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Deltaic and Dissected Reefs of the Far Northern Region

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Deltaic and dissected reefs of the far Northern Region

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[Plates 1 and 2]

The outer barrier reefs north of the ribbon reefs are composed of two distinctly different reef types, here called 'deltaic' reefs and far northern 'dissected' reefs. Two reefs of each of these types are described. The deltaic reef system is composed of 96 km of reef front characterized by the presence of regular, well defined channels containing very strong tidal currents, and also by the presence of a deltaic pattern at the reef back. The dissected reefs are the northernmost of the barrier reefs. They are composed of many small E–W elongate reefs interspersed by many wide channels. Both reef types are part of the one structure, their differing surface morphologies being attributed to bathymetric and hydrodynamic factors of the present and of the past.

Introduction

The previous paper (Veron & Hudson 1978) was concerned with the long series of more or less elongate reefs collectively known as 'ribbon' or 'wall' reefs. These reefs are characterized by a general similarity which allows them to be readily distinguished from other reef types including other types of barrier reefs. The ribbon reefs extend northward to about the level of Olinda Entrance (latitude 11° 14′ S) (figure 1), whereupon the barrier undergoes a gradual change from a ribbon system into a system of very different reefs that are here called 'deltaic' reefs, following Maxwell's (1968) terminology.

The deltaic reefs extend northward for a distance of approximately 96 km. They are composed of approximately 28 major reefs, 0.4–3.7 km in length, which are interspersed with about 33 major channels. Over this distance the deltaic appearance becomes increasingly more complex; major channels become less distinctive and are increasingly confused with an interlocking network of smaller channels. Thus at latitude 10° 10′ S the deltaic pattern consists of a thoroughly confused network or irregular elongate patches intermixed with a mass of channels, most of which are small and shallow. The general appearance is broadly similar to the outer edge of a mature river delta.

From this point north, the barrier line becomes increasingly simplified. The reefs and channels retain their irregular appearance but the channels become less interwoven. At about latitude 10° S the barrier consists of alternating elongate reefs separated by relatively well defined, straight channels. For the purpose of this account, these reefs are called 'dissected' reefs.

At its northern limit the barrier line consists of an irregular row of very small reefs which become increasingly difficult to distinguish in aerial photographs. Beyond the visible northern limit, Chart AUS 377 indicates a shallow area annotated 'strong ripplings'.

The only previous description of these reefs known to the author is that of Captain Blackwood

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(1844): 'From Pandora entrance the reef runs N.E.b.N., seven miles, to Olinda Entrance and is intersected by small but narrow openings unfit for shipping, and then gradually turns away N.b.W. running for a space of nearly ninety miles in an impenetrable line of reef, until Murray Island is approached'. Navigational charts (2354 and AUS 377) indicate the position of the reef line but no detail given can be recognized in aerial photographs. More recent reconnaissance maps (SC 54–16, 55–13, 54–12, 55–9, 55–5) from satellite photographs distinguish the approximate shape of major reefs, but again, detail is lacking. The present paper gives a simplified description of a major section of the Great Barrier Reef which has hitherto remained almost completely unknown.

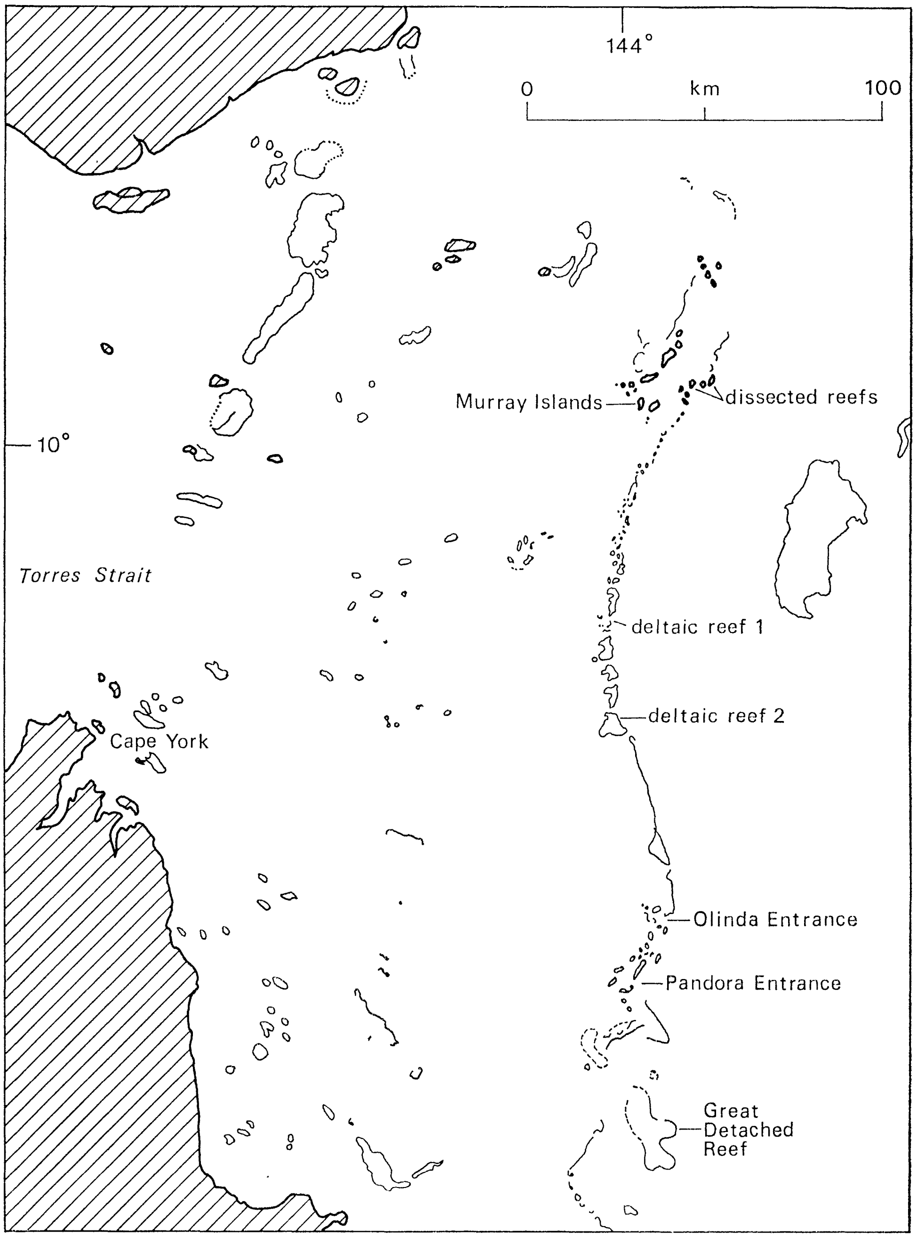

FIGURE 1. The northern shelf edge reef, showing place names referred to in the text and the positions of the deltaic and dissected reefs.

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Methods

This study was undertaken during the second far northern cruise of R.V. *James Kirby*. Methods used are as described in the previous paper except that no reconnaissance was made from chartered aircraft and no quantitative transects were attempted.

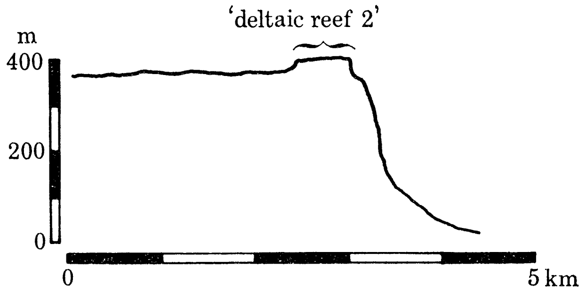

Figure 2. Profile of the deltaic reefs at the latitude of 'deltaic reef 2'. Drawn from soundings taken during the present study. Vertical exaggeration is 1 : 20.

