A MORPHOMETRICAL STUDY ON THE GEOGRAPHICAL DISTRIBUTION OF CORAL REEFS

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CONTENTS

Abstract

Various theories explaining the origin of coral reefs have been proposed since Darwin. However, the theoretical basis of the worldwide geographical distribution of coral reefs has not always been clear, as reviwed in Chapter 1. A new model regarding the geographical distribution of coral reefs is presented in this paper (Fig. 1).

The model postulated is as follows. Assuming that the continental shelf with a smooth surface extends from 30°N to 30°S, and that fluctuations in sea level and sea surface temperature repeat with the same magnitude during the Quaternary period, the geographical distribution of coral reefs can be expected to exhibit the following features.

1. In seas permitting the formation of coral reefs even during glacial ages, coral reefs would tend to grow at the shelf edge with a subsequent rise of sea level. The thickness of the coral reef limestones would be equivalent to the amount of the sea level changes. The reef type in such sea areas would be a barrier reef with pinnacles and knolls in a deep lagoon.

2. The width of a coral reef becomes narrower and shallower on approach towards the peripheral sea. The reef types may then alter from barrier reefs to fringing reefs.

3. The same geographical variation in coral reefs can also be expected on scattered islands from 30°N to 30°S and on completely drowned islands fringed by shelves in an open ocean. However, the reef type should be represented as an encircled reef like an atoll in this case.

The postulated model has been tested by using larger scale charts and by measurement of certain of the morphological properties of coral reefs such as Rw, Rd, Sw, Sd, Ldmax, and the number of knolls and pinnacles. The measured results are shown in Fig. 4 to Fig. 11 and Table 3.

The postulated model is supported by the following evidence. A zone of coral reef formation during periods of low sea-level stands has been confirmed from the coincidence of each geographical range with an Rd of about 100 meters and a W-ratio of 100%. This is also substantiated by the fact that Rd is roughly equivalent to the thickness of Quaternary reef limestones related to sea level changes during the Quaternary period (Table 1).

Seas which have permitted the formation of coral reefs even during periods of low stands of sea level, or glacial ages, are referred to as the "core zone". Seas which have expanded towards the north or south with subsequent rises in sea level constitute the "peripheral zone" (Fig. 15).

The geographical variation in the thickness of reef limestones is demonstrated as an overall, systematic decrease in Rd from the core zone to the peripheral zone. The geographical variation in the width of coral reefs is demonstrated as a W-ratio of 100% in the core zone which shows a systematic decrease towards the peripheral zone.

The geographical variation in reef types is also supported by the following findings. Barrier reefs and atolls center upon the core zone, while fringing reefs and apron reefs center upon the peripheral zone. Furthermore, the most frequent depths of Rd for each reef type are equivalent to the Rd of each zone, i.e. the Rd of barrier reefs and atolls coincides with that of the core zone, while the Rd of fringing reefs and apron reefs coincides with that of the peripheral zone (Fig. 14).

The geographical variation of the knolls and pinnacles in lagoons is roughly as follows. Most knolls center upon the core zone, while the range of pinnacles shows a wider distribution than that of the knolls. However, more specific and precise data are required on this subject.

The postulated model is also supported by the linear relationship, Rw/Rd = Sw/Sd (Fig. 12), and can be redrawn schematically as in Fig. 16.

The growth rate of a coral reef (Table 2) may possibly follow and approach the rate of sea level changes occurring throughout the Quaternary period. The amount and the rate of crustal movement (Fig. 13) appear to have almost no bearing on the explanation of the global distribution of coral reefs.

The present geomorphology of coral reefs must be based on karst topographies which have been eroded by subaerial solution. Therefore, Ldmax must be carefully evaluated. The proposed model effectively explains the geographical variation of coral reefs which have formed during the Quaternary period. However, explanations of the geographical distribution of coral reefs since the Tertiary or the Mesozoic also require a consideration of the regional plate tectonics, as indicated by Newell (1972) and Hori (1974).

1. INTRODUCTION

Coral reefs are organic landforms of the tropical and equatorial seas. Many scientists in the field have attempted to explain the origin of coral reefs. Due to the unique geomorphology, that is voluminous carbonate deposits produced by long-term biological activities, coral reefs have been vigorously studied by geomorphologists, biologists, geologists, chemists, and geophysicists.

The author's own work has concerned raised coral reefs on the Okinawa Main Island, Ryukyu Islands (Hori, 1967, 1968), a drowned karst and coastal geomorphology in the Bonin Islands (Kaizuka et al., 1968), raised coral reefs in Kenya, East Africa (Hori, 1970a,b, 1971; Toya et al., 1971, 1973), and certain problems of beachrock formation (Hori et al., 1972, 1973). The Ryukyu Islands and Bonin Islands are located on the periphery of a tropical sea, while East Africa borders an equatorial sea. The above research in the two contrasting areas stimulated the author's interest in the problem of coral reef formation, and a comparison of the two areas led him to develop an integrated model to explain the geographical distribution of coral reefs.

1.1. Purpose

Various theories such as Darwin's and Daly's have been proposed for the origin of coral reefs. However, at least regarding the non-local or regional, but worldwide geographical distribution of coral reefs, some of the proposed theories have not given satisfactory results.

The first purpose of the present paper is then to postulate a new model to explain the geographical distribution of coral reefs, as shown in Fig. 1. This model is based on the idea that the geographical distribution of coral reefs is principally controlled by sea level changes and fluctuations in the sea surface temperature which have served to limit the oceanic zones of coral reef formation during the Quaternary period.

The second purpose is to examine the validity of the postulated model. Certain morphological properties of coral reefs such as the ratio(%) between the width of the coral reef and the width of the continental shelf, and the depth of the basement of the reef edge, etc., were measured using charts of as large a scale as possible.

The final purpose is to give a schematic representation of the improved model, and to show in map form the two oceanic zones which permit coral reef formation during glacial ages and interglacial ages.

1.2. Previous works and problems

Past studies on the fundamental processes of coral reefs and the genetic explanation of their geographical distribution will be reviewed first in this section. Certain of the important problems will thus become clear.

Darwin (1842) gave a clear and general explanation of the evolution of coral reefs. Before Darwin, however, Lyell (1832) for instance regarded an atoll as a coral reef formed on the rim of a drowned volcanic crater. Darwin postulated a theory of coral reef evolution based on a model for typical oceanic islands girt with a coral reef. He proposed a successive change in reef type from a fringing reef through a barrier reef to an atoll, with gradual subsidence of the ocean floor. The worldwide distribution of the three fundamental reef types was shown on his map. He noted the depth of the reef wall basement, and on the basis of the data, the reef types were distinguished into two categories: fringing reefs whose reef wall basement was shallow, and barrier reefs and atolls with a deep basement. The distribution of barrier reefs and that of the atolls overlapped each other on the map. This indicates that the oceanic floor on which these two types are found has successively subsided. It is considered, therefore, that the two types are a natural consequence.

Though he himself stated, "(the idea of a gradual subsidence of an oceanic floor inferred from the distribution of barrier reefs and atolls) seems to me a marvellous thing" (letter to Agassiz in 1881; Himmelfarb, 1959, p. 105), Darwin concluded that the distribution of coral reefs and the variation of reef types depended fundamentally upon crustal subsidence. On the other hand, he admitted crustal upheavel movements around continents and islands arcs where there were many fringing reefs. However, he was confident that subsidence was an essential process for the formation of a coral reef. Noticing the existence of drowned valleys on the much indented coastline of a reef-fringed island, Dana (1872) maintained that this was direct geomorphological evidence of subsidence of the crust.

The criticism against the subsidence theory came from two points of view. First, on the strength of the findings of the voyage of H.M.S. Challenger, Murray (1880) suggested that an alternative mechanism underlay the process of coral reef formation. Subsequently, Semper (1881) and Guppy (1888) reported many elevated coral reefs in the unstable borderlands of East Asia and Melanesia. On the grounds that the deposits underlying the thin reef limestones could be interpreted as the pelagic sediments of the deep ocean reported by Murray, they offered a counterargument against Darwin's theory. The point of Murray, Semper and Guppy was that coral reefs accumulated on a stable marine platform under unchangeable sea level, and that lagoons were formed by solution. This is generally known as the marine planation theory. Agassiz (1898), Le Conte (1857), Sluiter (1890), Vaughan (1919) and Gardiner (1931) also held similar views. Their arguments, however, were only a fragmentary refutation of Darwin's comprehensive theory. They exerted little effect, especially regarding the explanation of the open ocean atolls to which special attention was paid by Darwin.

It was not until the glacial control theory was advocated by Daly (1910, 1915, 1916, 1917, 1919, 1925, 1934, 1948) that Darwin's theory was seriously challenged. This theory is based on climatic changes during the Quaternary and on the consequent "swing of sea level" and variation in sea temperature. The oceanic area of coral reef formation defined by Darwin never changed with time. The differentiation of coral reef types was entirely ascribed to subsidence of the crust. The facts on which the glacial control theory rested were as follows. The lagoon floor of atolls was found to be invariably confined to a depth of ca. 60–90 meters, and the relief of the lagoon floor was evenly flat. Daly estimated the lowering of sea temperature during the glacial age at 6°C (1910), 5°–10°C (1915), 5°C (1919), and 5°–7°C (1934). The lowering of the sea level was estimated at 80–90 meters (1910), 60–70 meters (1919), 60–90 meters (1915), 75–90 meters (1934) and less than 100 meters (1934). Consequently, oceanic chilling and smothering by sediments prevented the growth of coral reefs during the glacial age. Moreover, pre-existent coral reefs were eroded by wave action during the last glacial age, resulting in abrasion platforms. The above rate of marine erosion was calculated on the basis of the observed rate of retreat of the Chalk cliffs of Dover, that is, ca. 1 meter/year (Daly, 1910). With the subsequent rise in sea level during the postglacial age, coral reefs began to develop on the edge of the marine platform. They would then eventually become barrier reefs and atolls. Although the detail arguments of Darwin's and Daly's theories are left to Davis's excellent review (Davis, 1928), the geographical problem of coral reefs in Daly's theory is discussed in this chapter.

Daly used the two terms of coral reef zone (Daly, 1919) and coral sea (1934), which indicate the growing range of recent coral reefs. He admitted the existence of an oceanic area where coral reefs exceptionally continued their growth even during the glacial age. This, he described as "some area of the tropical belt" (Daly, 1934, p. 255). The Banda Sea is the case in point. The present monthly mean sea temperature of this area in 27°C or more. He thus considered that even if the sea temperature decreased by 7°C, coral reefs should safely continue to grow. As for the geomorphological evidence of no interruption in coral reef formation, he indicated that the widths of the reef patches, bank insets and atoll reefs in this area were extremely large (Daly, 1934). He noted the width of the coral reefs, as given by the distance between the strand line and reef edge, with respect to changes in the Quaternary sea level.

Thereafter, several discussions of factors determining the width of coral reefs were made. The width of fringing reefs and barrier reefs depends on the gradient of the continental shelf (Wiens, 1962, p. 114). In the case of atolls, it is closely related to the depth of the lagoon floor (Emery et al., 1954; Wiens, 1962). The width of atolls has also been considered in relation to their general shape (Stoddart, 1965). Daly's opinion regarding the width of coral reefs is of particular concern in this paper.

As mentioned, he considered that coral reefs were mostly prevented from growing during the glacial age due to lowering of the sea temperature. However, Bloom (1974) stated that the glacial chilling of the tropical oceans, which Daly and others envisioned as part of the glacial control theory of coral reefs, was greatly overestimated. The fluctuations in sea temperature with Quaternary climatic change will be discussed further in section 1.3.4., and the ecological significance of the sea temperature to hermatypic corals and coral reefs will be reviewed in section 1.3.3. Although it does not represent direct evidence, the distribution of recent hermatypic coral genera suggests that hermatypic corals may continue to live even during a glacial age. That is to say, it is very difficult from the biological viewpoint to explain that more than 50 genera of recent hermatypic corals, which have been shown in maps (Wells, 1954; Stoddart, 1969; Rosen, 1971), could become extinct every glacial age.

The question also arises that Daly based his theory on the observed retreat rate, ca. 1 m/year, of the Chalk cliffs of Dover, when explaining the formation of past abrasion platforms during periods of low sea level. According to recent observations in reef limestone regions, however, the mean retreat rate is some 0.1–1 mm/year (Stoddart, 1969, 1973). Therefore, Daly's opinion that the abrasion platforms were formed only during the last glacial age encounters difficulties (Galloway, 1970).

Recent studies have shown that the lagoon floor is not so evenly flat as Daly had estimated. Undulating drowned karsts have been reported (Emery et al., 1954; Shepard, 1970, etc.), and the antecedent karst theory advocated by Purdy (1974) is based on such evidence. The maximum depth of the lagoon floor appears to very geographically in accordance with the amount of precipitation (Purdy, 1974a; Hori, 1978, in preparation).

Nevertheless the "swing" of sea level emphasized by Daly as exerting a strong control over coral reef formation, is well supported by the thickness of Quaternary reef limestones obtained from deep borehole data and seismic prospecting, since the above thickness is found to be roughly equivalent to the mean magnitude of the Quaternary fluctuations in sea level. The evidence for climatic changes and sea level changes has thus become increasingly important in considering the process of coral reef formation.

Davis (1928) basically supported Darwin's subsidence theory. Although admitting the effects of Quaternary climatic and sea level changes, he developed them into his own coral reef theory. In particular, the geographical aspects of Davis's theory of coral reefs deserve more attention. He divided the oceans into "warmer seas" or "coral seas" and "cooler seas", while the peripheries of the coral seas were termed "intermediate belts" or "marginal belts". The latter therm was defined clearly in 1923, although in previous papers, Davis used the words "near the borders of the coral zone" (1918) or "reef-bordered coasts" (1919) for it. He considered that the lowering of sea temperature during the glacial age was 4–5°C (1928, p. 219) and that in the coral seas except the marginal belts, hermatypic corals were prevented from growing up, although a kind of calcareous algae (*nullipores*) lived continuously on and protected the reefs from wave action, whereas in the marginal belts, such *nullipores* were unable to survive and the pre-existing coral reefs dating from before the last glacial age were eroded down due to the consequent lack of protection. He therefore conclusively stated that Daly's glacial control theory should be tested in the marginal belts.

Davis himself was very interested in the coral reefs of the marginal belts. However he, as well as Daly, overestimated the effects on coral reef formation of sea temperature lowering and the intensity of wave action. In general, his attention was thus oriented not towards the reefs themselves but rather to the nature and forms of the sea cliffs behind the coral reefs. He also, like Darwin, proposed that the reef types depended fundamentally on vertical crustal movements. As a result, the decisive effects of climatic and sea level changes on the geographical distribution of coral reefs were given little consideration by Davis.

The antecedent platform theory of Hoffmeister et al. (1935, 1944) also belongs to the same category as the subsidence theory. This theory, however, accounts rather for the regional or local processes of coral reef formation than for the global distribution of coral reefs. Kuenen (1950, etc.) and Tayama (1952) adopted the position that Darwin's theory suffices to explain the basic processes of coral reef formation, but they fairly acknowledged the effects of Quaternary sea level changes on coral reef formation, and as a result an eclectic theory was advocated.

Tayama (1952) proposed that the table reef represented an ultimate reef type, which is a logical extension of Darwin's theory.

Regarding the geographical variation of each reef type, the above-mentioned theories thus offer three explanation: (1) it is simply an expression of differences in the evolution of the reef types, (2) it is controlled essentially by vertical movements of the earth's crust, and (3) it is an expression of the regional ecological and chemical factors related to the formational processes of coral reefs.

Both climatic changes and sea level changes have been widely recognized as important factors in coral reef formation, but the horizontal aspects of such variability have rarely been examined. Considering that reef types are controlled by sea level changes, the worldwide distribution of reef types should be well organized in a geographically systematic arrangement. Darwin did not incorporate this into his explanation of the latitudinal gradient of ecological factors relating to coral reef formation. Daly emphasized the significance of sea level changes. Davis extended Daly's idea towards the geographical problems represented by "coral seas" and "marginal belts". These geographical problems form the main subjects in this paper.

Recent studies on coral reefs have tended to concentrate either on details of the functional and morphological aspects of reef ecosystems, on the relations between coral reef formation and Quaternary sea level changes and crustal movements (e.g. Mesolella et al., 1970), or on the deposition and lithification of the sediments, etc..

1.3. Model explaining the geographical distribution of coral reefs

1.3.1. Definition and geographical scale of coral reefs dealt with in this paper

All major coral reefs of the world are dealt with here. This to say, all individual coral reefs which are drawn on charts of scale approximately 1/10,000 or 1/100,000 were studied, since the existence of coral reefs at this scale should be governed not only by local ecological controls but also by global climatic changes and sea level changes of the Quaternary.

The coral reefs studied in this paper must first be defined. Two excellent reviews on the definition of coral reefs have recently been published (Braithwaite, 1973; Heckel, 1974). The modern concept of the reef incorporates both morphological and ecological features (Braithwaite, 1973). Sedimentary geologists hold a dualistic view, comprising the ecologic reef in a genetic sense and the stratigraphic reef in a descriptive sense. Such a rigid definition is required when fossil reefs are identified. After all, it has been said that "coral reefs consist essentially of calcium carbonate secreting organisms with the capacity to build skeletons capable of withstanding wave action, and as a reult they form topographic features which rise from the sea floor to the sea level" (Stoddart, 1969). This paper adopts the same approach.

For the present purpose, those reefs which rise abruptly from the sea floor and whose summits reach sea level or are at the deepest 20 meters below sea level, were selected from the charts.

1.3.2. The distribution of coral reefs

Darwin (1842), Joubin (1912), Wells (1957a) and McGill (1958) have shown the worldwide distribution of coral reefs. According to their maps, the distribution of coral reefs is confined to a latitudinal belt roughly between 30°N and 30°S, and generally a remarkable development of reefs is found on the western side of each ocean. It is also noteworthy that the density of coral reefs corresponds well to that of the hermatypic coral genera (Wells, 1954; Rosen, 1971). The distribution of coral reefs is necessarily restricted by the existence of basement on which coral reefs can grow.

On the other hand, areas do exist where coral reefs would be expected and yet there are none. Examples include the coasts of West Africa, Mexico Bay, the Bay of Bengal, and the northern part of Brazil. These areas are characterised by the violent accumulation and mobility of their marine sediments. Moreover, certain other areas also lack coral reefs. These include areas where cold water appears, such as the eastern Pacific Ocean, those where active volcanoes exist, such as the New Hebrides, and those where the basement has long been stable at an unsuitable depth for the growth of coral polyps, such as the Seychelles Bank (Stoddart, 1973).

1.3.3. Ecological factors related to the distribution of coral reefs

It is essential to consider factors affecting the growth of coral reefs when explaining their distribution. Stoddart (1969) enumerated the environmental controls affecting both local coral growth and the general reef distribution as depth, temperature, salinity, emersion, water turbulence, and sedimentation. All of the above six factors are not of equal importance when discussing the worldwide distribution of coral reefs.

First, the local and regional environmental factors may be summarized as follows. Emersion is a factor in the resistance against exposure of the coral reefs during times of low tide. Water turbulence provides the corals with a fresh supply of water, removes carbon dioxide, and determines the growing depth of hermatypic corals (Rosen, 1971). Sedimentation is a local and regional factor, as mentioned in section 1.3.2.. Rates of sedimentation on the reefs may be greater during and after storms, but this is not such an important factor except in cases of the type emphasized by Wood-Jones (1910).

Salinity is also a local and regional factor. The range of salinity which permits the growth of hermatypic corals is 27–45‰, and the optimum range is 34–36‰ (Wells, 1975b; Kinsman, 1964). This salinity range is globally satisfied in all oceans where reef growth occurs. Its importance is clear in areas where the reefs are severely influenced by freshwater outflows and torrential rains.

Depth decides the degree of illumination, and the vertical distribution of hermatypic corals is delineated by the maximum depth where photosynthesis of symbiotic algae can occur. Wells (1957a) has clearly illustrated the relation between the depth distribution of corals, illumination, and sea temperature. According to his figure, the sea temperature does not vary much within 60 meters below sea level. It remains at 18°C even at a depth of 140 meters. However, the number of species of hermatypic corals abruptly decreases below a depth of 15 meters. This curve coincides satisfactorily with the illumination curve against depth.

Temperature is a global factor. Wells' figure was based on the observed temperature at Bikini Atoll, but even at Kure Atoll, Hawaii Is., which is the northern most atoll in the world, a temperature of 18°C is maintained at a depth of 80 meters (Dana, 1971). The lower limit of the annual mean sea temperature restricting the growth range of hermatypic coral is 10.6°C (Macintyre et al., 1969), and the upper limit is 39.5°C (Kinsman, 1964). The optimum range is between 25°C and 29°C, and the annual minimum temperature permitting vigorous growth of corals is 18°C (Vaughan et al., 1943). The vertical distribution of sea temperature thus gives a value of 18°C at a depth of 80 meters even in the marginal sea of a coral reef formation such as the Kure Atoll. Therefore, temperature does not exert a major control over the vertical distribution of hermatypic corals.

However, Yonge (1940) has indicated that temperature, especially the annual minimum temperature, restricts the horizontal global distribution of coral reefs. Wells (1954) and Rosen (1971) have also stated that the global distribution of hermatypic corals is principally determined by the latitudinal gradient of annual minimum temperature.

Summarizing the above points, it can thus be said that emersion, water turbulence, salinity and sedimentation represent local and regional factors restricting the horizontal distribution of hermatypic corals and coral reefs. Illumination and water turbulence are local factors limiting their vertical distribution. On the other hand, temperature, especially the annual minimum temperature, is the fundamental factor determining the global distribution.

1.3.4. Model for the geographical distribution of coral reefs

The sea temperature has of course not remained constant throughout the period considered. Daly's glacial control theory rests on the premise of Quaternary climatic and sea level fluctuations, as reviewed in section 1.2. Also, the changes in sea water temperature have nearly paralleled the Quaternary sea level fluctuations. Therefore, the growth range of coral reefs has necessarily expanded and contracted during the Quaternary period. The expected geographical distribution of reef topography as a result of these Quaternary events is considered next.

Hori (1970a, b) previously presented the following model for the geographical distribution of coral reefs (see Fig. 1). Consider a hypothetical ocean in which the annual minimum temperature is higher than 18°C, in accordance with the climate of a given age of the Quaternary period. Then, the zone of coral reef formation so determined is designated the "potential zone". In this potential zone, not only the temperature but also the depth, salinity, emersion, water turbulence and sedimentation are all assumed to permit maximum growth of the coral reefs. Further, there are no crustal movements. The continental margin is fringed by a continental shelf, which is sufficiently wide and smooth and continuous in its north and south extent that the corals grow to form the widest sustainable reef. Then, introducing fluctuations of sea level and sea water temperature during glacial and interglacial ages, it is clear that the coral reef distribution will be modified by these fluctuations. Further, it is assumed that the rate of the sea level changes never exceeds the growth rate of

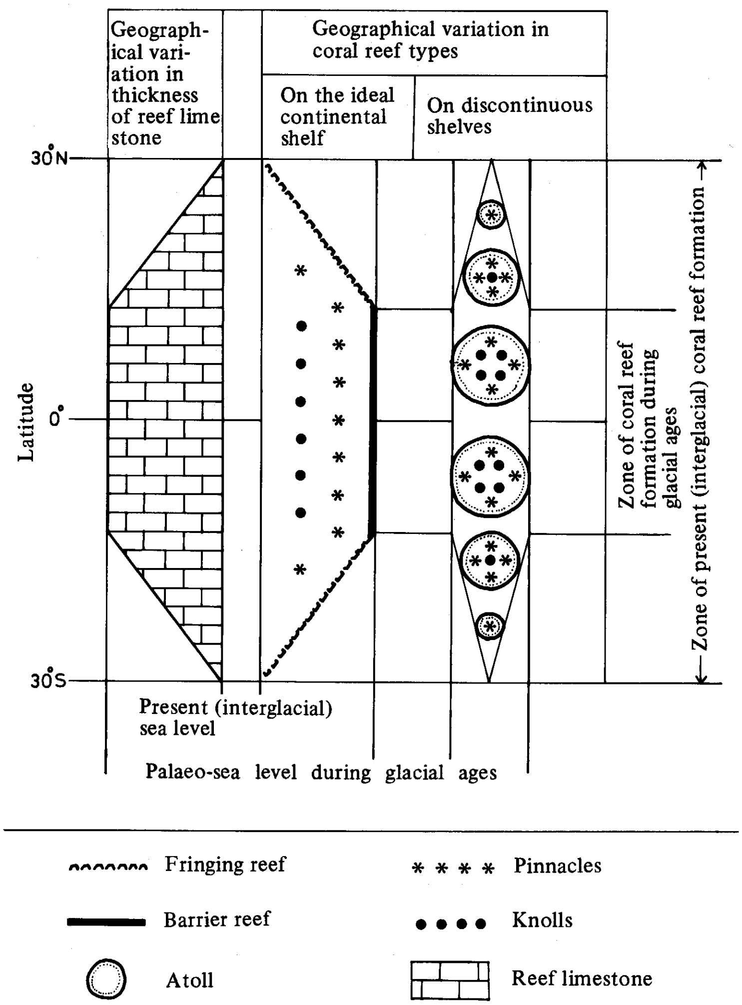

Fig. 1 Postulated model explaining the geographical distribution of coral reefs (modified from Hori, 1970a, b)

the coral reefs. Then, the only determining factor of the poleward extension of the coral reef distribution will be the annual minimum sea temperature.

Based on this model, the following differences in coral reef distribution would be expected between the equatorial oceans, where the coral reefs can grow even during a glacial age, and the peripheral areas of the potential zone, where the reefs begin to grow after termination of the glacial age.

(1) Thickness of reef limestones and width of coral reefs. The thickness of the reef limestones would increase towards lower latitudes, and thin towards the periphery of the potential zone. Moreover, the thickness of reef limestones in an oceanic area where there had been no interruption of reef growth even during the glacial age would be equivalent to the total rise in sea level.

(2) Reef types. In an oceanic area where reef formation took place uninterruptedly during the glacial age, the resulting reef type would be a barrier reef with many pinnacles and knolls dispersed in a wide and deep lagoon. On the other hand, the width of the lagoons would be narrower and shallower towards the periphery of the potential zone, so that the main reef type at the periphery would be fringing reef.

As for reefs on the surrounding continental shelf of oceanic islands aligned in a north-south direction in the potential zone (Fig. 1), similar results would be expected. Furthermore, assuming the existence of drowned oceanic islands at a period of low sea level, an atoll would be expected on subsequent rising of the sea level. In the case of atolls, the thickness of the reef limestone and width of the reefs would vary with latitude in the same way as in the case of the continental shelf.

At a time of submergence, the potential zone would narrow with time, and reefs formed during preceding transgressions would be exposed one by one. The exposed reefs would then be subject to terrestrial erosion, resulting in a karst topography.

The above-mentioned considerations are assumed to apply in the case of a mono-cycle sea level change. However, when the same magnitude of sea level changes occurred repeatedly throughout the Quaternary, similar effects can be expected.

2. METHOD AND RESULTS OF MEASUREMENTS

2.1. Method

2.1.1. Materials for testing the postulated model

How should the postulated model be tested? First of all, what materials are actually available for testing? Many monographs on local and regional reefs deal only with limited areas, and they do not always afford the required information such as depth of the reef edge basement, and of the continental shelf, and the width of the reefs and shelves. Under existing circumstances, only the use of charts is practicable for consistent measurement of the geomorphological properties of coral reefs on a worldwide scale. Charts of high accuracy are therefore required.

Reefs that are free from the influence of fluvial freshwater and of sediments transported from the rivers were selected for measurement. Clearly, the accuracy of testing of the postulated model depends on the accuracy of the relevant materials and charts.

2.1.2. Morphometrical measurement of coral reefs

What kinds of geomorphological properties of coral reefs represented on charts should be estimated? Daly measured the maximum depth of the lagoon floors. However, this does not always coincide with the depth of the reef edge basement (Hori, 1978, in preparation). Daly also measured the absolute width of the coral reefs. However, Wiens (1962, p. 114) indicated that the width of coral reefs was very variable according to the gradient of the continental shelf.

According to the model postulated here, the thickness of the reef limestone should coincide with the magnitude of the changes in Quaternary sea level, and the width of the coral reefs, which means the distance between the strand line and reef edge, should depend

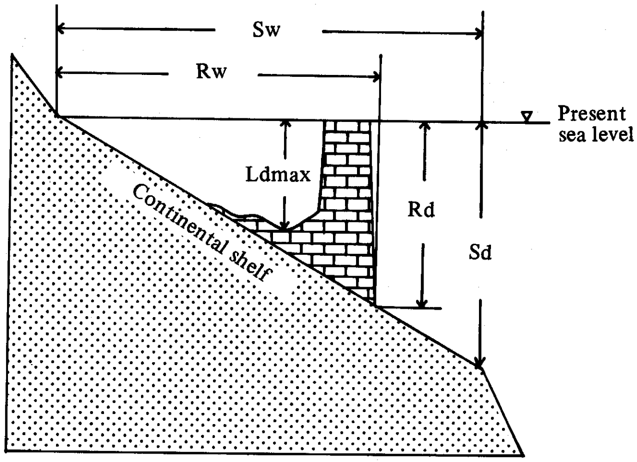

Fig. 2 Explanatory figure for morphometrical measurements

Rd : Depth of reef edge besement
Rw : Width of coral reef
Sd : Depth of shelf edge
Sw : Width of shelf
Ldmax : Maximum depth of lagoon floor
W-ratio (width ratio for the coral reef) = Rw/Sw x 100(%)

directly on the gradient of the continental shelf. It is therefore necessary to know the depth of the basement of the reef edge, which is interpreted as the depth of the starting point of reef growth. The depth of the basement of the reef edge is termed the "reef edge depth" in this paper, and written "Rd" for short (Fig. 2). On the other hand, the ratio of the width of the coral reef to the width of the continental shelf is also important. The continental shelf width is designated "Sw" here, and the width of the coral reef, "Rw". The width ratio (or W-ratio) is then given as follows:

$$\text{W-ratio} = \text{Rw}/\text{Sw} \times 100\ (\%)$$

Thus, Rw can always be compared with the W-ratio regardless of the real gradients and widths of the shelves.

