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THE FORMATION OF THE GREAT BARRIER REEF

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It is a modern myth that research on the Barrier Reef has left few problems to solve. In spite of its geological uniqueness, and its immense size, geological research in the Great Barrier Reef has been limited to only a few areas and has been conducted by only a few scientists. What then are we doing writing on the formation of the Great Barrier Reef? Fragmentary geological research has in fact been conducted in various parts of the Reef, much of it summarized in the inspiring work of Maxwell (1968). The present contribution is an attempt to update this work, so that the reader can assess just how much is still to be done.

The Great Barrier Reef has existed for millions of years. The present reefs are just one frame on a moving film, a film that has rolled for a very long time. How and when did the Barrier Reef form? How old are the reefs we see today? These are the questions that are occupying those few scientists who work on the Barrier Reef, and for which the present report provides only partial answers.

The Origin of the Great Barrier Reef - How and When?

The Barrier Reef occupies 74 000 km^2 of the 286 000 km^2 of the Queensland continental shelf and therefore forms an integral part of the continental edge, the origin of which is linked to the origin of the whole of the southwest Pacific. The major present-day features of the southwest Pacific, their relation to the Queensland continental shelf, and the distribution of important geological elements of the shelf are shown in Fig. 1. The principal events which moulded the general outline of eastern and southern Australia occurred between 80 and 50 million years ago. The Tasman Sea formed when rift faulting along a north to south line separated Australia from a landmass farther to the east. Only slightly later the Coral Sea Basin and the Southern Ocean were formed by similar processes of rift faulting and sea floor spreading. The birth of the Coral Sea Basin and the Tasman Sea had long lasting effects on the development of the Queensland continental shelf. As a direct result of the rifting and spreading in the Coral Sea Basin, immense tensional forces affected the adjacent landmass to the west (Fig. 2A & B), resulting in unequal subsidence, and the formation of marginal plateaux like the Queensland and Marion Plateaux (Fig. 1B, & 2C). The sinking of the Queensland Plateau drastically affected the mainland. A major north to south tension fault system developed between it and the mainland, the Queensland Trough occupying the area between. The margin of the Queensland continental shelf adjacent to the Queensland Trough is therefore faulted.

The effects of the opening of the Tasman Sea on the development of the southern Barrier Reef are less clear. One important suggestion is that the Capricorn Basin (Fig. 1B) forms the northern inactive extension of the rift system which lead to the opening of the Tasman Sea (Marshall - in press), the Bunker and Swains Highs forming the margins to the slowly sinking northern end of the rift system. Be that as it may, it is likely that by 50 million years before present (B.P.), the general outlines of the Queensland continental shelf had been sculptured (Fig. 2C) and the scene set for corals to invade, spread and build the Great Barrier Reef. This did not occur immediately, however. Fragmentary evidence from drill holes in the southern and northern Barrier Reef (Fig. 3) indicate that coral reefs started to grow only 18 million years ago throughout the area, but the earliest

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growth on the Queensland Plateau is dated at 60-25 million years B.P. Fig. 3 also indicates how the Bunker High and Capricorn Trough have affected the growth of coral reefs in the last 18 million years, while Fig. 1A & B shows the dependence of reef growth on these structural highs at the present time. While boreholes 2, 3, and 4 (Fig. 3) show reef growing since 18 million years, borehole 1 at Heron Island shows that reefs have existed there only during the last one million years. Parts of the Bunker High may therefore have been above sea level for a long time prior to one million years ago.

The Present-Day Reef System - How Old are the Reefs?

Earth history in the last million years has had an enormous effect on the growth of the Great Barrier Reef. From 1 million to 15 000 years ago, icecaps intermittently covered large areas of the Earth's surface. The last major glaciation (Wisconsin) lowered sea level more than 100 m below present level, and ended about 15 000 years B.P. No Barrier Reef could therefore have existed on the Queensland shelf if sea level was at -100 m. The present Barrier Reef must therefore be quite young, as it could only have formed after the sea level rose since 15 000 B.P. The data in Fig. 3 show that reefs started to grow 18 million years ago, so it is sensible to conclude that the Wisconsin lowering of sea level exposed previously formed limestone reefs to the rigors of subaerial erosion. Attacked by sun, wind, and rain, such a limestone surface would have developed a distinctive 'karst' topography similar to that seen in limestone areas today. Present-day reefs are therefore likely to be growing on a karst surface which was flooded during the rise in sea level after the Wisconsin Glaciation. Such a surface has been recognized below Heron Island (Davies, 1974) at a depth of -20 m, and probably underlies the whole of the Barrier Reef at about this depth. The history of the rise in sea level after the melting of the Wisconsin icecaps has been traced in eastern Australia by Thom & Chappell (1975) and is shown in Fig. 4. It can be seen that sea level was at -20 m, the lower limit for coral growth, only about 9 000 years ago. The immensity and diversity of this structure we call the Great Barrier Reef has resulted from growth in only 9 000 years, a very short time span in the geological time scales we have previously discussed. It is clear however that erosion of limestone surfaces at the present day produces surfaces of variable relief and shape, so this must also have occurred in the past. The -20 m platform is therefore sure to exhibit some variations in relief and shape, both of which must ultimately affect the ensuing growth of reefs. Other important factors also contribute, and they are factors about which even less is known. The rates of coral and reef growth and their relations to changing sea levels are factors which must play a major role in determining the present morphology of reefs. Valuable work has been conducted at One Tree Reef, by Kinsey (1972) in determining present day growth rates (Fig. 5). His potential upward reef growth rate of 3.1 mm per year agrees well with postulated figures for past growth rates by Chappell & Polach (1975). The physiography and geological development of One Tree Reef has also been studied by the author and colleagues within the Bureau of Mineral Resources. One Tree Reef is the only reef where long-term geological/biological studies have progressed so that the combined data may be used to unravel the historical development of the reef, and act as a model for the rest of the Great Barrier Reef.

