CORAL AND ATOLLS

CORAL AND ATOLLS

[illegible]

THE LATE GEORGE CLUNIES ROSS

CORAL AND ATOLLS

A HISTORY AND DESCRIPTION OF THE KEELING-COCOS ISLANDS, WITH AN ACCOUNT OF THEIR FAUNA AND FLORA, AND A DISCUSSION OF THE METHOD OF DEVELOPMENT AND TRANSFORMATION OF CORAL STRUCTURES IN GENERAL

BY

F. WOOD-JONES, D.Sc.,
F.Z.S., ETC.

RE-ISSUE

LONDON:
LOVELL REEVE & CO., LTD.
Publishers to the Home, Colonial, and Indian Governments
6 HENRIETTA STREET, COVENT GARDEN
1912

TO THE LATE
GEORGE CLUNIES-ROSS

Yours truly,
F. Wood-Jones.

PREFACE

For fifteen months I dwelt in Cocos-Keeling atoll. The charm of so remote a spot, the romance of its story and of its proprietor, and the fact that it was Darwin's atoll, were the reasons for my residence—its purpose was the medical care of the handful of men engaged in working the cable which breaks its journey from Australia to Africa upon the shores of the most northern islet of the group.

Upon this islet—Pulu Tikus—I lived, and shared its inconsiderable strip of coral land—some thousand yards in length—with fifteen Europeans, some twenty Chinese servants, three Malay boatmen, and two Hindoo clerks. The outlets for medical enthusiasm were therefore strictly limited, and much time was to hand for the study of the place and its fauna, and for speculating upon the problem of how so tiny a speck of land came to be made in the midst of that great waste of ocean.

I arrived early in June 1905, and lived upon Pulu Tikus until September 30, 1906. In January 1907 I returned, and, for a time, lived with the Governor at his home on Pulu Selma. During all these months I examined every portion of the atoll, became familiar with its living creatures, and made every endeavour to appreciate the life-processes of those most misunderstood of architects—the reef-building corals. Most of my days were passed in wading about the barrier flats, sailing or paddling a boat in the lagoon, or making excursions to the other islands of the atoll ring. The beauty of the clear water of the lagoon and the breaking surf of the barrier made these journeyings a perpetual delight, for the whole field-work of a coral-island naturalist is done amidst a splendour of tropical sunshine and luxuriant vegetation.

In all my doings I was aided and encouraged by the members of the Clunies-Ross family, and the kindly assistance of George Clunies-Ross—a man born with a true love of nature, trained by his life's work to observe, and familiar with every creature that lives within the confines of his domain—was always ready for my guidance. To him, and to the members of his family, I am deeply indebted, not only for an intimate knowledge of many things not easily known to a stranger, but for a splendid hospitality and a true friendship.

When, in 1907, I returned to the atoll and lived under his roof, I had the advantage of discussing with him those many details of coral-island biology which, though they may be guessed at, assumed, or scoffed at by a museum naturalist, are things familiar to a man whose long life of keen observation has been passed in their midst.

The greater part of this account of the atoll was written during my residence in the islands, and this fact I mention for two reasons: first, as an apology for scant references to former papers on the same subject; and secondly, as a guarantee that the ideas put forward are those actually arising out of the study of the atoll, and not of its literature.

A word must be said with regard to the native names employed in these pages. Throughout I have used those names to designate the islands, and the animals and plants that live upon them, which are in everyday use in the atoll; and for this I make no apology. I do not regret the fact that the names here used to distinguish the islands do not correspond with those on published charts. Did a stranger arrive in the atoll and ask his way of any one—native or European—to "Scævola Islet" or "Workhouse Island," he would certainly not arrive at his destination; and the giving of such made-up names to pieces of land already possessing well-known native names has nothing to recommend it. The names that I have employed are those in local and long-established use, and are those that every man, woman, and child about the atoll constantly employs.

Again, with the animals and plants, a native name is altogether useless unless it is the local word employed to designate the species. It is vain to urge that a particular word is not the one employed by Malays in the Straits to distinguish a certain fish, and therefore is not good Malay; for the stranger who is unacquainted with the word *chuchut* will glean no information about sharks in the atoll, though in Singapore he used an altogether different word. I have given native names for the Flora and Fauna of the group solely as a guide for any subsequent collector, and to him no names are helpful save those in actual local use. This I have done because in my own case I derived considerable help in the naming of species from the lists collected by Dr. C. W. Andrews in Christmas Island.

Some details of the zoology of the islands I have already published, for the most part in the *Proceedings of the Zoological Society of London*, and to this society I am indebted for permission to republish much of the contents of chapters viii., ix., and x. and of Appendix I. For the re-use of some figures I am also obliged to the Zoological Society, and for others to the editor of the *Badminton Magazine*.

Notes on the Fauna of the islands were published in the pages of the *London Hospital Gazette*, and with the kind permission of the editor of that journal some of these notes are incorporated here.

I owe a debt also to Mr. F. Hesse—general manager of the Eastern Extension Telegraph Company—to the officers of the company's ships, and to the shore staff of the cable station, for the use of material, and in many cases for the kindest personal help.

PREFACE TO RE-ISSUE

During the short period that has elapsed since the appearance of the first issue of this book some contributions have been made to our knowledge of submarine conditions which have a very direct bearing upon the debated question of the bathymetrical limit of the reef-building corals. Firstly, the "Michael Sars" North Atlantic deep-sea expedition has determined that light exerts a great influence on the Helland Hansen photometer at depths of 100 metres, and some influence even at 1000 metres; in the clear waters of tropical oceans this distance would almost certainly be greatly exceeded, so that it is safe to assume that some light asserts its influence very far below the limit at which reef-building corals live.

Secondly, a discussion which took place in the columns of *Nature* towards the end of 1910 produced the very welcome contribution of Mr. A. R. Hunt, who so long ago as 1882 had conducted researches regarding the Limiting Line of Sedimentation in wave-stirred areas, and determined the laws which govern its presence.

Both these contributions afford valuable additions to the subject-matter of chapter xxi., and furnish very real support for the conclusions arrived at.

CONTENTS

		PAGE
Preface		vii
Preface to Re-issue		x
Introduction		xxi

PART I. THE HISTORY OF THE ATOLL

CHAP.		
I.	The Discovery and Early History of the Islands	1
II.	The Origin of the Clunies-Ross Family	6
III.	1825–1854	15
IV.	The History of the Atoll, 1854–1871	27
V.	History of the Atoll from 1871	32
VI.	Native Customs	45

PART II. THE CORALS AND THE CORAL PROBLEM

VII.	The Early Stages of the Life-History of the Corals	57
VIII.	The Growth of the Coral Colony	69
IX.	The Life-Processes of the Coral Colony	101
X.	The Processes of Death in the Coral Colony	121

PART III. THE ATOLL AND ITS PROBLEMS

XI.	The Atoll as a Whole	135
XII.	The Submarine Bank on which the Atoll Rests	144

CHAP.		PAGE
XIII.	The Structure of the Barrier	151
XIV.	The Island Beaches	168
	(A) The Seaward Beaches	168
	(B) The Beaches of the Lagoon Shore	172
XV.	The Structure of the Islands	176
XVI.	The Lagoon	185
XVII.	The Climate and Prevalent Winds	201
XVIII.	The Theories of Atoll and Reef Formation put Forward until the Publication of Darwin's Theory of Subsidence.	212
XIX.	The Theories of Atoll and Reef Formation put Forward since the Publication of Darwin's Theory—The Theory of "Solution"	221
XX.	The Theories of Atoll and Reef Formation put Forward since 1880	232
XXI.	The Method of Development of the Reef Bank and the Reef	237
XXII.	Development of the Atoll	253
XXIII.	The After-History of the Atoll	262
XXIV.	The Development of other Coral Structures, and the Indications of Alteration of Land-Level	278

PART IV. THE FLORA AND FAUNA OF THE GROUP

XXV.	The Methods of Natural Colonisation	286
XXVI.	Ship-borne and Wind-borne Colonists	302
XXVII.	The Littoral and Marine Fauna	314

APPENDIX I. LIST OF THE FAUNA

	PAGE
Mammalia	335
Aves	338
Reptilia	345
Pisces	347
Mollusca	348
Lepidoptera	349
Hymenoptera	355
Diptera	356
Coleoptera	357
Rhynchota	360
Neuroptera	363
Orthoptera	364
Arachnida and Myriapoda	366
Crustacea	367
Vermes	369

APPENDIX II. LIST OF THE FLORA

Dicotyledons	371
Monocotyledons	377

BIBLIOGRAPHY 381

INDEX 384

ILLUSTRATIONS

		FACING PAGE
Portrait of the late George Clunies-Ross	*Frontispiece*	
Map showing the Position of Cocos-Keeling Atoll		1

PLATES

PLATE		
I.	Bungalow of the Telegraph Station on *Pulu Tikus*	44
II.	A Colony growing as a Plate-like Growth (*Montipora*)	74
III.	A Branching Growth approximating a Plate-like Form (*Madrepora*)	76
IV.	Chart of the Southern Group of Cocos-Keeling Islands	138
V.	The Barrier Flats and Seaward Beaches of *Pulu Tikus* at Low Tide	162
VI.	Barrier Pools left by the Fall of the Tide, *Pulu Tikus*	166
VII.	The Lagoon Shore of *Pulu Tikus*	172
VIII.	A Typical View of the Vegetation of the Atoll	178
IX.	Sand-piling of the Lagoon Side of the Island, *Pulu Tikus*	180
X.	The Lagoon from the Western End of *Pulu Tikus*	186
XI.	A Sunset in the Lagoon	200
XII.	A Small Colony of *Astræopora*	250
XIII.	A Fractured Surface of a Piece of Barrier-flat Breccia	254
XIV.	The Island Rise, Sea Beaches and Barrier Flats, Seaward Side of *Pulu Tikus*	256
XV.	The Raised Steps of Breccia Platform of *Pulu Tikus*	280
XVI.	Krakatoa as it appears to-day	290

PLATE		FACING PAGE
XVII.	Nest of *Merula erythropleura*	298
XVIII.	The Smaller Frigate Bird (*Fregata ariel*)	300
XIX.	The Nest and Eggs of the Philippine Land-rail	312
XX.	The Ikan P'dang	322
XXI.	Fauna of the Islands	346
XXII.	Natives clearing away the Growth of Klenchi (*Guielandina bundoc*)	372
XXIII.	The Spathe of the Coconut Palm	380
XXIV.	The Flower Spike of the Coconut Palm	380
XXV.	Young Nuts developing on the Flowering Stems when the Infertile Flowers have been shed	380
XXVI.	Young Coconuts in stage *klapa chinker*	380
XXVII.	Green Coconuts in stage *klapa muda*	380

IN THE TEXT

FIG.		PAGE
1.	A Wedding Group in Cocos-Keeling	52
2.	*Fungia*: Living specimen	58
3.	*Fungia*: Same Specimen Dead and Dried	58
4.	*Montipora* Colony, Living	60
5.	*Montipora* Colony, Dead and Dried	61
6.	A Section through a Portion of an Alcyonarian Coral to show the Relations of the Zooid to its Skeleton	62
7.	Larval Forms of Corals: Condition shortly after Extrusion	65
8.	Larval Forms of Corals	65
9.	Two Young Growths of *Seriatopora* that have started their Colonies upon a Living Oyster	66
10.	A Section through a Commencing Colony of *Cœnopsammia nigrescens*	67
11.	A Growth of *Porites*	73

G. PAGE
12. Example of a Coral Colony growing as an Encrusting Layer 74
13. Example of a Colony growing as a Tree-like Growth 75
14. Example of an Amorphous Type of Growth 76
15. Vegetative Reproduction in Corals 77
16. Vegetative Reproduction in Corals 78
17. Vegetative Reproduction in Corals 78
18. Vegetative Reproduction in Corals 79
19. Vegetative Reproduction in Corals 79
20. Vegetative Reproduction in Corals 81
21. Vegetative Reproduction in Corals 83
22. Colony of *Cœnopsammia Willeyi* growing from the Lower Surface of a Boulder 85
23. Types of Growth of *Montipora* 88
24. Types of Growth of *Madrepora* 89
25. Types of Growth of *Pocillopora* 90
26. A Colony of *Pocillopora* 91
27. Rough-water Type of Highly Branched *Madrepora* 93
28. Upper Surface (A) and Lower Surface (B) of a Partial Plate Growth 95
29. Diagram of Type of Growth of *Madrepora* when living in water free of sediment (*M. pulchra*) 96
30. Diagram of Growth of *Madrepora pulchra* when living in a habitat exposed to the action of sediment 96
31. Colourless *Stylopora* Colony from Deep Water (8–12 fathoms) 97
32. Colony of *Pocillopora* 98
33. The Influence of Environment on Coral Growth 99
34. *Millepora* Colony of the Type named *complanata* 102
35. *Millepora* Colony of the Type named *alcicornis* 103
36. Young *Porites* Mass grown equally round a Central Nucleus 107
37. Older *Porites* Colony in which the Lower Zooids are killed by Pressure 107

FIG.		PAGE
38.	Adult Colony of *Porites* in which the Upper Zooids are killed by Sediment	108
39.	A Small Colony of *Agaricia*	109
40.	Type of Repair of *Madrepora* when the "Dominant Apical Zooid" is not destroyed	113
41.	Type of Repair of *Madrepora* when the "Dominant Apical Zooid" is entirely destroyed	113
42.	*Montipora* Colony repairing a Branching Growth by an Encrusting Layer	117
43.	Colony partly killed by Deposition of Sediment	119
44.	Colony showing Death by Sediment overtaking it from below	126
45.	Specimen showing the Tunnelling of a Living Coral Colony by Boring Parasites	127
46.	The "Stings" caused by Contact with a Colony of *Millepora alcicornis*	132
47.	The Lagoonlet of *Pulu Luar* at High Tide	140
48.	Chart of Keeling Atollon	142
49.	Section of the Island and Barrier according to Darwin	152
50.	Transverse Section of the Submarine Ridge and the Cocos-Keeling Atoll	152
51.	Section of the Atoll and Submarine Slopes according to Dr. H. B. Guppy	152
52.	Theoretical Section to show: i. The Breccia Platform (black); ii. The Island Pile of Coral Fragments and Sand	153
53.	Theoretical Section of Funafuti Atoll	153
54.	Living Specimen of an Alcyonarian Coral	161
55.	The *Ikan Kakatua Ijou* (*Scarus*)	165
56.	Holothurians feeding at the Bottom of a Barrier Pool	166
57.	Western End of *Pulu Tikus*	174
58.	Diagram to Show the Prevalent Winds of the Atoll	203
59.	Illustration used by Darwin to make clear the Stages of "Subsidence" in Atoll Formation	219

FIG. PAGE

60. Photograph of a Coral Colony that has Living Zooids over its Entire Surface 249
61. Three Figures showing the Formation of a Crescent-shaped Island from some Original Obstruction to the Waves 258
62. Chart of the Cosos Atoll 260
63. Photograph of a Boulder of Alga-covered dead Coral Rock 265
64. Diagram to illustrate the Development of Keeling Atoll, Stage I. 272
65. Diagram to illustrate the Development of Keeling Atoll, Stage II. 273
66. Diagram to illustrate the Development of Keeling Atoll, Stage III. 274
67. Diagram to illustrate the Development of Keeling Atoll, Stage IV. 275
68. Diagram to illustrate the Development of Keeling Atoll, Stage V. 276
69. The Robber Crab 317
70. Small Crab that holds in its Claws two small Bouquets of Living Algæ 319
71. A Mixed Catch of Cocos-Keeling Fish 320
72. Landing a small Black and White Shark on the Seaward Beach of *Pulu Tikus* 321
73. A *Baracouta* taken on a Trolling Line in the Lagoon 323
74. The *Ikan Pareh* (*Dicerobatis Eregoodoo*) 324
75. The "Green Fish," *Ikan Ijou* (*Pseudoscarus*) 326
76. The *Ikan Buntal* (*Tetrodon Patoca*) 328
77. Egg of *Gygis candida*, laid on the Branch of a Grongang Tree 340
78. *Gygis candida* sitting on its Egg 341
79. Young *Gygis candida*, soon about to take its first flight 342

INTRODUCTION

I HAVE endeavoured to give in these pages an account of a very restricted and very isolated piece of land.

I have attempted to put on record as fully as possible its history, its physical conditions, and the state of its Flora and Fauna.

There are many reasons why this work should be done, and why, to-day, a census should be taken of the forms of life which have found a footing upon this tiny speck of land surrounded by a vast waste of ocean.

Before 1825 the isolation of the place was complete; for the next eighty years it was scarcely broken; but to-day the intercourse with the greater world is on the increase, and with this freer intercourse comes change—change in many unlooked-for ways.

Steamship routes open up new roads for animal emigrants; and nothing is more strange than the manner in which the balance of Nature may be upset in these isolated spots by the advent of what is apparently an inconsiderable addition to the Flora or Fauna. If any argument were needed for the utility of compiling uninteresting lists of the forms of life to be found upon the atoll, the story of Christmas Island would suffice. Were it not for the careful record of the Flora and Fauna of that island, made in 1897 by Dr. C. W. Andrews, a remarkable page in Nature's story would be lost for ever.

In the case of Cocos-Keeling it is fortunate that no less than three naturalists have left records of the state of the atoll over a fairly long period, and the accounts of Darwin, Forbes, and Guppy form invaluable landmarks.

The human story of the settlement is also ripe for chronicling, for much of the story of the Clunies-Ross family is forgotten, and my fortunate access to the journal of the Pioneer justifies the recording of this romantic story in its complete form.

With regard to the atoll itself, and the problems with which its origin and its physical conditions are surrounded, this human story is of importance, for three generations of observant men have watched its changes and marked the tendencies of its physical history.

I have endeavoured throughout this book to keep separate the observations I recorded in the atoll and the inferences which I drew from them; and this for the reason that, should the inferences prove ultimately to be incorrect, the observations may still stand as an index of the state of the atoll which may be of use to any subsequent investigator.

The record of the cyclones that have wrought havoc in the atoll has been given in the chapter dealing with the meteorological observations, but I regret that the story of their destruction, as told there, is not complete. On November 27, 1909, a cyclone, unprecedented in violence, swept over the group. The damage wrought in a few hours of storm is most vividly described in the Governor's own words:

"The barometer fell as low as 27·92—lower than I have ever known it fall before. We knew the day before that we were sure to have a very heavy storm, and we worked all day to secure and prepare for it; but unfortunately the whole of the preparations came to naught. At about six o'clock in the evening the cyclone was on top of us, and by eleven o'clock that night the centre passed over our islands. After that we had a lull for about half an hour, and then came the final blast, which carried away and finished everything. Scarcely a single thing withstood its fury. The cyclone was accompanied by great waves (sea-water, carrying sand with it, passed through the tower of my house, which is fifty feet high), and these waves left hardly anything standing. The whole of the villages, as well as the working sheds and stores, were levelled to the ground, or wasted and carried away by the sea. I could scarcely credit my eyes when daylight came; the wreckage was so thorough and complete that the islands were unrecognisable. Of my plantations of coconuts I am sure that not more than one tree in a hundred stood it; in consequence I have lost 800,000 trees, more or less. As for lighters and boats, more than 40 per cent. are lost, broken, or damaged.

"Altogether only five buildings stood upright, and these without roofs upon them. The whole of that night we were practically under water or in the water, wet and miserably bedraggled. Fortunately only one man was killed right off by a falling tree, and another died of exposure. It was simply miraculous how the people were saved, and the tales of their sufferings during that night are beyond belief. They were scattered by the seas all over the islands, and one can only say that Providence guided them into safety.

"We are plagued by mosquitoes, flies and other insects, all of varieties that I do not even recognise—and they pester the whole group, and make life a burden."

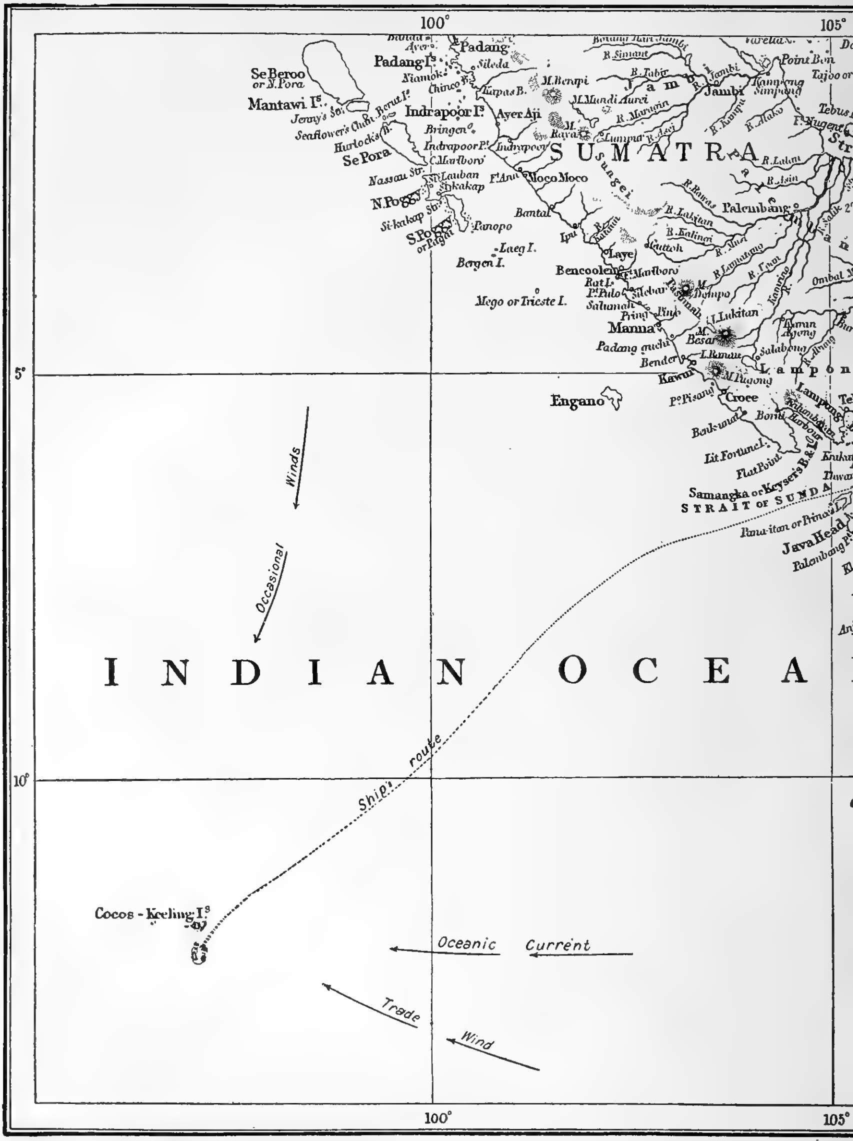
It is a sad duty to add this letter to the description I have given of the prosperity and order of the settlement as I last saw it. If it is permissible to extract interest from such a disaster, I would call attention to the importance of the arrival of presumed new species of insects with the wind. Again, the fact that the waves swept right over the islands, and deposited sand upon a tower fifty feet high, will serve to bring home to those who do not believe in the power of waves to shape atolls, and move "negro-heads," that the waves of the storm-driven blue ocean are not to be pictured at an inland fireside.

ADDENDUM TO RE-ISSUE

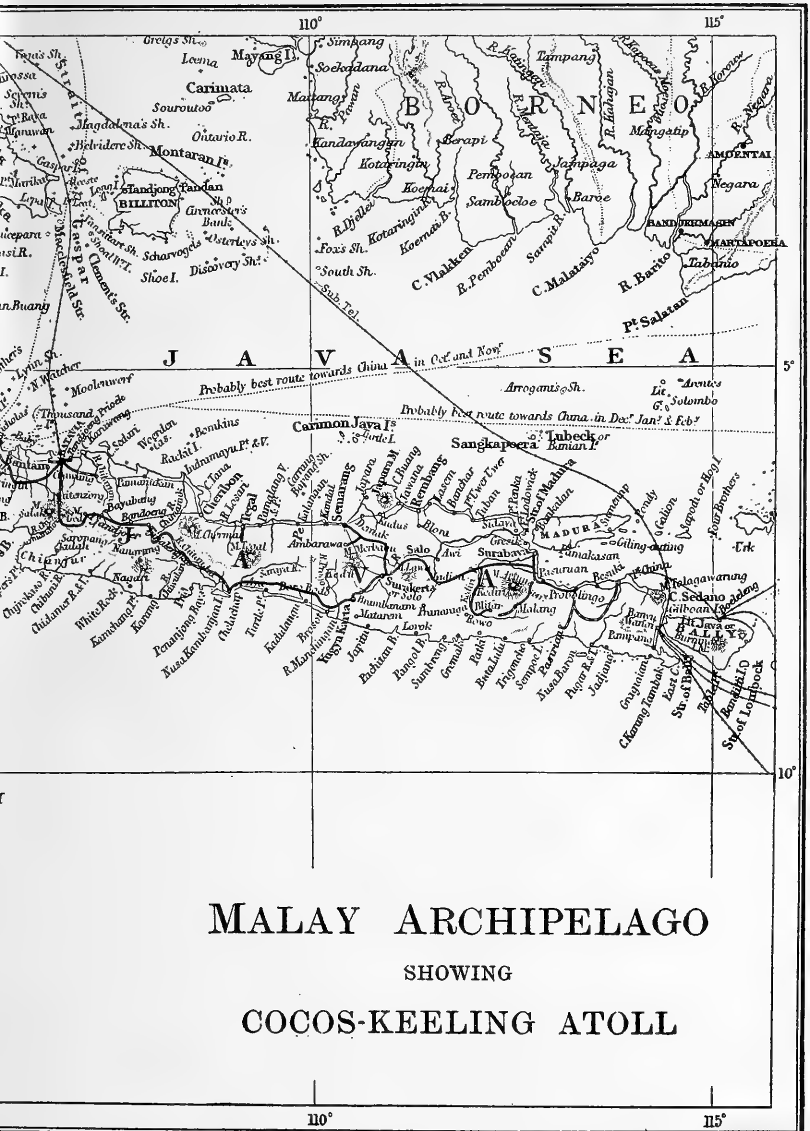
In April 1910, the Governor, whose ill-health had been aggravated by the hardships experienced during the cyclone, sailed for England. He was not fated to return. On July 7, 1910, he died in the island from which some three hundred years before, William Keeling had set out on his voyages of discovery. Keeling lies buried at Carisbrook, while hard by in Bonchurch churchyard George Clunies-Ross has found his last resting-place.

CORRIGENDA

On page 39, *for* "anixety" *read* "anxiety."
,, ,, 67, ,, "vessell" *read* "vessel."
,, ,, 145, ,, "Sherrard Osborne" *read* "Sherard Osborn."
,, ,, 199, ,, "neigbourhood" *read* "neighbourhood."
Index. "Andrew Ross," p. 286, *read* "Dr. C. W. Andrews."

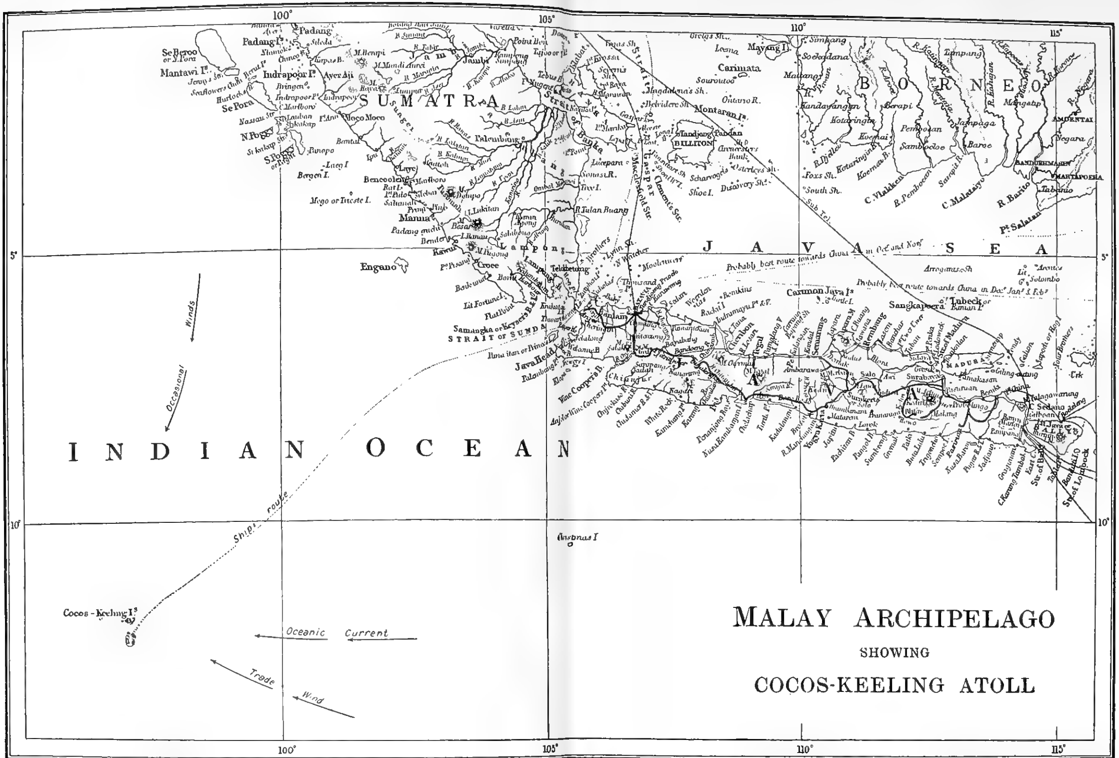


Lovell Reeve



. Limited.

Stanford's Geog! Estab^t, London



Lovell Reeve & Co., Limited.

Stanford's Geog! Estab!, London

PART I

THE HISTORY OF THE ATOLL

CHAPTER I

THE DISCOVERY AND EARLY HISTORY OF THE ISLANDS

FROM what has been said by way of introduction to this account of the atoll, it will be seen that the Cocos-Keeling Islands are worthy of some notice from the greater world for a twofold reason: first, for their being what they are—a perfect example of that most wonderful of geographical formations, a coral atoll; and the second, that they hold the records of a history of romance and adventure which rivals any of the imagined happenings of fiction.

The kingdom of the Cocos-Keeling Islands has a strange and attractive history—as instructive in its way as is that of any great nation, or any story that tells of the doings of the ruler and the ruled.

The drama of history loses nothing by reason of the smallness of its stage; and just as all the problems of life—all the social questions in their most elaborate and acute forms—may be seen outside a philosopher's front door; so may the never-ending story of monarch and rival monarch, of rule and misrule, and of treasons and plotting, which constitutes all history, be traced in miniature in the early doings of this little colony. There is always a popular attraction attaching to little kingdoms, and a halo of romance about the man who, greatly daring, has left the more beaten tracks of life to take upon himself the rule of other races, even though his people have been few, and his enterprise of but little import among the nations.

 A

Many such romances lie buried in obscurity, and from the early records of the traffickings of Englishmen and Asiatics a score of wonderful tales might be unfolded; for it is not only in fiction that the bo's'n who has gone ashore in foreign parts has been made a ruler, or the shipwrecked waif become a mighty monarch.

It is much to be regretted that such tales should ever be lost to the world, for each tells a story of enterprise and hardihood, and offers a picture of the greatest of the birthrights of the Englishman—the power that is born in him to rule an alien race.

From time to time stray paragraphs in newspapers, or more pretentious articles in magazines or chapters of books, have told the tale of the "Kings of Cocos"; and though the romance of the dynasty has always appealed to those who penned them, they have been strangely lacking in accuracy. The true details of the early days of the Clunies-Ross sovereignty have never been published, and I am fortunate in having at my disposal the original papers of the founder of the Settlement. It is my great regret that these documents are too lengthy to be published in their complete form, for they make a splendidly told story of adventure, written by the man who lived their pages through, and they tell in every line the fine robust ideals of Ross Primus, who risked so much on his venture at kingship.

The history of the atoll is a thing of to-day, for it begins only with the advent of the Clunies-Ross dynasty, and what details we know of the pre-Ross period are obscure and of no great interest.

Only one excuse could warrant the unearthing of all the early references to the atoll; and that is the possibility of tracing the past history of the islands, so that some notion of their geographical changes, and their formation, might be gleaned. But Cocos-Keeling is not of sufficient account in the world to possess a well-recorded history, and even were it to be complete, as we reckon history, it would probably not help us much in understanding the formation of the atoll, for no human record can hope to mark more than a day in its long life-story. I have, therefore, been brief in my references to the early chapters of the island history, and have only gathered together such fragments as seem fairly reliable and sufficiently interesting. Most of the details that are available have been collected by Dr. Guppy, who published an account of the islands in 1889; and others lie scattered through the Blue Books of the Straits Settlements Government. From both of these sources I have taken such odds and ends as help to fill in the gap between the time of the discovery of the group, and the arrival of Ross Primus.

There is no doubt that the islands were discovered by the early English navigators, and there seems most reason to assign to Captain William Keeling—after whom the northern atollon is named—the honour of their first finding.

In 1609 William Keeling, who was a captain in the service of the East India Company, sailed homeward from Bantam, and on this voyage it is supposed that he sighted the islands, and it is certain that his course must have lain close in their neighbourhood. And yet the actual record of their sighting does not appear to be forthcoming, for no reference was found to it in the account of his voyages: and no more direct evidence than the date of the first charting of the islands, and their name, associates Keeling with their discovery.

In any case it is probable that Keeling only saw the island that to-day bears his name, and the southern atoll—the Cocos Islands—were the independent discovery of another English navigator, and was made soon after Keeling's finding of the northern atollon.

Captain William Keeling was a man of some note—and many virtues—and in Carisbrooke Church in the Isle of Wight a tablet and an inscription bear testimony to his many merits. Keeling is depicted standing upon the deck of a ship, and the tablet witnesses that "Here lyeth the body of the right worthy William Keeling Esquire, Groom of the chamber to our Soverign Lord King James, General for the Hon. East India Adventurers, where he was thrice by them employed, and dying in this Isle, at the age of 42, An. 1619 Sept. 12th, hath this remembrance heer fixed, by his loving and sorrowful wife Ann Keeling." And then, more picturesquely, it goes on:

Fortie and two years in this vessel frail
    On the rough seas of life, did Keeling saile
A merchant fortunate, a Captain bould
    A courtier gracious, yet alas, not old.
Such wealth, experience, honour, and high praise
    Few men in twice as many years or daies.
But what the world admired, he deemed but dross,
    For Christ: without Christ, all his gains but losse;
For him, and his dear love, with merrie cheere,
    To the holy land his last course he did steere.
Faith served for sails, the sacred word for card,
    Hope was his anchor, glorie his reward:
And thus with gales of grace, by happy venter,
    Through straits of death, heaven's harbour he did enter.

Since the group has been for so long known by the name of its discoverer, it is to be regretted that nowadays this name is often dropped, and the group is simply called the Cocos Islands. Not only does this curtailing of the proper name of the islands ignore the claims of a worthy English navigator, but it leads to much actual confusion. For besides this group, there are others that are known by the name of Cocos Islands:—the Cocos of treasure fame, the Cocos in the Andaman group, the Cocos off the West coast of Sumatra, and other smaller islands so named from their bearing coconut palms are apt to be confounded with this atoll. So far has this confusion been carried that mistakes have been made, even by representatives of the Government, and the atoll has received an official visit intended for the Cocos Island in the Andaman group.

The southern islands—the Cocos Islands proper—were long known by the name of the Triangular Islands, and the name Cocos was given to them apparently by the Dutch. The northern atollon was called Keeling's Island, or occasionally Killing Island, until Horsburgh, the hydrographer to the East India Company (and after whom one of the islands is named) united the two groups of islands on his charts, and called them the Cocos-Keeling Islands. On many maps of the present day the atoll is named the Borneo Coral Reefs: a name that was given to the islands because Ross Primus took his household gods to the new home in a ship he named the *Borneo*: but Ross Primus himself always referred to the group as "Keeling's Isles."

In the study of the early history of the atoll the most important information might be expected from a comparison of the older charts with those made at the present day, for by this means we might hope to see what the modern tendencies of the atoll growth may be.

But unfortunately the charts that are available are few, and the islands are as a rule depicted so roughly that there is little safety in arguments based on any changes that may seem to have occurred.

In maps earlier than 1609 Dr. Guppy was unable to find any reference to the atoll, but in Dudley's "Arcano del Mare," published in 1647, the islands are charted in their correct position. The islands are also shown, but not named, in Blaeu's appendix to the "Theatrum Orbis Terrarum" of Ortelius of 1631, though in the edition of 1606 they are not indicated. The most important early record—because of the more accurate charting—is that in Van Keulen's "Zeefakkel" of 1753, where the islands are depicted by Jan de Marre, the Dutch navigator, who made his chart in 1729–30. Dr. Guppy reproduces this map, which is by no means a bad representation of the group, but I would hesitate to attach a high value to any theories based upon its truthfulness.

Beyond a few visits from passing navigators, there is nothing of historic interest to be noted until the year 1825, when according to Keating (in "Holman's Voyage") Captain Le Cour of the brig *Mauritius* temporarily occupied the atoll; and it is said that his name, and those of his crew, were carved on the coconut palms. This occupation could not have been of long duration, for on December 6 of the same year Ross Primus landed and found the islands uninhabited, and in his account of his settling he says no word of their recent occupation.

With the year 1825 begins the modern history of the atoll, the arrival of the present line of settlers, and the unfolding of the strange story of the early days of this modern Utopia.

CHAPTER II

THE ORIGIN OF THE CLUNIES-ROSS FAMILY

THE more recent history of the atoll tells the story of three generations of the Clunies-Ross family; and it is a record of remarkable human enterprise carried out in strange ways and in a strange place, by men of no ordinary stamp of mind or individuality.

For eighty years some member of the Clunies-Ross family—men standing out among their fellow men—has with the most wonderful endurance and pluck, and with a singular mixture of persistence and tact, ruled and fathered the people, and developed his island kingdom.

Although this little history includes but three generations, and comprises but eighty years, yet it is instructive of history in general, for much of the early doings of the family are now mere legend; much is forgotten, and much more is guessed at; and many are the conflicting tales that are at present current concerning the birth of the colony and its younger days.

The history of the Ross family is one of peculiar interest, and in variously distorted forms, fragments of it have on several occasions appeared in print. Each representative of the Straits Government who has come upon the annual visit to the islands has given some outlines of the life of the present proprietor—and no more picturesque figure could tempt the pen; yet of the early history of the family there is but little that has been published that can claim any real title to accuracy.

Ross Primus was a remarkable man, and every page of his story marks him out as one to whom a strange fascination belongs; as an example of those strong men whose lives are naturally interwoven with romance, and one to whom outlandish enterprise was his commonplace, and adventure his destiny.

The grandsire was the prototype of the grandson, and to-day Ross Tertius stands out a man remarkable among men—a monarch and a father among his own people and in his own islands; a strong man, and an able, in any company, in any land. George Ross to-day has all the masterful attributes of John Ross a hundred years ago, has all his ability and his dexterity, and his inborn power to rule: but to-day George Ross has his enterprise centred in a quiet and peaceful tropic isle, whilst a hundred years ago his grandsire fought and lived in those stirring scenes enacted under the flag of the Old East India Company.

Like many another notable race of men the Ross family shows in a remarkable degree the phenomenon of inherited prepotency, and the dominant features, both mental and physical, of the family type show a most wonderful persistence.

So far as concerns the origin of the race that has pioneered this strange enterprise, we need go no further back in history than the year 1715: for the events of that year were instrumental in shaping the after-destinies of the family, and without the '15 and its subsequent disasters, the Clunies-Ross family might still be treading the easy pathway of the Scottish gentry.

The year of the ill-fated rising of the Scots in defence of the rights of "James, son of James II. of England," found Alexander Clunies—called Clunies-Ross by right of his wife—doing great deeds for the Clan Chattan in Sutherlandshire: but one short year after, both he and his cause were in sorry straits.

When on February 5, 1716, James sailed from Montrose, he left a hopeless cause behind him: and when the English came by sea, nothing was left to the broken clans save to disperse; and to the broken leaders save to seek their homes—or their hiding-places.

It was a hiding-place that Alexander sought, and with his two young sons he went to the Orkneys, to tarry till time should heal the wound where a cannon-ball had removed his right leg, and in some measure mend the fortunes of his cause. But long before his wound was healed, his cause was dead: and in the horrid hue and cry that followed, he was forced to fly to Yell in the Shetland Isles, for even the Orkneys could not hide him now. In Yell he settled for the remainder of his days, and in Yell his eldest son James completed the sad work of breaking the old man's proud Jacobite heart by marrying Catherine Plapen—a Norwegian girl of plebeian descent.

This was the last straw for the old Jacobite, who had lost his home, his cause, and his estates; and so he cursed his son, and taking his claymore, he broke it in two; for the blade which had so long defended the family honour was useless now that this honour counted for so little to him who should defend it next. That the act might be the more complete, he burnt the records of the clan for whose pride his eldest son had shown so little respect; and cut off for ever the life that he had led, and the ideals that he had represented, from the prideless doings of his wayward son.

James and Catherine remained in the Shetland Islands and there their eldest son John was born: John afterwards married Catherine Clunies, who was a cousin of his, and they also continued to live in the family's adopted home. The eldest son of John and Catherine was named George, and he also married one of the many relatives that were now inhabiting this isolated home of theirs. His wife was named Ross, and by her he had a son, John Clunies-Ross, who was born in August 1786, and who afterwards became the first "King of Cocos."

Since no authentic account of John Clunies-Ross has ever been published, and since in those accounts that have appeared there has been but little agreement and but little truth, it will be best to give the story of his origin and his aims in his own words. The document from which I take his autobiography is a petition to the Hon. Sir T. Bladen Capel, K.C.B., Commander-in-Chief of the East Indies; and it was written from Cocos-Keeling for the purpose of obtaining a better recognition of his settlement at the hands of the British authorities.

He mentions that he had petitioned his late Majesty to recognise "Keeling's Isles" as a part of the British Empire, and then he goes on to tell his own history in the following words:

"To begin then at the beginning—I am a native of Zetland, descended maternally from a Norwegian family, and lineally on the paternal side from one of those ignorant, and therefore misguided, men who in the last century led forth many of the tribes of N.W. Scotland to assist with their swords, hundreds opposed to millions, Royal hereditary pretension against National Constitutional rights; and were in consequence mostly ruined, cut off, and expatriated.

"I may almost say that I was born at sea (Aug. 1785) the walls of my parents' bedchamber being often wetted by its spray—most of my waking hours were however spent in and on its waves from the age of towards three at most to thirteen, when I proceeded to serve apprenticeship to the Greenland whale fishery, from whence after making voyages to the Baltic and to China, etc., I proceeded to the whaling business in the Southern Sea department, where I was in May 1813 mate and harpooner of the ship Baroness Longueville of London—S. Chace master—and when she was put into the port of Coupang in the Island of Rimer to obtain refreshments and water before starting for England, the full cargo of spermaceti having been acquired in the space of sixteen months from thence, there lay in that anchorage a small Brig called the Olivia in want of a Commander and being hired and armed as a dispatch and coasting convoy vessel by the British Java Government.

"The resident of Coupang applied to Mr. Chace for an officer to supply that want, and I resolved to accept the offer altho' I had been what is called 'very lucky' in my vocation, being chiefly induced to take that resolution by consideration of the intelligence which had then been first received by us of the war, commenced by the American republic against Great Britain, and the consequent risk of capture in a single sailing and nearly unarmed vessel all the way to St. Helena, where only convoy was to be had.

"Having received charge of this vessel, I proceeded with her via Macassa and Beema, to Batavia, where first I saw the Brig's owner—and Alex Hare Esq. who was at that time British 'commissioner' alias Miniature Governor General over the Island of Borneo and 'Resident' alias Governor Particular of Banjarmassem the chief local British Establishment in that island."

This chance meeting with Alexander Hare was a great turning-point in the life of John Ross, and since their subsequent histories were so interwoven, it will be well to trace the life of Hare up to the time of the meeting in Batavia. As Ross Primus himself says, "as the subsequent history of this person became much connected with mine, and occasion has been made by himself for its previous portion to be also noticed by me," it is best to give some account of Hare, following the narrative of Ross Primus as closely as may be. Alexander Hare was the eldest of four boys, sons of a wealthy London watchmaker, and although the watchmaker was a pious and respected man, his eldest son showed early those signs of the eccentric degeneracy that marked and marred his later life. When a young man he went to Portugal, and became a clerk in Lisbon, and there he continued for some time; his next move was in the direction of the East, which seemed always to call him, and soon he appears in Calcutta as the agent for his firm. It was here that the magic of the East first took possession of Hare, and in all his subsequent doings we find him becoming steadily more Oriental, steadily more eccentric.

From Calcutta he went to Malacca as an agent and as a merchant, and in Malacca he gave vent to all his love of Oriental splendour, and started his slave retinue and his harem. From now onwards, whenever Hare is mentioned in the narrative of Ross Primus, it is always in association with the extraordinary collection of Oriental women who were his chattels, and who constituted his harem. He himself called them his "fiddle faddle, which whether wise or no, I am in the habit of considering necessary." Whilst in Calcutta, Hare met Mr. Raffles (afterwards Sir Stamford Raffles) that great and somewhat neglected man, who did so much for English prestige in the Far East. Mr. Raffles was at that time secretary to the Government of Prince of Wales Island, and his friendship had a marked influence on the eventful career of Hare. Not long after Hare's meeting with Stamford Raffles, the British expedition against Java was planned; and Lord Minto selected him to join the force—and no wiser choice could have been made. As a friend of Raffles, Hare joined the expedition and saw that wonderful achievement of Englishmen—an achievement whose fruits were afterwards wasted by English politicians—the British conquest of Malaya.

It was as a result of joining this expedition that Hare came to occupy the position in which Ross Primus found him, for when hostilities had ceased, the Sultan of Banjarmassem applied to the British Government to have a British resident attached to his kingdom, and Hare was appointed to the post. The Sultan gave to his new resident a large grant of land, for a great area of his dominions had been depopulated by pirates, and he hoped that a strong British resident, backed by the weight of British authority, would restore order and prosperity to his much-harassed people. But Hare was by no means a strong man, and at the outset he made a very bad step by choosing for his second in command a very ill-famed person named Vanderwadl. Vanderwadl was a Dutch adventurer of a very degraded type who was condemned to death for his crimes by the great Commander Daendels, and by an extraordinary coincidence was saved on the eve of his execution by the capture of Fort Cornelis by the British. Vanderwadl, saved from the gallows at the hands of his own countrymen, was chosen by Hare to act as his deputy, and in this choice there seems to have been little to recommend the candidate, save that his tastes and his mode of living coincided with the ideals of Hare.

Good results were not to be expected from the administrations of two such persons as Hare and Vanderwadl, and the result was not a happy one. They obtained convicts to do forced labour and open up the country, and started a general programme of misrule.

This state of things was still in progress when Ross Primus, who had been cruising among the islands for two years on behalf of the Government, met Hare, and was asked by him to superintend the harbour works of Banjarmassem. Ross accepted the position, and leaving the *Olivia* he commenced his new career by taking command of the Hon. East India Company's cruiser brig *Mary Anne,* a vessel of 300 tons and mounting twelve 12-pounders. He continued in this famous service, which has numbered in its ranks such men as Clive and Warren Hastings and to whose deeds we owe the British supremacy in India, and he left it only on the British cession of Malaya to the Dutch. Before Malaya was ceded, Alexander Hare went to Java, and left Banjarmassem in the charge of John Hare, his younger brother. During the time that Ross Primus had been engaged in his duties as harbour superintendent he had busied himself in shipbuilding, and had laid down a ship of 428 tons, which he had named the *Borneo.* The ceding of the British possessions to the Dutch found this his masterpiece still unfinished, and so, rather than leave the uncompleted work in the hands of the Dutch, he remained behind for eighteen months in order that he might in the end gain the fruits of his labour, and have the satisfaction of seeing his own ship launched.

The *Borneo* left the slips an accomplished success, and Ross sailed away in her in search of new adventures in some fresh enterprise.

Although John Ross had built the *Borneo,* the ownership of her passed largely into the hands of the two Hares, John Hare having 55-64ths, Alexander Hare 1-64th, and Ross 8-64ths, and Alexander Hare was appointed managing owner.

It was intended that the *Borneo* should sail between England, the Cape, and Malaya, and take a share in the trade in spices and coffees, and all those Eastern products which in the early days so easily built up the colossal fortunes of the

Eastern merchants. Ross sailed to Bencoolen and took Hare aboard, and then steered for the home from which he had so long been absent. At the Cape, Hare was landed, in order that he might make arrangements for the trading schemes of the partners. The first voyage was, however, such an ill-success that Ross despaired of making any money by the venture, and since he had for so long been prosperous in the East, he decided that he would take his wife—an Englishwoman named Elizabeth Dymoke—and his family to some new home.

The marriage of Ross Primus with Elizabeth Dymoke, like all the doings of his life, had in it a strong element of romance. It was in London that he met her and he encountered his future wife under rather curious circumstances.

The times were those of the activity of the Press Gang, and it chanced to young Ross that he nearly fell into the hands of these worthies. But although he had so strong a love of the sea, he had no mind to set out on a voyage in this fashion, and so after a brief encounter he took to his heels and bolted up the street, to avoid being taken by the gang.

The chase became a hot one, and as he was in some danger of being overtaken, he turned a corner on a sudden and dashed into the nearest house. It happened to be that of Samuel Dymoke, and in it the young man found shelter, for Elizabeth, taking pity on him, hid him and cared for him during the interval in which he dared not show himself abroad.

Ross fell in love with the girl who had befriended him and saved him from the Press Gang, and he married her. She and her children shared his adventures with him and prepared to start with him for his new land.

His choice of a new home ranged over many strange places, and in his journal are several interesting reflections upon the various advantages and disadvantages offered by such remote spots as Melville Island, the Falklands, Kerguelen, St. Paul's, Christmas Island, the Poggies, and Cocos-Keeling. Of the Poggy Islands he actually took out a lease in 1821, a "John Christie Esq." being the other lessee, but the Dutch possession prevented him from ever taking advantage of it.

He seems to have had a most peculiar taste to guide him in the choice of his new land: one thing he must have, and that was the sound of the sea always in his ears, and the cities of America were therefore not for him: whilst Australia he decided against, for he felt it an injustice to his children that they should be reared in "a country that had the taint of convicts."

He took his wife and children on the *Borneo* and returned to the Cape (May 1825), where Hare was waiting in a ship called the *Hippomenes,* commanded by James Ross, his younger brother.

Both ships cruised off, and it was agreed that they should meet at the Cocos-Keeling Islands. Ross Primus was the first to reach the meeting-place (Dec. 6, 1825), and waited for his brother until the 19th, but as the *Hippomenes* did not appear, he sailed away for the Cape again, and found that Alexander Hare had not long left. He then proceeded to London, for he felt that, as he had decided to make his home in Cocos, he had better make his position there somewhat more assured; and he therefore applied to John Hare—as a person of some authority—to get Government possession of the place. Then, thinking that all would be well, he went to sea again and arrived in Cocos on Feb. 27, 1827; there he found Hare fully established with his harem, and playing the role of despot to his heart's content.

The trading purposes of the *Borneo's* voyage were not yet completed, and so, as Ross Primus says, "I hutted my family on the isle, and continued my voyage." Later in the year he returned, and then began the dual occupation of Hare and Ross, and all the queer stories of the squabbles of the rival rulers in their tiny kingdom.

CHAPTER III

1825–1854

With dominions that comprise the whole breadth of great continents, and with subjects taxing man's powers of computation, it is an easy thing for monarchs to disagree; it is none the less so in an atoll with a population of less than two hundred souls, and an area of a few square miles, when two rulers attempt to wield their independent sceptres. There were no methods sanctioned by tradition in the government of the Islands and trouble arose early, and general disagreement continued without remission until the dual rule came to an inglorious end.

The two rival factions had settled in the atoll for very different reasons; Hare elected to come to Cocos because he was in some disgrace at home, for he had not satisfactorily settled his financial dealings with the East India Company—and he was glad to seek some secluded corner of the globe, where he could dwell free from all interference from his creditors; and free too from the prying eye of civilisation, that would look askance at his harem and his manner of living. With Ross Primus it was a shrewd business instinct, coupled with his love for the sea, that guided him to the atoll; for he saw the commercial advantages that Cocos-Keeling afforded.

In those days the Eastern produce, spices, coffee, and pepper, was sold from Eastern ports with great rapidity; and as the crops arrived at the coast only twice in the year much time was wasted for the ships engaged in the trade, for no reserve cargoes were kept, and a ship would have to wait long for her load, and take it aboard at the tardy convenience of the native merchants. Now Ross saw that a man with a thorough knowledge of Eastern produce, and familiar with the dialects of Malaya, could buy with great cheapness when the crops were abundant, and could, after storing his cargo, sell it to homeward-bound merchantmen with great advantage to himself. Such a storing-place he intended his new home to be, and he designed to run the *Borneo* between the Malayan islands and Cocos, and make the atoll into a depot for Eastern produce. It was for this purpose that he wished the islands to be taken under the protection of the Imperial Government:—but many disappointments awaited him. He had left his claims in the hands of John Hare, who was to represent his cause in London, but Hare played him false, and no help came from that direction. Ross next made direct petition to His Majesty King William IV. This method also failed, and so did his attempts to persuade the Government of Mauritius to take the islands under its charge. It was felt that Cocos-Keeling was too small and too remote for its protection at the hands of the Government to be warranted by its importance, and all the reward that Ross obtained for his repeated petitions was the visit of a British man-o'-war. In February of 1830 Captain Sandilands arrived at the islands in H.M.S. *Comet* and held an inquiry and furnished a report, but no further steps were taken. It is said that in the meanwhile Hare was in negotiation with the Dutch authorities, for his purpose was to persuade them to take over the protection of the atoll. This would seem to be a strange line of action for Hare to take, for his feeling for the Dutch in Malaya cannot have been friendly; and yet a Dutch gunboat—the *Blora* under the command of Mynheer Van de Jagt—arrived in October 1829, and reported on the condition of the islands, as a result—so it is said—of his negotiations. Neither Ross nor Hare produced any other result from their petitions than a visit of inquiry, and it is not surprising that this was the case, for the entire population of the atoll at the time only numbered 175 all told. Of these 175 colonists, 20 were white, and 10 of these were born in the islands: the remaining 155 were natives of Sumatra, Borneo, Celebes, Java, Baly, Sumbawa, Timor, New Guinea, the Cape, India and China. The extraordinary mixture of races in the settlers is accounted for, partly because Hare's women were recruited from various Eastern nations, and partly from the fact that the crews of the *Borneo* and *Hippomenes* doubtless contained the usual mixture of Asiatic seamen.

It would seem that the original intention of Ross Primus, of making his islands a depot for Eastern produce, did not last long, for in 1837—ten years after the original settlement—he had turned his attention to the natural products of the atoll, and describes his business as an "oil factory," and his trade and communications were mostly carried on with Mauritius. From this first establishing of the oil factory the whole industry of the islands has sprung, for it is the coco palm and its many useful products that form the sole commercial importance of the group to-day.

In connection with the coco palm a point of interest arises, for Dana has said "there is no known instance that any island never inhabited has been found supplied with coconut trees." It is often said that the coco palms in Cocos-Keeling were planted by Ross Primus, and it is pointed out that he did not come to the atoll to work copra or oil, and did not make mention of this industry until several years of his settlement were passed. But Darwin, when he visited the atoll early in 1836, describes it as being thickly covered with coco palms, and says that they constituted the whole prosperity of the place, the only export being oil from the nut, and the nuts themselves, which are taken to Singapore and Mauritius. Further than this, we have seen that when Captain Le Cour arrived in 1825—before Ross Primus had even come to the islands—he carved his name on the palm trunks; and in 1753 Van Keulen described the islands as being "wooded."

It is quite a mistake to suppose that the coconut is not easily planted by the agency of the waves, for unlike many other seed waifs that are borne in vain to the shores of coral islands, the coconut will germinate and flourish within reach of the salt water. Everywhere around the lagoon shores the process may be seen any day, and there is no reason to suppose that any human agency was involved in the first planting of the coconuts in Cocos-Keeling.

In the staple industry of the island Hare also took his share, but according to the island legends it was more for the purpose of keeping his retinue employed than for any definite commercial aim. It is said that when his men had prepared a quantity of oil, Hare was in the habit of going by night and removing the corks from the casks, that he might waste by darkness what his men had prepared by day. In this way he ensured a sufficiency of employment for the men of his party, and so protected himself and his mimic court from interference at the hands of idlers.

The small faction over which Hare ruled were held by him as slaves, for though he had been forced to take out certificates of emancipation, the business had made no difference to the status of his retainers. He so arranged it that the liberation paper was served on board the *Borneo* at Fort Malboro in 1820, and it was he who gave an explanation of the contents of the papers to the unknowing natives. Afterwards he made them all sign documents declaring that they and their children were his absolute property, and it was as his personal chattels that they came to the islands. It was over the question of slave workers or free colonists that Ross and Hare first fell to quarrelling. It was the policy of the pioneer of the Ross dynasty that all his people should be free men, "free," as he said, "except to commit mischief"; and many are the pious reflections in his journal concerning the slavery methods of Hare. Naturally enough this state of affairs caused much ill-feeling, and the quarrel was greatly aggravated by the very natural desertion of many of Hare's people to the camp of Ross Primus. It was the boast of the pioneer that none were weaned away from the rival settlement, but that protection was freely extended to those whom ill-treatment drove to seek a refuge with him.

As a matter of fact this neutral attitude did not last long—at any rate on the part of the natives—for Hare's people were mostly women, and those who came with Ross were for the most part men. Among the island stories there are to-day many well-told tales of nocturnal exploits; stories of heroic swims, of hasty flights, and adventures in which the women were stolen—not all unwilling—from Hare's camp, and carried off by the men of the Ross faction.

In this way Ross' little band of settlers grew larger by degrees, and his influence steadily increased; whilst Hare, with his ever-diminishing subjects, became more and more absorbed in the butterfly pleasures of his mimic court. It is said that Hare took up his residence on the islet that bears the name of Pulu Bras, from its resemblance in shape to a piled-up heap of rice. Pulu Bras is to-day a very small island, with an area of but a few square yards; and in the map of Jan de Marre of 1730 it is also shown as an inconsiderable piece of land. Yet in 1827 it is said that it was much larger, and was joined to the island next to it by a spit of sand. Great changes must have taken place with some rapidity in this portion of the island ring if the legend of his residence is true; and it is not altogether unlikely, for Pulu Bras is a pure sand island, and therefore liable to change with every fancy of the wind and waves; and some few years ago it is said that parts of his house were still to be seen upon it.

The original Ross settlement was made upon the Pulu Selma, but in consequence of the unfriendly relations with the neighbouring party on Pulu Bras, it was moved on to Pulu Atas, the most southern—and distant—portion of the island ring. The Pulu Atas settlement was, however, only a temporary one, for the silting of the southern portion of the lagoon was taking place so rapidly that in a very few years the colonists were forced to move back to Pulu Selma, in order to have an adequate waterway for their boats. The moving of the Ross settlement to Pulu Selma and the end of Hare's brief reign took place at about the same time, and both were recent events when Darwin came to the islands in the April of 1836.

The final disaster that befell Hare was a wholesale desertion of his followers, headed by one Neh Basir, who was born in Malacca, the descendant of parents presented to Alexander Hare by the Rajah of Banjer. Neh Basir afterwards married a slave girl named Daphne, belonging to Hare, and he died on June 19, 1893, at the age of 88. He formed one of the direct links with Hare's time amongst the Cocos-born Malays, and his descendants to-day are numerous.

Little by little Hare's influence diminished as his subjects gradually dwindled away, and before the end of ten years he finally retired from the island to die in Singapore. His attempt to realise his ideal—to be the monarch of a slavish Eastern court amidst the luxurious setting of a tropical coral island—had proved a failure. His band of musicians, his slaves, his courtiers, his harem, and his splendid sovereignty had slowly but surely slipped from his grasp, and the more stubborn, more practical rule of Ross Primus had ruined his Utopia.

Of Hare's reign there is little but tradition in the islands to-day, but many of the people are of course descendants of his retinue, and there is left at least one fine silver badge, which—popularly supposed to be the insignia of the keepers of the harem—is the old livery badge of the East India Company.

When Hare left the islands Ross Primus laid claim to the whole group, and was styled the King of the Cocos-Keeling Islands. It is Charles Darwin, the atoll's most noteworthy visitor, who gives us our first picture of the settlement—and it is not a very flattering one.

In April 1836 the *Beagle* arrived in the lagoon, and Darwin wrote in his journal an account of the atoll and its flora and fauna that to-day, after a lapse of 70 years, strikes one for its wonderful accuracy. Of the settlement he said: "The Malays are now nominally in a state of freedom, and certainly are so as far as regards their personal treatment; but in most other points they are considered as slaves. From their discontented state, from the repeated removals from islet to islet, and perhaps also from a little mismanagement, things are not very prosperous." His notes on the natives are of peculiar interest, and he says: "The houses of the Malays are arranged along the shores of the lagoon. The whole place has rather a desolate aspect, for there were no gardens to show the signs of care and cultivation. The natives belong to different islands in the East India Archipelago, but all speak the same language: we say the inhabitants of Borneo, Celebes, Java and Sumatra. In colour they resemble the Tahitians, from whom they do not widely differ in features. Some of the women show a good deal of the Chinese character. I liked both their general expression and the sound of voices." The most remarkable fact anent Darwin's notes is that he makes no mention of the Zulu people who came from the Cape with the original party. It is likely that they were not numerous, and yet their prepotent influence has been strongly marked on the physical stamp of the islanders of to-day.

