PROBLEMS OF THE GREAT BARRIER REEF.*

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INTRODUCTION.

When Professor J. Beete Jukes, M.A., F.G.S., naturalist to the surveying voyage of H.M.S. "Fly," landed on 7th January, 1843, on a small islet—First Bunker's Island—in the northern part of the Capricorn Group of islands, there began the first real investigation of the Great Barrier Reef of Australia. The interest taken in the reef by Jukes was different from that of Captain Cook, whose main interest was to avoid collision; and in the narrative of the voyage of H.M.S. "Fly," vol. i., a very faithful description of the reef is given.

It is fortunate that one with the training of Jukes was the first historian, for since then a generally accurate idea as to the nature of the reef has been available. Many investigators—notably W. Saville Kent, A. Agassiz, E. C. Andrews, C. Hedley, T. Griffith Taylor, P. Marshall, A. Mayer, and W. M. Davis—have investigated this great epicontinental mass of coral, and while, with the exception of Agassiz, there is a general support of the Darwinian subsidence hypothesis for the origin of the reef, there are many points of difference between the various investigators.

Of the existing examples of epicontinental reefs, the Great Barrier Reef of Australia is the best representative, and yet we find that for the last fifteen years there has not been any systematic work by Australian scientists. The amount of literature on coral reefs is stupendous, and many men of great eminence—such as Charles Darwin, Sir John Murray, J. D. Dana, A. Agassiz, and W. M. Davis—have devoted much time and attention to the problems associated with coral reefs and atolls.

W. M. Davis has pointed out that,† probably as a result of most of the investigators of coral reefs being zoologists, little trained in the physiography of shore lines and in structural geology, too little attention has been paid (even by Darwin himself)

* Read at the meeting of the Royal Geographical Society of Australasia, Queensland, 21st April, 1922.

† "Nature," 15th April, 1915, p. 190.

to the central islands within oceanic barrier reefs or to the mainland coast within a continental barrier reef. Davis, who is qualified so well to interpret the evidence of the islands and mainland coast, became a most ardent champion of Darwin's view after a visit in 1914 to the Great Barrier Reef. The position to-day is that, with the exception of Agassiz, those people who have actively investigated this great coral mass support Darwin's view as to the origin of coral reefs, or some slight modification of it.

After traversing the main results of these investigators, consideration will be given to the chief points of difference between them, and the problems which might be investigated further will be indicated.

THE FORMATION OF CORAL REEFS.

Dr. T. Wayland Vaughan, of the United States Geological Survey, has summarised* the conditions necessary for the vigorous growth of reef-forming corals as follows:—

(*a*) Depth of water, maximum, about 46 meters (25 fathoms);

(*b*) Bottom firm or rocky, without silty deposits;

(*c*) Water circulating, at times strongly agitated;

(*d*) An abundant supply of small animal plankton;

(*e*) Strong light;

(*f*) Temperature, annual minimum not below 18° C.; minimum average temperature for the coldest month in the year not lower than about 22° C.;

(*g*) Salinity between about 27 and about 38 parts per thousand.

Vaughan further states that, according to conservative estimates, reef corals can build a reef 46 meters (150 feet) within a period ranging from 1,800 years to 7,500 years; but in places a reef of such a thickness might be formed within 1,000 years according to J. Stanley Gardiner.

Coral reefs may be divided into three groups:—

(*a*) Fringing Reefs occurring along the shore;

* Ann. Rpt. Smith. Inst., 1917, p. 215.

(*b*) Barrier Reefs occurring further offshore with a lagoon several fathoms deep between the reef and the shore; and

(*c*) Atolls which are ring-like and enclose shallow lagoons.

Following the lead of Vaughan, one may classify the many coral-reef hypotheses under three or four headings.

I.—According to Darwin a fringing reef is first formed along the shore of the gently sloping bottom of a subsiding land area. As the bottom subsides the reef grows upward at a sufficiently rapid rate to keep it within the depth limits of the coral life. As the water deepens the fringing reef changes gradually into a barrier reef and eventually, if the subsiding land be an island, an atoll results. This is a very simple but necessarily incomplete statement of the Darwin-Dana hypothesis.