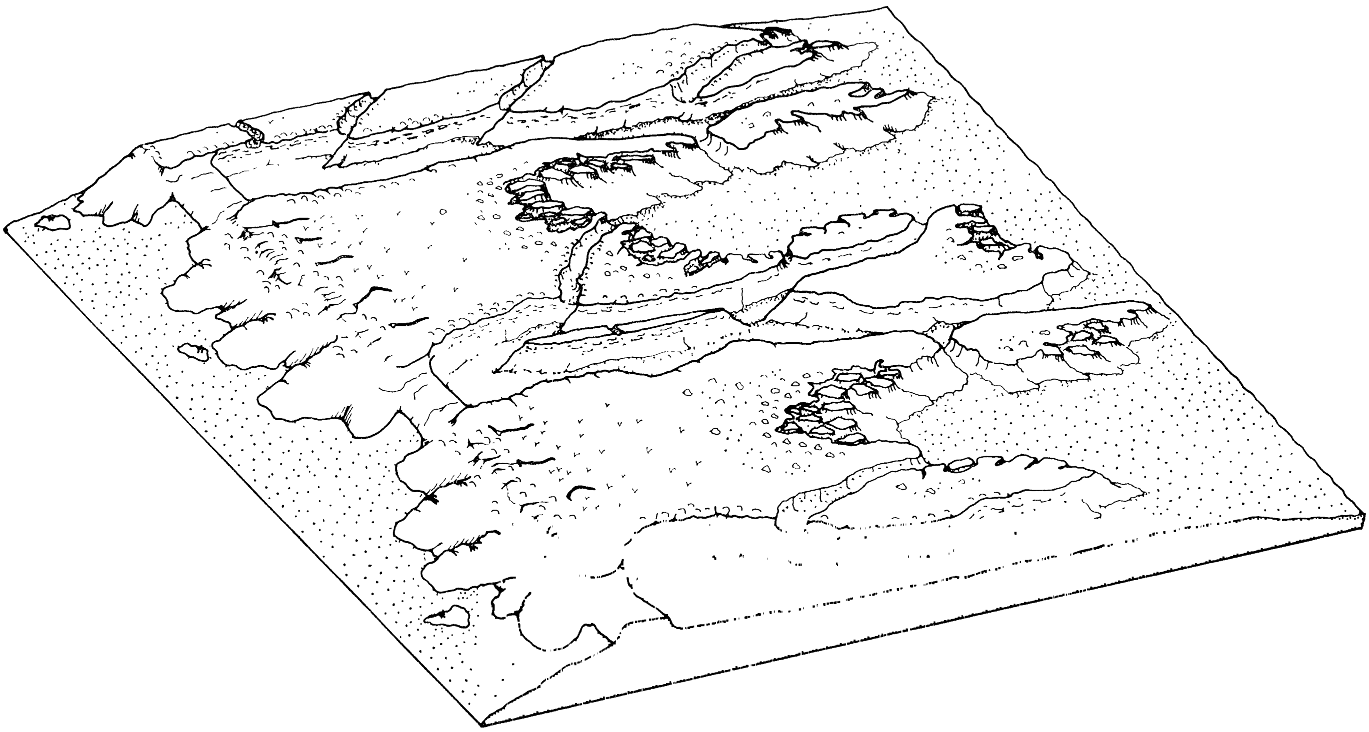

Figure 3. Three-dimensional reconstruction of a section of deltaic reef, showing the approximate spatial relation of features referred to in the text.

The deltaic reefs

The deltaic reefs are 140–150 km from the mainland, almost due east of Cape York. The continental shelf between the barrier reefs and the mainland is poorly chartered but seldom appears to be more than 30 m deep (figure 2) and contains large numbers of patch reefs. As noted above, the deltaic reefs at their northern extremity consists of a complex of interwoven narrow channels and reefs that, from aerial photographs, become confused. A few kilometres further south the deltaic pattern illustrated in figure 3 emerges.

Two reefs, here called 'deltaic reef 1' and 'deltaic reef 2' (figures 4 and 5, plates 1 and 2 respectively), were selected for study. They both lie in the northern half of the deltaic system, where the deltaic pattern is best developed, and have approximate latitudes of 10° 44′ and 10° 50′ S respectively.

The reef front

The front of deltaic reef 1 was characterized by a very sparse coverage of coral reaching a maximum of only 5 % at 3.5–5 m depth; *Acropora palifera* (Lamarck) was dominant. An unidentified sponge was also common. Other species of *Acropora*, especially *A. humilis* (Dana), *A. hyacinthus* (Dana), and *A. surculosa* (Dana) became relatively common at depths to approximately 11 m after which *Halimeda* became entirely dominant. The burrowing echinoid, *Echinostephus molaris* de Blainville, and various hydroids were relatively abundant on solid reef substrates. Calcareous algae were scarce.

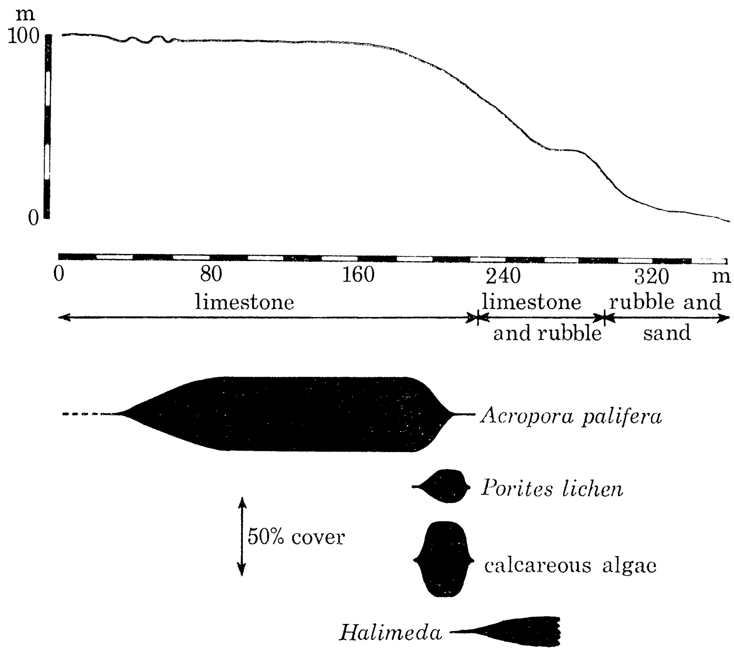

FIGURE 6. The outer slope of deltaic reef 2, showing in profile the distribution of substrate type and estimated percentage cover of corals and algae. No vertical exaggeration.

In marked contrast with reef 1, deltaic reef 2 (figure 6) had well defined zones of coral and algae. The substrate was similar, consisting of solid, wave-worn rock followed by a mixture of limestone and rubble, then rubble and sand. Coral zonation was distinct, *Acropora palifera* being dominant to a depth of approximately 15 m followed by a narrow zone of *Porites lichen* (Dana) which formed characteristic horizontal plates extending from the reef surface. Calcareous algae were very abundant in the *P. lichen* zone, the two forming an almost continuous cover. Below this zone the reef surface became increasingly composed of coral rubble and sand with *Halimeda* completely dominant.