Not only did he not mention the African element, but he also overlooked the Papuan people from New Guinea, and they too have left very visible traces of their woolly-headed characteristics; probably the Chinese character that he observed among the women was also the result of real Chinese blood—for its influence too is well marked to-day. This is a question of real ethnological interest, for it shows that the parental Negro and Chinese elements were in 1836 so inconspicuous that Darwin practically overlooked them; and yet after 70 years of intermarrying the resulting race may be said to depart from the typical Malay stock in two directions: first, and most conspicuous, is the Negro type; and second, the type that possesses Chinese characters. Some Cocos-born families possess Negro features to a remarkable degree and the race is a very fine one; the Chinese type is of a physique not nearly so good—it is held locally in some contempt—and resembles that found all over the seaboards of Malaya where Chinese and Malay intermarry. It may be said as a general rule that in intermarrying the African Negro and the Chinese both swamp the physical characters of the pure Malay—and so too does the Papuan, whose frizzy hair tends to persist in a race, despite the original straightness of the Malay locks.

Ross Primus was not in the islands at the time of Darwin's visit, and the place had been left in charge of one Leisk, who was one of the original colonists, and had been mate of the *Borneo.* Leisk figures again in the history of the settlement, and not in a very glorious light, but in connection with Darwin's visit he is only remarkable as being the author of those errors in the great naturalist's account of the atoll that lent support to the Theory of Subsidence of Coral Reefs.

It was under Leisk's guidance that Darwin examined the atoll, and the information that was imparted to Darwin was certainly not reliable, and in some cases I believe that there is no doubt that the inaccuracies of Leisk's statements influenced Darwin in his conception of the mode of formation of the group. In some measure, therefore, Leisk helped on the cause of the Theory of the Subsidence of Atolls.

With the departure of Hare, Ross Primus, with the rule of the whole atoll in his hands, did not at first find his path an easy one. The time of his assuming the sole authority was when the great southern whaling industry was still in a very flourishing condition, and when all the scum of the maritime populations of three continents was afloat in the Southern Ocean. In those days Cocos-Keeling was a place of call for whalers, for fresh water and fresh provisions were always to be had there. The ordeal of a prolonged cruise in a whaler was an experience that every sailor shrank from, and when, after months of hardships and brutality, the crews got ashore in the islands, they generally rejoined the ship with some of their number lacking. Many are the island tales of deserted whalers and their doings, but one runaway deserves special notice, for he became the subject of a petition to Sir T. B. Capel, and came near to making white man's war in the peaceful island settlement. This man was an American named Joseph Raymond, who deserted from *The Trusty*, a whaler which had come into the atoll in January 1836. He was a bad character, who had fled from justice in "Charlestown close by Boston in Massachusetts," having already served ten years for the murder of a negro. Raymond, whom Ross in his petition calls "the foreign anarchistical ringleader," joined with Leisk in opposing "duly constituted British authority in territory which if not British is at all events not American." The trouble became serious, for Raymond induced the natives to strike, enlisted other deserters in his cause, and did much damage to the settlement by setting fire to the working sheds and oil factory. It was to have a sure ground for thoroughly dealing with the rising that Ross Primus applied to the Admiral. Unfortunately, with the sending of the petition, the story as written by Ross Primus in his journal ends; but though no word is said as to the fate of Raymond, we learn that Leisk was duly banished to Batavia, and passed out of the island story.

A natural interest attaches to the fate of Raymond, for he was playing the desperate game of civil war and of attempting to usurp the authority in a place where a strong and resolute man made his own laws and dealt his own justice. Whichever way the game should chance to go, it was one that had of necessity to be enacted without the help or interference of outsiders, for no appeal could be carried to an authority nearer than Ceylon, where the Admiral was stationed at Trincomalee.

When Ross first discovered the plot, he says in his journal, "fortunately my previous suspicions and the gradual manner in which the whole affair had opened upon me had so far prepared me that I was not taken by surprise, in which case I had certainly bestowed upon the villain his quietus on the instant." This petition tells us all we know of the affair, and as Admiral Capel does not seem to have come to the islands and settled the business, it is to be presumed that Ross Primus managed to execute justice without the additional weight of outside approval.

Raymond may have been sent to Batavia, he may have been deported in another whaler—or he may have received his "quietus on the instant"; in any case he disappears from the history of Cocos-Keeling and John Ross continued his reign undisturbed.

Besides the whalers and the *Beagle* other vessels came to the island and brought visitors to Ross Primus from the outer world, for in sailing-ship days Cocos was a comparatively commonly visited place. For many years the Australian horse ships called at the atoll to take on water and fresh provisions, and their visits were fairly regular; until, as a consequence of the dangers of shipwreck on the barrier, the place was avoided by all boats save those in actual distress. A vast number of vessels have from time to time gone to pieces on the barrier, and the history of the atoll is a history of shipwreck—even the fauna of the place tells a tale of shipwrecked castaways.

With the cessation of the journal our knowledge of the doings of Ross Primus practically ends, for the sailing-ship visitors have left no record of the condition of the islands or the story of their ruler.

In 1842 and 1844 the atoll was visited by Dutch navigators. Mynheer J. J. Duintjer and Mynheer J. W. Retgers have made reference to the islands, but the petition to Admiral Capel marks the end of the accurately recorded history of the reign of the first settler in Cocos.

The remaining years of the life of Ross Primus were devoted to study, and a great deal of philosophic writing fell from the pen of this remarkable man. It is unfortunate that a great part of his writings was destroyed by a disastrous fire which gutted his house and consumed most of his possessions.

But some fragments remain, and one, a criticism on Darwin's essay on Coral Reefs, was published in the year after his death in the *Natuurkundig Tijdschrift voor Nederlandsch Indie* (deel. viii., Batavia, 1855). By a curious mistake this work is credited in the Royal Society's Catalogue of Scientific Papers to Sir J. C. Ross, the Arctic explorer, and, in the article already referred to by Dr. Guppy, to his son Ross Secundus.

Besides this publication, Ross Primus left to the world a two-volume treatise on the work of Malthus, a copy of which is now preserved in the Governor's house on Pulu Selma. It is a work of great erudition written from an extreme point of view, but, although it makes a fierce attack upon every premiss and every argument of Mr. Malthus, it cannot be said to detract greatly from the patiently drawn conclusions of that astonishing and suggestive cleric.

In 1854 the pioneer died at the age of 68. Concerning his death there is told one of the many interesting and romantic tales that form such a feature of the history which lives for the most part in the mouths of loyal and admiring narrators.

Upon the morning after his death, the present Governor—then a little boy of nine—was sent in a boat to fetch the crew of the schooner to the funeral. Although no boat had previously put off to the vessel, he found on his arrival that the captain and his crew were awaiting him, all dressed in black, with full knowledge of the sad event of the previous evening.

It seems that at sundown—when the spirit of Ross Primus fled—a sound had rushed through the air, and to each listening man upon the schooner had come the wail of the passing of the spirit of his beloved chief. The schooner lay far out in the lagoon, but the news came clear and unmistakable, and the boy rowed back a troop of silent men, who had needed no telling of the loss which they and the little kingdom had suffered.

Ross Primus was 41 when he made his island settlement, and he ruled as King of Cocos-Keeling for 27 years. He is buried in Pulu Selma, and Ross Tertius has honoured the memory of his grandfather by obtaining from Scotland a block of granite, which, carved by Cocos-born masons, makes a fitting monument for the grave of the pioneer.

The work of this strange man is one that is hard to picture in these matter-of-fact days, and it is difficult to properly estimate the hardihood of the man who took his family and "hutted" them in this remarkably isolated spot. His writings show him to have been of a philosophic turn of mind, and quaint reflections come into all the accounts of his extraordinary endeavours; yet the philosopher was a man of hard business capacity and of daring activity.

He ruled the scum of sailor-men and governed a staff of coolies mostly recruited from convict gangs; and he carried on the whole enterprise without the shedding of blood in a place where there was no appeal to authority save that which he wielded.

Piety is evident all through his journal, but it is a piety that becomes at times rudely interrupted by threats of violent justice to wrongdoers and speculations upon the successes of his enterprises. He was a man with a firmly settled belief in Divine justice; but, situated as he was in an isolated coral reef seven hundred miles from land, he by no means underrated his ability to be its successful instrument.

The story of Ross Primus is one that should not lightly be forgotten, for although his whole efforts were spent in a small and out-of-the-way corner of the world, he was of the stamp of the real pioneer and a man in every way remarkable.

CHAPTER IV

THE HISTORY OF THE ATOLL, 1854–1871

When the pioneer was dead, the rule of the islands descended to his eldest son, John George Clunies-Ross, who had for many years assisted his father in the work of administration, and afforded him the leisure to indulge his literary tastes. John George Clunies-Ross was one of the children who, with Elizabeth their mother, had been "hutted" on the islands in 1827; and in the islands he remained throughout his youth and early manhood. He was born in London, and was christened at Stepney, and he was but a small child when his father set about his enterprise of making a settlement upon the islands which he was afterwards to govern. His education had been received on the atoll at the hands of his mother and father, assisted by the Scotch mate Leisk; and although the foundations of his schooling would appear to have been slight, he was a man of remarkable aptitude for learning, and devoted the greater part of his life to study.

Of Ross Secundus there is no such vivid picture as that left behind by his father or that presented by his son, and of his governorship there is no clear or detailed record.

He appears to have been a philosophic man—a good observer and a true lover of nature—and somewhat of an idealist. In manner he was quiet and very reserved, and much given to a habit of silence.

In 1859, four years after his taking over the control of the settlement, he visited his native England, and this one brief journey home was the only occasion upon which he ever returned to the larger world; for the rest of his life was spent in his own atoll, and in expeditions among the islands of the Malay Archipelago.

Before he made this one excursion into the old civilisation which he had left with his childhood, the greatest event in the history of his governorship had taken place, for on March 31, 1857, H.M.S. *Juno* arrived in the atoll. It was a great occasion in the islands; with the firing of a royal salute, Captain Fremantle proclaimed the atoll to be a part of the British dominions; and the dream of the Cocos islanders was realised.

At the same time, the status of Ross Secundus as an absolute ruler was somewhat altered, for he was declared in the proclamation to be appointed as the Governor of the Settlement during Her Majesty's pleasure: the Dutch flag was no more to be hoisted upon the trading schooner of the islands, and Ross Secundus was to be responsible for the good conduct of the colony.

It would appear that all the demonstration and ceremony incidental to this visit of the man-o'-war was in reality the outcome of a very curious mistake, for it is said that the Cocos Island that was intended for annexation to the British dominions was one in the Andaman group, and not the atoll of Cocos-Keeling at all. However, the visit of the *Juno* marks a well-remembered epoch in the history of the settlement, and from that date the group ranks among the British possessions.

Captain Fremantle did not steam away directly the business of the proclamation was disposed of, but the *Juno* remained at anchor in the atoll for three months, and the events of this prolonged stay are not likely to be soon forgotten. It was a time of gaiety and change for all the islanders, and one that brought them into contact with much that was new to them, and it marked an eventful period in their quiet island routine of life.

A curious incident happened during the stay of the *Juno*, as before she steamed from the lagoon in June 1857, a Russian man-o'-war called in at the atoll, and seeing her there, saluted the British flag and retired, though this was presumably not the sole object of her visit.

The departure of the *Juno* left Ross Secundus as a Governor of a colony under the British rule, but the change of his status was merely a nominal one, for the colony was so remote from the sovereign power, and so absolutely his own, that the *Juno* virtually left him as she found him, the sole appeal of law and order.

Ross Secundus now set about developing the island industries and carrying on the work that had been begun by his father, and this he did with great success. The islands flourished and the plantations of coconut palms increased, and everything in the colony appeared to be on the high road to prosperity. In 1862, however, one of those periodic reverses that have been the lot of the settlement smote the islands, and a terrific cyclone wrecked the flourishing industries and laid the islands waste.

The whole disaster was the work of a few hours, and yet in this short time homes were demolished, working sheds were wrecked, and the coconut palms, which were the sole source of the island's wealth, were torn up by the roots or snapped like matchwood by the violence of the storm. The happy dream of prosperity was turned into an actuality of hardship and want, and all the philosophic patience which was the great characteristic of the life of Ross Secundus was needed to again start the building up of what was left of the little colony. He recalled his eldest son from Scotland, and with his assistance set out upon a vigorous endeavour to put to rights the havoc wrought by the cyclone.

Soon after this event the colony was again visited by a representative of the sovereign power, for in 1864 H.M.S. *Serpent*, a surveying ship, called at the islands. A survey of the group was conducted, and the affairs of the island were inquired into, and the damage done by the cyclone noted.

From the time of the visit of the *Serpent*, the history of the rule of Ross Secundus appears to have been without great incident, and nothing of importance is remembered to-day as marking out the events of this period. His eldest son—the present Governor—was working with him in the islands, and a great part of the administration of the settlement passed into the hands of this strenuous young man.

During these years of which we have no detailed account, Ross Secundus was engaged in fostering the industries of the colony, and in perfecting the code of island laws compiled by his father.

The legal code, which has been drafted by three generations of the Clunies-Ross family, is a matter for the contemplation of the modern jurist: for it has stood the stress of many crises, it has risen triumphant to meet several curious emergencies, and has proved equal to all the strains imposed upon it. In the framing of these laws Ross Secundus took delight, and with his son, a man of strong and vigorous policy, to act with him and carry on the work of the islands, he passed in a great measure from the active administration of the colony into a position of passive headship.

As well as a special aptitude in the details of legal enactments, Ross Secundus had a great inclination for the practice of medicine, and he became the physician of the islands. He had, of course, no medical training, but he was an ardent practitioner of such simple methods as were requisite for the combating of the sicknesses of coral island life, and the hygienic welfare of his people was his first care. Some extraordinary cures are credited to him, and he enjoyed a very exalted reputation among the people as a clever doctor and a marvellous healer.

For all this, and for his patient researches into the natural history of the islands, he received the native title of *Tuan-pandai*, or "the learned one," and to this day a cowry shell, in whose finding he took special delight, is called *siput tuan* (the master's shell) by the natives.

There can be no doubt that his philosophic bent of mind has caused but scant justice to be done to his character by those who have from time to time told the island story. He has been pictured by his biographers as a dreamer, and one to whom the practical details of life were of so little concern that he passed his days in idle speculation, to the detriment of the settlement and the people. But the philosopher was a man of action too, for no one who dreams only may rule a settlement of two hundred Malays, many of whom were of chain-gang blood, in an atoll seven hundred miles from land. The closing days of the life of Ross Secundus were spent in the enjoyment of the society of his family, and in the investigation of the natural resources of his islands.

In 1841 he had married S'pia Dupong, a Malay lady of Royal Solo blood, and a woman of the most remarkable force of character.

There are many stories told of her bravery and loyalty, and she exerted a great and beneficial influence over the people. She became the chief moral guide in the atoll, all her deeds echoed the nobility and generosity of her nature, and she always upheld with proud and unswerving loyalty the traditions of the old Malay stock. To her nine children were born, and, though she died many years before her lord, her name is one that will long be remembered in the islands, for she was a good and a brave woman.

In 1872 Ross Secundus contracted Java fever. Whatever the true nature of that complaint may be, it is one that runs a fatal course with great rapidity; he succumbed to it after a brief illness, and was buried in Pulu Selma.

His grave lies near to that of his father, and his memory as a wise and kindly ruler is dearly cherished by all the islanders.

CHAPTER V

HISTORY OF THE ATOLL FROM 1871

Of the nine children born to Ross Secundus, seven were sons: George, Charles, Edwin, Alfred, Alexander, Andrew, and John; and two were daughters: Isabella and Eliza.

George Clunies-Ross, the eldest child, was born in 1842, and at the age of 30 he was called upon to take charge of the islands, and guide the destinies of the colony after the death of his father. He had not been very many years in the islands with his father before he was called upon to take sole charge, for he only left Scotland and his studies in engineering to come to the settlement and render assistance in repairing the great destruction wrought in the atoll by the cyclone of 1862.

George Clunies-Ross—Ross Tertius—was educated at Elizabeth College in Guernsey, and afterwards he proceeded to Glasgow, where he took up, with great success, a course of engineering. This advantage of a practical Scottish education he shared with all his six brothers, for it had been the wise decision of his father to send all his boys to Edinburgh or to St. Andrews. The advantage Ross Tertius received, and that has stood him in such good stead, he has in his turn handed on, and all his four sons have been to Scotland for their education, Dollar and Edinburgh having known most of them.

Ross Tertius came to the atoll, a young man of the most energetic nature and in the most active period of his life, and very soon it was apparent in the islands that in him the spirit of Ross Primus, with all his courage and fortitude, was back again to rule and guide the colony.

From the study of books and machinery he passed to the study of the ruling of natives, and no better student ever set out to learn a subject the right understanding of which is given to very few.

It was not enough for him that his mind was stored with knowledge of matters never even imagined by his people; it was not enough that he was familiar with the construction of engines of the existence of which they did not dream, but he early determined that what the natives could do he would do too, and he would do better than any of them.

It is difficult to speak of the accomplishment of this self-imposed task without enthusiasm, for on their own ground he met the natives, he learned all their crafts, and in the performance of them he excelled them all. George Ross, who came to the atoll an ardent engineer and a student of books, had soon learned to cast the Jala-net and throw a fish-spear with greater accuracy than any one of his subjects; and to this day his pre-eminent skill remains. He learned to know the native character in all its details, good and evil, and in addition to his keen natural intuition, and his shrewd judgments of his fellow men, he came to possess a wonderful power to fathom the devious ways of the Asiatic mind which make for faithful devotion, or lifelong enmity towards the man who reads or misreads them.

The knowledge that Ross Tertius gained from the study of the natives was soon called into requisition, for during the closing days of the reign of Ross Secundus trouble broke out among a section of the imported Bantamese coolies.

A series of law-breakings and disturbances culminated in the particularly brutal murder of a woman at the hands of the ringleader of the Bantam malcontents. It was a time for action, and George Ross' blood was afire to avenge the woman's death, and to restore order and obedience to authority. He begged permission from his father to go in search of the man, that he might execute prompt justice upon him, but Ross Secundus was a man of more judicial instinct, and forbade any sudden and violent form of vengeance. George Ross promised his father that if he went off into the bush to find the murderer, and to avenge the death of the unfortunate woman, no word would ever come to his ears of what might happen at the meeting. But this did not satisfy the father's conscience, and milder methods were adopted.

Diplomacy did not succeed, and the discontented coolies assumed a threatening attitude. The climax was reached when, in an angry meeting outside the Governor's house, George Ross faced the blood-guilty leader of the malcontents. The people seemed out of hand, and the ringleader made one step towards George Ross. Things were at high tension, and swift action could alone save the situation and the lives of those in authority. Ross Tertius acted on the instant and struck the man to the ground with a cutlass before the eyes of all the people.

This prompt action produced an instantaneous effect upon the malcontents, and with the loyal co-operation of the Cocos-born natives, the gang was broken up, and the wretched murderer was handed over to the authorities in Java.

This event did not long precede the death of Ross Secundus, and the command that Ross Tertius had gained over the natives stood him in good stead when the difficult duty of taking sole charge devolved upon him. At his father's death, George Ross did not tacitly assume the Governorship, but calling all the people together he spoke to them, discussing the affairs of the islands and asked them to elect their ruler. The islanders were not slow to make their choice, and George Ross was duly installed as the elected Governor of the islands. He set about his duties with great resolution, and soon, under his guiding hand, the islands reached a pitch of prosperous tranquillity that they had not known before.

George Ross had already followed the example of his father in making himself more qualified to act in every way as the friend of his subjects by marrying a wife from among his own people. The lady who became his wife and the mother of his numerous children was named Inin, and she was a member of one of the original high-born Malay families that came to the islands with the pioneer. She was in every way fitted to be the wife of such a man as he, for she was as brave as he was, and as loyal: and she it was who saved his life on more than one occasion. Like S'pia Dupong, she was a woman of great and good influence over the natives, and nothing unseemly was done by them, lest she should be offended, and nothing ill-mannered, lest she should condemn the act.

In this way the influence of Inin was an extremely fortunate thing for the islands, for though it may be done in silence, and is apt to find but little place in a chronicle of the doings of men, the influence of a good woman may do works as great as those accomplished by the acts of a brave man.

In every way Inin helped her husband in his task of making the colony happy and prosperous, and while he ruled the men with his masterful will, she stood as law for the women, and ruled them by her example; and she ruled them well. The industries of the place rapidly improved, and George Ross and his wife took it upon themselves to teach their people and to guide them as if they had all been members of their own family.

The planting of coconut palms was carried out on a large scale, work was organised, and many new schemes laid down. Four years saw the whole aspect of the colony changed; for the Governor introduced modern methods into the working of his islands, and instructed his people in the use of European tools and appliances. He imported and set up machinery, built brick factories for the preparation of coconut oil, which was then the staple product of the islands. The prepared oil was sent to Java to be used as lamp-oil, for at that time all the lighthouses of the Malay Archipelago were lit up by the oil brought from Cocos-Keeling. Under his careful management, George Ross had the satisfaction of seeing his home cease to be a mere jungle-clad ring of islands, and become a place of ordered and fertile groves of coconut palms; and at the end of the first four years of his charge, everything was smiling on him and his colony. But in 1876, on January 25, the blow fell, and all the efforts of his four years of patient and loving toil were brought to naught by the passing of a cyclone. The cyclone of 1876 was one of the most severe that has ever visited the atoll, and it wrought extraordinary havoc in the settlement. Coconut palms were twisted and snapped off, and trundled before the wind like ninepins, so that the fury of the storm cut large glades through the plantations, often in most capricious fashion. Extraordinary freaks were played by the storm, for whilst it laid whole areas bare, others, quite close at hand, remained unharmed; and trees were selected as victims for its fury in the most haphazard manner. Atap roofs were snatched from houses and carried away, working sheds were laid low, and the factories so carefully constructed under the new régime were ruined.

A portion of iron from the roof of the Governor's house was whirled away by the storm, and made a plaything of the wind, and to-day the scars are to be seen upon a large tree, deep in the trunk of which it finally came to rest. The destruction caused by the wind did not account for the whole of the ruin, for the seas became tremendous, and overrode the limits of the barrier, carrying before them the wreckage of all that they could reach.

Life was preserved with difficulty, and, when the storm was spent, the stricken islanders had but little to comfort themselves with save what each man stood up in, and the wreckage of his possessions.

Thus were the fruits of George Ross' four years of work dissipated in the brief visitation of the storm, and the prosperous and smiling settlement was turned to a scene of desolation and misery. But although the tropical islands are liable to these sudden catastrophes, there is no place in which nature is so quick to efface the effects of the damage and to repair the loss that the few hours of storm can cause.

Neither was George Ross the type of man to despair in the presence of this reverse, and once again he put all his energies into the building up of the prosperity of the settlement. So well did he succeed in this, that when, in 1879, Dr. H. O. Forbes visited the atoll he found a happy and contented colony on the high road to the recovery of its lost fortunes.

In 1878 the islands underwent a political change, which, like the annexation of 1857, made but little difference to the internal affairs of the settlement. In November 1878 a proclamation was issued to the effect that the Cocos-Keeling islands were annexed for the purposes of administration to the Government of Ceylon, "to prevent any foreign Power stepping in and taking possession of them for the purposes of settlement or for a coaling station."

This change was the outcome, so it is said, of a report that Russian agents had been examining the atoll and its neighbourhood. Letters patent were granted to George Clunies-Ross, and until the visit of H.M.S. *Zephyr*, eight years afterwards, the Government of Ceylon remained as the immediate appeal for the settlers.

In August 1885, H.M.S. *Espoir* arrived at the islands, and Mr. E. W. Birch went ashore to make a thorough examination of the colony on behalf of the Government of the Straits Settlements. The outcome of this visit is a very interesting record of the condition of the settlement at the time, but Mr. Birch did not meet George Ross, for at that time he was absent from the islands on the first visit he had made to Europe since his arrival in the colony.

This first journey home was one of the most remarkable achievements of Ross Tertius, and was a piece of hardy enterprise, the full reality of which it is very hard to picture. When to-day we make ocean journeys in powerful, punctual steamers, it is difficult to realise the daring of George Ross, who built his own ship, and sailed her half round the globe, that he might take his children home to be educated.

During the life of his father the vessel had been laid down, and her design was the outcome of a great amount of thought and careful attention to detail, but the rate of her building was of necessity slow. She was a schooner of one hundred and seventy-eight tons, built in thorough Cocos fashion, with every minute detail laboured over until there was no part of her that was not perfect. The building of boats in Cocos is an object-lesson in these days of hurried business and scamped detail, and no vessels more thoroughly seaworthy than these island-built boats were ever launched.

No wood is bent or strained in their making, and every piece in their shell is cut from the natural curve of long-seasoned ironwood, for the Cocos islander is content to spend weeks on the fitting of a part whose making could be done in an hour by less thorough methods. All the skilled work of the islanders and all the best material of the islands was put into the construction of the schooner, and for patient years they laboured on her.

In 1884 she was ready on the stocks, was christened the *J. G. C.-Ross*, and launched as the islanders' triumph. In February of 1884, George Ross sailed from the lagoon. Aboard the schooner he had put his seven eldest children—four little boys and three little girls; and taking his brother Andrew as his officer, and some Cocos-born men to work the ship, he started on his remarkable cruise. The islanders all turned out to see their *Tuan* sail away in their own schooner to visit the outer world, and it was a moment of pride for the colony; a moment only equalled when they learned afterwards that their handiwork had been examined by the Board of Trade in London and classed as A1 at Lloyd's for eighteen years.

Throughout the whole length of the journey, George Ross and his brother kept watch and watch about; and as a testimony to their seamanship is the fact that, from the day on which she left the lagoon to the time of her arrival in port, she did not once have her mainsail lowered, although in her journey she encountered all sorts of weather. A stay of three weeks was made at the Cape, and one of a few days at St. Helena, and in August the *J. G. C.-Ross* arrived in the Thames. All hands were well, no mishap had taken place on the voyage, and George Ross took his seven children ashore and made arrangements for their education.

In every way it was a remarkable achievement, and the six months' navigating and alternate watching must have proved a severe strain on any man, but when to this was added the care of seven young children, this deed of Ross Tertius excites the greatest admiration.

Having seen to the requirements of his little family, and obtained an English captain to assist his brother Andrew in sailing the schooner to the atoll again, George Ross proceeded on his travels, returning to his island home by way of America.

The adventures of the *J. G. C.-Ross* were not ended with her safe arrival in the atoll, for eight years after her happy launching she passed mysteriously from the island story. The tale of her going is a curious one, and is worth recording as one of those real sea romances that are often more strange than any of those that find their way into books.

Early in February of 1892, an Italian barque, bearing the name *Luigi Raffo*, with a crew of mixed nationalities, put into the atoll. She was said to be on a journey from Java to Antwerp, and she arrived at the islands in a leaking condition. Soon after she had cast her anchor, a strong swell from the N.E. arose, and the maimed and unseaworthy ship was driven upon the rocks and wrecked.

Her crew, which consisted of eighteen of the very roughest sort of sailor-men, were thrown upon George Ross' hands, and it was not long before they began to give him very serious trouble. They created disorder in the villages, set a bad example to the natives, and in every way became such a nuisance in the place that there was nothing for it but to send them packing. The Governor placed the *J. G. C.-Ross* at their disposal, put aboard, for their safe-conduct, a Norwegian captain and eight of his best Cocos-born men. On February 29 they sailed from the lagoon, and before Andrew Ross, who piloted her out, had left her side, the ruffians had fallen to quarrelling. Her destination was Batavia, and her return was looked for with anixety, but from that day to this no word of her has ever come to the islands. Batavia never saw her. No mast or spar was ever picked up, nor was she ever identified afloat in any part of the world. What happened to her no man has ever told, but in the islands the belief is that the Cocos men and their captain were put overboard, and the Italians disguised her and sailed away. There are features in the case that lend a probability to this view, for when inquiries were made, it was found that the ship named *Luigi Raffo* was quietly lying in Genoa at the time of her supposed wreck upon the reef of Cocos-Keeling. It would appear as though the ship in which the Italians came was a pirated and disguised one, and it would be no surprise to many people in the atoll to find the *J. G. C.-Ross* still afloat under a new name. But her loss was a heavy one, and a great blow to George Ross and all his people, and nine good men went with her and left their wives to mourn.

George Ross did not return to the islands in time to be present at the visit of H.M.S. *Espoir* in 1885, and so the visit of representatives of the Straits Settlements Government was carried out in his absence. Nevertheless Mr. Birch amassed a great deal of valuable information concerning the atoll, and the report that he furnished to the Government is one of the best accounts of the conditions of the place that have been put on record. In August 1886, H.M.S. *Zephyr* made a visit of inspection with the object of granting to George Ross new letters patent, revoking those of September 10, 1878, by which the islands had been placed under the Government of Ceylon.

On Tuesday, August 24, 1886, the new letters patent were read to the people by Mr. A. P. Talbot. The ceremonies of 1875 were repeated, the Union Jack was hoisted, and a party of British bluejackets gave the royal salute and fired a feu-de-joie. A proclamation was given to the people and the Governor of the Straits Settlements was made their overlord, while a grant-in-fee of the islands was given to George Clunies-Ross. Since that time the visits of British men-o'-war have been fairly regular, and each succeeding Commissioner has noted the progress of the settlement and the beneficence of the Governor's rule.

The settlement of Cocos-Keeling had now become a peaceful colony devoted to the quiet development of the natural resources of the atoll; the strenuous times of its early days were past, and George Ross and his wife became more than ever the father and mother of the people rather than their rulers. George Ross, and his brothers Charles and Andrew, taught the men useful trades, and the carpenters of the islands are not easily to be matched among Malay people. Blacksmith's forges were set up, and kilns for the burning of coral boulders into lime were made, and soon there was but little that the island colony could not produce for its own immediate wants. Good dwelling-houses were erected, and rat-proof stores were constructed of bricks and mortar so that large stocks of rice could be kept in the islands, as a reserve, for use in times of any shortage caused by the delay of the island schooner. The people were encouraged in manly sports, and regular tournaments were held, at which throwing the spear and diving were keenly contested competitions. In these contests, George Ross far excelled the best of his people. The love of the Malay for his boats, his knives, and his spears was fostered, with the result that boat-building has reached a very high pitch of development, and the men have become the handiest boatmen and the most skilful spearers of fish to be met anywhere. Whilst George Ross was doing all this for the men, his wife was training the women. She took the girls to her own house and educated them thoroughly in domestic duties, teaching them ideals of moral conduct and habits of neatness and thrift.

It is difficult to over-estimate the success that has attended these efforts, or to exaggerate the degree of contented prosperity which reigned in the islands. By 1888 so great a peace had spread over the settlement that George Ross looked for other fields for the expansion of his colony.

On several occasions parties had gone from the atoll and sailed to Christmas Island, which lies some five hundred and twenty-five miles to the north and east of Cocos-Keeling. The extraordinary fertility of this uninhabited place, and its vast flocks of absolutely unsuspecting birds, were sufficient to tempt any man to make the passage, and it was no uncommon thing for George Ross to take a party of his men to camp upon Christmas Island. Expeditions were made to bring home some of the valuable timber that grew in such abundance on every mountain-slope of this fine island, and the advantages of a permanent settlement there were apparent to the Governor. In 1888 he therefore took his brother Andrew and a party of Cocos-born men, and making a clearing in the neighbourhood of Flying Fish Cove, he built houses and work-sheds and laid the foundations of a colony.

The little band of colonists set to work at once : coffee and coco palms were planted, the island supply of fresh water was conserved and wells were made for its storing. It seemed to George Ross that his ideals were to be realised, and that here he had a territory which did not know the confines of a few miles of barrier reef, and could at the most provide a livelihood for a few hundred active men. Christmas Island was clothed with virgin forests to the top of its plateau a thousand feet above the water-line, and it had never been inhabited or in any way exploited ; it was a field for unlimited enterprise, and for the expansion of the Cocos-Keeling colony. George Ross was a happy man; he dreamed of subjects to be numbered by thousands instead of by hundreds, and a sufficiency of hardy enterprise and pioneer work to shape the manhood of his people for many years to come. He at once took steps to obtain a legal tenure of the island, and in 1889 he made application to the Straits Settlements Government for a grant of land there. But he had not reckoned with the business instincts of men situated nearer to the sources of information than he himself was in his out-of-the-way corner of the earth. Specimens of the rocks of the island, collected by Captain Aldrich of H.M.S. *Egeria*, and by George Ross himself, had been submitted to experts at home, and found to consist of nearly pure phosphate of lime.

The greed of wealth would not allow the world to sanction an idealist like George Ross to establish a rural Utopia upon an island, the whole extent of the surface of which could be shovelled into the holds of ships and sold for high prices.

As a result of the negotiations, the Governor, in his secluded coral islands, had to give way to the men of business instincts at home, and in 1891 he became merely a part owner of a lease of the island. It was the beginning of the end of his daughter colony, for in 1897 the working of the island was taken over by the British Christmas Island Phosphate Company. The plantations of Liberian coffee, of bananas, and pepper had to go before the advance of machinery and the spoiler. One thousand Chinese coolies replaced the colony of Cocos-born Malays, and Sikh policemen kept order in a land where for a time the opinion of one man had been sufficient guarantee of good conduct.

Before the inrush of all the turmoil of wealth-getting, the wonderful fauna has had to give way. The unique rat (*Mus Macleari*) has been utterly destroyed, and the Christmas Island fruit pigeon (*Carpophaga Whartoni*) is fast following in its footsteps.

Christmas Island has become a remarkably successful commercial undertaking, but as a preserve for an interesting and isolated fauna, and as an ideal place for a peaceful Malay settlement, its day has passed. George Ross and his Cocos men have withdrawn from the island; they have abandoned for ever the scheme of their plantations and their larger colony, and centred all their energies on perfecting their home in Cocos-Keeling.

The Governor has busied himself with designing and erecting a fine house for himself, which is a monument to his patience and skill. He has imported building material from England and, with his own masons and carpenters, he has moulded upon his own designs a house the perfect construction of which is his pride. He has built turtle ponds and boat harbours, made good paths, laid down trolly lines, and generally improved the island of his residence so that it is a model of neatness and good order.

He has portioned out the work amongst his brothers and sons, so that each man has his duty, and every detail receives attention. It would be difficult to find anywhere a better ordered or more contented community than that of Cocos-Keeling, and everything about the settlement shows clearly the imprint of his master hand. Every scheme is his, and every detail of its execution is the object of his thought, and the outlet for his energies; and to this day George Ross remains a man as quick to think, and as ready to act upon the thought, as in the day upon which he felled the murderer and won the hearts of his people.

In 1889 Inin his wife died, to the sorrow of the whole population, and it was not until 6 years after that he married Ayesha, his present wife.

In 1901 the quiet seclusion of his island home was somewhat broken by the advent of the cable, and its necessary staff of workers, to Pulu Tikus; but the presence of visitors from the outside world has not in any way upset the peaceful routine of coral island life. Cable routes run to Pulu Tikus from Perth in Australia, from Mauritius and Africa, and from Batavia in Java; and so the news of all the world is known in this quiet spot. Yet so remote is Cocos and its settlement that even the busy messages of politics and commerce merely pass across its coral shores, and leave it still with all its wonted aloofness from the world and its strivings.

George Ross is still the one man in Cocos, and Cocos and its men still possess the same detachment from the world that has been their characteristic for the last 80 years, and it is to be hoped that for long this state of things may remain. Coined money is still unknown, for the parchment notes of George Ross are the sole medium of exchange; crime hardly exists, and without police or military, perfect order prevails. To chronicle a tithe of the doings of George Ross is impossible, for the life of the man has been a succession of stirring scenes, in every one of which he has been the central figure, and in every one of which he has played a man's part. A strong man and a good one, he has the rare privilege of seeing his work perfected, and of recognising in every corner of his home the order and prosperity he has brought about by his life's work, and the peace that he may long be spared to enjoy.

BUNGALOW OF THE TELEGRAPH STATION ON PULU TIKUS.

CHAPTER VI

NATIVE CUSTOMS

There are many customs practised by the natives of Cocos-Keeling which are of peculiar interest, for, in common with all Malays, they show in their ceremonies a curious mixture of practices that are entirely foreign to their professed creed of Islam.

At any time the Malay is but a lukewarm adherent to the orthodox religion, and it must be owned that the Cocos Islander does not come any nearer to the Islamic ideal of strict observances than do most of his kin.

The doctrines of the Koran are taught to them and they are professed Mohammedans, but, like all their race, they show clearly in their customs strong evidence of a pre-Islamic nature-worship.

They have a densely populated spirit world, the inhabitants of which are apt to intrude themselves into ceremonies of purely Islamic origin, and at times almost as much attention is paid to the requirements of the spirits as to the details prescribed by the orthodox religion. The hour of twilight is the one in which the denizens of the spirit world are apt to be abroad; it is a dangerous time for delicate folk and children, but for the woman who is pregnant it has the most terrors, and she must not be out of doors unless she carries a knife in her hand. It is out of deference to the spirits of animals that neither she nor her husband may kill any animal, for if the blood of any creature is spilled at this time, vengeance will be visited upon the unfortunate offspring. Concerning the reality of the visitation, there are many strange stories current in the atoll, and the doctrine of the potency of maternal impressions is one that always finds a ready credence in Malay communities. Spirits play an active part in all the ceremonies and observances connected with the birth of a child, and special precautions are taken to keep evil spirits far away from new-born babies.

Beneath the pillow upon which the baby lies is hidden a *parang*—the ever-ready knife of the Malay—and in the bed itself is placed a little broom, as a warning to noxious spirits that they must keep far from the child. The custom of placing a knife in the child's bed is very widespread throughout the world, and it even exists in some parts of England and Wales.

If, by some visitation of evil influence, an island baby chances to be born malformed, the handiwork of the devil is at once recognised, and steps are taken to undo the mischief wrought by Satan. The observances practised at the birth of a malformed child are curious, and concerning their utility—or the reverse—all argument is vain, for no one may convince people who have seen and known these things, the workings of which are the expected outcomes of their recognised cause. A woman who gives birth to a child that is in any way deformed does not immediately begin to deplore her hard fate, or to assume that the harm that is done is beyond repair, for she recognises that the devil has done the mischief, and she knows that if she sets properly about the thing she may make him undo his handiwork. No notice whatever is taken of the unfortunate child, but it is covered with a cloth and placed aside; the mother and the midwife discuss any general topics of conversation and try to pretend that nothing has happened. All concerned are determined that they will take no notice of the child while it bears upon its body the imprint of Satan's evil visitation. And, as a rule, the trick succeeds, for when at length the babe is uncovered, the deformity is gone, and the child is as strong and as whole as though it had never carried on its frame the manifestations of Satan's influence.

I know a little boy whose head is shaped just as are the heads of other little boys, and yet, when he came into the world, it was to present to his horrified mother a visage surmounted by two large protuberances like hen's eggs—and indeed eggs had been much in her mind of late. But he was covered up and ignored, and the mother's ruse succeeded: for her next look at her babe revealed only the rounded scalp and puckered red face common to all new-born babies. Other instances too are quoted in the islands, and cases of webbed fingers and clubbed feet seem easily amenable to this treatment.

Little children die—even on coral islands this cannot be prevented—and evil spirits are mostly at the bottom of it, and the knowledge of the influence of the spirits gives origin to a very curious custom. A woman who has had the misfortune to lose her baby suspects that the devil has a design upon her and her offspring—and a continuance of her trials only confirms her suspicions. If child after child is born only to die of infantile complaints, she knows that it has been decreed by the evil one that she shall not rear her baby, and so when next a child is born to her she pretends that it is not hers and places it in the road where some one is sure to see it before long.

The expected happens, for some other woman passing by sees the bundle, and, knowing the meaning of its presence, picks it up and carries the baby to her house. She mixes the child among her own children, and cares for it, and pretends that it is hers; and in this way the devil loses sight of the child and lets it grow up, forgetting that it is the offspring of a mother upon whom his curse was set.

The same idea underlies the custom which is prevalent in the islands of changing altogether the name by which a man has always been known, after he has recovered from a serious illness. A man who is smitten with a great sickness, and has been near to death, feels that it would be unlucky to rise from his bed still bearing the name by which the spirits knew him when such ill-fortune befell him, and so he takes a new name when he recovers; and goes among his fellow men known by a different title from that under which he passed when he was smitten.

One of the oldest retainers of the Clunies-Ross family—a fine man of mixed Zulu blood—whom I always knew as Ali, began life as "Tredin," but the "Tredin" was dropped, and never used again, after he had narrowly escaped death from fever.

The recovery from sickness is not, however, the only occasion upon which a Cocos native indulges in a change of name, for when the first child is born to a man and woman they straightway drop their names and take as their own the name they bestow upon their infant. The man prefixes "Pah" to his child's name and the woman prefixes "Mah"; and by the compounded names they are known henceforth. For instance, a man named Jenal married a woman named Itam, but when their child was born and had been named Angas, the father was ever after known as "Pah Angas" and the mother as "Mah Angas."

It might be imagined that this custom would create confusion, and lead to a great deal of uncertainty as to an individual's real name, but as a matter of fact it works out quite well in practice, and leads to no inconvenience. Moreover it possesses the advantage of conferring a desirable dignity on parenthood.

A child that has survived the chances of spirit interference during its babyhood has no important event to look forward to until the rite of circumcision is carried out. This ceremony takes place as a rule at about the age of ten, and the time of its performance depends upon the boy's proficiency in reciting from the Koran. Since the Koran is learned in Arabic, a language foreign to the Malay, the performance is not a test of great scholarship or great piety, and the recital consists merely of committing a certain number of verses to memory. The boy is gaudily dressed for the occasion, and he is decked out as only brides and bridegrooms are: like them he has his face painted, and his eyes adorned with a monstrous pair of black eyebrows. The feasting and celebrations are kept up for three days, and at the end of the rejoicings the boy is considered a man, who henceforth must wear trousers. The transition to trousers is more abrupt for the little Cocos boy than for his western brother, for it consists in a sudden change from nakedness to the wearing of the fully developed garments of manhood. He loses too his happy privilege of bathing in a state of nature, for no Cocos man or woman ever thinks of entering the water unclothed, and no more modest race exists than the dignified Malay.

The boy now turns out to work with the men, and takes his part in all the business of the island as a fully grown member of society.

He is now free to marry, but he generally waits until he is some years older, for it has been the wise policy of the Governor to attempt to put a stop to very early marriages among the people. The youngest bride that I knew of was a girl named Denning, who married at twelve, and the youngest bridegroom one Tarie, who was fifteen years old: but notwithstanding the disfavour in which early marriage is held, Cocos has had the honour of possessing a grandmother at the early age of twenty-eight.

The wedding is the grandest of all the island ceremonies. and the whole festivity is a long-protracted affair, and one in which much polite etiquette is essential. When two people fall in love, it is not the custom for the intending bridegroom to propose to the lady, but all the negotiations are carried out by his father with due formalities. The betrothal is arranged by the young man's father calling upon the parents of the maiden and offering a present—the *Mas kawen*—which is generally of gold, and usually nowadays takes the shape of English sovereigns. If the match is pleasing to the girl's parents the present is accepted, and the pair are considered as engaged, and they proceed to set about the preparations for their marriage.

Should one of the parents of the intended bride be dead, a strange custom is practised: upon the day before that fixed for the wedding the young couple go to the grave of the dead parent, and announce the fact that they are betrothed, so that the spirit of the departed one may be a party to their contract. Upon the day of the wedding the best friend of the bridegroom gathers all his male friends together and goes to the bridegroom's house, and after decking him out in finery and painting his face a hideous yellow, leads him out to make an attack upon the bride's house.

The bridegroom is truly a pitiful sight, for he is crowned with quaint headgear and adorned with flowers, his face is ghastly yellow with *kunyet* (turmeric), and is painted with double eyebrows and a false moustache. But he is the centre of attraction, and he walks proudly out, sheltered beneath an umbrella carried by his best man.

There is much firing of guns and shouting, and a warlike spirit prevails among the young companions of the bridegroom. Some go ahead and practise mimic sword-play, and all are gaily dressed and in high spirits, eager to take their places in the procession as it threads its way towards the bride's house. When the house is reached, the best of the fun begins, and the gun-fire becomes brisker and the noise louder, until at length the bridegroom mounts the house steps to claim his bride. But this is not made easy for him; his future mother-in-law rushes out to repulse his entry, and offers a brief but stubborn resistance to him and his young men;—for it is her part to defend her daughter.

When she fancies that she has resisted long enough, she gracefully yields, and then she welcomes her son-in-law, and leads him to the bride. The bride awaits him in the house, and, in token of her submission to her future lord, takes water in which rose petals and sweet-scented flowers are steeped, and, with due humility, washes his feet. The rejoicing now reaches its climax, and all who can gain entry into the house crowd in and join in singing and feasting and general merry-making of a very orderly and dignified character. During the singing, the bride and bridegroom sit on the floor with a pillow placed between them, and they eat, with great solemnity, from a dish containing *rujak,* a very pleasant mixture made of unripe fruit of various kinds compounded with sugar, salt, vinegar, and chillies, the presence of which at the wedding ceremony is essentially symbolic. The eating of *rujak* signifies that these two young people, who sit so solemnly on the floor, are preparing to enter into the bond in which they may taste together all the sweets and bitters of life; but I have not heard of any man who, coming upon too much chilli, gained timely experience from the *rujak*. When the singing is over and much incense has been burned, the bride and bridegroom rise from the floor, and set out side by side from the house on a journey to the parents of the bridegroom. An umbrella is held over each of them, and the procession forms for the return visit. Upon the house steps, the bridegroom's mother awaits the couple, and when they have mounted to the threshold, she takes a long scarf, called a *slendang*, and ties them together round the middle, in the sight of all the people. The happy couple stand face to face, with their noses almost touching, whilst the bridegroom's mother produces rice, boiled and stained with *kunyet*, and solemnly feeds them with a spoon. It is really a curious sight, for the queer expression that the false eyebrows lend to the pale yellow faces gives the young couple rather a sadly comic aspect, and the business of feeding with a spoon two people tied nose to nose is apt to appear ludicrous to a crude Westerner. The festivities are now continued in the house of the bridegroom's parents, but, in the feasting that follows, the poor young people take no part, for they sit solemnly aside, with very demure faces, until the whole business flags and comes to an end at about four o'clock in the morning.

After this very trying ordeal, they adjourn to their own house, if they have one, or, if not, to the house of either of their parents; and they embark upon their career of married life.

It is easy to see in the procedure of the marriage ceremony the remains of the more primitive marriage customs of the original tribal bands of the Malay stock. The mimic warfare of the capture of the bride, and the feigned resistance of her mother, are mere pale ghosts of the practices of the days in which a man sallied out from his home, and, with the help of his friends, captured a maiden from the company of a neighbouring tribe. The bridegroom's friend was his assistant in the raid, and to-day the descendant of the brother raider is seen, in our own weddings, as the best man, though custom has long since spared him the ordeal of making sword-

Fig. 1.

A Wedding Group in Cocos-Keeling.

The bride and bridegroom are wearing the flower-decked headgear.

play, or firing blank charges in the direction of the bride's mother.

Just as our best man is seen on a glorified scale in these Cocos wedding ceremonies, so is the custom of sending out wedding cake to absent friends displayed in its archaic form at the feasts of the Malays. The food that is to be used at the wedding feast—or indeed at any other ceremony of general rejoicing—is first blessed by the *Imam* (priest), and then distributed amongst those present, the blessing of the food being an essential and a religious function. The food that is blessed is, however, not all consumed at the feast, for portions of it are sent to all the friends and relations who were unable to be present at the rejoicings, in order that they may share in the blessings and goodwill to be derived from these occasions. The blessed food is called *brekat,* and custom dictates that the utensils in which the *brekat* was distributed shall be returned unwashed to the givers of the feast. The sending of *brekat* is an important piece of etiquette, and an extremely pretty custom, and it would seem likely that our wedding cake, although unblessed, is in reality a descendant of the *brekat.*

The other occasions of feasting, in addition to the rites of circumcision and of marriage, are the *S'kada bumi,* the *Banchahan,* and the *Slamatan.*

S'kada bumi is almost an equivalent for the harvest thanksgiving, and though the Cocos Islander has but little in the way of crops to be thankful for, he still maintains his *S'kada bumi* with much enthusiasm. The whole island joins in this festivity, for it is one of the greatest events of the Cocos Islanders' year, and elaborate preparations are made for it. When the feast of the *S'kada bumi* is over, the food that has been blessed is not all sent out as *brekat* to the living, but some is kept reserved for spirits. Little wicker baskets are prepared, and hung up in the branches of the trees, that the spirits may come and take the food that has been blessed, and so be partakers in the feast. The custom is evidently a very ancient one designed to make offerings to the spirits of the various crops and of the elements, and the human feasting, though at the present time the dominant feature of the ceremony, is probably a secondary thing.

The *Slamatan* is a feast given as a thanksgiving in honour of an individual, a prayer for his safe-keeping, or a thanksgiving for his safe return; the trips made by the Governor to England are the greatest of the occasions for the *Slamatan* to-day.

The *Banchahan* is a feast for children, and is a very pretty custom. The children all gather together in the house and courtyard of the giver of the feast; some come alone, some are carried by their mothers, and all are happy. The food is distributed to them, each child bringing a little bowl to take its share of the curry stuffs and rice, and great merriment and good-humour prevails on these occasions. When each child has shared in the feasting and merrymaking, the grown-up people take bowls of water, and all at once set about throwing the water over the crowd of children. A regular fusillade of water is kept up until, in a very short while, the elders have splashed and chased every laughing and happy child out of the compound. Throughout the feast there is much burning of aromatic substances, and little smouldering fires are placed beneath the beds of all the children in the house, and the ashes of these little fires (*abu bunchahan*) are carefully preserved. Should there be an absent child in the family of the giver of the feast, his portion of the food is put into a little bowl, and placed apart upon his bed, so that he, though absent, may share in the festivities of his family.

The ceremonies connected with death and burial are always of peculiar ethnological interest, and some of the customs of the Cocos Islanders are worthy of record. In common with many Eastern races, it is a strict duty among the Malays to watch by the body, from the moment that life has gone, until it is finally lowered into the grave. This duty is studiously carried out in Cocos, and in all the observances connected with burial an extreme reverence is shown for the body of the departed spirit. Immediately after death, the corpse is washed and little plugs of the fluffy natural island cotton are placed in the ears, and between the fingers. I do not know why the cotton is placed in between the fingers, nor do I know the reason for the curious practice of putting a needle into each pad, when the body is that of a woman who has died in childbirth. The origin of the custom seems lost in obscurity, but it is only one of the many details of special tender regard paid to the bodies of such women.

After the washing and the insertion of the cotton-wads, the body is wrapped seven times round with linen, and all the jewellery that was worn during life is left upon the corpse and goes to the grave with it. The actual funeral always takes place by water, and the island upon which the burials are made (Pulu Gangsa) is an uninhabited one, used for no other purpose. The corpse is placed in a wicker coffin, and the funeral cortège of boats follows it to the burial island, where the ceremony is conducted by the native priest, who reads verses from the Koran as the body is lowered by ropes into the grave. The wicker coffin is not buried with the body, but the corpse, swathed around with its linen wrappings, lies stretched upon its back upon the bare coral sand; a board is placed over the features to protect them from the falling earth, and the grave is filled in. In the case of a woman, it is the custom to bury the body with the head resting upon a little pillow made up of her own hair, for a Cocos woman never throws away the hair that she combs out at her toilet. There is a deep-rooted belief in all this: it is exceedingly unlucky to leave hair lying about, since an enemy may obtain possession of it and do *Jampei*, or witchcraft, with it. A woman therefore always keeps her hair, and upon it she rests at last in the grave. A wooden tombstone marks each grave, and it is shaped differently in the case of men and women. The tombstone which marks a man's grave is pointed as an arch at the top, whilst that upon a woman's grave is square; and in neither case is it elaborate. There seems to be no especial direction in which the grave is made, and the head is not constantly pointed in the direction of Mecca; but graves lie at all angles on the island, being made more with regard to the convenience of the site than to any geographical orientation. Upon each grave is placed a *Kema* (clam) shell filled with fresh water for the use of the spirit, and flowers are strewn about the grave by relatives of the deceased. The graves are carefully kept, and visits are paid to them at stated intervals, as a part of a regular routine of duty. The period of mourning is determined by a very curious custom. The wicker coffin is carried, and lowered into the grave, by means of a piece of stout rope; and after the burial, the rope is carefully unravelled, and portions of it are tied about the wrists of all the relatives of the dead person. This rope bracelet is never removed, but, in course of time, it rots through and drops off, and then it is known that the time of sadness is at an end, and the spirit of the departed desires no more mourning. Upon the whole it must be said that a Cocos funeral is a terribly sad and affecting ceremony; the community is so small that each loss is keenly felt; the relationship so intimate that all are mourners; and the sad procession of boats to the island of burial makes the ceremony a painfully impressive one.

PART II

THE CORALS AND THE CORAL PROBLEM

CHAPTER VII

THE EARLY STAGES OF THE LIFE-HISTORY OF THE CORALS

THE myriad coral colonies that grow in such luxuriance in the warm, clear waters of Cocos-Keeling are of course the most important of all the forms of life found in the atoll, for of coral the whole place is formed, and no particle of the dry land is made of anything save the bleached fragments of dead colonies. Every island is made of boulders of coral and coral sand; every rock is coral living or dead; and every portion of the barrier reef is composed of the remains of colonies torn from their beds below the sea. There are no stones in coral islands save those brought by man, or carried floating on the roots of trees, and the most commonplace of stones have been regarded as being of enormous value in some coral islands, when chance has cast them on the beaches.

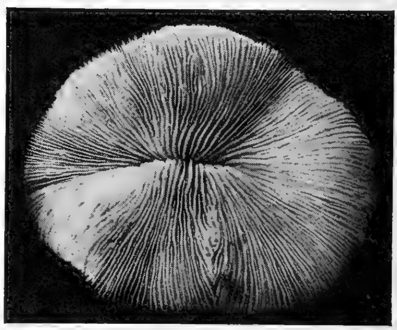
Every square inch of land in the atoll is coral, and coral in its living splendour clothes the seaward sides of the islands, and carpets the lagoon, wherever the conditions for its life are favourable.

Besides being of paramount importance, the coral beds are objects of very great beauty; but I think that the pictures that have been painted of the splendour of living coral are often over-coloured. The corals of the Cocos-Keeling atoll are not rainbow-hued, but are, for the most part, of a yellowish or greenish colour, with here and there a purple colony, and here and there a pink one. The "fairy bowers," so often described, exist only in certain spots where the water is sufficiently smooth to permit the more highly branched forms to flourish. The most abundant type of growth is in the shape of a large rounded, solid rock. It is the clearness of the water that gives the whole charm to the beauty of the coral beds, for the water is of an indescribable blue, and so clear that the bottom is plainly to be seen in depths of over 30 feet. Through the blue water the living colonies are seen as little trees and rocks scattered about in a confusion of colour and form. The whole scene is made alive, by the flickering of the moving water and the darting forms of brilliant fish, in a manner that is altogether charming; and the beauty of the whole water picture, rather than the beauty of the corals themselves, is the chief attraction of the coral beds.

FIG. 2.

Fungia: LIVING SPECIMEN.

FIG. 3.



Fungia: SAME SPECIMEN DEAD AND DRIED.

Some of the corals are hard, and their colonies form massive boulders or branching stony growths (Zoantharia), and some are soft and fleshy (Alcyonacea), and these spread out upon the rocks very much after the fashion of the fungi growing on trees. As only the stony colonies are of any importance as reef-builders, they alone will be discussed. It must not be imagined that the hard corals are dead things, or that a great stony boulder of *Porites* is merely a mausoleum upon whose surface life is flourishing. The coral that we are accustomed to see in its dried and bleached form is only the skeleton of a colony of zooids, each of which has its separate parts, although it is only a member of a great compound body.

All corals do not live in colonies, and many species of solitary corals are to be found about a reef. The comparison of a living solitary coral with the skeleton that remains after it is dead will give the best idea of the true nature of the specimens called "corals" in museums. The individual coral zooid is most like a common sea-anemone, and if an anemone be imagined to develop a calcareous skeleton, this skeleton would be very much like what remains when a solitary coral is dried and bleached.

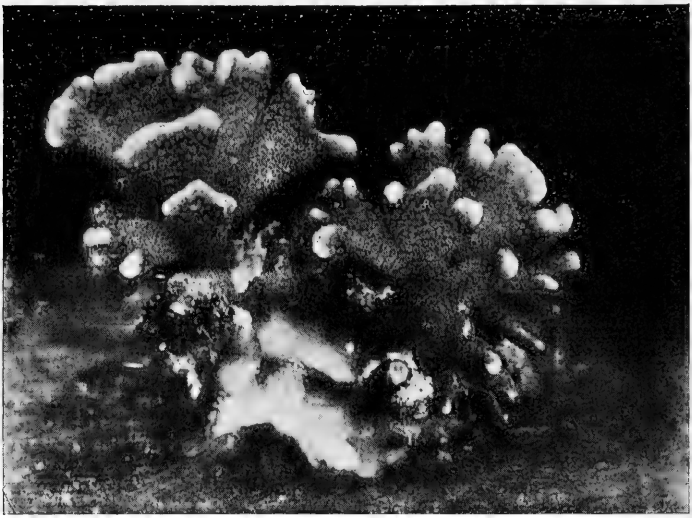
A vast aggregation of these skeletons, all very minute and all joined together in the form of a boulder, or a branching growth, constitutes what we know as "coral." There are many problems connected with the production of this "coral" and with the life-histories of the corals themselves, but of a great many of the most important details knowledge is strangely lacking.

How far all the myriad forms to be found upon a reef are to be considered as separate species, or only as mere varieties, is a point still open to debate; and a vast amount of work remains to be done before the question may be definitely settled.

The methods of feeding, of growing, and of reproducing—in fact all the life-functions of the corals—are but very little understood, for corals are usually studied when dead and dried in museums. It is for this reason that any work done actually upon a living reef is likely to help in the solution of vexed questions, for no real knowledge of corals is likely to come from the study of their dead remains, when far removed from the site on which they grew and from the actions of all those forces which influenced their growth.

Unfortunately it is common to measure the truth of observations made in the field by the knowledge that has been already gleaned from the uncertain data of museum

Fig. 4.



Montipora Colony, Living.

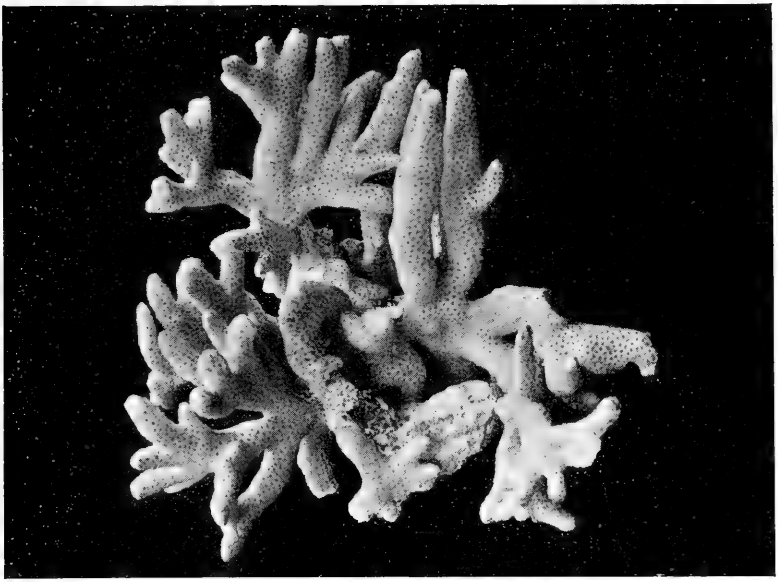
specimens, and until this state of things is changed corals will continue to be unpopular subjects for investigation with people who have the opportunities of studying their forms when alive.

The maze of literature that has been written upon the description of corals—often in necessary ignorance of any of the conditions of their life and growth—is devoid of any general interest, and is not very helpful.

Observations must be made upon the *living* zooid if we are to add to the real knowledge of these creatures, for it is essential that the life-history of the zooids must be carefully followed before we can form any conception of the real significance of their structure.

The corals, like many other animals that live sedentary lives as adults, are actively moving creatures when young.

Fig. 5.

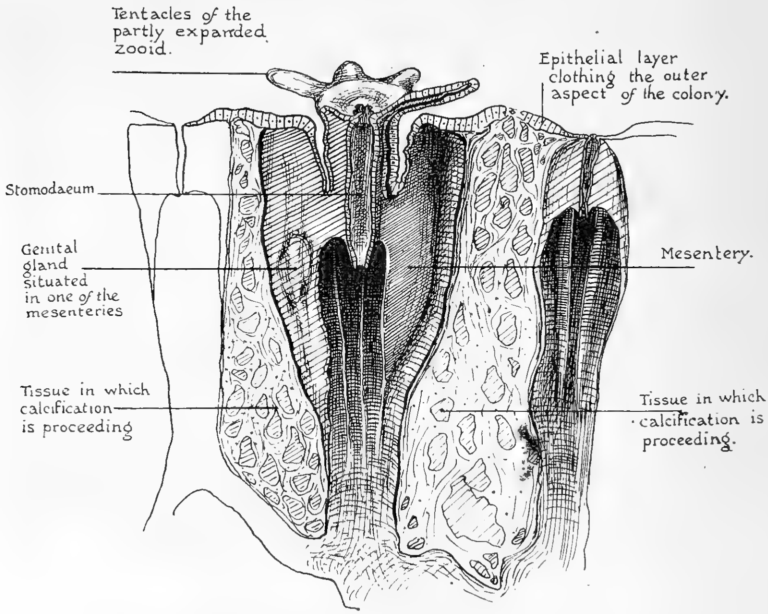


Montipora Colony, Dead and Dried.

