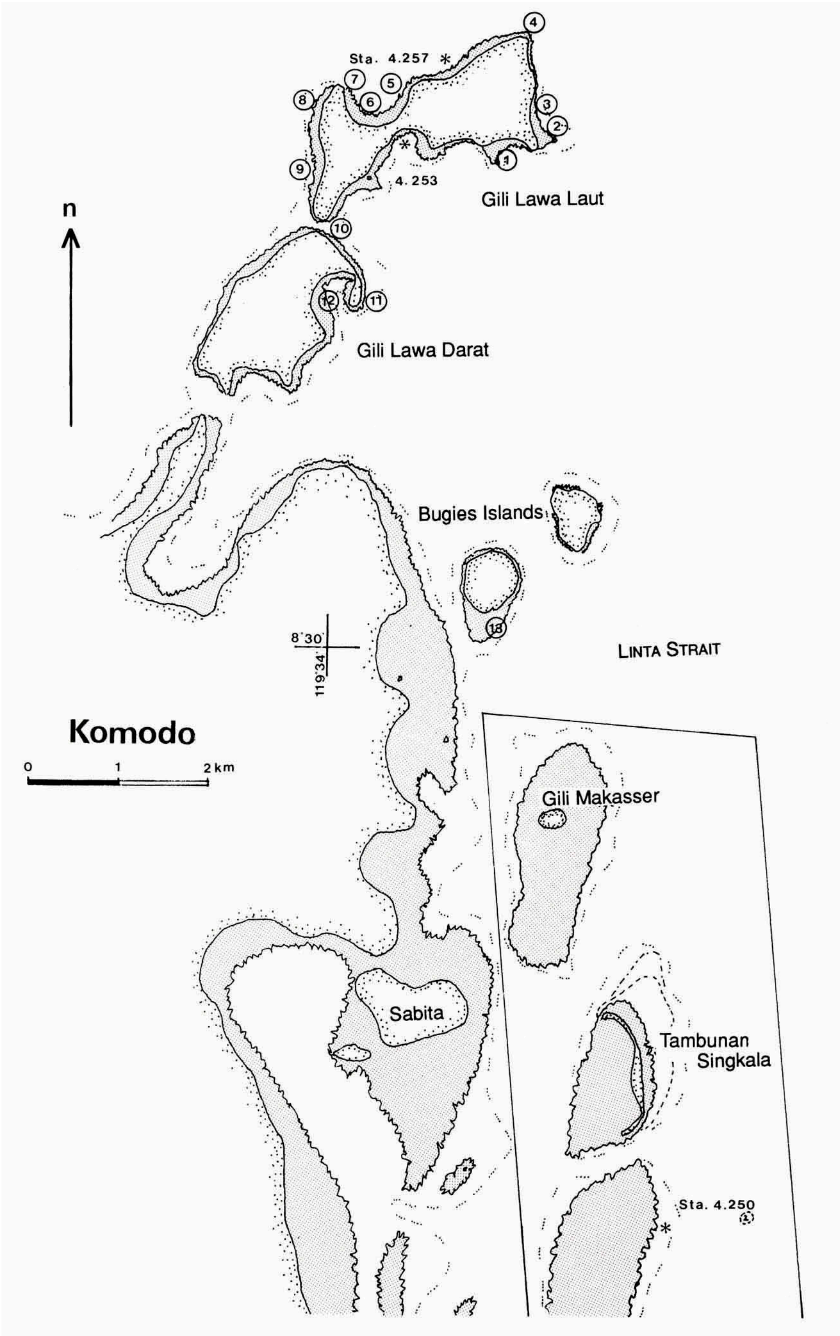


Fig. 8. Location of study sites in the Komodo area. Survey spots 1-13 and the three reef islands E of Sabita.