A section across One Tree Reef, compiled from bathymetric surveys and scuba investigations (Fig. 6-1), shows the reef growing on

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a platform which varies in height from -10 to -25 m. A 15-m cliff occurs on the south side, between -20 m to -25 m. Sea level reached this platform by around 9 000-9 600 B.P. (Fig. 6-2) and rose to the -10 m level by 7 800 B.P. Using a growth rate of 3.1 mm per year, a maximum vertical reef growth of 3.6 to 5.6 m would have occurred (Fig. 6-2). Though sea level reached its present position by 6 200 B.P., coral reef growth could have started on the -10 m platform at 7 800 B.P., so that between 7 800 and 6 200 B.P. 4.8 m of reef growth would have occurred on the -10 m platform (Fig. 6-3). Growth on this platform would then have reached the position of present sea level by about 4 400 B.P. (Fig. 6-4) while growth from the -20 m to -25 m platform would reach sea level much later, probably sometime between 1200 and 2500 B.P. A number of lessons can be learned from the above analysis. First, the depth of the growth platform determines the time at which the growing reef reaches present-day sea level. Secondly, this places constraints on the degree of reef modification by wave action in the shallow-water environment. At One Tree Reef, the development of the island and lee side accretion must postdate the time at which growth from -10 m platform reached sea level, viz. 4 400 B.P. (Fig. 6-5).

The relevance of the One Tree story to the rest of the Great Barrier Reef may be gauged by an analysis of bathymetric data surrounding other reefs. For example, Fig. 7 shows the relations of Arlington, Upolo, Oyster, and Michaelmas Reefs to the 17-m isobath. All the reefs appear to be located on a platform at around -17 m, which bears out previous conclusions (Davies, 1974) that a karst erosion surface forms the growth platform for Michaelmas Cay. It is clear from such evidence that the reefs of the Great Barrier Reef have all probably grown from such a platform, but one which varies in depth

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because of karst erosion. The different morphologies of different reefs is therefore due to the relations between the depth of the platform, reef growth, and the time when dominantly vertical growth was succeeded by lateral growth and modification.

Conclusions

The Barrier Reef has grown on the Queensland continental shelf, a feature which came into existence 50-60 million years ago as the result of continental drift, seafloor spreading, and tensional subsidence. Coral reefs began to grow 18 million years ago. The present-day reefs owe their shape and size to the depth and shape of the Pleistocene karst surface off which they have grown, and are only 8-9 000 years old. This magnificant present-day structure which we call the Great Barrier Reef has therefore grown in a very short period of time, and is probably only one of many Barrier Reefs that have existed in the area for the past 18 million years.

And Where to Now?

The Barrier Reef story is largely speculative, and has been pieced together from fragmentary evidence. The current climate of ultra conservative conservationism is stifling further research. A full understanding of its development requires integrated geological and biological studies of the problems. Deep boreholes are necessary to elucidate its early structural history while shallow holes to only 20 m will unravel the late Pleistocene to Recent story. That such information is equally important to biologists as well as geologists is not widely recognized. The growth rate studies of Kinsey together with the geological studies at One Tree, and the sea level extrapolations of Thom & Chappell place constraints on the maximum amount of biological evolution and rates of genetic change. Why are some coral islands luxuriously vegetated while others are bare? Why are various fish faunas peculiarly restricted to different parts of reefs and often to different reefs? How important is the widely reported Crown of Thorns starfish infestation in the story of the Great Barrier Reef? Could at least some of the answers to these problems lie in recognition of the stage of development which a reef has attained? Does not the starfish infestation pale into insignificance when viewed against the phenomenally rapid growth of the whole of Barrier Reef, as we know it today? Answers to such problems will only be found when viewed as a multi-disciplinary attack within a three-dimensional framework. Only then may someone write a definitive story about Australia's greatest heritage.

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Fig. 1 A. Bathymetry of part of the southwest Pacific adjacent to the Great Barrier Reef.

B. Principal morphologic zones in that part of the southwest Pacific adjacent to the Great Barrier Reef. Three important continental shelf structures: The Swains and Bunker Highs and the Capricorn Basin occur in the southern Great Barrier Reef. The margin of the northern Great Barrier Reef is faulted. (Modified after Mutter 1973)

Fig. 2 A. Relations between land and sea in the southwest Pacific 70-80 million years ago.