Beyond the meagre chances of distribution of living fragments by the waves, and the rare transport of colonies on floating logs, the adult life of a coral growth is of necessity absolutely fixed in the place where it is settled down. For when a coral larva becomes attached to a suitable base and lays the foundation of a colony it has no further hope of translation other than by chance accidents as the sport of the waves. The power of active movement is lost for ever with the settling down of the larva. For this adult inactivity the motile larval coral compensates: the younger stages are free-swimming creatures capable of propelling themselves through the water, and of being carried far and wide by currents, and in this way they are able to establish new colonies at a distance from the parent growth.

It is well known to the inhabitants of the atoll that the corals do reproduce themselves by freely floating embryos, and

Fig. 6



A Section through a Portion of an Alcyonarian Coral to show the Relations of the Zooid to its Skeleton.

it is a common thing to hear it said that a particular wreck or boulder became quickly encrusted with coral growth because it happened to settle down when the corals were spawning.

It would hardly be expected that in an environment so uniform throughout the year's cycle the corals would have a definite breeding season, and yet reproductive activity evidently undergoes periods of waxing and waning. At times it has been noticed that many colonies are ripe and are actively giving rise to embryos, whilst at other times no actively reproducing colonies can be collected.

The early stages of the young coral will be described but briefly, and only such details given as are necessary to make clear the manner of its life, and the manner of its attaining its adult condition.

The ova and spermaria are developed from the epithelium that covers the mesenteries within the body of the parent zooid: some differences in their distribution occur in different species, for in some cases only ova are found and in some only spermaria. When both elements occur together they may be developed separately on different mesenteries within the same zooid, or they may both be present on the same mesentery; any mesentery may be the site of development of ova and spermaria, but the ova always tend to be developed at the attached radial edge, and the spermaria at the free central margin. When mature, the reproductive elements are passed from the central cavity of the zooid along the stomodeum, and through the mouth out into the water, the passage being effected by jerking movements of the parent zooid.

The stage of development, in which the reproductive elements are liberated, varies considerably, for while some observers have seen the male cells and female cells extruded individually in the process of spawning, still it appears to be a more general rule that viviparous reproduction is adhered to, and a young embryo is extruded into the water. The segmentation of the ovum, and the early stages of the development of the larva, take place, as a rule, within the internal cavity of the zooid, and the larvæ are shot out through the mouth in successive batches. In *Maniciana areolata*, Duerden observed that a dozen or more larvæ were ejected at a time, whilst in *Porites clavaria, Favia fragum,* and *Siderastræa radians,* they came out singly or in twos and threes. As the process of spawning advances, and as more and more batches are ejected, the stage of development of the extruded larvæ becomes more advanced, and a colony which at a spawning time started by ejecting ova and sperm cells will give rise, as the season advances, to successively more perfectly developed larval forms. The process of development of the larvæ within the zooids takes place fairly uniformly all over a colony, so that any zooid that may be examined will show the larvæ, or reproductive elements, all in about the same stage of maturity. The actual period over which the extrusion of larvæ is spread may be several days, or even a week or two, and then, after the occasional appearance of a few stray individuals, the zooids cease to give forth larvæ, and relapse again into their normal state as members of the colony.

Zooids within the span of their lifetime are able to give rise to more than one crop of germinal elements, for a seasonal outpouring of the larvæ does not terminate a zooid's reproductive life. The capacity of a mature colony for reproducing its species is therefore potentially very great.

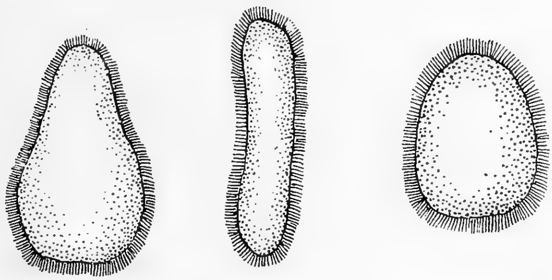
When first launched on an independent career, the young coral larvæ are little bodies from 1 to 3 millimetres in length; that is to say, they are slightly longer than the diameter of an average pin's head. They vary in shape according to their species; they may be oval, elongated, pear-shaped, or spheroidal: moreover, the larva has some power of altering its form, and, as growth proceeds, its original shape may become considerably changed.

The larvæ are active motile creatures, and their activity begins to display itself, as a rule, immediately after their first extrusion from the parent zooid: the source of their motile power is the one so commonly found in lowly swimming animals—the lashing of cilia.

The larval body is uniformly ciliated; that is to say, it is entirely covered with filamentous protoplasmic processes which move in a definite manner, and urge the animal through the water: the action of the cilia is wavelike, and, as a ripple of fine movements, spreads down the sides of the larva, much as the legs of a millipede move in their flowing sequence.

It is by the lashing of these processes that the coral larva moves forwards, and it is by means of the cilia that the movements of rotation, that some larvæ possess, are carried

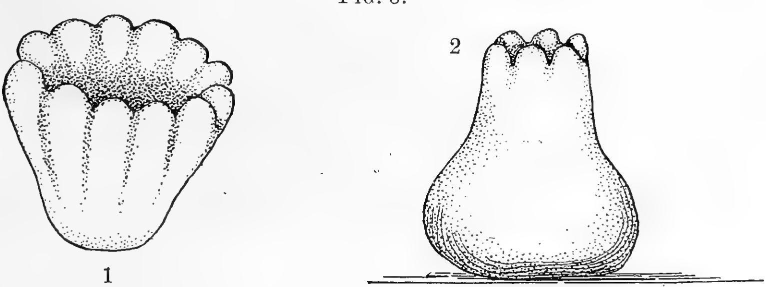
FIG. 7.



LARVAL FORMS OF CORALS: CONDITION SHORTLY AFTER EXTRUSION.
(After Duerden.)

out. The larva moves along with the site of the future mouth pointing backwards, and in those larvæ whose form is pear-shaped

FIG. 8.



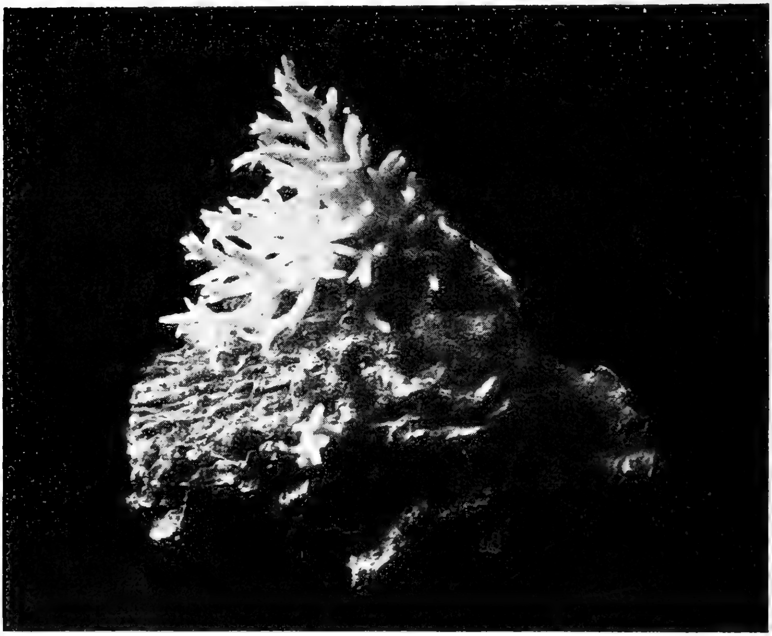
LARVAL FORMS OF CORALS.

No. 1. Larva of *Favia fragum*, Esper., about ten days old, but still free-swimming.
No. 2. Larva of *Favia fragum*, Esper., about a week after settling.
(After Duerden.)

it is usually the broad end that leads the way. On extrusion and after a few moments of quiescence, the larvæ watched in aquaria have been noticed to begin to swim about actively, but, after a day or two of this life, they settle down, and become fixed to some object by the end that is pointing forwards as they swim—that is, the end farthest from the site of the future mouth.

When first liberated they are opaque and solid bodies,

Fig. 9.

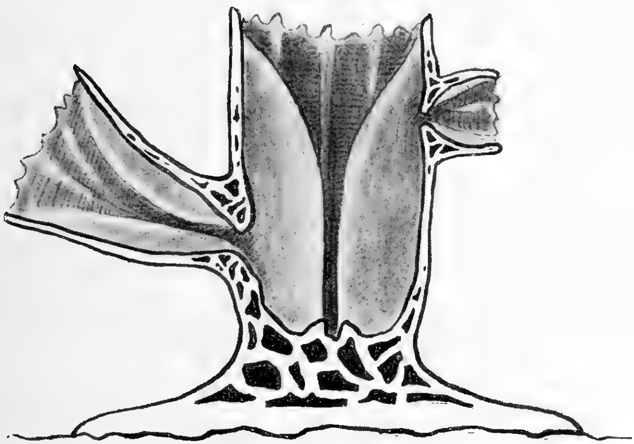


Two Young Growths of *Seriatopora* that have started their Colonies upon a Living Oyster.

and it is not until some days of their free existence have been passed that the dimple of the mouth begins to penetrate the solid body and hollow it out, and then the larva swells somewhat and becomes transparent. In colour the newly liberated larva is usually yellowish. As is so frequently the case in the adult, this is due to the presence of Zooanthellæ, which are vegetable cells living in the tissues of the coral.

These symbiotic algæ are crowded most densely about the region of the mouth, which is in consequence more deeply coloured, but, strangely enough, after the larvæ have lived their independent existence for some time, and have become possessed of a definite stomodeum and internal cavity, these

Fig. 10.



A Section through a Commencing Colony of *Cœnopsammia nigrescens*,

Showing the production of daughter zooids by budding from the sides of the parent.

Zooanthellæ are passed out through the mouth and into the water.

Although it has been said that the larva becomes fixed after a few days passed as an active, free-swimming creature, still, among those that have been watched in aquaria a great majority display a singular reluctance to settling down: among Wilson's larvæ of *Maniciana* many did not settle down until they had spent three weeks swimming free, and Duerden came to the conclusion that if fixation did not take place within the first few days, it did not occur at all, a though the larvæ continued to swim slowly about the vessell, and even rested temporarily on its sides. These wandering larvæ, though they live for several weeks, undergo no development. They never attain tentacles, they acquire no skeleton, and yet, if fixation does at length occur, it provides the necessary stimulus, and growth and development proceed vigorously even under unfavourable circumstances. A larva may in this period of non-development be carried far by currents, and it is evidently an important factor in the economy of corals that this stage of developmental inactivity should last long in some members of the brood, for thus the chances of the spread of a species become greatly increased. On the other hand, a larva may never wander from its parent colony; but may settle on some exposed portion, and start a new colony of its own upon its parent growth; or it may settle down in the company of a fellow, or several of its fellows, and start a compound colony which is in every respect similar to a growth that is the outcome of the activity of a single larva.

With the fixation of the larva a new phase commences in the life of a coral: the forwardly pointing end of the swimming larva now becomes its point of attachment, and it expands laterally to form the basal plate: the dimple of the mouth opens up to form the stomodeum, and the original solid larva becomes hollowed out by a central cavity. The animal becomes more complex, but into the precise steps of this differentiation of parts it is not necessary to enter; tentacles are budded out, mesenteries are formed in definite order, and the larva assumes the form of the adult zooid.

Calcium carbonate is laid down as the supporting skeleton, which in the end becomes "coral" in the popular sense of the word, and soon the pioneer commences the process of asexual reproduction by budding or by fission, and so lays the foundation of the complex body of the coral colony.

CHAPTER VIII

THE GROWTH OF THE CORAL COLONY

The coral embryo that has settled down, and started its processes of division and budding, becomes the father of the colony, and the rate of growth of this colony is a matter of some importance. Since coral colonies may be regarded as the bricks of which the whole edifice of an atoll is composed, it is of interest to know how fast these bricks are made beneath the sea that will one day tear them from their beds and heave them up to form dry land.

As a number of observations were made during the fifteen months of residence on the atoll, and some care was taken in recording these observations, and in eliminating errors, it will be as well to give in brief the actual figures arrived at. All the specimens measured were normal colonies growing in their natural habitat, and care was taken that the processes of measurement did not act harmfully upon the colony; in no case was a coral moved to its site of observation from a previous habitat. Branching forms were recorded by carefully measuring the branches at times when wind and tide permitted of accuracy, and by fixing a little band of copper round the branches at a distance of 10 centimetres from the distal extremity. Numerous branches, averaging 20 centimetres in length, were taken on many different colonies, and the distance of the band of copper from the tip of the branch was measured from time to time.

It is only fair to say that the results were extremely variable: branches would grow fast, and then pause; and some that for weeks showed no activity would suddenly enter on a period of unusually rapid growth.

The reason for these fits and starts of growth is not easy to see, for they take place quite irregularly in different colonies; but no colony measured in the atoll was exempt from them. In 100 days, from December 1, 1905, to March 10, 1906, a *Madrepora* branch grew 3·5 centimetres; and then from March 10 to July 24, a period of 136 days, no addition was made to its growth, and the branch though perfectly normal and healthy showed absolutely no signs of activity.

In one month, from December 31, 1905, to January 31, 1906, two *Porites* masses showed no increase in their measurements, and yet by July 31, one had added 9 centimetres to an original circumference of 180, and the other 13 to an original circumference of 219.

The period of the greatest activity of the *Madrepora* was the period of the most complete quiescence of the *Porites* and *vice versa;* and yet all the growths were measured under identical conditions, all lived in close proximity, and were subjected to the same influences of tide and season. The question of the cause of this waxing and waning of coral growth is interesting, and one that doubtless has great influences on the building of dry land, for the prolonged inactivity of any of the more important builders would necessarily mean an alteration in the rate of land-formation. It is obvious that any observations that only extend over brief periods of time cannot be taken as strictly accurate records of the rate of growth of corals, for the measurements may chance to be made during a passive phase, or during an active phase of the colony.

In order to eliminate in some measure the influence of this variability of growth, the observations were carried on for as long as possible. The chances of the sea and of storms cut many experiments short, but no case was used for obtaining results in which the measured period of growth had not exceeded 100 days. With the massive forms of growth this method of measurement could not of course be adopted, and direct measurements of the maximum circumference had to be taken at intervals. When a growth of *Porites* has reached the stage in which its upper surface is flattened and dead, the varying circumference of the growth represents practically the entire increase, and where possible such colonies were taken.

Put briefly, and in the form in which they are most readily comparable, the results were as follows: In 100 days the average growth of branching forms was 2·74 centimetres; that is to say, the distance of the copper band from the tip of the branch was, on an average, 12·74 centimetres after it had been in place for 100 days.

In English equivalents the growth is 1·09 *inches in* 100 *days, or roughly* 3·7 *inches in a year.*

In 100 days the massive forms of growth had increased on an average to the extent of adding $\frac{1}{37}$ of their original circumference to their growth.

That is to say, a massive coral 37 *inches in circumference will have increased its circumference by* 1 *inch in* 100 *days.*

This increase in the size of the colony is entirely effected by the multiplication of the number of the individual zooids composing the colony, and the multiplication is carried out by the division and budding of the already existing zooids. The various methods by which this division is effected differ from each other considerably; and it is necessary to touch briefly upon the chief methods by which a zooid reproduces itself.

It is as well to state at the outset, and thus avoid much further explanation, that the different methods of division, though highly characteristic of certain well-marked types of growth, are not definitely and unalterably fixed; and I think it is justifiable to dogmatise, and state that *any form of coral may upon occasion exhibit any form of division.* Since the resulting form of vegetative growth is purely the outcome of the type of division adopted by the zooid, then it follows that coral colonies may grow in many vegetative forms; and, again, these vegetative forms are not definitely fixed, for as any form of coral may exhibit any form of division, it follows that any form of coral may also, under different circumstances, exhibit any form of vegetative growth.

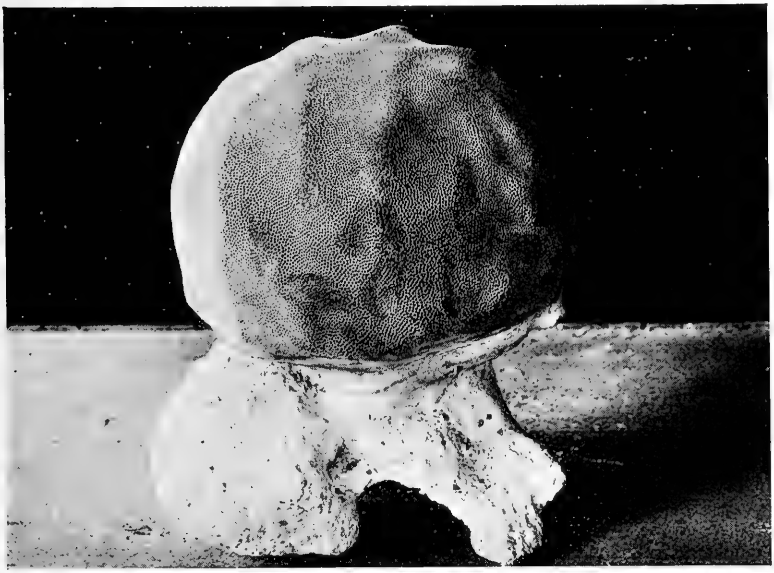
Speaking quite broadly, a colony may grow according to five different types of vegetative growth. It may grow as (1) a spherical mass, (2) an encrusting layer, (3) a free plate, (4) a branching tree-like growth, or (5) a mere amorphous lump; and though a definite inherent growth tendency is strongly implanted in the embryo, still the demands of the environment may call forth any type of vegetative growth.

The growth-forms are purely the results of repeated divisions of the zooids, and so it will be seen that the relative value, from a reproductive point of view, of the zooids in a colony is of the greatest importance. This consideration brings in its train the division of all the colonial corals into two groups of normal growth-forms; for all the zooids may take an equal share in the asexual reproduction, or, again, some may be of greater importance than others, and the asexual reproductive functions may be lodged in a very few individuals only. These two great divisions must be considered separately, for the rules that may be applied to their respective methods of growth are widely different.

Taking first the class in which every unit is of equal value, and going back to the earliest origin of the colony, it is easily seen that a zooid "A" settled on a nucleus will divide into zooids "B" and "C," and "B" will further divide into "D" and "E," and "C" into "F" and "G," and so on; each newly divided individual taking its equal share in future divisions. The natural outcome of this state of things is that, if the site of election of growth be a prominence, or, as is not uncommon, a small isolated fragment, then the equal divisions will tend to form a spherical mass. The rapidly growing colony will tend to surround the nucleus on all sides, and in this manner are formed those rounded masses of *Porites* and *Astræopora* commonly found lying free in sandy pools, which, when broken across, are seen to be formed around a central nucleus, which generally consists of a fragment of dead and altered coral.

It is of course but natural that the true spherical form cannot long survive in very large colonies, for the zooids growing below are of necessity killed by pressure. The mass will therefore become a hemisphere, and continue its growth as a rounded boulder. This boulder-form is a very common type of vegetative growth among the reef-building corals; for if the growth starts as a perfect sphere, it will ultimately assume this form, and if the colony starts its growth on a

FIG. 11.



A GROWTH OF *Porites*

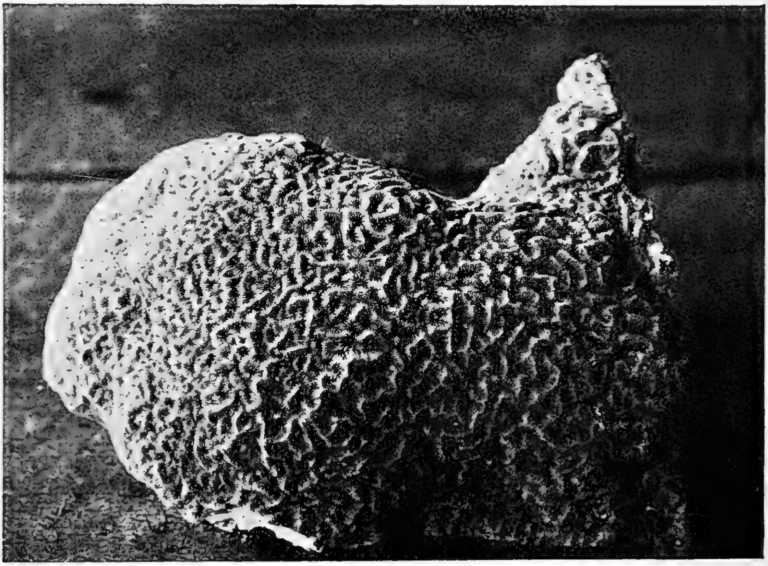
In which the colony has grown as an approximation to a sphere.

basis that is not an isolated fragment, it will start this mode of growth from its first beginning.

There are many different ways in which the asexual reproduction of the zooids is carried out, for the budding and division may proceed in various fashions. The principal types of budding vary from each other in the actual site of origin of the daughter zooid from the parent, and in the degree of the final separation of the two zooids. These types, I think, do not merit individual description here, for what was said previously is true for them all, and each, though highly characteristic as an inherent growth-form for a certain coral, may be assumed by many other corals.

One method of division that is important among corals with zooids of equal reproductive value is the type charac-

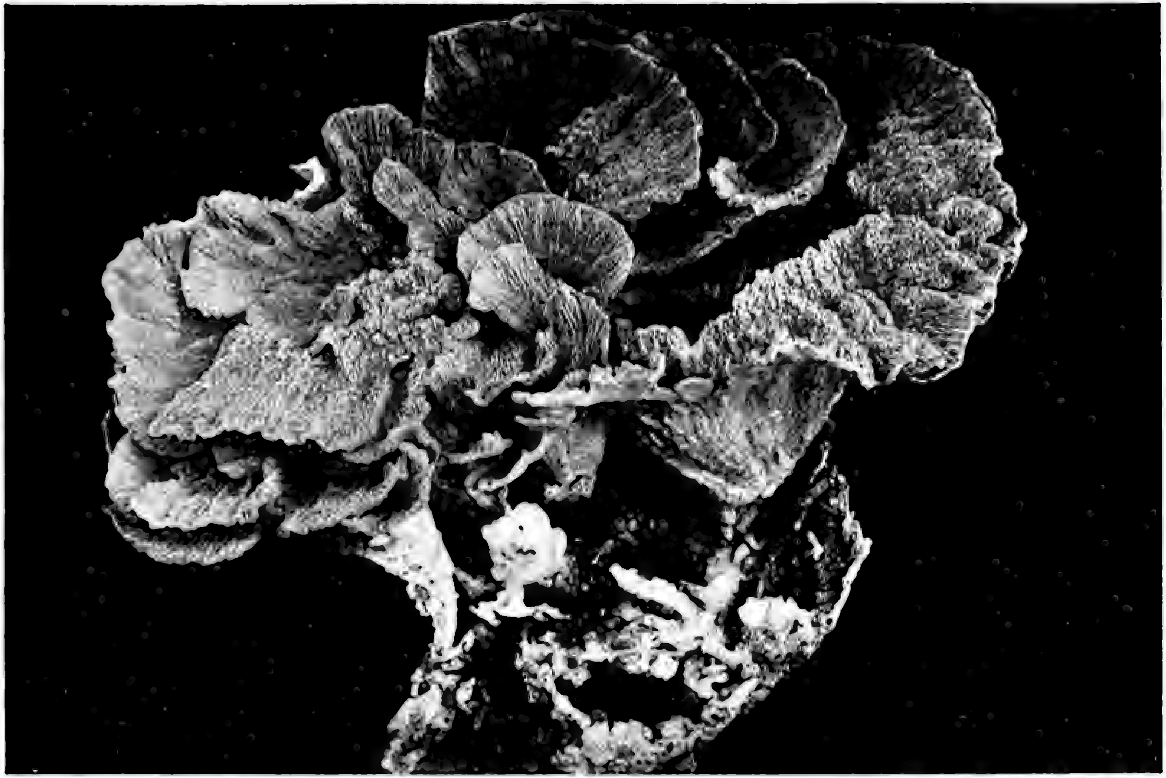
Fig. 12.



Example of a Coral Colony growing as an Encrusting Layer.
(*Pavonia.*)

teristic of the *Meandrinæ.* In these corals the complete separation of the divided zooids is never carried out by the calcareous partition-walls, and so a more or less linear series of zooid mouths is formed. Tentacles fringe the margins of this series, and the resulting skeleton exhibits those well-known fissure-like markings that have given museum specimens the name of "brain-corals."

Now even such a highly characteristic type of division as

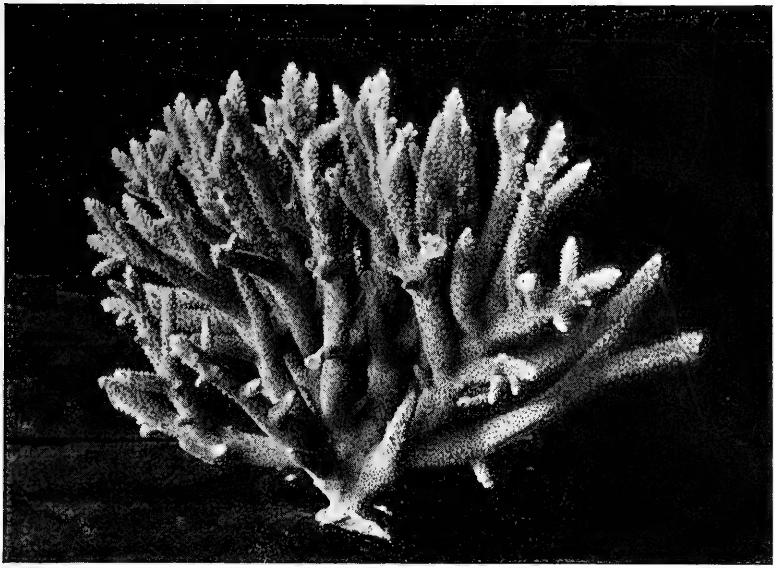


EXAMPLE OF A COLONY GROWING AS A PLATE-LIKE GROWTH (*MONTIPORA*).

that of the *Meandrinæ* may be assumed by other corals; and as sports, or even as localised patches in otherwise normal colonies: other corals may divide actively and yet form no calcareous partition-walls.

The meaning of these assumptions of an entirely foreign

Fig. 13.



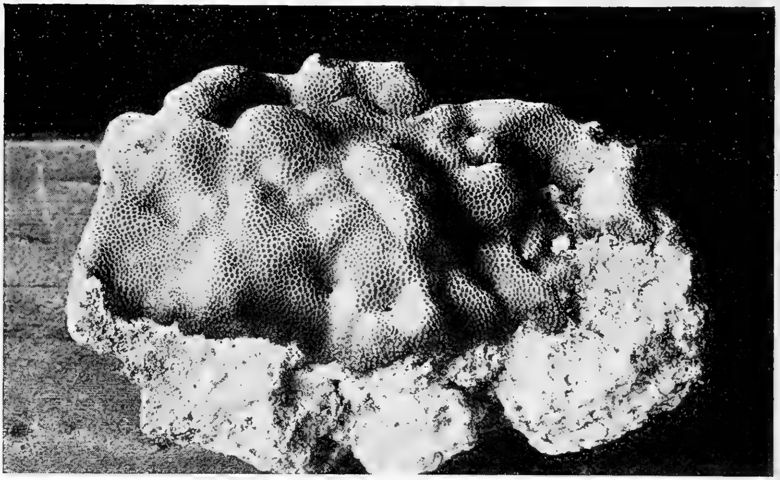
Example of a Colony growing as a Tree-like Growth. (*Madrepora.*)

method of division is somewhat difficult to understand, but when an *Astræa* exhibits Meandrine fission, it is usually a sign that the colony is not flourishing and is in an unsuitable site; it would almost appear that the building of unnecessary partition-walls was too great an effort for the unhealthy zooids.

Again, the thickness of the intervening partition between two adjacent zooids is subject to endless variation, and in consequence the surface-pattern and the density of the coral may vary widely within the limits of a species. The same variation is to be seen in the level of the site of origin of the lateral buds: this will have to be referred to later on when the cause of the variations is considered.

Another feature that is subject to an excess of variation,

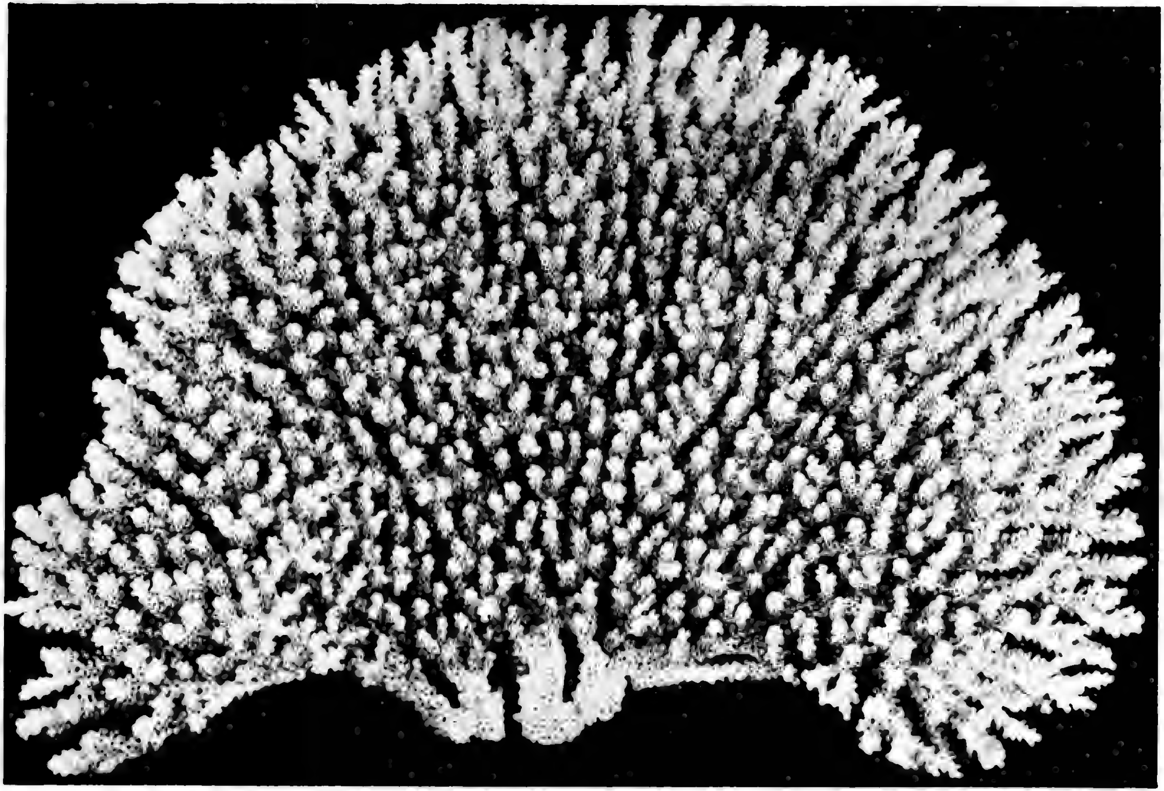
Fig. 14.



Example of an Amorphous Type of Growth.
(*Porites.*)

and must therefore be considered, is the amount of raising from the general surface of each individual corallite. Every corallite of the colony may be flush with the general surface, or it may be raised from it in varying degrees, and the degree of raising gives very characteristic appearances to the colonies. The degree of elevation of the corallite is no safe criterion for determining specific rank, for it is a variable factor depending altogether on the reactions of the coral to its environment. The portions of the coral body which lie between the actual corallites are also important in this connection, for many

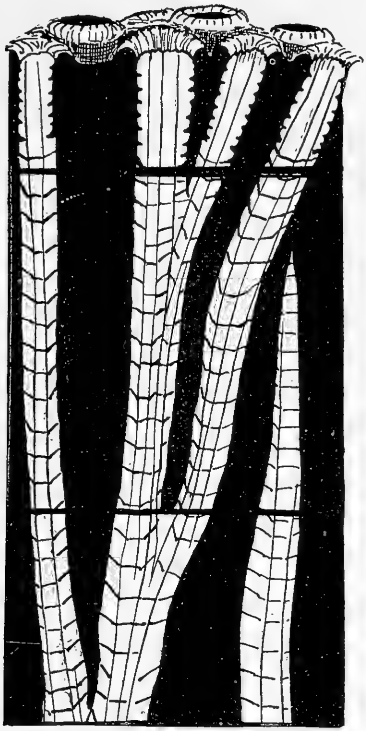
PLATE III.



EXAMPLE OF A BRANCHING GROWTH APPROXIMATING A PLATE-LIKE FORM (*MADREPORA*).

characters to which undue importance has been attached are displayed here. The interspaces may be smooth or rough, they may be sculptured in various fashions, and they may

FIG. 15.



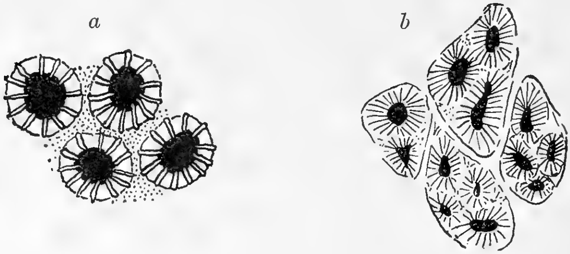
VEGETATIVE REPRODUCTION IN CORALS.

Diagram to illustrate reproduction by equal budding: the transverse lines show the surface-level at the time when division took place.

be elevated or depressed; but very great caution must be observed and the possibilities of variation must be given due consideration by any one who would assign specific rank to any of their forms.

Although a very large number of corals have the normal habit of reproducing equally from all parts of their surface, still evidences may be seen, at many points of most colonies,

FIG. 16.



VEGETATIVE REPRODUCTION IN CORALS.

a. Type in which the daughter zooids become completely separated.
b. Type in which separation of the daughter zooids is less complete.

that certain groups of zooids are more active than their fellows.

The special activity of these zooids may be due to purely local causes; it may be called forth merely by irritation of a

FIG. 17.

VEGETATIVE REPRODUCTION IN CORALS.

a. Further stage of incomplete separation of zooids
b. Meandrine type of division.

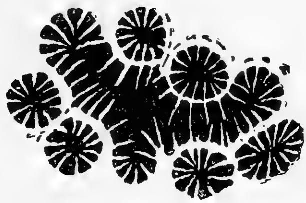
localised portion of the surface of the colony; or it may be a real alteration of vegetative habit. It is an outstanding fact in all the colonies observed for long intervals that the growth tends to become irregular—at different times different portions of the colony have sudden phases of active growth, and these may be due to no observable cause. Again, some zooids of the colony may have special advantages due to the environment, and will grow and divide excessively, in such a manner that they dominate the growth of the whole colony, and consequently modify its form. The conditions of the

Fig. 18.

Vegetative Reproduction in Corals.

Meandrine type of division: no separation of daughter zooids.

Fig. 19.



Vegetative Reproduction in Corals.

Diagram showing an *Astræa* assuming (as a sport) a Meandrine form of division. From an actual specimen.

environment may call forth special reproductive activity in any portion of the growth, and so in a colony, all of whose units are of equal importance, some part will be found to be growing onwards, whilst all the remainder of the zooids are practically at rest. In this way the typical hemisphere of such colonies may become modified as a creeping plate, an encrusting layer, a pseudo-branching form, or a mass of mere irregular nodules.

Thus, in those corals whose zooids are naturally of equal reproductive importance, forms may arise, as the result of physiological need, that simulate exactly other forms, the reproductive activities of the zooids of which are normally unequal.

Turning now to the corals that constitute the second class, and have some of their units specialised as active agents of growth, it is at once seen that the possibilities of variation of normal vegetative habit are greatly increased. All the elaborate branching forms, plates, and leaf-like growths belong to this class; and all are evolved by special peculiarities of the growing point. The zooids that constitute the growing point may take various forms: they may be arranged as a cluster, as a creeping edge, or as many varieties of terminal shoots of branches.

In the first instance, it is necessary to draw very sharp distinctions between two subdivisions of this group. In *Group* 1 come all those forms like *Montipora,* whose distal zooids are the newest formed members of the colony; and in *Group* 2 are included the *Madrepora,* whose distal zooid is the most ancient individual in the whole growth.

In dealing with *Group* 1 many forms have to be considered, for when the youngest are the active zooids their growth-cluster may be very variously disposed, and on its disposition the resulting vegetative form entirely depends.

When the growing zooids are arranged in linear series, a flat growth will result, which grows from one of its edges, or from them all; and in this way an encrusting layer or a free plate may be formed. Corals that grow with a linear growing point may settle down on a basis, and spread over it in all directions, taking an exact impression of every irregularity of its contour; and then, reaching the limits of the basis, they may grow from it as flat plates, spreading out from its margins. Such corals as grow in this fashion show many curious changes at their free margins, for although the superior surface of the encrusting layer can alone produce zooids, still at the free edge zooids will appear on both superior and inferior surfaces.

In connection with these partial plates a very curious fact is always demonstrated, for the whole surface structure of the coral body, and of the corallites, differs above and below; and this important fact will need further reference.

A coral may start from its first beginning by growing as free exfoliating plates, and then it may bear zooids on both surfaces of the plates, or on the upper surface alone. In every case where zooids are borne both above and below, there is the same marked difference of structure between the two surfaces.

When the linear growing point grows uniformly upwards, the resulting growth consists of a series of vertical plates; and when the growth takes this form, the structure of both

Fig. 20.

Vegetative Reproduction in Corals.

Diagrammatic section to illustrate the mode of growth of *Montipora:* the uppermost zooids are the most newly formed.

sides of the plate is identical, and zooids grow from both surfaces.

A plate-like growth is formed by a uniform and continuous growing edge; but the linear series of young growing zooids may not maintain their continuity: the growing edge may reach a certain size and then divide, and the resulting growth consequently takes the form of a plate, cleft at its edges, or of a branching form, all of whose branches are given off in one plane. This is a highly characteristic form of growth of one type of *Montipora* which is abundant in the islands, and it grades very naturally into the plate-like growths on the one hand, and into the complicated branching forms on the other.

In the many highly branched forms of vegetative growth, the growing zooids form a cluster, and this cluster divides as it grows upwards, with the development of many growing points at intervals on the parent stem. The cluster may be of various shapes, and its form determines that of the stem which results from it. The stem may be rounded or flattened, may be thin or thick, and it may branch at frequent intervals, or it may scarcely branch at all, so that straight rods of uniform thickness may be characteristic of the vegetative growth of the coral.

Another modification of this method of growth is that in which practically the whole colony represents the growing point, and then the entire mass grows upwards as a solid column; or the growing point may be confused and irregularly distributed, and then an irregular, lumpy amorphous mass results.

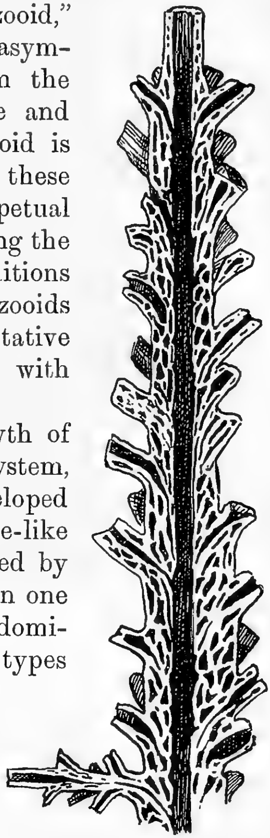
Whatever the vegetative growth may be, it is in these cases the product of a mass of growing zooids, and these zooids are being perpetually renewed, so that the growing point always contains the youngest individuals in the colony.

In *Group* 2, however, this state of things is entirely altered, for there one zooid, which is situated at the extremity of the stem, and which I shall call throughout the "dominant apical zooid," constitutes the growing point; and this zooid is the parent of the entire colony.

The zooid that settles down to establish a *Madrepora* colony has the peculiar innate property of perpetual growth and perpetual youth; and this original zooid grows up and up, budding new zooids from its sides, until destruction overtakes it. As a matter of fact, a *Madrepora* colony usually starts as a flat growth which spreads from its edges, but this method of growth lasts for only a very short time; and all the characteristics of the "dominant zooid"—which is here the central zooid—are even then well marked.

Besides possessing these peculiar physiological distinctions, the "dominant zooid" is marked off from its fellows by a distinctive anatomical feature, for it is symmetrical. Of the many thousands of daughter zooids budded off from the "dominant zooid," all are not alike; the great bulk are asymmetrical, and are but little raised from the general surface of the coral, but here and there a prominent and symmetrical zooid is given off. Like the "dominant zooid," these lateral zooids possess the power of perpetual growth, and they are the agents in forming the lateral branches. Under certain conditions only very few of these prominent lateral zooids are produced, and then the resulting vegetative growth consists of long straight stems with but few side-branches.

FIG. 21.



VEGETATIVE REPRODUCTION IN CORALS.

Diagrammatic section to illustrate the mode of growth of *Madrepora:* the "dominant apical zooid" is the oldest member.

The typical form of vegetative growth of the *Madrepora* is therefore a branching system, but many variants of this form are developed normally and abnormally. Pseudo plate-like growths are common, and they are formed by the anastomosis of numerous branches in one plane. Again, the importance of the "dominant apical zooid" is variable, and some types branch more after the type fashion of the *Montipora,* for a whole apical series of zooids may be symmetrical.

Having now reviewed, in some measure, the various methods of the formation of the vegetative growth of colonies, it is necessary to see how far these forms of growth are to be reckoned as specific qualities. Here a great difficulty arises, for an enormous amount of time and careful experiment must be devoted to the proving or disproving of each individual case; and though, after long familiarity with living corals, one may feel certain that two entirely different vegetative forms belong to the same species, yet the conclusive proof may be lacking.

Collecting very extensive series of variations will, in some cases no doubt, link up extremely diverse forms, and studying the repair of damaged specimens will serve to make others clear; but experimental breeding, and the rearing of identical species in diverse surroundings, must be the final test in most cases. Now this is a work of extreme difficulty, for an adult colony, when removed from its own environment and placed in a different one, almost invariably dies, and the artificial rearing of corals is very troublesome; my experience of corals in aquaria is that it is very difficult even to keep them alive.

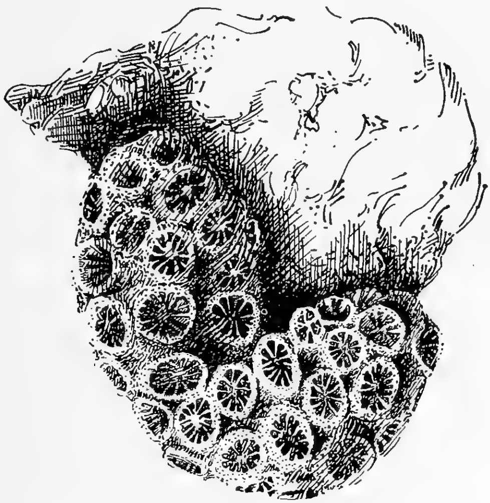
The only method that is open to every resident in places where corals flourish, and the one that I followed in the Cocos-Keeling atoll, is the careful noting of every modification of colonies the life-surroundings of which differ by reason of some influence that can be easily recognised. By this I mean that the corals of deep water and shallow water should be compared; those living in the surf and those living in calm spots should be noted; and the corals living exposed to sediment should be contrasted with those living where no sediment is being deposited.

These are extremes of habitat, and at first the corals of two entirely different environments will seem to be quite distinct, but every compromise of conditions will be found in different spots in an atoll, and with every grade of altered surroundings it will soon be seen that there is a modification of coral growth; and the more completely this method of observation is carried out, the more will the types of extremely different habitats be found to be linked up by intermediate forms. It will be best to study the influence of the different conditions of life-surroundings on the form of vegetative growth by taking the different possible modifications of environment in order; but first some general growth tendencies of all corals must be made clear.

As a rule, coral zooids and coral colonies tend to grow upwards, and the general form of vegetative growth depends on this fact.

To this rule there are two noteworthy exceptions in this atoll, and these corals (*Cœnopsammia Willeyi* and *C. nigrescens*)

Fig. 22.



Colony of *Cœnopsammia Willeyi*

Growing from the lower surface of a boulder.

generally grow with their zooid mouths turned downwards. Now I think these exceptions to be not without interest, for both these corals live in dark places—they prefer, in fact, the under sides of boulders, and they possess no symbiotic algæ in their tissues. They are coloured respectively red and black; and I would put it forward as a speculative idea, that it is the innate tendency of the symbiotic algæ to grow upwards, rather than any innate property of the corals themselves, that causes the general growth tendency of the corals.

It is true that the zooids on the lower surfaces of plate-forms grow downwards: but as a rule I believe those horizontal plates which bear zooids below are but variant forms of growth of other types: for such corals as have no growth-form except that of a flat horizontal plate do not as a rule bear zooids below.

Some further remarks must be made about plate-like growths; but here is a convenient place to refer to a rather strange fact to which Darwin called attention, that vertical plates grow so that they offer their flat surfaces to the currents. The same thing is true of growths that are branching forms, for then the plane of greatest branching is at right angles to the line of current. At first sight this seems a strange thing, for plates growing in rough water become so much more exposed to damage; and yet it is doubtless for the exposure of a larger surface of zooids to the food-bringing currents that the plate spreads in this direction. This phenomenon is especially notable in the *Millepora,* the broad laminæ or fan-shaped growths of which are always opposed to the line of the waves, even when the colony happens to dwell in very rough water.

Two general rules may therefore be laid down which apply to all the forms of growth that have been described: the first, that all corals having symbiotic algæ tend to grow upwards; the second, that all tend to offer their greatest surfaces to the line of currents.

We may therefore assume that every coral embryo that settles upon a site of election, and starts the foundation of a colony, has three inherent tendencies: it has its inherited type form of vegetative growth, and its inclinations to grow upwards and to oppose its growth to currents. Now these tendencies are affected by the nature of the water in which the embryo settles down; and for nearly every coral there is a modification of vegetative growth dependent on the environment: thus most corals have a deep-water form, a smooth-water form, a rough-water form, and numerous variations depending upon the amount of sedimentation that is taking place in the water of their habitat. A coral that grows in rough water is obviously exposed to injury; and those people who have stated that the home of election of the corals is the surf-beaten edge of the barrier have made an error of observation and of fact. The comparatively lifeless zone of a coral-reef is that part of the barrier which is exposed to the maximum force of the surf, with the rising and falling of the tide.

Such corals as do grow in the almost perpetual crash of the surf are of a very easily recognised type; and when contrasted with the forms of the same species that have lived in calmer waters, they appear to have very few points in common. The type of vegetative growth best suited to resist the force of the waves is of course the rounded or flattened massive boulder; and the *Porites* masses are the type to which all such growths tend to conform.

This rounded form of growth is brought about in several different ways: in *Porites*, and other corals, where the equal reproductive value of all zooids tends to the production of a sphere, it is of course the normal habit of growth; and so such corals have their natural home in the rougher water, and undergo their atypical modifications when developed in other sites.

All branching forms, when growing in rough water, are subjected to a change of habit of vegetative growth; and this change is a very interesting one. It will be pointed out when the process of repair is dealt with, that injury affects various forms of corals differently; and all these rough-water forms are in reality the result of perpetual injury.

It would be an obvious disadvantage to a coral to adopt a highly branching form when living on the surf-beaten portion of the barrier; for the colony would soon be wrecked and broken up by the waves. There is no *Montipora* in the atoll that lives by election in rough water, but occasionally colonies become exposed to strong currents; and then the perpetual injury to the upper portions causes the growing clusters to be broken up and confused; and the resulting growth is an irregular mass of short, stunted branchlets.

Montipora in rough water may also take on a creeping habit of growth and form encrusting layers on the surface of dead massive colonies; but they are not corals which are at all common in any but the calmest water. Their usual home is the lagoon, and the greatest normal departure from their favourite habitat is in the current-swept shallow inlets to the lagoon; and here an endless series of modifications may be

Fig. 23.

a *b* *c*

Types of Growth of *Montipora*.

a. In barrier pools. *b*. In deep water. *c*. In rough water.

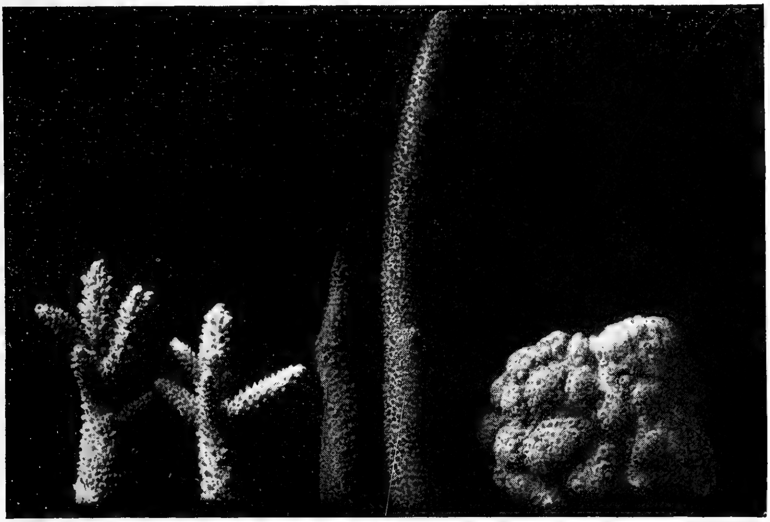
collected, ranging from branching forms to mere amorphous masses and encrusting layers.

The rough-water forms of the *Madrepora* are highly characteristic, and all depend on the processes which always occur in this group when the "dominant apical zooid" is injured. Instead of a growth that consists of few dominant zooids situated at the extremities of long branches, a rounded mass is formed; and it is composed of little groups of symmetrical zooids surrounded by others that are asymmetrical—each little group representing a branch in an extremely abbreviated form.

From these extreme rounded masses, with branches that are mere bosses on the general surface, every transition form may be collected, up to the highly developed lagoon types, with branches many feet in length.

Exactly the same results are produced in the *Pocillopora*, and here the rough-water type is a flattened growth, with

FIG. 24.



a *b* *c*

TYPES OF GROWTH OF *Madrepora*.

a. In barrier pools. *b*. In deep water. *c*. In rough water.

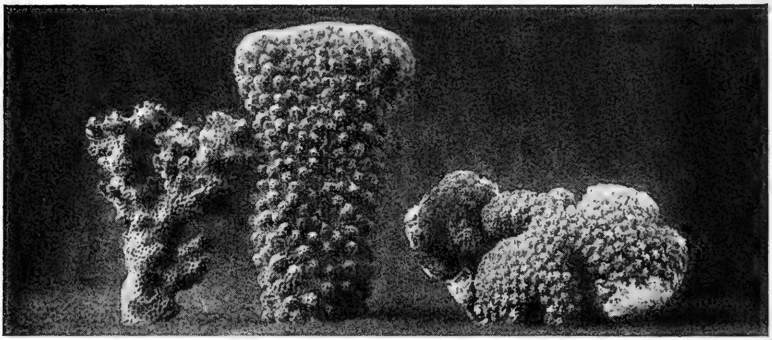
irregular divisions into separate lobes; each lobe representing a separate branching system.

The *Millepora* also show well-marked rough-water types; and that named *M. verrucosa* is the form which lives in the crash of the surf.

Any coral that chances to establish its colony in rough water exhibits, therefore, one well-marked characteristic: it always tends to form a rounded or flattened mass; and this for obvious mechanical reasons. It is a direct outcome of the conditions of the environment, and any zooid must conform to it or perish. Repeated injury to the growing cells is the determining cause of this method of growth; and though the fully developed colony is so totally different from the calm-water form, still the process is easily seen in the making by means of artificially inflicted injury.

Besides the alteration of the general appearance of the vegetative growth, the rough-water environment causes other

Fig. 25.



a *b* *c*

Types of Growth of *Pocillopora*.

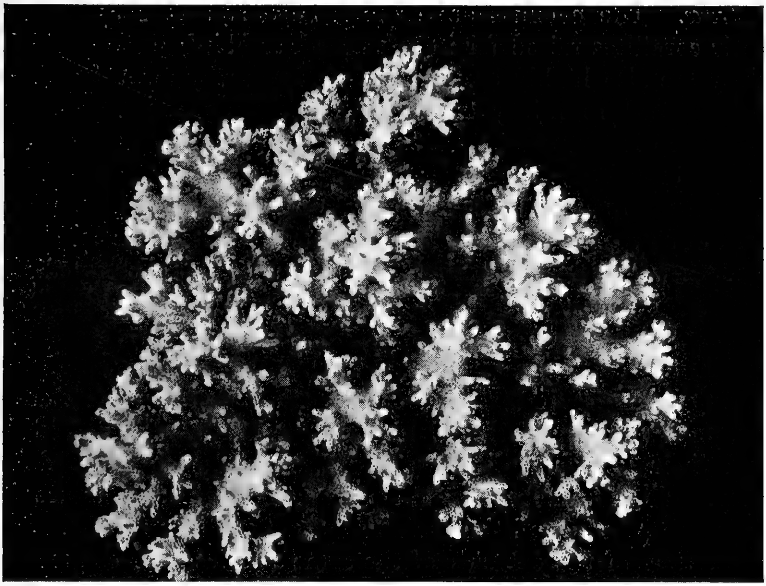
a. In barrier pools. *b*. In deep water. *c*. In rough water.

changes in the coral; for it is diagnostic of a rough-water coral that its structure is compact and dense, and its corallites tend to be flush with the general surface of the growth. The question of the raising of the corallites will have to be discussed again when the action of sedimentation is gone into; it must be stated here that though the levelling of the corallites in rough-water types is doubtless partly mechanical, it is also due to the fact that in rough water sediment does not tend to be deposited.

In marked contrast to the rough-water types are those forms of a species which happen to have become fixed in an environment where the water is more or less calm; and here, as every grade of environment is to be found, every grade of modification of the colony is represented.

Corals grow in great luxuriance on the wave-stirred outer slopes of the atoll, but this is a site by no means to be confounded with the surf-line of the barrier. They grow also in the numerous pools of the barrier flats, in the inlets to the lagoon, and in the lagoon itself; and each environment has its own peculiar conditions.

Fig. 26.



A Colony of *Pocillopora*

Whose growth is branched in complex fashion. This form is linked to the less highly branched forms by the reduction of its smaller branchlets.

In the barrier pools every modification of life-surroundings is to be met with, for these pools are of varied depth, they are filled with sand, or are of bare rock; and they have a varying exposure to the wave action of the barrier breakers.

Corals grow luxuriantly in most of them, and they afford the best field for experimental work. Since their conditions change with every cycle of the tides, they form the meeting-ground of nearly all the commoner species, for they afford in turn most phases of natural environment. Here are found the highly branched *Madreporæ* and *Pocilloporæ,* and many *Astrææ.* The colonies are distinguished as a rule by having their corallites raised, for in most pools sand is being deposited. They are also highly branched and of a bushy form, for they are exposed to injury by moving fragments, and so branch formation is stimulated, whilst the great development of individual branches is limited.

These rock-pool forms show naturally the graduating series of types which connects the rough-water forms and the smooth-water forms; and they show also the intermediate stages of the development of coral structures which are intended for the resistance of the action of sediment.

In the smooth-water forms the predominant feature of the colony is the fragile nature of the growth. Contrasted with the rough-water forms, these colonies are extremely lightly calcified, and their branching systems are distinguished by their delicacy. Their branches are long and slender, their structure is far more porous, and their whole appearance is quite different from that of the colonies of the same species that chance to reside in wave-beaten areas.

The smooth-water forms lead the way to those growths of corals which inhabit the deeper pools of the lagoon. The deep-water forms are the most fragile of all: their growths are more attenuated, and their branches are given off at far less frequent intervals. There is practically no damage inflicted on the growing points—whether they be growing clusters, or "dominant apical zooids"—and so lateral branch formation is never stimulated. Several of the forms of *Montipora* and *Madrepora* which occur in from 8 to 12 fathoms in the lagoon are mere cylindrical stems, of great length, and with practically no lateral branches whatever.

Besides the attenuated form and the absence of lateral branching, one other feature distinguishes the comparatively deep-water forms from those that inhabit the surface waters—and this is the general absence of pigment throughout every portion of the colony. Deep-water forms are therefore as a rule pale or entirely colourless.

It will be seen from these instances that the form of the

Fig. 27.

Rough-water Type of Highly Branched *Madrepora*.

From an actual specimen of *Madrepora pulchra* taken from the barrier.

colony varies as the outcome of the influences of the environment; and every embryo which settles in any habitat has to comply with the demands of the physical conditions, and modify its inherited growth tendency—or perish. Totally different forms are produced in totally different environments, but these forms must not be regarded as "species," for they are mere variations of vegetative growths in response to the necessities of the life-surroundings of the colony.

The type of vegetative growth is affected mostly by the physical conditions of the water in which it lives, but the actual structure of the coral depends greatly upon the presence, or absence, of sediment. Some very strange results are produced by waters in which sediment is held suspended, and from which it is being deposited. Sediment will alter the appearance of a coral more strikingly than any other influence. The deposition of sediment is the greatest agent in causing coral death: corals are very easily killed by even comparatively little sediment, and are profoundly altered by it, if they are to successfully resist its influence.

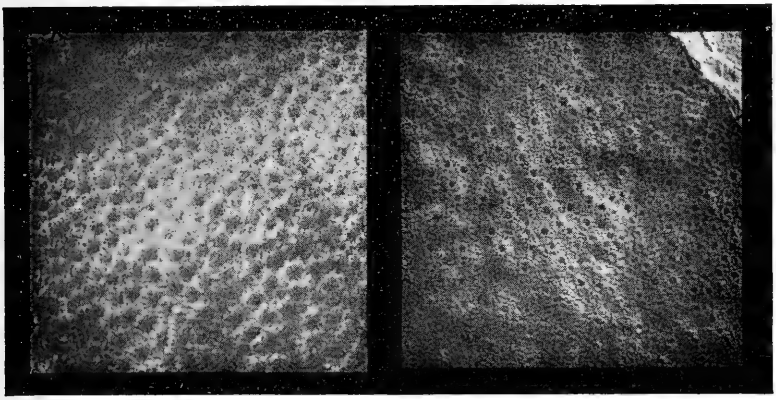
The extent of silt formation at the surface of an atoll in mid-ocean is hard to imagine, and it has certainly not been appreciated by those experimenters who have attempted to estimate the age of an atoll by catching the silt in a net as it passes into the lagoon. Adown the submarine slopes of the atoll, for a hundred miles east and west, the bottom was found by the cable soundings to be strewn with fragments of coral and finely triturated coral-sand, and it is only an uncertain and inconstant fraction which passes into the lagoon. Silt is one of the shifting influences of the atoll, and so may visit the coral colonies for only a brief portion of their lives, and then partial death and strange repair-growths result. In the lagoon, and in some portions of the barrier pools, silt is a constant factor, and here shows to the greatest advantage the modifications which it is capable of producing in coral growths. Speaking generally, silt alters the vegetative growth-form of colonies only in as far as it produces flat-topped rock masses by killing the uppermost zooids, and causes amorphous and irregular growths by partly killing the uppermost growing zooids of the growing points. But in the surface structure of the coral it produces great and wonderful changes. Its effects are best studied by comparing the upper and lower surfaces of partial plates. In these plates, the upper flat surface is alone exposed to the action of the deposition of sediment, and here the corallites tend to be small, and to be raised from the general surface, and the intervening spaces themselves tend to be sculptured and complicated in various ways. Below, the corallites are larger and are flush with the general surface, and the intervening spaces are flat and plain.

This condition is entirely the result of the attempt of the uppermost zooids to build a silt-resisting structure.

The corallites are smaller, and are raised from the general surface in order to minimise the chance of silt dropping in

FIG. 23.

A B



(A) UPPER SURFACE AND (B) LOWER SURFACE OF A PARTIAL PLATE GROWTH,

To show the differences in general structure.

and choking the zooid. The intervening coral body is variously sculptured and grooved for the carrying off of sediment which happens to lodge upon the surface of the colony. Wonderful series of modifications are formed in this way. A single species will show extreme variations in the size of its corallites, and in their raising from the general surface, when specimens collected from different habitats are compared. The size of the corallite and its projection from the surface are therefore not true specific features; for corals of identical species, from sediment-carrying water and from absolutely sediment-free water, exhibit great modifications of these characters.

The vegetative habit of a coral, as we have seen, is no true index of its species. Its method of asexual reproduction, the characters of its corallites and surface structure, and also its coloration, are equally variable.

Coloration depends on many, and very little understood, influences. Corals from deeper waters lose their pigment;

Fig. 29.

Diagram of Type of Growth of *Madrepora*

When living in water free of sediment. (*M. pulchra.*)

Fig. 30.