Daly interpreted Rd as being equivalent to the maximum depth of the lagoon floor, Ldmax, on reefs with deep lagoons. The relationship between Ldmax and Rd therefore represents an important problem. When measurements are carried out on charts, it is impossible in some cases to determine the Rd of barrier reefs and atolls since there is exact coincidence with the continental shelf edges. The values are expected to be in direct proportion to Rw (Fig. 1). Since the reef types are expressed as a set of Rd and Rw values according to the postulated model (Fig. 1), every point of measurement on the charts may be assigned to ont of the reef types so defined.

2.1.3. Charts used for measurement and their accuracy

The most standard and accurate charts covering the worldwide distribution of coral reefs may be the British charts. These are readily available in Japan, and were so used for measurement. However, they were supplemented by Japanese, Australian and U.S. N.H.O. charts. Regarding chart accuracy, the following points represented problems: errors in sounding, compilation, platemaking and printing, chart scale and projection (Hydrographer of the Navy, U.K., 1966; Kutsuna et al., 1967).

In the case of sounding data, the date and exactness of sounding must be considered when the depth is read off from the chart. Recently published charts (in this paper, most of those used for measurement were published in 1969–1974) were obtained wherever possible. The scale of the charts was of the order of 1/1,000 to 1/10,000, or in a few cases of the order of 1/100,000.

Charts are originally prepared for navigational purposes. Hence, the representation of shoals is very reliable, and the density of sounding points is higher around harbours and along sea routes. On charts of smaller scale, deeper records may also be omitted so that there is a predominance of shallower records. Accordingly, the measurements of Rd and Ldmax may be considered as the minimum record. Charts with contour lines are usually more accurate than those without such lines, and the error in depth may be less than one meter.

The problem of identification of coral reefs on the charts also requires specific mention. That is to say, although it is very easy to identify coral reefs in charts at lower latitudes, in the peripheral areas of coral reef-growing oceans it is sometimes difficult to make positive identifications due to the discontinuous distribution and smallness of the reefs in the topographical sense. In this paper, therefore, only those reefs which were clearly judged as coral reefs from the available data and supporting documents are considered.

2.1.4. Method of measurement

a. Selection of measuring sites

Measuring sites were selected as follows. First, those areas where coral reef growth is prevented due to the influx of fresh water from rivers or to the steepness of the coastal slopes, were excluded. Second, lines of measurement were determined so that Rd, Rw and Ldmax attained their maximum, except that the lines of measurement were always drawn perpendicular to the coast line.

The spacing of the measuring sites was not considered strictly, since it varies readily with chart scale, differences in area covered, and density of sounding records. However, sites where there was extreme variation in Rd and Rw were measured without fail.

b. Methodology

Cross sections of coral reefs were drawn along the lines of measurement. The horizontal scale of the cross sections was, as a rule, made coincident with the scale of the charts from which the sections were drawn. The vertical scale of the sections was set at 1 centimeter to 10 meters after converting fathoms into meters. Cross sections of very complicated relief were redrawn on an expanded scale. When coral reefs and continental shelves were well developed, readings of Rd, Sd and Ldmax were possible within an error of less than 5 to 10 meters. Errors in the W-ratio were limited to within several percentage points even though the chart scales varied. If reading of each of the items of depth and width on the sections was difficult, both extremes were adopted. If complete readings were for some reason impossible, the items were left unmeasured. Supplementary explanations are as follows (see Fig. 2)

Rd. It is difficult to read Rd in cases where the basement of the reef edge coincides exactly with the continental shelf edge. In such cases, therefore, the point of intersection of the reef edge line and the extended line of the lagoon floor is used to read Rd. Atolls and table reefs sometimes have terrace-like topographies on their fringes, which may correspond to continental shelves, especially on the leeward sides. In this case, Rd is read directly from the depth of the terrace-like topography. However, the reef edge of atolls and table reef usually descend towards the ocean floor with very steep slopes, and are often devoid of sounding records outside the reef edges. Since reading of Rd is then impossible, Ldmax is used as the shallowest record of Rd.

Sd. No problems arise in the case of typical continental shelves. However, some shelves do not display the distinctive knick point of the continental shelf slopes. In such cases, Sd is given by the maximum (or minimum) depth in meters, or by the range between the shallowest and deepest values.

Rw. The width of the reefs is defined as the horizontal distance (kilometers) between the shore line and measuring line of Rd.

Sw. The shelf width is defined as the horizontal distance (kilometers) between the shore line and measuring line of Sd.

Ldmax. This is the deepest sounding record observed along the measuring line in the lagoons. Each cross section across the deepest sounding record of each lagoon was drawn without fail.

Reef type. The reef type is judged principally from the planar form of the coral reefs and depths of the lagoon floor. Various reef types have previously been proposed. Darwin (1842) indicated fringing reefs, barrier reefs and atolls as the fundamental reef types. Tayama (1952) furthermore proposed the apron reef as an embryo type of the fringing reef, and almost-barrier reefs, almost-atolls and almost-table reefs as transitional reef types. He considered table reefs as the terminal reef type in the evolution of coral reefs. Tayama's classification of reef types is adopted here since it is well suited to the representation of continuous sequences of coral reef topography. On the other hand, the checklists of Bryan (1953) are also referred to when judging atolls and table reefs.

Neither the subsidence theory nor the glacial control theory raises untenable ojections to the three reef types proposed by Darwin. The classification of reef types proposed by Tayama is also acceptable, although it has nothing to do with morphogenetic processes.

Besides the above, the following other reef types have been proposed: bank barriers and bank atolls (Davis, 1928), pseudo-atolls (Molengraff, 1930), shelf-atolls (Fairbridge, 1950), and various reef types of atolls (Cumberland, 1956). Furthermore, reef types such as faros (Gardiner, 1903), micro-atolls (Kornicker et al., 1962), as well as various reef types suggested by Maxwell (1968), have been distinguished on the basis of smaller topographical criteria. Davies (1972) indicated another general descriptive classification of reef types. The various above-mentioned types of reefs, however, are not adopted here due to the insufficient consensus on classification systems.

On the other hand, patched reefs are distinguished in this paper in addition to the above-mentioned reef types, as proposed by Tayama (1952), in order to take account of the degree of horizontal continuity of the reef edges. A reef is defined as a patched reef when the reef edges are split by channels whose depth attains 20 meters or more and whose width

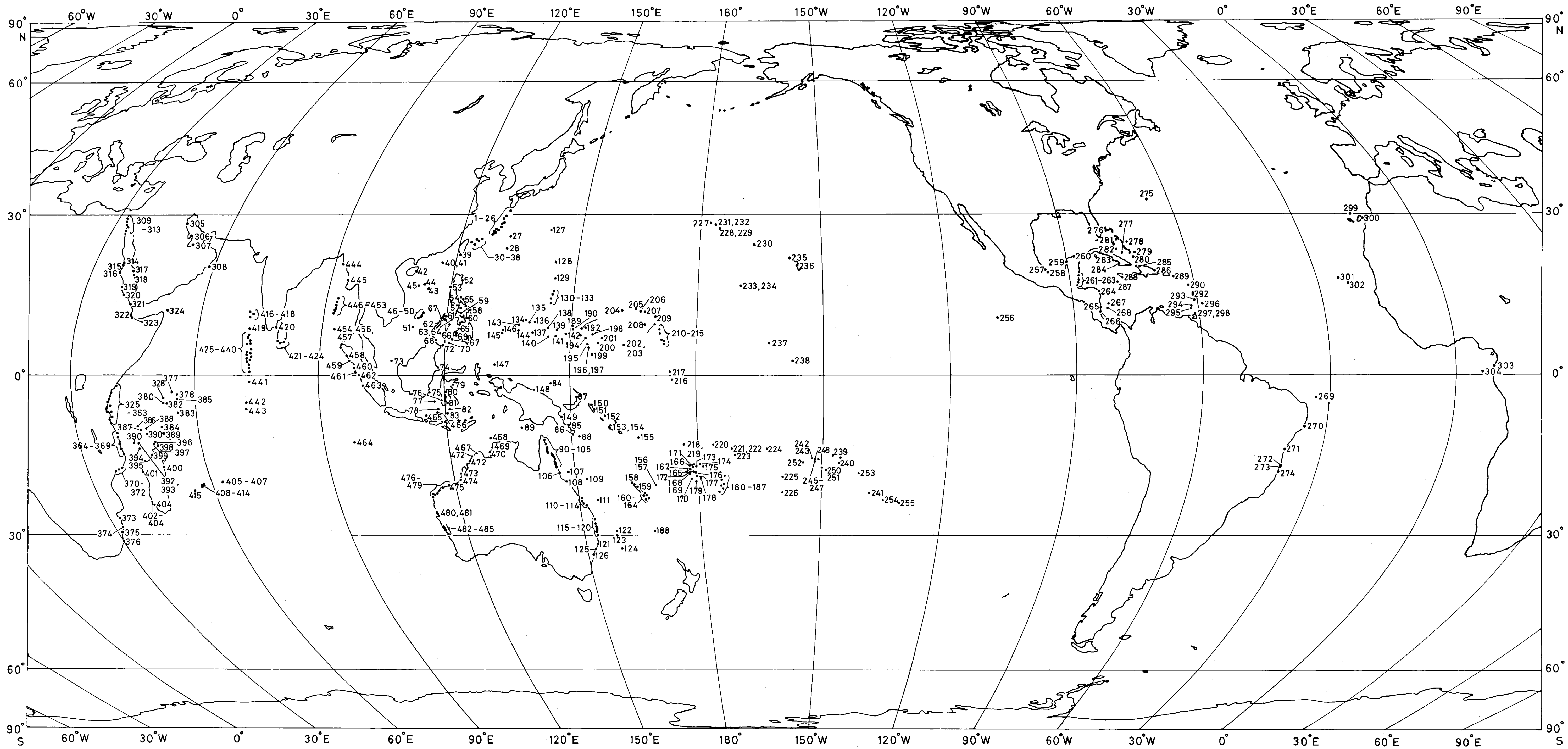

Fig. 3 Distribution of measuring sites

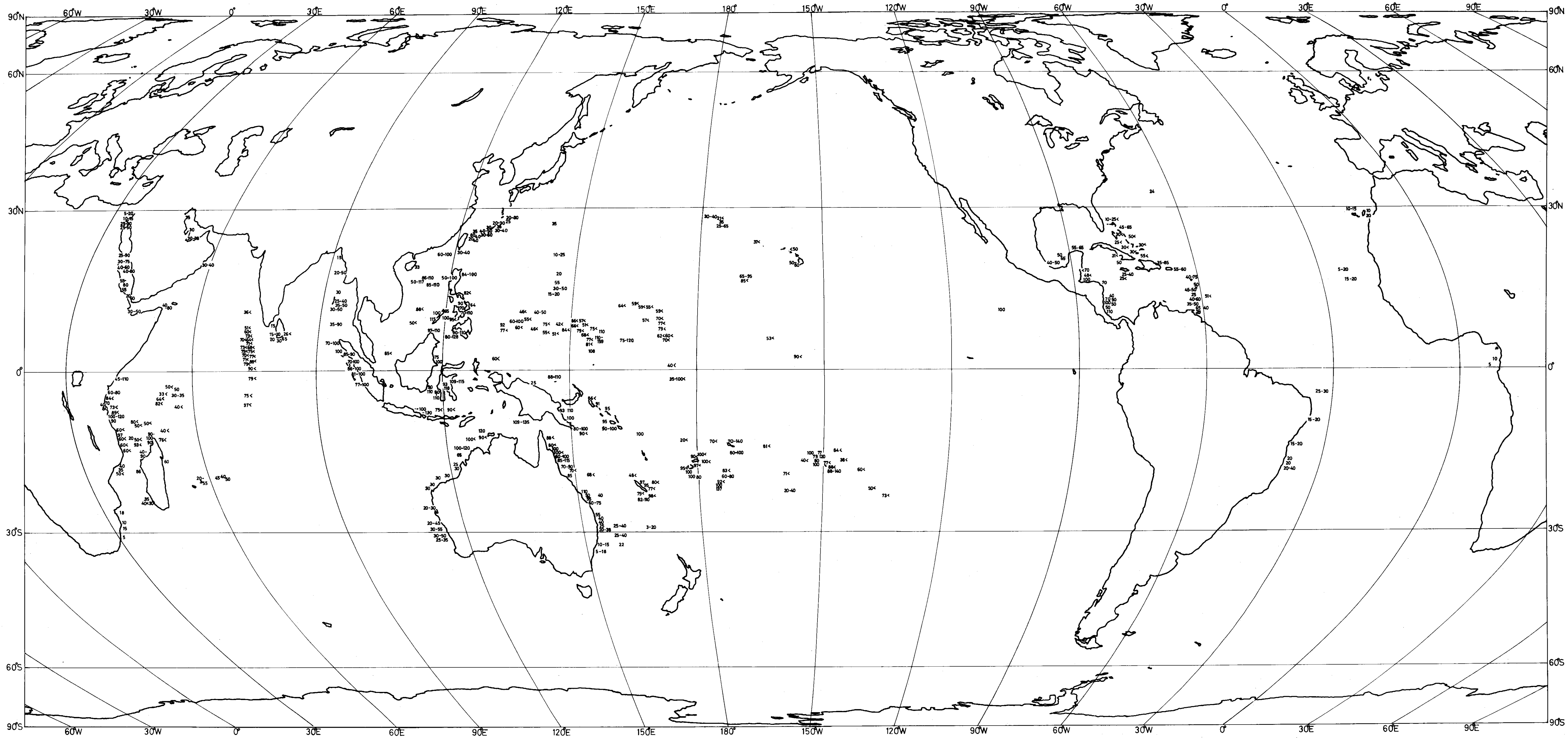

Fig. 4 Geographical variation of Rd in the world

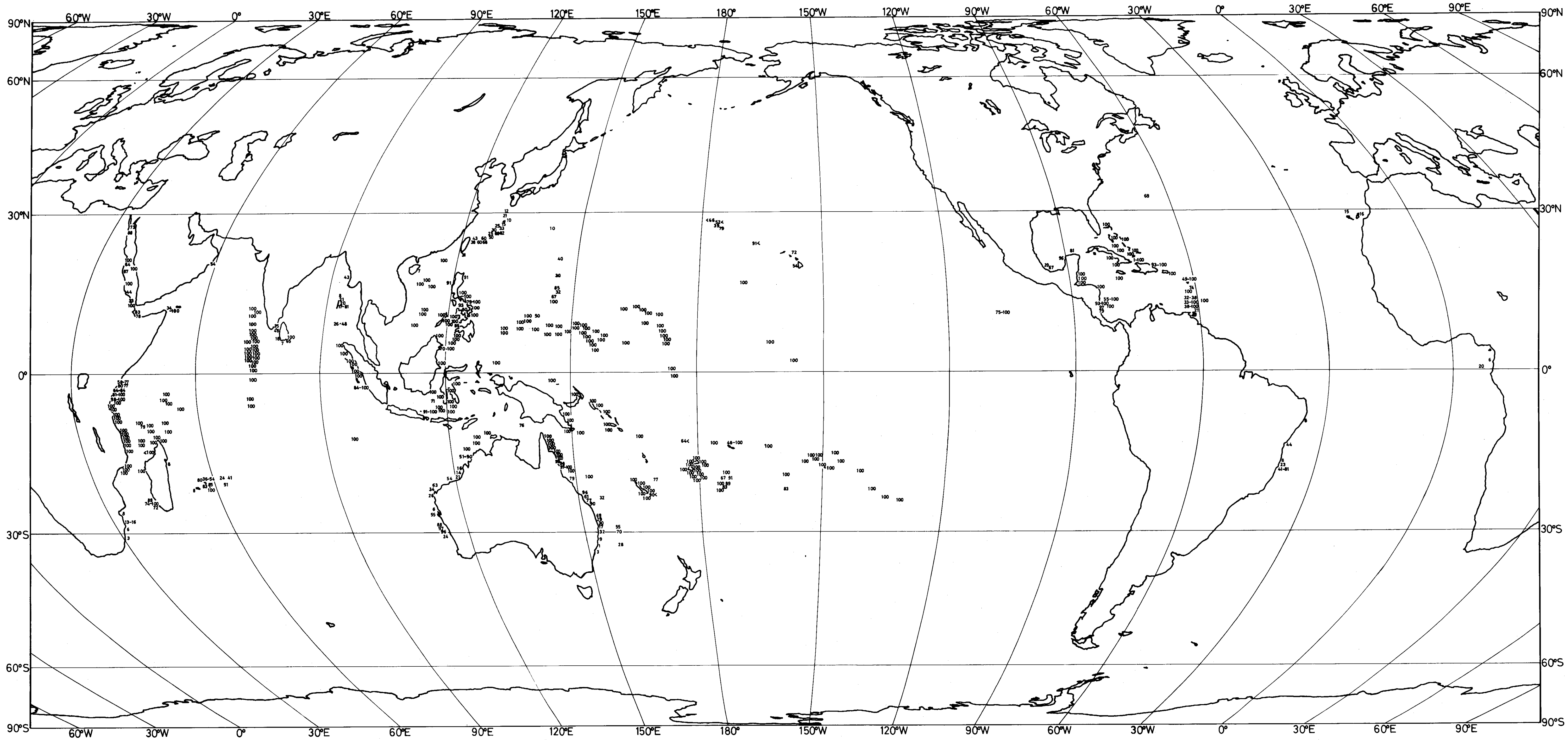

Fig. 6 Geographical variation of the W-ratio in the world

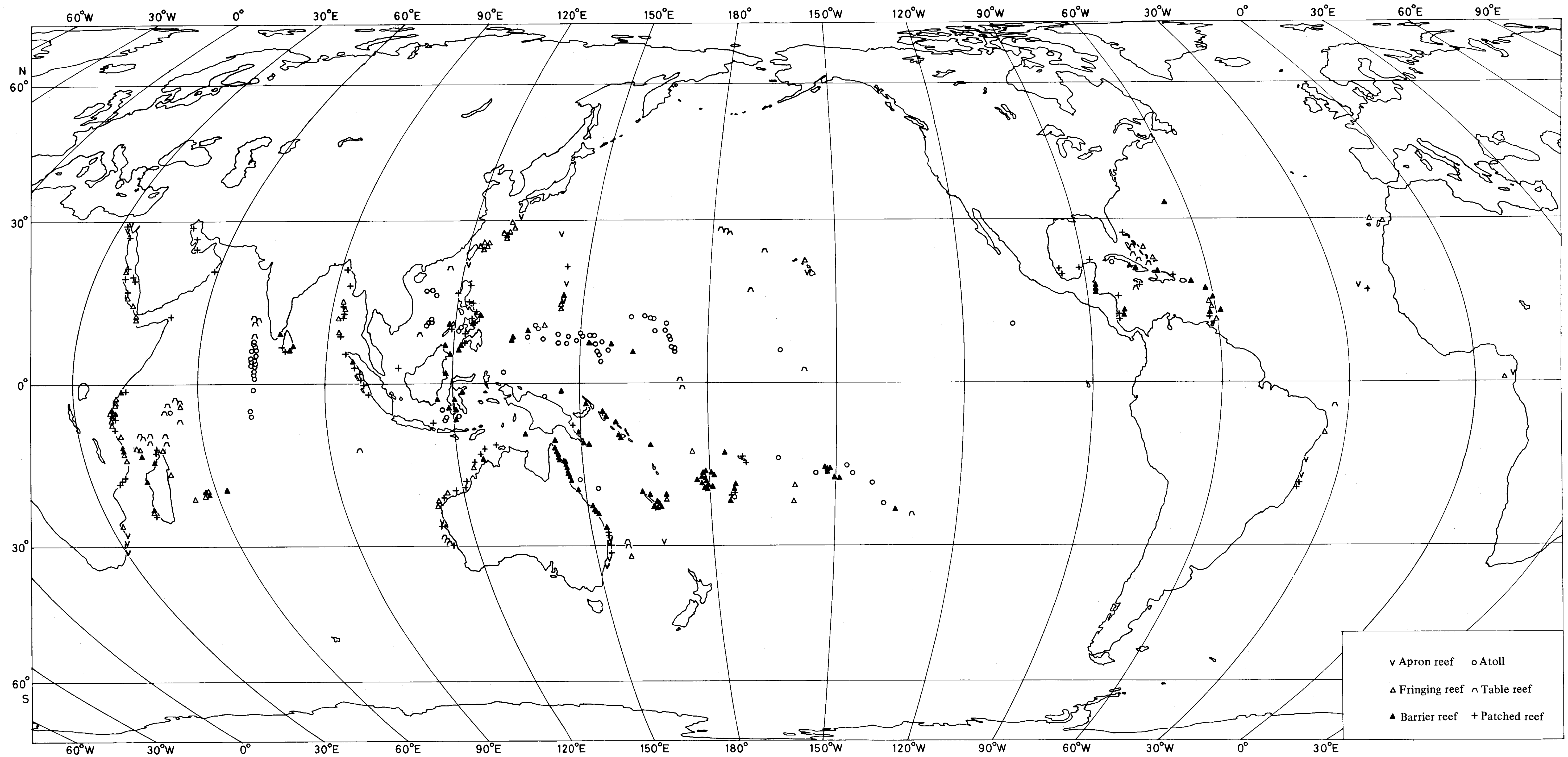

Fig. 8 Geographical variation of reef types in the world

exceeds that of the separated reef edges. The distinction between patched reefs and table reefs thus becomes an issue. However, most table reefs stand on the deep ocean floor and are isolated, and their major axis is generally longer (ca. 10^0–10^1km) than that of patched reefs.

Knolls and pinnacles in lagoons. Tower-like reefs are distributed in wider lagoons. Reefs which constitute a larger topographical unit but are isolated individually, are termed coral knolls (Darwin, 1842; Ladd et al., 1950), or knolls (Stoddart et al., 1966). On the other hand, various smaller reefs which are dispersed behind the reef edges and stand on shallower lagoon floors, are termed coral pinnacles (Gardiner, 1931), patch reefs (Umgrove, 1929), and platform reefs (Fairbridge, 1950). In this paper, however, the knoll and pinnacle only are adopted for short. Each is assessed as far as possible, although the frequent lack of precision in the representation of knolls and pinnacles on charts means that the records represent minimum numerical values.

2.2. Results of measurements

2.2.1. Distribution of measuring sites

The total number of measuring sites amounted to 485. The measured results are summarized in Table 3, and the distribution of measuring points is given in Fig. 3.

The full distribution of coral reefs was almost wholly covered in the measurements. However, although it is desirable that the coral reefs be evenly distributed in the present "potential zone" in order to test the model postulated in this paper, the actual distribution of coral reefs was rather uneven as shown in Fig. 3. Accordingly, it proved difficult to fix completely the boundary of the potential zone of coral reef formation during low stands of sea level and during subsequent high stands of sea level, based only on morphological measurements of the coral reefs.

2.2.2. Depth of reef edge basement (Rd)

The distribution of Rd is shown in Fig. 4. On the basis of geographical units among the oceans and of the tectonics zones, the measuring sites (Fig. 3) may be grouped into the following six regions.

(1) Ryukyu Islands – Philippines – East coast of Australia (sites No. 1–126).
(2) Bonin Islands – New Guinea – Fiji Islands – Tonga Islands (sites No. 127–188).
(3) Hawaiian Islands – Caroline Islands – Marshall Islands – Tuamotu Archipelago (sites No. 189–256).
(4) The Atlantic Ocean (sites No. 257–304).
(5) Western part of the Indian Ocean (sites No. 305–443).
(6) Eastern part of the Indian Ocean (sites No. 444–485).

The geographical variation in Rd is illustrated in Figs. 5-1 to 5-6 for each of the above regions. The following points are apparent from the figures.

Fig. 5-1. The dotted line, which was drawn by tracing the deepest values of Rd, indicates the general trend of its geographical variation. The shallowest values of Rd coincide mostly with the Ldmax of atolls, while the deepest records of Rd vary in the depth range between 100 and 130 meters, and latitudinally between roughly 20°N and 20°S. It is clear that the records of deepest Rd decrease polewards, reaching zero at 30°N and 30°S.

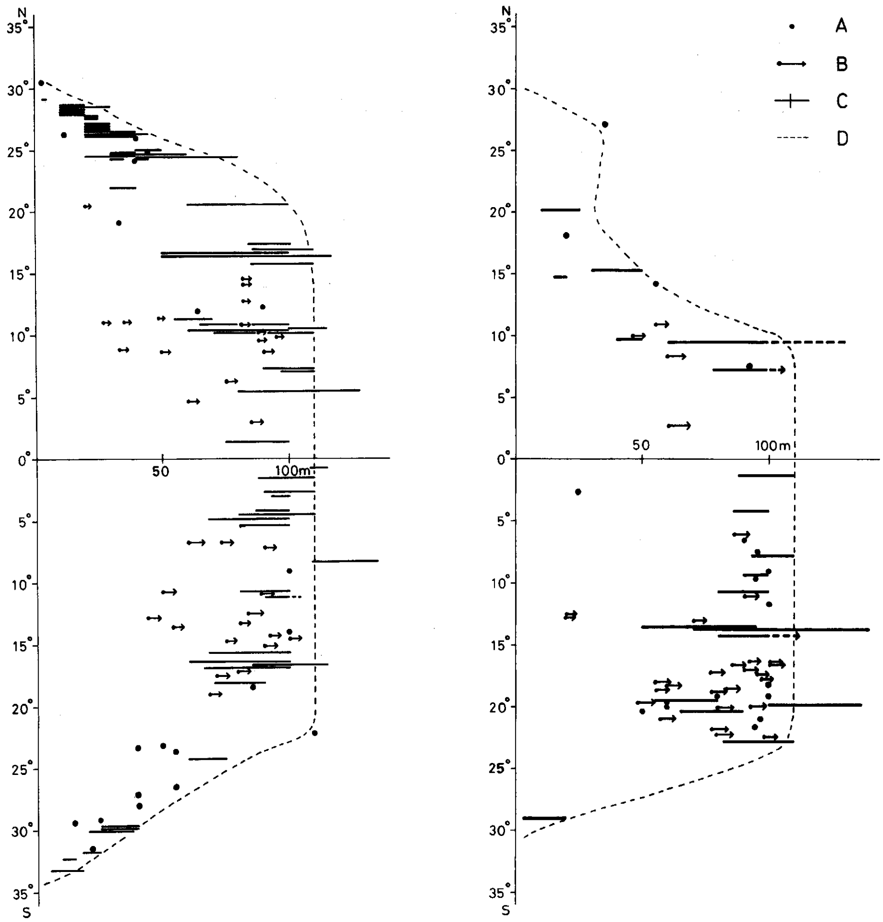

Fig. 5-1 Latitudinal variation of Rd: Nansei Shoto-East coast of Australia (sites No. 1–126)

Fig. 5-2 Latitudinal variation of Rd: Bonin Islands-New Guinea-Fiji Islands-Tonga Islands (sites No. 127–188)

Symbols for Figs. 5-1 to 5-6
A : Rd
B : Ldmax; an arrow means that Rd is deeper than Ldmax
C : Range of Rd
D : General tendency of the deepest Rd values

Fig. 5-2. This figure shows a similar tendency. The deepest records of Rd vary in the depth range between 100 and 130 meters, and latitudinally between 10°N and 23°S, so that the latter range is narrower than in the case of Fig. 5-1.

Fig. 5-3. Here, Rd shows rather varied records due to the discontinuous distribution of islands from north to south. The deepest record of Rd lies in the depth range between 100 and 150 meters, and latitudinally between roughly 17°N and 20°S.