B. Generalized picture of the tectonic picture between 60-70 million years ago.

C. Relations between land and sea in the southwest Pacific 50-60 million years ago. (Modified after Pinchin & Hudspeth 1974)

Fig. 3 Bore holes on the Great Barrier Reef. The relationships of four boreholes in the southern Great Barrier Reef to the postulated underlying structure in shown. Reef growth began at about 18 million years ago in Wreck, Capricorn, Aquarius and Anchor Reefs. (Modified after Maxwell 1973, Lloyd 1973)

Fig. 4 The position of sea level in Eastern Australia over the last 10 000 years. The depth of sea level and the time at which it was at that depth can be read off the X and Y co-ordinates. (Adapted after Thom & Chappell 1975

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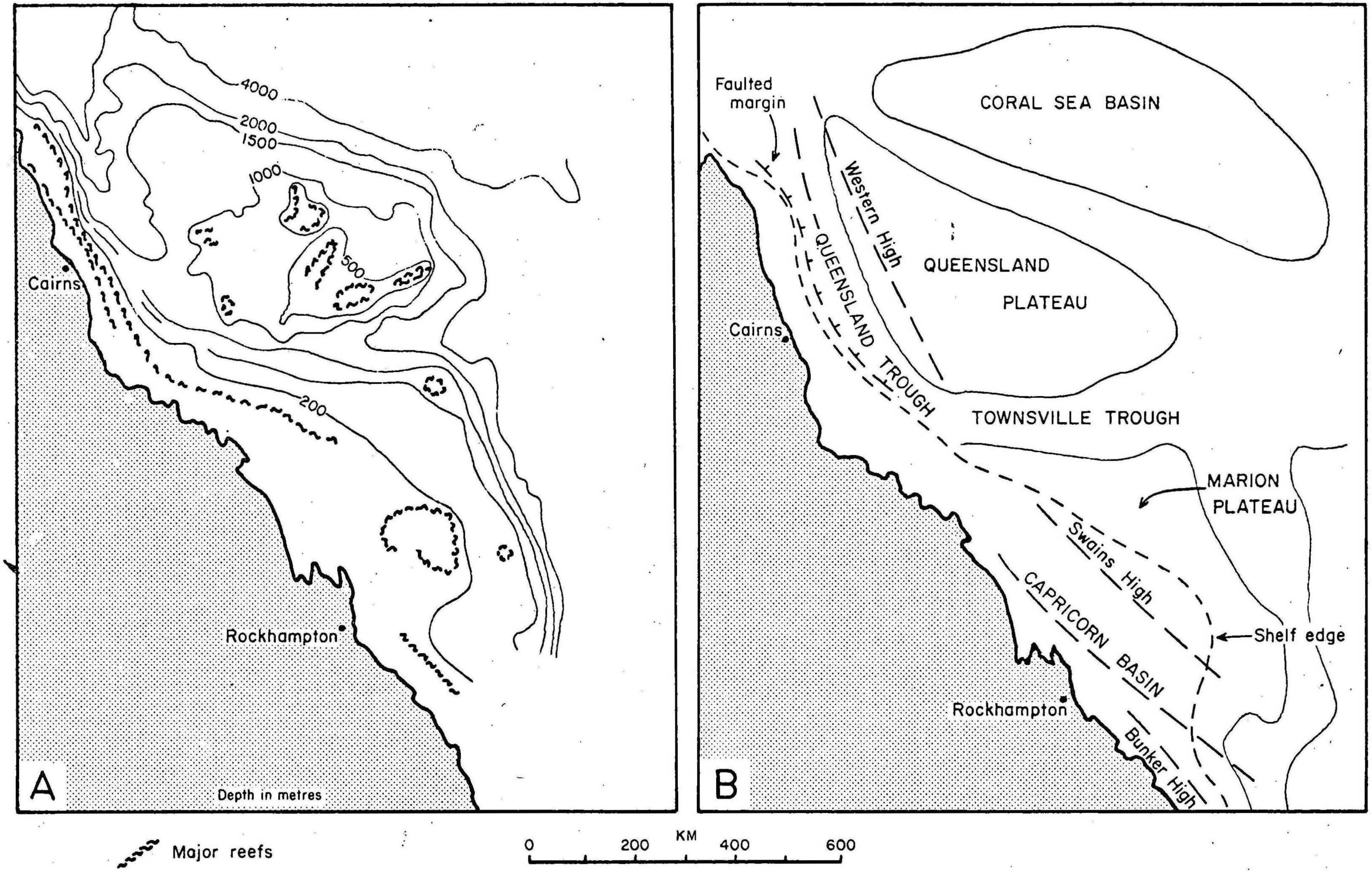
Fig. 5 A. Major morphological and sedimentary features of One Tree Reef. Most of the northwestern side of the Reef has grown since 4 400 BP. The Bathymetric Section A–B is that shown in Fig. 6.