Diagram of Growth of *Madrepora pulchra*

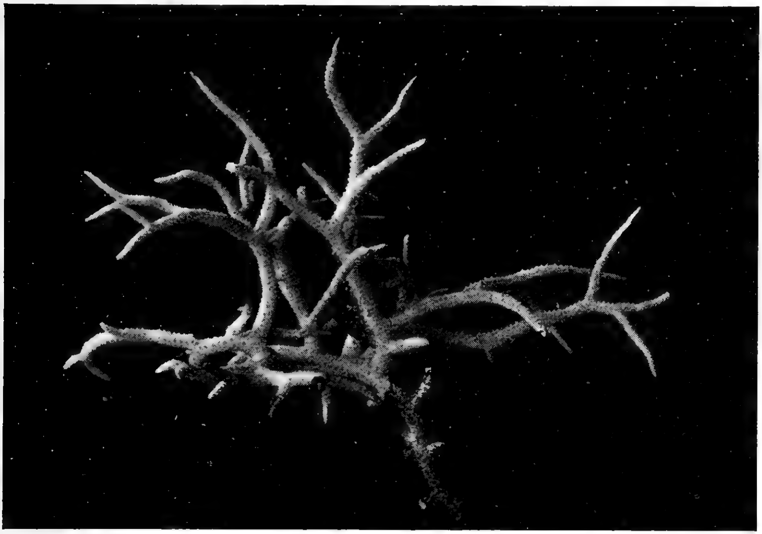
When living in a habitat exposed to the action of sediment.

and corals that are struggling hard in adverse circumstances—corals in fact that are about to die—become highly pigmented.

Corals identical in every other respect, and living side by side, may be differently coloured. Nothing is more familiar than the purple, brown, yellow, or greenish *Porites* masses which live under exactly the same conditions, as far as can be determined. Even one colony may be differently coloured in different parts. In *Pocillopora* there is a dimorphism of coloration, some growths being pink and some pale brown: the pink is a very beautiful and striking colour, and yet the corals are identical when dead, and the zooid in both cases is the same. *Montiporæ* vary from yellow to olive-green and brown, and yet the zooid is always of the same sulphur-yellow, and the coral is always identical in other respects.

The general coloration of the coral body cannot therefore be regarded as specific, and the coloration of the zooids also shows a strange inconstancy. Although, as a rule, the zooids

FIG. 31.



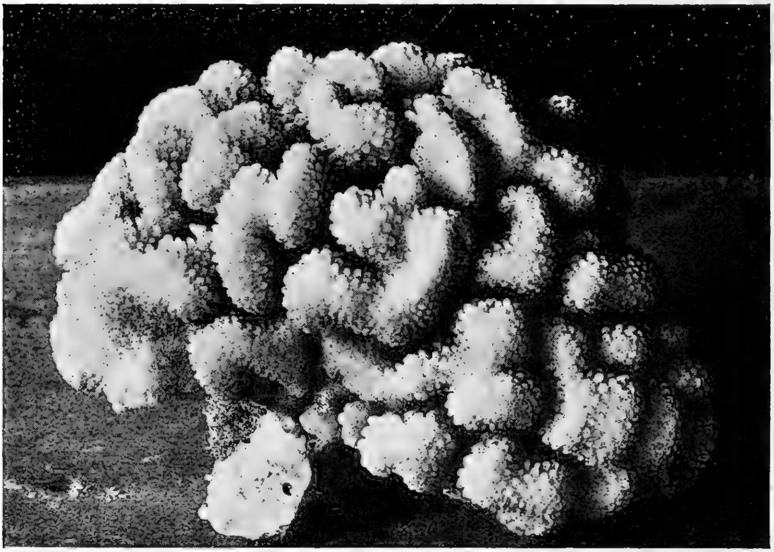
COLOURLESS *Stylopora* COLONY FROM DEEP WATER (8–12 FATHOMS).

When growing in more shallow water its branches are brownish yellow.

of different colonies of identical species—though the colonies may be very different in appearance—are similar, yet in one colony the individual zooids may be very variously coloured.

There is one very striking case, which is not uncommon in the atoll, of an *Astræa*, where the zooids on the upper surface are a fine fluorescent green, at the sides of the growth brown, and below white. And here it would appear—as also probably in the deeper water forms—that light had some influence on the production of the pigments. Despite this peculiar variation of the colour of the zooids in one colony, it remains a fact that the zooid is the true index of the species. In all the strange growth-forms and abnormal coloration of *Pocillopora* the zooid remains constantly brown; and in *Montipora*, con-

FIG. 32.



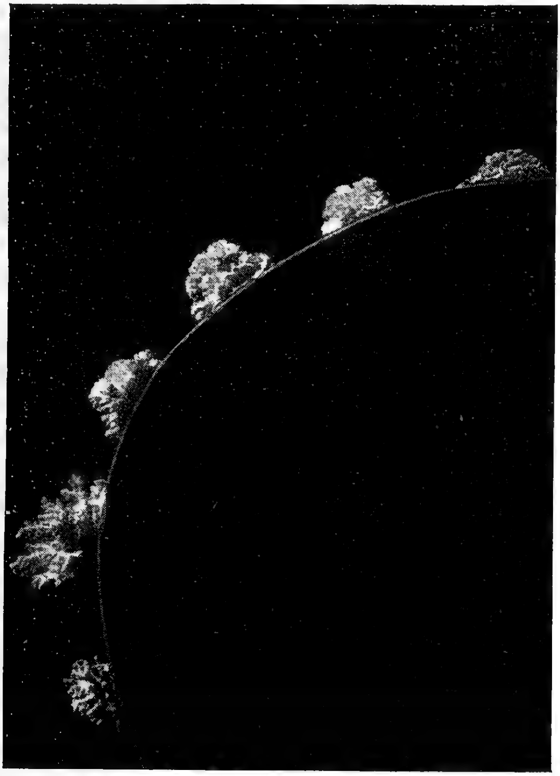
COLONY OF *Pocillopora*

Whose general colour may be either a delicate pink or a yellowish brown. In both cases the zooid is identical and coloured brown.

stantly pale sulphur-yellow. In *Stylopora*, whether the coral is the thinly branched and colourless deep form, or the thickly branched and brownish shallow-water form, the zooid is always of the same yellow colour.

In considering the vegetative forms of the corals of an atoll, it must always be remembered that the environment is not a constant one. Although the coral colony is absolutely debarred from changing the site of its growth, still the physical conditions of its surroundings are always altering. The terms rough water and smooth water, deep or shallow,

Fig. 33.



The Influence of Environment on Coral Growth.

Series of young colonies of *Pocillopora* in their position of growth upon a floating log.

and sedimenting or non-sedimenting, are therefore only comparative; for what to-day is a habitat free from sediment may in the course of a few weeks become the site of a copious deposition of silt. The rise and fall of the tide across the barrier must of necessity cause great changes in the life-surroundings of the corals in its passage; and so a colony, found in a calm pool, may for a part of its life be exposed to violent wave action. This must always be borne in mind, for the results obtained by careful collecting will not be pure. Corals may be found of different forms, growing in close proximity; but far from being evidence that they are different species, and not mere varieties, they demonstrate the fact that the physical conditions of their surroundings are inconstant, and that, for a cycle, each form is, in its turn, the most suitable.

The very inconstancy of the environment is one factor in showing the plasticity of the corals, for the partial death and repair caused by changed conditions afford striking evidence of the wonderful powers of varied building possessed by the zooids.

Experiment with constant physical surroundings must be the ultimate test of variability, and in this connection a very interesting case may be quoted. In the lagoon, a large portion of a tree-trunk was floated, and made fast to an anchor and chain; the wood was used to float a ship's moorings, and remained just two years in the water. When it was removed in 1906, several colonies of *Pocillopora* had started growths upon it, and they had taken up different positions around its circumference. The colonies growing above were flattened bosses; those on the sloping sides showed more tendency to branch; and those below its convexity were delicate branched forms.

Now the environments of these colonies were very different, and they were absolutely constant; at all states of the tide, waves broke upon the upper surface of the log, whilst the sides were in gently moving unbroken water, and the bottom was in comparative calm. The growths might be referred to many so-called species, and they represent many types found in the atoll, and yet no one may justly doubt that they are identical, and that their vegetative growth is entirely the outcome of their differing environment. I believe that this natural experiment indicates the lines along which the real understanding of the "species" of the corals is to be arrived at.

CHAPTER IX

THE LIFE-PROCESSES OF THE CORAL COLONY

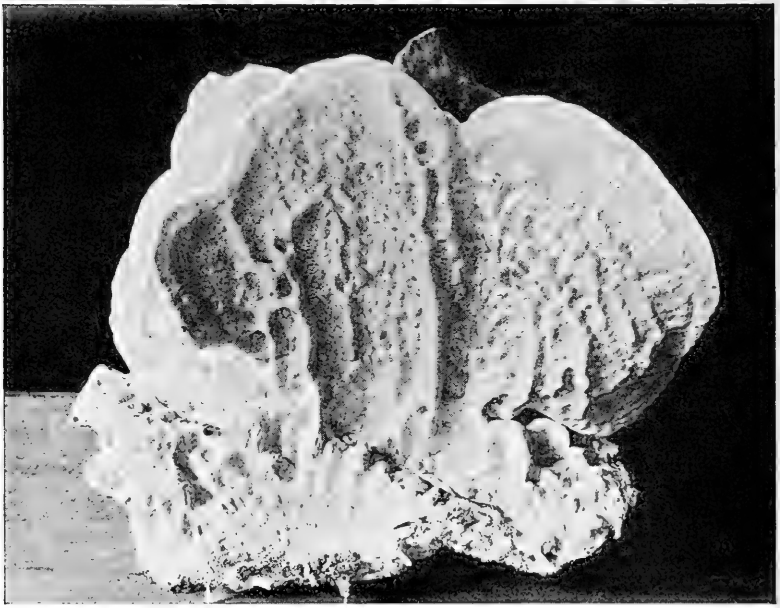
Although corals as adults do not have the power of independent motion, but must live and die in the spot where they originally settled down, still they have the characteristic that belongs primitively to all protoplasm—they are capable of resenting injury, and of moving their parts in response to stimuli. If, when in the course of a walk on the barrier, a mass of coral be found the zooids of which are actively extended, it is easily seen that a very slight stimulus will cause them all slowly, but very certainly, to retract. A light brush of the surface or a gentle touch will cause a slow response, and the zooids withdraw themselves over the definite area affected. Of the solitary corals *Fungia* furnishes a good example of resentment of injury, for if a living specimen be touched, the delicate tissues covering the rays of its skeleton slowly shrink and become pale, and this condition spreads as a slow and curious wave. The sensitive tissue of the creature thins out over the exposed portions and retracts into the spaces between the rays, so that, from being a delicately glandular and prettily coloured mass of soft tissues, it becomes an almost colourless piece of stone.

These movements of parts are the animal's only means of avoiding injury, and though they afford some protection to the more delicate parts of the zooid, a danger that threatens the whole mass of the coral is a danger that the coral cannot shield itself from.

There is yet another factor in the question of the repair and regeneration of corals, and it is the factor that is so intimately bound up with the problem of the limitless liability of the corals as a class to become modified and to vary.

When a name is given to this factor, and it is stated that the corals are a plastic group, it is not quite easy to say what that name should rightly connote; but although the words when used in their more common sense are not at all apt, I would say

Fig. 34.

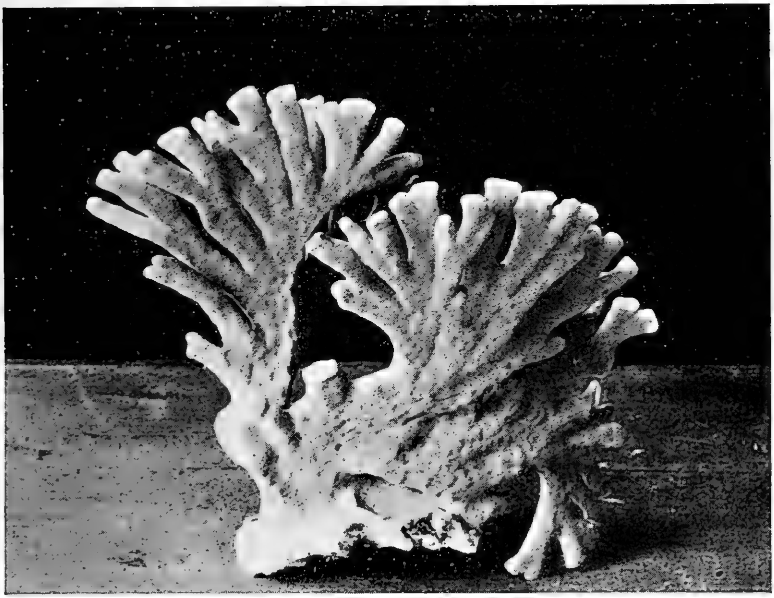


Millepora Colony of the Type named *complanata*.

that the corals are an impressionable and responsive class of animals. They are ready to comply with the demands of their environment; they are, within narrow limits, resourceful and capable of remarkable compromises between the contending forces of inherent growth-form and alterations demanded by changed surroundings.

Judged as we judge the higher animals, the corals are a class of unstable individuals: we can say definitely that a young elephant will grow up to be an elephant and no other beast; but we cannot say that an embryo *Millepora* will grow to be a branching *M. alcicornis* and not a plate-like *M. complanata* or *M. verrucosa;* we cannot foretell that a young colony of *Pocillopora* will certainly be *P. brevicornis* and not *P. nobilis*

FIG. 35.



Millepora COLONY OF THE TYPE NAMED *alcicornis*.

for, depending on the conditions of its surroundings, it might chance to be either.

This very plasticity shows itself not only within the limits of a certain species, but in the life of every actinozooid, for each member of a colony, or each solitary coral, shows in its life, its growth, and its repair, all those endless conformations to the demands of its environment which tend to produce change throughout the whole world of living things. An actinozooid, then, as an individual, possesses a birthright that gives it a maximum power of repair of damage, or regeneration of lost parts; and in the colonial forms, which are of special importance in the economy of the class, this power is greatly intensified.

In the group of solitary corals there is no very great interest attached to the processes of repair. The individual animal is at times damaged by injury, and the damage is repaired by the laying down of new calcified material, causing an irregularity in the symmetry of the animal. As a common feature of repair in any living thing, it may be noticed that the new material laid down tends to be excessive. Few large *Fungiæ* are to be found in which some injury has not caused the development of a quantity of irregular calcification where the delicate tissues of the animal have been split over the sharp edge of one of the rays. Excessive injury leads to local death, and local death may affect a very large area of a solitary coral without being necessarily fatal to the whole animal. The individual has but little power of repairing a large portion of its surface when once the area is definitely dead—very often for the reason that parasitic algæ and sponges attack the dead area.

It is not till the colonial forms are reached that the power of repair possessed by the corals is properly seen. In a colony composed of myriads of individuals each actively living, each capable of growth and repair, the very best conditions for repair are at hand, and this is further aided in many cases by the peculiar mode of growth of the colony. There are some inherent characteristics of the lowly animals amongst which the corals rank zoologically that are very wonderful, and which are opposed both to the order of things which prevails in the higher classes, and also to the popular conception of the life-history of the reef-building corals.

I think it is fair to say that the average belief with regard to the building of corals and coral-reefs is that the zooids live and grow, flourish and die, and that their dead bodies form mausoleums on which their progeny found their colony, and thus build islands. Now in contradiction to this is the biological fact that the actinozooid is a living thing which knows no time of youthful vigour, no waxing to a period of adult life, no waning to senility—it knows no age—it practically knows no natural death. There is no building on the dead bodies of ancestors, no perpetual dying and new birth. A colony of *Madrepora* will contradict this popular fallacy at one glance, for, whatever the age of the growth, the parent anthozooid flourishes till death or accident overtakes the whole. It is a wonderful thing—and one which is not, I think, generally considered—that the age of some of these individuals in every colony must be excessive, even reckoned as we reckon the age of higher animals. When we consider the very slow rate of growth of some corals, and the great size of some of the colonies to be seen every day on an atoll reef, and when we rightly understand their mode of growth, and recognise that the pioneer organism of the colony is still flourishing there, we cannot help being struck by the excessive antiquity of that organism as a living entity. That an apical zooid of a branching *Madrepora* colony should be ten years old seems wonderful, but these individuals are mere juveniles when some of the component zooids of massive growths are considered.

Throughout the prolonged life of these lowly animals the process of repair is a possibility, and a strange paradox is presented in some forms, for the most aged member of the colony shows the greatest activity in all the processes of renewal and repair.

The coral colony increases in size by the budding-off of new zooids and the deposition of new calcium carbonate in their tissues, and just as this is the ordinary mode of growth, so it is the ordinary mode of repair. The type of repair naturally tends to follow the type of growth of the injured colony; and the various genera of corals might be taken in order and the details of the repair of injury noted for each genus. But it is more likely that some idea of the bionomics of the group will be gathered from the general study of the phenomena as they affect the life-history of the coral than from a survey of the manner in which the, by no means satisfactory, classification of the types affects the phenomena.

I. *Among the colonial forms there is a sympathy of individuals, so that each member of a colony takes its share in resenting the injury to a part, and by an increased activity tends to compensate for its loss, or to assist in its repair.*

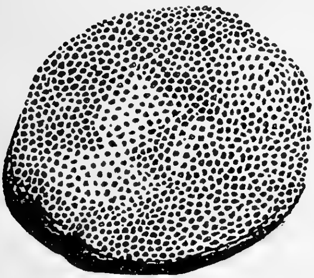
In connection with this sharing of each individual in the fortunes of its fellows and of the entire colony, it may be remembered that it was stated that the whole population of a colony may suffer shock from an injury inflicted upon only a small portion of it. Even the zooids remote from the seat of injury will frequently not re-expand for forty-eight hours after the injury was inflicted, and this is so even when the injury is very trivial.

Now after the receipt of an injury, the effect produced by this communal sympathy varies in different forms of coral, for in a colony, as we have seen, all the members may be of equal importance, or some may be of greater value than others as producers and directors of growth.

(A) In a coral such as the massive forms of *Porites,* where the growth-tendency is to form spherical masses, every living entity in the whole vast crowd of active members bears an equal share in building and in reproducing. It is this equality of all the zooids in the community which produces the characteristic spherical form of the young growth; and the equality of the zooids, plus the receipt of injury, produces the typical flat-topped circular rocks into which the old colony generally shapes itself. When a mass of *Porites* has attained some size as a sphere, the zooids which lie below are necessarily stamped out of existence by the weight of the accumulated mass. It is not often, of course, that the environment is so ideal that anything like a perfect sphere is ever formed, but still, in sheltered pools, many forms of corals may be obtained resting free on the bottom, with every portion of their surfaces living.

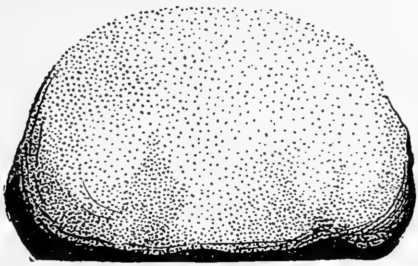
The original nucleus has been covered equally upon all sides, and the weight of the colony is not sufficient to cause the death of those zooids which happen to live on the under side. But as the mass increases in size and weight, death of the lowest zooids must inevitably occur, and the rest of the surface-area carrying on the compensating building will cause the growth to become dome-shaped. Theoretically, the dome

FIG. 36.



YOUNG *Porites* MASS GROWN EQUALLY ROUND A CENTRAL NUCELUS.

FIG. 37.



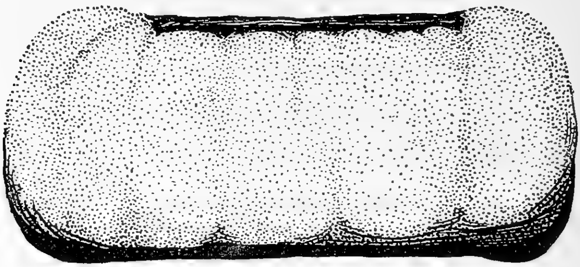
OLDER *Porites* COLONY IN WHICH THE LOWER ZOOIDS ARE KILLED BY PRESSURE.

shape would be the type of form of all the massive species which follow this method of growth and division, but practically the dome shape is far less common than the flat-topped rock, and this is for the reason that injury to the uppermost zooids is usual in the life-history of a colony.

When the dome has become of some size, its upper surface becomes large enough and flat enough to form a resting-place for sediment, and the uppermost zooids decline in activity, the compensating growth carries the sides farther out, and the colony tends, by the increase of the rest of the surface, to become still more flattened at the top. Injury caused by loosened fragments sweeping over the surface of the rocks, and the further deposition of sediment, finally cause the wholesale death of the zooids of the flattened tops. The zooids round the margins now form, by their active growth, swelling lips about the plateau, and make cushion-like bosses which tend to enclose a central flat depression in which sand accumulates, and on which other and differently growing species of coral may lodge and flourish.

This process may be described as the normal accident of the life-history of those species in which the equality of the

Fig. 38.



Adult Colony of *Porites* in which the Upper Zooids are killed by Sediment.

zooids of every portion of the colony is a life-condition. It furnishes a good example of the rule of Nature's utter disregard for the life of the individual, for all those zooids on the upper surface must certainly be killed by sedimentation or by injury, when they have succeeded in making their colony of sufficient size.

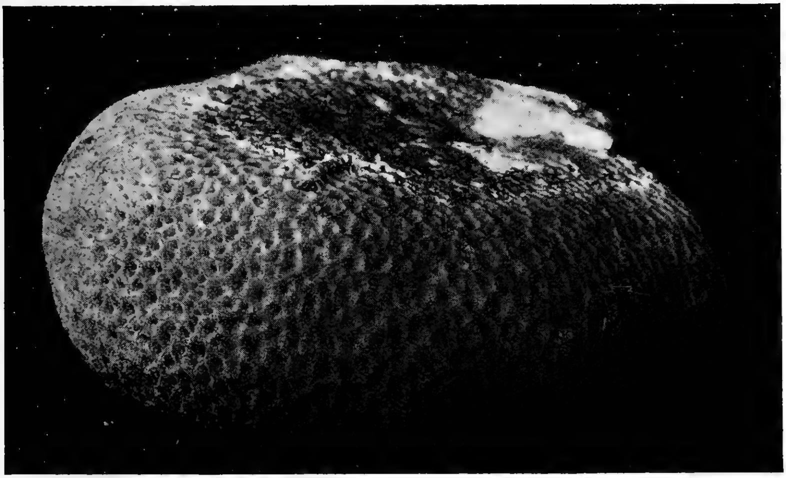
The existence of these flat-topped masses of *Porites* has been noted by practically every observer who has visited reefs of living corals, and various explanations have been given for their origin. I have come to regard these rocks as being of the utmost importance in the study of the question of the development of atolls, and the deposition of sediment upon a surface flat enough to allow of its resting I imagine to be the active agent in their causation.

I regard the finished colony of *Porites* as an atoll reef in miniature—the central dead area representing the lagoon and the raised margin representing the encircling reef; and the factor that calls into existence the flat-topped *Porites* colony also fashions the atoll-shaped reef.

This question will therefore be again referred to in the chapter dealing with the formation of reefs.

The same process which leads to the normal shaping of

Fig. 39.



A Small Colony of *Agaricia*

To show the death of the upper surface due to the dropping of sediment upon the colony.

massive coral colonies may be seen on a small scale at myriad points upon the surface of the growth. The actual amount of living tissue in a large growing boulder is very small, for the depth to which the living animal tissues of the zooid extend beneath the surface is very slight, and yet the calcified portion which extends from the living margin to the centre of the rock must in no way be regarded as the accumulated and dead remains of past generations. It is in reality the skeletons of those zooids whose mouths are now showing at the surface. It follows, therefore, that since the skeleton devoid of animal tissues is incapable of carrying out any repairs, a superficial injury is most likely to lead to the death of a definite area of zooids on the surface—this area representing the base of a cone whose apex is at the centre of the colony. The zooids over this area, if definitely destroyed in the extent of all their living animal tissues, are not regenerated, but a sympathetic growth takes place round the edges of the area. New material is thrown out, new zooids are budded off, and the dead area is finally invaded and covered from the active zooids of the edge. It is due to this process of repair that many of the boring molluscs become enclosed in corals, for when the surface has been attacked and killed, the margins by their sympathetic activity tend to bridge over the injured area and enclose the mollusc, which finally comes to rest in a cavity beneath the surface of the coral.

The rounded cysts found in the substance of most specimens of the massive corals, and which contain an encysted mollusc, are therefore not to be regarded as entirely the work of the mollusc, for they are due in part to sympathetic activity of zooids in the coral colony.

Besides boring molluscs, several species of worms attack corals and hollow out tunnels this way and that through their living substance, and here, too, the sympathetic reaction of the zooids is shown. The tunnels destroy whole groups of zooids and replace the solid skeleton of the coral by a series of tubes, and the strength of the whole colony is greatly diminished. Around these tubes the uninjured zooids divide and grow with increased activity, new calcium carbonate is thrown out, and an attempt is made to compensate for the destruction of tissue caused by the worm. Some curious results are brought about in this way, and specimens in which worm-boring has led to fantastic growth are always to be found, for few corals escape their inroads. A tunnel running superficially, or in the thickness of a plate-like growth, leads to an increased activity of surface-growth of the zooids, and the tunnel stands out boldly from the surface, covered and strengthened by an ever-advancing layer of coral. In this way a tunnel may actually bridge a space from one plate to another, and its mouth be carried out clear of the general surface of the coral; for where the tunnel goes the surface-layer of coral ever keeps pace.

(B) The question of the processes of repair becomes further complicated in those corals, such as the *Madreporæ*, in which all the members of the colony are not of equal importance. We have seen, in considering the mode of growth of such corals, that the very first individual in a colony may continue to flourish and lead the growth of the entire community as long as that community lasts. The original zooid which, as an embryo, settled on the basis that formed the site of growth may be the "directive" zooid of the entire colony, and the apical zooid may represent the oldest living animal matter in the community. But besides the "dominant apical zooid," others arise at intervals, by budding from the sides, which are possessed of more inherent vitality than their fellows, and from their first birth they tend to grow out as new directive zooids and lead to lateral branch formation—and besides these more virile lateral zooids are the hosts of individuals which in the normal condition of the growth reach no greater dignity than a uniform projection of their corallites.

Now when injury or destruction affects a portion of the colony, it reacts on individuals whose functionating values in the economy of the colony are not equal, and so we should expect that the result of injury or destruction would vary according to the different parts of the colony on which the maximum of damage falls. And this is the case. The actual results of repair of various injuries inflicted in experiment, or by Nature, show more clearly the relative values and functional activities of different portions of such a colony than will any amount of theorising or speculation.

1. If the injury be so inflicted that the branch of a *Madrepora* colony is broken transversely, and the injury is limited to a mere fracture of the cross-section, then the repair takes place by the activity of the "dominant apical zooid."

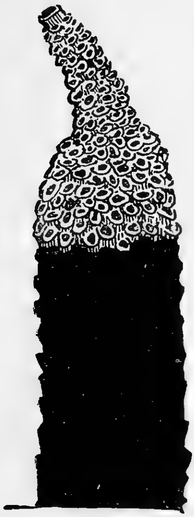
There is, as we have seen, no portion of a *Madrepora* colony which normally dies, and the obliteration of animal tissues in the proximal portion of any zooid is a late change. If the fracture takes place not very far from the end of a branch, the inherent vitality of the terminal zooid predominates, and it starts the repair by continuing to grow out in the direction of its original axis of growth, and by budding new zooids from its sides.

In a measured specimen which was fractured cleanly across one of the main branches without other injury to the colony, the apical zooid had, at the end of a hundred days, grown out 1 centimetre and had budded from its sides forty lateral daughter zooids; and the general surface of the fractured end showed seventy newly formed corallites of old and new zooids. During the same interval of time a branch of about the same diameter on the same colony, which had received no injury, had advanced by 1·5 centimetres and had added about a hundred and twenty new lateral zooids; so that, judged as growth in these corals must be judged, the rate of repair is a rapid one. In this case the dominant zooid is apical, and its superior vitality enables it to regenerate and to continue the growth along the lines of original branching; but if the vitality of the "dominant apical zooid" is definitely destroyed, a very different state of affairs is brought about.

2. If the "dominant apical zooid" is destroyed, and especially if the damage is extensive and affects a large area of a branch, the predominant functions of the apical zooid are taken over by the more vigorous lateral zooids, so that there is a tendency towards branch-formation below the site of injury.

This state of things, when put into terms of the life-functions of the colony, means that potentially almost any lateral bud possesses the inherent vitality of the apical zooid, but it is only in times of stress to the colony that this potential power becomes actual. A stem of a *Madrepora* colony may shoot up straight for the distance of a foot, and show nothing more worthy of the name of a branch than the normal projections of dominant zooids scattered irregularly over its surface; but if sufficient damage be done to it to destroy the apical zooid as well as a fair portion of its entire length, then the remaining part will at once start budding

Fig. 40.



Type of Repair of *Madrepora* when the "Dominant Apical Zooid" is not destroyed.

Process at the end of 100 days.

Fig. 41.

Type of Repair of *Madrepora* when the "Dominant Apical Zooid" is entirely destroyed.

Process at the end of 100 days.

with vigour. The best examples of this mode of repair are seen in those cases in which a colony is attacked by filamentous algæ. The thin green threads of this parasite enmesh the branches, and penetrating into their substance, lead rapidly and certainly to the death of the part attacked. Artificially produced injuries also provide good examples of this mode of repair. The first stage is noticed when, in contrast to the dead terminal portion, the living part swells out; its dominant zooids become more conspicuous, and their projections increase

H

until they arrive at a stage at which they themselves give off lateral buds. The number of these enlarged lateral zooids may be very great, but not all of them ever attain the dignity of actual branch formation.

By the end of a hundred days after the receipt of injury the uninjured central end of a branch is roughened all over its surface by the projections of lateral zooids, and those of them that will form new branches have already begun to develop secondary buds from their sides. This process cannot be spoken of with absolute accuracy as an actual repair, for the part injured surely dies, and its substance is never regenerated; but it is a process by which the sympathetic activity of the remaining zooids in the community is called into action, and the potential power of branch formation inherently lodged in the dominant lateral zooids is turned into a real power. The value of this process in the life-saving of a species is obvious, for the growth tendency of a *Madrepora* colony is to steadily develop upwards, and the limit of this upward growth is either at the water-level, or at a level at which protection from rough water and moving fragments afforded by the shelter of surrounding rocks is lost. Now a colony which grows up beyond its upward limit of safety will sooner or later have its terminal ramifications killed by exposure, or broken by waves or moving fragments. The injury that destroys the power of the apical zooid causes the lateral buds to branch out at angles to the parent stem, and spread fresh zooid-bearing surfaces far and wide in the area of safety. It is this process that is the great determining cause of the general growth tendency of *Madrepora* colonies, and the one that causes the deep-water and shallow-water forms of the same species to vary in their vegetative forms of growth.

3. If in a colony the injury is such that the apical zooid is neither injured nor destroyed, but the damage is limited to the surfaces of a branch, then the repair takes place as in colonies in which every zooid is of equal value.

This repair is well seen after experimentally inflicted injuries, and the process of carrying out the regeneration of the destroyed area is very like that previously described as occurring in those corals that grow like the massive forms of *Porites*.

The first step is the active marginal growth and the formation of an excessive quantity of new material, which, in the form experimented on (*Madrepora pulchra*), is at first of a light blue colour, and is semi-transparent. In this new material the mouths of corallites soon appear, and the edges become covered by a host of uniform zooids, which soon spread over the entire area destroyed by the injury, provided that the area is not too large, and that no alga settles on it in the meanwhile. It may be stated here that in experimental injury, many experiments fail for the reason that the destroyed or injured area commonly becomes a focus for the invasion of boring parasites, worms, molluscs, sponges, and algæ, and the pure results of injury and repair become complicated.

Where no such complication existed, areas of 5 by 5 millimetres, 20 by 8 mm., 20 by 10 mm., and 25 by 12 mm., were completely covered by new material with a multitude of new zooids in the course of 100 days, whilst larger areas were commonly attacked by sponges or algæ before repair was completed. Very much the same process is seen to occur when constricting metal bands are placed round branches. The zooids, where the bands exert their pressure, are destroyed, and the general growth of the branch and the sympathetic activity of the zooids at the margin of the injury soon tend to cause the band to sink into the substance of the coral, and to become completely embedded beneath the surface.

It was previously stated that the type of repair naturally tends to follow the type of growth of the injured colony; and this is generally true. If a coral has a particular mode of growth, and if it be in such an environment that its mode of growth is the one most suitable, then an injury is repaired or a part regenerated on the same type of growth as that of the colony. But the particular form in which a colony may be growing may not be the form best suited for successfully flourishing in that particular environment; and then, following an injury, a remarkable state of things is brought about, which may be stated as follows:

II. *A coral may repair an injury by a new growth of a different type from that of the colony, and in such cases the repair growth is of a form better suited to the environment than is the form of the parent colony.*

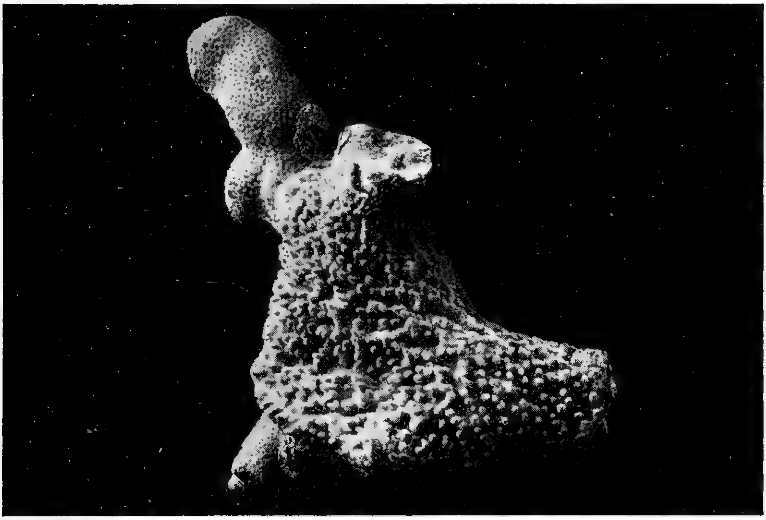
It must be borne in mind that the physical conditions of the atoll are not absolutely constant. Seasonal changes in sets and strength of currents are perpetually causing alterations at all points of the island ring, and a habitat may alter greatly in its physical conditions in the course of a few months. When a coral embryo settles down upon a basis, and starts the founding of a colony, the type of growth which will result will be that best fitted to the environment as the embryo finds it. But suppose that, after the founding and growth of a colony, the physical conditions of the environment change; rough water is admitted, silt settles down, or the water becomes shallow and calm: then the growth of the colony may not be the ideal one for flourishing under these new conditions.

In many places where the conditions are prone to vary, the habitat of the corals may alter in its physical nature in more or less regular cycles. Where, as at the eastern extremity of Pulu Tikus, a spit runs out, building sheltered pools and protecting the shore for a considerable distance, and then later on, in the periodical cycle of currents and eddies, is carried away, many corals must be subjected to a great variation of environment. In such circumstances no doubt many colonies die, for, as we have seen, a sudden change of habitat cannot be resisted when a form is well adapted for one definite kind of environment, and in any case the colonies are liable to injury and partial death in their changed surroundings.

When such injury falls on a coral not ideally situated, the repairing growth exhibits a strange independence, and, forsaking the growth-form of the colony, builds its repair in the form best suited to the new conditions of the environment.

This is a strange zoological fact, that the inherent growth-form, once stamped upon a well-established colony, continues to be the type of growth, though it be but ill adapted to its

FIG. 42.



Montipora COLONY

Repairing a branching growth by an encrusting layer.

habitat; and yet, when the continuity is once broken and a new start is made, the newly budded zooids can throw off the stereotyped method, and build anew to the altered conditions.

It is facts such as these which give some clue to the understanding of the vast range of variation occurring within the limits of a species, and make the establishing of a species a matter of extreme doubt, until every possible variation which different surroundings will stamp upon the type has been examined. We have seen, in following the life-history of corals, that the colony shows great adaptability, being able to mould its growth in response to the demands of its environment, and in this repair process it possesses a further power, for it can entirely alter the structure of an established colony.

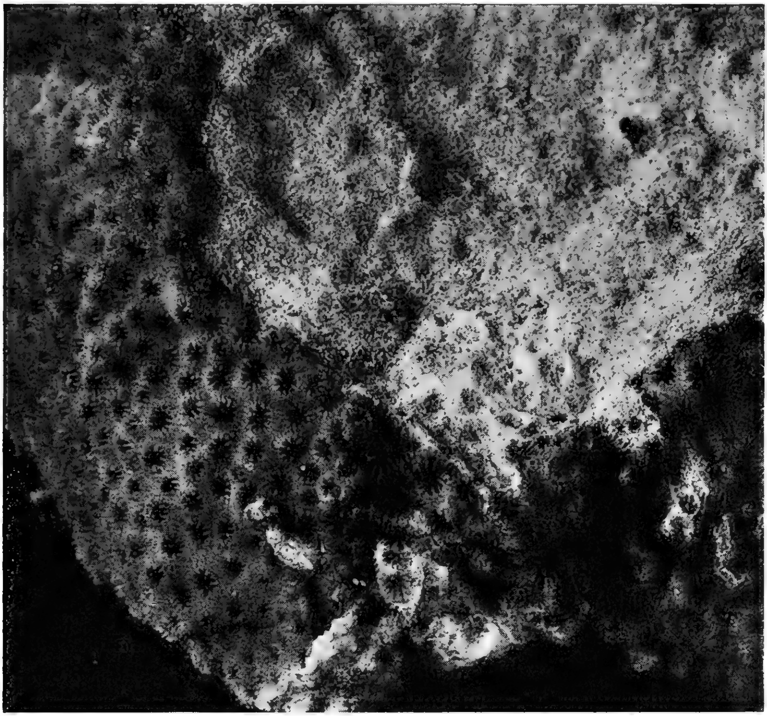
Numerous examples of this strange process may be seen. A branching *Montipora*, growing in a gap in the island ring, is found to have every colony dead or damaged in a greater or less extent of its whole growth. The damage is probably due to the fact that currents have altered the physical conditions of the habitat since the founding of the colonies, and that a greater rush of water has brought more sand and moving particles in contact with them, for the apical branches of all the colonies within a definite area will be found broken. The repair of this damage invariably takes the form of an amorphous encrusting growth covering the débris of the dying colony, the regenerated portion keeping pace with the destruction, and thus keeping the colony living—but living as an entirely different type of its species.

Madrepora colonies show the same phenomena, and very strange repair-forms of *Pocillopora* growing in rough water as encrusting growths may be found.

When, after repair, a *Madrepora* colony assumes an encrusting form, as it frequently does, the inherent tendency of its growth is still evident, for rising at intervals from its flat surface are numerous dominant zooids, which, were the opportunity afforded them, would form upward-growing branches.

It is by no means uncommon, in this process of repair, not only for the vegetative growth of the colony to be altered, but for the actual type of the corallum to be changed. When a *Montipora* repairs its own ill-situated and dying colony by an encrusting growth, the whole minute structure of the coral is changed. Instead of the smooth surface over which the fairly wide mouths of the corallites are dotted, is a coral with an outward appearance notable chiefly for its extreme roughness, due to the development of numerous papillæ at the bases of which open the minute corallites. The characters of the original growth and of the repair growth are so entirely different that they would certainly be regarded as two distinct species. Other examples of this entire change are not uncommon, and some very strange abnormalities may be found, which show that in repair, as in adversity and in alteration of

FIG. 43.



COLONY PARTLY KILLED BY DEPOSITION OF SEDIMENT,
Showing abnormal type of division.

environment, there is practically no limit to the developing of the different main types of growth by any coral. It is common in repair of injury, as it is in cases of adversity, that the bounding walls of the newly budded zooids are never completed, and repair by a pseudo-meandrine form of fission is often met with in many and widely separated species of coral.

*

It is common, too, to find that the repair-zooids have raised corallites, when those of the parent colony are flat, and in these cases it is probably silt that has caused the original damage.

The study of the repair in corals is therefore one not devoid of zoological interest, for it shows clearly that a type must never be considered as a species, in the way in which we regard species among the higher animals, until it has been seen in all its variations, and until all the possible modifications that repair produces have been studied.

That a type like the encrusting *Montipora* should be in reality the same species as the branching form would be considered as highly improbable, but when it is seen that the one type repairs its damage by the development of a new growth of the other type, there is no alternative but to regard them as identical species.

That the numerous types of *Millepora* and of *Pocillopora* should be but variants of a single species would seem at first sight to be very unlikely, for there is little enough likeness between the extreme forms, and yet their processes of repair show them capable of building to any of their diverse types, regardless of the nature of the parent growth.

If the processes which have been described, and the conclusions which have been drawn from them, be accepted, they can serve only to make clearer the great fact that morphology —the animal's type—is the outcome of necessity; and here the demands of necessity bring about change, not in the life-history of a species only, but in the life of the individual.

CHAPTER X

THE PROCESSES OF DEATH IN THE CORAL COLONY

THE subject of repair leads naturally to the consideration of the death of the organism, for when the destructive processes outweigh the resources of repair, then death must inevitably ensue.

There is one fact in the life-history of corals which the study of their processes of repair clearly brings out, and it is this, that all the methods of regeneration are more for the life-saving of the colony than of the individual. It is a rule with Nature that the life of the individual is of little moment: Nature has little care for individuals, though she strives always to maintain the life of the species. In a vast community of individuals, as is a coral colony, each separate member is but a part of the whole body, and the preservation of the colony is of more import than the saving of a few individuals. A branching *Madrepora* grows naturally upwards into the danger zone, and the terminal branches are inevitably destroyed, with the sacrifice of a myriad of zooids; but the result is a stimulus to lateral branching within the area of safety, and the colony continues to flourish.

In every massive growth starting to develop on all sides of a nucleus, those zooids that are budded below can never hope to live, and those on the upper surface will in all probability die. In all the processes of repair that have been described, it is not the individual which is mended, for an individual once badly damaged is not repaired; but the loss is made good by the growth of new zooids which assume the functions of those lost. Repair in colonial forms does not save the individual from death, but it preserves the life of the colony. Now loss by death in a colony is not always repaired.

We have seen that the flat tops of the massive growths of *Porites* remain devoid of living zooids, and in several types of growth, death of a portion of the colony is more or less usual. Among the branching *Porites* it is normal to find the lower portions of the growth dead, and no attempt made at their repair.

When it is said that the partial death of a colony is more or less usual in some types of growth, it is not in any way meant that the progress of coral formation is a building of the living zooids upon the dead bodies of past generations, for the partial death is due, as a rule, to very definite outside causes.

In this atoll the greatest cause of coral death has been quite an unusual one, but it has been a most instructive one, for it brings out some very interesting facts in the life-history of corals. In 1876 all the living coral of the south-east portion of the lagoon was entirely destroyed by the pouring out of foul water from a supposed volcanic vent at the southern side of the atoll. The picture presented by these denuded areas was described by Dr. H. O. Forbes in 1879, and by Dr. Guppy in 1888; and in 1906 there was still the same tract of dead coral on which the efforts at recolonisation have been practically unavailing.

This remarkable failure of the corals to repopulate a large portion of the lagoon is probably due to the fact that during the period immediately following the disaster various algæ, such as *agar-agar* and several other species, being of a faster and more hardy growth, stepped in and took possession of the area before the slow-growing corals could obtain a proper footing. The growth of algæ is in itself hostile to the life of corals, and, apart from that, the algæ beds in the lagoon are the greatest factors in catching silt and piling up the shifting sand-banks, the presence of which is so fatal to coral growth. These two factors, aided perhaps by subsequent minor poisonings, have so completely paralysed all coral activity that to the south of Pulu Selma there has been in many places no trace of new growth; and the abnormal death which occurred thirty years ago has remained unrepaired to this day.

Although such events as this are quite exceptional in the life-history of corals, or of coral islands, still the after-history of the disaster shows on a large scale the influences of those factors which in the normal life of corals tend to bring about their death. It is the silt and seaweed that have prevented corals from flourishing on their old site, and the silt and seaweed are to-day in the atoll the two great causes of coral death.

The influence of matter suspended in the water is one of the most far-reaching factors in the life-history of corals: it is to resist its effects that many of the vegetative forms are evolved; it is on account of the silt that many acres of the lagoon are devoid of coral growth; and it is probably on account of the presence of silt that wave action is so necessary to coral life, and that the unstirred depths below about 20 fathoms are comparatively bare of coral.

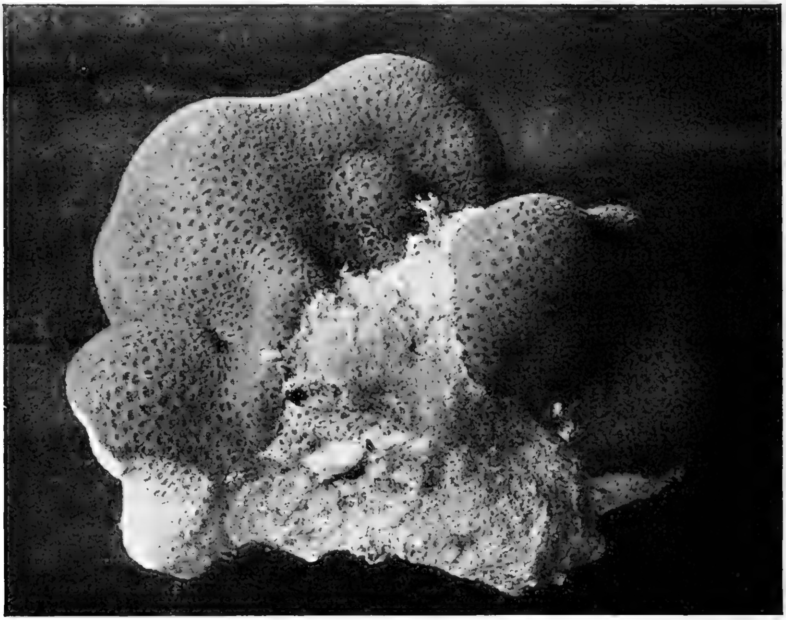
Silt, sand, or suspended matter may cause the actual death of corals in two ways: (a) *It may fall upon them and choke their zooids from above.* (b) *It may overtake them from below.*

Of these two actions examples are always to be seen in (*a*) the partial death of the tops of massive *Porites* colonies, and in (*b*) the stems and lower branches of branching *Madreporæ* which are normally lifeless. In these cases the death is only partial, for the reason that the colony is capable of resisting as a whole the amount of suspended matter normally present in the waters of its habitat; but if the amount be suddenly increased, the colony may be unable to resist it, and general death ensues. Evidences of this mode of death are seen in the gaps in the island ring where an alteration of current brings more silt than is usual to the growing colonies, and very interesting results may be produced experimentally. On December 13, 1905, several healthy living colonies of rough-water forms of *Madrepora* and *Pocillopora* were removed, without exposure or injury, from their habitat of rough barrier water, and without any delay were placed in marked sites in a sheltered sandy pool of the barrier flats. In the same pool, which is almost completely cut off from the sea at low tides, and then contains about 2–3 feet of water, and which is about 100 yards long by 20 wide, numerous corals live and flourish; calm-water forms of *Madrepora* and *Pocillopora*, capable of resisting silt, being the most abundant. The conditions of life in these barrier pools are peculiar. The pools are filled with sand, for the fragments which are triturated by their journey to and fro over the barrier are deposited in them, they contain the minute green filaments of the boring algæ, and at midday low tides they become heated by the sun to 93° Fahr. and more. Their coral fauna is practically always the same; *Madrepora* flourishes in its most highly branching forms, *Pocillopora* always has a good foothold, and the other species are in plenty, but hardly in a state of luxuriance. Bêche-de-mer in hundreds live in these pools, and crustacea, polychætes, mollusca, eels, and the myriad brilliant fish make up the conspicuous fauna. Of the many rough-water colonies which were transplanted experimentally into this environment, not one remained alive at the end of 50 days, and most were dead within a month. The first sign by which a colony shows that its environment is not suitable is by becoming highly pigmented. Both rough-water forms are, when flourishing, very pale corals, being usually of a light buff colour; but within a fortnight the transplanted colonies had become of a dark yellow-brown, and in *Madrepora* there was a more than usual tendency to lateral branch formation. In 20 days most colonies had some portion dead, and the dead parts became rapidly the site of growing algæ. In 30 days nearly all the numerous transplanted colonies were dead or dying, and by 50 days no portion of any colony remained alive. It was silt that had determined the death of them all; the stunted, flattened types of *Madrepora* and *Pocillopora* are both corals of a rough-water habitat, they are used to clear water in which there is little or no suspended matter, and not a single colony was able to withstand the slow but certain sedimentation of the barrier pool. When the silt had once fairly determined their death, the fine boring algæ completed the ruin. If any colony of branching coral be removed entire from the lagoon, it will be found that the lower portion is invariably dead ; but this death is in most cases not a natural one resulting from the senility of the zooids, but merely an index of the amount of silting up of the lagoon which has taken place since the establishing of the colony. Sand is ever being washed into the lagoon through the numerous gaps in the island ring, and most decidedly the tendency all over the lagoon is a gradual filling up, by the deposition of finely triturated fragments. The floor of the lagoon is fairly steadily rising, and those colonies of corals growing in its bed are for ever being encroached upon by the gradual rising of the sand level. The deposited sand most certainly kills the zooids with which it comes in contact, and the result is that the lower portion of every lagoon colony is killed. Silt then, in this atoll, is the most potent factor in causing coral death, and next in importance to the silt comes the seaweed.

There is a green alga which, at some seasons of the year more than at others, comes to the barrier pools in great quantities: it is a growth of fine green threads, and its effect on coral growth is really wonderful. A pool in which numerous flourishing colonies live, quite on a sudden may show the advent of this alga, and every portion of every colony, which may receive a chance injury, at once becomes the site of the growth of these fine threads. I believe that it is always at the site of injury that the attack of the alga starts, but its growth soon invades, and invariably kills, the living healthy portions of the colony. A colony once fairly invaded by this parasite rapidly dies, and yet it never succeeds in obliterating coral growth, for as suddenly as it came to the barrier pools it goes. Spring tides and hot weather seem to promote its growth, or perhaps lower the resistance of the coral colonies, for when the rock-pools are left long to swelter in the sun, with but little depth of water in them, then the alga seems to be most active. It is a great factor in causing the death of the atoll corals, and ranks in Cocos far in advance of the boring sponges, worms, or molluscs as a destructive agent.

The more obvious boring creatures do not cause damage

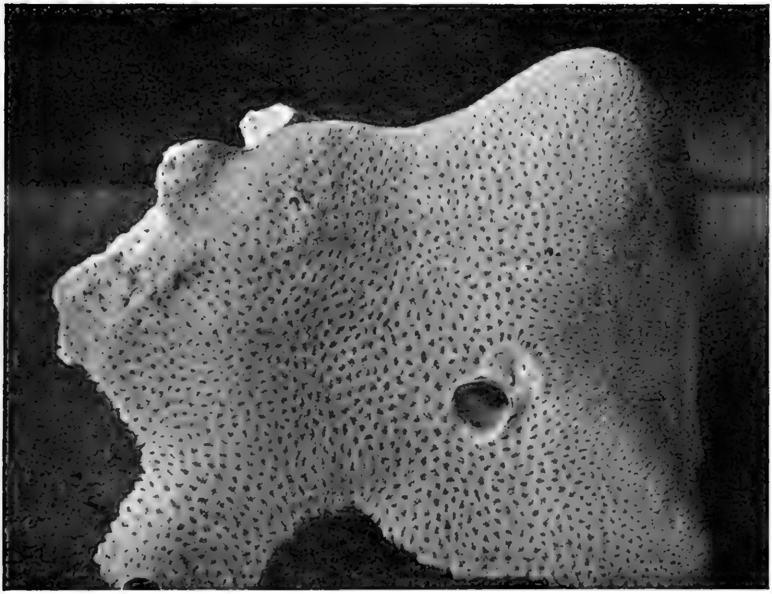
FIG. 44.



COLONY SHOWING DEATH BY SEDIMENT OVERTAKING IT FROM BELOW.

to the colony other than to weaken its structure, and lead to its more ready destruction by the action of the waves or moving fragments; and beyond this they cannot be rightly considered as effective enemies of coral growth. There seems to be indeed an almost symbiotic relation between certain boring animals and the corals that they have chosen as their hosts, for coral growth extends and strengthens their tubes by sympathetic growth, and the cavities of the molluscs in many cases expand the living area of the surface of corals by causing irritation and repair. It is an extraordinary thing to see the extent to which a colony of *Millepora complanata* may be riddled with the wide smooth-walled tubes, and yet not be appreciably weakened, and the resultant observation on such

Fig. 45.



Specimen showing the Tunnelling of a Living Coral Colony by Boring Parasites.

colonies is that the borings are very little harmful to the colony.

Another cause of coral death to which much importance has been attached is the exposure caused by the receding tide, for it has been said that corals cannot survive even a temporary exposure to the sun and air.

Since Darwin first claimed this as an axiom of coral bionomics, a great deal has been taken for granted with regard to the effects of exposure, and yet every fresh investigator has attached less and less importance to it. Now, as a matter of fact, there is no species of coral in this atoll that is not able to withstand an exposure of many hours to the midday sun, with from 6 inches to a foot of its apical growth above the water: there is no barrier species that does not normally suffer this at midday spring tides. There are many isolated rocks that are ordinarily exposed for two feet at low tide, on which living corals flourish luxuriantly. When season and winds combine to cause tides abnormally low, it is possible to go from island to island along the barrier flats, and for the greater part of the journey to walk in but a few inches of water; and if such a walk be taken during a low tide at hot midday, the smell of the exposed coral is almost overpowering and may be noticed far out in the lagoon. Coral has an odour that is peculiarly offensive when the growth is exposed to the air, and this strange odour is no sign of death, for a stinking coral when replaced in water or when re-covered by the rising tide, flourishes again. At such a low tide the barrier flats present a picture of bushes and boulders of living coral all freely exposed to the sun, all dry, all smelling very offensively, and yet the returning tide finds them all living as actively as when it left them. A coral may be taken from the bottom of the lagoon, may spend the best part of a hot day, high and dry, in the bottom of a boat, and yet, when it is replaced in the water, all its zooids will expand, and it will resume all its vigour. Exposure to the sun and air between tide limits plays but little part as a causative factor in the question of coral death. Of course no coral could grow beyond the normal high-tide level, but the remarkably level appearance of the barrier flats is not the result of the action of sun and air on the coral colonies so much as of the levelling effects of the waves, and the moving fragments which they wash to and fro. It is the grinding action of the surface waters at their level of maximum activity which determines the limiting level of upward coral growth, far more than the death of the apices from the effects of sun and air. The waves that sweep over the flats, and carry shorewards the fragments which they have broken from the seaward margin of the barrier, are for ever keeping the coral colonies within the limit of upward growth; but their action is not altogether detrimental to the corals, for though, where island beaches are formed, many fragments of living coral are cast ashore only to perish, still many more, where no such dry land exists, are safely lodged in a new resting-place. Broken fragments are swept across the flats, they lodge in pools, they become stranded under the lee of boulders, or are washed into the lagoon; and each of these fragments, if not too badly damaged, will form the nucleus of a new colony in a suitable habitat. If a large colony of *Madrepora* be broken up in the rock pool where it flourishes, the great majority of its fragments will continue to grow and branch out into new colonies; and if some of these fragments are swept onwards by the waves, they will form pioneers for the species when lodged in a suitable environment.

Freshening of the water from the excessive tropical rains has been said to cause wholesale death among the lagoon corals; and in high islands where rivers flow into the sea, the fresh water is well known to be a great cause of the absence of coral growth. Before Darwin's visit to the atoll it is said that an abnormal rainfall killed many corals, and again in 1866 the fresh water is said by the Governor to have stood for a height of several inches on the surface of the lagoon, so heavy and continuous was the rain. Again, in May 1896, the rains were abnormal, and the freshening of the water destroyed the lagoon algæ and fish; and this in such quantities that when Mr. Arthur Keyser visited the islands in July, the dead fish were still being cleared from the lagoon. There is no doubt that the rain would have to be long continued, for all those corals that live in rock pools are immune to the influence of the fresh water accumulated during a heavy downpour at low tide. When the tide is low and the rainfall is heavy, the rock pools undergo a remarkable degree of freshening, and so too does the lagoon if the weather is calm and the rainfall is a sudden one.

In the lagoon the surface specific gravity may fall to 1021, but I have never found it lower, and the perpetual churning of the waves prevents any marked evidences of freshening being observable near shore. Outside, in the ocean itself, there is such complete mixing of the waters at the surf-beaten barrier edge that it is not likely that the influence of the rain could be recognised.

On February 13, 1906, when ·28 of an inch of rain fell in ten minutes, the sp. gr. of the surface of the lagoon dropped from 1027 to 1021, and the temperature was 77°·5 Fahr.

On February 24, after ·5 of an inch of rain had fallen in half an hour, the sp. gr. was 1023, and the temperature 82°·7 Fahr.

On January 4, after 7·4 inches had fallen in twelve hours, the sp. gr. was 1021, with a temperature of 78° Fahr.

The surface of the fish-pond, which is a pit about 15 feet square, will show a reading as low as 1015 three days after a downfall of 5 inches in twelve hours, although its waters rise and fall with the tides, and the outside ocean shows no change after the downpour.

It is therefore mainly wave-action that obliterates the effects of tropical showers in freshening the salt water, and the coincidence of great rainfall and dead calm must be very complete, and very lasting, before anything approaching a general destruction of corals could result.

Many animals have been ranked amongst the enemies of corals, and Darwin classed some fish and the myriad Holothuridæ as causes of coral death. In this atoll Dr. H. O. Forbes has described the "*Scarus* feeding in the surf on the living coral," and has asserted that the *Kakatua* and other lagoon fish actually eat the living polyps. The observation has been several times doubted, and, so far as this atoll is concerned, it is certainly an error. There are no fish and no Holothurids in Cocos-Keeling lagoon, or on the barrier, that eat coral when it is living, though many different classes of animals contain great quantities of dead coral in their alimentary canals. The importance of the coral-haunting fish and the Holothurids as factors in atoll formation is great, but it is not as destroyers of living coral that they fulfil their rôle, for the coral that they take in at their mouths is already dead.

From the study of the life of the colony in different surroundings, and from the repair of injury, and death, in unsuitable habitats, I think it will be seen that the number of the true species of corals is by no means so great as is at present supposed. There is no doubt that a great number of our museum-made species are mere vegetative varieties, produced in response to the demands of the environment. I do not think it is possible to determine from a fragment of growth—often with no sufficient data—if it be a new species, or even a new genus, or if it be a mere vegetative variety of some already well-known species. There can be but little utility in the naming and describing, with great minuteness, of all these variations; for of this work there can be no end, and persistent collecting, from even such a small area as the Cocos-Keeling atoll, would yield such a variety of fragments as would occupy a lifetime to describe. In very many cases one single colony could be found to provide several types of growth, which, if presented as fragments, would be deemed to merit individual description as species. In such cases some factor in the physical condition of the surroundings will show, when the colony is *in situ*, the cause of these different modes of growth; but when the colony is transported to a museum, it presents a very striking puzzle.

One side of a colony may be shaded from light, sheltered from currents, or protected from silt; whilst the other side may be exposed to all these influences: and then it is but natural that the two sides should vary, and—knowing the wonderful plasticity of the zooids—the great differences are not astonishing.

Besides the occurrence of colonies which exhibit two or three well-marked types of growth, there are those that can only be called "undecided" forms, and these present growths that are intermediate in character between two well-marked and very diverse types. Such "undecided" forms are very common, but it is the natural instinct of the collector to pick out well-marked and well-grown forms as his specimens.

Fig. 46.

The "Stings" caused by Contact with a Colony of *Millepora alcicornis.*

In 1898, Professor Sydney Hickson made an exhaustive study of the so-called species of the hydrocoralline *Milleporæ*, and he came to the conclusion that there were "very strong reasons for believing that there is only one species of *Millepora*" (*P. Z. S.*, 1898, April, p. 256).

Previous to the writing of this paper he had come to the same conclusion concerning the Alcyonarian genus *Tubipora*, and regarded it as possible that the species of the Zoantharian corals might have to be considerably reduced.

The *Milleporæ* are exceedingly abundant in the atoll, and the well-marked forms *Millepora alcicornis, M. complanata*, and *M. verrucosa* are to be found in plenty. But these well-marked forms are all linked up by intermediate stages, and I have no doubt that all are variants of one species. In the atoll the *Milleporæ* are called *Karang gatal*—or "itchy corals," for they are capable of inflicting a painful sting when touched. The sting is like that of a nettle, but far more intense, and grave results may follow it. It is curious that of the three forms, *M. alcicornis* has the power of stinging more severely than the other two, but this fact does not necessitate their taking specific rank, and I do not doubt that there is but one species of *Millepora*. I do not doubt either that all the forms of *Pocillopora* which are found in the atoll are in reality one species; and I strongly suspect that there is only one species of *Montipora* in Cocos, although its varieties are legion. The species of *Madrepora* in the islands are in reality very few; many diverse forms are certainly identical species, but experimental breeding must finally settle how few these species are.

It is the same throughout the whole series of the Cocos-Keeling corals; there is a very limited number of species; and I would account for the origin of the many varieties, and the present confusion of their nomenclature, by the alteration of environment caused by atoll formation.

When the origin of the atoll is considered, it will be demonstrated that the whole structure is developed from an original submerged bank, and on this submerged bank I would imagine that the corals represented few species and few varieties.

The life-conditions all over the bank were fairly uniform, and there lived upon it *Pocillopora, Montipora*, and the other corals, exhibiting probably one form of growth only, and one that is represented by an intermediate type to-day.

With the origin of the heaped-up débris that forms the island ring, and with the formation of the barrier above the level of the tides, a gradual change occurred, and in the place of one uniform environment, an infinity of diverse habitats was produced.

The rough water of the barrier, the smooth water of the lagoon, the silting water of the inlets, and the clear water of the ocean, were marked off from one another; and the embryos of the originally similar corals had to grow dissimilar to adapt their vegetative types to the new-formed habitats.