Fig. 5-4. The coral reefs of the Atlantic Ocean are concentrated mostly within the Caribbean Sea. The continental shelves very seldom show ideal profiles, and their outer edge depths (Sd) are generally shallow (about 50 meters). The Atlantic Ocean is considerably different from the Pacific Ocean and the Indian Ocean, as judged from the distribution and topography of its coral reefs. Rd varies remarkably with latitude, and is changeable from east

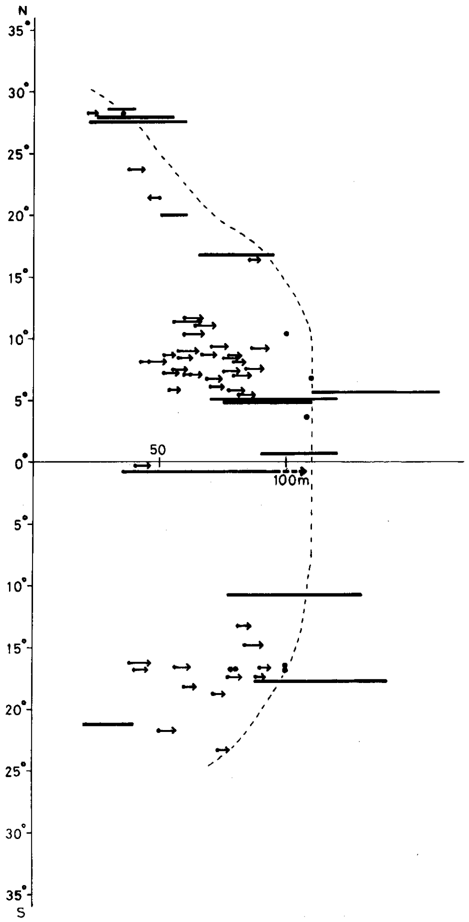

Fig. 5-3 Latitudinal variation of Rd: Hawaiian Islands-Caroline and Marshall Islands-Tuamotu Archipelago (sites No. 189 –256)

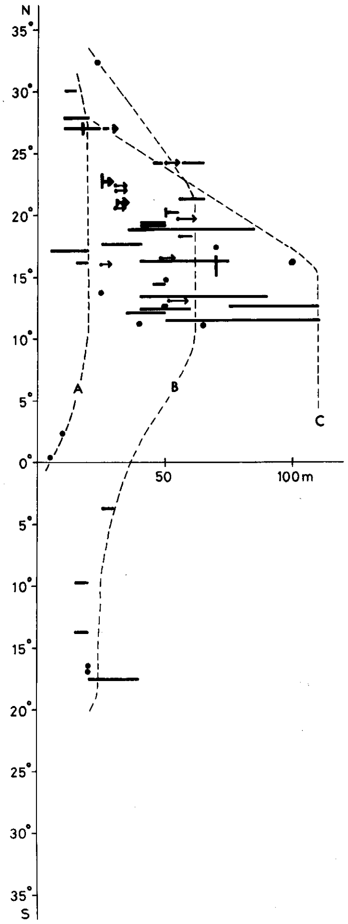

Fig. 5-4 Latitudinal variation of Rd: The Atlantic Ocean (sites No. 257–304)

A : The Eastern Atlantic Ocean
B : The Eastern Caribbean Sea
C : The Western Caribbean Sea

to west. Accordingly, the deepest records of Rd are grouped into the following areas: the Western Caribbean Sea, the Eastern Caribbean Sea to the east coast of South America, and the Eastern Atlantic Ocean. Three dotted lines indicating the deepest records of Rd in each area with latitude are shown in the figure. That in the Western Caribbean Sea shows the greatest records, and there is a very similar trend to the latitudinal variation seen in the Pacific Ocean.

Fig. 5-5. The deepest record of Rd is about 100 meters, and lies in the latitudinal range between 20°N and 15°S. Shallower records of Rd show a rather varied pattern. This situation may be explained as follows. First, the continental shelves in the Red Sea and off East Africa apparently consist of many blocks modified by tectonic factors, and the coral reefs in this area grow on these blocks. Therefore, it is often difficult to distinguish between the depth of the summit of the blocks and Rd. Second, the measuring points along East

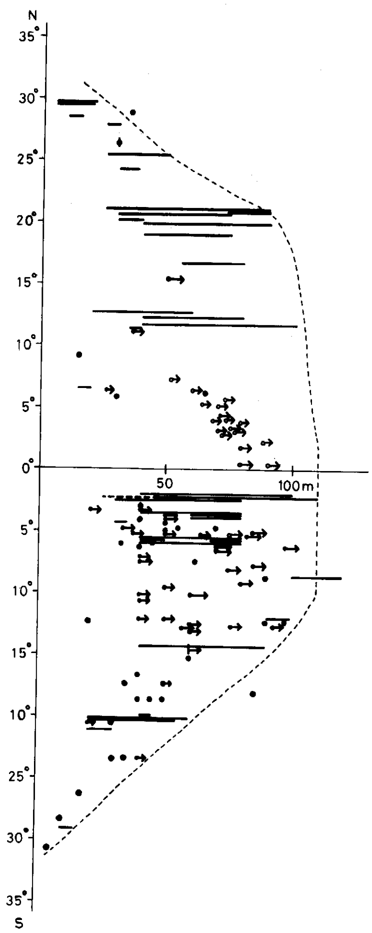

Fig. 5-5 Latitudinal variation of Rd: Western part of the Indian Ocean (sites No. 305–443)

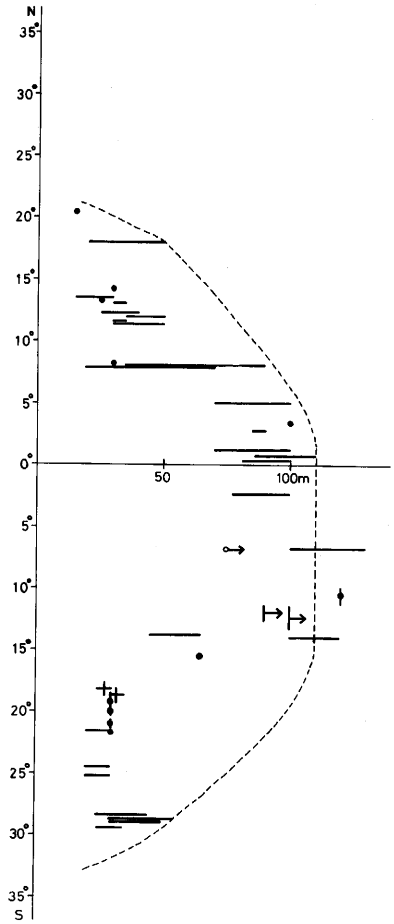

Fig. 5-6 Latitudinal variation of Rd: Eastern part of the Indian Ocean (sites No. 444–485)

Africa include some coral reefs which are directly influenced by sedimentation from rivers.

Fig. 5-6. There are few coral reefs around the Bay of Bengal due to the strong influence of sedimentation from rivers. The deepest range of Rd is therefore between 100 and 120 meters, and the latitudinal range of the deepest Rd is from 5°N to 15°S. Varied Rd values are characteristic of the western coast of Australia.

The results of the above measurements may be summarized as follows. A latitudinal range which maintains constant records of deepest Rd between 100 and 130 meters can invariably be recognized. This latitudinal range is generally wider towards the western part of an ocean, and narrower toward the east.

2.2.3. Width ratio for the coral reef (W-ratio)

The results for the W-ratio are shown in Fig. 6. The geographical variation of the W-ratio is almost equal to that of Rd. North to south variations in the W-ratio are shown in Figs. 7-1

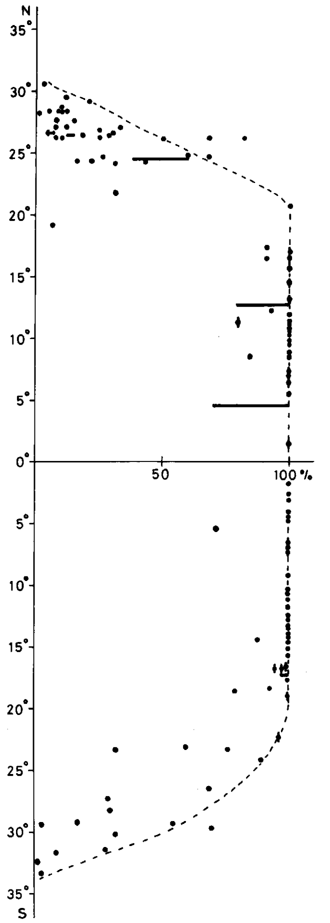

Fig. 7-1 Latitudinal variation of the W-ratio (Covered sites as in Fig. 5-1)

Symbols for Figs. 7-1 to 7-6
A : W-ratio: an arrow means that the expected W-ratio is not less (or greater) than the value indicated by the point
C : Range of the W-ratio
D : General tendency of the largest W-ratio

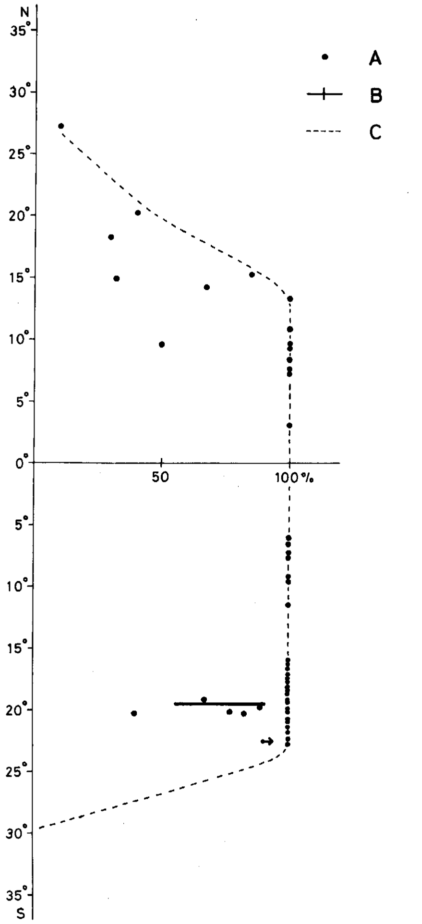

Fig. 7-2 Latitudinal variation of the W-ratio (Covered sites as in Fig. 5-2)

to 7-6 for the same areas as in Figs. 5-1 to 5-6.

The latitudinal range for which the W-ratio is 100% is clearly recognizable in the Pacific Ocean (Figs. 7-1 to 7-3). In Fig. 7-1, it extends between 20°N and 20°S; in Fig. 7-2, between 14°N and 23°S; and in Fig. 7-3, between 20 to 24°N and 24°S. Areas with values lower than 100% but lying within the general range of 100% W-ratio, are the New Hebrides Islands and part of the Tonga Islands between about 19°S and 20°S in Fig. 7-2, and parts of the Fiji and Samoa Islands between about 12°S and 15°S in Fig. 7-3. The coral reefs on the above-mentioned islands are prevented from growing fully and actively since there is

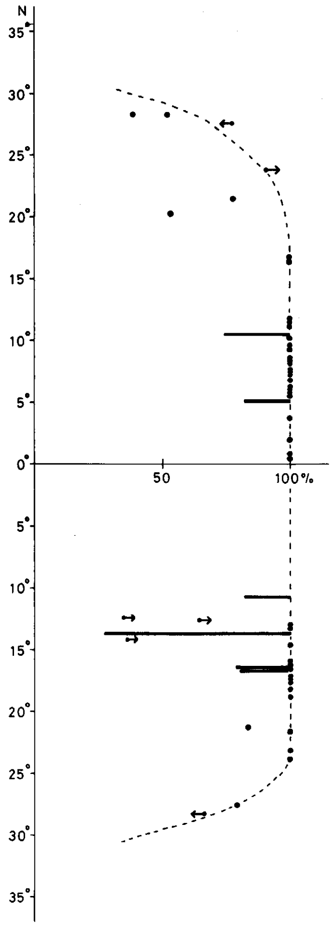

Fig. 7-3 Latitudinal variation of the W-ratio (Covered sites as in Fig. 5-3)

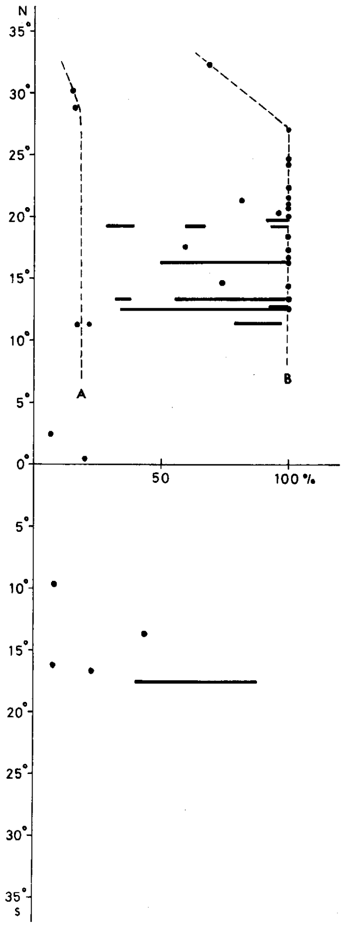

Fig. 7-4 Latitudinal variation of the W-ratio (Covered sites as in Fig. 5-4)

A : Eastern part of the Atlantic Ocean
B : The Caribbean Sea

insufficient suitable space for the reefs on the volcanic islands with steep slopes. Successive sedimentation also tends to preclude flourishing coral growth. The lateness in providing a basement for coral reef formation is significant in areas of relatively recent volcanic activity, such as parts of the New Hebrides Islands. The W-ratio successively decreases from the outer range of 100% W-ratio to zero percent at 30°N and 30°S.

In the Atlantic Ocean (Fig. 7-4), the latitudinal range of 100% W-ratio extends up to the Bahama Islands (27°N), and this is the highest latitude where 100% is attained. The W-ratio falls below 20% along the western coast of Africa, and below 44% along the coast of South America. The W-ratio at measuring site No. 274 indicates values of 44% to 88%, since the continental shelf is shallow up to the shelf edge but has high relief.

In the Indian Ocean, the latitudinal range of 100% W-ratio extends between 20°N and

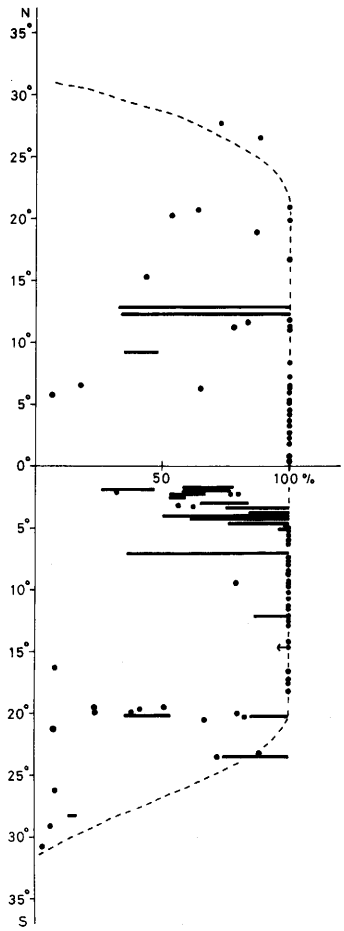

Fig. 7-5 Latitudinal variation of the W-ratio (Covered sites as in Fig. 5-5)

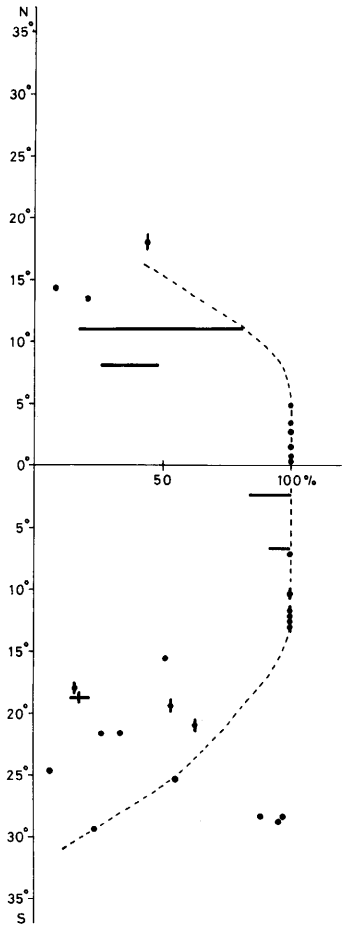

Fig. 7-6 Latitudinal variation of the W-ratio (Covered sites as in Fig. 5-6)

20°S in the western part (Fig. 7-5) and between 5°N and 14°S in the eastern part (Fig. 7-6). This pattern is very similar to the trend in Rd variation (cf. Figs. 5-5 and 5-6). The W-ratios between 12°N and 20°N in the Red Sea, and between 3°S and 7°S off East Africa are exceptional (see Figs. 6 and 7-5). The reason may be that the undulating continental shelves caused by tectonic movements often prevent attainment of the ideal (100%) W-ratio.

The variable W-ratios indicated between 5°N and 7°N off Sri Lanka, and between about 2°S and 3°S off northern Kenya, East Africa, may be attributed to sedimentation from rivers. The same cause may explain why the northern limit of the 100% W-ratio lies southward at almost 5°N in Fig. 7-6.

Abrolhos reef off the western coast of Australia at 28°N to 29°S (measuring sites No. 482, 483 and 484) shows a high W-ratio of 88% to 97% in Fig. 7-6. This is apparently an exception, and may be explained by the presence of an exposed core of pre-Cambrian granite which offers a better foothold for coral growth than the sands and calcareous

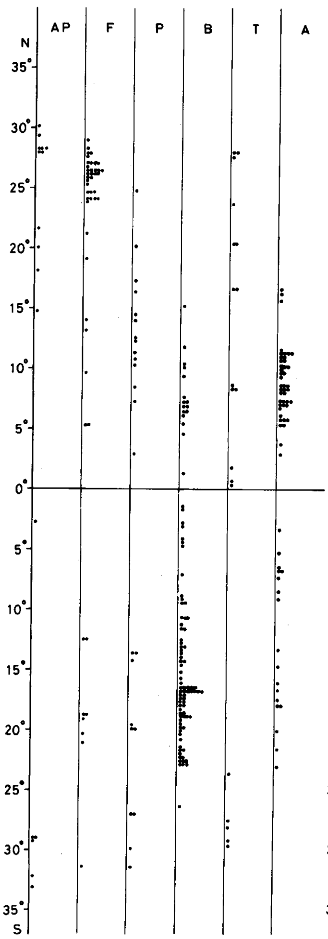

Fig. 9-1 Latitudinal variation of reef types: The Pacific Ocean

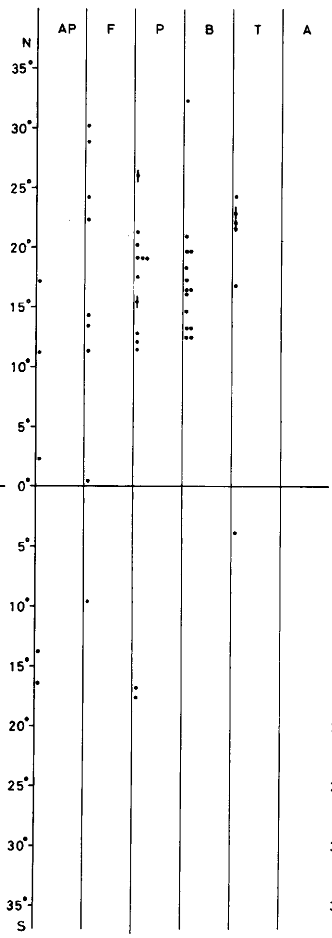

Fig. 9-2 Latitudinal variation of reef types: The Atlantic Ocean

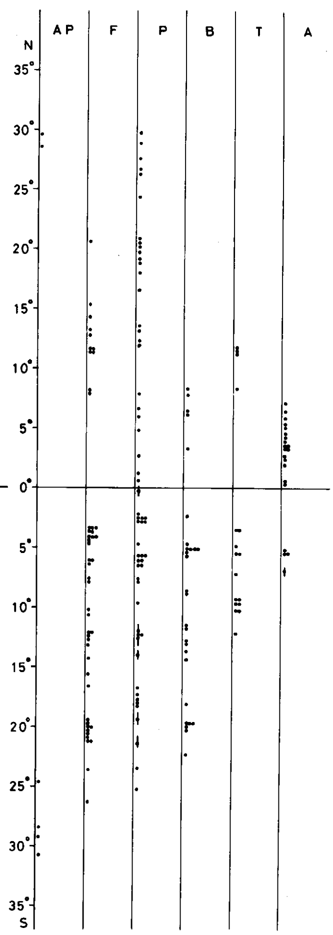

Fig. 9-3 Latitudinal variation of reef types: The Indian Ocean

AP: Apron reef, F: Fringing reef, P: Patched reef, B: Barrier reef, T: Table reef, A: Atoll

sandstones which are prevalent along this coast (Fairbridge, 1950, p. 370).

2.2.4. Reef types

The worldwide distribution of observed reef types is shown in Fig. 8. Among the 485 measuring sites, there were 30 apron reefs (6.2%), 98 fringing reefs (20.2%), 23 almost-barrier reefs (4.7%), 112 barrier reefs (23.1%), two almost-atolls (0.4%), 77 atolls (15.7%), 24 almost-table reefs (5.0%), 20 table reefs (4.1%) and 99 patched reefs (20.4%). The latitudinal variations of each reef type in the Pacific, Atlantic and Indian Oceans are shown in Figs. 9-1 to 9-3. In both Fig. 8 and Fig. 9, the barrier reefs, atolls including almost-atolls, and table reefs including almost-table reefs are included. Each reef type shows a rather systematic distribution, especially against latitude.

In Figs. 9-1 and Fig. 9-3, apron reefs are distributed in the peripheral seas at around 30°N and 30°S. Fringing reefs are distributed between 5°N and 29°N, and between 12°S and 31°S in the Pacific Ocean, while they occur between 8°N and 21°N, and between 3°S and 26°S in the Indian Ocean. There is no distribution of barrier reefs and atolls that is completely continuously across the equatorial seas. However, the barrier reefs are concentrated in the range between 15°N and 26°S in the Pacific Ocean, and between 8°N and 22°S in the Indian Ocean, and the atolls are concentrated in the range between 17°N and 23°S in the Pacific Ocean, and between 7°N and 7°S in the Indian Ocean.

The distribution of patched reefs extends over the whole range of coral reef occurrence. Patched reefs are frequently found in discontinuous parts of the fringing reef and barrier reef distributions. Table reefs appear in the range between 28°N and 30°S in the Pacific Ocean, and between 12°N and 12°S in the Indian Ocean. Those off the western coast of Australia at 28° to 29°S may be exceptional, as mentioned in the previous section. Table reefs are characterized by their wider range of cover than atolls.

In the Atlantic Ocean (Fig. 9-2), there are no remarkable systematic relationships among the reef type distributions. However, barrier reefs and patched reefs appear in the center of the Caribbean Sea, and fringing reefs and apron reefs occur off the coasts South America and western Africa.

Another problem to be considered is the distribution of reef types which have no connection with latitudinal gradient.

Carefully judgment of Fig. 8 indicates that apron reefs, fringing reefs, patched reefs and barrier reefs almost always appear on the shelves of continents and volcanic islands. On the other hand, some patched reefs, table reefs, and atolls are scattered in the oceans and marginal seas.

In conclusion, it can be said that atolls are distributed only in lower latitudes, whereas table reefs are found from lower latitudes to higher latitudes. Atolls having very discontinuous reef rims, and those having no reef rims but only knolls in lagoons, are defined as patched reefs. These patched reefs are distributed in the peripheral zone of coral reef formation.

2.2.5. Distribution of knolls and pinnacles

The accuracy of representation of knolls and pinnacles in charts needs careful consideration since it varies with the minuteness or roughness of the sounding data, and with the manner of expression on each chart or scale of chart. As a result, the quantity of knolls and pinnacles was estimated according to the procedure mentioned in section 2.1.4.b., and the cumulative curve is shown in Fig. 10. Based on this curve, the quantity of knolls and pinnacles may be divided into three groups: below 5, 5 to 19, and 20 or over. The latitudinal variation in the distribution of knolls and pinnacles is illustrated in Figs. 11-1 and 11-2. The following points may be drawn from these figures. First, the distribution of pinnacles which are of smaller topographic order than the knolls, has a relatively wide range from 30°N to 30°S (see the distribution "20 and over" in Fig. 11-1). Second, the knolls are distributed in a narrower range between 17°N and 24°S in the Pacific Ocean, and between 7°N and 14°S in the Indian Ocean. Most are limited to the lower latitudes. Third, scattered knolls and pinnacles show a higher concentration in the range between about 20°N and 24°S in the

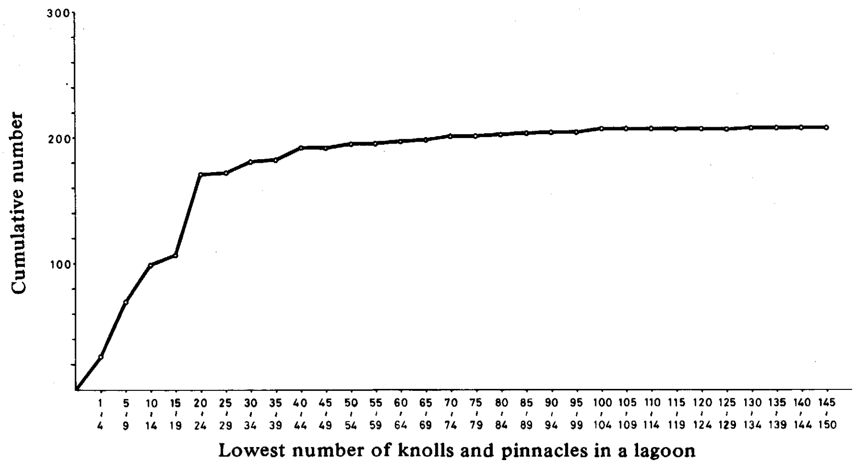

Fig. 10 Cumulative curve for the lowest number of knolls and pinnacles in a lagoon

Pacific Ocean, and between about 8°N and 15°S in the Indian Ocean.

3. DISCUSSION

The geographical variation in the topography of coral reefs is discussed here on the basis of measured Rd and W-ratio values. The oceanic ranges, on which coral reefs may grow during low stands of sea level and during high stands, will be discussed using the integrated results for Rd and the W-ratio, and the postulated model will be tested as a result.

3.1. Relationships between coral reefs, sea level changes and fluctuations in the sea surface temperature

3.1.1. Relationship between Rd and the W-ratio

Comparing the latitudinal variation of Rd in Figs. 5-1 to 5-6 with that of the W-ratio in Figs. 7-1 to 7-6, the deepest range of Rd (100 to 130 meters) can be seen to coincide almost with the range of 100% W-ratio, and both parameters decrease polewards at a similar gradient towards 30°N and 30°S. However, slight differences in latitudinal range of about 5° can be discerned. For example, the range of 100% W-ratio terminates at about 14°N in Fig. 7-2, although the range of Rd = 100 to 110 meters extends to about 10°N in Fig. 5-2. The same W-ratio in Fig. 7-3 extends from 20 to 24°N to 24°S, although the same Rd in Fig. 5-3 extends from 17°N to 20°S. Also, the same W-ratio in Fig. 7-5 extends from 20°N to 20°S, although the same Rd in Fig. 5-5 extends from 20°N to 15°S.

Based on Fig. 5-4, the northern limit of Rd = 100 to 110 meters lies at 16°N, but that of the 100% W-ratio in Fig. 7-4 lies at about 27°N. The reason for this particular difference will be mentioned later.

Comparing the geographical distribution of Rd in Fig. 4 with that of the W-ratio in Fig. 6, it can be seen that the area covered by Rd = about 100 meters is almost coincident with that having a W-ratio of 100%. However, Rd represents the vertical dimension of the solid

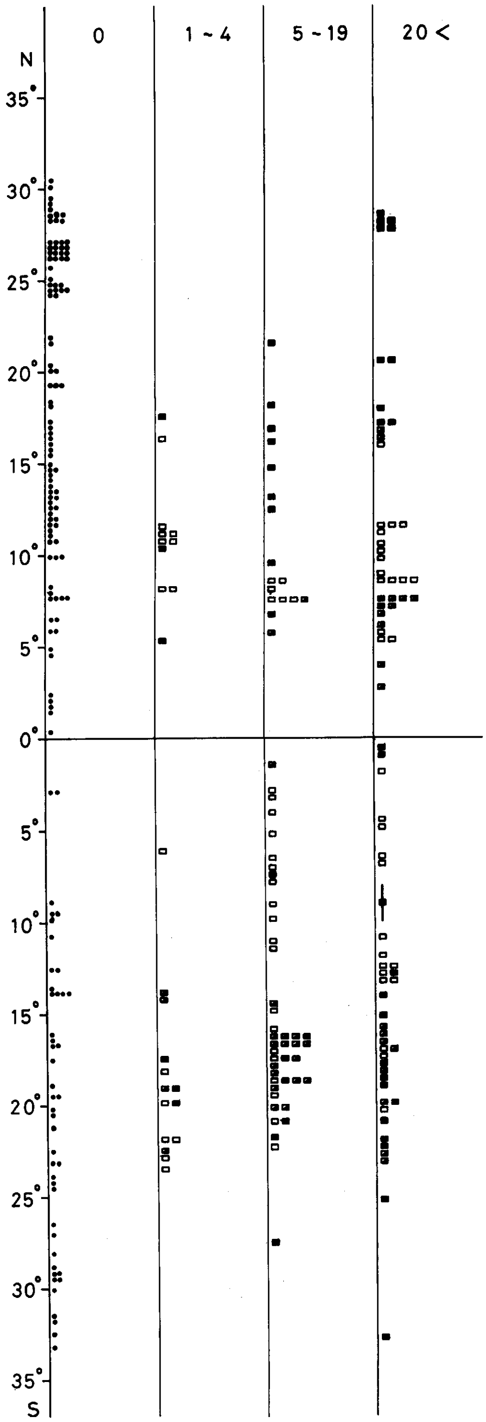

Fig. 11-1 Latitudinal variation in the number of knolls and pinnacles: The Pacific and Atlantic Oceans

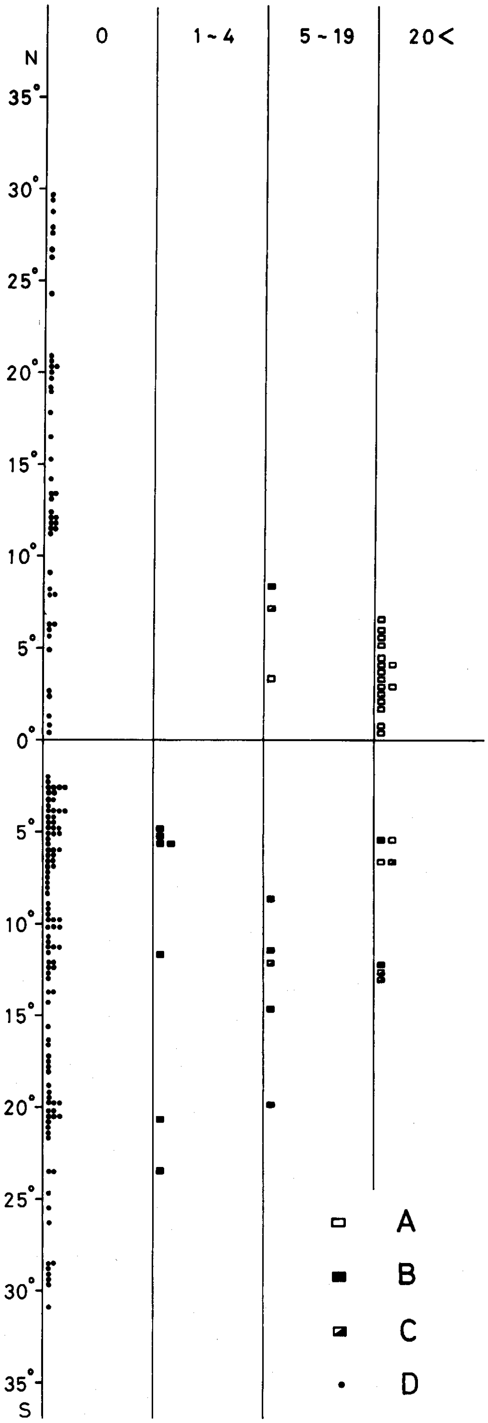

Fig. 11-2 Latitudinal variation in the number of knolls and pinnacles: The Indian Ocean

Symbols for Figs. 11-1 and 11-2
A: Knolls B: Pinnacles C: Knolls and pinnacles D: Without knolls and pinnacles
One symbol corresponds to one measuring site

form of coral reefs, and the W-ratio gives their horizontal extent. The two parameters are thus quite different from each other in a qualitative sense, in spite of the above-mentioned areal coincidence. This is a very important fact. An Rd value of about 100 to 130 meters implies coincidence with the value of Sd (see data in Table 3). Shepard (1948, 3rd ed., 1973, p. 277) also showed a similar value for the average depth of shelf edges in the world. On the other hand, a W-ratio of 100% means that Rw coincides with Sw, implying that the coral reefs begin to grow at the shelf edge. When Rd and the W-ratio both decrease towards 30°N and 30°S at a similar gradient, it can be considered that the basement of the reef walls becomes shallower towards the higher latitudes, and that the widths of the coral reefs narrow polewards. This geographical evidence exactly supports the model postulated in section 1.3.4.