B. Air photograph of One Tree Reef which occurs in the southern Barrier Reef in latitude 23°30'S, longitude 152°06'E.

Fig. 6 Bathymetric Section across One Tree Reef along a section A–B, and its development since about 9 600 B.P.

1. Present-day configuration.
2. Between 9 600 – 7 800 B.P.
3. Between 7 800 – 6 200 B.P.
4. Between 6 200 – 4 400 B.P.
5. From 4 400 – present day.

Fig. 7 The relation of some reefs in the northern Barrier Reef to the bathymetry of the area in which they grow.



4000
2000
1500
1000
500
200
Cairns
Rockhampton
A
Depth in metres
Faulted margin
CORAL SEA BASIN
Western High
QUEENSLAND PLATEAU
QUEENSLAND TROUGH
Cairns
TOWNSVILLE TROUGH
MARION PLATEAU
Swains High
CAPRICORN BASIN
Shelf edge
Rockhampton
Bunker High
B
Major reefs
0
200
KM
400
600

3

FIG. 1

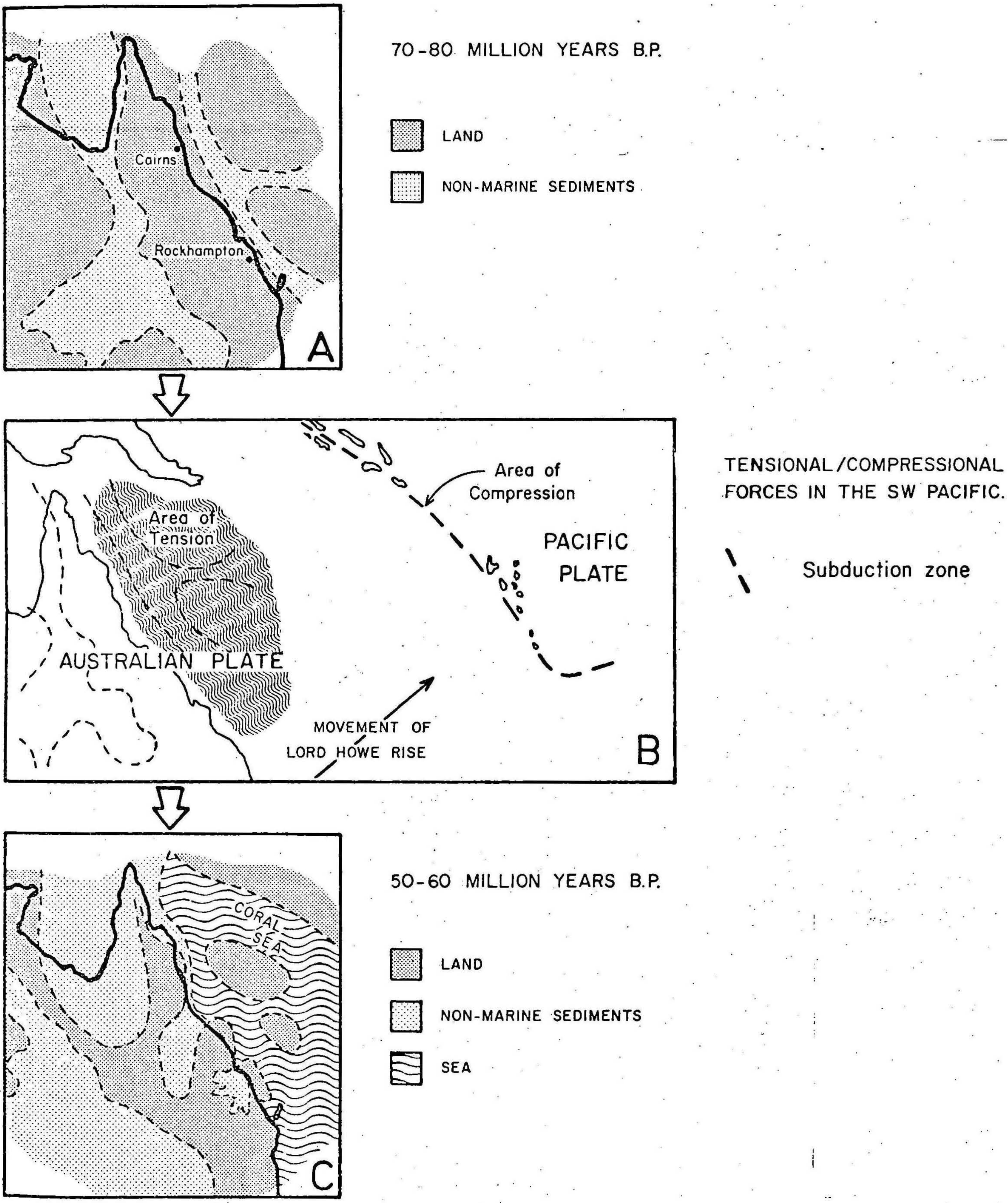

70-80 MILLION YEARS B.P.
LAND
NON-MARINE SEDIMENTS
Cairns
Rockhampton
A
Area of Compression
Area of Tension
PACIFIC PLATE
AUSTRALIAN PLATE
MOVEMENT OF LORD HOWE RISE
B
TENSIONAL/COMPRESSIONAL FORCES IN THE SW PACIFIC.
Subduction zone
CORAL SEA
C
50-60 MILLION YEARS B.P.
LAND
NON-MARINE SEDIMENTS
SEA