In this way the present infinity of types was brought about, and wherever the environment is changing to-day new types are developing to conform with its demands.

PART III

THE ATOLL AND ITS PROBLEMS

CHAPTER XI

THE ATOLL AS A WHOLE

I HAVE chosen to dwell somewhat fully upon the life-history of the coral colony for the reason that in the study of the development of atolls and reefs, a knowledge of the growth tendencies of the colony is an essential. The question of the formation of atolls is in reality a zoological one, for every square inch of their structure is the outcome of the activities of living creatures, and if we are to appreciate rightly the building of atolls, it is necessary to understand the lives of the zooids which produce them. In the portion of this book dealing with the corals themselves I have endeavoured to show that the study of corals cannot be properly conducted in a museum, by the examination of dead specimens far removed from the site of their growth, and from all the influences of their environment. In these chapters I would endeavour to establish the fact that the development of atolls and reefs is, in reality, a question to be studied by a careful inquiry into the mode of life of the coral zooids themselves;—that it is not a problem to deal with in laboratories or museums, for the laboratory can never be a substitute for the reef as a field for experience.

In the explanation that I shall furnish for the making of reefs and atolls, no other processes will be invoked than the normal growth tendencies of the coral zooids, and those effects upon land-making that may be seen wherever the winds and the waves act upon matter. I am convinced that the more we tend to divorce the study of the structures raised by the zooids from the study of the zooids themselves, the less will we tend to approach their true solution.

The subject-matter of these chapters may be taken as representing the outcome of a somewhat prolonged series of personal observations, made upon the living, growing reef, that supports one of the most perfect atolls that is in existence.

Lest my practical knowledge of coral formations should rest only upon the examination of a perfected atoll, I embraced the opportunity, afforded by the kindness of Captain Maclear Ladds, of the Singapore Pilot Service, of examining the many reefs and coral structures that lie in the neighbourhood of Singapore;—and I was further enabled to examine, though in no great detail, coral structures that fringe the shores of Sumatra, Java, Sumbawa, and the other Malayan Islands;—and finally to make the double journey of the whole extent of the Great Barrier Reef of Australia.

I was early convinced that "Subsidence" will not explain the development of all coral formations; and that "Solution" will certainly explain still less;—and, in the explanation that I would advocate, the chief agent is one that acts upon the living colony—and is "Sedimentation."

I am well aware that the harmful effects of Sedimentation have received previous attention, but I would extend their action, and I would make them by far the most important agents in producing all the forms of coral structures as we find them to-day.

The processes of Sedimentation which have been followed in their action upon the colony will therefore be studied as they are to be seen displayed upon a grander scale. It has been demonstrated how the harmful action of Sedimentation can produce an atoll-shaped rock a few feet in diameter, and it is logical to inquire if an atoll like Cocos-Keeling, whose lagoon is several miles across, might be produced in the same fashion. The atoll as a whole must therefore be examined.

The group consists of two separate atolls:—a small atoll to the north, which is Keeling Island proper; and a larger atoll, some 15 miles to the south—the Cocos atoll. The information concerning the changes in the atoll to be derived from old charts is practically nil, and it is a great mistake to place any reliance on what are, after all, only rough sketch-maps made by passing mariners. In some cases deductions have been made as to changes that are presumed to have taken place in the atoll, by noting the differences which exist between these old mariners' sketch-maps and modern charts. Such deductions are liable to cause grave error. In some cases such errors have been caused, and mention will be made of these as the subject comes under discussion.

The group lies in the eastern portion of the Indian Ocean, 12° 9′ south of the Equator, and 96° 53′ east of Greenwich; it is separated by some 600 miles from Java; some 500 from Christmas Island; some 2000 from Cape Leeuwin, Australia; and by about the same distance from Ceylon.

The atoll lies in the track of the South-East Trade winds, which blow for 300 days in every year; and in the Westerly Equatorial sea drift, which flows constantly past the islands.

Various accounts of the atoll have appeared from time to time, and its name must always remain associated with the theories of Charles Darwin, for when he made his visit in the year 1836 he saw, in certain features of the atoll, all the signs that he had previously pictured as being the evidences of gradual subsidence. It was the only atoll that Darwin ever examined, and it was the one on the examination of which the famous theory of "Subsidence" was founded.

Dr. H. O. Forbes visited the islands in 1879, and the outcome of this visit was the interesting account which appeared in "A Naturalist's Wanderings in the Eastern Archipelago," published in 1885.

Dr. H. B. Guppy made a stay in the group in 1888, and has published by far the best account of the actual structure of the atoll in the *Scottish Geographical Magazine*, vol. v., Nos. 6, 9, and 11.

Darwin's stay in the atoll was a short one lasting only ten days; Forbes stayed for three weeks, and Guppy, who saw far more than either of the two previous visitors, lived for ten weeks with the Clunies-Ross family. Neither Darwin nor Forbes landed on the Keeling atollon, and its description by Dr. Guppy was the first ever published—in fact Guppy was the first scientific man who ever landed on the island; and to this day Keeling remains one of the spots least visited by men that the world can still boast.

THE SOUTHERN GROUP

THE COCOS ATOLL PROPER

CALLED ON OLD CHARTS

THE TRIANGULAR ISLANDS

Some twenty-four islands enter into the composition of the atoll ring; twenty-three of these islands constitute a horseshoe-shaped rim to the lagoon, and the twenty-fourth lies in the gap of the horseshoe, where the lagoon communicates with the open sea.

All these separate islands (with the exception of Pulu Luar) rise from a common stratum of level coral breccia rock—the barrier flat; and this level stratum is in reality the rim of the great reef that paves the bottom of the lagoon, and falls away outside to the ocean depths. The rim of the reef is some twenty-five miles in length, and a total of about seventeen miles is covered by the dry land of the islands. The islands vary in size from such considerable pieces of land as Pulu Panjang—some six miles long and half a mile wide—to mere mounds detached from other islands, or breccia masses heaped on the barrier flats. The eight miles of the edge of the reef that is not dry land varies in its nature in different parts of the circumference, and these eight miles are the most interesting miles of the whole of the atoll, for they still show how the other seventeen miles have arrived at their present condition—how, in fact, coral islands are made on the rock

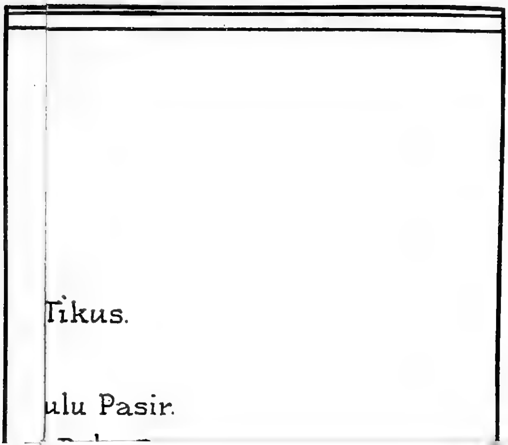

Tikus.
ulu Pasir.

PLATE IV.

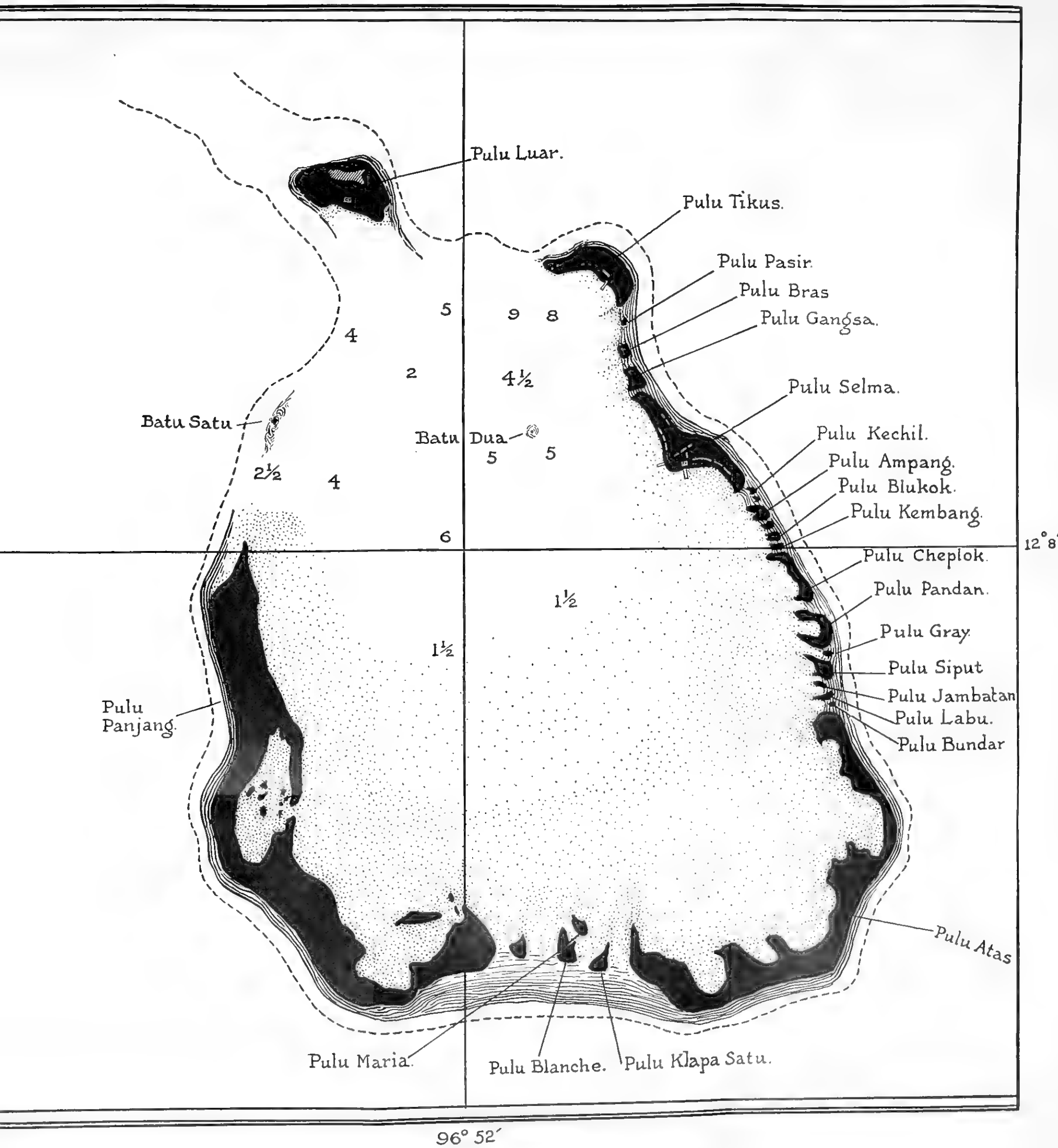


CHART OF THE SOUTHERN GROUP OF COCOS-KEELING ISLANDS.

flat. The essential feature which constitutes the varying factor, in the parts of the ring which are not the sites of islands, is the presence or absence of the barrier; for the barrier, which is the mainstay of the existence of the atoll, must always be regarded as potential dry land, although still belonging to the ocean. The barrier does not form a complete rim to the reef, but, as a pioneer, it outruns the land, and is wanting in only about three and a half miles of the whole circumference. The parts in which the barrier fails are situated to the north and west of the atoll ring, and the sailors' rule, that the entrance to a lagoon is to be found on the leeward side, is therefore justified.

The whole atoll is in the form of an ellipse with its long axis stretching in a south-easterly direction—prolonged in fact in the line of the prevalent wind, a common and neglected feature of atoll form. The ellipse is some ten miles long from barrier to barrier, and some seven miles across its short axis. The whole atoll therefore occupies very much the same area as does Christmas Island, its nearest neighbour.

The largest islands lie to the south of the ring, and Pulu Atas and Pulu Panjang are the largest land masses of the group. Not only are they longer than any others, but they are also much wider from sea beach to lagoon shore, they are the highest land in the whole atoll, and are evidently the oldest of any of the islands. The islands to the north are smaller, and, as a rule, very much lower; and they have evidently altered very little from their primitive condition of being mere heaps of coral débris. Pulu Tikus is one of the lowest of all the islands in the group, and its general elevation is only from two to three feet above mean tide-level; its highest point is raised some thirteen feet above the sea, and much of its surface is below the level of spring high tides. It is difficult to realise the extreme lowness of the islands of the atoll, and it is always a cause of surprise to any one who sees these things for the first time, although the fact may be perfectly familiar. As a homely illustration of the actual condition, it is useful to take the level of a railway line, to represent the sea, and then the platform of the station gives a very true idea of the height to which the islands rise above it. There are other differences between the windward and the leeward sides of the atoll. At the southern and eastern extremity the maximum of wind

Fig. 47.

The Lagoonlet of Pulu Luar at High Tide.

effect is seen, and sand covers the surface of the islands in wind-blown ridges of some depth, so that, in places, actual hills, thirty feet high, rise in Pulu Atas. The barrier flats are far wider on the south side of the group, and larger boulders are piled upon them; the sea beaches are steeper, and are composed of larger fragments; and lastly, the lagoon itself is far shallower in its southern portion.

It has been said that the atoll is horseshoe-shaped, and this form is not confined to the whole collection of islands, but is stamped on every constituent piece of land in the atoll structure. This is a very important point, and any explanation of atoll formation must also furnish some satisfactory reason for this shape belonging to the individual islands of the atoll ring. The incurving of the ends of the islands leads to the formation of the secondary lagoons that are present in Pulu Atas and in Pulu Panjang, and are foreshadowed in Pulu Pandan and Pulu Ampang.

One of the constituent islands is in reality an atollon, and encloses a lagoon which has altogether ceased to communicate with the sea. This island is the leeward one, named Pulu Luar, and the lagoonlet is situated to its leeward side; a few feet of water rise and fall in it, reaching it by tidal percolation; but a débris beach cuts it off from any direct communication with the leeward shore, where its entrance used to be. The changes that have taken place in this very interesting atollon will be further discussed when the method of formation of the islands is under consideration.

THE NORTHERN ATOLLON

KEELING ISLAND

Keeling Island lies some fifteen miles to the north of the Cocos atoll proper; it is an island that has been very rarely visited, and it is one of great interest. It is somewhat over a mile long from north to south, and is about half as broad as it is long. In its present condition it is an almost complete circle of land that encloses a shallow lagoon still communicating with the open sea. The lagoon contains something rather less than a fathom of water, and it is not the site of coral growth, but is occupied mostly by sediment banks and seaweed. The sea is admitted through a narrow gap on the eastern side—and much has been made of the fact that this opening is on the windward shore; but a glance at the chart will show that this is not in reality a lagoon entrance, and that no gap in the barrier is to be found opposite the channel.

The island is very densely covered with large timber trees, mostly *Pisonia inermis* and *Cordia subcordata;* while coconut

Fig. 48.

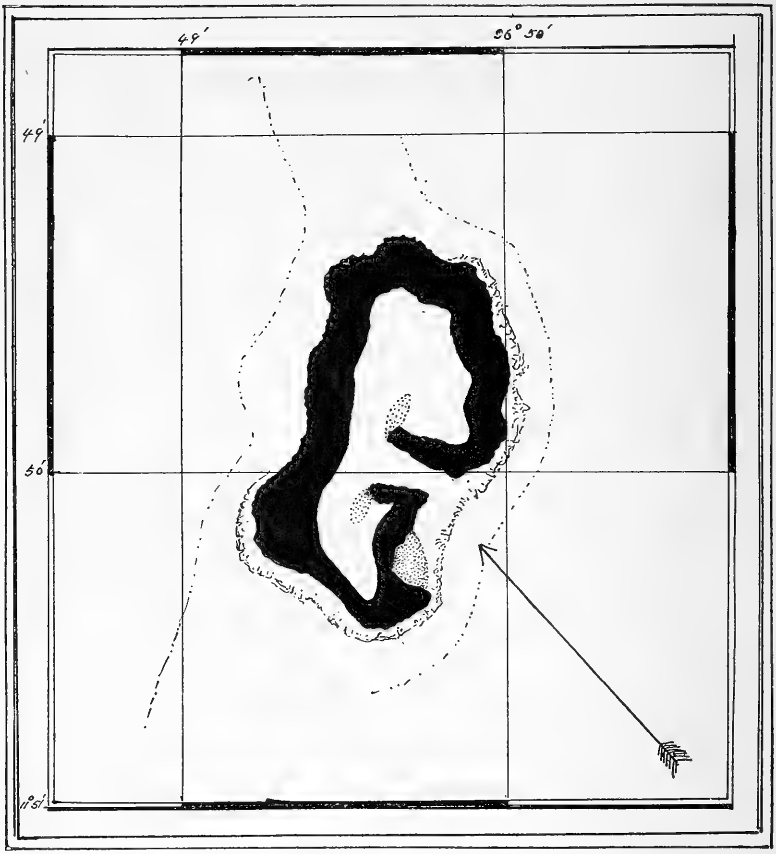


Chart of Keeling Atollon.
(Modified from Guppy.)

palms and a wealth of undergrowth make the whole place a very beautiful one. Vast crowds of sea-birds (*Fregata aquila, F. ariel, Sula sula, S. abbotti, S. piscatrix,* &c. &c.) live on the atollon. At the time of my visit, in June 1906, they were breeding in thousands. The southern and eastern shores of the island are steep, and truly marvellous seas crash on the south-eastern extremity of the land. The western and north-western shores of the island are composed of high sandy beaches, and at the north-western extremity—the leeward point—the barrier is deficient. The landing is a very hazardous one, and without an island pilot, well used to the locality, it would mean almost certain destruction, for the boat must be taken in over the barrier of the western shore, on the crest of a roller. At times, for very long spells together, no landing may be effected. The history of the changes that have been brought about in this very interesting atollon will have to be further referred to; but it is well to say here that it shows clearly an origin from at least two separate windward islands, whose old outlet was towards the north and west. The present gap which gives the sea entrance to the lagoon is the remains of the interval between these two islands, and is *not* the real lagoon inlet, nor comparable with the inlet into the southern Cocos atoll. The interest of the atollon lies in the fact that it shows a further stage of development than does the southern group, and it foreshadows the fate of atolls generally.

CHAPTER XII

THE SUBMARINE BANK ON WHICH THE ATOLL RESTS

The submarine slopes, by which the edges of the atoll reef descend to ocean depths, are perhaps the most important features in the whole of the structure of the atoll.

Every theory that attempts an explanation of the formation of atolls and reefs must be concerned with this decline from wave-beaten barrier to deep-sea bottom. Some misconception in the estimation of the gradient of this slope has probably caused certain inaccuracies in the ideas as to atoll formation. Since there is but very little reliance to be placed on some of the older soundings of very deep water, the nature of the ridge on which this atoll is situated has been always a good deal obscured; and such concrete expressions of its slope as have appeared in publications are shown by more recent soundings to have been mostly fallacious. The statement that the older soundings are often inaccurate is, I think, easy enough to substantiate, for with old-fashioned paying-out gear, errors were extremely difficult to avoid in very deep water.

Ten miles of sounding-line have been paid out, and no bottom found, in a place where the bottom was no more than three miles distant (see Maury, &c.); and, in the neighbourhood of this atoll, the older soundings are often contradicted by the more modern ones. The accuracy of the soundings of Fitzroy around the atoll, in which he found no bottom at 1200 fathoms 6600 feet from the shore, has been questioned by Admiral Sir W. L. Wharton (see *Nature*, June 19, 1890). I had not the apparatus, nor the opportunity, for making soundings; and I do not regret the fact, for deep-sea soundings are not to be made by amateurs, and are impossible without a well-found ship with modern gear. But I may make very definite statements about the depths of the ocean, and the submarine slopes of the atoll. Owing to the fact that I have had the soundings, made by the various cable ships of the Eastern Extension Telegraph Company, placed at my disposal (due to the kindness of Mr. F. Hesse, the General Manager of the Company), I am enabled to bring together a great mass of accurate information concerning the nature of the bottom in this part of the Indian Ocean.

These soundings consist of four different sets of observations. The first, and most valuable, are those made by the cable ship *Sherrard Osborne* when first an oceanographic survey was made in the region of the atoll, in order to test its suitability to become a cable station. The second set consists of a line of soundings, taken by the cable ship *Anglia*, to the west and south of the atoll, along the cable route to Rodriguez, and on to Mauritius. The third set was taken by the cable ship *Scotia*, and the soundings follow the cable route to the south and east to Perth, Australia. The fourth set was made by the cable ship *Magnet*, when sounding over the route taken by the cable north and east to the Sunda Straits. These various collections of soundings therefore embrace a very wide field of the ocean which has been brought within our accurate knowledge, and they furnish very safe ground for any assertions as to the contour of the ocean bed and the atoll slopes.

It is of course unnecessary to say that there are many reasons why these sounding lines cannot be reproduced, but the general information derived from them is sufficiently clear without the construction of a detailed chart of their actual routes. The soundings are taken at frequent intervals, and in the route from the atoll to Java there are 75 different soundings over the 600–700-mile course; and from most of these soundings I have examined specimens of the ocean bottom brought up with the apparatus. For the use of these specimens I have to thank the Telegraph Company and their captains, who have very kindly placed the material at my disposal.

When we come to look at the published sections of this atoll, the thing that is most obvious is the extraordinary abruptness with which the reef land falls to great depths; indeed it was thought that the landing of a cable in such a place would be futile, for the idea is natural that it would cross the edge of the reef abruptly, and hang into space for perhaps a mile or more before it found any support on the ocean bottom. To any one living on the atoll, this notion very easily comes—that the side of the reef is sheer, and falls to ocean depths with practically no break in its descent. I know for certain that most of those who come to the islands, for a stay that averages a year, go away with the impression that the barrier edge is the edge of a precipice of untold depth;—and it certainly looks like it.

When standing far out on the seaward edge of the barrier reef an appearance is presented as though the great masses of *Porites,* which show beneath the waves, are the extreme edge of the land, and beyond them is the dark blue water, which, in this ocean, tells of great depths. It seems as though at the surf-line there was a real edge on which waves broke, and which was the top of a cliff on which the atoll stood. From any inconsiderable height that an island affords this appearance may be seen to be unreal, and only apparent to the observer when he stands at the barrier level. From any greater height, the more gradual descent of the boulders can be seen beyond the breakers; and if a boat be sailed outside the atoll ring, any one may see the coral-clad hillside upon the crest of which the atoll stands.

The barrier reef, which in its submerged portions consists of living corals in large masses, is, for the most part, of light, and often brilliant tints; yellow patches of coral and white sand alternating with the darker colour of deeper holes, and making a conspicuous bottom in the clear water of a few fathoms depth. In from six to ten fathoms the rocks are plainly seen, but beyond that depth the overlying waters become so deep in colour that the brilliant bottom is lost. In places this transition is somewhat sudden, and soundings taken a quarter of a mile from the shore show twenty-five or thirty fathoms, whilst before half a mile is reached, towards the south and south-west, seventy and one hundred and ninety fathoms are recorded. It will be easily imagined that the sudden ending of the brightly coloured barrier rocks in the deep blue water outside gives the impression that the visible shore on which you live falls suddenly into the invisible depths of the ocean.

This is, however, not the case, for it is only into these trivial depths that the fall is abrupt; it is not a fall from shallows to great depths; and in many cases the varied coloured bottom of the boulder-strewn reef may be seen several hundred yards to seaward, gradually losing itself in the deepening blue waters.

Soundings taken a mile from the shore show a depth varying from one hundred and ninety to three hundred and thirty fathoms. On the route towards Perth, Australia, six fathoms were found at 0·95 miles from the atoll and at 1·45 miles the bottom had fallen to two hundred fathoms. On the route towards Rodriguez thirty fathoms were found at 0·90 miles, and two hundred at 1·05 miles. This then is the sudden drop, the descent within the limits of a mile or so into some two hundred fathoms. Two and a half miles from the atoll ring the bottom has fallen to a depth of from four hundred and fifty to five hundred and fifteen, or, roughly, an average of five hundred fathoms at two and a half miles. At five miles a depth of seven hundred and fifty fathoms is registered, but on the cable route to Java the five-mile limit gives a sounding of a thousand fathoms. In other directions one thousand fathoms are not found till six miles away—the old sounding of twelve hundred fathoms a mile and a quarter from the south-east shore being, perhaps, safely neglected. Upon the actual cable route to Australia, the bottom has only fallen to one thousand six hundred and thirty fathoms at a distance of 63·71 miles from the atoll.

Two thousand fathoms depth is found at an average of ten miles from shore, though fifteen miles are passed towards Java, and one hundred towards Australia, before this depth is recorded. Two thousand five hundred fathoms occur on an average at fifty miles, and an average of one hundred and eighty miles are passed before three thousand fathoms, or ocean depths, are reached.

Upon the actual cable lines the three thousand fathoms limit is reached at very varying distances. Towards Java, the ocean depth of 2950 fathoms is not met with before seventy miles are passed, whilst towards Rodriguez one thousand miles of the cable lie in depths less than 2910 fathoms, and the actual cable never reaches a depth of three thousand fathoms. Towards Australia, two hundred and fifty miles are passed, on the cable route, before a depth of 2960 fathoms is reached; and four hundred and thirty before the bottom falls to 3130 fathoms. The greatest depth sounded towards Australia was 3500 fathoms, in Maclear deep, at a distance of four hundred and fifty miles from the atoll; towards Rodriguez 3300 fathoms were met at two hundred and fifty miles from shore, and this depth shoaled again, at another two hundred and sixty miles farther on, into 1000 fathoms. Towards Java the bottom falls away to 3535 fathoms, but 3000 fathoms is the average depth of the trough which separates the atoll from Java. The Cocos atoll is, therefore, the summit of a great roll of the ocean floor which rises gradually, from the ocean depths of 3000 fathoms, at an average distance of something over a hundred miles.

Unfortunately, we do not know the soundings along the line that connects Cocos atoll to Christmas Island, but it may be that the ridge, from which that ancient atoll has been hoisted to a height of a thousand feet, is continuous with the ridge upon which the Cocos-Keeling group takes origin. Again, we have no very definite data of the condition of the ocean bottom to the north of the southern atoll, but it seems certain that a submarine ridge streches for fifteen miles to Keeling atollon; and it is said that this ridge is nowhere deeper than a hundred fathoms; indeed in calm weather it is said that the bottom may be seen in sailing between the two atolls.

To the north of Keeling the ridge probably stretches to Glendinning Shoal—a reef of which I have no definite knowledge, but I have been told by one of the captains of the Clunies-Ross schooners that he has often seen the discoloration of shallow water when on some of his numerous runs to Batavia.

It would be of great interest to sound over this northerly continuation of the ridge to determine its limits and its characters.

Soundings directly to the south of the southern atoll are also rather unsatisfactory, and the southern limits of the submarine ridge are quite uncertain; but it seems likely that the southern slope is more abrupt than that in other directions.

Along the sounding-line to Java, I have examined samples of the bottom brought up with the sounding-gear, and these samples, on the whole, confirm the state of things shown in the map of ocean bottom furnished in the *Challenger* reports, where the atoll is shown to stand in the midst of an area of Radiolarian ooze.

I have not examined the samples obtained by the sounding expeditions in the other directions, but the naked eye appearance of the specimens is described by the staff of the cable ships as being successively "coral fragments," "coral sand," "fine sand," "sand and mud"; and then, from a hundred miles from shore and onwards, "brown mud" was the unvarying nature of the bottom. In the neighbourhood of the atoll, coral fragments and pieces of *Nulliporæ,* with a coating of a whitish clay, composed of *Globigerina* and *Orbulina* remains, constitute the commonest sample. Adown the sides of the submarine slope, to a depth of over 2000 fathoms, the remains of organisms with calcareous skeletons far outnumber the siliceous organisms, and *Globigerina* and *Orbulina* are the predominant forms. This is the "fine sand" and "sand and mud"; its colour is greyish, and it has a distinct granular appearance. The "brown mud" is made up mostly of the siliceous remains of *Radiolaria*, &c., mixed freely with a brownish unorganised deposit.

From all samples there was a fairly large proportion of this unorganised débris, which consisted, in great part, of particles of pumice and irregular mineral crystalline forms, and with the deposit, from greater depths, a large admixture of the spicules of sponges was always found. From the limit of the drop of the reef, therefore, the foundation of the atoll would seem to be a great sedimentation slope, and certainly not a steep peak, rising suddenly from ocean depths to a wave-washed reef. The slope is certainly nothing like the picture that Guppy—its last investigator—made of it, for he said in a letter to Sir John Murray, published in *Nature*, p. 237, 1889: "Here the submarine slope slopes gradually down to 20 or 30 fathoms, but beyond this the descent is precipitous." The steep descent comes first, the gradual slope comes after. We may take the slope from the reef drop, to 2000 fathoms —that is to a distance of ten miles from the atoll—at an almost uniform gradient of one in five. From ten to fifty miles the slope is about one in eighty, and from that point onwards, at about one in a hundred, to the depths of the ocean. In other words, the *Globigerina* ooze slope is one in five; the *Radiolaria* ooze slope is about one in a hundred. When a section of this great ridge of ocean floor, with its flat top of reef, is made to scale, it is at once seen that a very wrong importance has been ascribed to certain features of an atoll. The islands are trivial things, the lagoon merely a slightly submerged reef, and the barrier an inconsiderable ring around its edge; it is only by a proper understanding of the relative proportions of these parts that a right interpretation of their origin may be arrived at.

CHAPTER XIII

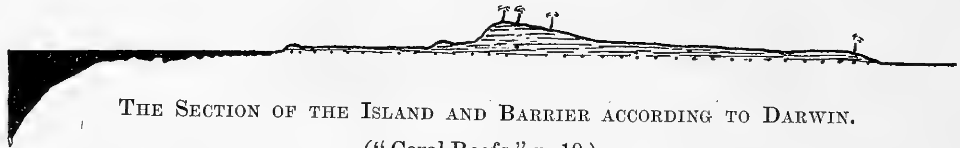
THE STRUCTURE OF THE BARRIER

For the purposes of description alone, it is necessary to give different names to different portions of the rock ledge that forms the outskirts of the table-land of the summit of this submarine ridge.

In the giving of many names to portions of a whole, much confusion may be caused, and a loss of the clear idea of the whole may be suffered in searching for the origins of the parts.

By the term "Barrier" is generally understood the ledge of the rock that stretches from the seaward margin of the land to the edge of breaking surf; and it is certainly fittingly named. But that ledge of rock is only a portion of a much larger bed, which forms the basis of the islands and even the rocks of the lagoon shore. In description some subdivision is necessary, but it must be understood that the several parts are in continuity, have been formed by the same agencies, have fulfilled the same functions, and constitute one homogeneous whole. The ledge of rock from the surf-breaking edge to the rising land of the island is conspicuous, its more or less level surface becomes exposed in varying degrees with the movements of the tides, and its continuity is unbroken to the first rise of the land. Here, at the seaward beach, its structure becomes more or less confused; loose fragments of broken coral boulders lie scattered on it, roughly strewn towards the sea, piled by the waves towards the land, until the piling up has become so considerable that the level which constitutes the island dry land has been attained. But the barrier properly speaking does not end here, for under the piled-up fragments of its landward margin its solid level stratum can be readily

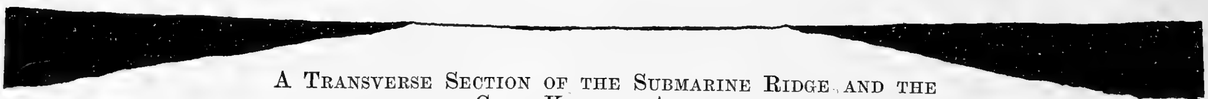
Fig. 49.



The Section of the Island and Barrier according to Darwin.

("Coral Reefs," p. 19.)

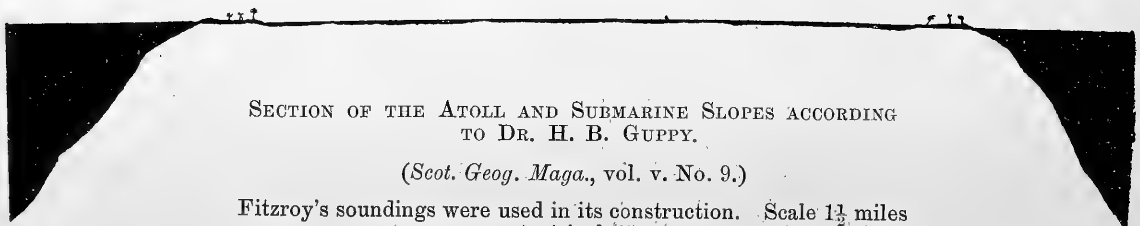
Fig. 50.



A Transverse Section of the Submarine Ridge and the Cocos-Keeling Atoll:

The submarine slopes being followed for a distance of ten miles upon either side of the atoll.

Fig. 51.

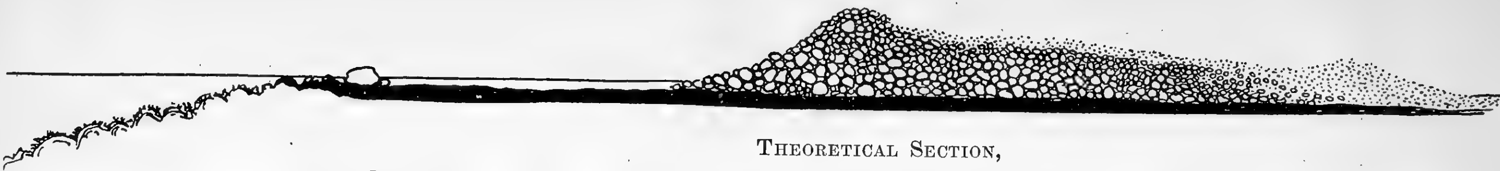


Section of the Atoll and Submarine Slopes according to Dr. H. B. Guppy.

(*Scot. Geog. Maga.*, vol. v. No. 9.)

Fitzroy's soundings were used in its construction. Scale $1\frac{1}{2}$ miles to 1 inch.

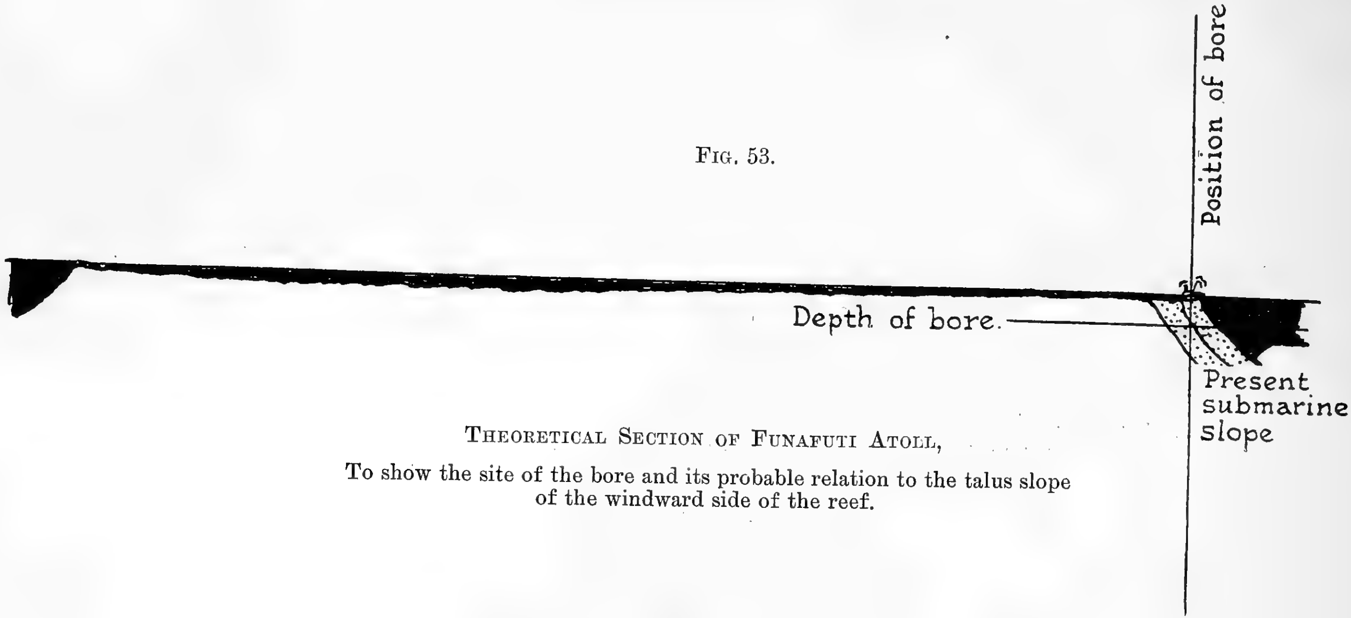
Fig. 52.



Theoretical Section,

To show : i. The breccia platform (black). ii. The island pile of coral fragments and sand. The tide is awash on the barrier, and one large boulder is shown, cast up on the seaward edge.

Fig. 53.



Theoretical Section of Funafuti Atoll,

To show the site of the bore and its probable relation to the talus slope of the windward side of the reef.

found. Under the accumulation of coral boulders, sand, and vegetable débris, which forms the island itself, it still continues unbroken; and on the lagoon side of the island again, in many places, it juts out as extensive slabs of rock, breaking the sand stretches which form the greater part of the lagoon shore.

This is all barrier, all one continuous layer of rock, all formed in the same fashion; and the function which the seaward edge now serves has in times past been carried on by every portion of the layer. Although the term "Barrier," as generally used, cannot perhaps be properly applied to this entire rock stratum, still it is only by considering it as a whole that a right understanding of its origin can be arrived at. To-day the seaward part alone acts as a functional barrier proper; in the geological to-morrow it may be buried under the land accumulation which it has helped to form; and in the geological yesterday that cemented layer of coral fragments which is found everywhere under the islands was the functional agent in resisting the waves, and in forming the dry land. Since the seaward portion alone can be called the "Barrier," and since the whole layer will have to be referred to again, we will call it the Breccia Platform, for it is a mosaic inlay of coral fragments, cemented together into a solid platform, stretching from surf-line to lagoon.

The barrier is the pioneer of the island, it is dry land potentially, and on the varying influences of wind and waves depends the disposition of the land for which the pioneer has laid the foundation. The dry land that the barrier has called into existence is in reality broken pieces of barrier, for the entire atoll is a débris formation, and the débris is recruited from the seaward edge of the barrier for the most part.

Imagine for a moment all this débris to be removed: no loose fragments of coral, no sand, no vegetation piled up. All that would remain would be a flat and roughly level ring of coral rock, firmly cemented, and making a broad and flat margin to the lagoon; only the Breccia Platform would be left in fact. This margin would be mostly awash; the waves would break on its seaward edge and the ocean swell rush over into the lagoon, exactly as it does to-day where the gaps in the dry land ring let the ocean and the lagoon communicate.

The Breccia Platform is, therefore, to be seen in its simplest form in the gaps in the atoll ring, in the places where no islands exist, and here it is usually called "Barrier" in its whole extent. In such places as this it may be easily examined at low tide, for, on a calm day, one can walk from one island to the next through the water which washes the rock flat. At the seaward edge of the flat is the line of surf, and the contrast between the blue rollers on the one side and the surf-washed rocks on the other is very marked; it is this contrast which gives the impression that the barrier edge is like the side of a house against which waves beat. Standing on the barrier, as near to the breakers as is possible, an appearance is presented as though at a line a few yards from you the deep ocean ended, and its blue rollers hit on a sharp upstanding edge of rock that caught their feet and scattered them in spindrift among the rocks on which you are standing. But this appearance is really a delusion, and on a very calm day, even from the level of the barrier, discoloured patches of bottom can be seen through and reflected in the rollers before they break; and from such trivial heights as it is possible to attain on a coral island, these patches are seen to stretch a long way to seaward of the breaker line. Moreover with the rise and fall of the tide this surf-line moves, coming nearer to and retreating further from the land; and no matter where the line be at the moment, the appearance presented is always the same—a sheer sharp edge on which deep ocean breaks.

The falling away of the rock ledge into the ocean is not in reality such a sudden fall as has been imagined, and its falling to the lagoon is very much more gradual. The barrier is then a wide rock flat, falling to the ocean at its outer edge, shelving to the lagoon at its inner edge, and extending almost entirely round the summit of the ridge.

There can be no doubt left in the mind of any one who watches the great ocean waves broken at the edge, and swirl and boil across the flats, only to fall back in broken confusion to the hindrance of the next oncoming roller, that there is something in the moulding of the barrier reef itself that makes it so successful a resister of the ocean's terrible and ever-acting force. No wall made by man could ever hope to withstand for long the perpetual bombardment of those great blue rollers of the Trade-driven Indian Ocean. The great secret of the success of the barrier reef is to be found in the peculiar curvature of its wave-swept surface. From the uneven edge on which large rocks are hurled and firmly seated, and on which the first force of the waves is spent, the barrier runs shorewards as a smooth Nullipore-covered platform which has a slight curve upwards. The barrier is a flattened arch, and the peculiar pitch of this arch is suited to the most efficient spending of the force of the waves. The waves that the boulder-guarded edge has broken become further spent in sweeping across the convex seaward margin, and finally exhausted by the uneven flats which line the shore; whilst the backwash from the spent waves seethes among the flats, and pours backwards with increasing force as the outer slope is reached. Every broken wave helps to be the undoing of its successor.

The only places in the atoll ring in which this rock flat is wanting are on the north-west, or leeward, side of the group; and here, although no breaking surf is present, and no sea-washed rock flats stretch outwards, the same coral boulders lie at a somewhat greater depth uninfluenced by the waves.

The flats of the barrier are entirely composed of coral, living or dead; and the coral that is living is a very small fraction of the whole. The dead shells of molluscs, the cast ectoskeletons of crustacea, the hard parts of echinoderms and other marine animals, are too unimportant a contribution to invalidate the statement that the barrier is entirely the product of corals.

In certain parts of the island ring it is true that the encrusting *Nulliporæ* constitute a very important part of the barrier. This *Nullipora* growth appears to be a very varying factor in atoll formation. Darwin described the *Nullipora* bed in this atoll,* and Dr. Guppy also called attention to the unusual thickness of its growth.† In describing the characters of the coral reefs of the Solomon Islands, Dr. Guppy ‡ came to the conclusion that *Nulliporæ* formed only thin layers that were unimportant in barrier building, but three years afterwards, when he came to describe the Cocos group, he mentions the slabs two feet thick which are commonly to be found broken from the surface of the outlying barrier boulders. It would appear that in these islands the *Nulliporæ* play a more than ordinary part, but as their presence is not universal at all parts of the atoll ring, it is evidently not at all essential to successful barrier building. On the other hand, the *Lithothamnionidæ* are particularly insignificant in the atoll, and they cannot possibly be of the importance that, in the Maldives and Laccadives, Mr. Stanley Gardiner § supposed them to be. They are found only in certain sites, far from the barrier edge, and the total bulk of all their remains cannot make a very great difference to the sum of the atoll's building assets.

From ocean to lagoon the character of the coral flat varies, and the changes that are seen are natural and easily explained ones; they throw a considerable light on the formation of the barrier, and of the whole structure of a coral island, or an atoll.

In the first place, the various forms of corals have a fairly defined site of election; but for all that their distribution is capricious, and is only roughly to be argued for any given spot of barrier from the knowledge gained at any other spot. From reading of accounts of the corals of atolls, the impression is easily gained that a remarkable order in their distribution exists; the corals of the reef and those of the

* "The Structure and Formation of Coral Reefs," p. 24.

† *Scot. Geog. Maga.*, vol. v. No. 9, p. 460.

‡ "Characters and Mode of Formation of the Coral Reefs of the Solomon Islands," *Proc. Roy. Soc. Edinburgh*, July 1886, p. 859.

§ "Fauna and Geography of the Maldive and Laccadive Archipelagoes, 1902," vol. i. part 2, p. 175.

lagoon are described, as well as those of all the intermediate situations; and the idea remains that a species is either a reef coral or a lagoon coral. Now it is as well to say at once that the distribution of the corals of this atoll does not follow any such hard and fast lines. There are several species which are always more abundant on the barrier, but they are also to be found in the lagoon, just as are the more typical lagoon corals to be found on the barrier. The essential feature in the distribution of atoll corals is that it is a distribution of types, and *not of species;* the barrier types are not species but are the barrier forms of lagoon species, and vice versa. The subject of the modification of the corals is an interesting one, and must force itself on the collector as he gains experience; for as he first makes his collections from the lagoon and the barrier he begins to believe that the number of species is without end, and it is not till he has spent some time in this pursuit that he comes to realise that the species are in reality few, but the adaptations of the corals to their environment are legion. The student of corals who should see these collections only when far from their site of growth would be entirely without a clue to account for the endless range of forms which any casual visitor to an atoll might collect. There are many factors which tend to modify the outward form of a coral's growth, and to confuse any one who, without a knowledge of their habitat, would attempt their classification. This point has been studied in connection with the corals themselves. When distribution is spoken of here, it is this distribution of types that is meant, a very different thing from a distribution of separable species.

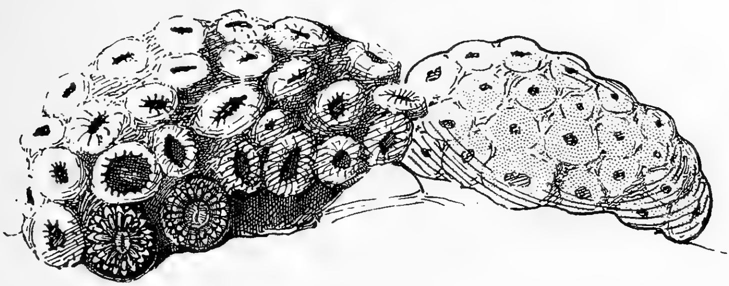
It has been said, and much weight has been given to the assertion, that the nearer to the edge of the barrier one goes, the more luxuriant becomes the coral growth. In this atoll, at any rate, this is definitely not the case; and any arguments for the formation of the atoll based on this assumption cannot be valid. It is not necessary to assume that corals flourish best in the surf-line because of the better aeration, or that they receive a more abundant supply of food, and so grow better; for the statement that these assumptions would explain is a statement that facts do not justify, and the assumption would appear to be far from true. It is true that some corals predominate on the seaward edge for the very reason that, as the area most commonly exposed to the surf is reached, many species that cannot withstand the rough usage are left behind, and the few dominate the picture. In that area on which the surf beats—the seaward edge of the barrier—living coral growth reaches its minimum of individuals as well as of species. The most luxuriantly growing of all the corals are not even represented far out on the barrier, for the simple reason that they could not withstand the conditions which obtain there. Towards the lagoon the corals increase in number and variety, and in the lagoon itself are some of the most luxuriant of all the growths, branching and laminated forms whose habit of growth does not permit of a successful struggle for existence in the perpetual tumble of rough water.

It must be borne in mind that these remarks apply only to the rock flat—the simple barrier in its whole extent—in those gaps of the atoll ring in which no islands are formed. Where an island is present, a disturbing factor comes in, for the island is a piling up of débris which rises from the barrier. The nearer the island therefore, the more the barrier becomes exposed at low tide; and although it is by no means true to say that corals cannot withstand an exposure of some duration to the sun and air, still they do not flourish best on any part of the barrier normally exposed at low tide. It is true, therefore, to a certain extent, to say that the farther one goes seaward on the barrier *from an island*, the more luxurious becomes the growth of coral; but this is an after-effect of the formation of the island, and must not be used as an argument in a theory to account for its formation.

I have stated that there is a roughly defined distribution of the types of corals on the barrier, and this distribution is one that is easily accounted for. The conditions of life on the seaward edge of the barrier are peculiar and severe; the competition for life takes place in a perpetual crash and rush of surf, and more than this, in an environment where, ever and again, loose fragments come hurtling along at the mercy of the waves. These conditions completely eliminate any delicately branching forms of coral, and only those which grow as rounded knobs, as stout short branches or plates, or as encrusting layers can hope to flourish. To live at all in that tumult of waves and moving masses of rock, only those things which are very hard and rounded, or are very soft and yielding, can exist free, all else must hide in crevices or creep in burrows. Of the very soft things which can stand these severe conditions are many of the *Alcyonaceæ*, which live in great abundance in depressions of the seaward edge of the barrier, and of the hard and rounded things are those most typical of all the barrier corals, the massive *Porites*.

An "outer edge" of the barrier has been spoken of, but the use of this phrase by no means implies that here the barrier ends. The submarine slope shelves away from the land; its line of retreat being the barrier flats, and on the strength of the waves and the amount of the tide variation will depend the slope of these flats. At dead low tide the surf-line has receded from the land until it has travelled a hundred yards or so, and has fallen by three or four feet from its high-water mark. At this low tide surf-line therefore will be the junction of that portion of the coral bottom which is subjected to the action of the surf, and the portion which lies undisturbed below. Storms, and the action of high waves, have at intervals displaced large rocks, and have then been powerless to trundle them up the flats; and so the "outer edge" of the barrier is in many places marked by the exposure of large and irregular rock masses at low tide. It must always be borne in mind in accounting for the disposition of the different parts of the barrier, that there is a perpetual force acting over a wide area, but the intensity of this force varies at different points of its activity; and its action is inconstant throughout. At the seaward edge its lifting force is greatest, for here the surge and swell of larger waves is felt; it is here, therefore, that the largest rock masses are moved. But again, its time of action is short, for only at dead low tide can it exert its full force; and so it comes about that large masses are displaced and frequently reseated on the "outer edge" of the barrier. It is over the intermediate part of the barrier that the maximum force is felt, for the crashing surf has the

Fig. 54.



Drawing of a Living Specimen of an Alcyonarian Coral which is abundant in the Rough Water of the Barrier.

Two Zooids are seen completely expanded and several others in the passive stage between contraction and expansion.

power to act during the rise and during the fall, and at all times, except at the very lowest spring tides, is this intermediate portion a battle-ground of surf and rock. Here, therefore, are the flats of level cemented rock, free of loose fragments, free of jagged edges, and free too of living corals; boulders are washed across and tend to level everything, and only the *Nulliporæ* may flourish. It is here that the finer particles are forced by the spin-drift, as by a sand-blast, into every crack and rift of the shore-washed rocks; this is the factory of the breccia. At the inner or shoreward edge of the barrier the wave action is powerful during high tide, and intermittent during the rise and fall. It is here that the smaller boulders come to rest; this is the factory of the débris which makes the island. It is easy then to see that on the barrier, as it stretches from an island to the ocean, actual living coral growth is not abundant. It is only in pools and under the shelter of rocks that corals can retain a foothold at all, and the picture of the active corals flourishing in the crash and swirl of the breakers is not a true one. We have seen that, as the barrier in between the islands is followed into the lagoon, the coral growth becomes more abundant; and again in the ocean, outside the surf-beaten edge, the active living coral growth increases, and in the six fathoms or so in which it is possible to see them clearly, large masses surpassing anything on the barrier, or in the lagoon, flourish on the submarine slopes.

Although living coral forms so small a portion of the actual barrier, still there is no part of the barrier that is not made of coral, but it is the dead and altered remains of past generations. The idea is common regarding the building of coral islands, that the coral grows and grows, and as it dies it forms the basis of the island; that in fact the coral is ever growing up, and the calcified part in time reaches to such a level that dry land is formed in the midst of the ocean. This of course does not, and cannot, happen. The barrier has not grown up by the growth of coral *in situ*, and the island has not come into existence through the direct activity of coral growth. Even those few living corals on the barrier are for the most part waifs and strays, living where they do because they have been washed there, and, as is their wont, have fixed themselves to the first safe anchorage that comes to hand. In the coral beds which lie on the submarine slopes of the atoll ridge large masses of *Porites*, and other forms, are ever growing in great profusion, and the rock is being slowly built up which will one day, during storm, be moved from its bed, lifted by the swell, and hurled shorewards by the surf. Many large masses are no more than lifted from their beds, and left to stand as outguards of the barrier, their sides becoming the site of further coral growth so that in time they become cemented in their place by the growth of the hardier species of barrier corals. Smaller masses are trundled farther toward the shore, and a belt of coral wreckage is deposited from the low-water surf-line of spring tides, to the high-water line of

THE BARRIER FLATS AND SEAWARD BEACHES OF PULU TIKUS AT LOW TIDE.

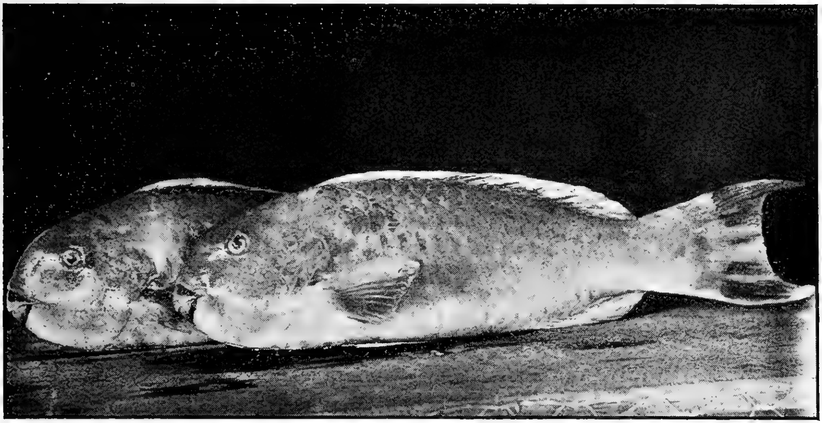
storms. It is this belt of wreckage, which happens to be composed of coral, that forms the barrier of coral islands. Now this boulder-strewn belt of shore varies in different parts of its breadth ; to the ocean edge are the large masses and deep pools with their sheltered and living corals, and inside this is the broad smooth belt formed by the perpetual sea wear.

Every block on this belt becomes firmly embedded in the platform, and cemented fast to its neighbour, and the whole surface is levelled by the waves and the fragments which they carry. Coral sand, formed in various ways, is driven into every chink, and a fine breccia of dead and altered coral is formed. The breccia becomes for the most part covered with living *Nulliporæ*, but it is not, as a rule, the site of any living coral growth. The landward edge remains loose, for there the fragments are trundled beyond the reach of ordinary waves, and on the breccia which has been formed in the past the piles of rounded sea-worn coral fragments lie; and of such fragments the coral island is formed. The structure of the barrier reef varies in different parts of the atoll ring, and it is different on the leeward and windward sides, as might be imagined. On the windward side, in such places as the neighbourhood of Pulu Atas, the barrier reefs are of great width, and stretch lagoonwards as long sand flats, which extend in between the islets as spits and shallows, far out into the lagoon. The smaller particles are swept on the farthest, and the fine sand formed from disintegrated corals and shells makes a gradually extending silt which has filled the ancient lagoonlets of the windward islands, and is gradually shallowing the windward side of the lagoon itself. Here too the barrier rock is evidently the most changed by extreme age, and the coral forming the breccia is often so altered that, in the finely tessellated fracture of the windward barrier, its original structure is often difficult to recognise. Amongst the other factors which tend to modify the structure of the barrier reef are the entrance and exit places of the currents of the lagoon, and remarkable changes take place in the more variable portions from time to time. During the early months of the year, at the eastern extremity of Pulu Tikus, a spit composed of rock fragments and sand, will form and extend far out into the lagoon, only to wane gradually during the next few months, with the deposition of sandy beaches at the western end of the island.

The barrier is the home of a myriad forms of life, but only those need be mentioned here which have an influence on its architecture, and so on the formation of the atoll. Fish in thousands live in its pools, and come and go with the rise and fall of the surf-line; and one of the strangest and most beautiful sights of the barrier is the crowd of brightly coloured fish seen mirrored in every oncoming wave. As you stand on the coral beach it seems that every wave must wash ashore these wonderful fish, and yet, as the sea sucks back and the foam clears, they are still quietly feeding in the clear water where there is only just enough depth for them to swim. Many of these fish are amongst the most important agents in the making of the coral sand which forms the cement of the island and the silt of the lagoon, and the most active of them all are the beautiful *Kakatua* (*Scarus*, sp.), the most conspicuous of the barrier fish. Darwin and Forbes, during their visits to the islands, watched these fish, and asserted that they fed on the living coral; but this is certainly not the case. As these bright green, or cobalt-blue, *Kakatua* go slowly along head downwards, and with a frequent flapping of their bright tails above the water as the wash flows back, they seem to be grazing among the corals as beasts among herbage; and if their stomachs are opened they are found to contain coral ground down to a very fine sand. But the coral from which this sand is made is dead, and has long been dead; for it is the coral of the cemented breccia, and it is only scraped off by the fishes' hard beaks as they rasp the boulders for their covering film of algæ.

If the feeding-spot of the bright fish be noted, and the boulders over which they have fed be examined, it will be seen that on every rock is the characteristic bite where the alga has been scraped from its hold, but any living coral will be found quite untouched. The part played by these fish in the making of sand must be considerable, for every rock of the barrier is scored by their hard beaks; and from ten to fifty or more will be in each of the many shoals which pass

FIG. 55.



THE *Ikan Kakatua Ijou* (*Scarus*),

Showing the hard beaks with which they score the coral boulders.

along the surf-line with the turning tide. As the average weight of dry sand in an individual's intestinal canal is nearly two ounces, the bulk of coral rock converted into sand by these creatures must be very great indeed. Other animal agents in the production of sand are the Holothurians, the sea-slugs or bêche de mer, of many species that lie scattered about all over the barrier and lagoon in countless thousands. They are from three feet long to less than an inch or so, and they are merely hollow animal tubes which act chiefly as sand-filters. They fulfil on the barrier and in the lagoon very much the same functions that the earth-worms do on land, for they pass through their bodies large quantities of dead material along with their food. The sand is taken in at the hard mouth, triturated and separated from its living inhabitants in the long alimentary canal, and ejected as a fine white mud freed from animal and vegetable particles. The wash of the waters must in a great measure mask any influence these

Fig. 56.

Photograph of Holothurians feeding at the Bottom of a Barrier Pool.

The photograph was taken through some two feet of water, without disturbing the Holothurians in any way.

animals have, in common with the earth-worms, on the alteration of level or position of the free-lying boulders, but their handiwork must be of some importance by reason of their very numbers. Countless worms bore the rocks and make tunnels on their surface; numberless molluscs live in the nooks and corners of every boulder, and when they die their shells are added to the sum of débris, but as workmen in the building of the barrier their rôle is an unimportant one. In addition to the animal agencies in sand-making, is, of course, the very

BARRIER POOLS LEFT BY THE FALL OF THE TIDE, PULU TIKUS. THIS PHOTOGRAPH SHOWS THE ENCROACHMENT OF THE SEA AND THE UNDERMINING OF COCONUT PALMS—ONE OF THE TEMPORARY PHASES OF ATOLL BUILDING.

much more important one of the grinding movements of the water. This is one of the greatest forces with which we have to deal in estimating the physical surroundings of the atoll, for it is carried on without ceasing. Every wave moves some fragment and triturates some particle, always tending to make finer and finer the broken pieces of coral which are for ever being removed from the coral beds beneath the surf-line. The branches and boulders become chips and fragments, and these in their turn are washed to and fro, becoming smaller and smaller in the process, and a diminishing scale of coral material is created, in which the first term is the growing boulder and the last is the fine white mud.

The great quantities of sand formed in a coral atoll may be realised when the silt banks are watched in their growth, and when it is remembered that not a tithe of the sand ever reaches the lagoon, but lies on the submarine slopes of the ocean bed for a distance of several miles all round the atoll.

The structure of the barrier reef is then in reality a simple one, it is a great platform built round the top of a large flat plateau, and, as a rampart, it encircles the summit for a distance of some seventeen miles.

CHAPTER XIV

THE ISLAND BEACHES

(A) The Seaward Beaches.

As the barrier varies in different parts of the atoll ring, so does the beach which rises from it, and so too do the trivial elevations that may be dignified by the name of the "coast-line" of the islands. This is but the natural outcome of the fact that the different aspects of the circle are exposed to different physical conditions. The physical forces that build the dry land are not uniformly distributed around the atoll, and the natural consequence is that the disposition of the land varies as its creative forces vary. Were we to have an accurate model of any atoll, we could tell from its examination which was its windward side and which its leeward, which were the islands exposed to the ocean's currents, and which were those protected from their scour. Since the building processes at work on the seaward side of the islands are different from those which shape the lagoon shore, it is but natural that the sea beaches and the lagoon beaches should differ in their nature. The ocean beaches consist essentially of a sloping pile of coral débris piled up on the breccia stratum as a basis; they form the merging-line of the island dry land and the barrier flats.

On the ocean side there are places where no beaches can be said to exist, for the island rises abruptly from the barrier flats. In such places a succession of miniature terraces, two or three in number, rise as steps of consolidated breccia and bear on their top step the steeply piled up boulders that make the shore-line of the island. In other places there has been a denudation of the island land, and the tide-washed flats, in which the roots of former generations of coco palms may be found, merge gradually into the island débris, there being no heaping up of boulders to resist the sea's encroachment; and here, with high tides and a strong wind, the sea will rush over the island in an alarming manner.

Although the seaward beach is usually made up of chips and fragments of coral, still, in some places, both the lagoon beach, and the sea beach may be composed of fine coral sand. Where the island is a pure sand formation it is generally sheltered on its seaward side by the accumulation of large boulders. Within the shelter formed by pieces of detached barrier, and on a firmly cemented rock basis, is piled fine sand and small débris which gradually slopes from the seaward edge upwards to the lagoon shore. Such a structure is the beach of Pulu Bras and of Pulu Pasir. No large pieces of coral enter into the formation, and on either side of that portion of barrier on which they have their basis, sand spits run out towards the lagoon. The seaward beaches are seen in their most perfect form to the windward of the atoll, and at the southern point of Pulu Atas, and at the south-east aspect of Keeling atollon, the beaches rise steeply piled to a height of twenty feet or more. No better idea of the wonderful force of the Trade-driven waves can be gathered than by studying these piles of massive boulders tossed up by storms. In these windward beaches there is very little sand, save that piled by the wind beyond the reach of the ordinary seas.