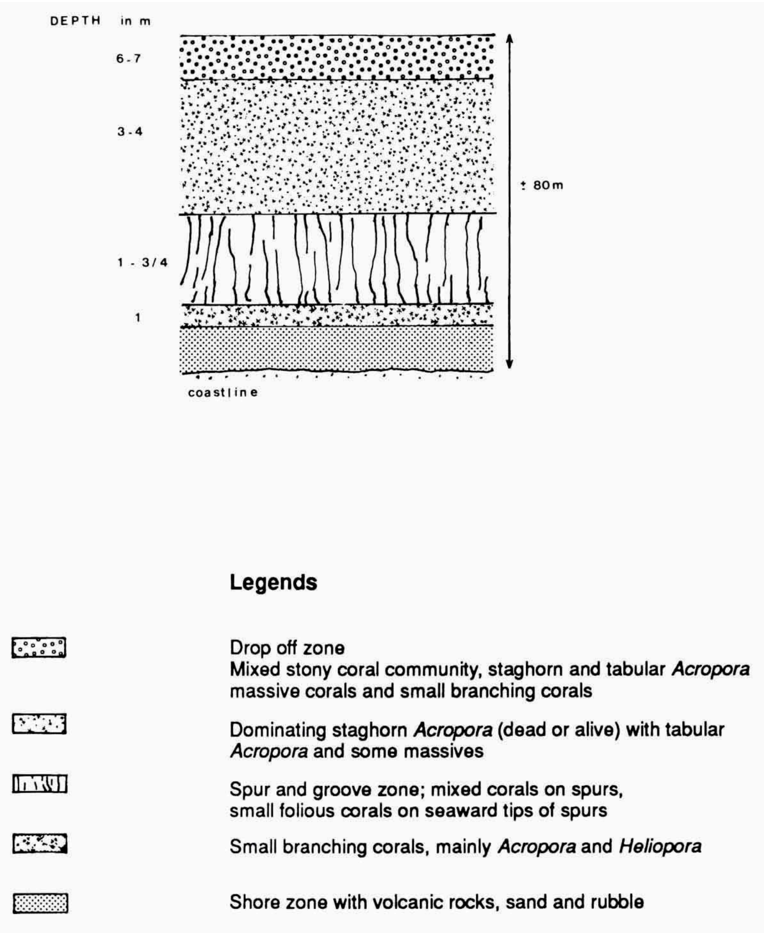


Fig. 9. Schematic zonation of the reef along the N-side of Gili Lawa Laut.