II.—The great rival hypothesis to that of Darwin was one put forward in 1863 by Carl Semper, and subsequently in a modified form in 1880 by John Murray. Semper, after studying the Pellew Islands, believed that atolls* could be formed in areas of stability or even uplift by the solution of the interior of limestone masses, and that erosion by currents and waves could develop channels behind fringing reefs and so transform them into barrier reefs.

Murray believed that atolls result from (*a*) the more abundant food supply on the outer margins of the reefs, and (*b*) the solution of dead coral rock in the interior portion by carbonated water. He also stated that barrier reefs have been built out from the shore on a foundation of volcanic débris or on a talus of coral blocks, coral sediment, and pelagic shells, the lagoon channel being formed in the same way as a lagoon.

This hypothesis, according to Murray, does not necessarily "call in subsidence to explain any of the characteristic features of barrier reefs or atolls, and that all the features would exist alike in areas of slow elevation, of rest and of slow subsidence."†

III.—The third class of hypothesis cannot be credited to any one man. It is that offshore reefs have formed on antecedent platforms during or after submergence where the conditions are favourable.

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* T. W. Vaughan: Ann. Rpt. Smith. Inst., 1917, p. 222.

† Murray, John: Proc. Roy. Soc. Edin., vol. 10, 1879-1880, pp. 505-518.

After preliminary work by Agassiz, H. B. Guppy, and R. T. Hill, we find E. C. Andrews in 1902 making the first definite statement of this view for the origin of the Great Barrier Reef. C. Hedley and Griffith Taylor subsequently endorsed the view of Andrews, and Vaughan offers the same interpretation for the coral reef areas in Florida, the West Indies, and Central America.

IV.—R. A. Daly is the chief exponent of the Glacial Control hypothesis, which holds that during the Great Ice Age the surface of the sea was lowered by the taking of water to form the great ice-sheets, and that during this period—the Pleistocene—the waves of the sea cut extensive submarine plains. As the ice-caps melted the released water raised the general sea-level, and, where with the warmer waters the conditions necessary for coral reef growth existed, luxuriant coral growths resulted.

PREVIOUS INVESTIGATIONS OF THE GREAT BARRIER REEF.

The results of Professor Beete Jukes's investigations, which are set out in vol. i. of the narrative of the surveying voyage of H.M.S. "Fly," are well known. Agassiz in 1896 stated that the general account of the Great Barrier Reef as given by Jukes for the year 1845 is by far the best we have on Queensland coral reefs, and after Agassiz had spent some considerable time actually going over the reefs he says that very little could be added to the description in chapter xiii. of the narrative of the voyage of H.M.S. "Fly."

According to Jukes the Great Barrier Reef commences with Breaksea Spit, in S. lat. 24° 30′, E. long. 153° 20′, and extends to Bristow Island on the coast of New Guinea, in S. lat. 9° 15′ and E. long. 143° 20′. This gives in a straight line a distance of about 1,100 geographical miles, or about 1,260 statute miles. The mean distance from the coast is about 30 miles; the outer edge being sometimes not more than 10 or 15, at others more than 100, miles distant from the shore.

The great lagoon strip enclosed varies in depth from 10 to 25 fathoms and has a sandy bottom. Towards the south, where the reef increases in distance from the shore, the lagoon depth increases

to 40 and in some places to 60 fathoms. Immediately outside the reef the water descends to profound depths. Jukes writes, p. 332—

> "The Great Barrier Reefs are thus found to form a long submarine buttress, or curtain, along the north-eastern coast of Australia, rising in general precipitously from a very great depth, but resting towards the north on the shoaler ground of Torres Strait, and towards the south on the bank stretching off from Sandy Cape. If it were to be laid dry, this great Barrier would be found to have a considerable resemblance to gigantic and irregular fortification, a steep glacis crowned with a broken parapet wall, and carried from one rising ground to another. The tower-like bastions, of projecting and detached reefs, would increase this resemblance."