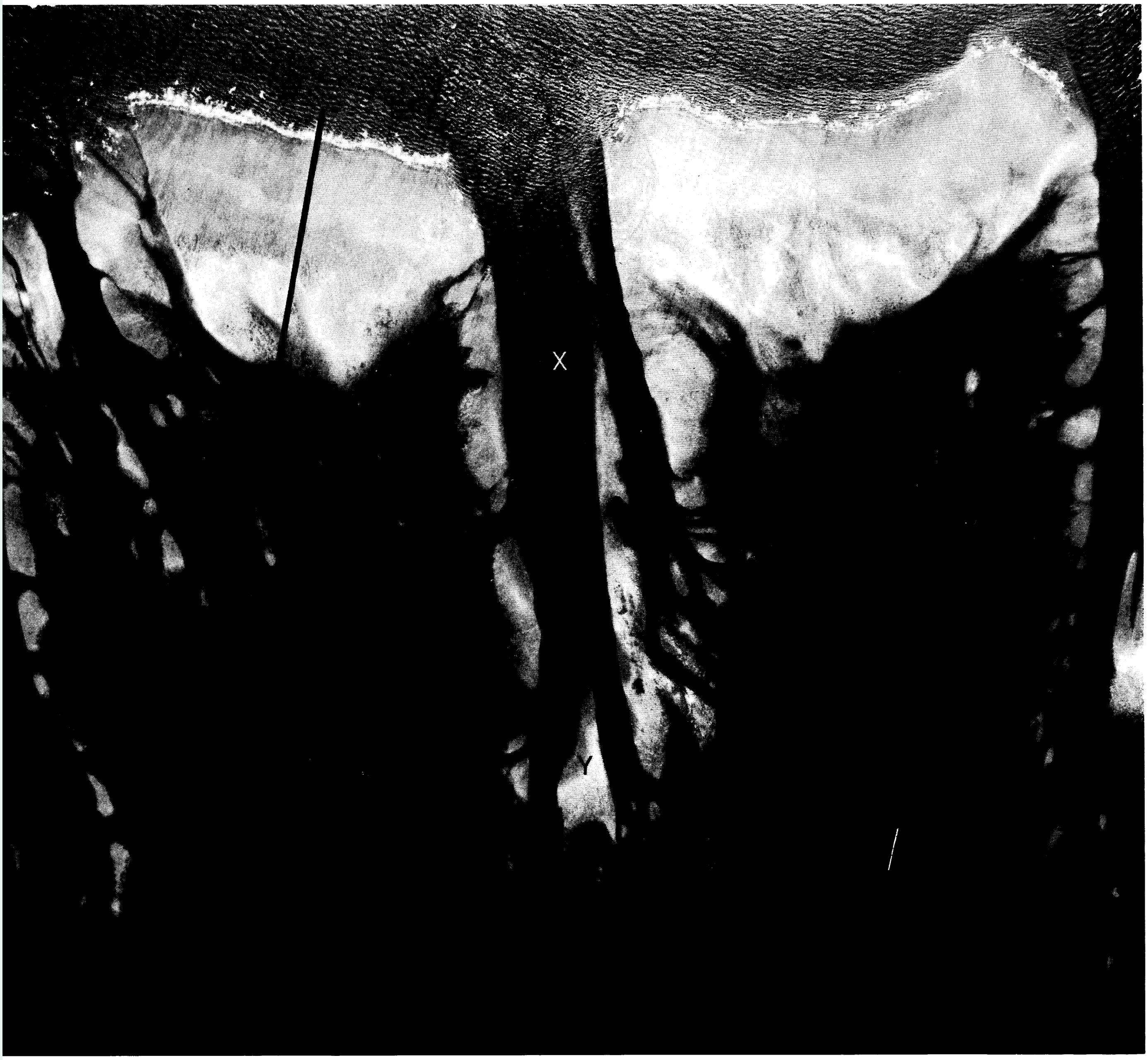

FIGURE 4. 'Deltaic reef 1', showing the position of the reef transect (figure 7). Reefs X and Y, referred to in the text and in figures 10 and 12, are indicated.

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Figure 5. 'Deltaic reef 2', showing the positions of the reef transect (figures 6 and 8) and the transect across the deltaic system (figure 9).

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The reef flat

As can be seen in figure 4, the reef flat of deltaic reef 1 is asymmetrical in shape and, like the majority of other deltaic reefs, is penetrated by irregular channels from the reef back. Figure 7 shows the correspondingly irregular profile, and indicates the nature of the reef surface and the percentage coral cover.

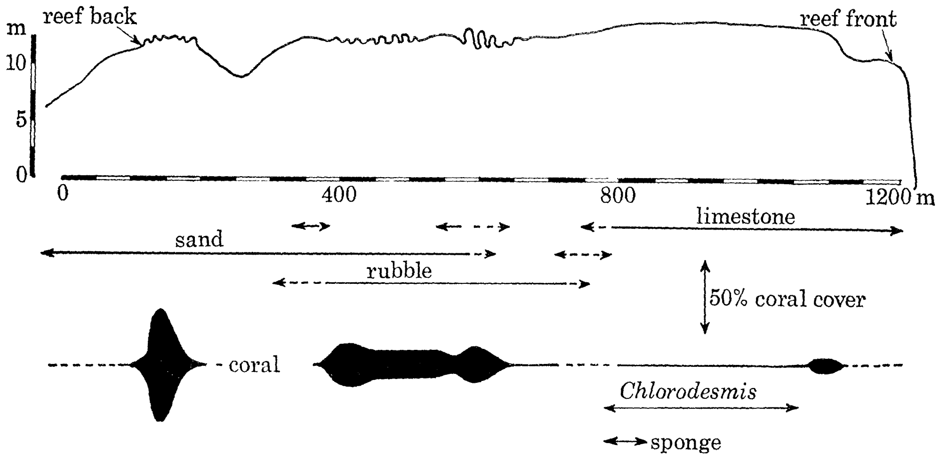

FIGURE 7. Deltaic reef 1, showing in profile the distribution of substrate type and estimated percentage cover of corals and other biota. Vertical exaggeration is 1 : 20.

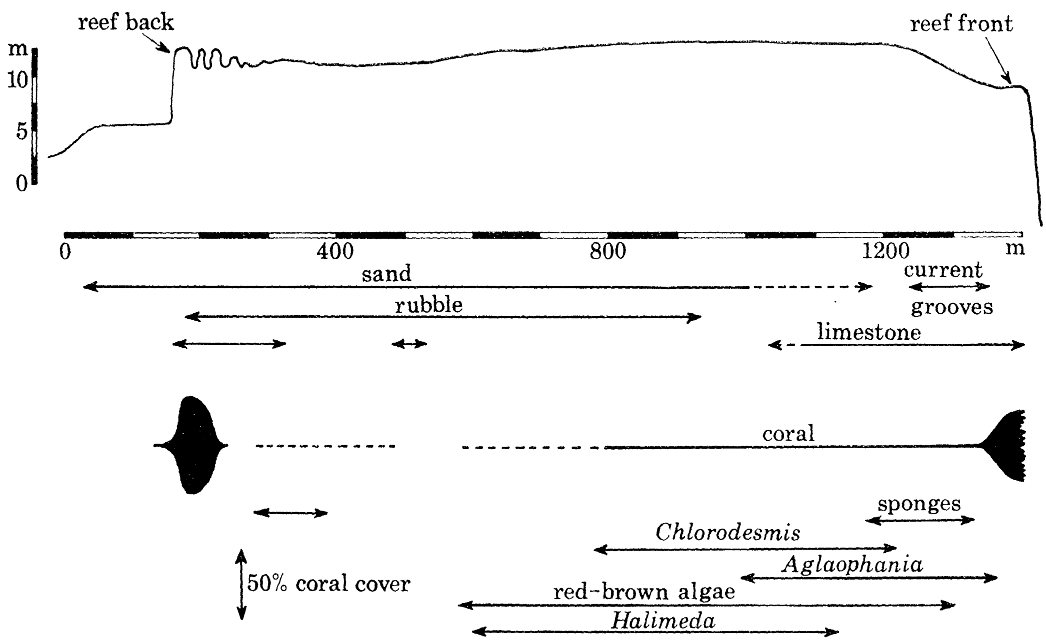

FIGURE 8. Deltaic reef 2, showing in profile the distribution of substrate type and estimated percentage cover of corals and other biota. Vertical exaggeration is 1 : 20.

The reef surface up to 120 m west of the reef front contained a series of current-worn grooves approximately 5 m apart and 15 cm deep. The surface of all the solid reef was mostly covered with close cropped filamentous algae, hydroids, occasional colonies of ramose *Millepora*, and *Acropora* spp., predominantly *A. humilis*. *Acropora palifera* was not present.