FIG. 2

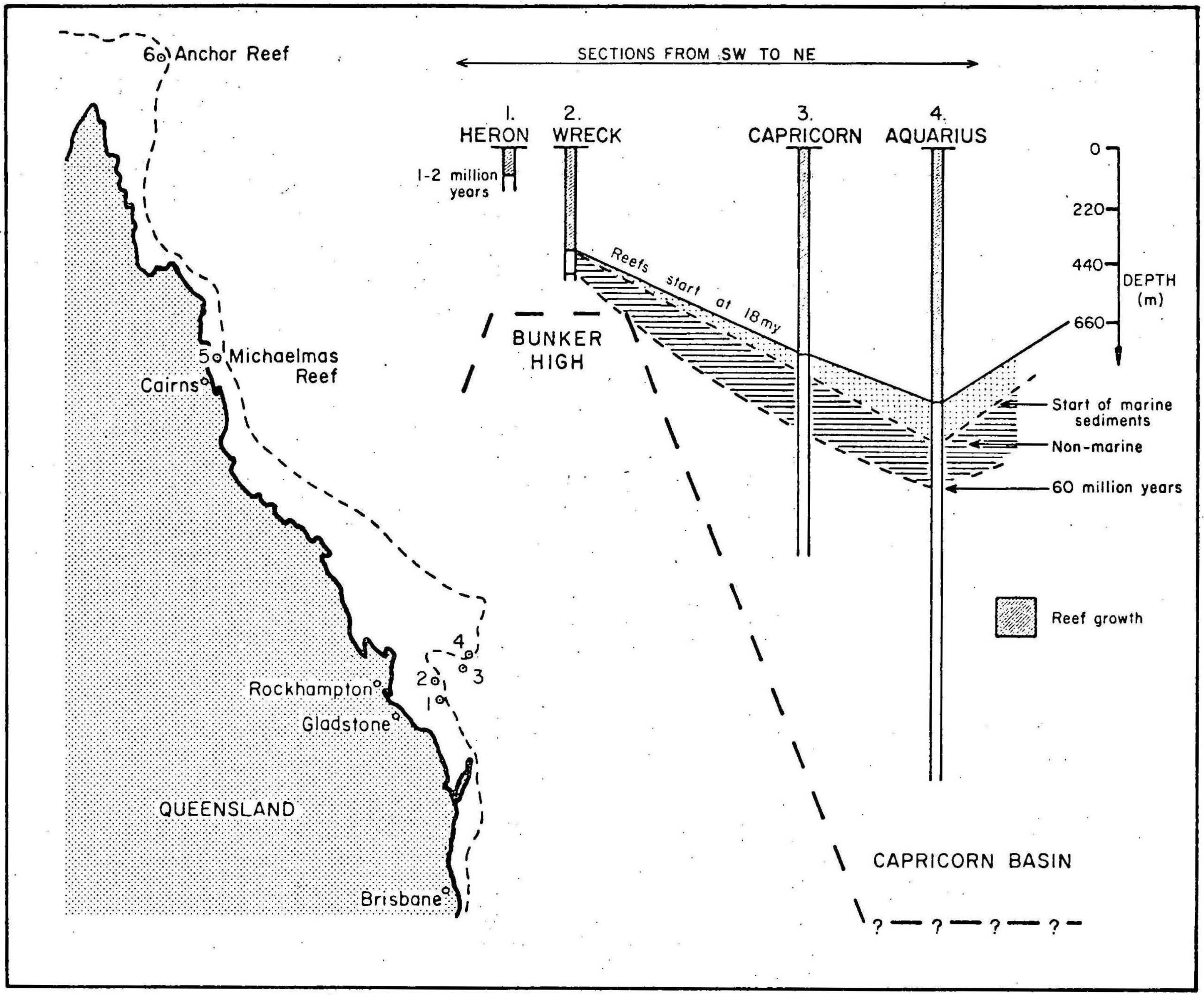

6 Anchor Reef
5 Michaelmas Reef
Cairns
Rockhampton
Gladstone
QUEENSLAND
Brisbane
1
2
3
4
SECTIONS FROM SW TO NE
1. HERON
2. WRECK
3. CAPRICORN
4. AQUARIUS
1-2 million years
Reefs start at 18my
BUNKER HIGH
CAPRICORN BASIN
0
220
440
660
DEPTH (m)
Start of marine sediments
Non-marine
60 million years
Reef growth
? ? ? ?