Jukes clearly noted the evidence of subsidence along the Queensland coast and also the most recent small elevatory movement. He writes*—

> "After seeing much of the Great Barrier Reefs, and reflecting much upon them, and trying if it were possible by any means to evade the conclusions to which Mr. Darwin has come, I cannot help adding that his hypothesis is perfectly satisfactory to my mind and rises beyond a mere hypothesis into the true theory of coral reefs."

Jukes in his well-known imaginary cross-section across the Great Barrier Reef indicated quite clearly that he regarded the thickness of the reef as very great indeed.

Professor A. C. Haddon, of the University of Cambridge, spent a considerable time in Torres Strait in 1880, and published his results in the Transactions of the Royal Irish Academy, 1894, vol. xxx. He gave descriptions and sketches of some of the reefs in the Torres Strait as part of his interesting paper on the geological relationships of Queensland and New Guinea. As a result of his work he also produced a valuable series of memoirs on the Fauna and Ethnology.

W. Saville Kent, who was Commissioner of Fisheries in Queensland, as a result of an extensive study of the Great Barrier Reef and its products, brought forth a beautifully illustrated monograph in 1893 which is very well known. W. Saville Kent followed Jukes in assigning the formation of the Great Barrier

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* *Op. cit.*, p. 347.

Reef to the depression in recent times of the northern part of the Australian continent, and he thoroughly concurred in Jukes's conclusions as to the origin of the continental shelf and the Barrier Reef as supplied by Jukes's section. Saville Kent, however, disagreed with Jukes as to the origin of "negro-heads," and unlike the latter he regarded them as jetsam resulting from hurricanes.

Among other things Kent* suggested that the great openings through the Barrier Reef were opposite the mouths of the principal rivers of Queensland (Trinity Opening, Flinders, Palm, Magnetic, Flora, Grafton Passages; Capricorn and Curtis Channels), and that, though now 30 to 80 miles distant, yet at one time these breaks were close to the mouths of the rivers and owe their origin to the fresh water and silt brought down by them.

In 1896 Alexander Agassiz paid a visit to the Great Barrier Reef, in April and May, in the steamer "Croydon," commanded by Captain Wm. Thomson, a member of this society. This scientist made a world-wide survey of coral reefs, and after his investigation found himself at variance with both Jukes and Saville Kent as to the origin of the reef, but he pays a great tribute to Jukes's description of the Queensland coral reefs.

He realised that a knowledge of the physical geography of the north-eastern coast of Australia had a great bearing on the successful study of the problem of the evolution of the Great Barrier Reef, and he introduced his paper† by a general account of the physical geography of the coast from Moreton Bay to Cape York. He then described the coral reef flats and patches from Breaksea Spit, Lizard Islands, &c., right up the coast. He discussed the origin of the "negro-heads" (p. 114) and he agreed with Jukes that they indicate a former elevation of the reef, and disagreed with Saville Kent, who advocated a tossing up by hurricanes. He stated (p. 127)—

> "The present condition of the Great Barrier Reef can be satisfactorily explained by the mere action of erosion and of denudation which has been going on for so long a period along the coast of Queensland."

Agassiz stated (p. 128)—

> "Darwin and Dana have both assumed, in their discussion

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* "Great Barrier Reef," pp. 111, 112, 132.

† Bull. Mus. Comp. Zool. Harv., xxviii., 1895, p. 95.

of the theory of coral reefs, that the subsidence which they claimed as necessary for the formation of barrier reefs and of atolls took place during the present epoch."

Jukes was followed by Kent in assigning the formation of the Great Barrier Reef to the depression in recent times of the north-eastern part of the Australian Continent. Agassiz agreed that this depression had gone on, but he stated that it must have taken place during the Cretaceous period. He did not require the intervention of subsidence to account for the Great Barrier Reef, for he considers it has been practically stationary since the Cretaceous period.