According to this model, the latitudinal range of an Rd of about 100 meters and of a 100% W-ratio should indicate the oceanic zone in which coral reefs are able to maintain growth even during the lowest stand of sea level. This zone would then expand towards higher latitudes on any subsequent rise in sea level. The measured results must be constantly checked against the postulated model.

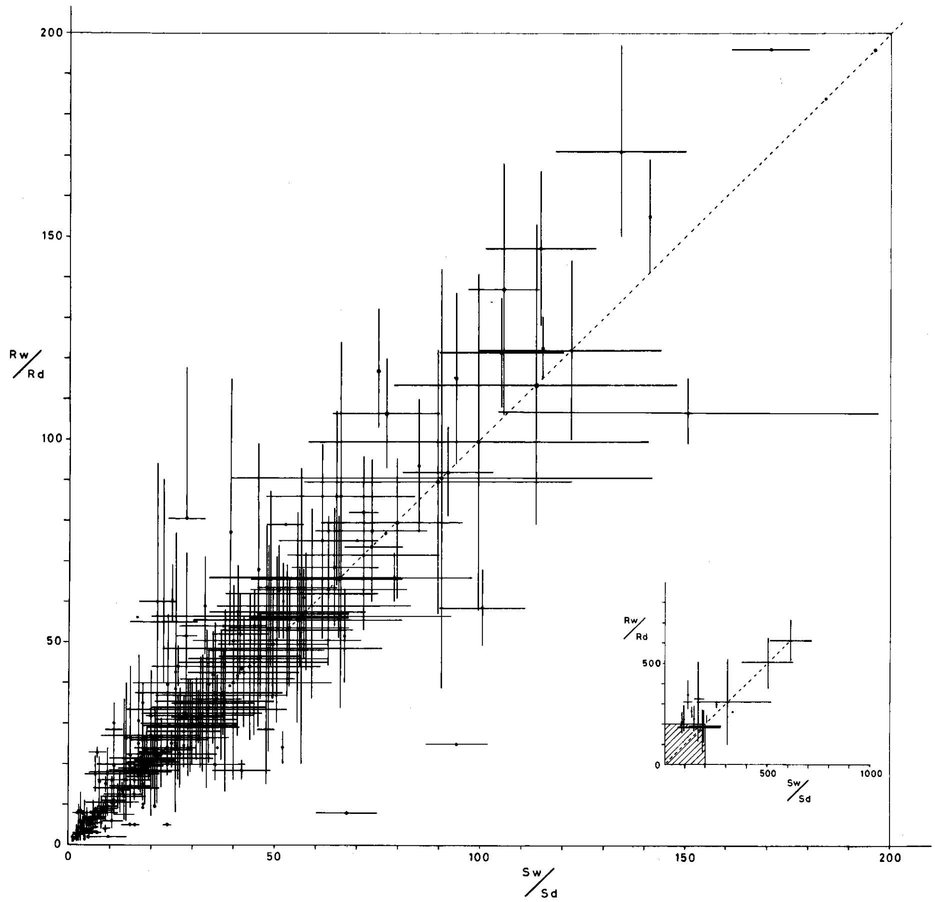

Fig. 12 Relationship between Rw/Rd and Sw/Sd

3.1.2. Relationship between Rw/Rd and Sw/Sd

Assuming that the coral reefs grow on an ideal shelf which has a completely smooth surface of gentle and even gradient and remains unifluenced by crustal movements, and that the lowest stand of sea level barely coincides with the depth of the shelf edge (Sd), then the direct relation Rw/Rd = Sw/Sd is possible in a geometrical sense. Values of Rw/Rd and Sw/Sd were calculated, and are shown in Fig. 12 plotted on the ordinate and abscissa, respectively. A good approach to Rw/Rd = Sw/Sd is clearly apparent in the figure, although there is an apparent divergent tendency, away from the origin, due to the chart scale.

The following summarizes various results obtained from Fig. 12. First there is a group of measuring sites (No. 229, 231, 260, 261, 274, 314, 417, 475, 481, 482, 483 and 484) where Rw/Rd clearly exceeds Sw/Sd, and it is interesting to note that they all mark coral reefs of the type found on convex, undulating shelves. Second, there is also a group of measuring sites (No. 42, 270, 272, 400, 407, 422, 474 and 485) were Sw/Sd clearly exceeds Rw/Rd, and these coral reefs are characteristically found on concave, undulating shelves.

The above two groups may be exceptional as a whole, and they represent a very

Table 1 Deep borehole data for coral reefs

Location	Total depth	Total sediments	Post-Miocene sediments	Quaternary sediments	References
	m	m	m	m	
Bermuda	427 33 & 43	171 21-24	171 21-24	ca. 75 –	Pirsson et al. (1913) Pirsson (1914) Newman (1959)
Midway Is.	168 & 500.9	381.4	140.8	–	Ladd et al. (1967)
Kita Daito Jima	432	432+	103	–	Sugiyama (1934) Ota (1938) Hanzawa (1940)
Bikini	778	778+	213	–	Emery et al. (1954)
Eniwetok	1,286 1,411 & 390	1,405	187	–	Ladd et al. (1960) Schlanger (1963)
Funafuti	348 –	348+ 550-760	348+ –	45-50+ –	Roy. Soc. (1904) Gaskell et al. (1953)
New Caledonia	226	225	–	70-130	Avias et al. (1967) Chevalier (1973)
Great Barrier Reef (general)					Lloyd (1973) Maxwell (1973)
Michaelmas cay	183	–	–	73-130	Lloyd (1973) Maxwell (1973)
Heron Is.	223	223+	136-154	131-154	Richard (1938) Richard et al. (1942)
Wreck Is.	578	548	ca. 290	121-161.5	Travis (1960)
Tahiti	–	90-100	–	90-100	Deneufbourg (1971) Chevalier (1973)
Mururoa	461 576 193	438 415 193+	–	ca. 100	Chauveau et al. (1967) Chevalier (1973)

interesting problem from the viewpoint of actual crustal movements. There is in fact no other significant deviation from the ideal straight line. The above evidence indicates a close relation between the topography of the coral reefs and the shape of the shelves.

3.1.3. Thickness and age of reef limestones as indicated by borehole data

Borehole data are useful for confirming whether the geographical variation in thickness of reef limestone indicated by the postulated model is valid or not. However, available borehole data for coral reefs are not always adequate, as shown in Table 1. The total sediments covered by deep borehole data at atolls have often been introduced to support Darwin's subsidence theory. On the other hand, the borehole data provide ample evidence of interruptions in sedimentation and fluctuations in sea level.

Based on Table 1, the thickness of the Quaternary reef limestones is 70 to 160 meters (mean thickness, 100 to 110 meters). Such values are almost equal to the deepest value of Rd.

Interruptions in sedimentation are often found in the higher Quaternary reef limestones and the uppermost interruption is called the Thurber discontinuity (Stoddart, 1969). Such interruptions may correspond to times when karst topography was formed at low stands of sea level. However, transgression facies are clearly indicated in the Quaternary reef limestones as a whole. The next point to be discussed is then whether the thickness of reef limestone can be explained in terms of the amount of sea level change and the relation between the rate of sea level change and the rate of coral reef formation, and by the relation between changes in sea surface temperature and the extent of coral reef formation.

3.1.4. Amount and rate of sea level changes and fluctuations in sea surface temperature

Various results and interpretations have been given for the amount and rate of sea level changes during the Quaternary (Guilcher, 1969). Recently, comparable results for the absolute height and ages of high stands of sea level since 100,000 to 130,000 Y.B.P. have been obtained (Mesolella et al., 1969; Steinen et al., 1973; Veeh et al., 1970; Chappell, 1974; Bloom et al., 1974; Konishi, 1967; Konishi et al., 1974; Machida et al., 1971, etc). Based on these results, the sea level at least since 130,000 Y.B.P. up to the present, has never exceeded the present sea level by as much as 10 meters.

On the other hand, the following data have been given for the amount of lowering of the sea level against its present level. At Barbados Island, the amount of lowering of the sea level was estimated at 65 to 75 meters on the basis of two raised coral reefs dated at 125,000 Y.B.P. and 105,000 Y.B.P., respectively (Steinen et al., 1973). In New Guinea, it was estimated at 65 to 75 meters on the basis of two raised coral reefs between the VI terrace and VII terrace, but at 120 to 135 meters between the I terrace and II terrace (Bloom et al., 1974). In kenya, East Africa, it was estimated at about 100 meters on the basis of the thickness of each of the terrace sediments (Hori, 1970; Toya et al., 1973).

On the other hand, the amount of sea level changes has also been calculated from fluctuations in the volume of glaciers from the viewpoint of glacial eustasy (Daly, 1934; Flint, 1947; Donn et al., 1962; Toya, 1966, etc.). Donn et al. estimated the lowest sea level during the Quaternary as about 138 to 160 meters below the present level. Toya calculated the lowest sea level during the Wurm as 135 meters below the present level. The other estimated difference was 80 to 120 meters. These values calculated on the basis of the volume of terrestrial glaciers are roughly equivalent to the amount of sea level change obtained from the submarine topography and shelf geology. Accordingly, the idea of glacial eustasy is supported by the available evidence.

The amount and rate of sea level changes are well known for the post-glacial transgression (Godwin et al., 1958; shepard, 1960, 1961, 1964; Jelgersma, 1961, 1966; Helfrich et al., 1965; Emery et al., 1967; Fujii et al., 1967; Milliman et al., 1968; Bloom, 1971, etc.). The transgression is considered to have begun at 19,000 to 15,000 Y.B.P. and to have almost attained the present sea level at 5,000 to 8,000 Y.B.P.. The overall amount of postglacial transgression was about 80 to 130 meters. The rate of transgression has been estimated at 0.6 mm/year (Emery et al., 1954) or 3 to 4 mm/year (Helfrich et al., 1965), but it is usually considered now as 5.7 mm/year at minimum and 18.5 mm/year at maximum.

The difference between the highest and lowest stands of sea level during the Quaternary due to the fluctuation of glaciers appears to be as great as the maximum value for Rd. However, our knowledge of the magnitude of the sea level changes occuring during the entire Quaternary period is still far from complete. Hence, its value will be estimated indirectly, and similar results are expected from the range of fluctuations in the δO^{18} curve obtained from deep-sea cores (Emiliani, 1955, 1958, 1966, 1971, Emiliani et al., 1963, etc.). The fluctuations in sea surface temperature with sea level changes are considered as a related problem.

It is estimated that the present pattern of geographical variation in sea surface temperature may resemble closely that at each interglacial stage during the Quaternary, and that the fluctuations in sea surface temperature have roughly followed the sea level changes. This is indicated by results for the O^{18}/O^{16} ratios of planktonic and pelagic foraminiferal species in deep-sea cores (Emiliani, 1966, 1971).

The overall amplitude of the glacial-integlacial sea surface temperature variations in lower latitudes as estimated by oxygen isotope analysis is 2°C to 8°C. Individual figures are 7°C to 8°C for the Caribbean Sea, 5°C to 6°C for the equatorial Atlantic Ocean, and 3°C to 4°C for the equatorial Pacific Ocean (Emiliani, 1955, 1958; Emiliani et al., 1963; Emiliani, 1971). Other authors have given values of 2°C for the equatorial Atlantic Ocean (Dansgaard et al., 1969), and about 6°C for the Indian Ocean (Oba, 1969).

On the other hand, Biewald (1973) has considered the geographical variations in reef edge depth (equivalent to the Rd in this paper) obtained from charts. He concluded that coral reefs were able to grow during the last glacial age in the seas bounded by the iso-depth line of 100 meters. The sio-depth line of 100 meters may be equal to the iso-thermal line of 18°C: this temperature is the lowest sea surface temperature which permits the growth and development of coral reefs. The last-glacial and post-glacial sea surface temperature amplitude may thus be obtained by subtracting 18°C during the last glacial age from the present sea surface temperature at the points of intersection between the iso-depth line of 100 meters and the present iso-thermal sea temperature lines. This method is the same as that used in the author's model explaining the coral reef distribution in the western Indian Ocean (Toya et al., 1973).

However, some question must arise over Biewald's consideration of the iso-depth line of 100 meters (Rd in this paper) as the low stand of sea level only during the last glacial age. It implies that the deepest values of Rd not only represent the low stand of sea level during the last glacial age but also the lowest stand of sea level throughout the Quaternary period. This will be clarified in the subsequent discussion. As a result, the chilling of the sea temperature during the glacial ages probably did not exert such a severely adverse influence on coral reef formation at least in low latitudes.

3.1.5. Growth rate of coral reefs

The growth rate of coral reefs is usually estimated by one of the following four methods (Stoddart, 1969): (1) measurements on individual coral colonies during a fixed period, (2) calculation from the rate of precipitation of calcium carbonate in coral skeletons, (3) direct observation of geomorphological changes in coral reefs during a fixed period, and (4) calculation from the rate of sedimentation of reef limestone based on borehold cores. In this paper, the two aspects of coral colony growth and coral reef growth are considered separately.

a. Reef coral colonies

Helfrich et al. (1965) have summarized the growth rate of coral colonies as follows using the many data obtained by Vaughan et al. (1943). (1) Greater rates occur where the average annual temperatures are higher. (2) Growth is faster in the Indian Ocean than in the Pacific Ocean, and faster in the Pacific Ocean than in the Atlantic Ocean. (3) Growth is faster for the more porous species than the dense, unbranched forms. Item (1) reflects the latitudinal gradient in coral growth rate indicated by Ma (1934), Yonge (1940), Hamada (1963) and Lewis (1968). For example, the growth rate of *Favia speciose* is about half in the northern peripheral sea when compared to the equatorial sea.

Recently, a new method for determination of coral growth rates has been developed using a radiometric technique (Moore et al., 1973).

On the other hand, as mentioned by Glynn (1973), the sighificance of the measured data and site of the coral colonies in the entire ecological setting must always be considered when growth rates of corals are calculated. Judging from the rates given by various authors, the upward growth rate of coral colonies is generally within the range of 5 to 100 mm/year, although the maximum recorded growth rate in the world is the 266 mm/year observed in *Acropora cervicornis* in Jamaica (Lewis, 1968).

b. Coral reefs

Measured upward growth rates of coral reefs are listed in Table 2. Most values were obtained by dividing the thickness of the reef limestones by the C-14 radiometric ages. The calculations used thin reef limestones of the Holocene. It may be concluded from Table 2 that the general range of growth rates of coral reefs is 0.7 to 8.5 mm/year, although the data refer only to a very short period of the Quaternary. On the other hand, the average upward growth rate since the Tertiary is only 0.2 mm/year, as calculated from deep borehole data at the Bikini and Eniwetok Atolls. The reason for this small overall growth rate must be that the reefs have experienced several periods of subaerial erosion. There is insufficient data on the growth rates of coral reefs in relation to thermal gradients, although this problem must also be discussed in the future from the above viewpoint.

As mentioned, the upward growth rate of coral colonies is some 5 to 100 mm/year, and that of coral reefs has been some 0.7 to 8.5 mm/year at least for the last 10^3 years. The

Table 2 Upward growth rates of coral reefs

Location	Upward growth rate (mm/year)	Dated cited	References
Bermuda	ca. 1.2 1.875	3.5m/2,980y 6m/3,200y	Ginsburg et al. (1971) Frazier (1970)
Florida Keys	4.270–8.549	7ft/250-500y	Hoffmeister et al. (1964)
North Jamaica	1.2	1.2m/1,000y	Goreau et al. (1974)
British Honduras			Purdy (1974)
Spanish cay	1.5-1.6	1.5-1.6m/1,000y	
Tobbaco cay	0.7-1.5	0.7-1.5m/1,000y	
Spruce cay	4.2-4.6	4.2-4.6m/1,000y	
Colson cay	1.1-1.5	1.1-1.5m/1,000y	
Laughing Bird cay	2.2-7.8	2.2-7.8m/1,000y	
Nuevo & Alacran Reef, Yucatan shelf	1.8-3.7	60-120ft/9,000y	Logan et al. (1969)
Eniwetok Atoll	1.82-3.35	6-12ft/1,000y	Thurber et al. (1965)
Hanauma Reef, Oahu, Hawaii	3.333	1m/300y	Easton et al. (1976)

growth rate of coral colonies indicates the local growth rate in the coral reef. It may thus be regarded as representing the maximum growth rate of coral reefs and be compared with the rising rate of sea level during the Holocene. In general, the growth rate of coral colonies is roughly equal to or higher than the rate of change of sea level, but the growth rate of coral reefs is equal to or less than the rate of the sea level change. The above-mentioned circumstances seem to be reflected in the fact that reef limestones of the Holocene usually form a relatively thin veneer, as shown at various localities (e.g. Purdy, 1974, 1974a).

It has obviously been difficult for coral reefs to keep up continuously with the higher rates of transgression during the Holocene. However, a variety of rates of sea level changes may be considered during the Quaternary period, although the details are unclear. Present coral reef limestones reflect the superimposition of all sea level changes during the Quaternary.

3.1.6. Crustal movements and coral reefs

Crustal movements are discussed next in order to evaluate the extent of their influence on the results of measurement. The relation between crustal movements and sea level changes in regions with coral reefs has been discussed precisely in the Barbados (Mesollela et al., 1969, etc.), New Guinea (Veeh et al., 1970; Chappell, 1974; Bloom et al., 1974) and Kikai Island (Konishi, 1967; Konishi et al., 1968, etc.) on the basis of the results of coralline radiometry of Th-230 and Rd-231 and the C-14 decay method. The amounts of crustal movement based on the palaeo-sea level dated at 125,000 Y.B.P. are shown in Fig. 13. The regions in the figure which show a higher rate of crustal movement (0.2 to 3 mm/year) are New Guinea, Kikai Island and the Barbados. They are all located in the subduction zone of arc-trench systems (Chappell, 1974). However, it is only very limited regions of the world that display higher rates of crustal movement.

On the other hand, the oceanic atolls categorized as (c) in Fig. 13 are subsiding at rates of

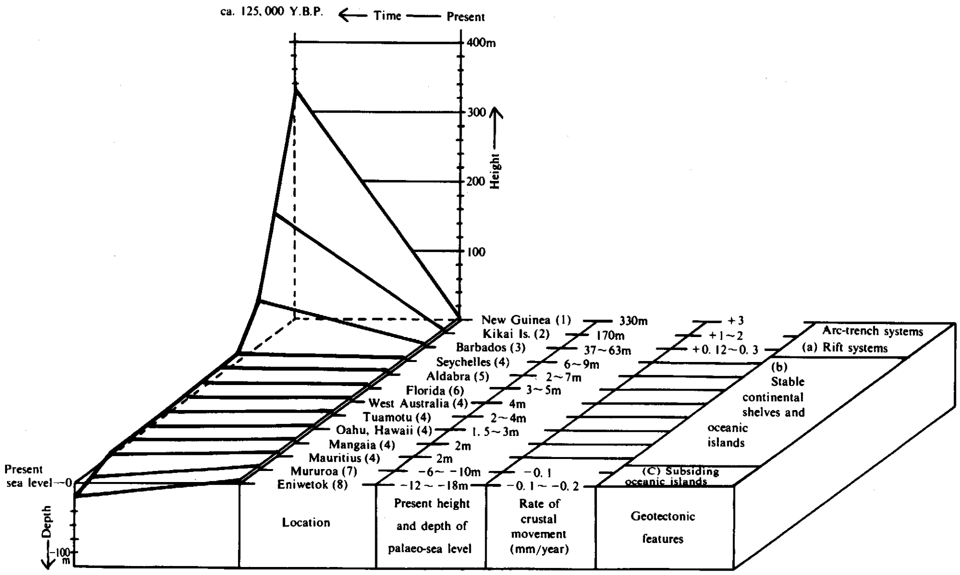

Fig. 13 Amounts of crustal movement derived from the present height and the depth of the palaeo-sea level dated at ca. 125,000 Y.B.P.

(1) Bloom et al. (1974) (2) Konishi (1967) (3) Mesolella et al. (1970) (4) Veeh (1966) (5) Thompson et al. (1972) (6) Osmond et al. (1965), Broeker et al. (1965) (7) Lalou et al. (1966) (8) Thurber et al. (1965)

some 0.1 to 0.2 mm/year or less. In these cases, both the rate of sea level changes during the Quaternary and the growth rate of coral reefs are higher than the rate of crustal movements above. The category (b) may have been the stablest, at least since 125,000 Y.B.P.

The values of Rd are more variable than those of the W-ratio (Figs. 5 and 7). Some influence from crustal movements is anticipated; however, the data are influenced by the scale and accuracy of the charts used, so that future studies based on data from other sources are required. In this paper, Rd values measured at localities with a high rate of crustal upheaval may be judged as minimum values for those localities.

In general, the geographical variation of Rd corresponds closely to that of the W-ratio. Moreover, the proportional relation, $Rw/Rd \fallingdotseq Sw/Sd$, has been positively tested in Fig. 13. Judging from these facts, crustal movements do not represent a major factor in testing the postulated model, although they should never be ignored.

3.1.7. Sea level changes controlling the formation of coral reefs: the core zone and the peripheral zone

It has been clarified by the discussion of measured results above that the formation of coral reefs has been under the direct control of sea level changes and fluctuations in sea surface temperature during the Quaternary period. The postulated model has been tested as a more general explanation of the geographical distribution of coral reefs than in our previous paper (Toya et al., 1973). According to the model, the latitudinal range shown by Rd values of about 100 meters and a W-ratio of 100% marks the sea area where coral reef formation continued even during low stands of sea level in the glacial ages. This area is named the "core zone" of coral reef formation. On the other hand, the area between the core zone and the extreme northern and southern limits of recent coral reef distribution is named the "peripheral zone". It consists of a northern zone in the northern hemisphere and a southern zone in the southern hemisphere. This peripheral zone may be roughly correlated with the marginal belt defined by Davis (1923), although the present author deliberately avoided use of the latter term in order to prevent confusion. The potential zones of coral reef formation limited by a mean monthly lowest sea surface temperature of 18°C both during high stands of sea level in interglacial ages and low stands of sea level in glacial ages, are termed the "coral reef formation zone".

3.2. Explanation of the geographical distribution of coral reef types

The geographical variation in reef types was discussed in section 2.2.2., and measured results were given in Figs. 8 and 9. Comparing the reef types in Figs. 8 and 9, Rd in Figs. 4 and 5 and the W-ratio in Figs. 6 and 7, the following points can be made.

Barrier reefs and atolls center on the core zone derived from Rd and the W-ratio. Fringing reefs and apron reefs are dispersed in the peripheral zone; in particular, apron reefs

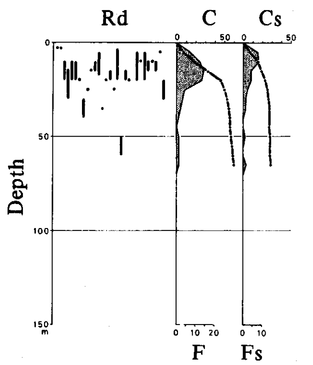

Fig. 14-1 Depth distribution of Rd for apron reefs

Symbols for Figs. 14-1 to 14-8

Rd: Values for Rd or the range of Rd for individual sites are shown separately, arranged in order of corresponding site numbers in Table 3 from left to right

C : Cumulative curve of Rd

F : Frequency of Rd

Cs : Cumulative curve of the shallowest value of Rd

Fs : Frequency of the shallowest value of Rd

• Rd

| Range of Rd

↓ An arrow indicates that Rd is expected to be deeper than its shown position

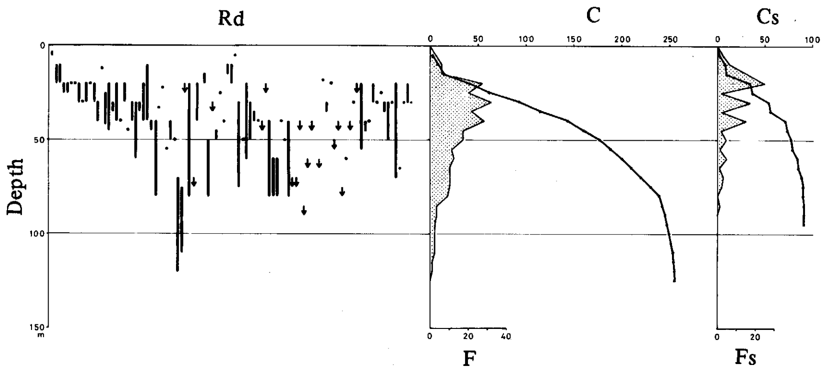

Fig. 14-2 Depth distribution of Rd for fringing reefs

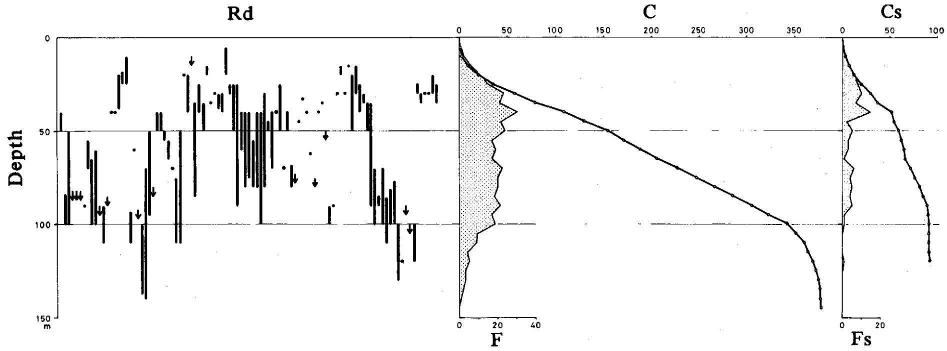

Fig. 14-3 Depth distribution of Rd for patched reefs

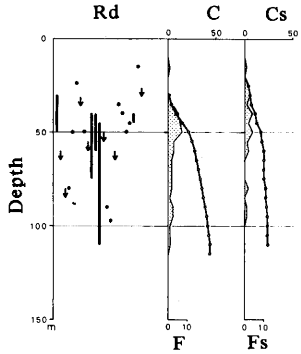

Fig. 14-4 Depth distribution of Rd for almost barrier reefs

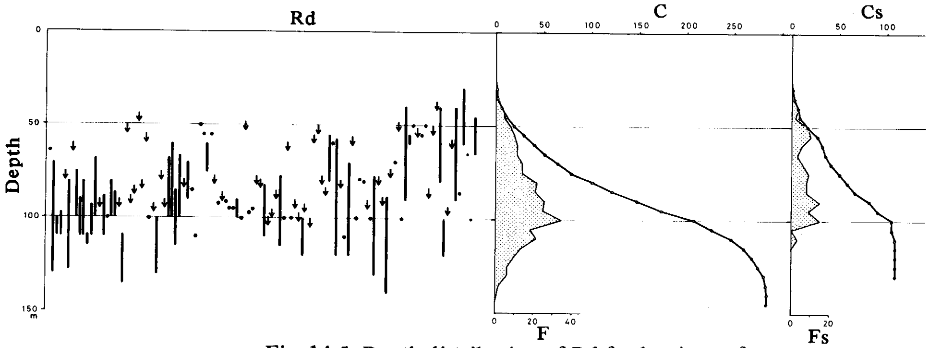

Fig. 14-5 Depth distribution of Rd for barrier reefs

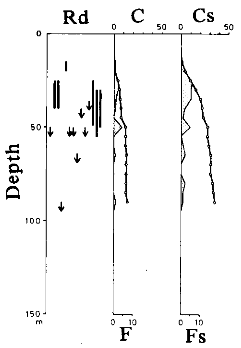

Fig. 14-6 Depth distribution of Rd for table reefs

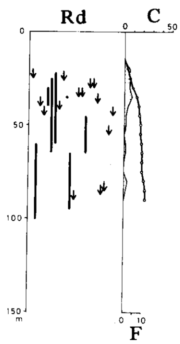

Fig. 14-7 Depth distribution of Rd for almost table reefs

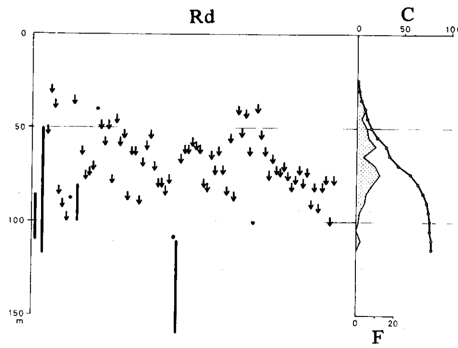

Fig. 14-8 Depth distribution of Rd for almost atolls and atolls

are distributed in the extreme areas. Patched reefs appear in both zones. Table reefs are similar in distribution to the patched reefs. However, closer analysis shows that this type appears principally from the border of the core zone into the peripheral zone. Futhermore, in relation to the continents and islands, a systematic arrangement of reef types, i.e. apron reefs, fringing reefs and barrier reefs, can be traced from the peripheral zone to the core zone along the fringe of the continents and oceanic islands. Patched reefs appear in both zones, since some are equivalent to fringing reefs and some to barrier reefs. Patched reefs are given the status of reef type only by reason of the extreme discontinuity of the reef rims. On the other hand, in the open ocean it appears that table reefs are changed to atolls in the peripheral zone towards the core zone, except for large oceanic islands with fringing reefs and barrier reefs.