FIG. 3

④

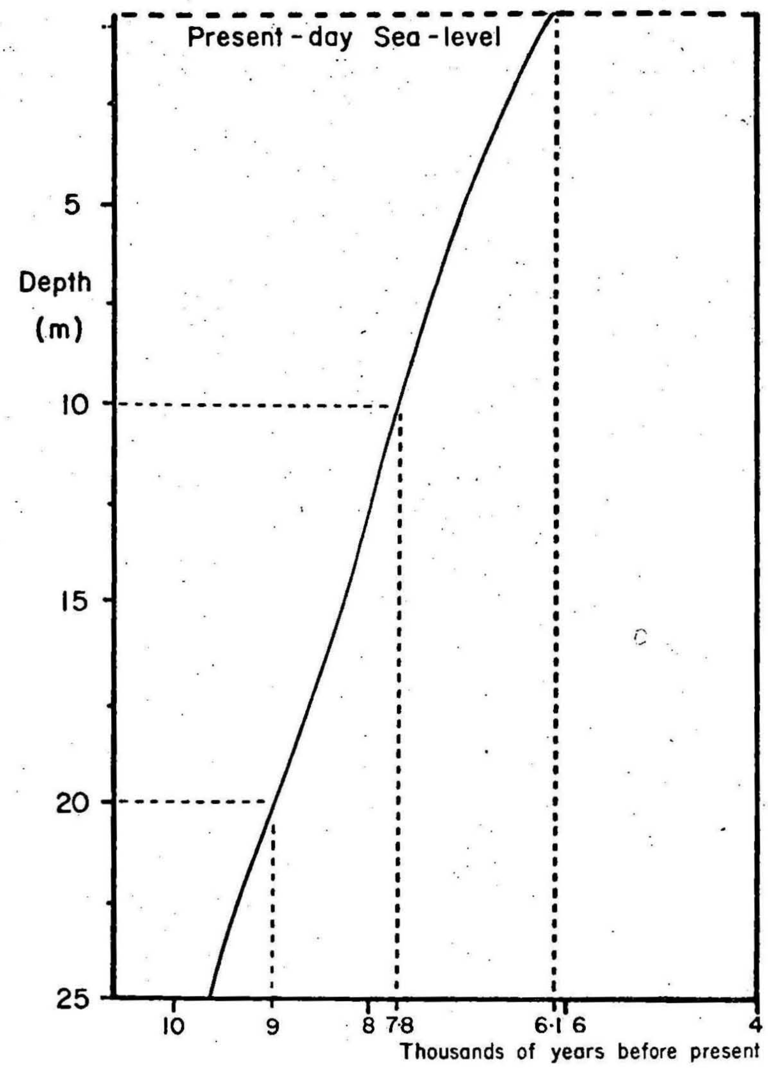
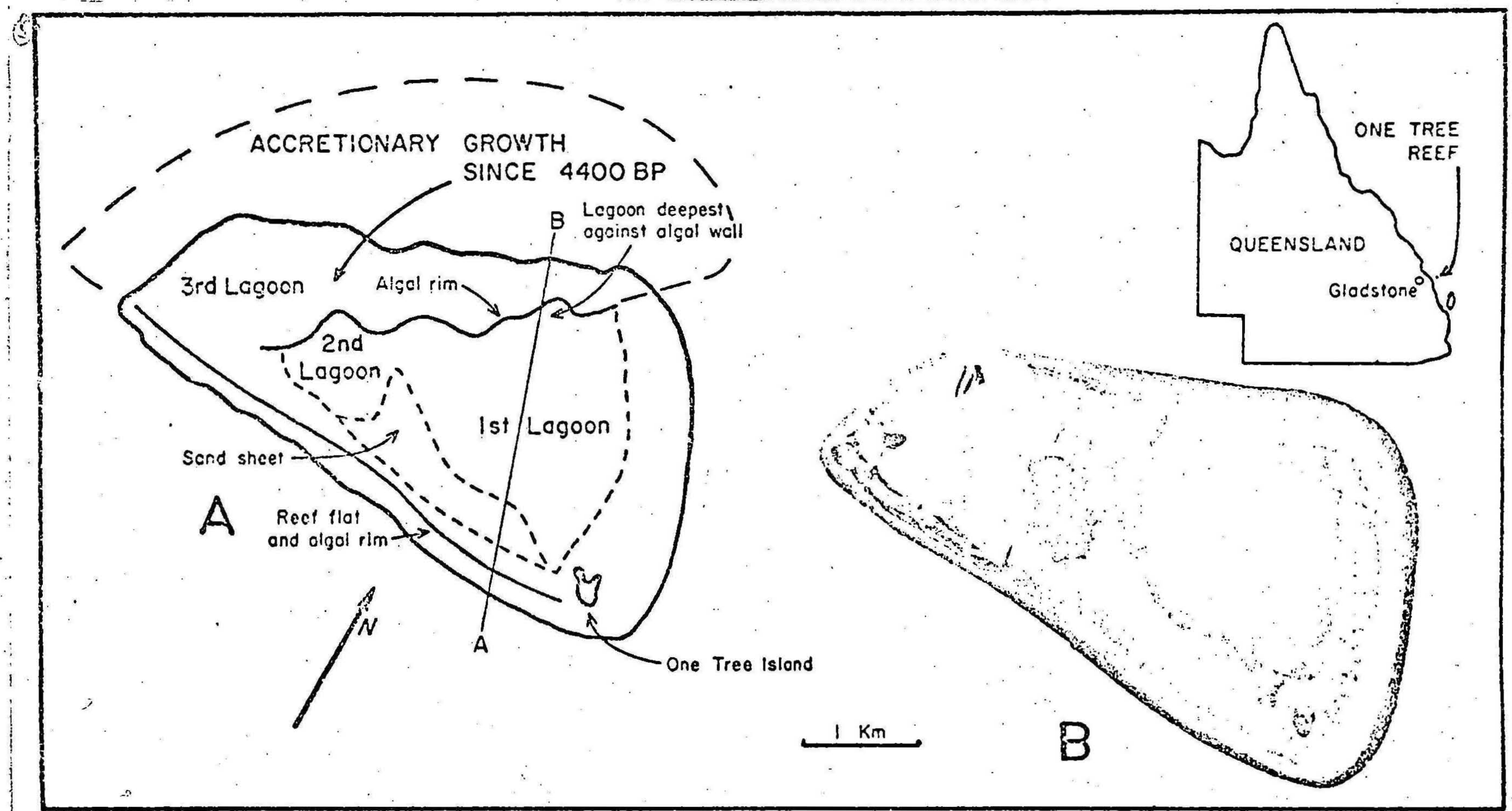