It is upon the eroded surfaces of the numerous continental islands similar to those now fringing the main coast-line that the coral growth has developed—not as a great thick mass according to Jukes's conception, but as a thin veneer.

Agassiz differed *in toto* from Kent's summary—

"The foregoing geological evidence (of subsidence in Tertiary and Cretaceous times) being trustworthy and true, the construction of the Great Barrier Reef of Australia under conditions of subsidence, and in accordance with the original hypothesis of Mr. Darwin, is proved."

In 1901 Mr. E. C. Andrews, now Government Geologist of New South Wales, and Mr. C. Hedley, of the Australian Museum, Sydney, visited the Middle Barrier, and in the Proceedings of the Linnean Society, N.S.W., 1902, Mr. Andrews published an extremely valuable paper on the "Physiography of the Queensland Coast and its Relationship to the Great Barrier Reef." His paper dealt in detail with the section he examined and in general with the whole reef. He concluded that the present reef dates from Pleistocene times and was followed by a very slight modern uplift.

Andrews paid very special attention to the main coast-line and the islands just as was done by Agassiz, and he pointed out that there were great numbers of precipitous islands rising from shallow water which rarely exceeds 10 fathoms in depth, and that these islands are often accompanied by fringing reefs and often by plains. He pointed out that in many cases the axes of the mountain ridges of the islands are parallel to the main coast-line and are separated therefrom by narrow channels (e.g. Hinchinbrook, Molle, and Albany Passages). He writes (p. 177)—

"The coincidence of Barrier Reef and present coastal contours points to an occupation by coral growths of a former coast-line, but the continuance in width of the shelf southwards of the limits of reefs (coralline) and the great shoals thereon points to a minor part only of the shelf being formed of coral growths.

"It would appear that the almost uniform and smooth bottom of the outer centre and eastern portions of the continental plateau, combined with the great depths from which the Barrier rises, argues a long period of marine erosion preceding the present cycle (i.e. the time involved in a movement of considerable extent or in the development of a submarine plain or peneplain) during which a uniform coast and smooth offshore bottom had been formed. The sinking of this uniform area allowed the sea to trespass far over the old coast sands into the ranges, and the corals—formerly prevented from forming barrier reefs, by reason of the practical coincidence of continental shelf margin and shore line, and the excessively turbid characters of the water on the narrow fringe of the continental shelf—proceeded in the clear waters of the shelf margin, now removed far seaward, to invest the whole width of the smooth offshore deposits with their masses, and establish themselves as the Barrier Reef.

"Some connection probably exists between the present reef passages (and parallel channels) and the old watercourses of the coastal area."

In 1906 Messrs. C. Hedley and T. Griffith Taylor visited the reefs near Cooktown, and in the Proceedings of the Australasian Association for the Advancement of Science, 1907, pp. 397-413, they furnished a highly valuable contribution to the Barrier Reef question. They made traverses across three reefs—the Hope Island Reef, the Cairns Reef, and the Bee Reef—and made careful observations on the different zones with respect to corals, &c. They made a special study of the "negro-heads," particularly on the Cairns Reef, and they found themselves agreeing with Saville Kent and in opposition to the views of Jukes and Agassiz as to their origin. Hedley and Taylor state that—

"The hypothesis of Kent is preferred by us on the following grounds:—Positively: The 'negro-heads' do not continue down into the ground but are perched as morainic blocks might be.

Jetsam would accumulate on the weather side of the reefs (where the 'negro-heads' are) not on the lee side (where they are absent). Negatively: An elevated reef in course of denudation would commence to wear on the windward side, where the attack is fiercest; the last surviving remnants should be on the leeward shore. Supposing that the 'negro-heads' are such remnants, why do they survive only where they ought earlier to disappear? The central portions, more than half a mile from either edge, might naturally be expected to remain as more or less solid 'mesas' long after the rest had been ground to sand. Such is not the case on Cairns Reef. Again, a former elevated reef should have remained intact beneath the wooded islets like Hope Island; whereas the only rock there is coral sand rock.''