On the other hand, a final and conclusive explanation cannot be obtained if the testing is based only on the coincidence of the horizontal distribution of reef types and the two zones defined from Rd and the W-ratio. Coral reefs are three-dimensional landforms. Thus, it is necessary to examine the vertical relationships.

The frequency distributions of Rd for each reef type are shown in Figs. 14-1 to 14-8. The characteristic values of Rd for each reef type are thus as follows: apron reefs, 10 to 20 meters; fringing reefs, 20 to 40 meters; almost-barrier reefs, 40 to 50 meters; patched reefs, 30 to 100 meters; barrier reefs, 80 to 110 meters; table reefs, 25 to 35 and 50 meters; almost-table reefs, 20 to 35 meters (somewhat unclear); almost-atolls and atolls, 60 and 70 to 80 meters. However, the data for almost-table reefs, almost-atolls and atolls utilize Ldmax. These values must therefore be regarded as minimum values for Rd.

It can be seen that the Rd variation for barrier reefs and atolls coincides with the Rd in the core zone, while the Rd variation for apron reefs, fringing reefs, table reefs and almost-table reefs coincides with the Rd in the peripheral zone. The Rd of patched reefs contains features of both zones. It is concluded therefore that the geographical variation of Rd on each reef type coincides with the horizontal variation of the reef types themselves.

The formation and geographical distribution of coral reefs during the Quaternary are thus effectively explained by the proposed model based on Quaternary sea level changes and sea temperature fluctuations.

4. CONCLUSION

The proposed model is as follows. Assuming that the continental shelf with a smooth surface extends from 30°N to 30°S, and that fluctuations in sea level and sea surface temperature repeat with the same magnitude during the Quaternary period, the geographical distribution of coral reefs can be expected to exhibit the following features.

1. In seas permitting the formation of coral reefs even during glacial ages, coral reefs would tend to grow at the shelf edge with a subsequent rise of sea level. The thickness of the coral reef limestones would be equivalent to the amount of the sea level changes. The reef type in such sea areas would be a barrier reef with pinnacles and knolls in a deep lagoon.

2. The width of a coral reef becomes narrower and shallower on approach towards the peripheral sea. The reef types may then alter from barrier reefs to fringing reefs.

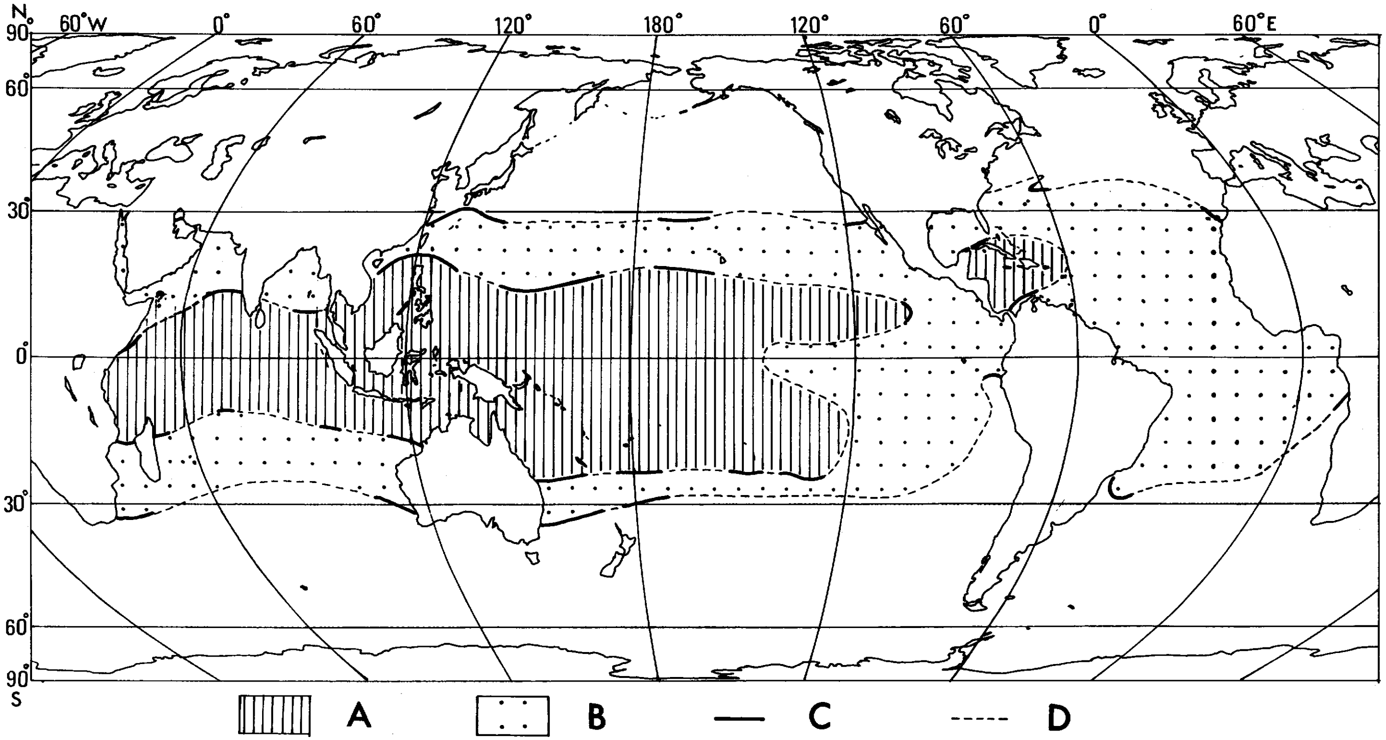

Fig. 15 The core zone and peripheral zone permitting coral reef formation

A: the core zone B: the peripheral zone C: boundary lines obtained directly from measurements D: dotted lines were obtained from iso-thermal lines for the coldest monthly sea surface temperature (The line for the core zone is 25°C. The line for the peripheral zone is 18°C.)

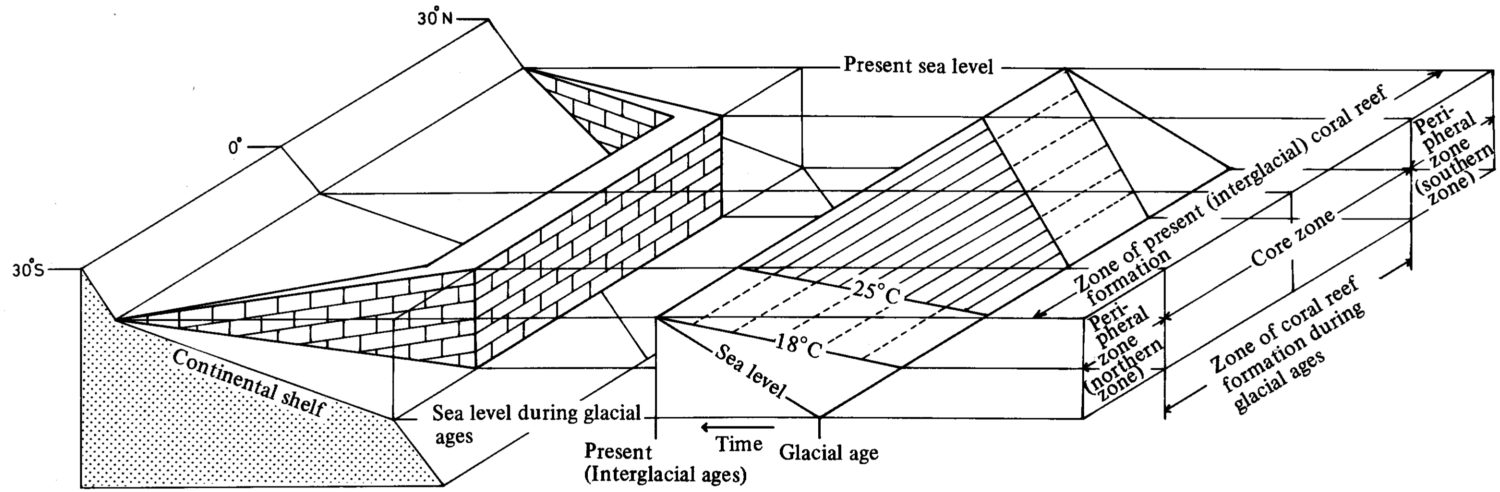

Fig. 16 Schematic model for coral reef formation on the continental shelf

3. The same geographical variation in coral reefs can also be expected on scattered islands from 30°N to 30°S and on completely drowned islands fringed by shelves in an open ocean. However, the reef type should be represented as an encircled reef like an atoll in this case.

The postulated model has been tested as follows. The zone of coral reef formation during periods of low sea-level stands has been confirmed from the coincidence of each geographical range with an Rd of about 100 meters and a W-ratio of 100%. This is also substantiated by the fact that Rd is roughly equivalent to the thickness of Quaternary reef limestones related to sea level changes during the Quaternary period.

Seas which have permitted the formation of coral reefs even during periods of low stands of sea level, or glacial ages, are referred to as the "core zone". Seas which have expanded towards the north and south with subsequent rises in sea level constitute the "peripheral zone", which may be divided into two subzones. One is the northern zone in the northern hemisphere, and the other is the southern zone in the southern hemisphere. The core zone and peripheral zone are shown in Fig. 15. The peripheral zone corresponds roughly to the marginal belt defined by Davis (1923), although use of the latter term is avoided since the definitions are different from each other.

The geographical variation in the thickness of reef limestones shown by the postulated model is demonstrated as an overall, systematic decrease in Rd from the core zone to the peripheral zone, and the Rd in the core zone is roughly equivalent to the amount of sea level changes occurring during the Quaternary. The geographical variation in the width of coral reefs is demonstrated as a W-ratio of 100% in the core zone which shows a systematic decrease towards the peripheral zone.

The geographical variation in reef types shown in Fig. 1 is also supported by the following findings. Barrier reefs and atolls center upon the core zone, while fringing reefs and apron reefs center upon the peripheral zone. Furthermore, the most frequent depths of Rd for each reef type are equivalent to the Rd of each zone, i.e. the Rd of barrier reefs and atolls coincides with that of the core zone, while the Rd of fringing reefs and apron reefs coincides with that of the peripheral zone.

The geographical variation of the knolls and pinnacles in lagoons (Fig. 1) is roughly supported as follows. Most knolls center upon the core zone, while the range of pinnacles shows a wider distribution than that of the knolls. However, more specific and precise data on knolls and pinnacles are required, and the problem must be studied in connection with karst topography.

The above exposition of the postulated model shows that the distribution range and topographical sequences of coral reefs in the world have been under the direct influence of sea level changes and fluctuations in sea surface temperature during the Quaternary period. Further support for this is also provided by the proportional relationship, $Rw/Rd = Sw/Sd$ (Fig. 12), and by the fact that the Rd of the core zone is roughly equivalent to the thickness of the Quaternary reef limestones.

The growth rate of a coral reef may possibly follow and approach the rate of sea level changes occurring throughout the Quaternary period. The amount and the rate of crustal movement appear to have almost no bearing on the explanation of the global distribution of coral reefs, although there is an influence on the development of coral reefs at the regional scale.

The present geomorphology of coral reefs must be based on karst topographies which have been eroded by subaerial solution at several periods of low sea-level stands during the Quaternary period. In particular, karstic relief is often found on large lagoon floors in low latitudes. Therefore, Ldmax must be carefully evaluated. The deepest values of Ldmax are almost equivalent to Rd from the viewpoint of geographical variations. However, the shallowest values of Ldmax seem to indicate a geographical gradient with the amount of precipitation. This may have a deep connection with the magnitude of karst topographies in the Indian Ocean and Pacific Ocean (Hori, 1978, in preparation).

According to the above-mentioned results and conclusions, the postulated model shown in Fig. 1 can be redrawn as in Fig. 16. It should be understood that the sea level has of course repeatedly fluctuated along the general sea level curve indicated in the figure throughout the Quaternary period.

5. SIGNIFICANCE OF THE CONCLUSION AND FURTHER PROBLEMS

The subsidence theory sought to explain the origin of coral reefs on the basis of vertical movements of the sea floor. On the other hand, the glacial control theory attempted to explain the formation of coral reefs on the basis of the effects of sea surface temperature on coral reef growth. However, this theory failed to account for the geographical distribution of coral reefs adequately. The model postulated in this paper, on the other hand, gives clear explanations of these problems.

A set of geomorphological units such as the lagoon, knolls and pinnacles, and the reef rim is organized as a reef type, and its systematic geographical distribution can then be demonstrated by the results of actual measurements. Changes in the formational zone of coral reefs during the Quaternary are then shown on a map (see Fig. 15).

It is possible to estimate, under ideal conditions, the width of coral reefs, thickness of reef limestones and reef types at any given site on the basis of the above-mentioned approach. Therefore, a comparison of the general properties of the reef topography with actually observed cases should provide a correct evaluation of such factors as the regional and local crustal movements and the ecological control participating in the process of coral reef formation.

Further problems to be considered are as follows. The model postulated in the present paper was tested using morphometrical measurements from a number of charts. However, the soundings given in the charts were by no means entirely adequate and correct for this purpose. The model must therefore be re-examined in detail using data from depth recorders or large scale submarine topographic maps (e.g. where the scale is of the order of 1/1,000). Furthermore, in order to make a radiometric dating survey, coral heads must be collected by skin diving or by using submarine boats, and boring must be carried out at the reef walls in the core zone and peripheral zone. In this way, a stricter examination of the author's model will be possible.

As indicated by Konishi et al. (1974), the relation between raised coral reefs and the Thurber discontinuity (Stoddart, 1969) must be clarified. It should then be possible to demonstrate whether or not the constructed coral reefs corresponding to each palaeo-sea level indicate the same geographical variations in the W-ratio and Rd as are predicted by the postulated model.

Finally, the limits of the model proposed in the present paper should be recognized. It can explain effectively only the geographical variations in coral reefs which have formed during the Quaternary period. The reef limestones exceeding 1,000 meters encountered in deep borehole data cannot be explained directly by the author's model. They require a consideration of the regional plate tectonics, as indicated by Newell (1972) and Hori (1974).

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(J): in Japanese

(J-E): in Japanese with English abstract

Appendix

Table 3 Table of morphometrical attributes of coral reefs in the world

Notes and symbols

1. The distribution of measuring sites is shown in Fig. 3.
2. Charts used for measurement
   - 362 .... Without alphabet, British chart No. 362
   - J216 .... Japanese chart No. 216
   - Aus 365 ..... Australian chart No. 365
   - Am5505 ..... American chart No. 5505
3. Add. chart ...... Additional chart
4. Morphometrical attributes considered (see Fig. 2)
   - Rw .... Width of coral reef
   - Sw .... Width of shelf
   - W-ratio ...... Rw/Sw x 100 (%)
   - Rd .... Depth of basement of reef edgs
   - Ldmax ...... Maximum depth of lagoon floor
   - Sd .... Depth of shelf edge
5. Reef types
   - Ap .... Apron reef
   - F .... Fringing reef
   - aB .... Almost barrier reef
   - B .... Barrier reef
   - aA .... Almost atoll
   - A .... Atoll
   - aT .... Almost table reef
   - T .... Table reef
   - P .... Patched reef
6. Number of knolls and pinnacles (This depends to some extent on the conditions of chart representation)
   - K .... Knolls
   - P .... Pinnacles
   - K.P .... K >P
   - P.K .... P >K
   - △ .... 0 – 4
   - ○ .... 5 – 19
   - ◉ .... 20<

Site No.	Region		Charts used for measurement			Loca
			No.	Scale	Add. chart	Longitude
1	Ryukyu Is. (Nansei shoto)	Yaku shima	J216	1:12,138	J182a J1221	130°31′ E
2	〃	Suwanose jima	J218	1:12,122	J182a	129 43 E
3	〃	Takara jima	J218	1:24,242	J182a	129 13 E
4	〃	Bay of Nase, Amami Oshima	J218	1:12,137	J225	129 30 E
5	〃	Somachi, Kikai jima	J218	1:12,137	J225	130 E
6	〃	Kasari peninsula, Amami Oshima	J225	1:112,500		129 42 E
7	〃	〃	J245	1:25,000	J225	129 36 E
8	〃	Bay of Yakiuchi, Amami Oshima	J246	1:20,000		129 11 E
9	〃	Bay of Isu, Amami Oshima	J230	1:30,000		129 23 E
10	〃	San, Tokuno shima	J183	1:14,384	J182b	128 59–129°E
11	〃	〃	J183	1:14,384	J182b	128 59–129°E
12	〃	Kametsu, Tokuno shima	J183	1:11,918	J182b	129 1–3′E
13	〃	Iheya jima	J229	1:29,530	J182b	127 58–128°E
14	〃	〃	J229	1:29,530	J182b	127 53–56′E
15	〃	Izena jima	J229	1:29,530		127 58–128°E
16	〃	Unten Harbor, Okinawa jima	J227	1:20,000	J22	128 E
17	〃	Sesoko jima	J240	1:12,232	J226	127 51–52′E
18	〃	〃	J240	1:12,232	J226	127 51–52′E
19	〃	Bay of Oura, Okinawa jima	J242	1:24,573	J226	128 7–8′E
20	〃	Bay of Oura, Okinawa jima	J242	1:24,573	J226	128 2–7′E
21	〃	Naha, Okinawa jima	J243	1:20,000	J222	127 40–41′E
22	〃	Hamahiga jima	J228	1:40,000		127 58–128°3′E
23	〃	Bay of Nakagusuku, Okinawa jima	J228	1:40,000		127 48–128°E
24	〃	Zampa misaki, Okinawa jima	J222	1:75,000		127 39–43′ E
25	〃	Lukan–sho, Okinawa jima	J222	1:75,000		127 29–40′ E
26	〃	Sakihara zaki, Okinawa jima	J222	1:75,000		127 48–51′E
27	〃	Minami Daito jima	J1210	1:72,500		131 14–19′E
28	〃	Okino Daito jima	J1210	1:36,339		131 10–12′E
29	〃	Yoron to	J226	1:200,000		128 27–30′E
30	〃	Shimochi jima	J241	1:40,000		125 9–10′E
31	〃	Irabu jima	J241	1:40,000	J1205	125 8–17′E
32	〃	Yae bise, Miyako jima	J1205	1:100,000		125 10–30′E
33	〃	Tarama jima	J1205	1:100,000		124 35–50′E
34	〃	Obama jima	US topomap	1:50,000		124 E
35	〃	Yonaguni jima	〃	1:50,000		122 57–128°3′E

tion	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls &
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	pinnacles
30° 27′N	0.07	5–14	1	3	–	100	2	5–14	+	–	–	–	–	–	–	–	–	–
29 36 N	0.24	2	12	3	–	80<	8	<3	+	–	–	–	–	–	–	–	–	–
29 9 N	0.25	1.2	21	3–5	–	–	5–8	–	–	+	–	–	–	–	–	–	–	–
28 24 N	0.25	5	5	10–20	–	140	1–3	4	+	–	–	–	–	–	–	–	–	–
28 19 N	0.23	2.2	10	10–20	–	100	1–2	2	–	+	–	–	–	–	–	–	–	–
28 25 N	0.6	6.5	9	15–30	–	140	2–4	5	+	–	–	–	–	–	–	–	–	–
28 28 N	0.5	5	10	10–20	–	140	3–5	4	+	–	–	–	–	–	–	–	–	–
28 18 N	0.25	2.3	11	10–20	–	150	1–3	2	+	–	–	–	–	–	–	–	–	–
28 9 N	0.6	5.9	1	20	–	130–140	3	4–5	+	–	–	–	–	–	–	–	–	–
27 52–53′N	0.4	5	8	10–20	–	130	2–4	4	–	+	–	–	–	–	–	–	–	–
27 51 N	0.4	5	8	20–25	–	110<	2	<5	–	+	–	–	–	–	–	–	–	–
27 43 N	0.6	4	15	20–25	–	135	2–3	3	–	+	–	–	–	–	–	–	–	–
27 1 N	0.6	7.5	8	20	–	140	3	5	–	+	–	–	–	–	–	–	–	–
27 1 N	0.6	5.1	12	20	–	90–100	3	5–6	–	+	–	–	–	–	–	–	–	–
26 55–56′N	1	4	25	20–30	–	100–130	4	3–4	–	+	–	–	–	–	–	–	–	–
26 42–44′N	1.8	6	30	30	–	110–120	6	5	–	+	–	–	–	–	–	–	–	–
26 39–40′N	0.5	7<	<7	20–30	–	–	2–3	–	–	+	–	–	–	–	–	–	–	–
26 37 N	0.4	1.4	29	20	–	110	2	1	–	+	–	–	–	–	–	–	–	–
26 30–33′N	0.87	6–7	12–15	20–30	1	130–140	3–4	4–5	–	+	–	–	–	–	–	–	–	–
26 29–30′N	2	11	18	30–40	3.6	130–140	5–7	8	–	+	–	–	–	–	–	–	–	–
26 15–16′N	1.2	12.4	10	12	–	110	10	11	–	+	–	–	–	–	–	–	–	–
26 19 N	5.5	8	69	25–42	(23)	100–110	13–22	7–8	–	+	–	–	–	–	–	–	–	–
26 15 N	18	22	82	20–45	–	95	40–90	23	–	+	–	–	–	–	–	–	–	–
26 24–26′N	1.5	6	25	30–35	–	90–100	4–5	6–7	–	+	–	–	–	–	–	–	–	–
26 4–9′N	1.8	22	8	20–40	–	90–100	5–9	22–24	–	+	–	–	–	–	–	–	–	–
26 5–8′N	3	6	50	40	–	100	8	6	–	+	–	–	–	–	–	–	–	–
25 48–58′N	0.1>	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
24 28 N	0.2	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
27 0–1′N	1.3	4	33	20–30	3–4	100<	4–7	<4	–	+	–	–	–	–	–	–	–	–
24 45–54′N	3.9	6.5	60	45	4	100	9	7	–	+	–	–	–	–	–	–	–	–
24 45–50′N	12	17.6	68	30–40	30	100	30–40	18	–	+	–	–	–	–	–	–	–	–
24 55–25°5′N	–	–	–	40–50	–	100–110	–	–	–	–	–	–	–	–	–	–	+	–
24 40–50′N	–	–	–	30–60	–	100<	–	–	–	+	–	–	–	–	–	–	–	–
24 10–25′N	2.5	16	16	30–35	14	100–140	7–8	11–16	–	+	–	–	–	–	–	–	–	–
24 25–29′N	1.5–2.5	4	38–60	20–40	–	115	4–13	3	–	+	–	–	–	–	–	–	–	–

Site No.	Region		Charts used for measurement			Locat
			No	Scale	Add. chart	Longitude
36	Ryukyu Is.	Hateruma jima	US topomap	1:50,000		123°45-50'E
37	〃	Iriomote jima	J199	1:30,000		123 41-43'E
38	〃	〃	J199	1:30,000		123 39-41'E
39	Taiwan	Nanwan	J250b	1:30,000		120 45 E
40	Tung-Sha-Tao	(Pratas Is.)	362	1:72,000		116 39-57'E
41	〃	〃	362	1:72,000		116 39-57'E
42	Hai Nan Tao		3991	1:500,000		110 50-20'E
43	Macclesfield	Bank	270	1:389,330		113 35-50'E
44	Paracel Is.	Amphitrite Group	94	1:334,850		112 14 E
45	〃	Crescent Group	94	1:334,850		112 30-47'E
46	North danger		1201	1:111,400		114 16-24'E
47	Thitu Is. & reefs.		1201	1:111,400		114 18-23'E
48	〃		1201	1:111,600		114 10-18'E
49	Loai Ta Is. & reefs.		1201	1:111,400		114 18-35'E
50	Tizard Bank & reefs.		1201	1:136,500		114 12-45'E
51	Spratly Is.		1201	1:25,000		111 55 E
52	Philippine Is.	Luzon Is.	3805	1:500,000		122 17-22'E
53	〃	〃	3805	1:500,000		119 55-120°6'E
54	〃	〃	3808	1:500,000		123 6-11'E
55	〃	〃	3808	1:500,000		123 30-40'E
56	〃	Samar Is.	3808	1:500,000		124 25-39'E
57	〃	Masbate Is.	3808	1:500,000		123 0-15'E
58	〃	Samar Is.	3808	1:500,000		125 27-34'E
59	〃	Panay Is.	3808	1:500,000		123 10-124°0'E
60	〃	Bohol Is.	3810	1:500,000		124 40 E
61	〃	Parawan Is.	3809	1:500,000		119 38-120°20'E
62	〃	〃	3809	1:500,000		119 28-33'E
63	〃	Kagayan Is.	3809	1:500,000		121 22-28'E
64	〃	〃	3809	1:500,000		121 15-25'E
65	〃	Mindanao Is.	3809	1:500,000		123 12-20'E
66	〃	Tubbataha reefs.	3809	1:500,000		119 53-120°22'E
67	〃	Palawan Is.	967	1:725,000		118 30-59'E
68	〃	〃	967	1:725,000		117 35-118°35'E
69	〃	Mindanao Is.	3811	1:500,000		122 23-36'E
70	〃	Sulu Archipelago	928	1:431,350		121 0-45'E

ion	Rw	Sw	W-ratio	R d	Ld max	S d	Rw/Rd	Sw/Sd	Reef type									No. of knolls & pinnacles
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	
24°3-5'N	1	3.2	31	40	−	100	3	3	−	+	−	−	−	−	−	−	−	−
24 22 N	0.6	2.7	22	40−45	−	140	1−2	2	−	+	−	−	−	−	−	−	−	−
24 18−20'N	2.7	6.3	43	40−80	−	140	3−7	5	−	+	−	−	−	−	−	−	−	−
21 57 N	1.3	4.2	31	30−40	−	100	3−4	4	+	−	−	−	−	−	−	−	−	−
20 35 N	28.8	28.8	100	20<	20	−	<44	−	−	−	−	−	−	−	+	−	−	P ●
20 35 N	28.8	28.8	100	60−100	15	110	29−48	26	−	−	−	−	−	−	+	−	−	P ●
19 01−26'N	7.5	110	7	33	−	140	23	79	−	+	−	−	−	−	−	−	−	−
15 20−16°20'N	141	141	100	85−110	110	110−140	128−166	101−128	−	−	−	−	−	+	−	−	−	K 21<
16 45−17°0'N	165	165	100	86−110	86−110	110<	150−192	<150	−	−	−	−	+	−	−	−	−	−
16 26−29'N	36	36	100	50−117	48	117<	31−72	<31	−	−	−	−	−	+	−	−	−	K 4
11 22−30'N	16.5	16.5	100	49<	49	−	<34	−	−	−	−	−	−	+	−	−	−	K 5
11 3−5'N	8.9	8.9	100	27<	27	−	<33	−	−	−	−	−	−	+	−	−	−	K 1
11 2−3'N	14.3	14.3	100	35<	35	−	<41	−	−	−	−	−	−	+	−	−	−	K 3
10 40−55'N	41	41	100	81<	81	81<	<51	<51	−	−	−	−	−	+	−	−	−	K 3
10 10−25'N	70.7	70.7	100	88<	88	88<	<80	<80	−	−	−	−	−	+	−	−	−	K 21
8 39 N	2.5	2.5	100	50<	−	−	<5	−	−	−	−	−	−	−	−	+	−	−
17 21−28'N	12.5	13.8	91	84−100	−	100	13−15	14	−	−	−	−	−	−	−	−	+	−
16 25−36'N	25	27.5	91	50−100	−	106−140	25−50	20−28	−	−	−	−	−	−	−	−	+	−
14 5−42'N	78	78	100	82<	−	90−130	<95	60−87	−	−	−	−	−	−	−	−	+	−
13 57−14°35'N	74	74	100	82<	−	82<	<90	<90	−	−	−	−	−	−	−	−	+	−
12 40−48'N	27−34	34	79−100	82<	−	82<	<33−41	<41	−	−	−	−	−	−	−	−	+	−
12 14−19'N	28	30	93	90	−	100	31	30	−	−	−	−	−	−	−	−	+	−
11 57−12°0'N	10	10	100	64	64	70−140	16	7−14	−	−	−	+	−	−	−	−	−	−
11 15−41'N	72	90	80	55−70	−	120	105−131	75	−	−	−	−	−	−	−	−	+	−
10 8 −18'N	20	20	100	70−110	40<	100−110	18−29	18−20	−	−	−	+	−	−	−	−	−	−
10 50 N	30	−	−	65−100	−	−	30−46	−	−	−	−	−	−	−	−	−	+	−
10 0−20'N	47.5	47.5	100	60−100	−	100	48−79	48	−	−	−	−	−	−	−	−	+	−
9 55 N	7.5	7.5	100	95<	95	95<	<8	<8	−	−	−	−	−	+	−	−	−	−
9 40−50'N	17	17	100	88	88	88<	19	<19	−	−	−	−	−	+	−	−	−	−
8 40 N	8.5	10	85	90<	−	120−130	<9	8	−	−	−	−	−	−	−	−	+	−
8 51−56'N	18	18	100	33<	33	−	<55	−	−	−	−	−	−	+	−	−	−	−
10 24−40'N	65	65	100	100−115	97−115	115	57−65	57	−	−	−	+	−	−	−	−	−	−
6 35−7°35'N	126	126	100	97−110	97	110	115−130	115	−	−	−	+	−	−	−	−	−	−
7 8−23'N	35	35	100	90−110	−	110	32−39	32	−	−	−	−	−	−	−	−	+	−
6 0−35'N	111	111	100	75<	75	75<	<148	<148	−	−	−	+	−	−	−	−	−	−