A zone of coral growth, mostly of ramose *Acropora*, occurred 570–820 m west of the reef front, *A. palifera* being dominant for the last 100 m. The substrate in this zone was mostly sand and *A. palifera* rubble. A second, narrow band of coral growth occurred at the reef back, consisting primarily of ramose *Acropora* species interspersed with large *Porites* colonies.

Deltaic reef 2 differed from reef 1 in being wider and more uniform in shape and appearance, but the surface features, as indicated in figure 8, were nevertheless essentially similar.

The outer zone of rich coral growth (described above), dominated by *A. palifera* and *A. humilis*, ended abruptly 50 m west of the reef front. Behind this zone was the area of maximum wave action when the hard substrate was carved into an irregular series of grooves 0.3–2 m deep and 30–50 m long, running perpendicular to the reef front. Algae and hydroids were the dominant cover; these decreased in abundance until, 820 m from the front, the reef appeared almost devoid of life. A brief but well defined zone of *Phyllospongia foliascens* (Pallas), with colonies evenly spaced 1–2 m apart, adjoined the coral zone at the reef back. The latter zone, visible in figure 5 was dominated by *A. palifera* and *A. humilis*, as was the coral zone of the reef front.

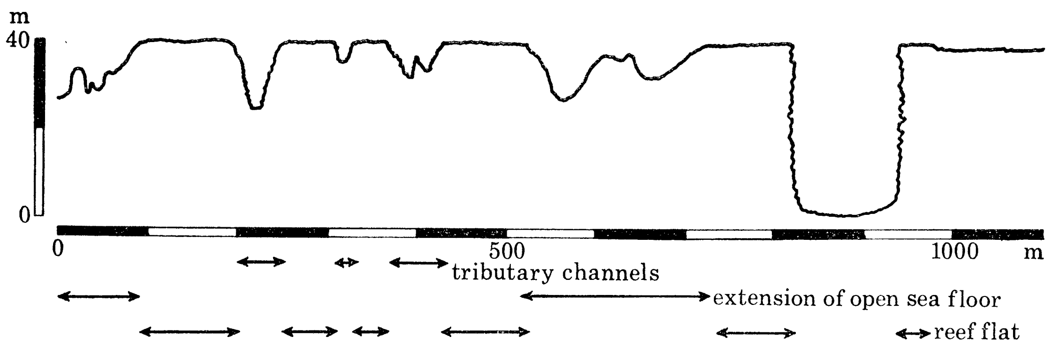

FIGURE 9. Profile of part of the deltaic system along the line indicated in figure 5 (see text). Vertical exaggeration is 1 : 5.

The deltaic system

Figure 9, compiled from direct observation using SCUBA, is a profile of the deltaic system south of deltaic reef 2 along the line indicated in figure 5.

At its northern end, the transect covered a terrain of soft calcareous sand and rubble from a depth of 18 m. The slope to the first reef flat was covered by extensive outcrops of *Acropora intermedia* (Brook) and *Porites andrewsi* (Vaughan) at depths below 3 m. Above 3 m, *A. palifera* became dominant and, with *Stylophora pistillata* (Esper), *Pocillopora verrucosa* (Ellis and Solander) and *A. humilis*, formed a coral cover of approximately 80 % of the area of the first 100 m of reef. Calcareous algae were abundant and the whole reef surface was well cemented.

Between 100 and 330 m (figure 9) were three tributary channels, respectively 50, 20 and 60 m wide. These channels had rugged, irregularly eroded surfaces of reef rock and coral debris with little or no faunal or algal cover. The upper edges of the channels were covered with corals of the species dominant on the reef flats plus thickets of *Millepora tenera* (Boschma). Their floors were covered with sand and rubble except for the small channel which had a cemented limestone floor.

Between 330 and 720 m there were two converging areas of reef flat which make up the southern and northern walls of the third tributary channel and the first main channel respectively (see figure 5). Coral cover on these flats was approximately 20 % and was dominated by *A. palifera*, *A. humilis* and *Porites lobata* (Dana), with some *Stylophora pistillata*. The reef surface was very hard and well cemented by calcareous algae. Toward the edge of the main channel the reef became corrugated by small regular grooves about 30 cm deep.

The deeper area between these reef flat areas, which represents an extension of the open sea and sea floor, was mostly flat and was covered with sand and rubble with large patches of blue-green algae and *Acropora* species.

The reef flats adjoining the main channels were similar to the first reef flat area described above. Coral cover decreased markedly with increasing distance from the channels. The transition zone between the reef flat and the deeper areas that are extensions of the open sea floor (i.e. those areas appearing dark in figure 5) was composed mainly of poorly cemented reef with approximately 5 % coral cover, dominated by *Porites* spp. and the hydroid *Agloaphania cupressina*. Below approximately 6 m the reef surface became covered with soft calcareous sand and an almost continuous, although sparse, cover of *A. formosa* (Dana).

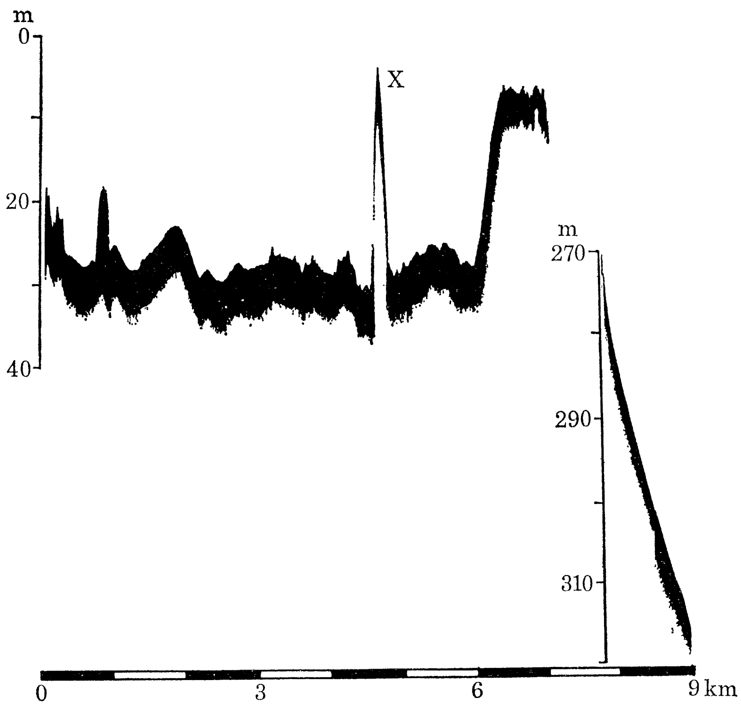

FIGURE 10. Echo sounding down the channel south of deltaic reef 1. Reef X is indicated in figures 4 and 12 (see text). Vertical exaggeration is 1 : 134.

The major channels

The major channels reaching the reef front are mostly uniform in size and general appearance. Those of the northern half of the deltaic system are up to 0.7 km across and 5.5 km long. Further south the channels become wider and shorter and the deltaic pattern less distinct.

Depth soundings taken along the centre of four channels (one channel south of deltaic reef 1,

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two south and one north of reef 2) indicated that their depths were mostly uniform throughout their length with an overall range of 18–35 m.

The sounding south of reef 1, reproduced here as figure 10, is characteristic. At the outer edge of each channel was a ridge connecting the two adjacent outer slopes. The ridge was saddle-shaped with the axis of the saddle lying along the reef front. Figure 3 gives an impression of the ridge as determined from soundings, from observation from small boats and from Scuba diving on the ridge.

Tidal currents in the channel were very strong, especially within 2–3 h of low tide when little water movement occurs over the reef surface. One estimate of 3.8 m/s was made from the *James Kirby* while maintaining a constant position inside the outer ridge on an ebb tide. On the ridge itself the current forms standing surface waves up to approximately 2 m high. These waves are visible in figure 5 where they are seen to extend as finger-like projections from the channels for distances of up to 1.7 km.