Hedley and Taylor supported the general idea put forward by Andrews as to the origin of the Great Barrier Reef and state (p. 406)—

''It may be allowed—though Darwin deprecated the idea—that the continental shelf was ready prepared with numerous banks representing eroded islands, just reaching to within the required distance of the surface, when the first coral builders came.''

These authors also put forward a very probable hypothesis to account for the type of atolls found along the Great Barrier Reef. They hold that they are shaped by currents and are mostly wind-induced.

In 1913 Dr. A. G. Mayer, of the Carnegie Institution, spent some time on Murray Island in Torres Strait, and with his staff carried out a very extensive series of observations on the Ecology of the Murray Island Coral Reef, which were published in 1918 in vol. ix. of the Papers from the Department of Marine Biology, Carnegie Institution of Washington.

When the British Association for the Advancement of Science visited Australia in 1914 it extended an invitation to Professor W. M. Davis, of Harvard University, the founder of modern physiography. With the joint help of funds from the Shaler Memorial Fund and the British Association for the Advancement of Science, W. M. Davis spent the greater part of 1914 visiting a number of islands in the Pacific Ocean and also the Great Barrier Reef. He* was of the opinion that the Great Barrier Reef—

* ''Nature,'' 15th April, 1915, p. 191.

"Has grown upward during the recent subsidence by which the Queensland coast has, after a long period of still-stand, been elaborately embayed, as was pointed out by Andrews in 1902. A very recent uplift of some 10 feet has occurred, as was long ago noticed by Jukes. There is much reason for believing that a broadened reef-plain, with extensive land-fed deltas along the continental margin, had been formed before the recent subsidence took place; and it is this broadened reef, now submerged, that is thought to form the 'platform' on which the Great Barrier Reef has grown up."

W. M. Davis is an undoubted champion of the Darwinian hypothesis, and he not only satisfactorily accounts for the Great Barrier Reef but also for the elevated reefs of New Guinea, Fiji, and elsewhere.

Since the investigations by Professor W. M. Davis apparently no further investigations into our great coral mass have been made.

PROBLEMS AWAITING INVESTIGATION.

After a perusal of the foregoing pages it is clear that, while there may be a preponderating opinion amongst the investigators of this great reef in favour of Darwin's view or a modification of it, there are several points on which elucidation is required. Many of these points are well worthy of investigation, and the first steps in that direction might well be taken by this Society.

The general condition of the Great Barrier Reef is not known. Is it in a static condition or one of elevation or of subsidence? Are all parts of the reef or reefs in the same condition? Has there been a sympathetic growth of the coral mass with the downward movement of the eastern coast of Australia? Does the Great Barrier Reef mark the original western margin of the Pacific Ocean? Or, if not, does it mark the north-eastern coast-line of Australia in late Tertiary times? Do the passages through the great epicontinental coral growth mark the pre-existing channels of the present great rivers of Queensland? Is there any movement of the sea-floor between the great reef and the mainland? If there is, is it uniform or spasmodic? Also, is it general or local?

Other questions might be asked, but the above furnish a list long enough for the present.

In the early hours of the morning of 7th June, 1918, Brisbane was affected by a rather severe earthquake shock. Records obtained

by Father Pigot, S.J., at Riverview College, Sydney, and by others, point to the source of that earthquake shock as being at no great distance to the east of Bundaberg. On more than one occasion the submarine cable from Bundaberg to New Caledonia has broken over a trough which is known to exist to the east of Breaksea Spit. A knowledge of the position, extent, and modification of this trough or hole is highly desirable. A recharting of the area and comparison with previous and future charts would without doubt lead to results of an interesting and valuable nature.

In other directions, too, much remains to be known of our Great Barrier Reef. For defence purposes it is obvious that the fullest knowledge of the fearful complex of coral reefs should be available. It happens that these areas are rich in pearl-shell, bêche-de-mer, trochus, sponges, turtle-shell, and other valuable articles of commerce. What are we doing with these our potential sources of wealth—ours, for the Queensland boundary extends to the outside of the Great Barrier Reef? Not only are we not using these sources of wealth, but we are allowing others to use them in an unlicensed and uncontrolled manner.