Of whatever formation the beach may be, it is its chief characteristic that, in its minor details, it is perpetually changing with the cycle of months and years; and a daily walk round an island, during a year's progress, will note perpetual alteration in the disposition of sand and rock, in the distribution of silt bank and channel; each changing always as the currents around the atoll wax and wane locally. To-day a boulder-piled rise will merge to the sea by a sandy beach and form a temporary spit, on which the cast ectoskeletons of crustacea, the dead echinoderms, shells of all sorts, and algæ, will come ashore in profusion; and in a few weeks' time it will be gone, and the breccia platform will be laid bare to the rise of coral boulders.

The nature of the beach depends entirely on the force of the sea which usually beats upon it. Where the waves are normally high, and the shore is exposed to the full force of the Trade-driven swell, the surf will rush over the submerged flats at full tide, and exert its whole energy on the boulders of the beach. It is in such places that the island rise is abrupt and the beach is made up of great masses piled one upon the other. All the sand, and the smaller débris, is washed away, only to be deposited on any part of the shore where a normally calmer state of things prevails. The character of the beach is, therefore, a map, which, when studied aright, gives up its story of the effects of the currents and winds, and the negative or positive movements to which the shore platforms have been in the past subjected; but the temporary piling of sand or its temporary removal must not be taken as evidences of actual changes of level, or of constant action. On the seaward beaches is thrown the flotsam and jetsam that reaches the group from the outside world, and one of the principal items,—one that has in many places caused a considerable alteration in the character of the islands—is pumice. The greater part of the pumice found in the group arrived after the eruption of Krakatua: being washed up in 1883 in vast quantities. This pumice, lightest of all the wrack that the sea has piled up, has been carried for varying distances into the island from the seaward beach, and shows, as an index, the limit of surf action in the island building that has been reached in twenty-three years. It occurs in great quantities as rounded sea-worn masses, some being a foot and more in their long axis, but the majority varying from the size of marbles to that of cricket balls. Besides the Krakatua pumice, which lies to-day mostly on the seaward beaches, and for a few paces into the island itself, there is older pumice which may be found almost anywhere in the breadth of the dry land. Pumice has been arriving from somewhere ever since the first appearance of land in the atoll ring, and has, during the period of its stay, undergone much decomposition. The Krakatua pumice is almost uniformly grey, and is fresh and clean: but pumice exists far from the sea that has become impregnated with foreign substances, and is in many places entirely fragmented. The various stages of pumice degeneration may be traced from the sea beach to the interior of the island. Some of the pumice has never been grey, and rounded blocks of a black and cinder-like substance are here and there found in the parts of the island where pumice has been most freely washed ashore. This pumice does not appear to belong to any one particular period, for it is found to-day on the beaches, and in the islands, but its composition wherever found appears to be the same, and, on fracture, its internal part is always shining and fresh-looking, if it be picked up on the beach or far in the centre of an island. Pieces of wood, the timbers of ships, well covered with barnacles and often with portions of copper still attached to them, float ashore from time to time, and in the history of the islands many interesting finds have been made.

Many hard seeds and seed-pods are washed ashore with every high sea, and it is an interesting fact that there are quite half a dozen commonly found seeds, which will grow if planted, but which have never, by the agency of waves or birds, succeeded in making a footing in the islands. Various large beans are common on the beaches, and I have succeeded in growing them, but in all the islands there is no plant of their kind that has grown from a sea-tossed waif. The waves transport the seeds to the high-water mark and leave them there, and there seems to be no agent in the atoll to effect their removal to a suitable site for growth to commence. Rarer finds are large masses of gum resins whose place of origin I do not know. The ocean beaches are the resting-places of all sorts of jetsam from the barrier and the coral beds which lie upon the submarine slopes of the atoll. Shells in great variety, coral fragments, the harder portions of crustacea and echinoderms are thrown up in great profusion by every tide. It has repeatedly been stated, and very often doubted, that the dead masses of some corals will float. Dr. H. B. Guppy found many large blocks of coral in the atoll, which when returned to the sea were found to float buoyantly.* These coral masses are not at all uncommon on the seaward beaches, they are mostly sea-worn and ancient, and, so far as I observed, all belonged to one species of massive *Astræa* with very large zooids. The skeleton floats by reason of the many spaces securely walled off by the septa. The most interesting thing about these stranded lumps of coral is the fact that no species at all like them is to be found living in the atoll. In the ocean between the atoll and Java Heads, and in the Banka Straits, I have seen these floating masses pass by the ship in company with the smaller lumps of pumice which seem to be for ever floating in the ocean in this part of the world.

Some of the masses are very large ; one that I found on the seaward beach of Pulu Tikus was nearly three feet in diameter ; it was a difficult undertaking to roll the great mass back into the sea, and yet, when at length it reached the water it floated readily. It had been long in its position at the top of the beach, and it must have been a time of severe storm that tossed it beyond the reach of the normal waves; for though it was left floating, no sea at that season was powerful enough to heave it back again, and, after bobbing along the shore of the island for many days, it was lost sight of. Portions of this boulder would not float in fresh water, but this is not invariably the case, and some floating boulders are freely buoyant in fresh as well as salt water.

(B) The Beaches of the Lagoon Shore.

In contrast to the surf-beaten, rock-bound shore which stretches along the ocean side of the islands is the calm sandy beach—a place of lapping waves and gentle slopes—by which the island dry land falls to the lagoon. The lagoon beach is typically composed of sand of a peculiar whiteness which the sunshine makes dazzling, and which is entirely composed of fine particles of coral, mixed only with fragments of broken shells.

* *Scot. Geog. Maga.*, vol. v. No. 6, p. 287.

PLATE VII.

THE LAGOON SHORE OF PULU TIKUS, TO SHOW THE SAND-PILING BY A WESTERLY WIND.

This sand is made in many ways which will need detailed examination, but the most important of all the agents in its making are the grinding movements of the wave-driven boulders on the shore platform, and the myriad beaked *Scari* which are perpetually reducing dead coral masses to fine sand.

The sand is the lightest of all the degradation products of the coral, and is carried the farthest both by the waves and by the wind; it is the fluctuating currency of the land, and is deposited and swept away, accumulated and withdrawn, as it makes and unmakes new land. In all the fluctuations of this sand movement there is a compensation, and if a westerly wind piles up the lagoon shore a foot higher with sand at one point of the atoll ring, it has robbed some other part, and has left a breccia platform exposed, instead of a gently sloping sandy beach.

The great extent of the inner margins of the island ring consists of this white sand beach on which lines of *agar-agar*, and other lagoon algæ, mark the excursions of the tide; but in places it is broken by breccia platforms, exactly like the shore platforms of the seaward barrier. These rock layers, often broken and displaced by the sucking action of scours and eddies, stretch out from the accumulated island sand and run far into the lagoon, becoming continuous with the dark patches which break the stretches of blue-green water, and mark the site of the lagoon breccia rocks.

It must not be imagined that these breccia slabs, found on the lagoon shore, have been formed *in situ* under the present conditions. The only site of typical breccia formation is the surf-beaten barrier, and the breccia slabs of the lagoon shore were laid down in the distant past, when the present lagoon shore was the wave-beaten outpost of the island plateau. Although typical breccia—the well-consolidated mosaic of coral fragments — is not formed on the lagoon shores, yet the same forces that produce the seaward breccia are always acting in a lesser degree on the lagoon shore. The gentle lapping waves of the lagoon shore are for ever tending to weld sand particle to sand particle, just as the surf of the ocean is always consolidating the larger fragments together.

Just as round the sand nucleus of the ocean barrier

Fig. 57.

The Western End of Pulu Tikus,

Showing the worn coral masses that are piled on the beach by the waves. The presence of the large rounded boulders is due to the strong currents rushing out of the lagoon entrance.

calcium carbonate is ever being deposited, so on the lagoon beaches this nuclear increment is ever being added. The whole question of the formation of breccia turns on the consideration of the welding force of the waves and the materials with which they have to work. On the ocean side the fragments are wedged together, sand is driven home, and by the cementing action of deposited calcium carbonate the whole is consolidated into a massive mosaic. On the lagoon shore the materials are in a fine state of division, and the force is not nearly so great, and so the product formed is beach sandstone, or beach sandstone in which are embedded coral fragments after the manner of conglomerate. All degrees of fineness and consolidation of the beach sandstone are to be found. A fine loose sandstone represents the minimal product of the process—the hard mosaic breccia, the maximal; and all intermediate grades are to be found, their composition depending entirely upon the wave force that was exercised in their making. Some specimens show an interesting stratification, and tell of different forces which have been brought into play on the lagoon beaches at different periods of the island building.

On the lagoon shores, where there is an exposure to strong currents, as on some parts of Pulu Panjang and the western end of Pulu Tikus, the sand accumulation cannot take place, and here the wide areas of the beach are made up of broken coral fragments. These fragments are water-worn from their ceaseless movement upon each other, and they remain entirely uncemented; but this condition gives way to the normal, even sandy stretches wherever the normal conditions of the lagoon shore prevail.

The sandy lagoon beaches outrun the islands, and at their extremities form sand spits stretching towards the lagoon. This is a very characteristic feature of the atoll islands. The islands tend to be crescents; the lagoon beaches exaggerate this crescent shape, and so the extremities of the islands curve to the lagoon as tapering sand spits. Between these sand spits the ocean communicates, across the barrier flats, with the lagoon. On the southern or windward side of the atoll it is only natural that the light sand should have been driven to its farthest extent, by wave action across the flats, and by wind action across the islands; and here it is that we find the broadest stretches of sandy beach, the highest sandy shores, and the most extensive lagoon shallows. Here, too, are found the island lagoonlets with wide areas of coral silt, but this more fittingly belongs to the description of the island than the beach.

CHAPTER XV

THE STRUCTURE OF THE ISLANDS

In describing the general structure of the atoll it was noted that not only did the whole system of islands tend to be circular, but that the general plan of the atoll—the "fairy ring"—was foreshadowed in the structure of every constituent island; and a glance at the chart will show this fact. The most common form of the islands is the crescent, and this is only to be expected, as many of them are considerable portions of the circumference of the atoll ring: but this feature goes still further, and in many cases the extended horns are bent inwards until the island itself becomes an incomplete circle, and itself rises to the dignity of enclosing a lagoonlet. Pulu Panjang encloses two such lagoons, and Pulu Atas three; whilst Pulu Ampang major and Pulu Pandan are advanced approximations to the circular form.

These lagoonlets are places of great interest, for they have to some extent a flora and fauna of their own; they also show the final stage of coral degradation, for they are composed of a white, chalky—almost slimy—ooze, which is dry at low tides, and partly dry for the greater part of the whole tide cycle. The degradation of the coral sand that has taken place in the lagoonlets is doubtless partly a sub-aerial decomposition, and partly the life-work of the many creatures that live in these oozy flats. The "fiddler crabs" (*Gelasimus*, sp.) with one great pink claw, larger than all the rest of the crabs, live in myriads in little holes in the white mud; and when disturbed they beat a steady line of retreat, marked by the rolling onwards of a pink wave, which fades away before you, as each one seeks refuge in his burrow. The large *Kapeting Balong* (*Cardiosoma*, sp.) lives round the margin of the lagoons; and many forms of smaller crustacea, sand-hoppers, worms, &c., dwell on the flats and furnish food for the shore birds which frequent these places.

The chief vegetation consists of bushes of "tea tree" (*Pemphis acidula,* Forst., *Kayu Burung*) which grow on the higher parts—islands during high water, and mounds when the tide is out; these and pioneer coco palms are studded all over the white mud. Some coarse grasses (*Lepturus repens,* Forst.) that bind the loose sand with their spreading roots, are also agents, and apparently active ones, in helping to win these lagoons to the island dry land. These lagoonlets differ of course from the great lagoon of the atoll in that they have no depth of water, and no growing coral; but they are formed in the same way as their larger representative and their fate—that of slow silting with coral sand—foretells the history of the lagoons of atolls in general.

The approximation of the individual islands to a crescentic form is due to a very obvious cause. At those tide-washed gaps which separate island from island is the connection of the outer ocean with the lagoon; for here, at high tide, the rollers sweep across the barrier flats. Every wave which breaks on the barrier washes minute fragments of coral, and fine coral sand, across the flats, and deposits its load of silt in the stiller waters of the lagoons. It is but natural that the suspended matter becomes first heaped up at the sides of the gap, for here the current slackens first, and so the extremities of the islands become the site of the deposition of sand-banks, which are formed as in-curved continuations of the land. Dr. Guppy has laid much stress on this simple phenonenon as an agent in land formation, and it is certainly an important one in the shaping of the islands: in fact it is a continuation of the very process which has, in the past, shaped the atoll itself. The current that lays down the banks at the ends of adjacent islands still continues to carry silt in its moving waters, and this is ultimately dropped farther out in the lagoon, opposite the gap. Sand-banks in the lagoon therefore, when far out, tend to be opposite the interspaces of the island ring, whilst nearer shore they tend to be continuous with the ends of the islands.

Although there is a certain amount of constancy in the shape of the islands in the ring, there is a very great diversity in their size; and the largest islands lie to the south of the group.

Pulu Panjang and Pulu Atas are by far the largest pieces of land; not only are they longer, but they are wider from sea beach to lagoon shore than the other islands, and their seaward margins are amongst the highest pieces of land in the atoll. Whatever the size or shape of the island, it must always be borne in mind that the dry land is a heaped-up collection of débris: the islands are made of flotsam and jetsam, of which of course the greatest constituent is dead and broken coral. It is only to be supposed that time, with the sub-aerial alteration of coral, the growth and death of all sorts of vegetable products, and the action of the winds on the lighter particles, should have done much to alter the original appearance of the land. The larger islands towards the south are those that have, to-day, the least of the original features of their origin: the coral fragments have become disintegrated and buried beneath the accumulated generations of fallen trees, fallen leaves, and the husks of the coconuts.

It is the regulating policy of the islands that the husk of the nut is not used for the purposes of commerce, and so no fibre is made and no coir exported, but the husk rots where it falls, for all the nuts are husked as they are picked up. In this way the thickly vegetated islands have accumulated a considerable depth of soil. One of the important factors in the formation of this vegetable mould is the large *Kapeting Balong* (*Cardiosoma*, sp.), which plays, on a grand scale, the rôle of the earth-worm. It burrows the land through and through, and undermines the heaps of husks with its tunnels—almost as large as rabbit-holes—so that a considerable part of the fibre becomes buried. The buried husks rot, and more earth is formed for future generations of coconuts to take root in, and for future generations of the *Kapeting* to till. Not only the

A TYPICAL VIEW OF THE VEGETATION OF THE ATOLL.

Kapeting Balong but several other species of land-living crabs have a habit of taking the fibre into their burrows, and so deliberately burying it, and the influence of efforts at tilling carried out by these large creatures, which exist on some of the islands in great numbers, must be considerable. The land-living crustacea are then the earth-worms of the group, in as far as their function in the formation of vegetable mould is concerned; and the earth-worm which does exist on the atoll is so very uncommon that its share is negligible.

The stem of a coco palm that has fallen lasts whole but a very short time, the wood of the centre of the trunk is soft, and soon by the agencies of the myriad millepedes (native name—*kaki ribu*) and the natural processes of decay, the trunk becomes hollowed out, and nothing but a shell of bark is left. Every cyclone wind which visits the islands lays low many hundreds of trees, and their rotting remains form another source of soil, and another cloak for the coral débris.

Besides the husk of the nut, the coco palm is perpetually shedding fronds, for as it grows up and up the lowest fronds drop off leaving those rings on the trunk which mark the upward growth—and these fronds are always being added to the land accumulations. The remainder of the vegetation of the islands is characterised by a tropical mushroom rapidity of growth; the papias spring up fresh and green to a height of twenty feet, and, like great weeds, die down and rot. There is nothing more strange than the manner in which these luxuriant trees appear after wet weather in a soil consisting of nothing save coral chips and a little sand. At the end of a dry period, the advent of a good spell of rain will produce green shoots from every fissure of the surface of the ground, and the most luxuriant of all the green things is the papia, or, as it is called in the islands, the *Katis*.

Even amongst the largest trees the *Ampol* (*Pisonia grandis*) has been well called the "cabbage tree," for a branch the thickness of a man's thigh is not to be trusted with a man's weight: and no tree of any age is to be found that has not some large portion rotted away Vegetation springs up rapidly and as rapidly dies; during droughts the islands will be parched and brown, every plant save the coco palms will look leafless and dead: but the next day if rain comes, the whole appearance of one of the more barren islands like Pulu Tikus will wholly change, and all the white coral surface of the land will be green with sprouting seeds. The rapidity of the cycles of vegetation is a thing to be reckoned with in considering the alteration of the primitive structure of the islands.

In connection with the formation of vegetable mould, the influence of the heavy rainfall must be considered, for the rate of the washing of surface accumulations through the loosely strewn coral chips is very wonderful. In Pulu Tikus coco palms have lived and died for generations, their trunks have decayed, their leaves rotted: and yet on the surface of the greater part of the island no soil accumulation is to be seen. As a matter of fact the extreme barrenness of the islands is more apparent than real, for if a few inches of the coral débris be scraped from the surface, the vegetable earth is found below, intermixed with the lower layers of coral, where it has been washed by the rain. On Pulu Tikus forty tons of earth were imported from the Botanical Gardens of Singapore; in 1902 it was landed, in 1905 any trace of it was hard to find. It is such facts as these that make the presence of phosphates deep in the soil of high coral islands easy to explain: for every shower that falls dissolves any surface substance readily soluble, and carries it in solution as it percolates through successive layers of loosely packed coral, thus giving it the very best opportunity to enter into chemical combination.

Another factor in the after-history of the island is the drift sand, which, under the influence of the winds, builds up the surface of the island beyond the limit of the sea action. Many of the islands are thickly covered with sand; some are even entirely composed of sand, and an interesting characteristic of those islands, into whose formation no large fragments of coral have entered, is their uniformity of contour.

SAND-PILING OF THE LAGOON SIDE OF THE ISLAND, PULU TIKUS.

When an island is formed of the typical coral débris, consisting of detached slabs of breccia, boulders and fragments, it is always evident that its windward margin is its highest land, and, on section, it is roughly wedge-shaped, the apex of the wedge being towards the lagoon:—for the island has been built by the waves from the ocean side, and its wave-beaten shore is piled the highest. On the other hand, when an island is made of sand it is moulded mostly by the wind, and the effect of the wind is to drive the light sand farther and farther towards the leeward side, so that the island rises from the ocean shore to the lagoon beach—the apex of the wedge being towards the ocean. So marked is this effect of wind formation that, in the case of Pulu Bras, the seaward shore rises as a gradual sandy slope, and ends abruptly towards the lagoon as a sand cliff twenty-seven feet high, which is the leeward limit of the island. On all the islands this wind-driven sand makes some covering for the coral basis, and most often it is collected into characteristic ridges and mounds, making some little break in their otherwise level surface. As the sand is being built up all over the islands, even in those parts where wave action has long ceased to have any influence, it must have been one of the most considerable of the agents in raising the land from its sea-made level. The action of the wind-driven sand has doubtless, in a great measure, waned since the islands have become thickly planted with coco palms, and now is probably secondary in importance to the influence of the vegetation itself.

On the lagoon shore the sand is the only material from which the island now builds, and the wind-driven particles are forced back by the lapping waves of the lagoon, with the result that a characteristic rise of sand marks the fall to the inner shore, just as the boulder rise marks the seaward edge.

The outcome of these various building forces is that the atoll islands have not only a characteristic geographical shape, but they also possess a characteristic land contour. The seaward edge is piled the highest, and is the mountain range of the island—in Pulu Tikus, on the lee of the atoll, reaching thirteen feet at its highest point; and in Pulu Atas, to the, windward, rising to a "hill" of thirty feet.

From this sea-bank the land falls to the centre of the island, where in some instances there are many hollows below the high spring-tide level. Towards the lagoon the land rises again as an inconsiderable sand ridge, and thence falls gently away to the lagoon. In Pulu Tikus, which is the island that has undergone least change from the bare débris condition of its first making, the greater part of the surface of the land is bare coral fragments with a very sparse admixture of sand and vegetable mould, and there has been very little building up of the interior of the island. The result is that most of its surface is raised but a foot or two above high-water level, and a considerable part of it is below, and as the débris is easily permeable to water, the burrows in which the *Kapeting Balong* lives are usually filled with salt water almost to their mouths. Wherever a hole is dug, the water is found just below the surface, and large puddles are formed in many places at every high spring tide; whilst the water in a fish-pond, some thirty feet from the lagoon shore, follows all the movements of the tide with but little delay. There are many facts of great interest in connection with this sponge-like condition of the islands, which permits the sea to fill them at high tide, and leave them when the tide is low.

It is this condition that gives rise to the curious phenomenon of rising and falling wells of fresh water, which can be made on a great many of the islands, and to account for which many suggestions have been put forward. It has been said that the sea water at the height of the tide percolates into the island, and, as it goes, it becomes filtered through the coral so perfectly that in the middle of the island it becomes quite fresh, and may there be tapped as good drinking water in wells. That filtration by the accumulation of dead coral could be so complete as to remove sodium chloride from its solution is an assumption so bold that its acceptance could only be justified by the careful exclusion of all other possible causes of the freshening of the water: and as a matter of fact the other and more likely causes have not been excluded. In Pulu Tikus fresh water cannot be obtained in wells, and Pulu Tikus, being the island that has retained most of its original features, shows in this as in the case of other phenomena the half-formed product that more easily tells its origin. At high tide the water rises, the fish-pond fills up, the *Kapeting's* holes show water a few inches below the surface, and puddles form in the more low-lying parts of the island. At low tide a visit to the barrier will show this water running out of the land again, welling up in holes and trickling down the beach as the sponge empties. If, on this island, a hole be dug as far from the sea as possible, the water that is met a foot or so below the surface will be found to be either quite fresh, brackish, or wholly salt; and it depends entirely on the amount of recent rain which of these three conditions is found. After a wet period, fresh water will be found anywhere towards the centre of the island, and it will rise and fall in the hole as the tide goes through its cycles: but when the dry weather sets in the fresh water becomes more and more brackish, and in the course of some days becomes entirely salt again. The reason for this is easily seen, for since the land is so little raised above the ocean-level, the water which the accumulated rains produce must lie as a subsoil water very near to the surface, and, as it is lighter than the sea water, it rises and falls as a surface layer with the movements of the tide.

Fresh water will remain separate as a surface layer even in the open sea for a considerable time. After a tropical downpour in Singapore roadstead the surface specific gravity was lowered from 1026° to 1021°, and on two occasions in this atoll so continuous was the rain that large numbers of fish died from the freshness of the water, for the rain stood for a height of several inches on the surface of the salt waters of the lagoon.

The diffusion which takes place slowly in the sea takes place still more slowly when the rain water, after percolating through the porous débris of which the island is composed, lies in the depressions of the compact breccia layer that forms the basis of the islands; and in an island so porous as is Pulu

Tikus, the complete mixing takes, at the fastest, a period of many days. In the larger and more consolidated islands, where the building up of the land level has advanced further, this subsoil water exists as a large pool on the breccia basis, and is only displaced by the movements of the tide water. A very prolonged drought would no doubt affect all the wells of the atoll in time; but so large is the accumulation of subsoil water that forty tons a day could be taken from a well in Pulu Selma for the Australian horse ships, without affecting the quality of the water, if the well were given a rest of an hour in the middle of the day. No restrictions of any kind are placed upon the using of the well water by the natives of Pulu Selma, and domestic water for cooking, washing, and bathing, as well as water for their gardens and industries, is taken freely from these wells; and yet, even in the prolonged drought of 1905–6, the water very fairly retained its freshness. The water found in Pulu Luar is the best well water in the group, and is that used by the Ross family for drinking purposes. Under no conditions does it ever become brackish, doubtless because its use is restricted, and the well is situated in the centre of the island, and therefore far from the sea. The water of Pulu Selma has a degree of hardness that makes it difficult to lather with ordinary soaps, though with the island soap, made from coconut oil, it always lathers freely:—with this soap, however, sea water can be used for washing purposes.

The finding of fresh water in wells dug on coral islands is a common thing, and in the low islands of the Pacific and in the West Indies these wells are made by the natives; but the water is apt to be scant and brackish, and this atoll is somewhat unusually favoured.

The reason for the constant freshness of the wells is, of course, the heavy annual rainfall, and the yearly seventy inches does away with any necessity to collect water in holes in coconut palms, or to regard water as a great luxury, as is the case in some low islands. But on such of the islands as Pulu Tikus, where no wells can be made, all the water must be condensed for drinking, and collected from the roofs for domestic purposes.

CHAPTER XVI

THE LAGOON

In accounts of atolls it is often found that the lagoon is regarded and described as though it were a pit—a sort of lake that is situated on the summit of a submarine mountain; often it is supposed to be the water-filled crater of a volcano.

So long as such ideas concerning the nature of the lagoon are held, no description of it is at all likely to depict its real features, for no descriptions written under this belief will ever make it apparent that the lagoon is really the top of a broad reef, around whose edges a ring of islands is raised. In this description it is assumed throughout that the lagoon is a slightly submerged reef, whose surface has undergone some modifications owing to its partial enclosure by the island ring. The lagoon is a sheet of water with an area of some twenty-five square miles, and over the whole extent of its area the after-effects of its enclosure by the islands have not been equal. The result is that to-day the lagoon may be divided, for the purposes of description, into two parts: a southern shallow part; and a northern deeper part. It is of importance to note that the shape of this southern part is exactly that already described as belonging to the sandy lagoon shores of individual islands. If all the southern islands, from Pulu Ampang on the east to Pulu Panjang on the west, be imagined as one continuous reef, then the shallow part of the lagoon is exactly what we would expect its lagoon shore to be. It is also of importance to notice that this crescentic shallowing of the southern portion is gaining on the deeper northern part, exactly as the crescentic sand beaches of the individual islands gain on all parts of the lagoon. The same process is evidently at work on a larger scale, and a line of transition from coral shoal to sand-silted lake is sweeping, as a crescent, from south to north.

The entrance to the lagoon is situated to the north of the atoll, and here the bottom of the lagoon merges with the comparatively shallow areas of the coral ridge, and is seen in its most luxuriant growth, and in its most primitive condition. Between Pulu Luar and Pulu Tikus the barrier is entirely wanting, and in this gap the original coral bed lies at a few fathoms' depth with its luxuriant mixed growth of massive corals undisturbed by violent wave action. This coral bed is, no doubt, the type of the original condition of the whole area of the ridge now occupied by the southern atoll and the northern atollon of Keeling Island.

The shallow southern part of the lagoon extends in the form of a great horse-shoe, skirting the inner shores of the islands, and invading at its margins the northern deeper part. Its area may be roughly taken as slightly more than half the total lagoon area, or about thirteen square miles. Large areas of its most southern parts are dry at low water, and covered by a few feet of water only at full high tide. The more northerly and central parts of the shallows are covered by anything less than a fathom of water at low tide. The bottom of this part is, however, not at all uniform, and deeper hollows are studded about the central portions of the greater part of the southern shallows.

Along the inner shores of the large islands, Pulu Atas and Pulu Panjang, the long sand flats are dry for a mile or so at low tide, and at full high tide a great part of this flat has no more than an inch or two of water on it. Towards the shore, these flats become continuous with the oozy white mud which collects in the lagoonlets of these two islands, and towards the lagoon they slope gradually to the slowly deepening water, which is clearly indicated as a bright green belt, merging afterwards to the characteristic deep blue.

Bushes of *Pemphis acidula* and pioneer coconut palms stand here and there as outposts of the land: and it is the policy of the islands that these pioneers are not interfered

THE LAGOON FROM THE WESTERN END OF PULU TIKUS, LOOKING TOWARDS PULU PASIR, THE SMALL SAND ISLET.

with ; for the advance of vegetation is the surest way of winning dry land from the silt regions. In the reclaiming of the lagoon shallows a grass (*Lepturus repens*) plays a great part, for it binds the shifting sand firmly with its long trailing roots, and makes firm dry land out of the useless shallows.

In 1827, when the permanent settlers first arrived in the islands, the silting of the southern portion of the lagoon was not nearly so far advanced as it is to-day. The schooner which the islanders made for their use was actually built in Pulu Atas, and launched from it; and it sailed in and out from the settlement on the island to keep up the necessary traffic of the atoll. Before ten years had passed, however, the silting of the southern end of the lagoon had proceeded so far that the boat channel became obliterated, and schooner traffic with the settlement was cut off. It was for this reason that the site of the settlement was moved to Pulu Selma, the island which it still occupies, situated in the northern deeper half of the lagoon. It would appear that the southern anchorage has never been used for any other craft than the island-built schooner, for ever since the atoll has been charted the safe anchorage has been given as Port Refuge in the lagoon off Pulu Tikus, or else without the lagoon altogether in the gap between Pulu Tikus and Pulu Luar.

Although the whole story of the southern part of the lagoon discloses a steady progress of the conversion of a coral-studded stretch of water into sand flats, still, at any one point, some indications might be seen, from time to time, which would seem to contradict the general trend of the process. Beach sand has been seen to be the fluctuating capital of the islands and of the beaches: and, in exactly the same way, the silt sand of the lagoon is the ever-varying factor in the ceaseless minor variations, which are always going on in some part of the whole extent of the lagoon. Sand spits and shallows wax and wane; banks are piled up, and then soon after scoured away, but in the manner of these changes there is no general influence upon the atoll structure as a whole, and purely local conditions determine the balance of the processes at work in any given spot. To any one who has for long watched these minor—yet striking—changes, it must be evident how fallacious are those arguments concerning the age of atolls, or the manner of atoll formation, which are based on the measurement of the quantities of sand piled up, or denuded, in any one point in the whole circle of more than twenty miles. Where in the island ring the sea runs strongly through the gaps and into the lagoon, spits are formed wherever, by some interference, the current slackens; in this way the crescent shape of the islands is brought about, and the great sand flats of the southern portion of the lagoon are accumulated.

Drift sand is the main factor in causing the shallowing of the lagoon, and drift sand it may be safely said will, lacking some general upheaval, be the agent which will ultimately win the lagoon to the dry land; but it is the most inconstant and capricious agent, and no man may say that so many feet will be laid down this year, and so many next, and that therefore in a certain meaningless number of years the lagoon will cease to exist. The very presence of the sand in the lagoon introduces a complication into the question, for sand is one of the most potent causes of coral death; the shallowing of the lagoon by the accumulation of coral growth must therefore be arrested when the shallowing by sand deposit sets in. It is under these circumstance that the very slight building influences of *Lithothamnionidæ* come into play, for they do not appear to be so sensitive to the influences of silt as are the corals. In certain places at the southern side of the atoll, in the border-line region of barrier flat and lagoon flat, the growth of these calcareous algæ occupies a fairly large area, which is free of living coral in any quantity: but apart from arresting the drift sand in their meshes they do not have any influence on the rate of building. It must not be imagined that the great southern part of the lagoon is by any means devoid of living coral colonies, for dotted about at intervals are some of the most luxuriant of all the coral growths. It has been said that the distribution of the living colonies on the barrier and the barrier flats was a distribution of *types* and not of *species;* and exactly the same assertion holds good with regard to the lagoon. The same corals that live on the barrier are also found in the lagoon. At the same time it is quite correct to say that some *types* are definitely confined to certain definite environments, and this forms one of the most interesting pages in the study of living corals. This subject has already been discussed and so no further details will be added here: but it must be insisted that sand and silt are the most important agents in the causation of death of corals, and that their presence acts in two ways: (1) It may fall on them and choke their zooids from above, or (2) It may overtake them from below. Some idea of the rate of the silting of the lagoon may be gathered by measuring the dead lower portions of the great branching colonies of *Madrepora;* for these corals do not normally die in their lower portions, and the dead area represents the amount of silting that has taken place, *in the immediate neighbourhood of the colony,* since its first establishment.

Sand then is the great architect of the lagoon, and while it inevitably kills the coral growths, it more than counterbalances for this by its own building efforts.

The still waters of the lagoon are harmful to the coral colonies in another way, for large areas of the shallow water are covered by great beds of algæ. Where algæ exist abundantly corals do not flourish. *Agar-agar* and many other seaweeds cover a considerable portion of the lagoon, making characteristic dark patches on the bottom. One such large bed exists in front of the eastern end of Pulu Tikus, and many are found in the southern portion of the lagoon, and these beds flourish to the absolute exclusion of coral growth. There is in particular one very fine green alga that occurs even in the barrier pools, and is particularly inimical to coral growth. At certain seasons of the year these fine green threads are found, as drift-weed, in every pool; and as they wash to and fro in the tide they become entangled among the branches of the corals. Wherever the threads obtain a fair lodgment, a green mat-like growth is spread on the surface of the coral, and the fate of those portions of the branches upon which it settles is sealed. The coral slowly dies, and on the dead portion the alga becomes thickly encrusted, its filaments spread out and are washed away to find a fresh resting-place among the neighbouring branches. In sheltered pools, where the process can be watched, it is easily seen that the alga is one of the most potent factors in causing coral death; and doubtless in the lagoon, where the beds of algæ occupy many acres, the factor is one of great importance; certain it is that in the algæ beds the corals do not flourish.

The sand and the seaweed between them have in some measure banished the living corals from certain parts of the lagoon, and the actual fraction of its whole area covered by living coral I would judge to be less than the half that, in 1836, Darwin estimated.

Of the southern part of the lagoon, the western half is the area that is most thickly covered with coral growth; and the bottom of the lagoon is here chequered over with coral colonies in a very characteristic fashion. Large masses of *Porites*, with actively living zooids only present round their sides, give rise to large, and roughly circular, flat-topped rocks; and on the flat tops live the more active branching forms of *Madrepora*. In the sand, isolated and small colonies of *Porites*, all approximating to a circular form, lie scattered about; the great majority of the colonies being far less luxuriant than those of the same species that live in the ocean beyond the barrier edge, or in the northern half of the lagoon. The nearest parallel that I can draw to the condition of coral growth on the lagoon bottom is the manner in which gorse bushes may be dotted about upon a hillside; it is a series of scattered groups disposed about at quite irregular intervals. The groups of coral colonies are of very varying size, but they nearly always contain the same set of types of vegetative growth.

I was particularly fortunate, during my residence in the atoll, in being able to accompany the boats engaged in clearing the coral from the southern part of the lagoon. The great boulders are shifted with crowbars by the Malays standing in the water up to the level of their chests, and, with much skill, large masses are rolled and hoisted into a lighter, where the corals and their teeming symbiotic fauna can be well studied. The work is undertaken partly for its own utility, and partly to obtain the boulders for enclosing turtle-ponds, and also for burning into lime. Thanks to the kindness of Mr. Andrew Clunies-Ross I was able to take part in these expeditions, and the experience gained by seeing and handling so much coral from different areas of the lagoon gives some confidence for dogmatism as to the disposition of living corals within the lagoon.

Time after time, as the coral was hoisted into the lighter, the same sequence of types showed. The basis was nearly always formed of a large colony of massive *Porites,* mostly dead, and only here and there at its periphery showing signs of activity; the older portions giving a resting-place to *Astrææ* and branching types of *Madrepora,* and, at its edges, the *Montiporæ* and the various plate growths which are a common modification of many species. In the sand around these masses are the branching types of *Madrepora* and *Montipora,* which crumble to pieces and break as the boulders are raised; and growing at intervals, and usually in the deeper parts—so that the Malays must dive to procure the specimens—are the large leaf-like growths of *Echinopora lamellosa.* Here too grow the rounded stems of the branching *Porites,* which are of a varying shade of greyish yellow or greyish purple when alive, but which, when the coral is dead and exposed to the air, turn black. Growing upon the boulders of massive *Porites,* and also living free in the deeper pits, are the fine colonies of the most delicate of all the corals—the pure white *Seriatopora,* which has received amongst many other specific titles that of *caliendrum.*

Of all the lagoon types of coral, those of a branching habit are the most numerous and appear to be thriving the best, and the type of growth of *Madrepora* known as *pulchra* covers unquestionably more ground than any other type. The western half of the southern area of the lagoon is therefore fairly well populated by coral colonies, and a very definite set of types is usually found gathered together as a composite mass of growths, these masses being dotted about in irregular fashion all over the bottom of the lagoon.

The eastern side of the southern end of the lagoon is more barren of corals than the western side; and this state of things is owing to the effects of the strange happenings of the year 1876.

As a sequel to a cyclone which visited the atoll in the January of that year, there occurred an event which to this day has left its imprint plainly marked on the coral growth of the lagoon. When the storm had died down for some thirty-six hours, it was noticed that a spring of dark-coloured and malodorous water was welling up into the lagoon from a source somewhere between the southern end of Pulu Selma and the northern end of Pulu Cheplok. The foul water continued to ooze out for some ten or fourteen days, and it slowly spread all over the eastern portion of the southern end of the lagoon. Dr. H. O. Forbes visited the atoll two years after this event, and has well described the lifeless state of the area over which this water flowed. In "A Naturalist's Wanderings," p. 22, he says: "Its whole eastern half was one vast field of blackened and lifeless coral stems, and of the vacant and lustreless shells of giant clams and other Mollusca paralysed and killed in all stages of expansion. Everywhere both shells and coral were deeply corroded, the coral especially being in many places worn down to a solid base. Since the catastrophe, there has been, till almost the day of my visit, no sign of life in that portion of the lagoon; I saw very few fishes, and only here and there a new branch of *Madrepora* and *Porites*. I found only one *Tridacna* alive (its three years' growth being twelve inches in length and thirteen in breadth)."

This description forms a very good basis for estimating the time that is occupied by the corals in renewing their growth, and we have a further landmark in Dr. H. B. Guppy's account written in 1888.

In the *Scottish Geographical Magazine*, vol. v. p. 570, he says: "The corals on the shallow flats naturally suffered most from the intensity of the destructive fluid, and even when I examined this locality twelve and a half years after the event much of it appeared a lifeless waste. The dead trunks and branches of the arborescent Madrepores that had once flourished here literally covered the bottom in places. Multitudes of the shells of the *Tridacnæ*, rotten and decayed, strewed the ground; and even the pits displayed on their bare slopes numbers of dead detached plates of *Echinopora lamellosa* that had once clustered thickly around their sides. Yet it was evident enough that the corals were in places beginning to resume their sway. Thus, the flats immediately south of New Selma have long since been clothed afresh with rapid-growing branching *Montiporæ* and other corals; and even where life seemed completely absent, a closer inspection usually discovered a few young growing corals and small living clams. However, at least a quarter of a century will have to succeed the event before the growth of corals can disguise the destructive effects of 1876." In 1905 and 1906 I spent very many days in drifting all over this eastern area of the lagoon. With a companion in a boat, a start would be made from the south, and as, with the wind and tide, the boat slowly drifts over the lagoon, every foot of the bottom may be carefully examined. Anything that demanded close examination was dived for, or waded to, and in this way a very intimate knowledge was acquired of the present state of the coral growth. Although thirty years have gone by since the pouring forth of this destructive water, distinct evidence of its effects are still abundantly clear; and the time of final repair must certainly be put forward considerably beyond Dr. Guppy's limit. There are many places to-day where there are practically no signs of life amongst the dead coral masses that cover the bottom, and algæ have for the most part been the successors of the coral life.

I have watched the dead coral fields for a period of fifteen months, and failed to detect any signs of life in some portions of them. I have seen the crumbling masses raised into the coral lighter, and boulder after boulder will be rolled in without any one of them showing the minutest portion of new growth attached to it. To the south and west of Pulu Selma there are still large areas that are only occupied by the remains of the corals killed in 1876, and the thirty years that have elapsed seem to have accomplished but little repair when the masses are seen raised to the surface. But before this extreme slowness of repopulation may be taken as a fitting criterion for any estimation of the rate of coral growth, the conditions which have prevailed during the interval of thirty years must be reckoned with. In the first place the algæ, of which there were many beds on the adjacent areas untouched by the foul water, have, by reason of their more rapid growth and greater hardihood, taken possession of a very large part of the area that suffered the damage. Before the more delicate and slower growing corals could recover their activity, and recolonise their ground, the algæ had invaded it; and as we have seen, the advent of abundant growth of algæ terminates all activity in the coral colonies. When once the seaweeds had fairly settled on the spot, the invariable accompaniment of their growth took place, and sediment began to accumulate in the beds which they had formed. This fact is clearly seen wherever algæ are settled—that the lagoon begins to shoal with increased rapidity; algæ in the lagoon play very much the part of the grass on the shore flats, for they enmesh the drift sand and hold it fast. The environment therefore becomes one of rapid silting, and no environment is more inimical to coral growth. It is, therefore, not alone by reason of the slow growth of the coral that this area has not become repopulated with coral colonies; for the time that has elapsed since the destruction is ample for very advanced growth to have taken place.

All over the whole of the southern shallow portion of the lagoon are deeper holes, which show plainly as darker patches in the clear water: and a fair general picture of this part of the lagoon is that of a wide stretch of white sand, with here and there patches of coral rocks, and here and there deeper holes. The coral rocks rise almost to the surface at low water, and they are for the most part of a bright yellow colour, being colonies of the most abundant type of *Porites.* At intervals are beds of yellow branching *Madreporæ* and fields of green and white algæ; the whole seen through a fathom or so of clear green water. Upon the sandy bottom the rills of wave action are clearly to be seen, running east and west—the imprints on the bottom of the Trade-driven waves of the lagoon. There are, however, very many places in the lagoon where the coral growth is not nearly so freely scattered as that just pictured, and in areas over which the foul water never exerted its baneful influences are stretches of white coral sand, where a coral mass will have no neighbour nearer than one some fifty yards away.

From the southern shallows the lagoon deepens towards the north, where it becomes a basin with an average depth of from four to five fathoms. Even in this deeper part, however, there are many spots where the growing masses of coral rise to within a few inches of the surface at low water;—some are even normally exposed at all low tides. One such mass rises from Dymoke shoal in the northern basin, opposite Pulu Selma, and this rock—known to the natives as *Batu Dua,* or "The number two rock"—is exposed for some two feet at most low tides. The transition from the shallow portion of the lagoon to the deeper portion is very easily seen in the colour of the water, and at places the line of demarkation is very sharply cut. The clear green water of the shallow sand-covered portion passes, often very abruptly, into a very beautiful blue,—a clear wonderful blue, which can never be described or made real. The entrance into the lagoon is between Pulu Luar and Pulu Tikus, and here ships may be safely navigated by one knowing the locality. A good anchorage stretches in front of Pulu Tikus with from three to eleven fathoms of water. It is possible for vessels of shallow draught to enter the lagoon between Pulu Luar and Pulu Panjang, both to the north and to the south of Turk Reef (*Batu Satu,* "The number one rock"), but the channels are intricate and liable to considerable changes from the rapid growth of coral masses.

The growth of corals all over this part of the lagoon is very luxuriant, and very large colonies of *Porites* are to be seen in the deep blue water; here also large growths of *Millepora* are seen, and both the great plates of the type *complanata* and the branches of the type *alcicornis* are to be recognised. *Millepora* colonies are as a rule absent, or represented only by very sickly looking growths, over the southern shallows; but in the northern basin some of the specimens are among the finest to be found anywhere in the atoll.

To the westward the lagoon shelves slowly to the open sea, and here great masses of coral are to be seen growing in the greatest profusion. The site is one in which practically no sedimentation is taking place, for in any weather the sea is a confused one in the gap between Pulu Luar and Pulu Panjang. When the wind comes from the west, or north-west, very heavy seas roll into this gap, and the whole interval is filled by great white-crested rollers, making any entry to the lagoon an impossibility.

The northern basin of the lagoon presents an altogether more varied picture than the southern portion, for it shows every phase of the transition from shoal to submerged reef. It shows at its southern limits the destruction of coral growth by sedimentation, and the shallowing of the lagoon by sand accumulation; at its northern limits, the absence of sedimentation, and the shallowing of the lagoon by coral growth. Some of the coral boulders in the northern basin have grown with very great rapidity, and their removal from the boat anchorage opposite Pulu Tikus is occasionally necessary. Most of these boulders are very large colonies of *Porites*, which are for the most part yellow coloured, and here grow in the form of slightly flat-topped spherical masses. Another part of the lagoon which is undergoing considerable change, brought about by the activity of coral growth, is the best channel to Pulu Selma, but here it is great beds of the typical form of

Madrepora pulchra which are causing the alteration. These beds are bringing about a somewhat rapid shoaling of the lagoon in this spot, for *M. pulchra* is a type of colony well formed to resist some degree of sedimentation; and not only are the colonies growing very actively, but are holding in their dead lower branches a great amount of drift sand. They are therefore forming banks, with living branches actively growing at the summit, and sand, held fast among the dead branches, at the base. Another type of colony thriving in this environment is a plate growth of *Montipora*, approximating to the type named *M. circinata;* it plays very much the same part as *Echinopora lamellosa* does in the southern shallows, and grows upon the sides of the banks, holding the sand back behind its broad leaves.

Although the water is, in many places, six or eight fathoms deep over wide stretches in the northern part of the lagoon, the nature of the coral colonies that lie below can nearly always be made out, and where the lagoon falls to the open sea, between Pulu Tikus and Pulu Luar, the parti-coloured bottom may be seen for a very great distance. The fall from the shallow waters of the lagoon to the ocean outside is not nearly so abrupt as has been imagined, for the entrance, lying to the north, corresponds with the northward tailing out of the bank on which the atoll is formed—the bank upon whose northern extremity Keeling atollon is situated. When sailing from the lagoon, the bottom is seen as a patchy background through water that becomes increasingly blue; at first yellow masses of *Porites* alternate with white patches of sand, and blue patches of the deeper holes; then the patches blend more, and lighter yellow areas and darker blue areas alone are seen. When still farther from the atoll only the larger patches show at all, and the appearance is somewhat that seen when looking from a hillside upon distant fields, differently coloured by various growing crops. Alternations in colour are seen for long; and the whole picture, from minute detail to complete blurring, fades slowly. I can speak of this point with some certainty, for I have many times been in and out of the lagoon, and have, on calm days, taken a small boat round the seaward side of Pulu Tikus. These beds of coral outside the lagoon are the sites of the most luxurious coral growth to be seen anywhere in the atoll; and *Porites* grow in colonies whose size is not approached by any in the lagoon, or on the barrier.

It is well known to sailors that from some lagoons the water issues, at the falling of the tide, with such force that the passage of a ship into the entrance may be an impossibility. Although there is no tide rip from this lagoon which offers any serious obstacle to navigation, still a strong current is always running out of the lagoon, past the west end of Pulu Tikus, to impinge on the southern and eastern shores of Pulu Luar. The gaps in the island ring that lie to the south and east are inlets for the Trade-driven ocean; in the run between Pulu Tikus and Pulu Pasir the set is always lagoonwards, whatever the state of the tide. As a consequence of this, all the flotsam from the lagoon shores of the inhabited islands is swept away towards the mouth of the lagoon, and it is the well-justified island custom when anything has gone adrift to look for it first on the shores of Pulu Luar. With the rarer westerly winds the opposite effect is produced, and a strong current running into the entrance of the lagoon is brought about; the waters of the lagoon become banked up, and much destruction of the sandy beaches usually takes place. The wind-driven lagoon water becomes raised above its normal level, sand is swept away, and the old barrier stratum exposed; trees are undermined, and bushes uprooted; and did a visitor spend only a few days in the atoll, after the coming of a strong westerly wind, he would surely give the world his certain conviction that the sea was rapidly encroaching on the land. In this way, I feel sure, arise some of the conflicting opinions of men who spend but a few days or hours in an atoll; for the visit may chance to be made after a period of denudation by one wind, or after a period of sand accumulation caused by the antagonistic wind. Were the length of the stay to be measured by months or years, the visitor would see the banks come back: the ancient barrier stratum covered again with a thick bed of white coral sand; and the whole beach raised again by the agency of the wind and waves. He would even see, in all probability, a series of little terraces made in the sandy shores as gradually waning high tides built to their maximum levels; then he might possibly think that the land was steadily gaining on the sea. It is always assumed in estimating any changes in the shore-line that the surface of the ocean stands constantly at the same level, and yet, strange though this may appear, it is not always safe to assume this. It is apparently one of the strange phenomena of far-out blue water that its mean surface-level is subject to considerable variation. Of this strange fluctuation in level, such a place as the atoll forms a very interesting index—it is the Plimsoll-mark of the ocean's variations. During my stay in the islands I have seen, for a week at a time, and without any variation in the tides, the curious condition of the barrier never being once exposed at low tide. The tides went through their usual excursions, the high tide being higher than normal, and the low tide not so low as normal; but the whole surface-level of the ocean was set at a higher plane than was ordinary. This state of affairs is doubtless brought about by the banking up of the waters of the Indian Ocean, and the event happened after a report had come over the cable that a violent storm of long duration had raged in the neigbourhood of the island of Rodriguez. It was the time of neap tides, and so the increased high tides did not reach the striking level that they would have done had the event happened during spring tides; but the phenomenon was a very striking one. It is easy to see that if a change of ocean-level—even of very brief duration—were to be accompanied by a combination of high winds and spring tides, imprints would be left on the islands which might appear to indicate a shore movement of several feet. It would not be at all likely that these appearances would be rightly interpreted by a visitor to the atoll who had not seen the process in its making.

The average tidal variation is from three to four feet, and the tide's turn takes, as a rule, about an hour and a half to travel from the south of the lagoon to the north—a distance of about eight miles. The amount of tidal variation is an important factor in determining island elevation, and this will be again referred to in the consideration of the mode of formation of the islands.

The lagoon being shallow, calm, and more or less enclosed, is considerably warmer than the surrounding ocean, and some parts—as for instance the back water enclosed by the sand spit at the northern end of Pulu Panjang—are distinctly hot after a day of calm and sunshine. A surface temperature of 85° Fahr. is a very common one for the open waters of the lagoon.

A SUNSET IN THE LAGOON.

CHAPTER XVII

THE CLIMATE AND PREVALENT WINDS

From its position in mid-ocean, and 12° 9′ south of the Equator, the group derives all its peculiarities of climate. It lies to the south of the monsoon area, that is to say, the South-East Trade wind is not normally reflected on its course for any constant part of the year; for though winds other than the South-East Trades do reach the islands, there is no season of the year in which a reversed wind constantly prevails. The slackening of the Trades, from north to south, reaches the group in the early months of the year, and then "doldrum" calms and uncertain winds are the prevailing type of weather; but it is quite incorrect to speak of the "change of the monsoon" in the Cocos-Keeling group, although the phrase is by no means infrequently used.

As it is south of the monsoon area, and therefore has no monsoon seasons, so it is too far north—too near the Equator—to be subject to obvious hot and cold seasons; there is a period of the year normally more dry and hotter than the remaining months, but the mid-oceanic position of the group deprives even these seasonal variations of any really obvious effect, the variation being, when averaged, but very slight in amount.

All the data for these meteorological records have been taken with the Telegraph Company's instruments, and those used here cover a period from Dec. 1901 to Dec. 1905. They may be relied on both as regards the accuracy of the instruments and of the observers.

It must be remembered, in estimating the amount of seasonal variation to which the group is subjected, that all the observations have been taken on Pulu Tikus, which is a small and comparatively sparsely vegetated island, and that as a consequence, the rainfall, as registered for this island, probably does not represent truly the rainfall of the group as a whole. During those months in which the minimum rainfall is registered by the Pulu Tikus instrument, rain, in some considerable quantities, falls on Pulu Atas and Pulu Panjang. Were the records to be taken on these larger pieces of land, which lie six miles away, I think there is no doubt that the annual rainfall would have a higher index, and at the same time be more uniform throughout the course of the year.

That these meteorological records help in the understanding of the scant, but interesting, fauna and flora is only natural; for every living thing must reach the islands as a chance plaything of the winds or waves; but since the true explanation of the origin of atolls lies in the appreciation of the physical forces with which they are surrounded, they should help, if rightly interpreted, in understanding the method of island building. For this reason it is very fortunate that so accurate a set of observations is available, for the details of the climatic conditions of the group which have hitherto been published do not give a satisfactory working basis.

THE PREVALENT WINDS.—The prevailing winds are the S.E. and the E.S.E. which constitute the Trade winds. The normal variation of the Trades includes winds blowing from the S.E., E.S.E., and E., and the winds from these quarters blow on an average for 300 days in every year. It must not be thought, however, that the odd 65 days are consecutive days occupied by any change of the Trades, for as a matter of fact the 300 days are very equally distributed over the twelve months.

The wind blows from the S.E., E.S.E., or E. as follows, the numbers being averaged from the records of four years:

IN

Jan. 23 days	Feb. 18 days	March 23 days	April 23 days
May. 23 ,,	June 26 ,,	July 27 ,,	Aug. 27 ,,
Sept. 27 ,,	Oct. 28 ,,	Nov. 28 ,,	Dec. 27 ,,

The early months of the year are those in which the wind is subject to the greatest variation, and in these months

FIG. 58.

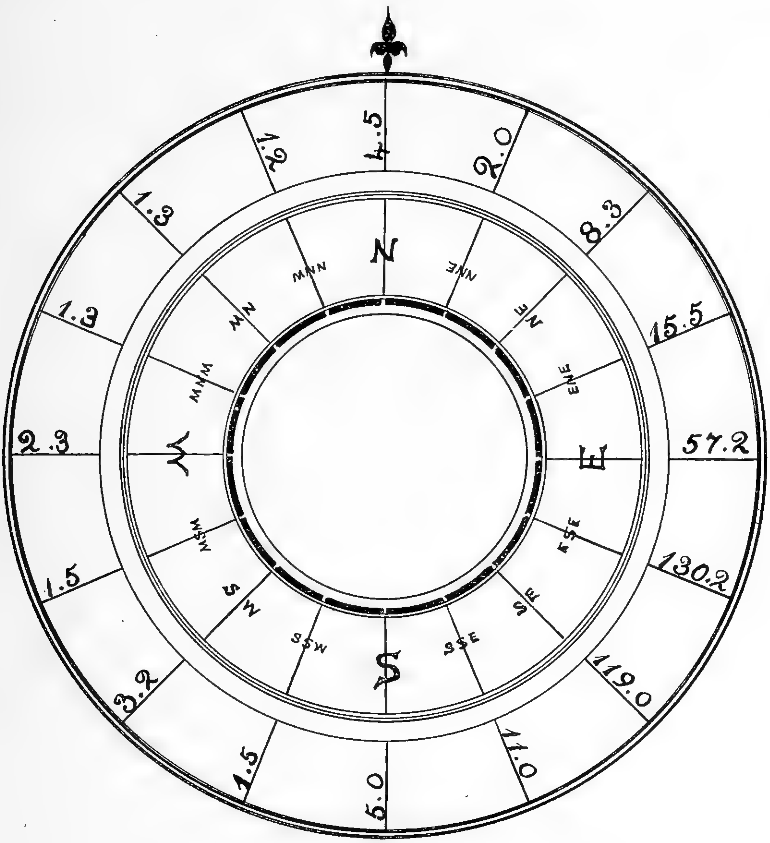


DIAGRAM TO SHOW THE PREVALENT WINDS OF THE ATOLL.

The figures opposite each point of the compass show the average number of days in a year in which the wind comes from that point.

northerly winds blow at intervals, and these winds bring rain-squalls and unsettled weather generally.

Although this slight variation is clearly shown in the table, it will be at once seen that the monsoon influence is not marked; there is nothing that could be entitled to the name of "the change of the monsoon."

The Trades blow a steady cool breeze day and night, and they become another agent, and a potent one, in keeping up that uniformity of conditions which is the outstanding feature of the climate of the group. They give to the islands their peculiar individuality, their sounds of rustling palm-leaves and breaking surf, they give them their even temperature and steady barometer; and more than this, they have impressed themselves on the very formation and structure of the group itself.

The sky is seldom cloudless, partly of course for the reason that so large an expanse of sky is always in view, but partly too for the reason well known to sailors, that clouds as a rule *do* mark the site of coral islands. Captain Maury, in his "Sailing Directions," even goes further than this, and says: "These cloud piles . . . are often seen to overhang the lowest islet of the tropics, and even to stand above coral patches and hidden reefs, 'a cloud by day' to serve as a beacon to the lonely mariner out there at sea." A lower stratum of large fleecy cumuli moving steadily in the line of the Trades, and an upper and very high stratum of thin long-drawn cirrus, appearing by contrast almost stationary; this is the most ordinary sky picture, and will serve for the great majority of days in the year. The upper stratum has, at times, a real opposite movement to the lower, and whilst the cumulus masses are drifting from the south and east, the overlying cirrus comes from the north and west. This is well known to the islanders, and is looked on, and rightly, as a sign of coming rain. Although the northerly winds form such an inconspicuous constituent, when seen in the graphic representation of the winds, still they are important winds for the islands, for they bring the rain; they bring to-day, and doubtless have brought in the past, new waifs and strays as tentative additions to the fauna of the islands. After northerly winds, even of short duration, dragonflies are almost invariably seen on the islands. They do not make a successful footing, and they do not become permanent additions to the fauna, doubtless because of the scarcity of fresh water; but they show by their coming the lines by which pioneer species may invade distant islands and, finding a suitable environment, become settlers. Stray birds, as swallows and wagtails, have come after these winds, but their stay is brief.

It is the northerly and westerly winds that bring the cyclones which have played so important a part in the history of the Ross settlement, and considering the extreme lowness of the islands, and the normal force of the wind and waves, it seems wonderful that anything should be left standing after a cyclone has passed the group. Four recorded cyclones have visited the islands, and on two occasions have practically left them waste.

In 1862 a cyclone wrecked the settlement; again in 1876, on Jan. 28, terrible damage was done, and the flourishing condition of the little band of settlers was turned again to hardships and privations. The third cyclone occurred on Feb. 4, 1893; the wind was mostly from the north and north-west, the barometer remained between 29·82 and 29·45 inches from 6 A.M. on Feb. 4 till 6 A.M. on Feb. 6, and during that time 30,905 coconut palms were uprooted and much other damage was done. On March 4, 1902, a fourth cyclone swept over the group, and it is recorded by the Pulu Tikus meteorological records. At 9 A.M. the barometer stood at 29·40 and between 10 A.M. and noon fell to 28·95 inches. The wind, which at first blew steadily from the south-west, gradually worked round with increasing force until it blew from the nor'-nor'-west with cyclonic violence. No measurement of rainfall was possible as the rain-gauge was wrecked, nor was it possible to take other observations. Over 2000 coconut palms were uprooted on Pulu Tikus alone, and upwards of 300,000 trees were blown down in the entire group, and yet this was by no means comparable to the former cyclones for its violence. In the cyclone of 1876, of which a graphic hearsay account is given by Dr. H. O. Forbes, the aneroids are said to have fallen to 26·5 inches and then to have stuck, and the mercurial readings became impossible as the storm carried away the barometer. Certain it is that this storm did great damage, and to-day scars in trees are pointed out and carefully remembered as the exit or entrance marks of sheets of roofing-iron; numbers of trees were uprooted and whole areas of the islands were denuded; and what is of greater interest, the waves rose and deposited wrack and jetsam 150 yards above the normal high-water mark.

Rainfall.—The annual rainfall, as taken by the Pulu Tikus instrument, gives an average of 70·23 inches; the actual annual amounts being:

In 1902	50·73 inches
In 1903	79·75 „
In 1904	78·31 „
In 1905	72·14 „

The fall of rain as registered for Pulu Tikus is probably the minimum of any portion of the group, and the rainfall of Pulu Atas or of Pulu Panjang could be taken at a figure considerably higher. The annual rainfall is therefore a heavy one, although Dr. Guppy states, after a stay of ten weeks in August and the two following months, that "probably it does exceed 40 inches in the year."

One curious phenomenon needs especial mention in connection with the subject of the rainfall, and that is the sudden advent of a shower of rain from an absolutely cloudless sky. When all the sky is blue and no cloud is to be seen from horizon to horizon, save those masses lying far out to sea, a shower will suddenly descend. On the hottest and most calm of days the phenomenon is most prone to occur, and the pelting of large drops of rain at such a time is a very striking occurrence. It has impressed the native mind, for in some Malay communities these showers are considered as signs of ill-luck—and to be caught in a shower from a cloudless sky foretells a death by violence.

As a rule the greatest rainfall occurs in the first half of the year, April being the wettest month and October the driest; the average fall for each month being:

Jan. 8·03 ins.	Feb. 3·60 ins.	March 8·37 ins.	April 12·50 ins.
May 8·76 „	June 7·65 „	July 9·37 „	Aug. 2·73 „
Sept. 1·42 „	Oct. 1·02 „	Nov. 7·51 „	Dec. 3·01 „

(The readings for November are probably exceptional, for in Nov. 1903, 14·38 inches, the maximum rainfall for a single day, fell. Leaving 1903 out and taking only 1902, 1904, and 1905, the average rainfall for November is 1·85 inches.)

This amount of rain is distributed over an average of 156 days every year. The actual number of days on which rain fell being as follows:

In 1902	148 wet days
In 1903	190 „ „
In 1904	139 „ „
In 1905	149 „ „

These 156 wet days are distributed, on the average, among the twelve months as follows:

IN

Jan. 9·5 days	Feb. 10·7 days	March 14·5 days	April 18·8 days
May 16·2 „	June 15·0 „	July 18·7 „	Aug. 15·2 „
Sept. 9·7 „	Oct. 10·0 „	Nov. 11·3 „	Dec. 9·5 ,

Temperature.—The mean temperature of the islands is 81° and the mean daily variation is 9·06°. It must be remembered in making estimates of the temperature of the group that the maximum is a very sustained one, the greatest heat does not last for merely an hour or two of noontide sunshine, but, with very trivial variations, is felt during a greater part of the day.