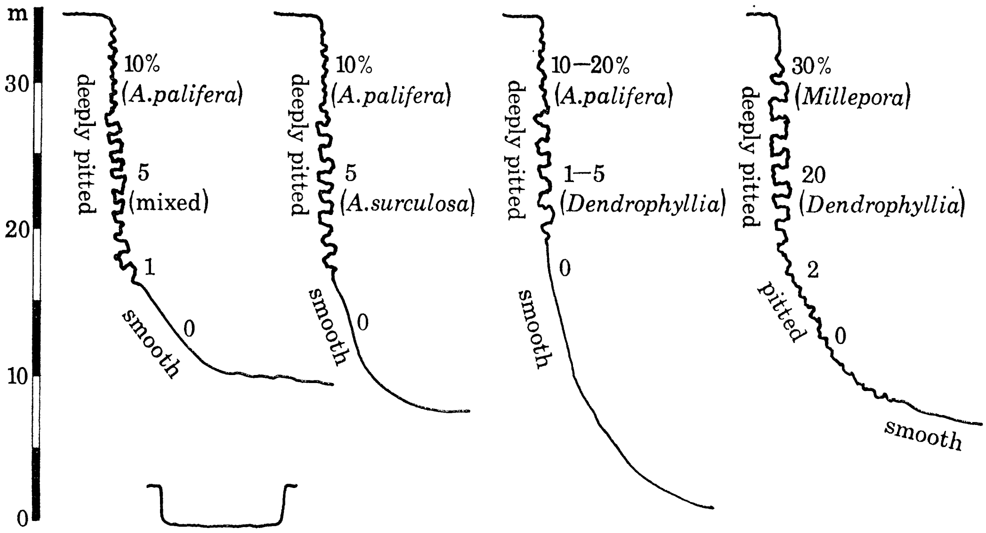

Figure 11. Surface features and shapes of the walls of different major channels. The dominant corals and percentage cover are indicated. Inset: the general shape of major channels shown without vertical exaggeration.

The surface of the outer ridge was hard and well cemented. To a depth of approximately 7.5 m about 60 % of the surface was almost exclusively covered with flat, encrusting *A. palifera* colonies which gave the appearance of a flat, irregular pavement. Mixed coral species then occurred to a depth of 12 m, at which point the coral cover was approximately 10 %. Between 12 and 21 m (on the front of the outer ridge) the coral cover decreased to $< 1\,\%$; soft corals, especially *Lobophytum*, were dominant. Only occasional corals, mainly faviids, were found below 21 m; the still hard substrate had a sparse cover of filamentous red–brown algae, filamentous green algae, *Halimeda* and fine hydroids.

Various profiles of major channels are compared in figure 11. In each case the walls descended vertically to a depth of 12–19 m, then curved in a regular fashion to form the channel floor at depths of approximately 25–33 m. The vertical walls were always deeply pitted; sometimes the pits were in the form of horizontal, current-worn grooves up to 2 m deep. The curved part of the channel walls were mostly slightly pitted or smooth. The flat channel floors were mostly smooth and hard; in some places regular current worn undulations were formed, in others, ridges of coarse sand and or rubble.

Small, elongate reef patches frequently occurred in the centre of major channels. Figures 3 and 10 show these reefs in lengthwise profile. Their bases were much more elongate than their tops, so much so that the bases of successive reefs appeared to connect to form a central ridge running along much of the centre of most major channels. Figure 12 is a N–S profile across the middle of one such patch, 925 m long at the surface, indicated in figure 4. The reef appeared to be completely symmetrical and to have walls essentially similar to the walls of the major channels.

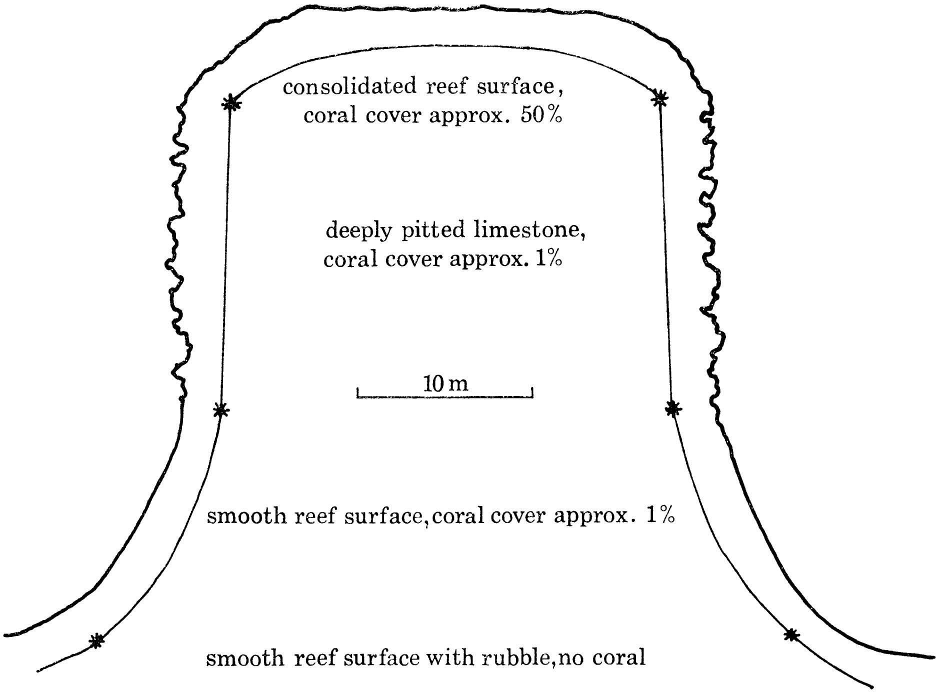

Figure 12. Profile across reef X, shown in figures 4 and 10.

A second type of reef frequently occurred at the backs of major channels where they branched into small channels leaving roughly triangular reefs with sharply defined apices pointing east, and irregularly shaped inner slopes.

The apex of reef Y (figure 4) is similar to the eastern point of reef X (figure 4). It gradually sloped to a depth of 31 m. To a depth of 2 m, the coral cover was approximately 10% and consisted almost exclusively of *A. palifera*. The coral cover increased to approximately 60% at 2–10 m depth with encrusting species of *Millepora* and *Porites* becoming dominant. At 10–18 m the consolidated reef gave way to rubble at which point soft corals, especially *Lobophytum*, became dominant. Few hard corals were observed below 26 m.

The western side of reef Y (figure 4) is well protected from wave action and currents and is essentially similar to the backs of the major reefs. The floor consisted of soft calcareous sand which sloped gently to a depth of 7.5 m, 170 m from the centre of the reef back. Very large massive *Porites* spp. and *P. andrewsi* colonies, visible in figure 4, occurred between approximately 50 and 170 m. Beyond 170 m from the reef back the depth increased and the substrate became a coral-free mixture of sand and rubble.

The dissected reefs

The dissected reefs, as noted above, extend northward from the northern limit of the deltaic reefs for a distance of approximately 35 km. Over this range they become progressively simplified in appearance, so that toward their northern end (figures 13 and 14) they resemble a continuing series of small elongate plug reefs.