Site No.	Region	Charts used for measurement			Locat
		No.	Scale	Add. Chart	Longitude
71	Philippine Is. Sulu Archipelago	928	1:431,350		120°11–17′E
72	〃 〃	928	1:431,350		119 18–35′E
73	Borneo & Celebes Is. Kepulauan Natuna Besar	1311	1:500,000		107 20–108°10′E
74	〃 Borneo Is.	2636	1:740,000		118 39–48′E
75	〃 〃	2637	1:725,500		116 30–118°20′E
76	〃 Celebes Is.	2637	1:725,500		119 11–33′E
77	〃 Doang Doangan Kechil	2637	1:725,500		117 10–118°0′E
78	〃 Sabalana or Postilloa Is.	2637	1:725,500		118 20–119°20′E
79	〃 Celebes Is.	3616	1:709,000		121 54–122°0′E
80	〃 〃	3616	1:709,000		120 14–36′E
81	〃 〃	3616	1:709,000		120 18–46′E
82	〃 Taka Boné Raté (Tigar Is.)	3616	1:709,000		121 5 E
83	〃 Tona Jampea	3616	1:709,000		120 23–37′E
84	New Guinea Hermit Is.	3723	1:50,383		144 59–145°7′E
85	〃 Papua	2055	1:300,000		149 20–27′E
86	〃 〃	2032	1:300,000		150 18–33′E
87	Bismarck Archipellago, New Britain Is.	3553	1:263,000		151 32 E
88	Louisiade Archipelago, Tawa Tawa Mal reef	2033	1:300,000		152 10–45′E
89	Australia Torres Strait	2759	1:470,000		133 –144 E
90	Australia Great Barrier Reef, Cape York	2354	1:300,000		142 40–144°0′E
91	〃 Near Cape Grenville	2920	1:148,300	2354	143 10–59′E
92	〃 Cape Weymouth	2920	1:148,300		143 25–45′E
93	〃 Cape Direction	2921	1:148,000		143 33–50′E
94	〃 〃	2921	1:148,000		143 30–144°0′E
95	〃 North of Claremont Point	2921	1:148,000		143 32–144°3′E
96	Australia North of cape of Melville	2922	1:147,000	2355	144 15–25′E
97	〃 Barrow Point	2922	1:147,000		144 40–51′E
98	〃 Red Point	2922	1:147,000		144 47–145°4′E
99	〃 Lookout Point	2923	1:146,800		145 14–37′E
100	〃 Cape Bedford	2923	1:146,800		145 20–45′E
101	〃 North of Cowie Point	2924	1:145,000		145 25–50′E
102	〃 Yule Point	2924	1:145,000		145 31–146°3′E
103	〃 Buchan Point	2924	1:145,000		145 40–146°10′E
104	〃 Cape Grafton	2350	1:145,230		145 56–146°13′E
105	〃 Cooper Point	2350	1:145,230		146 5–35′E

ion	R w	S w	W-ratio	R d	Ld max	S d	Rw/Rd	Sw/Sd	Reef type									No. of knolls &
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	pinnacles
5°36'–44'N	19.3	19.3	100	80–128	80–128	128	15–24	15	–	–	–	+	–	–	–	–	–	–
4 40–47'N	30	30–44	70–100	60<	55	60–140	<50	21–50	–	–	–	+	–	–	–	–	–	–
2 30–3°35'N	–	–	–	85<	–	85–117	–	–	–	–	–	–	–	–	–	–	+	–
1 18–32'N	33.5	33.5	100	75–100	75	100	34–45	34	–	–	–	+	–	–	–	–	–	–
2 50 S	223	223	100	90–110	93	110	203–248	203	–	–	–	+	–	–	–	–	–	K 7
4 20–36'S	50	50	100	80–110	79	110	45–63	45	–	–	–	+	–	–	–	–	–	K ●
5 15–50'S	25.5	36	71	80–100	81	100<	26–32	<36	–	–	–	–	–	+	–	–	–	K15<
6 50 S	50	50	100	60<	60	60<	<83	<83	–	–	–	–	–	+	–	–	–	K25<
1 43–50'S	20	20	100	109–115	109	115	17–18	17	–	–	–	+	–	–	–	–	–	K·P ●
2 54–3°11'S	42	42	100	93–100	93	100	42–45	42	–	–	–	+	–	–	–	–	–	K·P ○
4 53–56'S	50.5	50.5	100	68–100	68	100	51–74	51	–	–	–	+	–	–	–	–	–	K·P ●
6 25–7°5'S	72	72	100	73<	73	73<	<99	<72	–	–	–	–	–	+	–	–	–	K·P ●
7 5–8'S	19	19	100	90<	90	90<	<21	<21	–	–	–	+	–	–	–	–	–	K5<
1 29–35'S	18	18	100	88–110	88	110	16–20	16	–	–	–	+	–	–	–	–	–	P ●
9 7–12'S	16.5	16.5	100	100	97	100	17	17	–	–	–	+	–	–	–	–	–	K5<
10 40–50'S	28	28	100	80–100	81	100	28–35	28	–	–	–	+	–	–	–	–	–	K ○
4 4–11'S	13	13	100	86–100	86	100	13–15	13	–	–	–	+	–	–	–	–	–	K15<
11 0–15'S	75	75	100	90<	90	100<	<83	<75	–	–	–	+	–	–	–	–	–	K ○
8 –10°S	–	–	–	109–135	109	135	–	–	–	–	–	+	–	–	–	–	–	P ●
10 45 S	138	138	100	50<	50<	50<	<276	<276	–	–	–	+	–	–	–	–	–	K ●
11 42–55'S	85.8	85.8	100	88<	88	88<	<98	<98	–	–	–	+	–	–	–	–	–	K ●
12 30–35'S	38.5	38.5	100	83<	50<	83<	<46	<46	–	–	–	+	–	–	–	–	–	K ●
12 51 S	32.6	32.6	100	44<	44	44<	<74	<74	–	–	–	+	–	–	–	–	–	K ●
13 6–17'S	54	54	100	80<	44	80<	<68	<68	–	–	–	+	–	–	–	–	–	K ●
13 28–45'S	67	67	100	54<	54	80<	<124	<84	–	–	–	+	–	–	–	–	–	K ●
13 56–14°10'S	30.7	30.7	100	100	100	100	31	31	–	–	–	+	–	–	–	–	–	P·K △
14 0–20'S	32	32	100	92<	92<	92<	<35	<35	–	–	–	+	–	–	–	–	–	P·K ●
14 11–33'S	47	53.7	100	100<	130	130	<47	41	–	–	–	+	–	–	–	–	–	K·P ●
14 34–50'E	52	52	100	75<	75<	75<	<69	<69	–	–	–	+	–	–	–	–	–	K·P10<
15 11–14'S	44	44	100	90<	90<	90<	<49	<49	–	–	–	+	–	–	–	–	–	K·P ●
15 46–57'S	45.7	45.7	100	68–100	100	100	46–67	46	–	–	–	+	–	–	–	–	–	K·P ●
16 18–44'S	64	64.5	99	60–100	100	100	64–107	65	–	–	–	+	–	–	–	–	–	K·P ●
16 31–44'S	58.7	60	98	85–115	115	115	51–69	52	–	–	–	+	–	–	–	–	–	K·P5<
16 34–50'S	45.7	48	95	66–100	100<	100<	46–69	<48	–	–	–	+	–	–	–	–	–	K·P5<
17 4–24'S	62.4–64.6	64.6	97–100	79<	100<	100<	<79–82	<65	–	–	–	+	–	–	–	–	–	K5<

Site No.	Region		Charts used for measurement No.	Scale	Add. chart	Loca Longitude
106	Australia	South of George Point	2349	1:300,000		146°20'–147°10'E
107	〃	Tlinders Reefs	864	1:145,230	2349	148 20–33'E
108	〃	Bowling Green	348	1:300,000		147 29–148°15'E
109	〃	Marion Reef	3719	1:145,000		152 13–17'E
110	〃	Swain Reef	346	1:300,000		151 49 E
111	〃	Cato Reef	349	1:72,636		155 22 E
112	〃	Near Capricorn channel	345	1:300,000		150 45–152°25'E
113	〃	Heron Is.	345	1:300,000		151 23–152°11'E
114	〃	South of Bunker Group	345	1:300,000		152 5–48'E
115	Australia	Barwon Bank	Aus365	1:300,000		153 6–45'E
116	〃	Moreton Is.	1029	1:300,000		153 26–36'E
117	〃	Fingal Head	1029	1:300,000		153 35–45'E
118	〃	North Evans Reef	1029	1:300,000		153 27–49'E
119	〃	Woody Head	1028	1:300,000		153 23–45'E
120	〃	Red Bank	1028	1:300,000	1026	153 14–34'E
121	〃	Mermaid Reef	1028	1:300,000		152 46–153°5'E
122	〃	Middleton Reef	Aus213	1:50,000		159 4–9'E
123	〃	Elizabeth Reef	Aus213	1:50,000		159 1–7'E
124	〃	Lord Howe Is.	Aus213	1:25,000		159 0–4'E
125	〃	Charlotte Head	1027	1:300,000		152 33–54'E
126	〃	Near Lake Macquarie	1027	1:300,000		151 38–152°10'E
127	Ogasawara Shoto,	Chichi jima	J1082	1:14,585	1100	142 9–12'E
128	Mariana Is.	Maug Is.	910	1:25,000		145 12–14'E
129	〃	Pagan Is.	910	1:72,000		145 46 E
130	〃	Rota Is.	910	1:49,000		145 8–9'E
131	〃	Saipan Is.	1101	1:30,000		145 41–43'E
132	〃	Tinian Is.	1101	1:50,000		145 37–38'E
133	〃	Guam Is.	1101	1:150,000		144 40 E
134	Caroline Is.	Ulithi Is.	772	1:250,000		139 35–43'E
135	〃	Zohhoiiyoru Bank	772	1:250,000		139 56–59'E
136	〃	Fais Is.	772	1:25,000		140 31–32'E
137	〃	Sorol Is.	772	1:100,000		140 23–25'E
138	〃	Faraulep Is.	772	1:100,000		144 33 E
139	〃	West Fayu Is.	772	1:50,000		146 44 E
140	〃	Woleai Is.	772	1:25,000		143 50–55'E

tion	R w	S w	W-ratio	R d	Ld max	S d	Rw/Rd	Sw/Sd	Reef type									No. of knolls &
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	pinnacles
18°10'-30'S	84	90	93	70-90	70	100<	93-120	<90	-	-	-	+	-	-	-	-	-	K3<
17 34-44'S	29	29	100	71<	71<	71<	<41	<41	-	-	-	-	-	+	-	-	-	K6<
18 25-35'S	93	117	79	85	70	120	109	98	-	-	-	+	-	-	-	-	-	K6<
18 56-19°16'S	37.7	37.7	100	68<	68	68<	<55	<55	-	-	-	-	-	+	-	-	-	K9<
22 0-40'S	216	225	96	110	100	125-140	196	161-180	-	-	-	+	-	-	-	-	-	K5<
23 15 S	3.6	11.3	32	40	4	125	9	9	-	-	-	-	-	-	-	+	-	-
23 6 S	102	168	61	50	-	140	204	120	-	-	-	+	-	-	-	-	-	-
23 19-50'S	75	97.5	77	55	50	100	136	98	-	-	-	+	-	-	-	-	-	K 5
24 3-32'S	81	90	90	60-75	57	75-100	108-135	90-120	-	-	-	+	-	-	-	-	-	-
26 30 S	43.5	63	69	55	55	110-130	79	48-57	-	-	-	+	-	-	-	-	-	-
27 8 S	5.4	18.6	29	40	-	110	14	17	-	-	-	-	-	-	-	-	+	-
28 12 S	9	30	30	40	-	120-140	23	21-25	-	-	-	-	-	-	-	-	+	-
29 10 S	6	36	17	25	-	100	24	36	+	-	-	-	-	-	-	-	-	-
29 22 S	1.2	36	3	15	-	100	5-10	36	+	-	-	-	-	-	-	-	-	-
30 1 S	11	34.5	32	20-38	-	100	29-55	35	-	-	-	-	-	-	-	-	+	-
31 46 S	5.1	60	9	18-25	-	115	20-28	52	-	-	-	-	-	-	-	-	+	-
29 26-30'S	6	11	55	25-40	13	100	15-24	11	-	-	-	-	-	-	-	+	-	-
29 54-58'S	8.8	12.5	70	25-40	16	100-140	22-35	9-13	-	-	-	-	-	-	-	+	-	-
31 31-34'S	2.3	8.3	28	22	-	60-100	10	8	-	+	-	-	-	-	-	-	-	-
32 15-19'S	0.6	40.5	1	10-15	-	130	4-6	31	+	-	-	-	-	-	-	-	-	-
33 8-15'S	1.5	51	3	5-18	-	145	8-30	35	+	-	-	-	-	-	-	-	-	-
27 4-6'N	0.9	8.7	10	35	-	110	3	8	+	-	-	-	-	-	-	-	-	-
20 1-2'N	0.4	1	40	10-25	-	-	2-4	-	-	-	-	-	-	-	-	-	+	-
18 6 N	0.3	1	30	20	-	-	2	-	+	-	-	-	-	-	-	-	-	-
14 8 N	1	1.5	67	55	-	100	2	2	-	+	-	-	-	-	-	-	-	-
15 14 N	3.3	3.9	85	30-50	16	50	7-11	8	-	-	+	-	-	-	-	-	-	-
14 57 N	0.8	2.5	32	15-20	-	100<	4-5	<3	+	-	-	-	-	-	-	-	-	-
13 15 N	4.1	4.1	100	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
9 47-10°2'N	18.8	18.8	100	46<	46	-	<41	-	-	-	-	-	-	+	-	-	-	K40<
10 51-53'N	5	5	100	55<	55	55<	< 9	<9	-	-	-	-	-	+	-	-	-	K 1
9 46 N	0.3	0.6	50	40-50	-	100<	1	1	-	+	-	-	-	-	-	-	-	-
8 8 N	3.6	3.6	100	46<	46	-	< 8	-	-	-	-	-	-	+	-	-	-	K 2
8 36 N	4	4	100	75<	20	75<	< 5	<5	-	-	-	-	-	+	-	-	-	-
8 4-6'N	4.9	4.9	100	42<	42	42<	<12	<12	-	-	-	-	-	+	-	-	-	K 1
7 21 N	11	11	100	55<	55	55<	<20	<20	-	-	-	-	-	+	-	-	-	K·P15<

Site No.	Region		Charts used for measurement			Loca
			No.	Scale	Add. chart	Longitude
141	Caroline Is.	Lamotrek Is.	772	1:100,000		146°16–24′E
142	〃	Pulap or Tamatam Is.	772	1:50,000		149 25 E
143	〃	Yap Is.	1485	1:12,500		138 9 E
144	〃	Ngulu Is.	977	1:250,000		137 30 E
145	〃	Palau Is.	977	1:50,000		134 32–33′E
146	〃	〃	977	1:250,000		134 27–29′E
147	〃	Helen Reef	977	1:145,000		131 45–56′E
148	New Guinea	Vanimo Harbour	Aus389	1:25,000		141 18 E
149	〃	Herculas Bay	Aus575	1:300,000		147 42–52′E
150	Solomon Is.	Bougainville Is.	3420	1:250,000		155 27–31′E
151	〃	〃	3419	1:250,000		155 52–57′E
152	〃	Gagi Is.	3402	1:250,000	2894	158 10–14′E
153	〃	Guadalcanal Is.	1469	1:250,000		159 32–36′E
154	〃	〃	1469	1:250,000		159 32–36′E
155	Santa Cruz Is.	Vanikoro Is.	17	1:50,000		166 59 E
156	New Hebrides Is.	Aneityum Is.	1071	1:12,000		169 46 E
157	〃	〃	1071	1:24,000		169 44 E
158	New Caledonia	N.W. Coast	936a	1:323,000		163 42–164°E
159	〃	Near Passe de Cap Baye	936a	1:323,000		165 26–35′E
160	〃	Kanala Bay	936b	1:320,800		166 1–6′E
161	〃	Kuakua Bay	936b	1:320,800		166 42–45′E
162	〃	Récif Toombo	2907	1:100,000		166 27–42′E
163	〃	Neo Kui Reef	936b	1:320,800		166 45–167 E
164	〃	North of Kunie Is.	2906	1:100,000		167 10–25′E
165	Fiji Is.	Viti Levu Is.	845	1:142,960		176 55–177°31′E
166	〃	Yandua Is.	381	1:150,000		177 44–178°16′E
167	〃	Viti Levu Is.	381	1:150,000		177 43–50′E
168	〃	〃	167	1:142,000		178 2 E
169	〃	Mbenga lagoon	167	1:142,000		178 2–3′E
170	〃	Kandavu Is.	167	1:142,000		178 25 E
171	〃	Vanua Levu Is.	379	1:150,000		178 39–44′E
172	〃	Viti Levu Is.	488	1:100,000		178 36–48′E
173	〃	Vanua Levu Is.	382	1:144,000		179 14–15′W
174	〃	Budd Reef	416	1:150,000		179 38–47′W
175	〃	Exploring Is.	416	1:150,000		178 40–179°W

tion	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls &
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	pinnacles
7°27′–31′N	14	14	100	51<	51	51<	<27	<27	–	–	–	–	–	+	–	–	–	K12<
7 32–39′N	12.5	12.5	100	84<	40	84<	<15	<15	–	–	–	–	–	+	–	–	–	K 8
9 29–30′N	2.9	2.9	100	60–100<	44	130	3–5	2	–	–	+	–	–	–	–	–	–	P5<
8 18–36′N	37	37	100	60<	60	60<	<62	<62	–	–	–	–	–	+	–	–	–	K20<
7 15–21′N	8.4	8.4	100	77<	77	100<	<11	<11	–	–	–	+	–	–	–	–	–	K. P10<
7 30–32′N	7	7	100	92	55	92	8	8	–	–	–	+	–	–	–	–	–	K·P ◉
2 48–3°1′N	24.7	24.7	100	60<	60	60<	<41	<41	–	–	–	–	–	+	–	–	–	K·P30<
2 40 S	0.6	–	–	25	–	–	2	–	+	–	–	–	–	–	–	–	–	–
7 45–50′S	21	21	100	93–110	–	110	19–23	19	–	–	–	–	–	–	–	–	+	K5<
6 5–7′S	11.8	11.8	100	86<	86	86<	<14	<14	–	–	–	+	–	–	–	–	–	K 4
6 25–28′S	11.8	11.8	100	91	75	91	13	3	–	–	–	+	–	–	–	–	–	K4<
7 29–38′S	18	18	100	95	95	95<	19	<19	–	–	–	+	–	–	–	–	–	P5<
9 26 S	7	7	100	95	73	95	7	7	–	–	–	+	–	–	–	–	–	–
9 27–28′S	7	7	100	90–100	75	90–100	7–8	7–8	–	–	–	+	–	–	–	–	–	–
11 35–36′S	4.5	4.5	100	100	99	100–110	5	4–5	–	–	–	+	–	–	–	–	–	K5<
20 8 S	1.9	2.5	77	80<	37	100–110	2	2–3	–	–	+	–	–	–	–	–	–	–
20 15–18′S	2.4	6<	44	50	18	100<	5	<6<	–	+	–	–	–	–	–	–	–	–
19 42–20°S	47.2	47.2	100	48<	48	48<	<98	<98	–	–	–	+	–	–	–	–	–	K 3
20 59–21°4′S	21	21	100	97	75	97	22	22	–	–	–	+	–	–	–	–	–	K15<
21 23–27′S	12.8	12.8	100	95	66	95	13	13	–	–	–	+	–	–	–	–	–	–
21 52–56′S	9.6	9.6	100	77<	77	77<	<12	<12	–	–	–	+	–	–	–	–	–	K2<
22 20–34′S	38	38	100	79<	79	79<	<48	<48	–	–	–	+	–	–	–	–	–	K·P ◉
22 41–47′S	30.5	30.5	100	82–110	110	110	28–37	28	–	–	–	+	–	–	–	–	–	K15<
22 30–36′S	27<	30	90<	98<	<98	0–150	<28	20–30	–	–	–	+	–	–	–	–	–	K·P10<
17 30 S	65	65	100	95<	95	95–140	<68	46–68	–	–	–	+	–	–	–	–	–	K·P20<
16 40–47′S	60.8	60.8	100	85<	85	85<	<72	<72	–	–	–	+	–	–	–	–	–	K20<
17 15–27′S	20.3	20.3	100	77<	77	115	<26	18	–	–	–	+	–	–	–	–	–	P5<
18 16–18′S	4.3	4.3	100	100	77<	100	4	4	–	–	–	+	–	–	–	–	–	P5<
18 19–30′S	19.2	19.2	100	59<	59	–	<33	–	–	–	–	+	–	–	–	–	–	P·K ◉
19 3–5′S	4.3	4.3	100	100	57	100–140	4	3–4	–	–	–	+	–	–	–	–	–	P·K3<
17 1–19′S	34.5	34.5	100	90<	90	90<	<38	<38	–	–	–	+	–	–	–	–	–	K30<
17 47–50′S	21	21	100	97<	84	100<	<22	<21	–	–	–	+	–	–	–	–	–	K·P ◉
16 42–49′S	14.7	14.7	100	100<	88–100	100–120	<15	12–15	–	–	–	+	–	–	–	–	–	K·P20<
16 28–34′S	19.1	19.1	100	92<	92	<140	<21	14<	–	–	–	+	–	–	–	–	–	K·P5<
16 5–17°S	41.7	41.7	100	100<	100<	100–140	<42	30–42	–	–	–	+	–	–	–	–	–	K·P ◉

Site No.	Region		Charts used for measurement No.	Scale	Add. chart	Loca Longitude
176	Fiji Is.	Ngau Is.	1251	1:36,300		179°15–16'E
177	〃	Moala Is.	1252	1:36,300		179 56–58'E
178	〃	Totoya Is.	1248	1:24,200		179 53 W
179	〃	Matuku Is.	1247	1:12,100		179 45 E
180	Tonga Is.	Vavau Is.	3098	1:73,360		173 57–58'W
181	〃	Ha'apai group, Ofolanga Is.	3097	1:12,100		174 28 W
182	〃	〃	3097	1:12,100		174 27–28'W
183	〃	Lifuka Is.	473	1:17,270	3099	174 23–24'W
184	〃	Southern portion of Ha'apai group	3100	1:72,600		174 36–38'W
185	〃	〃	3100	1:72,600		174 46–48'W
186	〃	Nomuka group	474	1:72,600		174 30–54'W
187	〃	Approaches to Nuku alofa	2363	1:50,000	1385	175 1–11'W
188	Norfolk Is.	Sydney Bay	1110	1:6,000		167 56 E
189	Caroline Is.	Mclaughlin Bank	970	1:924,380		148 0–10'E
190	〃	Namonuito or Onon Is.	970	1:924,380		149 38–150°20'E
191	Caroline Is.	Nomwin or Namolipiafan Is.	970	1:250,000		151 41–56'E
192	〃	Murilo Is.	970	1:250,000		152 1–19'E
193	〃	Truk or Hogolu Is.	982	1:125,000		151 49–53'E
194	〃	Losap Is.	909	1:75,000		152 40–45'E
195	〃	Nomoluk Is.	909	1:50,000		153 8 E
196	〃	Satawan Is.	909	1:125,000		153 28–45'E
197	〃	〃	909	1:125,000		153 29–35'E
198	〃	Oroluk lagoon	909	1:250,000		155 9–25'E
199	〃	Nukuoro Is.	909	1:50,000		154 57–155°E
200	〃	Ngatik Is.	909			157 10–21'E
201	〃	Ponape Is.	981	1:36,000		158 18–22'E
202	〃	Kusaie or Ualan Is.	978	1:10,000		163 1–2'E
203	〃	〃	978	1:20,000		162 57 E
204	Marshall Is.	Eniwetok Atoll	984	1:300,000		162 7–20'E
205	〃	Bikini Atoll	984	1:300,000		165 12–34'E
206	〃	Rongelap Atoll	984	1:310,150		166 45–55'E
207	〃	Rongerik Atoll	984	1:109,150		167 27 E
208	〃	Kwajalein Atoll	984	1:403,200		167 28–45'E
209	〃	Ailuk Atoll	984	1:145,150		169 56 E
210	〃	Maloelap Atoll	984	1:414,700		170 51–171°13'E

tion	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls &
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	pinnacles
18°2–4′S	4.9	4.9	100	55<	55	100<	<9	< 5	–	–	–	+	–	–	–	–	–	K·P10<
18 35–36′S	3.3	3.3	100	50<	50	100<	<7	< 3	–	–	–	+	–	–	–	–	–	K·P10<
18 59 S	2.6	2.6	100	77<	55–62	77<	<3	< 3	–	–	–	+	–	–	–	–	–	K·P10<
19 9 S	1.7	1.7	100	80	64	80	2	2	–	–	+	–	–	–	–	–	–	P1<
18 39–45′S	12.3	12.3	100	83<	83<	<140	<15	9<	–	–	–	+	–	–	–	–	–	K·P5<
19 36 S	0.6–1.0	1.1	55–91	55–80	–	80<	1–2	<1	–	–	–	+	–	–	–	–	–	–
19 36–37′S	0.8	1.2	67	60	–	100	1	1	–	–	–	+	–	–	–	–	–	–
19 48–49′S	4.8	5.4	89	60	30	90–100	8	5–6	–	–	–	–	–	–	–	–	+	P·K ◉
19 57–20°10′S	24	24	100	92<	92	92<	<26	<26	–	–	–	–	–	–	–	–	+	K·P10<
19 57–20°6′S	22.5	22.5	100	100–137	100	100–137	16–23	16–23	–	–	–	–	–	–	–	–	+	K·P10<
20 12–24′S	40	48.3	83	65–90	63	100–140	42–62	35–48	–	–	–	–	+	–	–	–	–	K20<
20 57–21°6′S	24.3	24.3	100	57<	57	120	<43	20	–	–	–	+	–	–	–	–	–	P10<
29 4 S	0.2–(0.7)	–	–	3–(20)	–	–	(4)–7	–	+	–	–	–	–	–	–	–	–	–
9 3–15′N	36	36	100	86<	86	–	<42	–	–	–	–	–	–	+	–	–	–	–
8 35–45′N	80.4	80.4	100	66<	66	66<	<122	<122	–	–	–	–	–	+	–	–	–	K11
8 30–35′N	30	30	100	57<	53	57<	<53	<53	–	–	–	–	–	+	–	–	–	K17
8 35–46′N	41.5	41.5	100	51<	51	51<	<81	<81	–	–	–	–	–	+	–	–	–	K25
7 13–40′N	50	50	100	79<	79	79–140	<63	36–63	–	–	–	+	–	–	–	–	–	K·P ◉
6 54 N	9.8	9.8	100	68<	68	68<	<14	<14	–	–	–	–	–	+	–	–	–	P10<
5 54–56′N	5.5	5.5	100	77<	77	77<	< 7	< 7	–	–	–	–	–	+	–	–	–	–
5 20–30′N	35	35	100	77<	77	77<	<45	<45	–	–	–	–	–	+	–	–	–	K30<
5 25–30′N	18.1	18.1	100	81<	81	81<	<22	<22	–	–	–	–	–	+	–	–	–	K30<
7 27–36′N	30.8	30.8	100	75<	75	75<	<41	<41	–	–	–	–	–	+	–	–	–	K·P30<
3 50–52′N	6.9	6.9	100	108	108	108<	6	< 6	–	–	–	–	–	+	–	–	–	K·P30<
5 50–51′N	21.5	21.5	100	110–159	159	<159	14–20	14<	–	–	–	–	–	+	–	–	–	K20<
6 52–53′N	4.2	4.2	100	110	86	110	4	4	–	–	–	+	–	–	–	–	–	P·K ◉
5 20 N	1–1.2	1.2	83–100	70–120	50	120	1–2	1	–	+	–	–	–	–	–	–	–	–
5 21 N	1.3	1.3	100	75–110	68	110	1–2	1	–	+	–	–	–	–	–	–	–	P 2
11 20–38′N	40.5	40.5	100	64<	64	64<	<63	<63	–	–	–	–	–	+	–	–	–	K60<
11 30–39′N	42	42	100	59<	59	59<	<71	<71	–	–	–	–	–	+	–	–	–	K80<
11 10–26′N	37.2	37.2	100	59<	59	59<	<63	<63	–	–	–	–	–	+	–	–	–	K35<
11 18–24′N	25.8	25.8	100	55<	55	55<	<47	<47	–	–	–	–	–	+	–	–	–	K70<
8 43–9°24′N	80.6	80.6	100	57<	57	57<	<141	<141	–	–	–	–	–	+	–	–	–	K85<
10 13–28′N	28.1	28.1	100	59<	59	59<	<48	<48	–	–	–	–	–	+	–	–	–	K90<
8 39–55′N	47.7	47.7	100	77<	77	77<	<62	<62	–	–	–	–	–	+	–	–	–	K50<