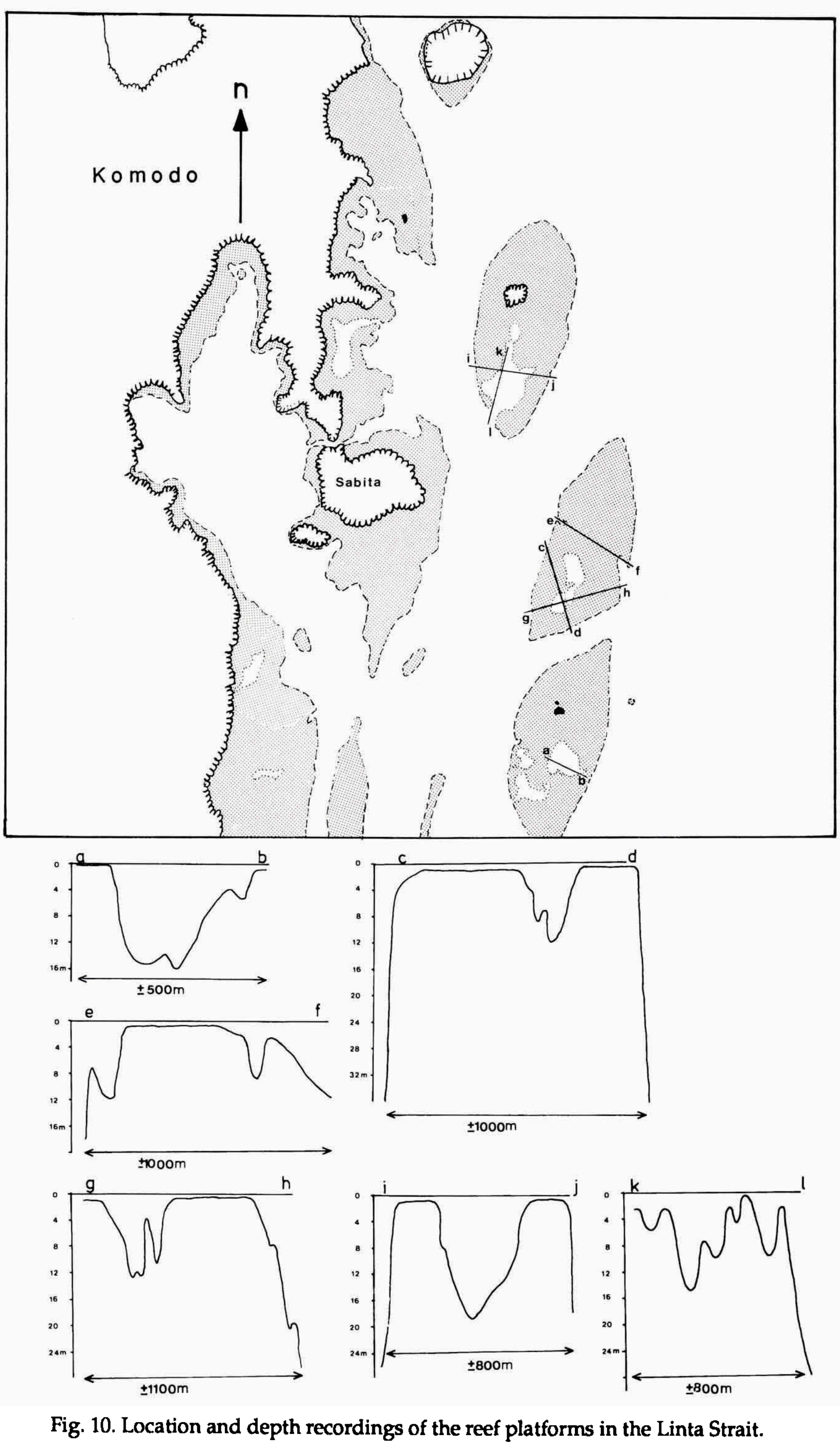


Fig. 10. Location and depth recordings of the reef platforms in the Linta Strait.

Fig. 11. Reef map of Gili Makasser.

Coral communities

Small branching stony corals and staghorn *Acropora;* locally staghorn *Acropora* predominating

Small branching and folious stony corals

Small branching stony corals only, low relief

Folious stony corals predominating among mixed corals (small branching, massives, tabular *Acropora*)

Massive corals dominating among mixed corals; alcyonarians locally very common

Alcyonarians predominating; stony coral patches

Marine plant communities

Seagrass and massive stony corals

Seagrass with dispersed coral patches

Seagrass

Ulva spec. (leafshaped *Ulva* stands, including two species)

- Ulva overgrowing small branching and folious corals
- Ulva (10-30% cover) over sandy/rubble bottom

Unidentified plants (seagrass, *Halimeda* or *Ulva*)

Substrates

Sand/rubble

Rubble with locally coral patches

Rubble rampart, shingle walls

Island (above HW)

Cover classes

a. 10 - 30 %

b. 30 - 60 %

c. > 60 %

Other

Limit of aerial survey, 5-15 m depth

Spurs

Lagoon or open sea

Fig. 11a. Legends to figs 11-13.