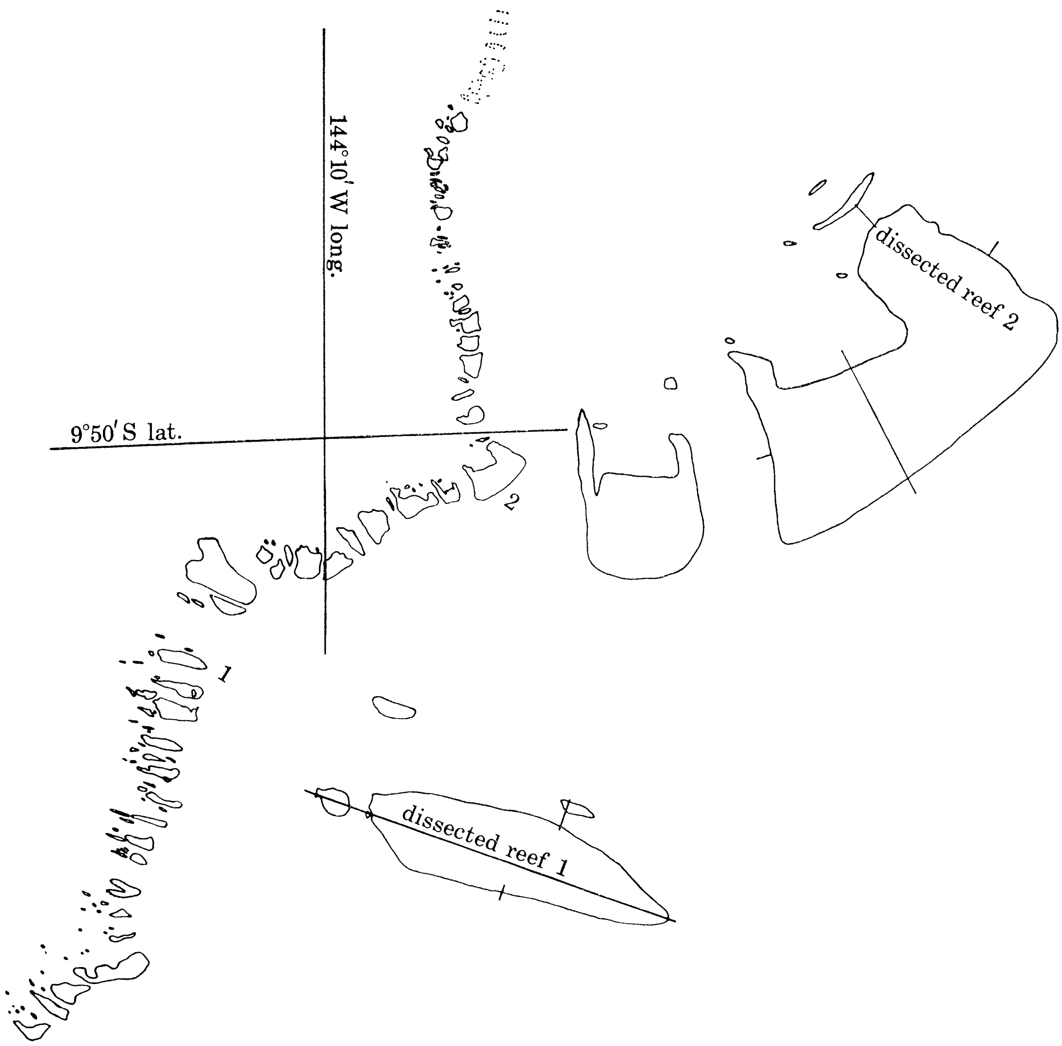

Figure 13. The northern dissected reefs and (insets) the two dissected reefs studied, showing positions of transects referred to in the text.

Two reefs indicated in figure 13, here called 'dissected reef 1' and 'dissected reef 2', were selected for study. They both lie eastward of the Murray Islands and have approximate latitudes of 9° 53′ S and 9° $50\frac{1}{2}$′ S respectively. Reef 2 is the northernmost major reef of the barrier system; reef 1 is a small elongate reef which is more representative of other reefs in the area.

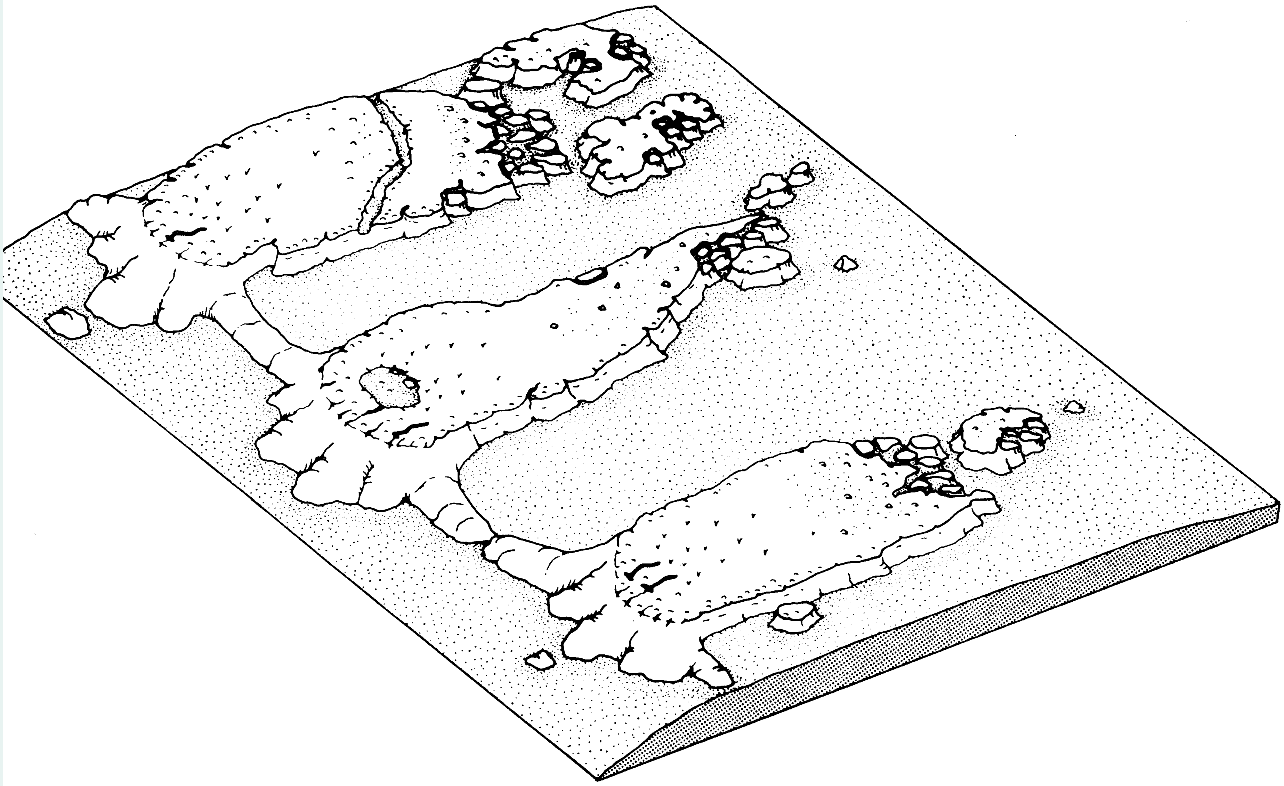

FIGURE 14. Three-dimensional reconstruction of a section of dissected reefs, showing the approximate spatial relation of features referred to in the text.

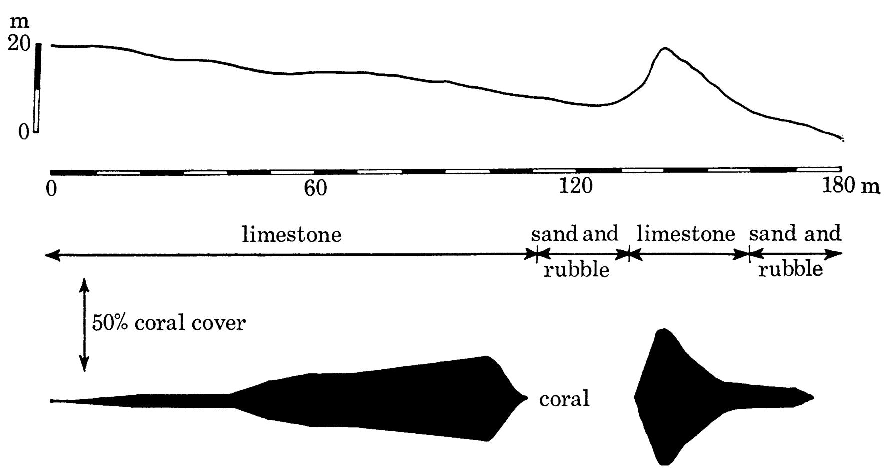

FIGURE 15. The outer slope of dissected reef 1, showing in profile the distribution of substrate type and estimated percentage cover of corals. No vertical exaggeration.