Mr. C. Hedley, of the Australian Museum, has written to me as follows:—

> "The Government regulations which control these fisheries allow them to be exploited by vagrant licensees down to the point at which exhaustion refuses the least profit. By a fortunate accident, it is unprofitable to lift the last ton of pearl-shell, the last bêche-de-mer, or the last trochus. For if by superior energy or ability the coloured fishermen could manage to collect the last specimen and leave none to breed, the regulations would allow him to thus destroy the industry.
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> "A patriotic policy might aim to replace the present wandering and foreign population which subsists on our marine tropical products, by resident European fishermen. To accomplish this a system of cultivation is required: preliminary to cultivation there should be zoological research and legislative protection. The cultivator should be taught how to grow his crops and then the profits of his harvest should be assured to him.
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> "How the pearl-shell, the trochus, and the bêche-de-mer breed is not yet properly understood. For success in terrestrial agriculture, an intimate knowledge of structure and function of

grain, fruit, and domestic animals is essential and has been obtained. It is more difficult but not impossible to obtain these details for marine animals. The best way to proceed would be to carry out the recommendation of the Royal Commission of 1908 to establish a marine biological station equipped with a strong staff of zoological investigators.''

As Dr. T. Wayland Vaughan so truly states*—

''The results of the investigation of coral reefs are valuable to geology not so much because of discoveries immediately concerning corals as because of the additions to knowledge obtained through a study of great complexes of geologic phenomena among which corals and coral reefs are only incidents.

''Further investigations of the phenomena associated with coral reefs are among the pressing desiderata of geologic research.''

SUGGESTED INVESTIGATIONS.

This Society should take active steps to see that something is done in the further investigation of this wonderful coral reef, and I would suggest for its earnest consideration the following matters as being of the utmost importance scientifically and otherwise:—

I. Careful complete charting, including the making of vertical sections, of at least three island points on the Great Barrier Reef, one each in the northern, middle, and southern regions, and recharting at intervals of a decade.

At the same time a complete survey of the fauna and flora of these points should be conducted. Raine Island in the north, Masthead Island in the south, and some suitable point in the Middle Barrier are suggested.

Raine and Masthead Islands are mentioned because much is already known of their fauna, flora, and reefs.

II. Careful charting of several of the more important troughs or valleys in the Great Barrier Reef and also in the lagoon area, and recharting at intervals of a decade.

The valley near Breaksea Spit might with advantage be surveyed at an early stage.

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* *Op. cit.*, p. 238.

III. General survey of the economic resources, especially in respect to trochus, bêche-de-mer, pearl-shell, sponges, and turtle-shell.

IV. Conducting of experiments on the growth of corals under varying conditions as carried out by Dr. F. Wood Jones in Cocos-Keeling, by Dr. A. G. Mayer at Tutuila, and by Dr. T. Wayland Vaughan at Florida.

In addition there should be representation to the governmental authorities of the unfortunate results likely to follow unlicensed exploitation of the reefs.

The investigations which have been conducted on the Great Barrier Reef have now been pointed out in a general way, and the manner in which the investigators have come here. Visitors such as Jukes, Mayer, and Agassiz have done much, while Andrews, Hedley, and Griffith Taylor have added their quota. For fifteen years, however, no Australian scientist has taken up any systematic study of this great heritage of ours, but we have had visitors from America and elsewhere, generously subsidised, conducting scientific investigations. What are we doing? Why do we not play our part?

The exploitation of the economic wealth of the Great Barrier Reef by foreigners has gone on and we stand idly by. Is that right? Surely this Royal Geographical Society is capable of making some definite move to point out our proper path! We have in this country men of training, energy, and ability to carry out these desirable investigations. Let us see that facilities are provided for the work to be done.