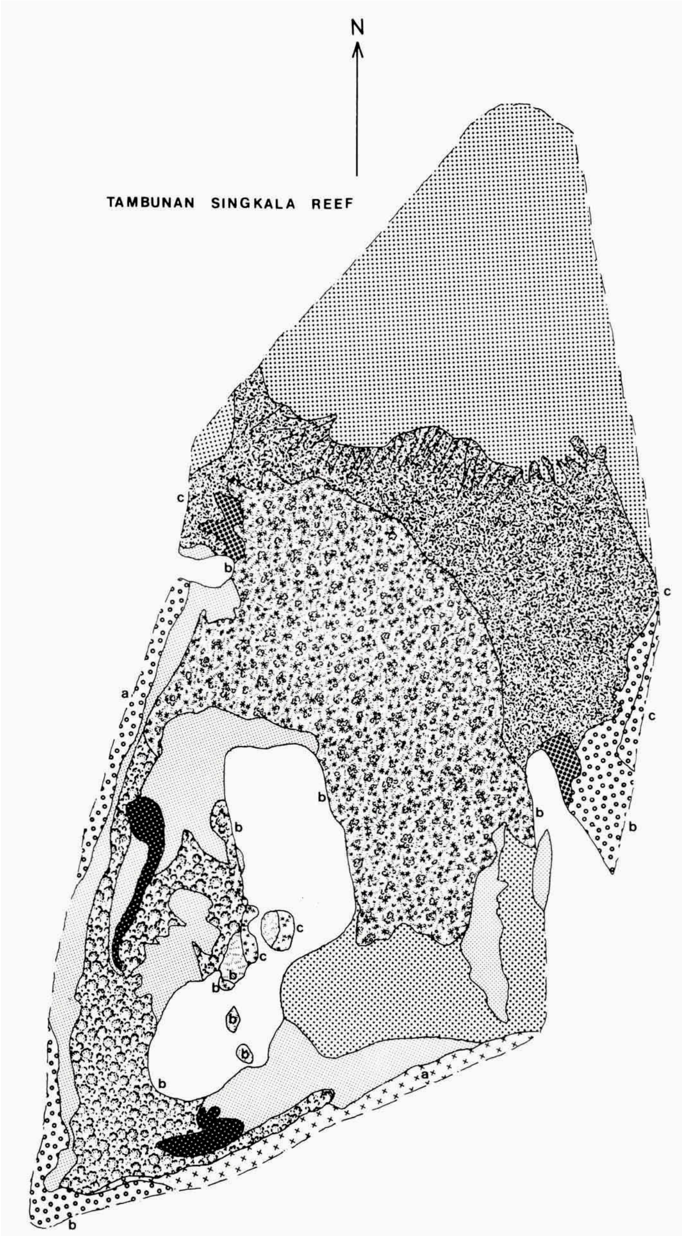


Fig. 12. Reef map of Tambunan Singkala.

Fig. 13. Reef map of nameless reef south of Tambunan Singkala.