The reef front

The front of dissected reef 1 (figure 15) had a very gradual slope. At 6 m depth it was poorly cemented and had a coral cover of approximately 5 %. At 9 m the face became horizontal and the coral cover increased to 30 %. *Acropora palifera* was the dominant species and (unusual for an outer reef face) *Goniopora* was also abundant. At 12 m the coral cover reached about 50 %

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but ended abruptly in a small valley of sand and rubble at 15 m. At 100 m from the crest there was a slight elongate ridge rising to 14 m depth and densely covered with coral, again mostly *A. palifera*. At greater distance the coral gradually gave way to sand and rubble, the last corals, of very mixed genera, occurring at a depth of 21 m.

The front of reef 2 was only very briefly observed. Corals were abundant near the surface but were largely replaced by sand and rubble at depths greater than 10 m.

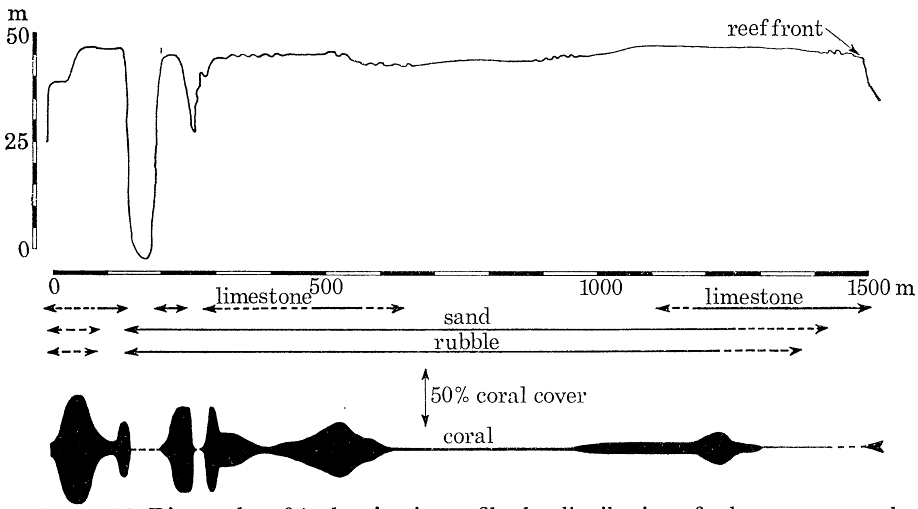

FIGURE 16. Dissected reef 1, showing in profile the distribution of substrate type and estimated percentage cover of corals. Vertical exaggeration is 1 : 20.

The reef flat

As figure 16 shows, there was no clearly delineated reef front, nor was there any marked development of spur and groove formation in dissected reef 1. Most of the reef face consisted of dead coral cemented by calcareous algae. Shallow drainage grooves with smooth surfaces about 1 m across were common. The coral cover remained at 1 % or less and consisted almost entirely of *Acropora* species, especially *A. palifera* and *A. humilis*. Dead colonies up to 11 cm high were frequently observed to within 80 m of the front. Clumps of *Xenia*, 2–30 cm diameter, and patches of sparse, filamentous algae, were the only other biota observed.

The consolidated reef surface began to be pitted about 220 m west of the reef front and at 270 m contained valleys 60 cm deep with flat sandy floors. Between 270 and 350 m the coral cover consisted almost exclusively of *A. palifera* which increased to as much as 30 % then decreased again as the area of eroded reef, filled with sand and rubble, increased. *Acropora palifera* cover increased again at about 950 m from the reef front, reaching 50 % cover at 1000 m. At 1050 m, *A. humilis* replaced *A. palifera* as the dominant species and, apparently as a result, the area of consolidated reef greatly decreased. The reef flat remained a varied mixture of *Acropora* species, especially *A. humilis*, and rubble, until the lush coral of the reef back margin was reached.

Dissected reef 2 had a more clearly defined front and a greater coral cover than had dissected reef 1 (figure 17). Again, there was little development of spur and groove formation. Behind the front the reef flat was well consolidated and had the drainage grooves noted above. The coral cover decreased rapidly until, 130 m west of the reef front, it reached zero. Small clumps of *Xenia* and small amounts of algae occurred to about 80 m. The reef flat between 130 and

250 m west of the reef front, which consisted only of flat, hard limestone, was almost devoid of visible life.

At 250 m the limestone gradually became covered by sand along with a varied biota dominated by small spherical coral colonies. At 310 m the reef flat was exclusively sand and rubble with a coral cover of 1–5 %, consisting mostly of *Acropora* series dominated by *A. humilis*. Small valleys with sandy floors started to occur at 430 m, getting wider and deeper as the depth of the reef surface started to increase. At 580 m the reef surface consisted of extensive areas of dead and living *A. palifera*, penetrated by vertical-sided valleys averaging 2 m deep and 10 m wide. Towards the reef back the surface was variable in depth and consisted of irregular patches of *A. humilis* or *A. palifera* dominated reef and valleys of sand and rubble. The reef back margin occurred abruptly at 650 m.

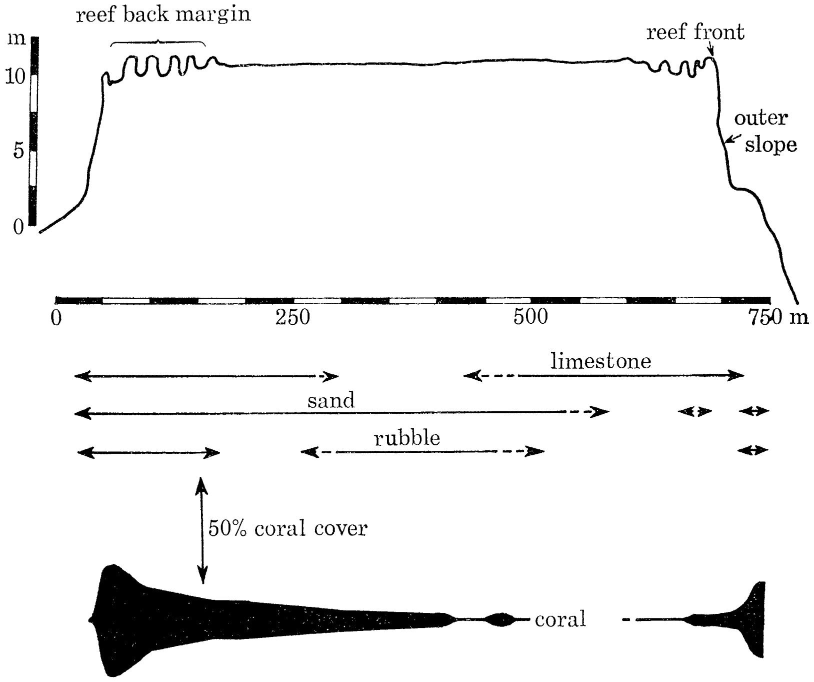

FIGURE 17. Dissected reef 2, showing in profile the distribution of substrate type and estimated percentage cover of corals. Vertical exaggeration is 1 : 20.

The reef back margin and sides

Change in coral cover with depths at the reef back margin of dissected reef 1 is illustrated in figure 16. At 1220 m west of the reef front *A. hyacinthus* became the dominant species and was combined with large colonies of *Porites* species and many other *Acropora* species at the edge of the reef back. The small reef patch indicated in figure 13 was separated from the main reef by 90 m of sand and coral rubble reaching a depth of 21 m. The eastern edge of the reef patch was mostly composed of *A. palifera* which was largely replaced by *A. humilis* toward the centre. Coral cover at the western edge reached 100 % and consisted mostly of ramose *Acropora* species. This zone ended abruptly at 10 m depth when the reef edge became nearly vertical. The ahermatypic coral, *Tubastrea micranthus* (Ehrenberg), was abundant to a depth of 27 m, at which point the reef face became submerged in sand and rubble.