Present - day Sea - level
Depth
(m)
5
10
15
20
25
10
9
8
7·8
6·1
6
4
Thousands of years before present

FIG. 4



(Xerox copy only)

FIG. 5

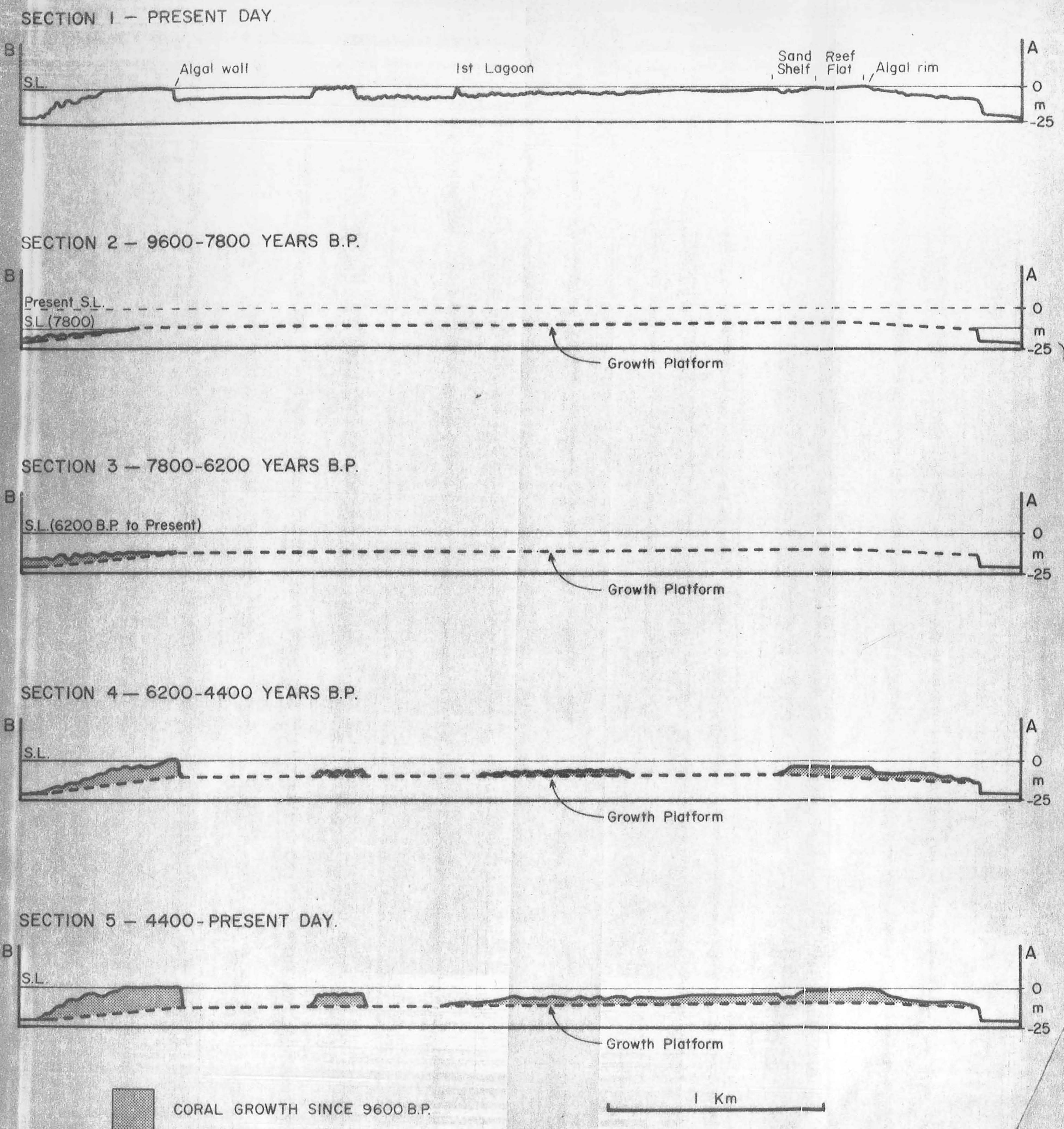

SECTION 1 – PRESENT DAY
B
A
S.L.
Algal wall
1st Lagoon
Sand Shelf
Reef Flat
Algal rim
0
m
-25
SECTION 2 – 9600-7800 YEARS B.P.
Present S.L.
S.L. (7800)
Growth Platform
SECTION 3 – 7800-6200 YEARS B.P.