The Pulu Tikus observations differ somewhat markedly from those that have previously been reported from the group. They differ, as do the barometric readings, from those that have been published in the Blue Books of the Straits Settlements, and which were based on the observations taken by the Clunies-Ross instruments. Most of the discrepancy is doubtless accounted for by the fact that the Pulu Tikus readings are taken at 9 A.M. and 3 P.M., whilst the Clunies-Ross observations are recorded at 6 A.M. only. The mean temperature is therefore actually several degrees higher than the generally quoted 72°. Dr. Guppy's observations on the temperature are also misleading; he gives the mean temperature as "about 78·50°"; but there is no doubt that in the limits of his short stay he had no real basis for fixing a mean temperature without consulting the Clunies-Ross readings.

The highest temperature recorded during the time that my results cover is 94·3° on April 2, 1903, and the lowest is 61·0° on August 4, 1904, whilst the maximum daily variation is 24·80°.

The average maximum and minimum readings for the different months are as follows:

	Max.	Min.		Max.	Min.
Jan. . .	91·1°	72·2°	Feb. . .	90·4°	72·3°
March . .	90·0°	72·9°	April . .	90·8°	73·8°
May . .	89·3°	73·0°	June . .	86·5°	71·3°
July . .	86·7°	70·0°	Aug. . .	86·1°	69·4°
Sept. . .	87·4°	71·0°	Oct. . .	87·8°	72·5°
Nov. . .	89·4°	72·1°	Dec. . .	89·6°	72·3°

Barometric Readings.—The barometer shows steady readings throughout the course of the year, the average monthly variation being ·220 ins. The average maximum reading of all the months is 30·128 ins., which is considerably higher than that recorded by the Clunies-Ross instrument.

The averages of the maximum and minimum readings of each month for four years are as follows:

	Max.	Min.		Max.	Min.
Jan. .	30·091 ins.	29·921 ins.	Feb. .	30·091 ins.	29·935 ins.
March .	30·062 ,,	29·627 ,,	April .	30·097 ,,	29·707 ,,
May. .	30·092 ,,	29·973 ,,	June .	30·097 ,,	29·955 ,,
July. .	30·102 ,,	29·916 ,,	Aug. .	30·136 ,,	29·983 ,,
Sept. .	30·154 ,,	30·019 ,,	Oct. .	30·144 ,,	29·988 ,,
Nov. .	30·129 ,,	29·961 ,,	Dec. .	30·342 ,,	29·930 ,,

The highest reading recorded by the Pulu Tikus instruments is 30·966 ins. in December 1904, and the lowest is 28·95 ins. during the cyclone of March 1902; but in April 1888 a reading of 28·00 ins. is recorded in the Blue Book without any accompanying note of unusual weather.

Apart from these bare records of the instrumental readings, some other influences of the meteorology of the place must be told. So tiny a speck of dry land in the midst of so much water must of necessity have some peculiarities of its climatic conditions, and besides the perpetual mystery of the few inconsiderable feet of coral débris remaining intact in so restless a spot, there are many other individualities of the physical surroundings of the atoll that are of interest. The Trade winds are, of course, the outstanding feature of the atoll's climate, and they are the determining influence which must always be appealed to in solving most of the problems connected with the coral circle. It is said that the region of coral islands is usually one of "light winds and calms, even where the Trades are blowing strongly all around them" (Capt. Maury). It is certainly true that the lagoon and the leeward islands are places of comparative calm, but this is more for the reason that the ring of vegetation, 60 feet high, gives them a very real protection than that the Trades are lulled in their neighbourhood. There are days, but at the most only one or two in each year, that may truly be called calm, and for the rest the Trades blow a steady breeze, with a force of from 10 to 25 miles an hour, making every coconut palm toss and sway, and keeping up a steady sea within the lagoon. Exceptional times of course occur in which the Trades die down abnormally, and then, as for instance in the early months of 1906, there are prolonged periods in which the lagoon is almost unrippled, and even the windward islands are almost deserted by the breeze. The high annual rainfall of 70·23 inches gives rise to the curious phenomenon of the fresh-water wells in which water fit for drinking rises and falls with the movements of the tide. On Pulu Tikus no fresh water may be found in wells, and though, in the more rainy months, fresh water is to be found at a depth of a foot or so below the surface of the land, it soon becomes brackish, and finally entirely salt; long rainless spells therefore occasion great inconvenience, and the island vegetation soon becomes parched in the hotter part of the year. It is the presence of so much rain that prevents the accumulation of guano on the bird-covered Keeling Island, and it is the rain that, carrying the droppings in a state of solution through the permeable coral, causes the deposition of the phosphates which occur in the upper layers of the soil of Cocos-Keeling, and which have made Christmas Island of so great a commercial importance.

From time to time in the history of the islands long rainless spells have occurred, and during 70 consecutive days at the end of 1905 only ·37 of an inch fell; and this very small quantity was distributed over nine separate showers. During the whole of these dry periods rain-clouds are for ever coming up and passing by the islands, and it has long been noticed here that a rain mass will divide before reaching the coral ring, and part pass away to the south and part to the north. This is an interesting fact and is of such common occurrence that an explanation must be readily to hand; and it is doubtless this, that the overheated coral, which in the sunlight dances and quivers with a dazzling whiteness, gives rise to such a column of heated air that the upward-rushing mass is sufficient to cut the oncoming rain-cloud into two parts. This is the explanation, I have since learned, that was also furnished by Mr. J. D. Hague to account for a similar state of things in Jarvis Island. Quite apart from rain-storms, clouds may be often seen to melt away as they come over the group, becoming thinner and thinner as they meet the hot air and finally vanishing as they pass over one of the larger land masses. The opposite phenomenon also occurs, and clouds are formed over the lagoon by the extra evaporation from its surface; these are the clouds that, on calm fine days, are noticed by the sailor to stand poised above atolls. The lagoon is shallow, and is hotter than the ocean water; there is a tremendous evaporation going on from all over its surface, and the water vapour is swept upwards in the rising column of hot air till, meeting with the colder layers above, it condenses and forms the private sky of the lagoon. The island ring is in fact the one and only radiating object in the midst of the ocean, but since it is really a sponge work it can never rapidly cool at night, because of the great warm-water jacket which surrounds and permeates it; the consequence is that the deposition of dew is a very rare phenomenon indeed. A curious state of things is therefore brought about in the physical conditions of the islands, for the excessive radiation from the heated surface prevents the fall of rain, and yet the night fall of temperature of the surface of the land cannot become so great that dew can be deposited. There is then no compensation here, but only a vicious circle of overheated coral and cleft rain-clouds, without the accompanying blessing of dew.

The result of dry weather when prolonged is accordingly severe and the vegetation suffers; the undergrowth fades and becomes parched and brown; the leaves fall from the trees, and the coconuts drop prematurely, leaving the islands very bare and waste. It is the opinion of the Clunies-Ross family that, despite the increased planting of coconut palms, these dry periods are becoming more frequent and more prolonged; though strange to say the wells on Pulu Selma never become exhausted, despite there being no restriction placed on water using.

Thunder and lightning are very rare, and when observed the phenomenon is usually far distant; storms other than cyclones play no part in the history of the islands, for the absence of large areas of land to undergo rapid heating and cooling saves them from sudden atmospheric variations.

CHAPTER XVIII

THE THEORIES OF ATOLL AND REEF FORMATION PUT FORWARD UNTIL THE PUBLICATION OF DARWIN'S THEORY OF SUBSIDENCE

It is only to be expected that so strange a geographical formation as a coral atoll should have given rise to abundant speculation on the part of thinking people; and when the origin of these isolated rings of dry land in the midst of great oceans came first to be considered much difference of opinion prevailed. Even to-day it cannot be said that there is complete unanimity.

Atolls have always been mysterious, and I do not think that I underrate the state of the present-day knowledge when I say that the mystery even now is not entirely cleared away. When, for the explanation of a fact in Nature, you may find to hand many rival theories, whose several makers put them forward as individually adequate, then it is certain that the explanation of that fact is still to be made clear, either by reconciling the contending theories or by establishing a new one in the place of all.

Concerning the origin of atolls, the warfare of rival explanations cannot be said to have yet ceased; and the number of theories that have been brought forward from time to time shows plainly that the halo of mystery, with which the early navigator endowed the coral rings, has to this day remained in the minds of many. Travellers' accounts of all that they saw and heard, when far from their fellow-men, have undergone a regular evolution, just as the travellers themselves have done: and the evolution and progress of modern scientific travel is easily followed in the literature left behind by successive generations of pioneers. In the early days it was but natural that, after a prolonged and uncomfortable voyage, the sighting of a calm stretch of water girt round with a ring of luxuriant islets should have impressed the romantic voyager as something mysterious in which he saw the hand of Providence. And when he came to know that the whole strange structure was the work of living creatures, he, following the lines of thought of his day, read into the whole the extraordinary human vanity of the lower creatures striving with ordered activity to create new fields for man's enterprise.

The coral rock of which the islands were built was the work of living things, and these living things, although he did not appreciate them zoologically, he knew to be at work creating dry land in the midst of oceans. The building of islands was their function, and they built them of a circular shape, so that within the barrier which they, by their life and death had raised, their offspring might be safely reared, and sent forth to carry on the good work of island building. Such were the views of Flinders, and the ordered circular building by the zoophytes is characteristic of the time of the acceptance of these theories. Nothing seemed more true and yet more wonderful than the little beasts conspiring together to make that circle of dry land, knowing it to be the proper way to enclose a piece of water, where they might in safety establish a breeding-ground and a nursery for their kind—and a safe anchorage for the mariner.

With the advent of the zoological traveller—the scientific man who wandered over the earth during the Renaissance period of zoology—this mode of thought became for the most part obsolete among educated people. But it is characteristic of the Romantic age of zoological travel, that the impressions which it stamped upon the popular mind have been lasting ones; and the reason for this is very easy to see. The traveller of the Romantic age was a man who made a voyage of adventure. He, as a traveller, observed with varying accuracy the phenomena that he met with; and assimilated with varying credulity the stories that were told him; and then he gave his adventures and his Natural History to the public as an interesting pot-pourri.

The scientific man of to-day can reach the popular mind in no such way; he has no record of stirring adventure; he is as a rule a specialist whose bare results are not acceptable to a wide public. The result of all this is that when Natural History is served up for that period of childhood when Nature's wonders are of interest to nearly all, and when most people gather their ideas of Nature, it is from the writings of the Romantic age that the greater part of the information is culled. It is in travellers' tales that we as children delighted, and the plates that adorned these tales bid fair to outlast the tales themselves. All this is but natural, for it must be admitted that it is the fault of modern zoological literature that it is devoid of interest, except to a very limited number of specialists. I do not think that the man exists who, merely possessing a thirst for information and a general love of Nature, could read with any pleasure the mass of modern literature on the corals and coral islands. It is easy to recall the time when we were told or when we read of coral islands, and revive a thought association of busy living creatures building, building—always building and dying—in the midst of the ocean. By their efforts these living creatures made the islands where the waving palm trees grow, and where the weary mariner may rest in the calm lagoon, and gather in the green island groves all the splendid fruits of the tropics.

It is, I believe, a common enough idea that the coral creatures build coral, much as bees build honeycomb, but the comb is to them their dwelling-place and their mausoleum, and the comb is raised up and up from the depths of the sea as the busy creatures build below. Such ideas are of course no longer tenable, and serve only as landmarks of the time when the whole of Nature's happenings were explained by reading into the great puzzle the direct intervention of Providence on man's behalf, and by giving to the lowest of creatures most of the emotions and all the instincts of human beings. Although this mode of thought has long since departed from all ordered investigations of scientific subjects, still, in the history of the theories of atoll formation, it lasted long; and many careful researches must be made and accepted before an explanation so easy and so comfortable is quite forgotten.

It was in a great measure the increasing knowledge of the conditions of the ocean bottom that tended most to modify the prevalent ideas of the nature of atolls, and as we have learned more and more of ocean soundings so have our ideas of coral islands been slowly corrected. Many of the theories that were put forward in the early days are not without interest to-day, for in many cases the modern theories are but compromises, in which the remnants of an older explanation are easily detected.

One of the older theories that must claim some share of attention—for, in a modified condition, it survives still—is that which seeks to explain the usual form of atolls by assuming the island ring to be a coral growth built around the crater of a volcano. The well-known cone shape of the typical volcano gives rise to the characteristic form of the atoll; the lagoon is the water-filled crater, round which the islands stand in a more or less perfect ring, being built wherever the rim of the crater comes sufficiently near to the surface of the sea. This theory received authority by appearing in Lyell's "Principles of Geology" (vol. ii.) in 1832; but, even if no rival theory had so soon been destined to overthrow it, the many and obvious objections to it would have rendered its general acceptance impossible. No terrestrial volcanoes are known with craters so vast as are many atoll lagoons, and no mountain chain so strangely level as are the low island groups scattered in the Pacific Ocean. Despite the improbability of this view, the majority of the stray visitors who have come to this atoll have fancied that somewhere in the lagoon was the deep hole of the crater, and have believed themselves to be living on the rim of a vast volcano. The Rev. E. C. Spicer, who as naturalist accompanied H.M.S. *Espoir* in 1885 on behalf of the Straits Government, was struck by the appearance of the narrow strip of land and the enclosed lagoon, and said "the resemblance of the whole to a giant crater is very striking." Even to-day it is held by some that atolls may be formed on ancient craters; Prof. A. Agassiz says "atolls may also be formed upon the denuded rim of a volcano crater as at Totoya and Thombia in Fiji." * These however, must be very special cases and do not justify any general statement.

It was with the voyage of the *Beagle* that the era of the specialist zoological traveller dawned, and it was as the result of the visit of her great naturalist to this group in 1836 that modern scientific thought was directed towards the question of the origin of atolls.

Although it is commonly assumed that Darwin formulated his views of atoll formation as a result of his study of Cocos-Keeling, still he definitely states that "the whole theory was thought out on the West Coast of South America, before I had ever seen a coral reef." † Cocos-Keeling was the first atoll that Darwin ever saw, and the only one he ever examined; and in it he believed he found evidences of those events that he had pictured as constituting the past life of an atoll. To some extent, doubtless, Darwin was influenced by what was told him in the islands, and the whole of this information was certainly not accurate, but the observations made by Darwin are to-day as true as when he recorded them.

Of Darwin's theory of atoll and reef formation it must be said, that it was a piece of reasoning more masterful than any of its rivals, and more complete in its detail; but it must also be said that the theory of subsidence when invoked in the formation of the Cocos-Keeling atoll does not meet with any support. The theory of SUBSIDENCE must be referred to in some detail; but it is necessary at once to say that many of the views of Darwin's successors were views that Darwin himself had originated, and the validity of which he had admitted under certain conditions: in the discussion of the origin of reefs and atolls this fact is often overlooked.

* See *Nature*, 1903, p. 547.

† See the Introduction to Charles Darw'n's "Coral Reefs," by J. W. Williams (and other quotations from the same source).

As the theory of Subsidence ushers in the modern epoch of coral-reef theories, it will be best to explain, before these views are discussed, what problems the question offers, and what details must be explained by a theory that is to be a useful one.

In order to save wearying repetition, these problems will be briefly taken in order, and the merits and the shortcomings of the various theories will be measured for each individual problem. In every case the consideration of the subject falls naturally into three divisions: the views held before Darwin's day, Darwin's work itself, and the theories put forward in opposition to Darwin's representing three distinct epochs in the evolution of our ideas of coral-island formation.

The First Point that requires an explanation is the nature and origin of the submarine bank on which the atoll rests:—*i.e.*, on what structure did the corals first start to build the islands? The question of the nature of the "basis" assumes great importance from the fact that the depth of water in which the reef-forming corals can grow is strictly limited. The basis of every atoll must therefore be an elevation, rising so near to the surface that reef-building corals may flourish on it.

This fact consequently presupposes the existence of a very large number of submarine mountains, dotted all over the Indian and Pacific Oceans, and all with their peaks approximately of the same height.

Now no terrestrial formation such as this is known to exist; and it was this fact that led Darwin—rather than assume such an apparently impossible condition of submarine configuration—to bring forward his well-known theory of subsidence. But it must always be borne in mind that he admitted that, were such banks at hand, they could furnish the basis for atolls.

To Semper he wrote (Oct. 2, 1879): "I always foresaw that a bank at the proper depth beneath the surface would give rise to a reef which could not be distinguished from an atoll formed during subsidence"; and again to Alexander Agassiz

(May 5, 1881): "I have expressly said that a bank at the proper depth would give rise to an atoll, which could not be distinguished from one formed during subsidence."

It is often overlooked that Darwin ever admitted any alternate hypothesis to that of subsidence, and it is well, therefore, to quote his own words to show that he fully recognised a state of things which, subsequently brought forward anew, became a rival theory. Not only did he admit that, were banks existent in the ocean of the necessary depth below the surface, they would become the sites of atolls in a coral-bearing sea; but he further acknowledged that, were signs of elevation and *not* depression common in atolls, his theory would not be valid. To Semper he wrote: "But I fully agree with you that such cases as that of the Pelew Islands, if of at all frequent occurrence, would make my general conclusions of but very little value."

The Pelew Islands are peaks in the Caroline group, where Semper found coral reefs raised up from 400 to 500 feet, and only 60 miles away from them are typical atolls.

Having seen what was Darwin's attitude towards other views of atoll formation, it will be well to consider in some detail his theory of subsidence; for it is almost entirely in connection with the question of the foundation of the atoll structure that his theory has its individuality and its importance.

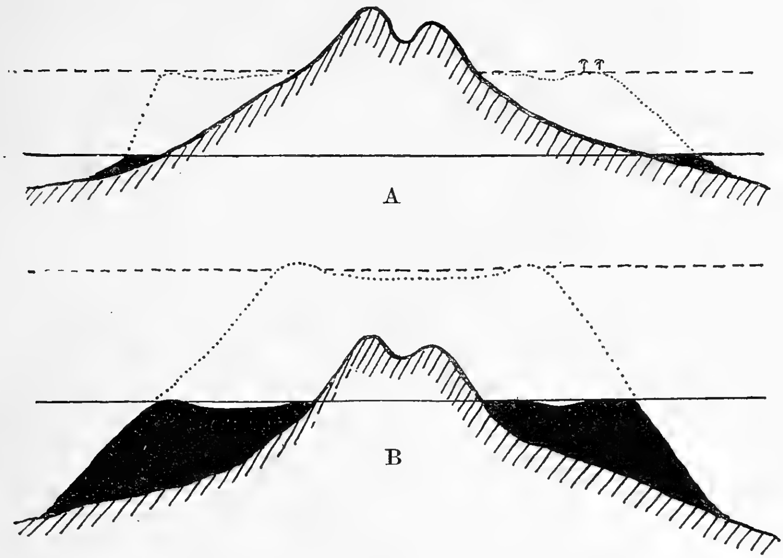
No better idea of it can be given briefly than Darwin's own diagram, which shows at a glance the main points of the explanation that he furnished for all coral formations.

In the first place, a high oceanic island is pictured, situated in a sea favourable to coral formation; on the submarine slopes of this island corals will flourish and form a reef around the land. (See Illustration A.)

This first stage is of course no fictitious state of things, for many instances of high islands surrounded by barriers are known.

Now if the whole structure be imagined to sink slowly, the corals of the barrier will grow, and compensate for the subsidence, and Darwin assumed that the corals of the outer edge would grow best; for he said that the corals love the surf, where they are better aerated and more abundantly fed. There is no compensating factor for the sinking land, and if this process continues for some time, the second stage is

Fig. 59.



The Illustration used by Darwin to make clear the Stages of "Subsidence" in Atoll Formation.

arrived at, and the island remains, surrounded by a moat, the lagoon channel, which is again encircled by the barrier reef, now standing out some distance from the island. This second stage is again a geographic reality. (See Illustration B.)

From this stage the atoll is easily derived; the subsidence continues, the reef outside compensates by coral growth, the land, uncompensated, finally disappears within; thus the typical lagoon is formed:—a salt lake, in which a peak of land is buried. Such, in brief, is the theory of subsidence.

The basis of the atoll is therefore, on this theory, a sinking one ; and, in an advanced case, is a bed of ever-thickening coral; for as the land continues to sink, the upward building of the coral adds new layers to the accumulating coral bed.

THE SECOND POINT that any theory attempting the explanation of atoll formation must make clear is the regularity of the tendency to a circular shape. So constant is this feature that the explanation of it must be intimately bound up with the proper history of the development of the structure. Darwin's theory possessed this charm, that it carried with it, in the picture of the disappearing peak with its outlying reef, an idea of the development of a ring formation, which is very easy to understand.

The atoll shape comes about in the making of the structure by subsidence, and is afterwards maintained by the corals of the outer edge of the reef growing faster than those on the inner edge. The corals of the central portion are those that fare worst both as regards their supply of oxygen and of food, and they also have to contend against the adverse influences of sediment and impure water; in this way the lagoon becomes a stereotyped feature of the atoll. The vigorous growing edge of the reef afterwards became the site of an accumulation of wave-tossed débris, which gradually rose into the dignity of island dry land; and so a circular ring of islands was formed around a central lagoon. The formation of all the characteristic features of a typical atoll is, therefore, very naturally explained by Darwin's theory of the reef foundation.

As a side issue of this aspect of the question, a THIRD POINT arises, for it is obvious that the shape of the individual islands demands some explanation. In Darwin's theory there is no special provision for dealing with this problem.

THE FOURTH POINT is that any theory which deals with the formation of atolls, and attempts to explain their formation, must also take into account the other coral formations—the fringing reef and the barrier reef. In respect of this detail the theory of Subsidence was quite satisfactory, for the explanation brought all these structures into an ordered sequence.

CHAPTER XIX

THE THEORIES OF ATOLL AND REEF FORMATION PUT FORWARD SINCE THE PUBLICATION OF DARWIN'S THEORY—THE THEORY OF "SOLUTION"

THE voyage of the *Beagle* had given Darwin the information necessary for completing the development of his theory of atoll formation. The voyage of the *Challenger* furnished the material for the origin of the rival attempt at the solution of the problem, and the formation of a definite new theory to replace that of Darwin.

On April 5, 1880, Dr. John (now Sir John) Murray published, in the *Proceedings of the Royal Society of Edinburgh*, a paper on "The Structure and Origin of Coral Reefs and Islands."

The new theory thus brought forward differed essentially from the theory of "Subsidence" in practically every detail, for Murray started with the knowledge—which was not available for Darwin—that submarine banks *did* exist in the ocean. In this new theory, the basis of the islands or reefs was not a sinking one, and in the place of the sinking peak of land, Murray pictured a volcanic elevation of the floor of the ocean. This elevation reaches to the depth limit of coral growth by one of two processes: if it were originally projecting above the water it becomes worn down by the action of the waves, and if it is too far below the surface, it becomes raised by the deposit upon it of *Globigerina* and *Pteropod* ooze.

"The soundings of the *Tuscorora* and *Challenger* have made known numerous submarine elevations; mountains rising from the general level of the ocean bed, at a depth of 2500 or 3000 fathoms, up to within a few hundred fathoms of the surface. Although now capped and flanked by deposits of

Globigerina and *Pteropod* ooze, these mountains were most probably originally formed by volcanic eruption" (p. 507).

Such, in brief, is the basis which Murray furnished for the building of reefs and islands. Upon this basis the corals form a reef, and at the outer edge of the reef the corals grow best, because here they are enabled to obtain most food. Murray gave up the idea that the corals of the edge of the reef thrived most because of their better supply of oxygen, but he retained the notion that the oceanic currents brought more food to the edge of the reef, and so enabled the corals to grow more freely. The lagoon becomes formed, and continues to grow in size, by the "solution" of the dead coral which forms the central part of the reef—in Murray's own words: "Larger quantities of lime are carried away in solution as a bicarbonate from the lagoon than are secreted by the animals which can still live in it; the lagoon thus becomes widened and deepened" (p. 511).

The whole theory of atoll formation on the volcanic mountain base is summed up in this way in the original paper. "That when coral plantations build up from submarine banks they assume an atoll form, owing to the more abundant supply of food to the outer margins, and the removal of dead coral rock from the interior portions by currents and by the action of the carbonic acid dissolved in sea water" (p. 517). This theory has been further elaborated by Murray, by Murray and Irvine (*Nature*, June 12, 1896), and by James G. Ross (*Nature*, March 15, 1880); and it has received new embroideries from the work of Mr. Stanley Gardiner in the Maldives and Laccadives.

The prevalent shape of the constituent islands of the atoll ring appears to be the subject of no special attention in this theory, and it is not apparent how other coral structures, as fringing reefs and barrier reefs standing far out from shore, are made at all easy of understanding.

The views of Mr. Stanley Gardiner have been put forward in his work on "The Maldives and Laccadives," published in 1902, and more fancifully in an article in *Nature* (p. 371, 1904). In these publications, at least four distinct methods of atoll formation are postulated, and these are briefly stated as follows:

Method No. 1.—An elevation of the ocean floor becomes covered with sediment; it reaches the depth at which reef corals flourish, and a reef is developed upon it. "Boring organisms enter on its central part and cause the rock to decay. Sand-feeders follow and triturate up the fragments, throwing a constant stream of fine mud into suspension in the water, to be removed by tidal and other currents. Assisted by the solution of coral in sea water, a lagoon is formed in the centre of the reef, and passages are cut later from it along the lines by which its muddy water escapes."

Method No. 2.—High land rising from the ocean is first present, this high land becomes disintegrated and broken down, and finally, by the action of currents, reduced to a level plateau some depth below the surface of the sea. On this plateau Mr. Gardiner pictures an atoll to be very readily formed. "At depths below 50 fathoms it is obvious that from the first the organisms on the periphery of the bank so formed would grow more rapidly, and so an atoll as such would directly arise. The whole action might proceed with extreme rapidity."

Method No. 3.—A high oceanic island is pictured with a fringing reef around its shores, denudation and solution remove the island land, and the reef stands out from the shore as a barrier reef. "Subsequently the edge of the terrace grows outwards and its inner part is removed as in (1), forming a barrier reef. Eventually the original island, owing to similar causes, disappears, leaving an atoll. This method is of quite wide occurrence in areas where elevated coral reefs are found." The stages of progress in this third method are, therefore, those pictured by Darwin, but their manner of development is widely different.

Method No. 4 grants that subsidence alone, or subsidence plus the agencies brought into methods Nos. 1 and 2, may cause atoll formation.

The development of all coral structures therefore presents no difficulties if the work of Mr. Gardiner is accepted, for the choice of four different ways of building these strikingly uniform formations is presented.

Not only is a choice of four methods given, but the question of the development of an atoll from a reef is made simple because in one case "boring organisms" conveniently "enter on its central part," and in another because it is "obvious" that the corals grow faster round the periphery. The situation is further made more satisfactory by incorporating Darwin's theory with the ideas which Darwin deprecated, and which are generally used in opposition to his conclusions.

It will be noticed that in Method No. 3, the theory—which is an extension of that of Murray—has been used to explain the presence of barrier reefs, though I do not know if *all* barrier reefs are supposed to arise in this way by supporters of these theories.

This particular method (No. 3) of making an atoll appears to me to need for its acceptance an utter disregard for everything that is at all probable in connection with the story of the warfare of sea and land. The picture of the high island towards the completion of the process, when, after having stood resisting in a troubled sea, it so conveniently crumbles to pieces within the calm of an encircling barrier reef, appears to me to be contrary to all natural laws.

What form of denudation and solution could be invoked to remove a large oceanic island when its barrier reef of soluble coral remains intact?

It must be a widespread and potent force, for "this method is of quite wide occurrence in areas where elevated coral reefs are found."

In Method No. 1 the forces consist of "boring organisms," "sand-feeders," and "the solution of coral in sea water." It cannot be "the solution of coral in sea water," for that would remove the barrier and leave the island; it cannot be wave or current action, for the barrier has now protected the land;—all that remains is the "boring organisms" and "sand-feeders."

The fact of the cutting down of land below the level of the sea by currents has been called into question by geologists.* Admiral Sir W. L. Wharton has given instances in which the process has been carried out. Graham's Island in the Mediterranean is a notable example of this; but it must be remembered that the destruction of a loosely piled volcanic structure, cast up to-day and washed away to-morrow, is a very different thing to the removal of an oceanic island girt about by a barrier reef.

Professor Alexander Agassiz has also added the testimony of his great experience in favour of this method of preparation of the submarine base. In a paper read before the Royal Society in 1903, he says: "Denudation and submarine erosion fully account for the formation of platforms." Agassiz also demands a rising, rather than a sinking, of the areas over which coral formations are found, and in the same paper he says: "Throughout the Pacific and Indian Oceans, and the West Indies, the most positive evidence exists of a moderate recent elevation of coral reefs."

Dr. H. B. Guppy is another believer in the theories of Murray; he brought his views forward in a paper published in the *Proceedings of the Royal Society of Edinburgh* in July 1886. The paper was the outcome of his investigations in the Solomon Islands, and in addition to finding confirmation of Murray's views, he also postulated a movement of elevation. Dr. Guppy doubted the power of coral growth to raise a reef to a greater height than some five fathoms below the surface, and, at p. 367, he speaks of "the inability of detached submerged reefs to raise themselves within the constructive power of the breakers without the assistance of a movement of elevation."

When in 1888 Dr. Guppy came to examine the atoll of Cocos-Keeling his views, at any rate with regard to the *importance* of the effects of "solution," seem to have slightly changed. In his account of the atoll (*op. cit.* p. 578) he says: "I do not, however, consider this [solution] as a very effectual

* See Mr. Ernest Schwarz, *Nature*, 1904, p. 581.

repressive agency in the present closing scene of the atoll. The accumulation of coral débris is too patent a fact. When we walk through a field of Madrepore and sink knee-deep into the friable débris of many preceding generations of this coral, we realise the fact that dead coral accumulates and is but partially removed in solution. Still there can be no doubt, as shown by Murray, Irvine, J. G. Ross and others, that the solvent action of sea water has a repressive effect on the rate of reef growth."

Dr. Guppy, in the course of his examination of this atoll, made an important contribution to the study of coral structures by formulating a very definite theory to account for the prevalent shape of the constituent islands of the atoll ring; this theory will be mentioned again, for it affords a valuable addition to our knowledge of coral formations.

Since the theory of Solution, in some of these modified forms, is the one that obtains the greatest general acceptance at the present day, it is necessary to examine its virtues, and its shortcomings, in some detail. The theory is put forward to explain (1) the formation of the original lagoon, and (2) how that lagoon "becomes widened and deepened."

With regard to (1), I think that the theory does not in reality offer an explanation of the method of atoll formation, and with regard to (2), the condition that it would explain is contrary to experience, for atoll lagoons tend, as a rule, to become smaller and shallower.

Then, even if the conditions presumed to be brought about by this agency were conditions that experience showed to be real, there is no definite proof that this agency could bring them about; there is, so far as I can see in the published writings of the advocates of this theory, no direct observation of the working of "solution" made actually in an atoll lagoon. Sir John Murray, in his original paper of 1880, at p. 511, says "larger quantities of lime are carried away in solution as a bicarbonate from the lagoon than are secreted by the animals which can still live in it." In a paper published in 1890 * he

* Murray and Irvine, *Nature*, June 12.

says, however : " Turning now to the lagoons and lagoon channels of coral islands, *it is believed* * that large quantities of carbonate of lime are in the same way being dissolved from these shallow basins as well as from the deposits of the deep sea, but under somewhat different circumstances. In the case of a shell falling to the bottom of the sea, it is continually brought into contact with new layers of water, which has the same effect as if a continuous stream of water were passing over the shell. In the case of the lagoons this last is what takes place. The water which flows in and out of the lagoons twice in twenty-four hours passes over great beds of growing corals, and from all the observations we have is largely charged with carbonic acid, owing probably to the larger number of animals on the outer reef over which the water passes on its way to the lagoon."

Throughout the writings of Sir John Murray much stress is laid on " the water which flows in and out of the lagoons twice in twenty-four hours," and this for the reason that it gives the operations of solution a better chance to act. It is true that the level of the lagoon rises and falls with the cycles of the tide, and that the alterations in level give rise to local currents in the inlets of the lagoon ; but this does not affect the whole lagoon, and to imagine the process as anything akin to that which happens as a shell falls through the depths of the sea is a mere fallacy.

When a shell falls from the surface of the sea to greater depths it passes through *new* layers of water, each, with the increasing depth, being more potent for solution. In the case of the lagoons this last is what does *not* take place. The rising tide raises the lagoon waters, the falling tide lowers them, but the waters of the lagoon are not changed twice in twenty-four hours. The action of " solution " in the lagoons of atolls may therefore be accepted as being only a theoretical action, and the actual proofs of its working do not seem to have been established.

Although there seem to be no published observations to prove that material is " carried away in solution " from a

* Italics by present author.

lagoon, still Sir John Murray has shown quite conclusively that matter is being removed in suspension. At p. 515 (*op. cit.*) he says: "Very strong currents run out of the entrances into lagoons and lagoon channels, and when the tow-net was used, it showed that a large quantity of coral detritus was being carried seawards."

This is an easily verified observation, but it needs some amplification, for it is only true for certain inlets, or at certain states of the tide. If other inlets had been visited, for instance those on the windward side, or if the turn of the tide had been awaited, then currents running *into* the lagoon would have been detected, and their burden of detritus would have been found to be even greater. In the Cocos-Keeling atoll, Dr. Guppy estimated "that at least 5000 tons of sand and débris derived from the breaker edge of the reef are annually transported by the currents through the passages between the islands into the lagoon, nearly all of which is deposited at or near the lagoon's margin." The importance of this water-borne sand will be dealt with more fully, but the undoubted fact of its coming to the lagoon in greater quantities than it leaves it, negatives the idea that, even in suspension, matter is commonly robbed from a lagoon.

Besides this failure of the common history of atoll lagoons to show any signs of the action of "solution," or to demand any such explanation for their origin or development, there is an inherent improbability in the theory as a whole. Darwin, on the very first publication of the theory, detected this weakness, for in a letter written to the late Mr. T. Mellard Reade on September 22, 1880 (quoted in *Nature*), he says: "It is astonishing that there should be rapid dissolution of carbonate of lime at great depths and near the surface, but not at the intermediate depths where he places his mountain peaks." This is of course a very pertinent point, and one that does not appear to have had any definite answer, although it was again raised by Dr. R. von Lendenfeld in *Nature* of May 8, 1890. Dr. Lendenfeld sums up the stages as follows: "First a limestone cone is built, because the lime is deposited more rapidly than it can be dissolved. Then a lagoon is formed because the solution exceeds the accumulations, and this on the same spot, and in still shallower and less powerfully dissolving water."

The late Mr. T. Mellard Reade has also pointed out that if solution does in reality form the lagoon at the top of the bank, it ought to dissolve the bank itself much more easily (*Nature*, March 22, 1888), and Mr. Hedley in the same journal (August 4, 1904) has also shown this weakness of the theory. As a matter of fact the work of Murray and Irvine appears to show very clearly that at the surface of the sea calcareous deposits take place, whilst at greater depths they tend to become dissolved; certainly calcareous deposits take place in atoll lagoons. It is easily seen that brecciated rock and sandstone are formed in the lagoon by the actual deposition of calcium carbonate. The deposition of calcium carbonate is a very widespread phenomenon in the lagoon, so that, granting that sea water dissolves coral, its action cannot be a very destructive one where rapid deposition of calcium carbonate is taking place.

There are some features of a fully developed atoll which have been urged in support of the theory of solution. In Sir John Murray's first paper, he says (p. 515): "At the Admiralty Islands, on the lagoon side of the islets on the barrier reef, the trees were found overhanging the water, and in some cases the soil washed away from their roots. It is a common observation in atolls that the islets on the reef are situated close to the lagoon shore. These facts point out the removal of matter which is going on in the lagoons and lagoon channels."

Now with regard to the first statement, it is fair to say that it is identical with Darwin's observations in the Cocos-Keeling atoll, which gave him such strong confirmation of his own theory. That any real weight could be attached to it was denied by the objectors to Darwin's theory—and quite rightly, for the condition is only one of those temporary phases of atoll life which come and go with seasons and winds.

I am quite convinced, as a result of watching the Cocos-Keeling atoll for fifteen months, that these temporary phases are misleading, for there is no evidence to show that they represent the normal process of development. The observation can therefore carry no more weight when urged to support the theory of solution than when it was used as evidence of the reality of subsidence.

With regard to the position of the islets on the reef, it will be pointed out, in studying the development of the atoll, that this is entirely the outcome of the force of the waves which first raised the islets, and the subsequent seaward growth of the reef edge.

Since the examination of the fully developed atoll lends no support to this theory, it is natural to inquire whether the study of its earlier stages will yield any evidence in favour of the theory that its lagoon is caused by solution. One of the most important additions to the study of coral structures was made by Admiral Sir W. J. L. Wharton, who pointed out that the great reefs of the China Sea, and elsewhere, had an atoll form when far below the surface of the sea. These ringed reefs are not in reality "drowned atolls," but are reefs in the process of development, but it is difficult to see how solution can possibly produce the condition found in them.

From my prolonged observations of the Cocos-Keeling atoll, I am convinced that the theory of "solution" does not at all account for its development, its present features, or its future history.

Not only does no feature of the atoll yield any support to the theory, but a great many of them definitely contradict it. The lagoon shore is steadily gaining on the lagoon, all round the atoll ring. The lagoon is steadily shoaling by the deposition of sand brought into the lagoon by currents. Calcium carbonate is being deposited in the lagoon, making beach sandstone and conglomerate, and causing the old dead fragments to become harder, and heavier, than they were during life. The dead colonies of coral are not dissolved and removed from the lagoon, for it is definitely known that great numbers of such colonies have been standing for thirty years—an observation of very great importance in this discussion. The present condition of Keeling Island and of Pulu Luar is prophetic of the future of the whole atoll: the evidence it affords is in direct opposition to any hypothesis of a deepening or widening of the lagoon by a process of "solution."

CHAPTER XX

THE THEORIES OF ATOLL AND REEF FORMATION PUT FORWARD SINCE 1880

In the space of more than twenty years that has elapsed since the first publication of the theory of "solution," several other views upon coral formations have been put forward; but although many observers have dissented from the "solution" theory, no new concrete idea has been formulated to account for all the phases of coral formations. In the discussions which have taken place upon the subject it has been, as a rule, a question of accepting the "solution" theory in the place of the older views of "subsidence"; and yet there are many observers who appreciate the fact that "subsidence" will not explain all coral structures—and who yet do not accept "solution" as an explanation for the typical form of atolls.

Professors A. Agassiz and Semper were early opponents of the idea of a subsiding basis; but, in 1903, Agassiz said (*Nature*, 1903, p. 547) that in his work "no attempt was made to establish any independent general theory." It would appear that the general tendency was to revert to the ideas of Chamisso—views that were put forward in "Kotzebue's First Voyage," long before Darwin formulated his famous theory. Chamisso supposed that the surf was the home, by election, of the reef-building corals, and so those colonies upon the outer edge of the reef grew faster than those within—and in this way a circular reef was formed. What was lacking in Chamisso's theory was a base upon which to build this reef. The failure was entirely due to the scant knowledge of the ocean bottom at the time when the theory was put forward: when Darwin overcame the difficulty he adopted the views of Chamisso to a great extent. It is not true that corals live best in the surf: the observation has been repeatedly made that the surf-line is practically barren of living coral growth: but it *is* true that the corals of the outer—submarine—edge of the reef grow most luxuriantly, and Chamisso's ideas were in the main correct.

The structure that Chamisso erected upon an unknown base requires but little elaboration when Semper, Agassiz, and Murray have demonstrated the foundation to be a reality—and for the making of this structure neither subsidence nor solution is called upon.

The idea that the reef corals delight in the crash of the surf must be given up, and so the original suggestion of a better aeration of the outer coral colonies, causing their more rapid growth, has also been abandoned. Combined with this idea of a more abundant supply of oxygen to the outer corals is the supposition that they are also in a position to obtain more food, and so to thrive better than those which get the water only after it has passed over the outer rim. Semper attached great importance to the currents which flow about a reef, and Professor Hickson, in the Celebes, noted the effects of the currents upon coral growth. Mr. G. C. Bourne, from a study of Diego Garcia (*Proc. Roy. Soc.*, 1888, p. 458), came to the conclusion that currents were among the most important agents in causing the shape of coral reefs, and he says, "The strength and direction of currents appears to me to be the main influence of coral growth; that the behaviour of currents on meeting an obstacle with sloping shores explains the super-abundant growth of corals on the outer slopes of a reef, whether submerged or awash; that the growth of corals on the periphery of a bank being in great excess of the growth in its interior portions is sufficient to explain the formations known as atolls and barrier reefs." Yet the workings of this particular current influence still await an explanation.

These views therefore agree in placing Chamisso's bank on the base that Agassiz, Semper and Murray pictured; but the method of the more rapid growth of the edge is modified.

Agassiz and Semper both showed that frequently the base was a rising one, but Semper admitted that at times it was not impossible for atolls to be formed on sinking bases. He says ("Animal Life," English Trans., International Scientific Series, vol. xxi. 1906, p. 456): "I regard it as quite possible that under certain circumstances a subsidence may be combined with the formation of atolls, and even that it may once have been the sole cause of their formation; but I cannot admit that subsidence is alone sufficient to explain all the conditions and relations of coral reefs, or even of predominant importance."

The theory of subsidence was accepted, and strongly advocated, by Dana, and he even went a step farther than its originator, for he was unable to conceive that, even if banks did exist at the proper depth, an atoll structure could be developed upon them without the intervention of a movement of subsidence. This possibility Darwin had always allowed. He said: "If such a bank lay a few fathoms submerged, the simple growth of the coral without the aid of subsidence would produce a structure scarcely to be distinguished from a true atoll; for in all cases the corals on the outer margin of the reef, from having space and being freely exposed to the open sea, will grow vigorously and tend to form a continuous ring, whilst the growth of the less massive kinds on the central expanse will be checked by the sediment formed there, and by that washed inward by the breakers; and as the space becomes shallower, their growth will also be checked by the impurities of the water, and probably by the small amount of food brought by the enfeebled currents, in proportion to the surface of living reefs studded with innumerable craving mouths." This I consider to be one of the truest pictures ever drawn of the development of an atoll reef, but Darwin did not imagine it to be the mode of formation of the majority of atolls; and Dana observed: "If such patches of submerged bank existed, the lagoon structure would still be as inexplicable as ever" (*op. cit.* p. 220).

The newest epoch in the investigation of coral structures is opened by the detailed study of the atoll of Funafuti carried on by no less than three successive expeditions. The object of the examination was the making of a bore through the island and its basis in order to determine if the necessary depth of coral reef, which a theory of subsidence demands, was found to exist in reality. In the volume in which the results of this successful boring are published ("Atoll of Funafuti," *Roy. Soc.*, 1904) the core obtained, to a depth of 1114½ feet, is described in its entire length, and the conclusion appears to be that the whole extent of the core had been formed at a distance of no more than 50 fathoms from the surface, and consists of a continuous formation of reef rock. Reef corals were found as casts in the lower limits of the core, and if these corals are in the position of their growth, then a gradual subsidence must have taken place during the formation of the atoll. On the other hand, to my mind, the description of the core reads far more like a section of a talus bank, with surface forms of corals and foraminiferæ, piled in disorder as a débris slope. Since the bore was driven on the extreme—windward—edge of a reef some ten miles across, there is no reason why this should not in fact be the talus slope of an originally smaller reef, the primitive boundaries of which are to be found somewhere nearer the middle of the present lagoon. If the original submarine bank had grown seaward only half a mile in all its long history, its talus bank would have been pierced by the bore, and its condition would in all probability have been just what is seen in the actual bore.* This is made easy of understanding by means of a diagram drawn to scale. (See Fig. 53, p. 153.)

This objection is not urged in the spirit of destructive criticism, for it seems to me that some atolls may have been formed on subsiding bases: but to my mind it renders it quite impossible to say that any process of subsidence caused the development of this atoll of Funafuti. More recently Mr. Hedley has shown—and here the evidence appears to be conclusive—that the Great Barrier Reef of Australia is the site

* On this point see also Hedley, *Natural Science*, xii., March 1898, p. 174.

of definite subsidence. It does not necessarily follow that the features of this coast-line are brought about by the growth of coral reefs on a sinking basis, for, as Hedley says ("Coral Reefs of the Great Barrier," p. 10): "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." The coral reefs are definitely established upon a sunken basis, but that is not the same thing as saying that the sinking caused their present disposition.

In this same paper, Mr. Hedley carried on the work of Guppy and of Kramer in the appreciation of the force of the winds and waves in the formation of crescent and horse-shoe islands and reefs, and, on the whole, this wind formation is one of the most distinct advances made in the study of coral structures.

I think it may therefore be said that there is no one generally accepted method by which it is agreed that all coral formations are brought about. Some reef spots show signs of elevation, and some of depression, and some fail to give any indication of change, so that land movements may not properly be claimed to be the cause of any features that are constant. Upon a stationary basis again, there is no generally accepted method for building the characteristic features of the fully devoloped atoll or barrier reef.

CHAPTER XXI

THE METHOD OF DEVELOPMENT OF THE REEF BANK AND THE REEF

Sedimentation in the Open Ocean.—It is a statement which will not be disputed that sediment is for ever dropping from the surface of the ocean. When the real nature of the material which composed the floor of the ocean was made known, and the hard remains of a number of animal forms were recognised, it was at once asked: do these forms live at the depths at which their remains are found, or are they surface-living creatures, whose heavier parts have dropped from the surface waters after the death of the animal? The tow-net revealed the animals during life as surface-living forms; and many investigations—especially the *Challenger* reports—have made all the processes of deep-sea deposit quite clear.

Not only are the troughs of all the oceans lined with ooze of slightly varying nature, but the elevations which arise from them are also clothed with the same deposit. There is then a perpetual shower of sediment from the surface of the ocean. Calcareous and siliceous remains of pelagic organisms, volcanic dust, and other less considerable constituents form a never-ceasing rain of particles from the surface-water to the ocean depths. They drop, and line the ocean bed: they drop, and cover ocean slopes and elevations, and come to rest wherever the absence of wave action will let them settle.

This certain knowledge prompts a very natural inquiry as to the extent to which this sedimentation building may take place. Supposing some elevation to be present on the ocean floor, or supposing more sediment to be deposited in any one particular spot, by reason of some ocean current; how far below the waves would the rising mound come to a standstill?

In other words, where, below the surface of the sea, will dropping particles fail to come to rest, and cease to form banks? We do not know, and beyond saying that *somewhere* in the ocean there is a level, below which particles may rest and sedimentation take place, and above which particles are prevented from settling by the movements of the surface waters,—we cannot definitely go. This level is one of such great importance that I propose to look upon it as a definite plane, occurring over every ocean, and to give to it the name of the Limiting Line of Sedimentation.

We may attempt to find out where this line may be expected to exist by ascertaining how far beneath the surface of the ocean the effects of wave action are felt; but on this point our knowledge seems to be rather scanty. Dana, in his "Corals and Coral Islands," 1875, has collected a certain amount of information concerning this question, and he quotes M. Siau (*Comptes Rendus,* t. xii. p. 744) for the assertion that ripple marks are present at a depth of 94 fathoms to the north-west of St. Paul's Roads. Various other estimates have been made, and 83 fathoms, 50 fathoms, and 15 fathoms are some of the figures arrived at. De la Beche is responsible for the statement that sand and mud are stirred up, so that they discolour the water, at the depth of 15 fathoms;—it is evident therefore that this depth is above the *Limiting Line of Sedimentation.*

It would not be expected by any one with a knowledge of the sea that the level of the *Limiting Line of Sedimentation* would be the same for all waters; for the normal rollers of the Trade-swept ocean must affect a far greater depth than the short seas of land-locked basins. It would not be expected even that it would be at the same level at all times in the same sea, for in monsoon areas it would be probably different in two monsoon seasons. Still, for all parts of all oceans there is an average line separating the wave-stirred upper layers from the still, quiet waters of the ocean depths.

Sedimentation Banks.—It is, therefore, an easy matter to picture the development of a sedimentation bank in the ocean. It may, perhaps, rise from ocean depths, in places where the oceanic currents deposit more abundant sediment, or it may build on some already prepared elevation; we can at any rate assert that, wherever its formation starts, it will certainly end at the *Limiting Line of Sedimentation.* Great numbers of these banks are known, and their very number does not warrant their mention. They may be built, perhaps, on volcanic elevations (Murray), on denuded volcanic islands (Wharton), or on denuded remains of ancient land (Stanley Gardiner); or they may be built on inequalities of the ocean floor not included under these heads, or be raised from ocean bottom by sedimentation alone. I do not know that we have much evidence to show what they may be; and I do not think that we have *any* reason to believe that they are all volcanic.

For the explanation of the development of coral structures I do not think it is to be greatly deplored that we cannot assign a common origin to them all, for in their development they are all essentially sedimentation products, and so have to adhere to the laws governing its deposition.

The Bathymetrical Limits of the Reef-building Corals.—It is next natural to inquire at what point, below the level of the waves, may the growth of the reef-building corals start; and on this matter again our evidence cannot be said to be complete. Dana collected all the evidence at his disposal, and placed the limit at 20 fathoms; Darwin, from his data, set it at from 20 to 30 fathoms; and Stanley Gardiner, from a series of dredgings in the Maldives and Laccadives, has confirmed Darwin's estimate. By the careful work of Basset-Smith upon the Tizard and Macclesfield banks (*Ann. Mag. Nat. Hist.*, 1890, p. 353), the knowledge of the distribution of the reef-builders has been greatly increased, and the bathymetrical range has been found to be far more extensive than was supposed. In a series of dredgings, in depths between 31 and 45 fathoms, Basset-Smith found 19 species of living corals, *and 12 of these species are typically reef species.* The most remarkable result is the certain knowledge that a species of *Favia* was flourishing at a depth of

45 fathoms. The actual details of the species, as given in the paper, are as follows: "*Stylopora,* 1 species; *Favia,* 1 species at 45 fathoms; *Pavonia,* 1 species; *Leptoseris,* 1 species; *Phyllastræa,* 1 species; *Psammœora,* 1 species; *Montipora,* 3 species, one in 44 fathoms; *Rhodaræa,* 1 species; *Alveopora,* 2 species."

It is therefore safe to say that, in this part of the China Sea at any rate, the species that we meet with at the surface may live quite well at something over 40 fathoms. Nor would I put this depth as the absolute limit of their range, for the results of dredging are always somewhat uncertain, and the experience of the difficulty of obtaining specimens from beds that can be actually seen must make any one cautious of assuming that negative results of dredgings mean necessarily absence of coral growth. I have seen beautiful branches of *Stylopora* come up on a fishing line from 12 fathoms, after I had failed to bring up specimens with a far more elaborate contrivance.

The Reasons for the Restricted Bathymetrical Range of Reef-building Corals.—Dana suggested the lowering of the temperature of the water at greater depths, but the temperature of depths far below the range of the reef-builders is not sufficiently low to exclude coral growth; and Dana admitted that temperature could not account for the whole of the phenomenon.

It has been said that it is because the conditions for forming calcareous skeletons are only present at comparatively shallow limits; and it is pointed out that deep-sea corals are lightly calcified. There is, no doubt, some truth in this, but 30 or 40 fathoms would seem a narrow limit to set as the maximum depth at which satisfactory calcareous skeletons could be formed by the reef-building corals, when solitary species, as *Caryophyllia clavus,* which I have taken in quantities from a cable at 380 fathoms, and which has been obtained at much greater depths, possess a highly calcified corallum. Again, it is possible that the *Lithothamnionidæ* and *Nulliporæ* flourish, and build their skeletons, in great masses in depths far below the bathymetrical limits of the reef-building corals (Stanley Gardiner, *op. cit.* p. 175).

Mr. Stanley Gardiner has said that, in determining the cause of the 30-fathom limit, "the real factor is the light, which to reach the commensal algæ has to penetrate the tissues of the polyps as well as the water" (*op. cit.* p. 177). Now, without wishing to controvert the assertion that corals "feed mainly by their commensal algæ," I would point out the fact that light is certainly not essential for their feeding. It has been my invariable experience with the corals in this atoll that they are actually absolutely nocturnal in their activities. It must be noticed by every one who visits a reef that, during the hours of daylight, the zooids of the corals are not expanded; they are in a passive phase, from which a further stage of retraction may result on stimulus—but they are practically never expanded. It is most instructive when examining a reef to see great soft masses of *Alcyonaria* with myriads of zooids expanded and waving in the current, and alongside it a rock colony of *Porites* in which not a single member shows activity.

It is also one of the most striking things to examine the reef corals by night, and see the extent of alteration their appearance undergoes, when the full expansion of their zooids occurs. Mr. J. E. Duerden observes: * "As a general rule the polyps are not expanded to their full degree during the day, either on the reef or in the laboratory; but the process begins immediately after sunset, and full expansion is maintained for the greater part of the night. In the morning the polyps are again found retracted." These observations were made in Jamaica, and so the habit is not one that is due to locality, and I think we may therefore regard it as the fact that the reef-building corals are active and that they feed in the dark. I agree with Mr. Duerden in the observation that artificial light appears to have no effect on zooids already expanded in the dark. Again, the corals are certainly not entirely dependent on their commensal algæ for their food-supply, for any one may

* *Memoirs National Acad. Sci.*, vol. viii., 7th Memoir, p. 419 (1902).

see the reaching out of tentacles, and the engulfing of particles, when a crushed-up shell-fish is dropped upon a colony by night. Solitary *Fungiæ*, which I have kept alive, will take into their mouths portions of the flesh of oysters considerably larger than a pea.

On the strength of this positive evidence, I therefore discard light as being the determining cause of the bathymetrical limit of distribution of the reef-builders.

It now remains to inquire if there is any other factor which can with more justice be claimed as a cause of the absence of the reef-building corals below 30 or 40 fathoms. Early in my examination of the atoll, I concluded that it was undoubtedly the presence of sedimentation. Everywhere, in all parts of the reef, the most patent fact in the economy of the corals was that sedimentation was the most potent cause of coral death, and the most important influence upon all phases of their existence. I therefore postulated a region in the ocean where reef-builders could not live, because sediment was always falling upon them and remaining undisturbed upon them; and another in which they could flourish, because particles were not allowed to remain and choke them, owing to the stirring action exerted by the waves. I arrived at this conclusion in ignorance of the fact that two definite pronouncements, of an almost similar nature, had already been made. Agassiz had said: "There seems to be no simpler explanation of the limited bathymetrical range than that of the baneful action of silt held in suspense near all reefs"; and Sir A. Geikie had said that the depth to which currents cut down land "is probably nearly coincident with the lower limits of the reef-builders."

So influential a factor is sediment in the life-history of all reef-building corals that it is one of the greatest causes of the many modifications of vegetative growth embraced within the limits of a "species." Attention has already been called to this in considering the coral colony, and it is unnecessary to recapitulate the evidences of the various changes that sediment brings about in the appearance of a colony. It is certainly the greatest enemy to activity, and the most potent cause of death in corals.

It may therefore be said to be an axiom in coral bionomics that *an area in which sedimentation is taking place is one in which the reef-builders will not flourish.* It is then possible to say that reef-building corals will not live below the *Limiting Line of Sedimentation,* and this without special regard to the nearness of reefs, or the presence of land-cutting currents, but as a general statement. I have said that we do not know precisely where this line may be, and that it will vary in different places from purely local causes, but wherever it may be reef-coral growth will be excluded from the depths below it, and the surface water above it will—other conditions being favourable—offer a suitable site for their development. We may therefore lay it down as a law that *the bathymetrical limit of the reef-building corals extends to the limiting line of sedimentation,* and that this exact level will be the outcome of purely local conditions.

It may be objected that, if the reef-building corals are presumed to be unable to live below the limiting line of sedimentation, how is it that many species of solitary corals are found in far deeper water; for if sediment is the real cause of death, how do some species resist its action?

There seems to be but little doubt that it is the common type of growth of these deep-water corals which explains their ability to withstand the action of silt. Most of them are flat discs, or more or less wide-mouthed cups: they are not, as a rule, honeycombed with a series of small openings, as are the reef-builders. It would seem at first sight that this type of growth was perhaps the most ill adapted to resist the effects of sedimentation, for a larger proportion of the zooid surface is exposed to the dropping particles. The large living specimens of the *Fungiæ,* which lie scattered about in sheltered pools on the barrier flats, afford the best examples of the extreme degree of flattening of the corallite, and exposure of the zooid: the study of the habits of these *Fungiæ* offers the explanation of their ability to live in a silting environment.

If such a specimen be watched, as sand particles are poured over its surface, it will at once be seen that there is a very perfect mechanism for ejecting the silt. The delicate tissues, which clothe the rays of the coral, shrink back from the intruding substance; and a curious wave spreads along the partitions, from the central end towards the periphery, and the foreign body is borne along in the wave. The same process is employed in the ingestion of food; but in that case the particle is passed on from the periphery to the centre. If an oyster is crushed, and its contents scattered over the surface of a large *Fungia*, the whole of the soft tissues of the coral shrink together at first, as a result of the stimulus, and then, slowly, successive contractions and expansions sweep the individual particles towards the central portion of the disc, where they disappear from view. Later on, the small bright fragments of oyster shell, which were taken in along with the food, are seen to be migrating towards the periphery, where they are thrown off. The *Fungia* therefore protects itself by getting rid of the sediment which comes in contact with it; and the mechanism must need to be a very effective one, for *Fungiæ* will live in pools in which vast numbers of particles are moving about, and the skeleton of a dead *Fungia* always collects large quantities of sand.

It is probable that all those deep-sea corals which have a flat or wide-mouthed type of growth get rid of the foreign substances that fall within their mouths, after the same fashion as the *Fungiæ;* and so they are indifferent to the presence of suspended matter in the water, provided that the deposition of sediment does not proceed at such a rate that it overwhelms them entirely. With the small mouths of the reef-builders this process may be quite impossible, and sediment that settles on a colony cannot be got rid of in this way; the individual corallites become filled with sediment, the zooid becomes choked, and death ensues.

The definite knowledge that sedimentation areas are certainly excluded from reef-coral growth, whilst wave-stirred areas are particularly favourable, marks an important stage in the study of the problem, for it now becomes evident that oceanic banks may rise to the *Limiting Line of Sedimentation;* and from that line the reef-building corals may start their building operations.

THE FORMATION OF REEFS.—Theoretically, where the one process leaves off the other begins; but, practically, it is most probable that a host of other creatures help to bridge over the gap between the cessation of the building by sedimentation and the building of the corals of the reef. It is probable that the *Nulliporæ, Lithothamnioneæ,* and other calcareous algæ outstrip the reef corals in their bathymetrical range, and they probably begin to clothe the summit of the sedimentation bank. As they grow, fragments of their growth die, or become broken off and are added to the foundation of the reef. Animals with hard tissues live on the reef, and their remains become added to the débris; the whole surface becomes raised, and at the same time consolidated. Particles, which could find no resting-place upon the bare exposed bank, doubtless become held fast in the uneven surface of the growth that has now clothed its summit; and sedimentary action may again add its increment, although the whole structure is now within the wave-stirred area. It is probably in this fashion that the foundation of the reef is laid and the immediate clothing of the sedimentation bank is brought about—the lower forms making a platform upon which the corals themselves actually build.

The pioneers of coral growth are probably not those species which are represented at the wave-washed surface of the fully developed reef. Many deep-sea corals have been found to clothe submarine banks, and the work of Basset-Smith and J. Y. Buchanan has established the ability of these corals to raise banks by their own growth from very considerable depths. It is these corals (*Dendrophyllia, Heliopora, Lophohelia,* &c.) which first contribute, by their building, to make a coral reef on a sedimentation bank.

SITES OF REEF CORAL BUILDING OTHER THAN SEDIMENTATION BANKS.—Since the reef-building corals may start their growth upon any bank that may happen to lie at or above the *Limiting Line of Sedimentation* it follows that any elevation of the ocean floor, which rises to this plane, will furnish the corals with a suitable basis. I do not doubt that many other formations than the slowly formed sedimentation banks become the basis of coral structures; for land that has sunk beneath the waves will also furnish the necessary building ground. Land that has risen by earth movements to a station within the wave-stirred zone, or loose volcanic structures that have been denuded by the waves, may also become the sites of reef-coral growth; and doubtless in many cases they have done so. In these cases the top of the platform may rise near enough to the surface to be directly clothed with the reef corals, or the intermediate building of calcareous algæ, and deep-water corals, may take place; or it may not reach so high a plane, and the processes of sedimentation may be called in to fill up the necessary interval.

It matters not what the base may be, so long as its platform comes within the wave-stirred area. It may happen, therefore, that the corals begin their growth on platforms already having an upward or a downward earth movement, and these movements will doubtless continue after the development of the reef, with varying effects upon its structure.

It is contended that, for the development of a coral reef, some basis that reaches the wave-stirred limit is essential; and on such a basis a reef will form, when the other conditions, such as the temperature of the sea, are favourable. In some places, I do not doubt, a downward earth movement has brought a base to the necessary depth for reef development: the Great Barrier Reef of Australia is almost certainly an example of this. In other places, an upward earth movement has probably brought up some elevation sufficiently near to the surface, and coral reefs have become developed on the basis thus brought within their domain. The loose structure of suddenly erupted oceanic volcanic islands may doubtless be cut down by waves and current, to some height at, or above, the *Limiting Line of Sedimentation;* but the cutting down of continental land to a depth of 150 fathoms by currents in mid-ocean (Gardiner) requires a greater measure of proof than has been adduced. These may be the sites of coral reefs, but in mid-ocean it would seem probable that the banks upon which reefs and atolls are formed are essentially sedimentation structures; and those which do not actually start as purely sedimentation banks ultimately develop the characters of such foundations.