The south side of dissected reef 1 sloped downward at a constant angle of about 45° to reach the sea floor at 32 m depth. The floor was mostly composed of *Acropora* and free-living fungiid corals, especially *Fungia fungites* (Linnaeus), *F. echinata* (Pallas) and *Halomitra* sp. The upper 10 m of the reef edge had a coral cover of up to 80 %, with ramose *Acropora* species dominant.

The reef face of the north side was similar in appearance. A sandy floor was reached at 17 m. There were two elongate ridges of limestone elevated approximately 3 m between the small reef strip, shown in figure 13, and the main reef. The water depth near the reef strip reached 21 m.

The reef back of dissected reef 2 in the line of the transect is similar to that of reef 1. The reef face sloped steeply to 11 m where it became submerged in sand. Between 11 and 18 m depth, the floor consisted of very irregular patches of sand, rubble and eroded limestone. An almost horizontal sea floor of sand and rubble occurred at 18 m.

The reef back margin at the centre of the northern wing sloped steeply to a sand and rubble sea floor at 37 m. Coralline algae and *A. palifera* dominated the upper 11 m, at which depth the coral cover rapidly decreased to less than 1 %. The northern side of the reef was essentially similar except that the reef face was vertical to 37 m. The southern side of the reef was very similar to the southern side of dissected reef 1 with sand and rubble being encountered at 18 m.

Discussion

The differences between the ribbon reefs described in the first paper of this series and the reef systems described in this paper appear to have both a bathymetric and a hydrodynamic origin. The deltaic and dissected reefs are basically extensions of the shelf edge reef system occurring beyond the influence of the Queensland Trench. They do not form the western rim of the trench as do the ribbon reefs and hence their outer faces do not plunge to great depth. Perhaps as a result they do not have the deep openings and passes which separate most successive ribbon reefs and which permit the passage of the tidal currents to and from the continental shelf. They form an effective barrier 131 km long to tidal movement. However, tidal range, which is uniformly near minimal for the Great Barrier Reef (G.B.R.) throughout the whole distance of the ribbon reef system, increases rapidly towards the Torres Strait (Maxwell 1968); so does the volume of water involved, as the continental shelf widens over the area of the Torres Straight and the western Gulf of Papua. These factors combine to produce the very strong tidal currents characteristic of the whole Torres Strait region.

Clearly, the northern barrier reefs, which provide such a formidable obstacle to tidal movements, have their present morphologies largely determined by them. This applies especially to the deltaic reefs, where the barrier continues both to the north and south.

Reefs of the Pompey Complex in the Southern Region of the G.B.R. have been described by Maxwell (1970) as being 'deltaic', and certainly that term can be applied equally to both reef systems. Both are characterized by the presence of well defined channels containing very strong tidal currents. As Maxwell stated, the currents serve to scour the passages while the reef body serves to localize depositions which provide bathymetric elevations suitable for reef colonization.

In other respects, however, the Pompey Complex differs greatly from the northern reefs, primarily in being composed of a multitude of enclosed and semi-enclosed lagoons interspersed through a matrix of channels, reef zones of varying elevations and sand zones. Brief personal observation indicates that the major channels are not as steep-sided as those of the northern reefs; those investigated were asymmetrical, having western walls steeper than eastern ones, with currents running obliquely to them, over the reef flat. The single channel sounded had a relatively uniform depth of 98–109 m throughout its central portion (i.e. about three times the depth of the northern reefs), and a very wide outer region rising to a relatively uniform 32 m. Soundings perpendicular to, and parallel with, the outer reef face revealed a broad continental slope scoured to about twice normal depth seaward of the openings of major channels.

No other reef systems within the G.B.R. province appear to have much in common with those described in this paper. None have similar bathymetric or hydrodynamic situations, nor have other reefs had a comparable evolutionary history. It is these three all-important factors, in combination, which have given the northern barrier reefs their present distinctive morphologies. The third factor, the evolution of the reefs, is discussed in the third paper (Veron 1978, this volume).

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FIGURE 4. 'Deltaic reef 1', showing the position of the reef transect (figure 7). Reefs X and Y, referred to in the text and in figures 10 and 12, are indicated.

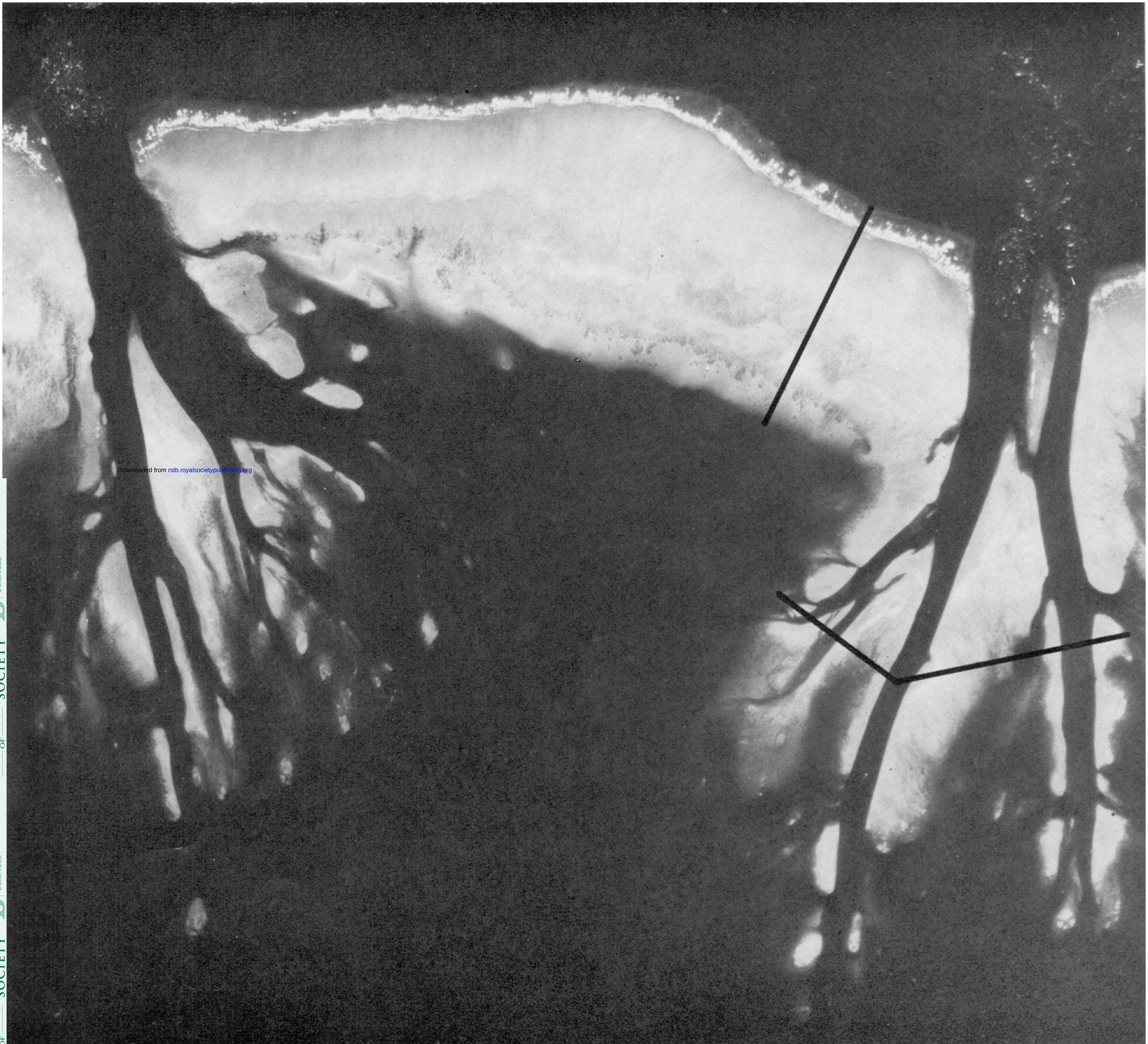

FIGURE 5. 'Deltaic reef 2', showing the positions of the reef transect (figures 6 and 8) and the transect across the deltaic system (figure 9).

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