Site No.	Region		Charts used for measurement			Loca
			No.	Scale	Add. chart	Longitude
211	Marshall Is.	Aur or Ibbetson Atoll	984	1:414,700		171°2–11'E
212	〃	Majuro Atoll	984	1:164,900		171 2–24'E
213	〃	Wotje Atoll	988	1:103,670		169 48–170°15'E
214	〃	Arno Atoll	988	1:159,820		171 34–45'E
215	〃	Mili Atoll	988	1:284,550		171 44–172°6'E
216	Gilbert Is.	Nonouti Reef	768	1:50,000		174 16–28'E
217	〃	Abemana Atoll	743	1:25,000		173 50–52'E
218	North of Fiji Is.	Rotuma Is.	2992	1:72,900		177 8–9'E
219	〃	〃	2992	1:72,900		177 8 E
220	〃	Îles Wallis	968	1:24,000		176 8–9'W
221	Samoa Is.	Upolu Is.	1339	1:75,000		172 1 W
222	〃	〃	1339	1:75,000		171 45 W
223	〃	Tutuila Is.	1729	1:25,000		170 39–40'W
224	East of Samoa Is.	Suvorov Is.	1174	1:36,500		163 6–7'W
225	Cook Is.	Aitutaki Is.	1264	1:18,000		159 48–49'W
226	〃	Rarotonga Is.	1264	1:6,060		159 46 W
227	Hawaii Is.	Kure Is. or Ocean Is.	J2019	1:50,000	1142	178 17–23'W
228	〃	Pearl and Hermes Reef	J2019	1:100,000	1142	175 43–59'W
229	〃	Pearl and Hermes Reef	1141	1:75,000		175 43–176°3'W
230	〃	French frigate shoals	1141	1:100,000		166 8–20'W
231	〃	Midway Atoll	J2017	1:35,000		177 21–28'W
232	〃	〃	J2017	1:35,000		177 22–29'W
233	South of Hawaii Is.	Johnston Reef	Am5505	1:12,500		169 22–34'W
234	〃	〃	Am5505	1:12,500		169 22–34'W
235	Hawaii Is.	Oahu Is.	1378	1:80,000		157 45–50'W
236	〃	Hawaii Is.	1490	1:15,000		155 50–51'W
237	South of Hawaii Is.	Palmyra Is.	2867	1:15,000		162 5 W
238	〃	Christmas Is.	Am1823	1:15,000		157 19–30'W
239	Tuamotu Arch.	Rangiroa Atoll	1175	1:15,000	998	147 43 W
240	〃	Fakarava Atoll	1175	1:37,500	998	145 40–43'W
241	〃	Mururoa Atoll	1175	1:150,000		138 47–139°2'W
242	Society Is.	Bora Bora Is.	1107	1:25,000		151 45–47'W
243	〃	〃	1107	1:25,000		157 46 W
244	〃	Tahaa Is.	1107	1:25,000	1103	151 32 W
245	〃	Raiatea Is.	1107	1:30,000	1103	151 23–24'W

tion / Latitude	Rw km	Sw km	W-ratio %	Rd m	Ld max m	Sd m	Rw/Rd %	Sw/Sd %	Reef type Ap	F	aB	B	aA	A	aT	T	P	No. of knolls & pinnacles
8°8-15′N	24.1	24.1	100	79<	79	79<	<31	<31	−	−	−	−	−	+	−	−	−	K12
7 5-9′N	39.7	39.7	100	62<	62	62<	<64	<64	−	−	−	−	−	+	−	−	−	K·P20<
9 25-32′N	38.3	38.3	100	70<	70	70<	<55	<55	−	−	−	−	−	+	−	−	−	K130<
7 1-6′N	24.3	24.3	100	60<	60	60<	<41	<41	−	−	−	−	−	+	−	−	−	K·P50<
6 7 N	42.1	42.1	100	70<	70	70<	<60	<60	−	−	−	−	−	+	−	−	−	K·P40<
0 41-42′S	22.5	22.5	100	35-100<	29	35-100<	<23-64	<23-64	−	−	−	−	−	−	+	−	−	P ●
0 21-22′N	13.8	13.8	100	40<	26	40<	<35	<35	−	−	−	−	−	−	+	−	−	P ●
12 30 S	0.7<	1.1	64<	20<	−	−	<4<	−	−	+	−	−	−	−	−	−	−	−
12 29 S	0.6<	1.7	35<	20<	−	80<	<3<	< 2	−	+	−	−	−	−	−	−	−	−
13 2 S	2.4	2.4	100	70<	53	70-120	<3	2-3	−	−	−	+	−	−	−	−	−	P ●
13 43-49′S	5.6-(11.7)	11.7	48-(100)	70-(140)	−	130-140	8	8-9	−	−	−	−	−	−	−	−	+	−
13 44-49′S	2.6-(9.5)	9.5	27-(100)	50-95	−	95-120	3-5	8-10	−	−	−	−	−	−	−	−	+	−
14 16-19′S	(25<)	7	(36<)	80-100<	−	120-130	3	5-6	−	−	−	−	−	−	−	−	+	−
13 14-20′S	13.1	13.1	100	81<	81	81<	<16	<16	−	−	−	−	−	+	−	−	−	K40<
18 52 S	2.1	2.1	100	71<	−	71<	< 3	< 3	−	+	−	−	−	−	−	−	−	−
21 11 S	0.5	0.6	83	20-40	−	−	1-3	−	−	+	−	−	−	−	−	−	−	−
28 23-27′N	11.3	17<	<66	30-40	14	90<	28-38	<19<	−	−	−	−	−	−	+	−	−	P ●
27 47-53′N	23	29	79	25-65	25	−	35-92	−	−	−	−	−	−	−	+	−	−	P ●
27 46-48′N	25.9	33<	<78	22-60	22	100<	43-118	<33	−	−	−	−	−	−	+	−	−	P ●
23 41-23°52′N	25.5<	28	91<	37<	27	−	<76	−	−	−	−	−	−	−	+	−	−	P ●
28 9-20′N	11.6	22.4	52	21<	21	135-140	<56	16-17	−	−	−	−	−	−	+	−	−	P ●
28 10-21′N	8.8	22.8	39	35	−	130-140	25	16-18	−	−	−	−	−	−	+	−	−	P ●
16 43 N	20.3	20.3	100	65-95	20	95-140	21-31	15-21	−	−	−	−	−	−	+	−	−	P ●
16 41 N	22.5	22.5	100	85<	(53)	85<	<26	<26	−	−	−	−	−	−	+	−	−	P ●
21 28-31′N	4.8	6.8	72	<50	15	110-130	10<	5-6	−	+	−	−	−	−	−	−	−	P10<
20 2 N	1.3	2.4	54	50-60	−	100-120	2-3	2	+	−	−	−	−	−	−	−	−	−
5 52-54′N	3.5	3.5	100	53<	53	53<	< 7	< 7	−	−	−	−	−	+	−	−	−	P·K5<
1 59 N	20.5	20.5	100	90<	9	90-120	<23	17-23	−	−	−	−	−	−	−	+	−	−
14 57 S	34.5	34.5	100	84<	37<	84<	<93	<93	−	−	−	−	−	+	−	−	−	K5<
16 5 S	54	54	100	38<	38<	38<	<142	<142	−	−	−	−	−	+	−	−	−	K5<
21 49-53′S	27.5	27.5	100	50<	50	50<	<55	<55	−	−	−	−	−	+	−	−	−	−
16 30 S	2.8	2.8	100	56<	48	56<	< 5	< 5	−	−	−	+	−	−	−	−	−	P5<
16 32-34′S	3-3.8	3.8	79-100	100	10<	100	3-4	4	−	−	−	+	−	−	−	−	−	−
16 39-40′S	2.8	2.8	100	79	60	79	4	4	−	−	−	+	−	−	−	−	−	K·P5<
16 41 S	2.6	2.6	100	80	71	80	3	3	−	−	−	+	−	−	−	−	−	K·P10<

Site No.	Region		Charts used for measurement			Loc
			No.	Scale	Add. chart	Longitude
246	Society Is.	Raiatea Is.	1107	1:12,500	1103	151°26'W
247	〃	〃	1107	1:25,000	1103	151 29–30'W
248	〃	Huahine Is.	1107	1:30,000		151 2–4'W
249	〃	Moorea Is.	1382	1:36,309		149 51 W
250	〃	Tahiti Is.	1382	1:145,500		149 24 W
251	〃	〃	1382	1:145,500		149 12 W
252	〃	Mopelia or Mopihaa Atoll	Am77	1:77,000		153 57 W
253	Tuamotu Archipelago	Hao Atoll	3664	1:40,000		140 54–56'W
254	〃	Gambier Is.	1112	1:75,000		134 50–135°1'W
255	〃	Oeno Is.	987	1:50,000		130 43–40'W
256	Eastern Pacific	Clipperton Is.	1936	1:50,000		109 12–15'W
257	Gulf of Mexico, Near Vera Cruz, Mexico		374	1:37,500		95 55–96°5'W
258	〃	〃	374	1:150,000		95 46–59'W
259	〃	Bay of Campeche	2626	1:290,000		90 30–92°13'W
260	〃	Campeche Bank	1205	1:1,094,000		89 40 W
261	British Honduras	Middle long Cay	959	1:125,000		88 1–17'W
262	〃	Gladden Spit	1797	1:125,000		87 59–88°21'W
263	〃	Zapotilla Cays	1573	1:121,500		88 15–32'W
264	Nicaragua	North of Mosquito Coast	2425	1:146,000	1218	82 5 –83°10'W
265	〃	Mosquito Coast	605	1:146,000	1218	82 25–83°30'W
266	〃	Black bluff	1139	1:146,000		83 11–38'W
267	Old Province Is.	Catalina Harbour	1334	1:18,150		81 22–24'W
268	St. Andrew Is.	Johnny Cay	1511	1:28,900		81 42 W
269	Brazilian Coast	Atol das Rocas	388	1:40,000		33 47–52'W
270	〃	Pôrto de Maceió	3978	1:25,000		35 41–43'W
271	〃	Sororo Cussu Reef	2262	1:267,360		38 50–39°W
272	〃	Recife da Coroa Alta	3156	1:297,076		38 30–39'W
273	〃	Recife de Itacolomis	3157	1:292,000		38 40–39°9'W
274	〃	Parcel das Paredes	3157	1:292,000		38 10–39°10'W
275	Bermuda Is.	North East Breaker	334	1:60,000		64 40–42'W
276	Bahama Is.	Little Bahama Bank	399	1:318,800		78 35–79°10'W
277	〃	Columbus Bank	277	1:295,000		75 23–28'W
278	〃	San Salvador Is. or Wallings Is.	393	1:163,000		74 28–29'W
279	〃	Mayaguana Is.	393	1:167,000		72 59–73°1'W
280	〃	Hogsty Reef	393	1:100,000		73 45–53'W

at ion	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls &
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	pinnacles
16°44'S	1.6–2	2	80–100	90<	58	130–140	< 2	1–2	–	–	–	+	–	–	–			K·P5<
16 44 S	2.3	2.3	100	100	51	100	2	2	–	–	–	+	–	–	–			–
10 44 S	1.8–2.2	2.2	82–100	77–130	33	130	1–3	2	–	–	–	+	–	–	–	–	–	–
17 29 S	1.5	1.5	100	77<	53<	77<	< 2	< 2	–	–	–	+	–	–	–	–	–	P2<
17 29–30'S	3.2	3.2	100	88<	43	88<	< 4	< 4	–	–	–	+	–	–	–	–	–	K·P5<
17 43–44'S	11.6	11.6	100	88–140	40–55	<140	8–13	8 <	–	–	–	+	–	–	–	–	–	K·P5<
16 49 S	8.9	8.9	100	40<	40	40<	<22	<22	–	–	–	–	–	+	–	–	–	P·K15<
18 7–9'S	15	15	100	60<	60	60<	<25	<25	–	–	–	–	–	+	–	–	–	P·K ◉
23 3–10'S	19.7	19.7	100	73<	73	73<	<27	<27	–	–	–	+	–	–	–	–	–	P·K ◉
23 56 S	5	5	100	–	2–3	–	< 8	–	–	–	–	–	–	–	–	+	–	–
10 17–19°N	4.5<	6	75–100	100	101	100–150	5 <	4–6	–	–	–	–	–	+	–	–	–	P·K1<
19 10–25'N	9.9	25.1–36	28–39	40–50	–	100<	20–25	<25–36	–	–	–	–	–	–	–	–	+	–
19 4–15'N	19.5	29.3–33	59–67	40–50	–	100–150	39–49	20–33	–	–	–	–	–	–	–	–	+	–
20 13 N	156.6	163.9	96	50–55	–	65	285–313	252	–	–	–	–	–	–	–	–	+	–
21 20–34'N	153.2	188.2	81	55–65	–	140	236–279	134	–	–	–	–	–	–	–	–	+	–
17 18 N	27.5	27.5	100	70	24	70	39<	39	–	–	–	+	–	–	–	–	–	P30<
16 32 N	40.4	40.4	100	48<	48	48<	<84	<84	–	–	–	+	–	–	–	–	–	K·P ◉
16 7–16'N	34.6	34.6	100	100	75–97	100	35	35	–	–	–	+	–	–	–	–	–	P·K ◉
15 –16°50'N	242.9	242.9	100	70	–	70	3.5	3.5	–	–	–	–	–	–	–	–	+	–
12 45 N	117.1–125.8	125.8	93–100	75–110	–	110–130	106–168	97–114	–	–	–	–	–	–	–	–	+	–
11 32–37'N	40.2–49.6	51.1	79–97	50–110	–	110	37–99	46	–	–	–	–	–	–	–	–	+	–
13 22–24'N	2.4–4.4	4.4	55–100	40–(90)	–	100	3–11	4	–	–	–	+	–	–	–	–	–	P5<
12 36 N	2.9	2.9	100	50	10	50<	6	< 6	–	–	+	–	–	–	–	–	–	P8<
3 52 S	5.4	–	–	25–30	–	–	18–22	–	–	–	–	–	–	–	–	+	–	–
9 40–42'S	3.2	28–39	8	15–20	–	80	16–21	35–49	–	+	–	–	–	–	–	–	–	–
13 50 S	9.4	21.4	44	15–20	–	70<	47–63	<31	+	–	–	–	–	–	–	–	–	–
16 12–30'S	5	60.9	8	20	–	60–70	25	87–102	+	–	–	–	–	–	–	–	–	–
16 51 S	12.3	52.6	23	20	–	70<	62	<75	–	–	–	–	–	–	–	–	+	–
17 30–40'S	46.7–102.2	115.9	41–88	20–40	–	60–80	117–511	145–193	–	–	–	–	–	–	–	–	+	–
32 22–32'N	13	18.9	69	24	24	50–70	54	27–48	–	–	+	–	–	–	–	–	–	P ◉
26 30–27°25'N	113.8	113.8	100	10–25<	10	–	<4.6–11.4	–	–	–	–	–	–	–	–	–	+	P5<
21 58–22°13'N	28	28	100	30 <	30	30<	<93	<93	–	–	–	–	–	–	+	–	–	P ◉
24 7–13'N	9.8	9.8	100	50 <	–	50–80	<20	12–20	–	+	–	–	–	–	–	–	–	–
22 20–22'N	5	5	100	30 <	3	30<	<17	<17	–	+	–	–	–	–	–	–	–	–
21 41 N	10	10	100	30 <	8	30<	<33	<33	–	–	–	–	–	–	+	–	–	P5<

Site No.	Region		Charts used for measurement			Lo
			No.	Scale	Add. chart	Longitude
281	Bahama Is.	Wide opening	408	1:26,400	2077	76°41'-77°13'W
282	〃	Great Bahama Bank	2009	1:295,380		76 56-77°6'W
283	Cuba Is.	Cayo Grande	3800	1:200,000		78 36-79°9'W
284	〃	Near Cape Cruz	3799	1:200,000		77 15-50'W
285	Haiti Is.	Port de Cap Haitien	465	1:25,000		72 8-12'W
286	〃	Bahia Samana & approaches	463	1:200,000		69 5-12'W
287	Around Jamaica Is.	Pedro Bank	450	1:334,900		78 5-10'W
288	〃	Jamaica Is.	446	1:277,430		76 57-77°10'W
289	Veirgin Is.	South of St. John Is.	130	1:282,600		64 40-42'W
290	Leeward Is.	Guadeloupe	885	1:130,000		61 39 W
291	Windward Is.	Martinique Is.	371	1:79,700		60 48-53'W
292	〃	〃	371	1:79,700		60 59 W
293	〃	St. Lucia Is.	1273	1:72,000		60 53-56'W
294	〃	The Grenadines	2872	1:72,000		61 11-23'W
295	〃	Grenada Is.	2821	1:71,500		61 30-37'W
296	Barbados Is.		2485	1:100,000		59 27-29'W
297	Tobago Is.	Great River Shoal	505	1:75,000		60 26-38'W
298	〃	Buccoo Reef	505	1:75,000		60 49-59'W
299	Canarias Is.	Selvagem pequena	365	1:20,000		16 1 W
300	〃	Isla de Lanzarote	886	1:12,500	1870	13 30-32'W
301	Arquipélago de Cabo Verde	Ilha de Santo Antão	369	1:18,000		25 6 W
302	〃	Ilha da Bōa Vista	369	1:50,000		22 58-59'W
303	Cameroun Coast,	Punta Campo	1888	1:300,000		9 32-46'E
304	Ilha de São Tomé	Ilhén das Cabras	1595	1:50,000		6 43-44'E
305	Persian Gulf	Madaira Reef	3773	1:150,000		48 25-58'E
306	〃	Al Qatar	3790	1:150,000		51 15-17'E
307	〃	Jarirat al Yas	3952	1:150,000		52 30-49'E
308	Muscat & Oman	Masira Is.	3519	1:53,000		58 38-43'E
309	Red Sea	Gulf of Suez	2373	1:150,000		32 30-38'E
310	〃	〃	2373	1:150,000		32 35-41'E
311	〃	〃	2373	1:150,000		33 0-13'E
312	〃	Shab Ali	2375	1:150,000		33 47-58'E
313	〃	Cannon Reef	3043	1:75,000		33 57-34°1'E
314	〃	Rawaya Anchorage	3722	1:76,950		37 10-24'E
315	〃	Mayetib Is.	3722	1:76,950		37 17-23'E

cation	Rw	Sw	W–ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls & pinnacles
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	
24°5–26'N	61.3	61.3	100	45–65	–	65	94–136	94	–	–	–	–	–	–	+	–	–	P20<
22 15–23°25'N	129.9	129.9	100	25<	10	25<	<520	<520	–	–	–	–	–	–	+	–	–	P ●
20 56–21°29'N	84	84	100	31<	31	31<	<271	<271	–	–	+	–	–	–	–	–	–	P30<
19 50–20°33'N	98	98	100	50	48	50	196	196	–	–	+	–	–	–	–	–	–	P ●
19 46–48'N	6.4–7	7	91–100	55<	20	80	8–13	9	–	–	+	–	–	–	–	–	–	P5<
19 0–10'N	18.6–20	20	93–100	35–85	25<	85	22–57	24	–	–	–	–	–	–	–	–	+	P5<
16 50–17°9'N	36.8	36.8	100	25<	–	–	<147	–	–	–	–	–	–	–	+	–	–	P5<
17 41–49'N	15.8	26.6	59	25–40	–	40	40–63	67	–	–	–	–	–	–	–	–	+	P3<
18 13–18'N	9.9	9.9	100	55–60	55	60	17–18	17	–	–	–	+	–	–	–	–	–	–
16 19–24'N	7.4	7.4–15	49–100	40–75	27	75	10–19	10–20	–	–	+	–	–	–	–	–	–	P5<
14 40–42'N	8	10.8	74	50	30–42	80	16	14	–	–	–	+	–	–	–	–	–	P5<
14 27–28'N	1.7	1.7	100	45–50	–	50	3–4	3	–	+	–	–	–	–	–	–	–	–
13 43–45'N	2.3	6.1–7.2	32–38	25	–	70–90	9	7–10	–	+	–	–	–	–	–	–	–	–
12 34–38'N	7.6–23	23	33–100	40–60	20–57	60	13–58	38	–	–	+	–	–	–	–	–	–	–
12 6–7'N	4.3–11.4	11.4	38–100	35–50	–	50–60	9–33	19–23	–	–	–	–	–	–	–	–	+	–
13 3–5'N	2	2	100	51<	51	51<	< 4	< 4	–	–	–	+	–	–	–	–	–	–
11 10–12'N	3.4	16.1	21	65	–	100	5	16	+	–	–	–	–	–	–	–	–	–
11 10–25'N	4.1	23.6	17	40	–	130	10	18	–	+	–	–	–	–	–	–	–	–
30 1–4'N	0.4	2.6	15	10–15	–	60–100	3–4	3–4	–	+	–	–	–	–	–	–	–	–
28 56–58'N	0.7	4.4	16	10–20	6	100–140	4–7	3–4	–	+	–	–	–	–	–	–	–	–
17 12 N	0.3	–	–	5–20	–	–	2–6	–	+	–	–	–	–	–	–	–	–	–
16 8–10'N	1.8	–	–	15–20	–	–	9–12	–	–	–	–	–	–	–	–	–	+	–
2 19 N	1.5	25.5	6	10	–	<130	15	20<	+	–	–	–	–	–	–	–	–	–
0 24–26'N	0.3	1.5	20	5	–	50	6	3	–	+	–	–	–	–	–	–	–	–
28 45–29'N	43.2	–	–	35	–	–	123	–	–	–	–	–	–	–	–	–	+	–
26 10–43'N	41	–	–	30	–	–	137	–	–	–	–	–	–	–	–	–	+	–
24 8–28'N	40.5	–	–	30–38	–	–	107–135	–	–	–	–	–	–	–	–	–	+	–
20 6–10'N	5	9.3	54	30–40	–	100	13–17	9	–	–	–	–	–	–	–	–	+	–
29 45–48'N	3	–	–	5–20	–	–	25–60	–	+	–	–	–	–	–	–	–	–	–
29 40 N	1.8–9.5	–	–	5–20	–	–	9–190	–	–	–	–	–	–	–	–	–	+	–
28 36–44'N	5.6	–	–	10–15	–	–	37–56	–	+	–	–	–	–	–	–	–	–	–
27 45–53'N	16.5	22.5	73	25–30	–	90	55–66	25	–	–	–	–	–	–	–	–	+	–
26 39 N	6	6.8	88	25–50	–	50≤	12–24	<14	–	–	–	–	–	–	–	–	+	–
20 58 N	23.5	23.5	100	25–90	–	90≤	26–94	<26	–	–	–	–	–	–	–	–	+	–
20 47 N	2.7	4.2	64	30–90	–	90	3–9	< 5	–	+	–	–	–	–	–	–	–	–

Site No.	Region		Charts used for measurement No.	Scale	Add. chart	Loc Longitude
316	Red Sea	Qad Eitwid Reefs	81	1:192,300		37°23′–41′E
317	〃	Lunka Channel	321	1:20,000		40 18–25′E
318	〃	South of Al Qunfidha	322	1:200,000	138	40 50–41°8′E
319	〃	North Masawa Channel	164	1:290,000		39 1–18′E
320	〃	South Masawa Channel, Dahlach Reef	171	1:200,000		40 21 E
321	〃	Near Straits of Bab El Mandeb	143	1:382,000		43 1–13′E
322	Gulf of Aden	Iles Musha	253	1:37,500		43 10 E
323	〃	Zeila	253	1:286,000		43 30–42′E
324	〃	Kal Farum or Kaal Firaon	100	1:300,000		51 53–52°10′E
325	East Africa	Pate Is.	668	1:75,000		41 1–12′E
326	〃	〃	668	1:75,000		41 0–11′E
327	〃	Manda Is.	668	1:75,000		40 59–41°9′E
328	〃	〃	668	1:75,000		40 56–41°2′E
329	〃	Lamu Is.	668	1:75,000		40 51–58′E
330	〃	〃	668	1:75,000		40 49–55′E
331	〃	South of Lamu Is.	668	1:75,000		40 49–53′E
332	〃	Malindi approaches	667	1:37,500		40 8–14′E
333	〃	〃	667	1:37,500		40 6–13′E
334	〃	〃	667	1:37,500		40 6–13′E
335	〃	Kilifi	238	1:24,180		39 52–55′E
336	〃	〃	238	1:24,180		39 52–55′E
337	〃	Mombasa	616	1:75,000		39 44–50′E
338	〃	〃	616	1:75,000		39 43–50′E
339	〃	〃	616	1:75,000		39 39–49′E
340	〃	Mwamba Wamba Reef	663	1:37,900		39 9–17′E
341	〃	Fungu Nyama Reef	663	1:37,900		39 9–16′E
342	〃	Niule Reef	663	1:37,900		39 8–14′E
343	〃	Yambe Reef	663	1:37,900		39 8–11′E
344	〃	Karange Reef	663	1:37,900		39 6–10′E
345	〃	Pemba Is.	3310	1:300,000		39 45–53′E
346	〃	〃	3310	1:300,000		39 51–53′E
347	〃	〃	3310	1:300,000		39 35–44′E
348	〃	Maziwi Reef	3310	1:300,000		39 0–7′E
349	〃	Mwamba Alek	3310	1:300,000		38 51–39°0′E
350	〃	Zanzibar Is., Shearwater Patches	3310	1:300,000		39 0–18′E

ation	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls & pinnacles
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	
18°58'-19°5'N	28.3	32.7	87	40-60	-	100	47-71	33	-	-	-	-	-	-	-	-	+	-
19 49-20°2'N	2.8	2.8	100	40-90	-	90<	3-7	< 3	-	-	-	-	-	-	-	-	+	-
18 55-19°1'N	-	-	-	40-75	-	75-90	-	-	-	-	-	-	-	-	-	-	+	-
16 38-45'N	18.3	18.3	100	55-80	-	-	23-31	-	-	-	-	-	-	-	-	-	+	-
15 20-34'N	4	9	44	50<	-	100<	<8	< 9	-	+	-	-	-	-	-	-	-	-
12 52-58'N	5-15.3	15.3	33-100	20-60	-	60	8-77	26	-	+	-	-	-	-	-	-	-	-
11 44-45'N	2.4	2.9	83	40-100	9	-	2-6	-	-	+	-	-	-	-	-	-	-	-
11 21-26'N	18.6	23.7	78	35-40	-	60	47-53	40	-	+	-	-	-	-	-	-	-	-
12 14-28'N	4.8-14	14	34-100	40-80	-	80	6-35	18	-	-	-	-	-	-	-	-	+	-
2 9-20'S	15.8-21	27.2	58-77	45-110	13	160	14-47	17	-	-	+	-	-	-	-	-	-	-
2 12-22'S	12.4-15.8	23.6	53-67	40-100	-	165	12-40	14	-	-	-	-	-	-	-	-	+	-
2 16-28'S	7.5-13.1	27.8	27-47	30-80	-	180	9-44	15	-	-	-	-	-	-	-	-	+	-
2 19-28'S	6	18.8	32	45-50	-	120	12-13	16	-	-	-	-	-	-	-	-	+	-
2 18-28'S	11.5-12.8	21.8<	53-59	40-70	-	-	16-32	-	-	-	-	-	-	-	-	-	+	-
2 20-28'S	12	15	80	40	-	135	30	11	-	-	-	-	-	-	-	-	+	-
2 24-28'S	6.8	9.8	77	25-50	-	<140	14-27	7 <	-	-	-	-	-	-	-	-	+	-
3 13-15'S	6.5	11.6	56	40	-	<180	16	6 <	-	+	-	-	-	-	-	-	-	-
3 16 S	5.8	9.4	62	40<	-	160-180	<15	5-6<	-	+	-	-	-	-	-	-	-	-
3 18 S	7.7-9.9	11.8	65-84	20<	-	155-180	<39-50	7-8	-	+	-	-	-	-	-	-	-	-
3 38 S	3.9	3.9-4.8	81-100	40-80	-	100-180	5-10	2-5	-	+	-	-	-	-	-	-	-	-
3 38 S	3.5	3.5-4.6	76-100	60-80	-	100-180	4-6	2-5	-	+	-	-	-	-	-	-	-	-
4 0-3'S	2.7-3.2	3.2	84-100	60-80	-	80	3-5	4	-	+	-	-	-	-	-	-	-	-
4 2-7'S	3	3-6	50-100	40	-	130-180	8	2-5	-	+	-	-	-	-	-	-	-	-
4 9-15'S	1.4	1.4-2.3	61-100	50	-	-	3	-	-	+	-	-	-	-	-	-	-	-
4 58-59'S	13.3-13.6	13.6	98-100	55	55	55	24-25	25	-	-	-	+	-	-	-	-	-	P5<
5 1-3'S	12.9-13.4	13.4	96-100	50	49	50	26-27	27	-	-	-	+	-	-	-	-	-	-
5 5 S	8.6	8.6	100	84<	70<	140-150	<10	6	-	-	-	+	-	-	-	-	-	-
5 7 S	4.9	4.9	100	50<	20-30	-	<15	-	-	-	+	-	-	-	-	-	-	-
5 11-13'S	7.6	7.6	100	50<	35	-	<15	-	-	-	-	+	-	-	-	-	-	-
4 41-56'S	15-19.8	19.8	76-100	70	-	70	21-28	28	-	-	-	-	-	-	-	-	+	-
4 58 S	3.6	3.6	100	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
5 12 S	19.2	19.2	100	37<	37	-	<52	-	-	-	-	+	-	-	-	-	-	P3<
5 30 S	11.7	11.7	100	40-80	29	80	15-29	15	-	-	-	+	-	-	-	-	-	P2
5 48 S	13.5	-	-	40-50	-	-	27-34	-	-	-	-	-	-	-	-	-	+	-
5 48 S	16.5	-	-	68-80	-	-	21-24	-	-	-	-	-	-	-	-	-	+	-