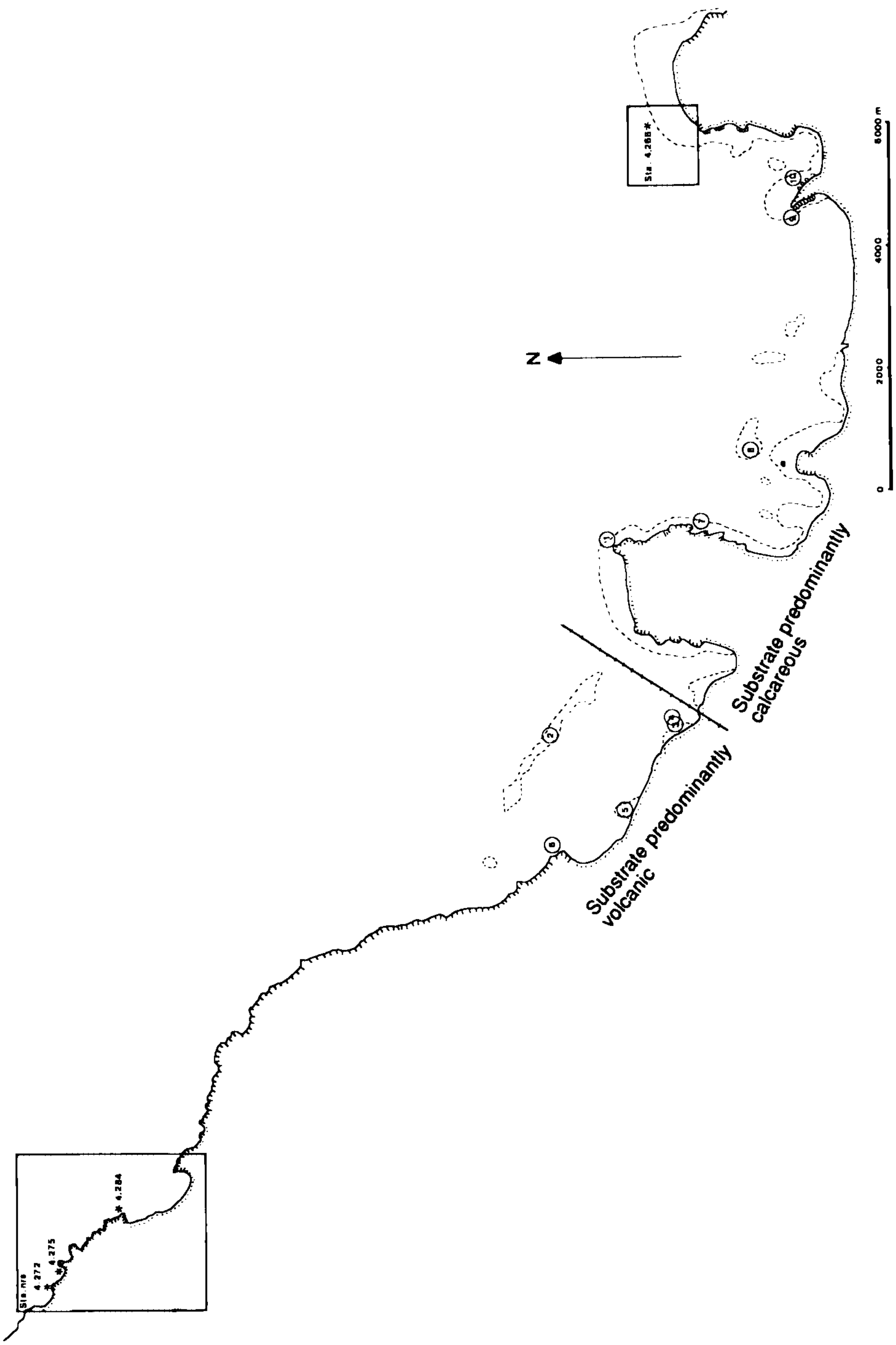


Fig. 14. Location of study sites N of Sumbawa.

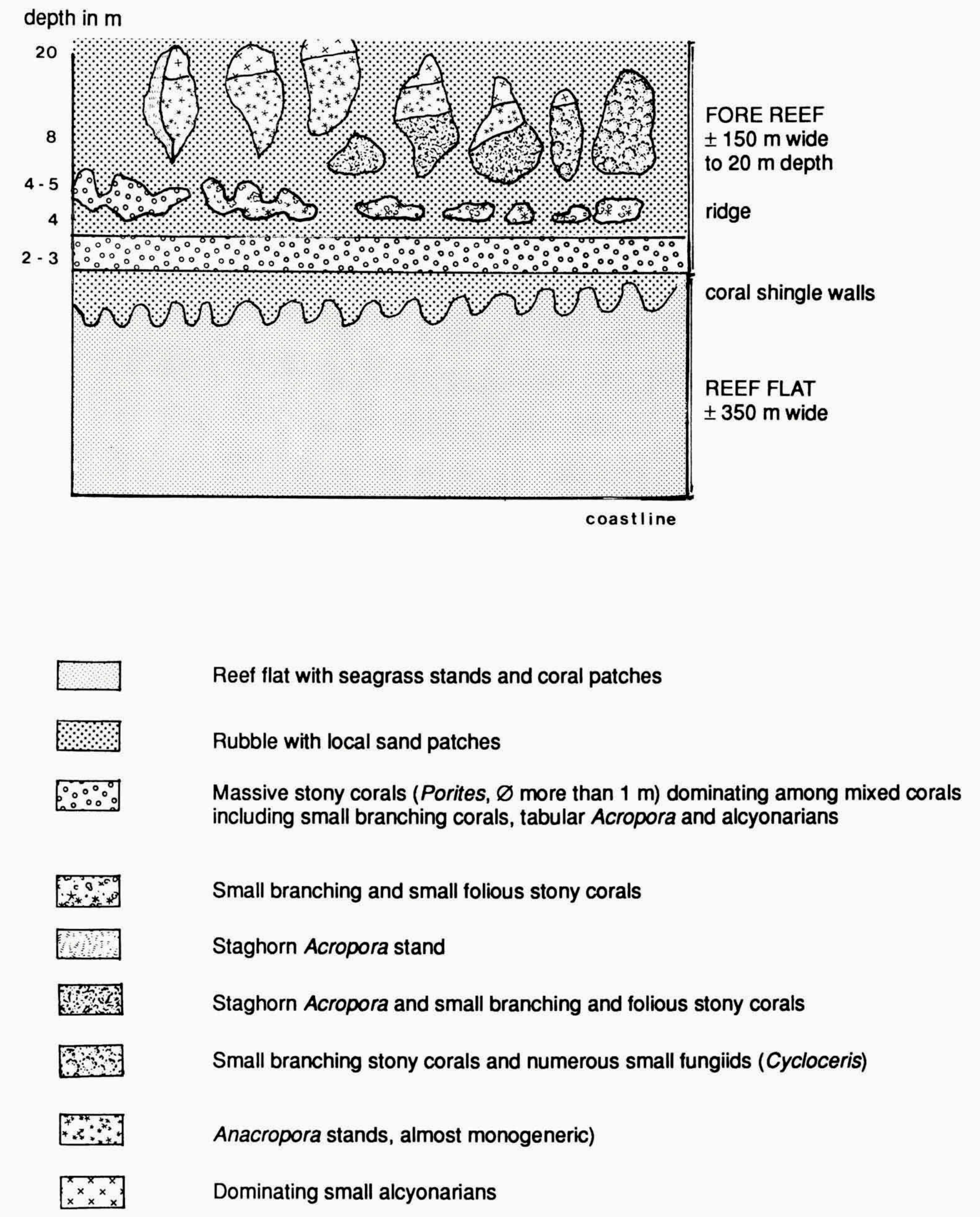


Fig. 15. Sketchy reconstruction of the reef off Tanjung Buru, Sanggar Bay, based on subsea surveys.