S.L. (6200 B.P. to Present)
Growth Platform
SECTION 4 – 6200-4400 YEARS B.P.
S.L.
Growth Platform
SECTION 5 – 4400-PRESENT DAY.
S.L.
Growth Platform
CORAL GROWTH SINCE 9600 B.P.
1 Km

FIG. 6

(7)

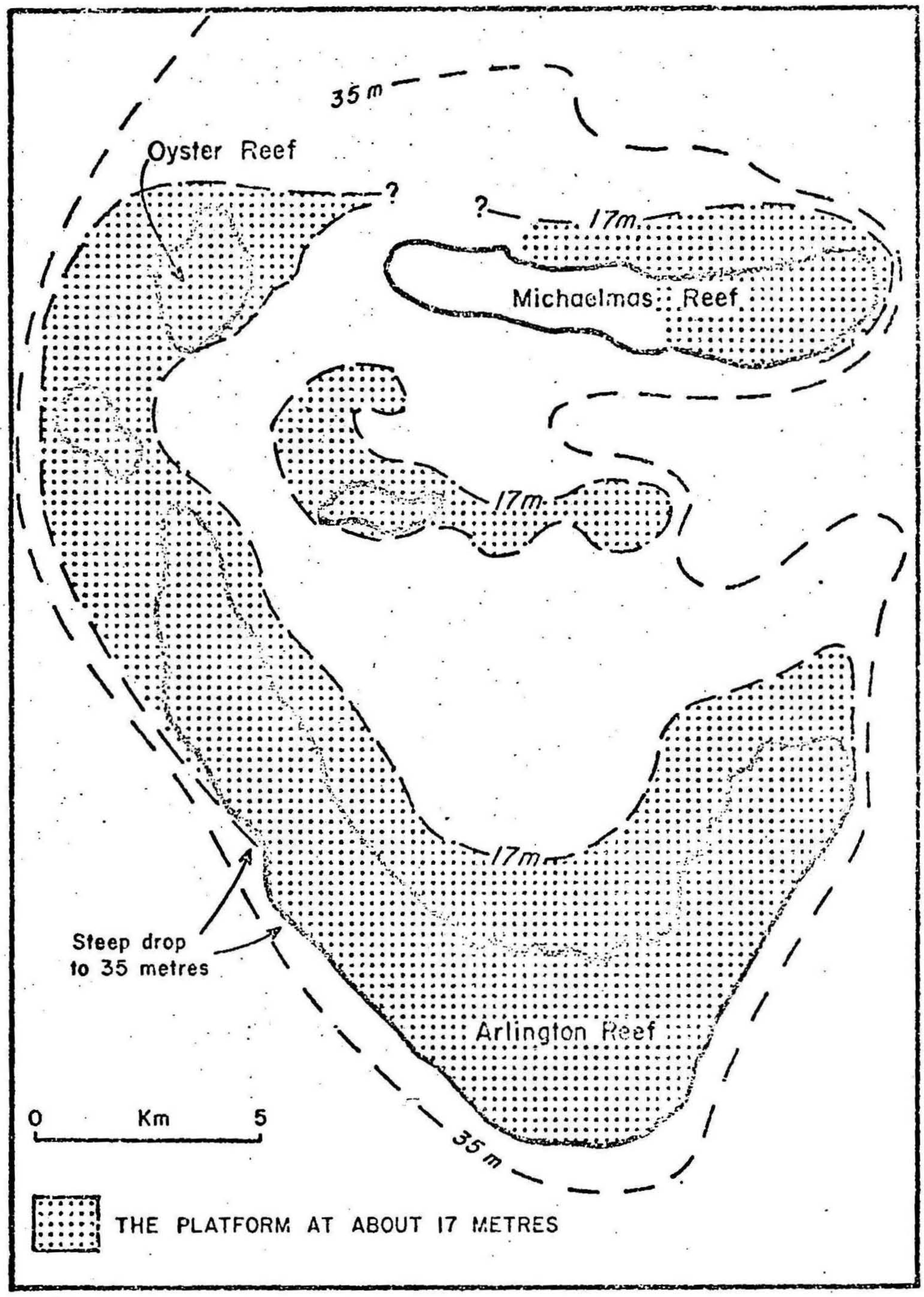

35 m
Oyster Reef
?
?
17m
Michaelmas Reef
17m
17m
Steep drop
to 35 metres
Arlington Reef
0 Km 5
35 m
THE PLATFORM AT ABOUT 17 METRES

FIG. 7