Site No.	Region		Charts used for measurement No.	Scale	Add. chart	Locat Longitude
351	East Africa	Zanzibar Is.	3310	1:300,000		39°21–26′E
352	〃	〃	3310	1:300,000		38 50–39°11′E
353	〃	〃	3310	1:300,000		39 22–27′E
354	〃	〃	3310	1:300,000		39 0–12′E
355	〃	〃	3310	1:300,000		39 31–33′E
356	〃	〃	3309	1:300,000		39 33–36′E
357	〃	〃	3309	1:300,000		39 15–26′E
358	〃	Mafia Is.	1032	1:146,000	3309	39 30–52′E
359	〃	〃	1032	1:146,000	3309	39 54–56′E
360	〃	〃	1032	1:146,000	3309	39 44–50′E
361	〃	〃	1032	1:146,000	3309	39 38–40′E
362	Coast of East Africa	Jewe & Luala Reefs	1032	1:146,000	3309	39 22–36′E
363	〃	Kilwa Kisiwani	661	1:78,879		39 32–36′E
364	〃	Mtwara	3308	1:300,000		40 15–18′E
365	Coast of Mozambique	Baia de Tungue	3308	1:300,000		40 33–42′E
366	〃	Baixo Nameguo	2938	1:300,000		40 27–41′E
367	〃	Baixo Vadiazi	2938	1:300,000		40 26–40′E
368	〃	South of Porto America	2938	1:300,000		40 33–37′E
369	〃	Baixo do Pinda	2937	1:300,000		40 43–48′E
370	〃	Ilha de Moma	2935	1:300,000		39 26–32′E
371	〃	Ilha Silva	2935	1:300,000		38 43–49′E
372	〃	Pentaloon shoals	2935	1:300,000		37 47–38°1′E
373	〃	Machangulo	644	1:80,000		32 56–33°3′E
374	Coast of South Africa	Near St. Lucia Bay	2089	1:300,000		32 25–29′E
375	〃	Glenton Reef	2088	1:300,000		31 43–32°6′E
376	〃	Beach Terminus	3795	1:150,000		30 25–32′E
377	Seychelles Group	Bird Is.	724	1:35,000		55 12 E
378	〃	Denis Is.	724	1:50,000		55 38–41′E
379	Amirante Isles, African Is.		724	1:75,000		53 19–25′E
380	〃	D′Arros Is.	724	1:75,000		53 17–19′E
381	〃	St. Joseph Is.	724	1:75,000		53 17–23′E
382	Île Desroches		724	1:300,000		53 35–45′E
383	Coetivy Is.		724	1:200,000		56 5–16′E
384	Providence Is.		724	1:300,000		50 59–51°7′E
385	Seychelles Group	Praslin Is.	1072	1:132,000		55 40–42′E

ion Latitude	Rw km	Sw km	W-ratio %	Rd m	Ld max m	Sd m	Rw/Rd %	Sw/Sd %	Reef type Ap	 F	 aB	 B	 aA	 A	 aT	 T	 P	No. of knolls & pinnacles
5°48′S	8.4	8.4	100	73<	−	73<	<12	<12	−	−	−	−	−	−	−	−	+	−
6 S	12	−	−	45	−	−	27	−	−	−	−	−	−	−	−	−	+	−
6 S	5.4	5.4	100	40−80	−	−	7−14	−	−	+	−	−	−	−	−	−	−	−
6 9 S	15	−	−	33	−	−	45	−	−	−	−	−	−	−	−	−	+	−
6 9 S	3.6	3.6	100	70<	−	−	<5	−	−	+	−	−	−	−	−	−	−	−
6 18−20′S	7.5	7.5	100	70<	−	−	<11	−	−	+	−	−	−	−	−	−	−	−
6 23−28′S	14.4	−	−	40	−	−	36	−	−	−	−	−	−	−	−	−	+	−
7 30−40′S	36	−	−	62	−	−	58	−	−	−	−	−	−	−	−	−	+	−
7 40 S	2.5	2.5	100	40<	−	−	<6	−	−	+	−	−	−	−	−	−	−	−
7 57−58′S	8.4	8.4	100	85<	−	−	<10	−	−	+	−	−	−	−	−	−	−	−
7 59−8°10′S	21	21	100	75<	−	−	<28	−	−	−	−	−	−	−	−	−	+	−
8 37 S	24.8	24.8	100	100−120	60<	120	21−25	21	−	−	−	+	−	−	−	−	−	P5<
8 51−54′S	10.1	10.1	100	90	22	90	11	11	−	−	+	−	−	−	−	−	−	−
10 11−14′S	8.1	8.1	100	60<	−	−	<14	−	−	+	−	−	−	−	−	−	−	−
10 46−48′S	3.9	3.9	100	40<	−	−	<10	−	−	+	−	−	−	−	−	−	−	−
11 26−30′S	25.5	25.5	100	97	22	97<	26	<26	−	−	+	−	−	−	−	−	−	P1 0<
11 37−41′S	27	27	100	60<	20<	60<	<45	<45	−	−	+	−	−	−	−	−	−	P3<
13 6 S	6	6	100	60<	−	60<	<10	<10	−	+	−	−	−	−	−	−	−	−
14 12−15′S	10.5	10.5	100	60<	−	60<	<18	<18	−	+	−	−	−	−	−	−	−	−
16 42−50′S	18	18	100	40	−	40	45	45	−	−	−	−	−	−	−	−	+	−
17 5−19′S	27	27	100	35	−	35	77	77	−	−	−	−	−	−	−	−	+	−
17 27−47′S	43.5	43.5	100	50<	−	80−100	<87	44−54	−	−	−	−	−	−	−	−	+	−
26 13 S	0.6	8	8	18	−	100<	3	<8	−	+	−	−	−	−	−	−	−	−
28 25 S	1.2	7.5−9.6	13−16	10	−	50−100	12	8−19	+	−	−	−	−	−	−	−	−	−
29 1−9′S	2.4	39	6	10−15	−	90<	16−24	<43	+	−	−	−	−	−	−	−	−	−
30 47−51′S	0.3	11.3	3	5	−	90<	6	<13	+	−	−	−	−	−	−	−	−	−
3 42−43′S	6 <	−	−	50<	−	−	<12<	−	−	−	−	−	−	−	−	+	−	−
3 48−49′S	3 <	−	−	50<	−	−	<6<	−	−	−	−	−	−	−	−	+	−	−
4 53 S	9.8	9.8	100	33<	33	−	<30	−	−	−	−	−	−	−	+	−	−	−
5 24−26′S	2.3	2.3	100	64<	−	−	<4	−	−	−	−	−	−	−	−	+	−	−
5 24−26′S	7.5	7.5	100	82<	−	82<	<9	<9	−	−	−	−	−	−	+	−	−	P20<
5 35−42′S	19.5	19.5	100	37<	27	37<	<53	<53	−	−	−	−	−	+	−	−	−	P 3
7 6−9′S	3−22	22	36−100	40<	−	40<	20−55	<55	−	−	−	−	−	−	−	+	−	−
9 22 S	12	12	100	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−
4 20−23′S	4	−	−	30−35	−	−	11−13	−	−	+	−	−	−	−	−	−	−	−

Site No.	Region		Charts used for measurement			Loc
			No.	Scale	Add. chart	Longitude
386	Aldabra Group		710	1:25,000		46°12–33′E
387	Assumption Is.		718	1:75,000		46 30–33′E
388	Cosmoledo Group		718	1:75,000		47 30–40′E
389	Farquhar Is.		718	1:20,000		50 58–51 12′E
390	Astove Is.		718	1:50,000		47 43–46′E
391	Comoro Is.	Mohéli Is.	2066	1:20,000		43 46 E
392	〃	Anjouan Is.	2066	1:20,000		44 24 E
393	〃	〃	2066	1:30,000		44 31–32′E
394	〃	Mayotta Is.	2741	1:98,000		45 0–7′E
395	〃	〃	2741	1:98,000		45 7–8′E
396	Madagascar	Andramahiba Bay	1002	1:104,000		49 3–10′E
397	〃	〃	1002	1:104,000		48 52–48′E
398	〃	Baie de Loky	679	1:50,000		49 42 E
399	〃	Narendri Bay	704	1:145,000		47 27–35′E
400	〃	South of Cap Lohatroz	677	1:150,000		49 52–50 16′E
401	〃	Maintirano	3868	1:350,000		43 22–44′E
402	〃	Le Grand Recif	692	1:64,980		43 38–46′E
403	〃	Baie de St. Augustin	692	1:64,980		43 43–45′E
404	〃	Nosy Ve	692	1:64,980		43 33–39′E
405	Rodriguez Is.	Port South East	715	1:48,424		63 26–30′E
406	〃	Quatre–Vingts Brisans	715	1:145,000		63 17–21′E
407	〃	Northern part of Passe au Sable	715	1:145,000		63 5–20′E
408	Mauritius Is.	South of Black River Bay	711	1:100,000		57 18–21′E
409	〃	Near Dariembelle Point	711	1:100,000		57 29 E
410	〃	South of Danish Entrance	711	1:100,000		57 47–50′E
411	〃	Barraque Point	711	1:100,000		57 48–50′E
412	〃	Near Passe St. Gerant	711	1:100,000		51 41–49′E
413	〃	East of Rietz Passe	711	1:100,000		57 39–44′E
414	〃	West of Port Louis	711	1:100,000		57 20–27′E
415	Île de la Réunion	Coast about St. Gilles	1497	1:24,220		55 10–14′E
416	Laccadive Is.	Chetlat Is.	827	1:36,290		72 41–42′E
417	〃	Kiltan Is.	827	1:36,290		73 0–1′E
418	〃	Amini Is.	827	1:45,000		72 44 E
419	〃	Minicoy Is.	827	1:58,050		73 2–3′E
420	SE India	Near Adams Bridge	68a	1:305,600		79 5–8′E

ation	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Sw	Sw/Sd	Reef type									No. of knolls &
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	pinnacles
9°25′S	37.9	37.9	100	80<	22	80<	<47	<47	–	–	–	–	–	–	+	–	–	–
9 43–46′S	5.6	7.1	79	50<	–	110	<11	6	–	–	–	–	–	–	–	+	–	–
9 41–45′S	19.7	19.7	100	50<	7	50<	<39	<39	–	–	–	–	–	–	+	–	–	–
10 7–14′S	24.4	24.4	100	40<	15	40<	<61	<61	–	–	–	–	–	–	+	–	–	–
10 3–5′S	4.5	4.5	100	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
12 16–17′S	0.7	–	–	20	–	–	4	–	–	+	–	–	–	–	–	–	–	–
12 9 S	0.5	0.5	100	50<	–	60–90	< 1	1	–	+	–	–	–	–	–	–	–	–
12 12 S	1.3–1.5	1.5	87–100	40<	–	90–100	<3–4	2	–	+	–	–	–	–	–	–	–	–
12 56 S	13.7	13.7	100	93<	93	93<	<15	<15	–	–	–	+	–	–	–	–	–	P·K ◉
12 59–13°4′S	10.5	10.5	100	57<	57	57<	<18	<18	–	–	–	+	–	–	–	–	–	P·K ◉
12 5–11′S	18.7	18.7	100	90–100	48	90–100	19–21	19–21	–	–	–	–	–	–	–	–	+	P·K10<
12 9–15′S	14	14	100	90	31	90	16	16	–	–	–	–	–	–	–	–	+	–
12 43–45′S	2	2	100	76<	–	76<	< 3	< 3	–	+	–	–	–	–	–	–	–	–
14 25–33′S	<19.6	19.6	<100	40–90	40	90	<22–49	22	–	–	–	+	–	–	–	–	–	P5<
16 27–46′S	4.5	60	8	60	–	80–100	8	60–75	–	+	–	–	–	–	–	–	–	–
18 21–5′S	64.8	64.8	100	86	42–86	86–100	75	65–75	–	–	–	+	–	–	–	–	–	–
23 28 S	12	13.6	88	35	16	40	34	34	–	–	+	–	–	–	–	–	–	P3<
23 32′S	1.4–1.9	1.4–1.9	74–100	40<	–	40–130	<4–5	1–5	–	+	–	–	–	–	–	–	–	–
23 38′S	8.1	11.2	72	30	–	35<	27	<32	–	–	–	–	–	–	–	–	+	–
19 47–50′S	5.8	14	41	40	20–29	80	15	18	–	–	+	–	–	–	–	–	–	–
19 46–52′S	7.3	14.2	51	50	–	80	15	18	–	–	+	–	–	–	–	–	–	–
19 45–48′S	6.5	27.6	24	45	–	75	14	37	–	–	+	–	–	–	–	–	–	–
20 25 S	5	6	83	30	–	40<	17	<15	–	+	–	–	–	–	–	–	–	–
20 31–32′S	1	1.5	67	20<	–	–	< 5	–	–	+	–	–	–	–	–	–	–	–
20 20–22′S	5.5–6.5	6.5	85–100	30–60	27	80–100	9–22	7–8	–	–	–	+	–	–	–	–	–	P3<
20 13 S	1–1.5	2.8	36–54	20–55	–	70–80	2–8	4	–	+	–	–	–	–	–	–	–	–
19 48–20°4′S	6	15.3	39	40–45	13	140	13–15	11	–	–	+	–	–	–	–	–	–	–
19 51–20°0′S	4	17	24	40–45	5.5	80	9–10	21	–	+	–	–	–	–	–	–	–	P6<
20 9–10′S	2	2.5	80	40	–	80	5	3	–	+	–	–	–	–	–	–	–	–
21 2 S	0.4	5.1	8	20–30	–	120	1–2	4	–	+	–	–	–	–	–	–	–	–
11 41–42′N	1.8	1.8	100	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
11 29 N	2.2	2.2	100	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
11 6–8′N	4.5	4.5	100	36<	–	–	<13	–	–	–	–	–	–	–	–	+	–	–
8 17–19′N	5.2	5.2	100	–	15	–	–	–	–	–	–	–	–	–	+	–	–	P10
9 0–15′N	1.1–1.5	3.1	35–48	15	13	50–65	7–10	2–3	–	–	+	–	–	–	–	–	–	–

Site No.	Region		Charts used for measurement			Loc
			No.	Scale	Add. chart	Longitude
421	Coast of Slilanka	Uheliya Reef	3700	1:145,000		79°43–57′E
422	〃	Goda Gala	3700	1:145,000		80 12–15′E
423	〃	Great Basses Reef & ridge	3265	1:145,000		81 20–33′E
424	〃	Little Basses Reef & ridge	3265	1:145,000		81 39–45′E
425	Maldive Is.	Iharandiffulu Atoll	66a	1:292,000		72 46–73′E
426	〃	Miladummadulu Atoll	66a	1:292,000		72 52–73°4′E
427	〃	〃	66a	1:292,000		73 11–24′E
428	〃	Fadiffolu Atoll	66a	1:292,000	3324	73 27–33′E
429	〃	South Malosmadulu Atoll	66a	1:292,000		72 47–73°4′E
430	〃	Male Atoll	3324	1:145,000	66b	73 20–40′E
431	〃	South Male Atoll	66b	1:292,000		73 20–30′E
432	〃	Ari Atoll	66b	1:292,000		72 42–56′E
433	〃	〃	66b	1:292,000		72 41–57′E
434	〃	Felidu Atoll	66b	1:292,000		73 24–45′E
435	〃	North Nilandu Atoll	66b	1:292,000		72 49–73°3′E
436	〃	Mulaku Atoll	66b	1:292,000		73 21–36′E
437	〃	South Nilandu Atoll	66b	1:292,000		72 51–73°3′E
438	〃	Kolumadulu Atoll	66b	1:292,000		72 54–73°22′E
439	〃	Haddummati Atoll	66b	1:292,000		73 17–34′E
440	〃	Suvadiva Atoll or Huvadu Atoll	66c	1:292,000		72 56–73°31′E
441	〃	Addu Atoll	2067	1:25,000	66c	73 6–14′E
442	Chagos Archipelago	Peros Banhos	3	1:360,000		71 44–59′E
443	〃	Great Chagos Bank	3	1:360,000		71 15–72°31′E
444	Coast of Burma	St. Martins Reef	3493	1:145,000		92 2–19′E
445	〃	Robinson shoal	3771	1:145,000		93 55–94°26′E
446	Andaman Is.	Slipper Is.	3103	1:96,000		93 12–22′E
447	〃	East Is.	3103	1:96,000		93 5–16′E
448	〃	Long Is.	3145	1:48,000		92 56–59′E
449	〃	Port Cornwallis	2986	1:24,230		93 5–7′E
450	〃	Elfin Patch	2455	1:28,580		93 1–3′E
451	〃	Havelock Is.	1419	1:96,700		93 2–12′E
452	〃	Blair Reef	514	1:14,570		92 44–47′E
453	〃	Rutland Is.	1398	1:96,200		92 28–38′E
454	Nicobar Is.	Revello channel	842	1:50,000		93 24–28′E
455	〃	Kamorta Is.	841	1:25,000		93 31–32′E

ation	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls & pinnacles
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	
6°35'N	5.1	27.6	18	15–20	–	70–80	26–34	35–39	–	–	–	–	–	–	–	–	+	–
5 49–6°0'N	1.5	20.3	7	30	–	80–90	5	23–25	–	–	–	–	–	–	–	–	+	–
6 5–14'N	16	24.7	65	65	32	90–100	25	25–27	–	–	–	+	–	–	–	–	–	–
6 22–28'N	11.3	11.3	100	26<	26	–	<43	–	–	–	+	–	–	–	–	–	–	–
7 1 N	23.4	23.4	100	51<	51	51<	<46	<46	–	–	–	–	–	+	–	–	–	K·P15
6 23–26'N	21.9	21.9	100	60<	60	60<	<37	<37	–	–	–	–	–	+	–	–	–	K40<
5 45–58'N	34.2	34.2	100	73<	73	73<	<47	<47	–	–	–	–	–	+	–	–	–	K40<
5 20–28'N	20.1	20.1	100	64<	64	64<	<31	<31	–	–	–	–	–	+	–	–	–	K40
5 8 N	30.7	30.7	100	70<	70	70<	<44	<44	–	–	–	–	–	+	–	–	–	K40<
4 21–30'N	39.9	39.9	100	71<	71	71<	<56	<56	–	–	–	–	–	+	–	–	–	K100<
4 N	19	19	100	68<	68	68<	<28	<28	–	–	–	–	–	+	–	–	–	K50<
4 5–7'N	26.9	26.9	100	73<	73	73<	<37	<37	–	–	–	–	–	+	–	–	–	K100<
3 51–53'N	29.8	29.8	100	79<	79	79<	<38	<38	–	–	–	–	–	+	–	–	–	K100<
3 22–25'N	40	40	100	75<	75	75<	<53	<53	–	–	–	–	–	+	–	–	–	K90<
3 12–14'N	28	28	100	70<	70	70<	<40	<40	–	–	–	–	–	+	–	–	–	K40<
3 2–4'N	27.7	27.7	100	77<	77	77<	<36	<36	–	–	–	–	–	+	–	–	–	K70<
2 49–50'N	22.8	22.8	100	71<	71	71<	<32	<32	–	–	–	–	–	+	–	–	–	K60<
2 23–25'N	50.2	50.2	100	88<	88	88<	<57	<57	–	–	–	–	–	+	–	–	–	K100<
1 58 N	28.6	28.6	100	79<	79	79<	<36	<36	–	–	–	–	–	+	–	–	–	K40<
0 29 N	61.3	61.3	100	90<	90	90<	<68	<68	–	–	–	–	–	+	–	–	–	K70<
0 39 N	13.7	13.7	100	79<	79	79<	<17	<17	–	–	–	–	–	+	–	–	–	K20<
5 20 S	25.6	25.6	100	75<	75	75<	<34	<34	–	–	–	–	–	+	–	–	–	K35<
6 23–25'S	139.7	139.7	100	97<	97	97<	<144	<144	–	–	–	–	–	+	–	–	–	K40<
20 23–45'N	18.9	–	–	15	–	–	126	–	–	–	–	–	–	–	–	–	+	–
17 53–18°8'N	26.1	60.2	43	20–50	–	120–130	15–42	46–50	–	–	–	–	–	–	–	–	+	–
14 11–13'N	1.4	16.8	8	30	–	100–130	5	13–17	–	+	–	–	–	–	–	–	–	–
13 39 N	4.3	20.2	21	15–30	–	110–130	14–29	16–18	–	–	–	–	–	–	–	–	+	–
12 21 N	4.3	–	–	25–40	–	–	11–17	–	–	–	–	–	–	–	–	–	+	–
13 16–18'N	0.9	4.6	20	25	–	80–100	4	5–6	–	+	–	–	–	–	–	–	–	–
13 0–2'N	2.2	–	–	30–35	–	–	6–7	–	–	–	–	–	–	–	–	–	+	–
11 59 N	2.9–12.6	15.5–17.4	17–81	35–50	9	110–140	6–36	11–16	–	–	–	–	–	–	–	–	+	–
11 41 N	0.8	–	–	30–35	–	–	2–3	–	–	+	–	–	–	–	–	–	–	–
11 23–38'N	4.8	–	–	30–50	–	–	10–16	–	–	+	–	–	–	–	–	–	–	–
7 59 N	3–4	–	–	35–90	–	–	3–11	–	–	–	–	–	–	–	–	–	+	–
8 2 N	0.6	–	–	30	–	–	2	–	–	+	–	–	–	–	–	–	–	–

Site No.	Region		Charts used for measurement			Locat
			No.	Scale	Add. chart	Longitude
456	Nicobar Is.	Approaches to Nancowry Harbour	841	1:25,000		93°28-30'E
457	Greater Sunda Is.	North of Sumatra	2777	1:500,000		95 8-21'E
458	〃	N.W. Coast of Sumatra	2778	1:500,000		96 49-54'E
459	〃	〃	2778	1:500,000		97 20-32'E
460	〃	〃	2778	1:500,000		98 14-46'E
461	〃	South of Panjang, Sumatra	2779	1:500,000		98 15-99°3'E
462	〃	Fatahol Mobarak, Sumatra	2779	1:500,000		99 6-27'E
463	〃	Erasmus Reef, Sumatra	2780	1:500,000		100 22-34'E
464	Cocos (Keeling) Is.	South Keeling Is.	2510	1:37,500		96 50-53'E
465	Great Sunda Is.	Kangean Is., Kwong Eng Reef	1653c	1:500,000		115 32-116°25'E
466	Sabalana (Postillon) Is.	Dog Reefs	1696	1:510,450		118 32-48'E
467	NW Australia	Long Reef	1716	1:177,000		125 20-126°0'E
468	〃	Flinders Shoal	2759a	1:4,700,000		129 20-130°15'E
469	〃	Sahul Bank	2759a	1:4,700,000		125 18-130°5'E
470	〃	Hibernia Reef	2759a	1:4,700,000		123 20-129°42'E
471	〃	South of Heywood Shoal	2759a	1:4,700,000		123 47-125°7'E
472	〃	Adéle Is. & Lynher Bank	Aus323	1:300,000	2759a	121 25-124°30'E
473	〃	North of Lagrange Bay	1207	1:300,000	1048	120 30-121°50'E
474	〃	Patterson Shoal	1048	1:690,560		119 50-121°32'E
475	〃	Bedout Islet	Aus739	1:150,000	1048	118 25-119°7'E
476	〃	Sailfish Reef	Aus741	1:150,000	2759a	116 22-35'S
477	〃	Rosily Is.	Aus743	1:150,000		114 45-115°15'E
478	〃	North West Cape	Aus744	1:150,000		114 3-10'E
479	〃	〃	Aus744	1:150,000		114 3-5'E
480	West Australia	Fitzroy Reefs & Darwin Reefs	Aus331	1:300,000		112 20-113°26'E
481	〃	Dampier Reef	Aus331	1:300,000		112 19-113°54'E
482	〃	Wallabi Group	Aus8	1:37,500		113 25-114°20'E
483	〃	Eastern Group	Aus81	1:37,500		113 35-114°28'E
484	〃	Pelsart Group	Aus81	1:18,750		113 42-114°35'E
485	〃	Leander Reef	Aus81	1:300,000		114 14-57'E

ion	Rw	Sw	W-ratio	Rd	Ld max	Sd	Rw/Rd	Sw/Sd	Reef type									No. of knolls & pinnacles
Latitude	km	km	%	m	m	m	%	%	Ap	F	aB	B	aA	A	aT	T	P	
7°59′–1°0′N	0.6–1.1	2.3	26–48	20–70	–	100	1–6	2	–	+	–	–	–	–	–	–	–	–
4 58 N	26	26	100	70–100	–	90–100	26–37	26–29	–	–	–	–	–	–	–	–	+	–
3 27–37′N	21.5	21.5	100	100	90–100	100	22	20–22	–	–	–	+	–	–	–	–	–	K5<
2 48–54′N	22	22	100	85–90	–	85–90	24–26	24–26	–	–	–	–	–	–	–	–	+	–
1 15–25′N	67.5	67.5	100	70–100	–	90–100	68–96	68–75	–	–	–	–	–	–	–	–	+	–
0 45–46′N	89	89	100	86–110	–	86–110	81–103	81–103	–	–	–	–	–	–	–	–	–	–
0 21 S–0°8′N	66	66	100	81–100	–	81–100	66–81	66–81	–	–	–	–	–	–	–	–	–	–
2 25–29′S	19–22.5	22.5	84–100	77–100	–	77–100	19–29	29	–	–	–	–	–	–	–	–	–	–
12 5–13′S	15.2	15.2	100	–	20	–	–	–	–	–	–	–	–	–	+	–	–	P ◉
6 30–54′S	100–110	110	91–100	100–130	–	130	77–110	85	–	–	–	–	–	–	–	–	+	–
6 32–7°3′S	61.3	61.3	100	75<	75	75<	<82	<82	–	–	–	–	–	+	–	–	–	K・P40<
13 40–55′S	33.6	–	–	45–65	–	–	52–75	–	–	–	–	+	–	–	–	–	–	–
9 46–11°20′S	220.9	220.9	100	120	–	120	184	184	–	–	–	–	–	–	–	–	+	–
11 15–13°0′S	564	564	100	90<	–	<150	<627	376<	–	–	–	–	–	–	–	–	+	–
11 19–13°17′S	714.4	714.4	100	100<	–	<140	<714	510<	–	–	–	–	–	–	–	–	+	–
13 50–14°28′S	169.2	169.2	100	100–120	–	120	141–169	141	–	–	–	–	–	–	–	–	+	–
15 30 S	169	331	51	65	–	100	260	331	–	+	–	–	–	–	–	–	–	–
17 55–18°30′S	18	111	16	25–30	–	140	60–72	79	–	–	–	–	–	–	–	–	+	–
18 10–19°10′S	34.5	165.7–255.5	14–21	30–35	–	130–160	99–115	104–197	–	–	–	–	–	–	–	–	+	–
18 30–19°57′S	44.3	82.5	54	30	–	100	148	83	–	–	–	–	–	–	–	–	+	–
19 30–20°29′S	2.7	–	–	30	–	–	9	–	–	+	–	–	–	–	–	–	–	–
20 55–21°34′S	42.8	68.3	63	30	–	110	143	62	–	–	–	–	–	–	–	–	+	–
21 37–47′S	4.8	14.3	34	20–30	–	60	16–24	24	–	+	–	–	–	–	–	–	–	–
21 38–49′S	2.7	10.5	26	30	–	60	9	18	–	+	–	–	–	–	–	–	–	–
24 32 S	5.1	88.5	6	20–30	–	110	17–26	80	+	–	–	–	–	–	–	–	–	–
25 21 S	82.5	150	55	20–30	–	130	275–413	115	–	–	–	–	–	–	–	–	+	–
28 16–33′S	73.5	84	88	25–45	–	85	163–294	99	–	–	–	–	–	–	–	+	–	–
28 26–47′S	88.5	91.5	97	30–55	–	65	161–295	141	–	–	–	–	–	–	–	+	–	–
28 47–56′S	78	81	96	30–50	–	90	156–260	90	–	–	–	–	–	–	–	+	–	–
29 23–32′S	17	72	24	25–35	–	65–80	49–68	90–111	–	–	–	–	–	–	–	–	+	–
								Total	30	98	23	112	2	77	24	20	99	