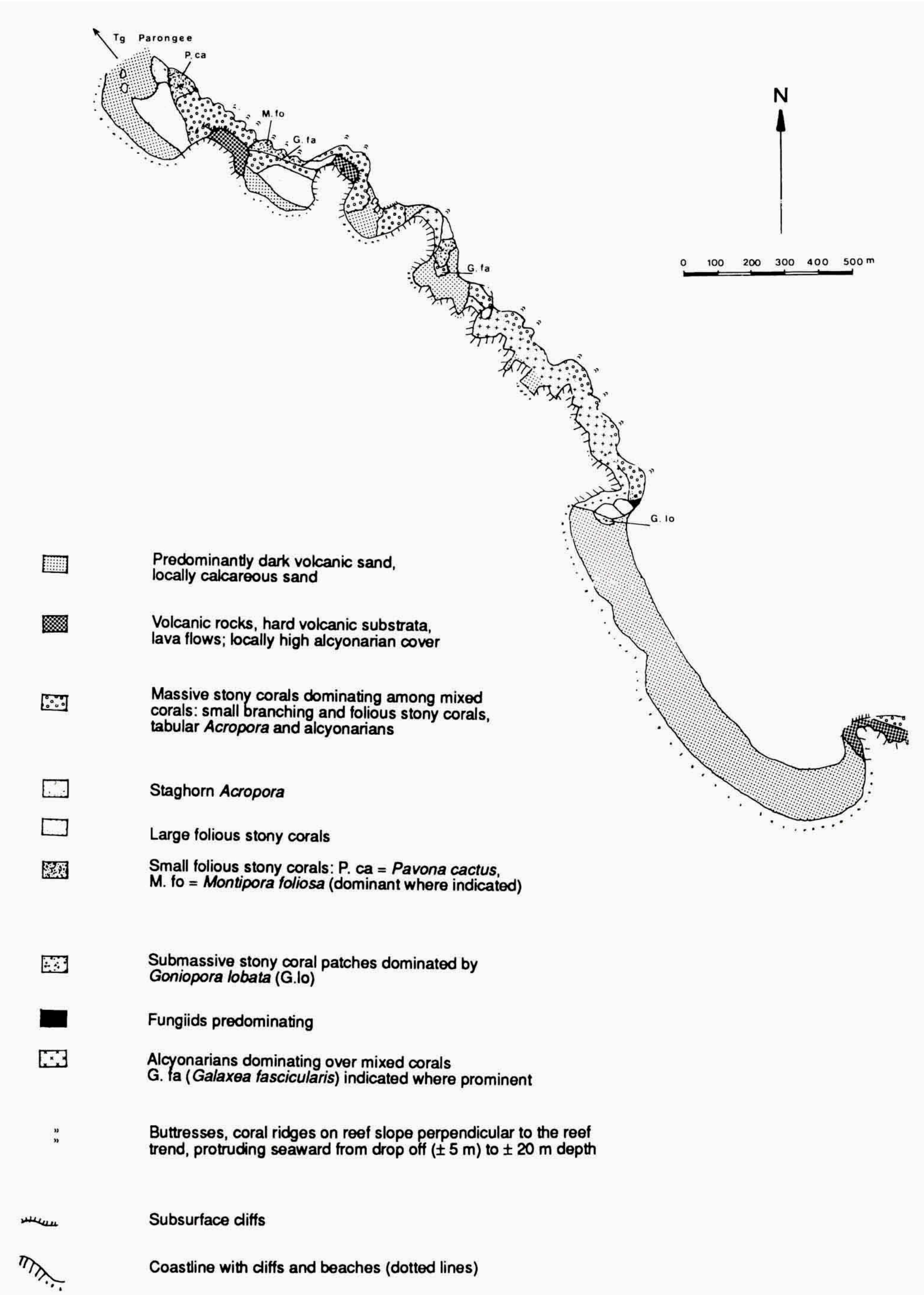


Fig. 16. Sketchy reconstruction of the narrow fringing reef along the Tambora volcano based on underwater surveys and orientation surfacings. The accentuated coastline was withdrawn from aerial photographs dating from 1948.