The After-Development of the Reef.—We have therefore arrived at the stage in which a bank has become clothed with a growth of the true reef-building corals. The whole patch has risen towards the surface, and consists, in all probability, of a scattered series of colonies, lying in irregular confusion about the top of the bank. This is of course a well-known stage, and great numbers of such reefs are present in seas that are favourable to coral growth.

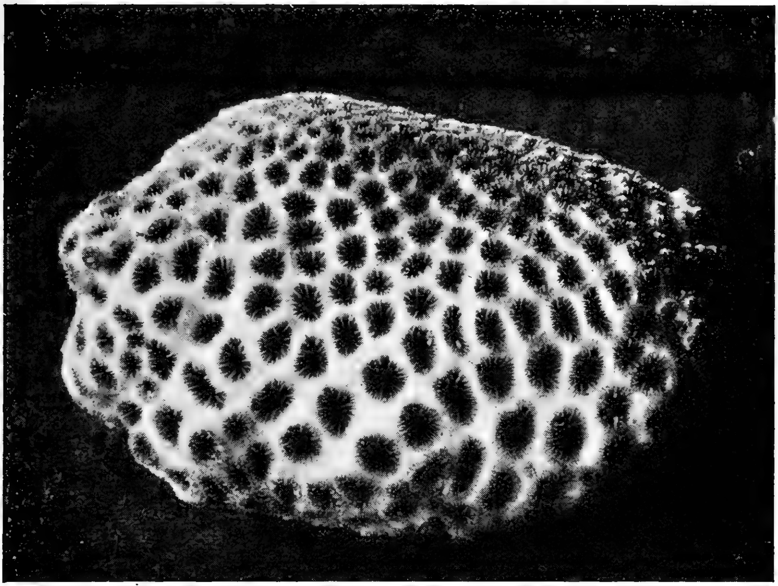
It remains now to follow the progress of this coral reef between the *Limiting Line of Sedimentation* and the surface of the sea; and to see what factors will bring about the changes that are known to be developed in this process. It is here maintained that in this stage again the action of sedimentation plays the leading part in the history of the reef. In order to study the action of sedimentation upon reefs, some idea of its workings may be gained by following the process as it affects colonies. This question will first be dealt with.

There is a very common condition of certain coral colonies which has received special attention in the works of both Darwin and Semper, namely, the state of the flat-topped rocks formed by the old colonies of *Porites*. As actually seen upon the reef, the colonies consist of great boulders of rock—for it is the large colonies that best exhibit this form—the tops of which are flat, or even somewhat hollowed; the flat surface is destitute of living zooids, but it is ringed about by a raised, rounded edge of healthy members of the colony. The dead flat surface of the rock is generally occupied by a layer of sand, and, in the lagoon, algæ and other forms become established upon it. Darwin assumed that in these rocks upon the barrier he saw the mark of the limit of coral building to tide-level, for the dead flat top of the rock he regarded as being the result of the exposure of the zooids above low-tide level. Semper also took tide-level to be the cause of this formation, but he added the accumulation of sand, and the occasional presence of fresh water from showers of rain, to the effects of exposure to sun and air. I have given an account of the development of these flat boulders, as I have observed it in the atoll, and, in this account, the exposure to sun and air has been excluded as a causative factor in the great majority of cases.

A colony of *Porites* is composed of a number of individuals, every one of which has like powers of division and reproduction; it therefore follows that when an embryo settles upon a small and isolated nucleus, the colony which it gives rise to will tend to assume the form of a sphere. Such spherical colonies are, as a matter of fact, often to be found lying free in rock pools; but they can never grow to any size as spheres, and no large colony ever has anything like a truly spherical form. The dome-shaped rock is the type of all larger colonies: it is developed gradually from the spherical type by the death of all the zooids in that part of the colony that is subjected to pressure; *i e.*, the side of the sphere upon which the colony was lying. A dome-shaped colony may grow to a great size, and some of the largest of all the colonies of the type *P. lutea*, which live upon the submarine slopes of the outside of the atoll, are very perfect domes. As a rule, wherever sedimentation is taking place with rapidity, the dome shape is lost, and the flat-topped rock is produced. Colonies in the lagoon, deep and undisturbed by tide-level, assume this form; colonies in barrier pools that lie many feet below the lowest fall of spring low tides become flat-topped, and it is evident that it is not the low-water exposure which is responsible for the assumption of this form.

A dome-shaped colony grows larger and larger, its outline becomes the segment of an ever-increasing circle, and the top of the colony, therefore, becomes increasingly flattened. When this process has gone on for some time the flattening of the rock enables sediment to find a resting-place upon its upper

Fig. 60.



Photograph of a Coral Colony that has Living Zooids over its entire Surface.

No zooids are as yet killed either by pressure or by sedimentation.

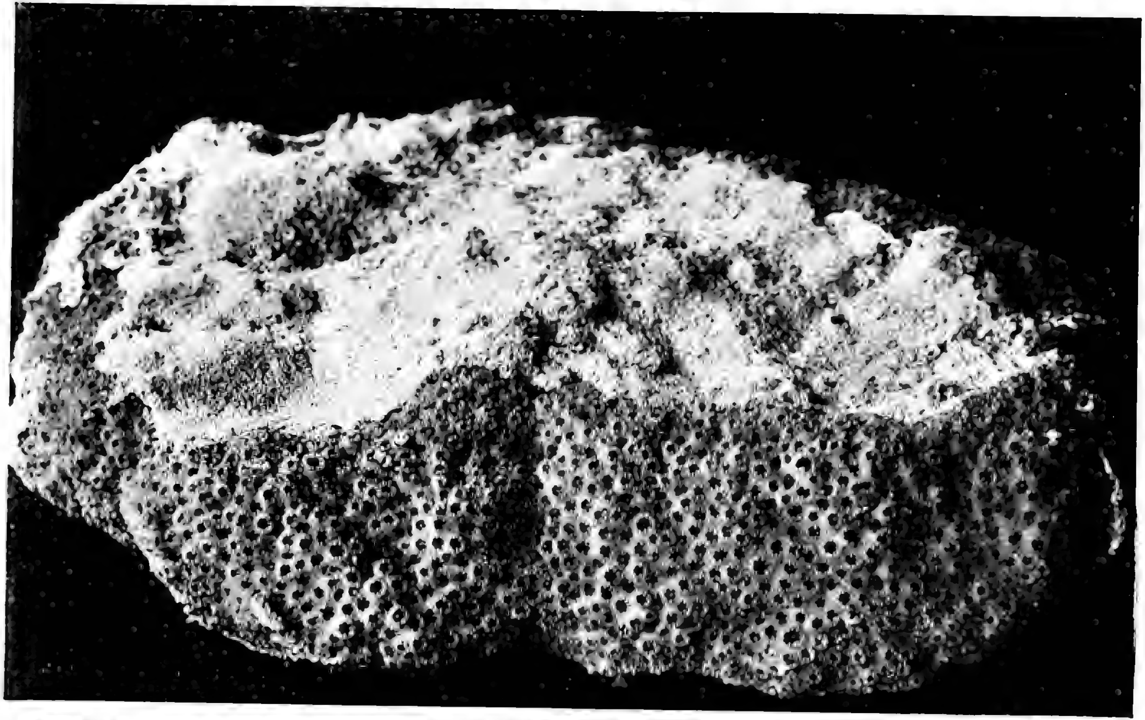
surface; and the activity of the uppermost zooids declines as this aspect of the dome becomes increasingly favourable to the settlement of silt. The flattening becomes increased by the margins rising, till finally the central portions are entirely killed by sediment, and a flat sand-strewn area is produced, surrounded by the raised rolled edges of actively dividing zooids which are untouched by sediment. Upon the barrier there is no doubt that injury of the upper zooids, caused by moving particles sweeping backwards and forwards in the waves, greatly hastens the progress of this change; for comparatively small rocks may here become flat-topped; but even when injury starts the process, the destructive action of sedimentation completes it. Some importance is attached to this method of the formation of flat-topped rocks, because it is believed that the process helps in the understanding of some other points in coral bionomics.

In the course of a walk over the barrier flats, it may easily be seen that flat-topped colonies do not assume an absolutely uniform plane, as they should do if exposure caused the phenomenon, and that dome-shaped colonies may very often be found to be raised higher than flat colonies. Cases that are particularly instructive are met with in the sharp-edged pools common in some parts of the barrier flats. In these the breccia layer will be found to cease suddenly, and an overhanging ledge forms the margin of the pool, into which the particles that are swept across the flats are always pouring. They may be only three feet deep at low tide, and fifty yards or more in length. Numerous colonies of corals will be found in them, and all the colonies of *Porites* that are of any size will be flat-topped, whilst bordering the edge of the breccia rock, three feet above them, there is a flourishing growth of *Pavonia* of the type *P. repens*, Brug. The *Pavonia* lives upon the under side of the overhanging edge, and is free of the sediment which sweeps over the flats to be deposited over the lower area occupied by the *Porites*.

Not only does the deposition of the sediment produce the flattening of the tops of these *Porites* colonies, but it also affects, in various ways, the growth-forms of other species living in the pools; but these other modifications do not concern the present inquiry.

Now a dome-shaped rock of *Porites* is a colony of a myriad individuals, and it is not an illegitimate stretch of reasoning to compare it to a reef that is composed of a myriad colonies.

The individual colony, under the action of sedimentation, has come to consist of a flat, sand-strewn area ringed around by a raised vigorous margin of growing coral zooids; it is



PHOTOGRAPH OF A SMALL CORAL COLONY TAKEN FROM A DEEP POOL, TO SHOW THE DEAD AREA OF ITS UPPER SURFACE CAUSED BY THE DROPPING OF SEDIMENT UPON THE ZOOIDS. THIS COLONY REPRESENTS AN ATOLL IN MINIATURE.

suggested that this effect will also be produced on the reef itself, and there are very many facts that go to support this suggestion. The rising reef becomes the site of the production of much débris, dead colonies are reduced to coral sand by the many sand-producing agencies of the reef; and this sand becomes held in suspension in the water moving over the surface of the reef. The reef, therefore, in a great measure provides its own suspended matter, but added to this is the shower of particles held in suspension in the surface waters. This accumulation of particles will, doubtless, find lodgment on the uneven surface of the coral bank; and, in its to and fro journeyings across the bank, it will tend to exert the maximum of its influence upon the flat central area of the reef. In this way it is easily seen that the central colonies of the reef, just as the central zooids of the colony, will tend to decline in vigour, and their growth will not be so rapid as that of the colonies situated nearer to the edge. The growth of the reef as a whole will, therefore, tend to be more rapid at its margins, and less rapid at the centre; thus a somewhat concave upper surface to the bank will be developed. The fate of the colony is again reproduced; sediment becomes accumulated in this central depression, and coral growth becomes still more reduced; and a stage is arrived at, in every way comparable to that followed in the *Porites* colony, of a flat-topped plain, ringed around with a healthy growing edge of coral. So far, it may be objected, this development of the reef is pure hypothesis; but it is a hypothesis that is capable of receiving very real support from the actual condition of those submarine coral banks which have been at all adequately surveyed. The stage at which we have arrived is exactly that seen in reality in such reefs as the Tizard and Macclesfield Banks in the China Sea.

Admiral Sir W. L. Wharton has described these banks in *Nature*, Feb. 23, 1888, and Dr. Bassett-Smith in the paper already quoted. Tizard Bank is 32 miles long and 10 miles wide: it is flat and lies at a depth varying from 30 to 47 fathoms, and its raised edge is only some 10 fathoms below the water. Eight reefs on this edge have already reached the surface, and three bear islands upon them.

Macclesfield Bank lies farther to the north; its depth is from 40 to 60 fathoms, and its edge is from 10 to 19 fathoms below the waves. Prince Consort shoal, the Great Seychelles Bank, and a great many others present a like condition, and are in fact atolls below the waves, representing, on a grand scale, the condition of the flat-topped *Porites* colonies. Other reefs are representatives of the other stages which we have noted in the development of these colonies; some are dome-shaped, and others are flat, the activity of the central colonies not having diminished, and the rim being as yet undeveloped.

It would seem to be possible that some dome-shaped reefs might rise near to the surface of the sea as domes, just as we have seen the *Porites* colonies do on the barrier; their history then becomes similar to that of these colonies, and when they reach the waves their central portions will be less vigorous than their outer margins.

We have now arrived at the stage at which we may picture a coral reef risen near to the surface of the sea; its central platform is depressed; its colonies are less vigorous in their growth, and sediment is being deposited upon its floor. The changes have so far been brought about by the effects which sedimentation produced naturally upon coral growth. No other agency is involved in this explanation than the easily verified reaction of the living coral colonies to the harmful effects of particles deposited upon them.

The development of the great edged reefs goes on unseen below the surface of the sea, but the process may be realised in watching the evolution of the flat-topped *Porites* colonies, and the changes in the many smaller reefs to be found in the lagoon. There are a hundred diminutive submerged atolls to be seen any day in the coral-covered sedimentation banks of the eastern side of the Cocos lagoon; for every little mound that rises near to the surface shows the condition that I have imagined and described.

CHAPTER XXII

DEVELOPMENT OF THE ATOLL

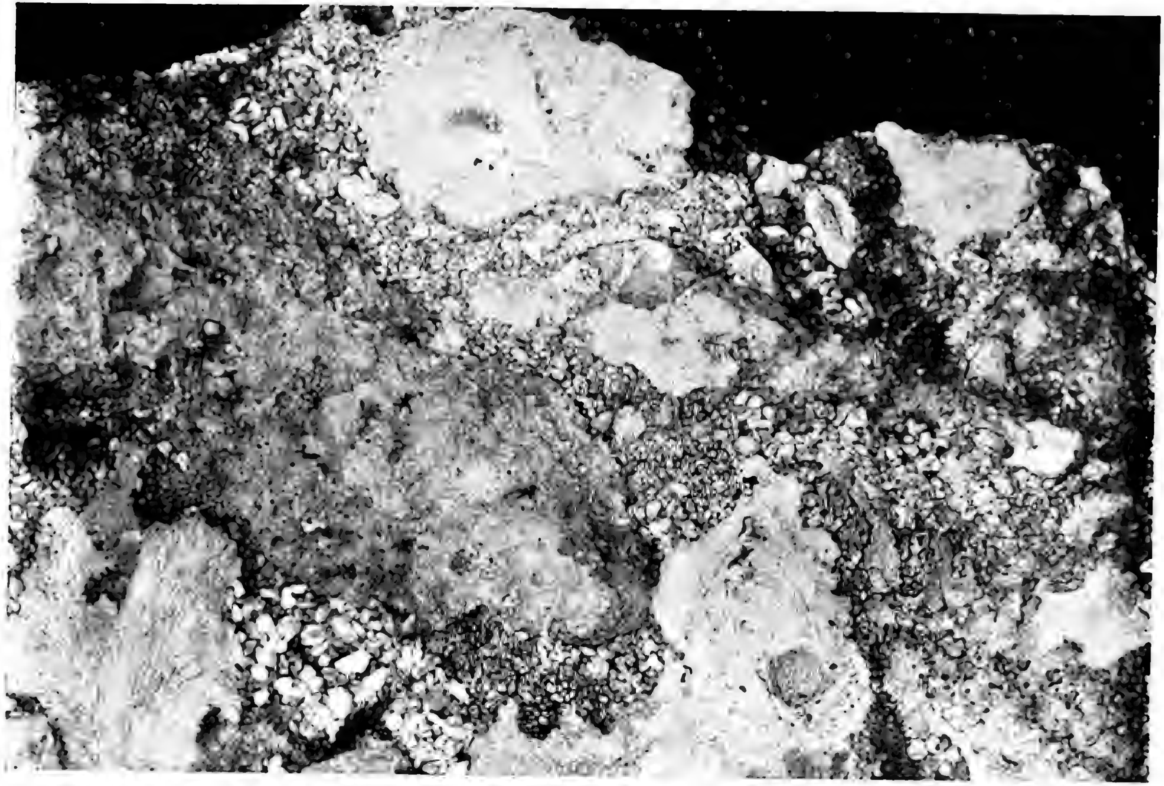
The Formation of the Barrier.—The rim of the reef is now lying a little way below the surface of the sea, and it is obvious that, since it is raised by the agency of living coral colonies only, there it must stay, so long as no other building factor comes into play.

The corals themselves can never grow beyond the tide limit, and form dry land of their own efforts; and a submerged reef would stay submerged for ever if its rising depended upon coral growth alone. With the advent of the reef near to the surface of the sea, however, a very different set of building agencies comes into play, and a very great change is introduced in the history of the coral-clad plateau.

We have seen that the whole structure of the atoll consists in reality of a level, and slightly raised, rim around the margins of an extensive reef, and that on this level rim islands of coral débris are placed at intervals. It is therefore necessary, first of all, to follow the method of formation of this level rim,—the barrier flats. This process of formation, again, is one that can always be seen in the making, and the composition of the barrier rock itself easily gives the explanation of its origin.

When the reef-edge has risen so near to the surface of the sea that the waves may act upon it powerfully, some colonies, or some portions of colonies, will be uprooted from the extreme edge, and shifted on to the tops of their fellows that lie nearer to the centre. These accumulations of broken corals will tend to increase, and the reef edge will become the site of many irregular elevations, so that in time waves will break upon some part of the edge of the bank. *This is the beginning of the* *barrier*. Where large fragments lie piled in uneven masses, smaller fragments will collect, and fill in the interspaces; the waves will wedge them home, and tend to make the whole thing solid. Upon the lee of these elevations, grains of coral sand and lighter particles will collect, and find their way into the chinks left in the rock piles. A very important action now begins to take place, for around each small coral particle, as a nucleus, a crystalline deposition of calcium carbonate takes place; particle is held to particle, and the fine sand that has been driven by the force of the waves into every tiny interspace becomes a cement that holds the coarser fragments firmly together. The result of this action is that a conglomerate is made of irregular fragments, broken branches, and coral sand; the whole mass cemented by a deposition of calcium carbonate around the particles. The deposition of calcium carbonate is not confined to an encrusting layer around the particles; it takes place in the dead coral itself, and the individual fragments become harder and heavier than they were during life.

A breccia mass, as hard as concrete, is thus formed about the fragments which some chance storm first cast upon the rim of the reef. It is obvious that, since the process is the outcome of wave action, it will start first of all upon the windward side of the reef; and at the point of maximum wave action we may expect to see the first piling up of the boulders that will afterwards form the barrier. Ultimately, other portions of the ring will be affected—probably in the first instance during storm weather—and the piled-up rim will spread, as a horse-shoe, around the rim of the reef. The sequence is, in all probability, somewhat as follows. A time of storm brings waves that are abnormally powerful across the reef spot; upon the windward side their feet will be caught, and during the height of the storm some boulders of massive corals will be lifted and cast upon the top of their neighbours, where they will come to rest. Under more normal conditions of wind and wave, accumulations will take place about these dislodged boulders, and they, by their own growth,



PHOTOGRAPH OF A FRACTURED SURFACE OF A PIECE OF BARRIER-FLAT BRECCIA, TO SHOW THE INCLUSION OF SMALL PARTICLES AND THE CEMENTING OF THE WHOLE MASS.

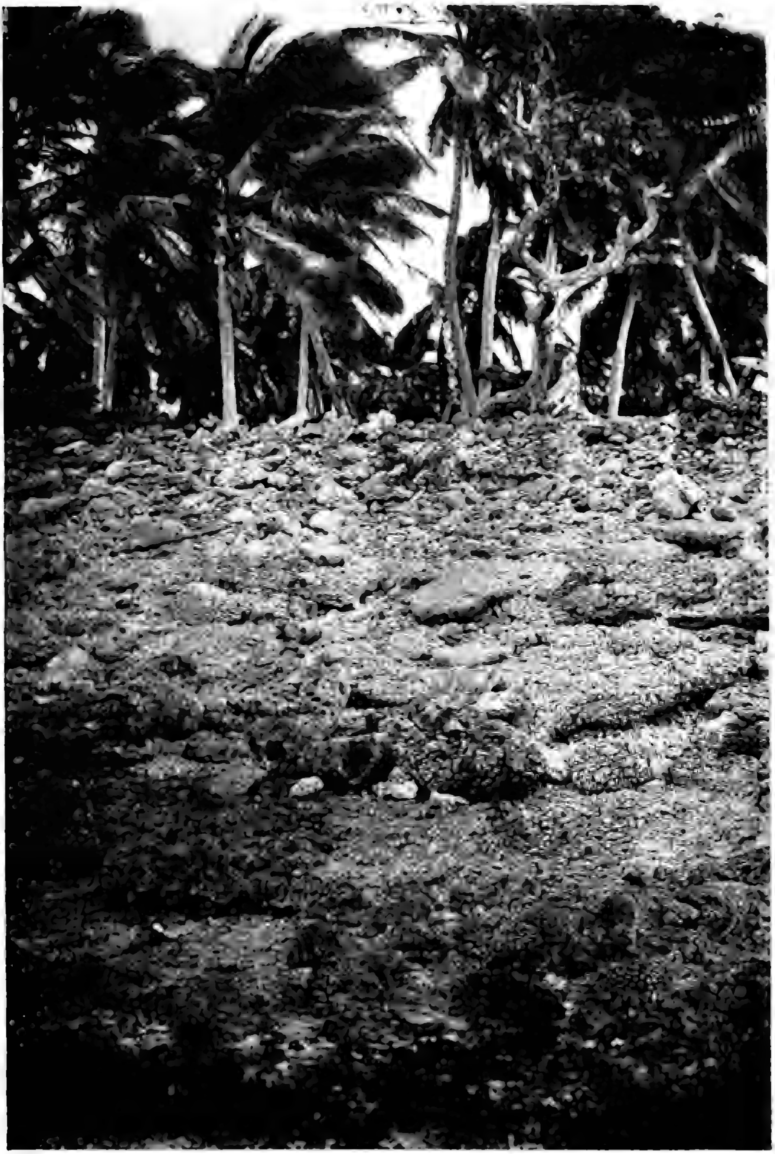
or the growth of neighbouring colonies, or by the welding of smaller fragments, will be firmly reseated on their new site. A point on the reef is thus formed upon which the waves will break in ordinary weather. In time the process spreads, and instead of there being only one point upon which waves break, a line of breakers will be formed; and as the line continues to grow it will become a crescent, tailing off around the edge of the reef. Smoother water will be present within the protecting crescent, and there fragments that have been hurled inwards from the edge will become lodged. These fragments, again, become welded by the deposition of the calcium carbonate around the particles driven among them, and the breccia masses tend to become a continuous rampart. Waves will break upon the boulder-piled edge and sweep across this rampart, and, as they do so, will become spent:—there will therefore be a tailing off of the breccia layer within, and we may expect to find sand and sediment deposited in such a way as to build up a shore internal to the platform. With the perpetual sweep of waves across the platform, and the constant addition of new fragments and the deposition of calcium carbonate, the whole becomes levelled, or approximately levelled; its completed stage will be that of a uniform concrete platform, ending sheer at its outer edge, and tailing off as a débris slope within. The level it assumes will be that of the point of the maximum intensity of wave action at all tides. When the tide is low the waves will crash upon the outer edge and move large masses of rock in times of storm; but as the tide rises the surf-line sweeps on across the flats and rushes with decreasing force to their inner edge. At high tide, therefore, smaller fragments will be swept across the flats and be left there with the fall of the tide, so that the inner edge becomes raised. The intermediate part will bear the full brunt of the surf during the rising and the falling of the tide, and so it will become the most levelled by wave action. The outer margin will receive the first force and the great lifting power of the ocean waves, and so will become the site of the biggest of the masses that the waves may lift and toss up, but are unable to move farther by reason of the waning of their force. In this way the characters of the typical zones of the barrier become developed.

We have seen that the first part of the barrier will be formed at the windward side of the ring, and here its development will be always most complete; the larger masses will be upon its outer border, and its level zone will be far wider than in any other part of the circle. Now, in the case of an atoll that lies in the zone of the Trade winds, this will be a very marked feature of the barrier; and in the Cocos-Keeling atoll it is particularly striking.

It will be seen that the very perfection of the windward barrier tends still further to protect the leeward side of the reef; and it does this with such effect that the waves are altogether powerless to bring about the changes that produce barrier formation. Upon the leeward side the boulders are not raised, the breccia platform is not made, and there is no rampart at the level of maximum wave action over which the seas rush. There is, therefore, a leeward gap in the barrier.

Since the waves are always rolling across the ocean in one direction, it is only their feeble echo that washes against the lee side of an atoll in the Trade wind zone, and so the mariner's maxim, that the entrance to an atoll lagoon is on the lee side of the atoll, is a very well-founded one.

It has been said, in the description of the Cocos-Keeling atoll, that the barrier is the pioneer of the dry land, and that wherever the barrier exists it is potentially the site of island formation: a most important stage in atoll formation has therefore been arrived at. With the completion of a portion of the barrier, a turning-point is arrived at in the history of the reef, for now, instead of remaining as a wave-swept circle, it easily becomes a fully developed atoll. The stages of the process are easily seen, in miniature, at any point in an atoll ring; and the whole process of island building may be studied at any of the inlets between two adjacent islands. Just as the first step in the formation of the barrier consisted of some chance boulder being hurled by storms upon the top of its fellows, so



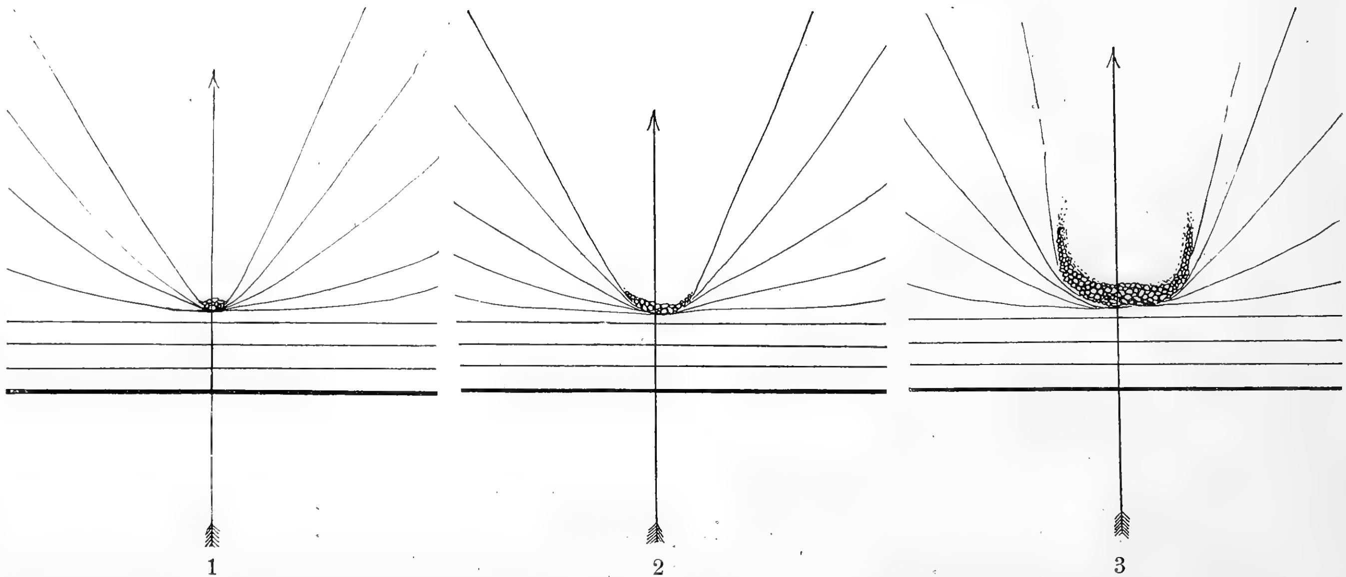
THE ISLAND RISE AND SEA BEACHES ON THE SEAWARD SIDE OF PULU TIKUS.

the island starts to form by some boulder being tossed by the waves upon the platform of the barrier. With the advent of any permanent obstruction to the waves a new set of conditions is brought into play.

During my stay in the Cocos-Keeling atoll, I became impressed by the very marked influence of any hindrance to the waves and current, and the changes brought about in this way were fully studied. In the same atoll Dr. Guppy had previously called attention to the facts, and his account was the first that established the real cause of the development of island form. In 1907 Mr. C. Hedley further followed out these processes during his examination of the Great Barrier Reef of Australia, and the whole sequence of events, from the rising of some permanent hindrance to the wash of the currents to the development of an island, or even of an atoll, may be taken as fully established. The steps in the process are very simple, and they may be watched in any stream of running water; for the development of a sand-bank in a river follows very much the same rules as those that apply to the formation of atoll islands. The boulders which the high seas have tossed on the barrier flat stand in the line of the waves that sweep across the flat; the current strikes them and rushes along their face, and dividing, sweeps on in fan-shaped currents from their extremities. Behind the obstruction an area of calm is created, and here small particles come to rest so that, after a time, a little sand-bank is raised. The currents that become slackened by meeting the obstacle drop their burden of sediment in lines that stream from its extremities, and they tend to raise a V-shaped bank, with the apex of the V at the point of obstruction. As the original obstruction grows larger, by the addition of new fragments washed against it, the area of slackened current increases, more and more sediment becomes deposited, and a bank of coral débris and coral sand is piled upon the barrier. This is the nucleus of the island, and such nuclei may be seen at many points of a barrier ring.

When the nucleus has attained a somewhat greater

Fig. 61.



Three Figures showing the Formation of a Crescent-shaped Island from some Original Obstruction to the Waves.

The arrow represents the direction of the prevalent winds.

dignity, it will mark the limit of the march of the waves across the barrier flats, for they will break upon its edge, and anything that they may sweep over the flats will be added to its growing pile. There is, however, a limit to the extent of the building seaward, for the force of the waves will not permit the resting of fragments till they have become spent by some lengthy journey over the flats. There is also a limit to the land building lagoonwards, for the force of the spent waves is not sufficient to carry material any farther; and so the rim of land must of necessity be a narrow one. There is, however, one way in which the land pile may spread—and that is by the extension of its extremities in crescent form. The currents that make the tailing-off of the sand-bank in the diverging lines from a single obstruction come into play at the extremities of the linear island, with the result that the land becomes bent inwards, and runs towards the lagoon as incurved banks. Meanwhile, on other spots of the barrier flats, others of these island nuclei will be developed, and the history of them all will be similar; save that those to the lee side may be expected to develop more slowly and to rise to lesser heights. These nuclei will therefore grow around the ring, ever reaching out towards each other, and tending to form a dry land circle. But, as they approach each other, the channel that separates them becomes filled by a more rapidly moving stream of water; its rush becoming steadily increased as its channel becomes narrowed. There is therefore a limit to the growth of adjacent islands under normal conditions, for the streams that pour through the gaps between them are too rapid to allow of the resting of sediment. We may therefore expect to find the adjacent extremities of two islands to be carried lagoonwards as incurved banks, and to be separated by a channel of rapidly flowing water. In the description of the lagoon this condition was pictured, and the depositing of the sediment carried by the current, as banks farther out in the lagoon, was described.

The whole of this method of island building has been pictured as though it proceeded regularly, and gradually, over

Fig. 62.

Chart of the Cocos Atoll,

To show the effects of the prevalent winds upon island—and atoll—formation.

a long series of years; but I do not imagine this to be at all the fashion of development of the atoll. Every detail of its structure points to the fact that the increments to its building have been added at quite irregular intervals: it seems as though the land had taken a rapid stride, and then had ceased from growing; the quiescent period being again followed by great additions to its substance. I think it may be taken as a law of atoll growth that the processes of formation take place by fits and starts. The evidences that we see of sudden building increments are without doubt the evidences of storms of exceptional violence; and it is no doubt the unusual events of wind and wave that initiate every process of atoll formation, and that give fresh stimulus to the progress of their completion.

We have therefore arrived at the stage in which bare débris islets are raised about the edge of the reef, and in their formation nothing, save the normal growth of coral, the deposition of calcium carbonate, and the natural effects of the winds and waves, is involved.

That the final formation of the atoll is entirely dependent upon the prevalent winds and seas seems to me to be quite clear, and for its proof the examination of the charts of atolls, and atoll groups, is all that is needed. Professor W. J. Sollas has said (Brit. Ass. 1893) that clear evidence of the truth of the theory of Subsidence is seen in the fact that atolls tend to be elongated in the direction in which the group to which they belong is stretched. Now far from taking this as evidence that a line of subsidence had taken place, I would regard it as showing that the wind and waves that made the whole group shaped each individual atoll of the group.

The shape of the group, the shape of the atoll, and the shape of the individual islands is impressed by the agency of the normal winds and waves; and the stimulus of origin, and the increments of building, are the outcome of the exaggerated violence of the normal winds and waves.

CHAPTER XXIII

THE AFTER-HISTORY OF THE ATOLL

THE atoll, as far as we have at present considered its development, consists of a wave-washed barrier crescent surmounted by a series of piles of débris which are also crescent-shaped. The islands, so far, are mere masses of broken coral branches and loose boulders, heaped up in confusion by the waves, and a very long period of time may be passed without any advance from this condition being made.

The "Button Islands" (between Pulu Pasir and Pulu Bras) of the eastern side of the Cocos atoll are to-day mere piles of débris and their development has not proceeded in any way since they were first charted by Van der Jagt in 1829; but this is not the usual history of such structures. As a rule, the heap of loose coral fragments becomes a consolidated and vegetated island; and in the process the winds are the most influential agents.

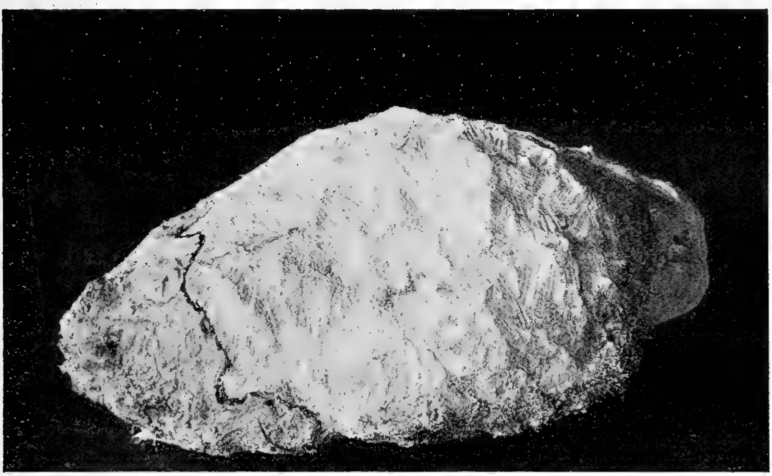
It is obvious that the height to which the seas may pile the boulders is limited, and the limit depends upon the amount of tidal variation, and the violence of the storms that pass over the tract of ocean in which the atoll lies. The influence of the range of tidal variation is easy to account for, and the greater the rise and fall of the tides, the higher in all probability will the island be; for since the tides have a greater excursion upon either side of their level of maximum wave force, it follows that the range of possible building will be greater from this level when the tidal variation is a large one. When the tides have an excursion of 3 feet it may be roughly said that 1 foot 6 inches of broken water will be available for land-building above the level of the barrier: when the excursion is 5 feet another foot is added to its range of activity, and so with increasing tidal excursion a greater elevation of island-building is possible.

The influence of great storms upon the height of island-building is easily seen, for it is simply a question of how far up the débris slope may the largest waves of the greatest storms hurl any additional fragments. Pumice represents the tell-tale of maximum wave action, for a fairly large fragment of light pumice is the float that the spindrift of a broken roller will carry farthest in front of it; and pumice, in most of the islands, has been flung over the crest of the sea beaches and on to the island land. Storms of exceptional violence, such as that which visited this atoll in 1876, have overridden their rampart so completely that waves have swept into the islands for a distance of 150 yards from their seaward margins. It is only the possession of positive data of this kind that makes it possible to realise how any sea could toss some of the enormous rocks of massive corals to a height of fifteen feet or so, after a journey of more than a hundred yards across the reef flats.

Upon the lee side of the atoll the waves may only toss fragments to the top of a bank some three or four feet high, and in Pulu Tikus the most exposed portion only has been sea built to a height of thirteen feet. Upon the windward side the building rises higher, the wall of the sea beach is steeper, and is composed of far larger boulders than the sea beaches of the lee side. The rampart here may be piled to a height of twenty feet, and the blocks that enter into its composition are often far too large for any man to move.

When the pile of débris has risen as high as the waves can cast their burdens, it must cease from further growth from sea influence unless some storm of quite exceptional violence visits the group, or unless the seaward edge of the barrier reef grows farther seaward. Since we have seen that the distance of the island from the barrier edge is regulated by the force of the waves—the windward islands being farther from the edge than the leeward islands—it is evident that the seaward margins of the island will advance as the seaward margin of the barrier advances. The seaward advance of the barrier edge is of necessity very slow, for a vast amount of submarine building must take place before the wave-washed edge can grow outwards. The barrier edge probably grows outwards as the outcome of unusually high seas, and the evidences that are to be seen of sudden increase of island building have probably been preceded by similar increases in barrier building. With the exception of these uncertain and irregular methods of building the sea is, therefore, powerless to further add to the growth of the island's dry land; it is the wind that completes the moulding of the pile of coral débris. When the building by coral boulders and fragments ceases, the building by coral sand begins; in all the stages of the after-history of the atoll, sand is by far the most important factor. The sources of this sand are manifold. Most of the sand is made on the barrier, where the grinding of wave-driven fragments is for ever taking place. On the flats, the broken branches of *Madrepora* and fragments of massive colonies are for ever sweeping backwards and forwards in the waves, and being reduced to smaller and smaller particles. Sand is always being produced all round the atoll ring, wherever rough water moves fragment on fragment; and vast quantities are always in the process of production, becoming increasingly fine as the waves carry the particles shorewards. Compared with this method of sand production, it is probable that any others are of quite trivial importance, but of such as do make an appreciable contribution, I am convinced that in the Cocos-Keeling atoll, at any rate, the fish of the family *Scarus* are by far the most important. With their hard beaks these fish are always nibbling the masses of dead coral upon which *Nulliporæ* and other algæ have become encrusted; they actually bite deep grooves into the rock and the linear scores that they leave upon the boulders are easily identified, although Europeans usually fail to associate them with the fish which undoubtedly produce them. The most important sand-producing species is a blue *Scarus*—native name *Kakatua Ijou*—which weighs, as a rule, about five pounds; this blue fish feeds round the barrier in thousands, and its attention is wholly confined to the coral rocks of the atoll, for no other feeding-ground exists for over five hundred miles. I have shot large numbers of *Kakatua Ijou,* and have examined their intestinal con-

Fig. 63.



Photograph of a Boulder of Alga-covered Dead Coral Rock,

To show the bites of the fish of the genus *Scarus.* The black line marks the edge of the alga covering not bitten away by the fish.

tents. Every fish that I have killed has been filled with coral sand of its own producing: the average weight of washed and dried sand found in them is two ounces. Considering the activity of these fish and their vast numbers, the addition that they make to the sand-supply of the atoll must be very considerable. Both Darwin and Forbes have described these *Scari* as eating the living coral, but there is no doubt that the observation is incorrect, for they never by any chance touch a living colony.

The Holothurians are also a source of some sand-production, but I do not think that their contribution is a very serious one. It is true that they contain large quantities of sand—indeed Dr. Guppy, who attached much importance to their influence, calculated that fifteen of them passed a ton of sand through their bodies every year. It is quite possible that some such figure may hold true, but I do not regard this ton as any addition to the island's sand capital, for the Holothurian has merely passed it through its body. It was sand when it went in and it is sand when it comes out, so I do not think that the Holothurian is a serious rival of the *Scarus* in this respect or a great agent in sand-production. The influence of the various boring molluscs and worms is again still less, and their importance as sand-producers is trivial indeed, and has, as a rule, I think, been very considerably overrated. In the Cocos-Keeling atoll there are only two agents that produce sand from solid coral rocks in any appreciable quantities; one is the waves of the barrier and the other is the fish of the genus *Scarus*, and the influence of these latter has hitherto, I believe, been entirely neglected or very much under-estimated.

The sand, by whatever method it is produced, is the lightest of the particles that the waves carry—it is the finest product of coral trituration—and it will therefore be the last burden to be deposited by the waves. The boulders are left on the barrier edge; the smaller fragments are deposited on the barrier flats or added to the island pile; but the sand is carried high up the seaward beaches, or far out into the lagoon. The sand that is thrown upon the island beaches becomes dried in the sun, and scattered over the island land by the winds. The effects of this wind-blown sand have been seen in the examination of the islands, and the characters of wind-made islands have been noted.

The islands of the windward side of the reef will be the first to obtain an abundant supply of sand, and their rough coral boulders will soonest become clothed by a layer of sand. In places, great mounds of sand will become piled up—these are the atoll mountains, and they may rise to a height of 30 feet under favourable conditions.

Ridges of sand will be thrown across the islands, and will rise in the lee of any prominent boulder, and stretch away from it on the line of prevalent wind. In time, the general surface of the land becomes raised as a whole until, in the case of the windward islands, there is no trace to be seen of the original low coral débris-pile that forms their foundations. The leeward islands will remain long unclothed by sand, and when the windward islands are already covered and thickly vegetated, the leeward islets will still be mere piles of broken coral. Some islands are built almost entirely of sand by the agency of the wind, and then they may attain a height of some 30 feet as pure sand-heaps; when this is the case, the highest land is on the leeward side, as we have already seen in the description of the islands of this atoll. I think that the importance of wind building, in the after-history of the islands, is generally rather neglected, but the reality of it may be appreciated by observing that all of the older trees of the windward islands are buried for a very considerable distance by the sand that has been accumulated during their lifetime. The principle which is involved in this completing of the island characters is one that is of general application, for upon the western bank of the Nile in Nubia I have watched every stage of land-making under the influence of wind-blown sand. Here, where the sand from the Western Desert is for ever blowing over the granite land of the Nile valley, I have watched all the details of ridge-formation, the burial of boulders, and the general elevation of land-level, such as I had already noted in this atoll. The arrival of sea-cast seeds is the next event in the island history, and of all the coral island vegetation the coconut is the pioneer. Although Dana says that "there is no known evidence that any island never inhabited has been found supplied with coconut trees," still it is a fact that coconuts have been noted on this atoll ever since its discovery in the early part of the seventeenth century, and there is no evidence of any inhabitants being in the islands previous to 1825.

The coconut owes its success as a pioneer to the fact that it will start its growth wherever the waves toss it. This may be seen at any point of the atoll, for the nuts that are dropped into the sea will be washed up again upon some other beach, and, if they come to rest upon a patch of sand, they will start their growth straight away.

Other hard seeds arrive and are blown by the wind into places that are suitable for their growth, and an abundant vegetation grows up. Another source of land-building is now added, for as the vegetation increases, leaves and branches become added to the sand accumulations, and the covering of the coral débris proceeds with added rapidity. It might be thought that, with the luxuriance of tropical vegetation, a vegetable mould would very rapidly accumulate, but as a matter of fact it is not so, and, on the islands that have no depth of sand, the perpetual addition of dead leaves and nut husks seems to make but very little difference. The reason for this is the presence of the heavy annual rainfall, for as fast as the leaves fall and rot, the rain washes their remains into the interstices of the porous coral heap.

With the addition of the vegetation the atoll island is completed, and the condition of a sand-built vegetated strip of land is one that lasts for a long time in its history.

The sand that is made by the barrier waves and by the fish is not all flung upon the land and built up by the winds, for some of it is always rushing through the inlets to the lagoon, and being deposited from the water in various places. We have already noted the method of incurving the island's ends by the tailing out of sand-banks into the lagoon, and this process is one that continues all through the life of the island. With the elongation of the horns, the area of smoother water that stretches between them increases and becomes the site of more sand deposit: in this way the lagoon shores become widened. This process again takes place with greater rapidity at the windward side of the atoll, for there the supply of sand is the greatest, and the lagoon beaches are under the shelter of the islands. Wide stretches of sandy beaches are therefore laid down upon the windward side of the lagoon. It is easily seen how the forces that shape the whole atoll into a horse-shoe, or an incomplete circle, are acting on the individual islands, and that the incurving of the ends of the islands may easily bring about the partial enclosing of a portion of the lagoon between the horns. Horse-shoe-shaped islands are thus produced, and by the deposition of sand-bars they come to enclose a private lagoon of their own. This process is well seen in the Cocos atoll, where all stages of the evolution are at hand.

Each island of the reef therefore tends to become atoll-shaped, and to enclose its own little lagoon. In the Maldives this process is seen in great completeness, and it has advanced so far that, in the case of many reefs, a series of small atolls stand ringed about a central lagoon. When an atoll lies in the region of the Trade winds, it would seem as though the islands to the lee side of the reef could never become atollons, for although their extremities are incurved by the water running through the inlets, the wash of the lagoon waves would always be likely to lead to the unmaking of banks, when the lagoon was sufficiently large to afford any sort of sea. The Maldives are in the monsoon zone, and therefore get a seasonal change of wind: but I notice, from the charts, that the western atollons are most complete; and I would suspect the west monsoon to have the greatest influence on their building. The final stage of the process that leads to individual islands enclosing their own lagoons is the filling in of the area that they have enclosed. Many agencies come into play in this, and the most important is again the wind-blown sand. The agent of second importance is the vegetation; and crabs of the genus *Gelasmus*, and *Cardiosoma*, also play their part, very much after the fashion of earth-worms. A fine white mud is produced in these little lagoons by the decomposition of the coral sand; bushes of *Pemphis acidula*, coconut palms, and coarse grass take root in the mud; sand is driven about their roots, and the whole area is slowly reclaimed.

One other fate may befall the island in the course of its after-history:—it may become joined across the reef flat to its neighbour or neighbours. We have seen that the reason why islands do not normally unite round the edge of the reef is that, as the channel between them narrows, the current of water becomes swifter, so that the deposition of sediment in the channel is impossible. If, for any reason, the current between two islands should slacken down, then the deposition of sediment will begin, and island may stretch across to island; this is, of course, what actually happens. Many things may lead to a slackening of the current in the inlets; a storm of unusual violence may cast boulders into its channel, and be powerless to move them farther. Other fragments collect against them, and the channel may become blocked up, the wind-blown sand will then complete the work, and join the islands across the gap.

The closure may be more gradual, and in this gradual blocking the beds of calcareous algæ no doubt play some part. As a rule the inlets to the lagoon are not favourable sites for coral growth, and some stunted colonies of *Montipora* alone live in them; but here the only considerable beds of the *Lithothamnioneæ* are found. Within the meshes of the growth of these algæ much sand becomes held, and, in many spots, it would seem that they are steadily filling up the channels, and will in the course of a great many years succeed in blocking the waterway.

Besides the sand that is deposited as continuations to the extremities of the islands, a vast amount is carried on into the lagoon. A part of this goes, as we have seen, to the making of broad beaches to the lagoon shores of the islands, and a general filling in of the lagoon. The sediment borne in the middle of the stream is carried on the farthest, and, with the slackening of the current, it is dropped as banks far out in the lagoon. This point has received some previous notice, and it is mentioned again as it is one of some importance; the proper understanding of it makes clear some of the changes in the after-history of atolls. As a general principle it may be laid down that the currents in the windward inlets set constantly lagoonwards. These currents always carry large quantities of coral sand, and as the stream becomes first retarded at its margins, the first sediment to be deposited is in lines along its sides, forming the continuation of the island extremities which we have seen. The central part of the stream sweeps on, and only becomes slowed down as it loses itself in the waters of the lagoon;—the sediment that it contains will therefore be deposited *opposite* the gap in the island ring.

It is easy to see that if the lagoon were only a small one, and the islands that composed the ring were very few, then it might chance that the windward inlet into the lagoon came to lie opposite to the leeward entrance to the lagoon. It might also happen that the sediment brought in by the windward inlet would not be carried right through the lagoon and out into the ocean beyond, but would be dropped as a bank actually in the entrance itself. It is maintained that this is what in reality happens in some atolls. The condition that would be met with, when the process was completed, would be a *windward entrance to the lagoon;—but this windward entrance is guarded by a barrier reef.* This is exactly the condition that is found to-day in North Keeling atollon. The gap is to the windward, but the windward barrier is complete—there is no entrance to the leeward, but the lee barrier is absent. The current that has swept into the lagoon, through the windward gap, has made the sand-spits incurving the land which were noted by Dr. Guppy; and it has also raised a sand-bank, so large that it has blocked up the real leeward entrance to the lagoon. The sand-bank that is deposited by the current becomes raised high enough for the waves to cast some of it above their reach; the wind then comes into play, and a wide sand-barrier is made across the old lagoon entrance. The sand-bar continues to grow, and the whole of the leeward side of the atoll becomes a wide sandy stretch, probably far broader than the original dry land of the windward island.

It is almost impossible to judge of the method of formation of any atoll not actually visited and examined; but from the charts, I would expect that some of the atolls in the Laccadive Archipelago were the outcome of this method of building.

Fig. 64.

Diagram to illustrate the Development of Keeling Atoll.

Stage I, in which two crescentic islands are raised upon the windward side of a horse-shoe-shaped barrier flat.

The Chetlet and Kiltan atolls strongly suggest this process, and Mr. Stanley Gardiner says " practically all land lies on the eastern or leeward side of the reefs, the group being completely exposed to the gales of the south-west monsoon, while it must be largely protected by India from those of the north-east."

This condition he ascribed to "elevation and subsequent erosion, the latter having completely removed all save traces of

FIG. 65.

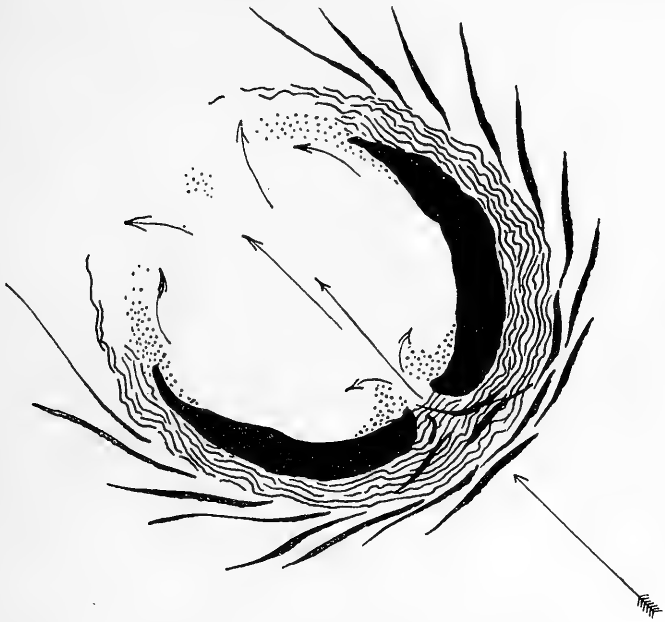


DIAGRAM TO ILLUSTRATE THE DEVELOPMENT OF KEELING ATOLL.

STAGE II., in which sediment is being dropped as banks continuing the island extremities, and also as a sand-bank opposite the windward inlet.

the land from the western reefs." Without an actual examination of the atoll, it is easily possible to fall into error, but the process which has, without doubt, caused the characters of Keeling atoll, would also seem to be quite sufficient to explain the form of these Laccadive atolls.

In larger atolls this process does not happen, for the sediment-carrying current drops its burden before it reaches the entrance to the lagoon. In this way the windward part of the lagoon will commence to shoal. The shoaling of

Fig. 66.

Diagram to illustrate the Development of Keeling Atoll.

Stage III.—The further development of the formation of sand-banks in the leeward lagoon entrance.

the lagoon of the Cocos-Keeling atoll is proceeding steadily, and year by year more and more sediment is laid down upon its bed. Such shallowing is the probable fate of all lagoons. Two agencies are at work; coral growth tends to fill up the lagoon slowly, and sedimentation tends to fill it up more rapidly; but, as we have seen, these two factors cannot act in the same area. As a matter of fact the two processes work quite separately, and the sedimentation spreads as a wave across the lagoon, first killing the corals and then shallowing

FIG. 67.

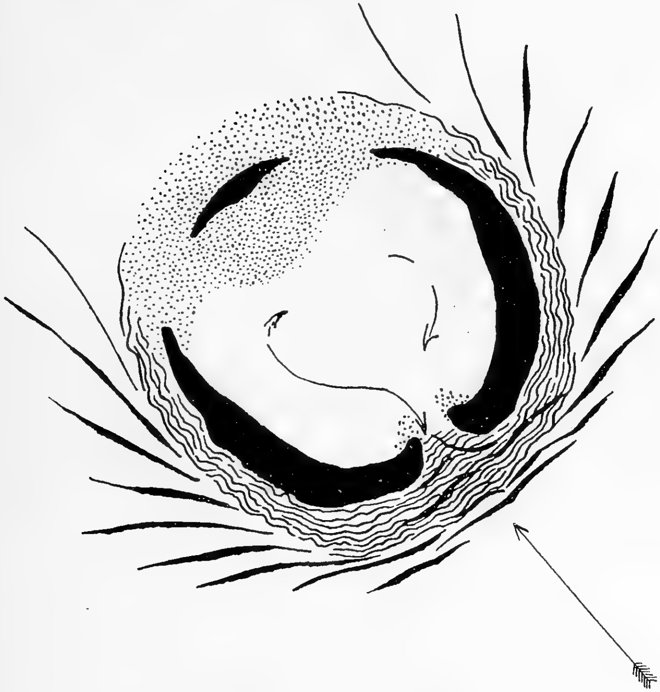


DIAGRAM TO ILLUSTRATE THE DEVELOPMENT OF KEELING ATOLL.

STAGE IV.—The sand-bank completed and a part of it already made into an exposed bank by the action of the waves.

the water by its own efforts. In time, this process will spread across the whole area of the lagoon, and the processes which have obliterated the secondary lagoonlets of the horse-shoe-shaped islands will finally fill in the main lagoon. This chain of events has of course already occurred in many atolls, and Pulu Luar in this group is an example of the final stage of atoll-making—a stage in which a rim of slightly

FIG. 68.

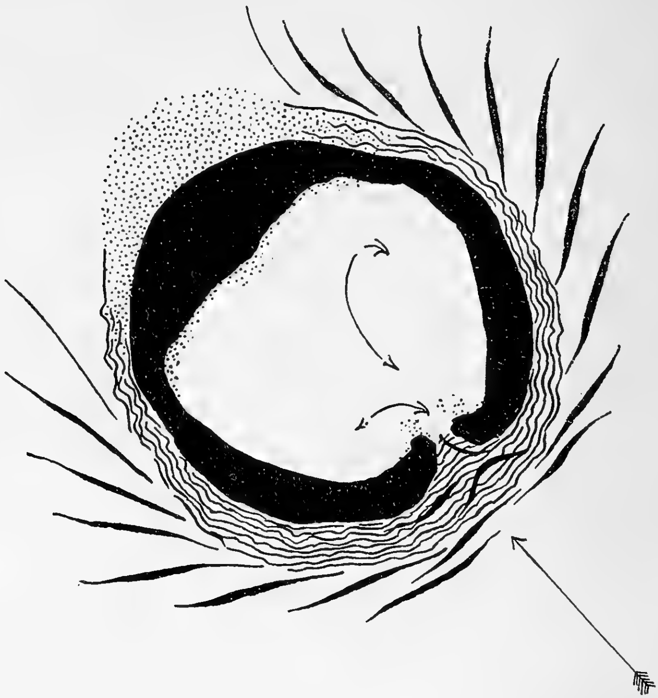


DIAGRAM TO ILLUSTRATE THE DEVELOPMENT OF KEELING ATOLL.

STAGE V.—The final stage, in which a large area of leeward land is formed, and the only inlet to the lagoon is to the windward. The inlet is guarded by a barrier and to the lee side of the atoll no barrier is developed.

raised land surrounds a central basin, wholly or partly dry at all states of the tide.

We have followed the fate of the sand that becomes cast upon the land, and of that which becomes deposited in the lagoon, but this by no means represents the whole of the sand which is produced around the reef. A vast quantity never reaches the barrier flats, but falls down the submarine slope, and adds to the sedimentation bank upon which the reef rests. Another great contribution is removed again from the lagoon by the currents which run out of the leeward channels, and this too is added to the submarine bank.

In the Cocos-Keeling atoll the current that runs from the lagoon mouth impinges upon another island—Pulu Luar—and on its windward shores sand-building is taking place with some rapidity. This is not, however, the common fate of sediment removed from a lagoon, for in ordinary cases it would be swept to sea, and dropped so as to form an elongation of the bank to leeward. By the addition of sand and fragments that drop from the edge of the reef, the submarine bank is therefore always tending to grow; but there is every reason to imagine that its growth will be very slow. The additions to the bank will enable the reef margin to advance seawards and so the whole atoll may become enlarged, but this must be an extremely slow process in an atoll that has its origin in very deep water. But I do not doubt that all atolls, and especially those in shallower seas, grow outwards upon banks of their own talus, and that this outward growth is an important factor in atoll construction.

The atoll has therefore reached its full development, and, short of any actual change of land-level, it will remain at this stage for an incalculable time, its only alteration being a very tardy spreading of its boundaries. In these final stages of atoll development the presence of sediment is again the dominant factor. Sediment played an all-important part in the early stages of the formation of the structure, and in its closing scenes it again becomes the guiding and directing influence.

CHAPTER XXIV

THE DEVELOPMENT OF OTHER CORAL STRUCTURES AND THE INDICATIONS OF ALTERATION OF LAND-LEVEL

I HAVE already said that no concrete theory of atoll formation may be considered as at all satisfactory unless the principle that underlies it can also be used to explain the development of other coral formations. It therefore becomes necessary to see what support the ideas connected with the processes of "Sedimentation" will gain from an examination of fringing reefs and barrier reefs. Now I take it as a strong argument for the truth of these views that when I came to apply them to the formation of a barrier reef, I found that I was the third in a succession of investigators who had quite independently conceived that the real factor in the formation of barrier reefs was the process of "sedimentation."

So long ago as 1856, Professor Le Conte had given it as his opinion that barrier reefs were fringing reefs whose growth was "limited on one side by the muddiness of the water, and on the other by the depth." *

Dr. Guppy, without knowing of this explanation, had come to the same conclusion, and had published his observations in 1884.† When in the Cocos-Keeling atoll—and without a knowledge of either of these papers—I realised that the picture I had drawn of the processes of sedimentation would easily account for all the features of a barrier reef.

Since the reef-building corals will begin constructing upon any platform that rises to within the area above the *Limiting Line of Sedimentation*, it follows that a reef will form

* *American Journal of Science*, 2nd series, vol. xxiii. p. 46.

† *Proc. Linn. Soc. N.S.W.* vol. ix. Part 4.

about any land whose submarine slope gives this necessary foundation.

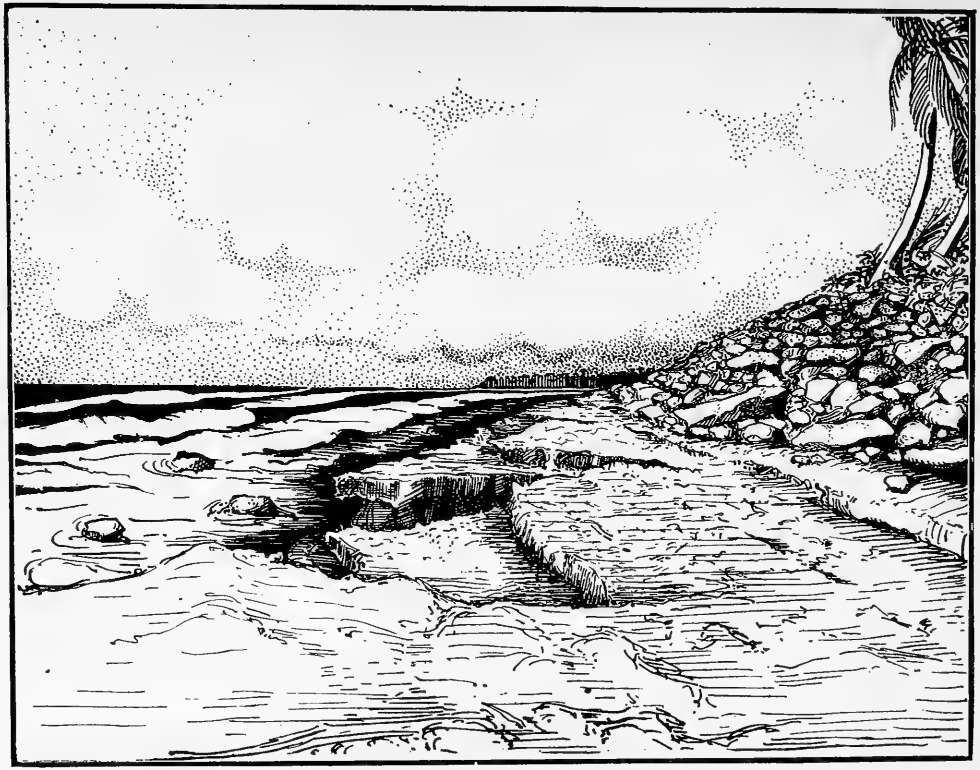
In this way a fringing reef will be formed, and it will be able to extend seawards as far as its submarine base stretches within the required limits, and after its land base is exhausted, upon a bank of its own talus. But, near the shores of the land that it fringes, the water will commonly carry a heavy load of sediment, which has been washed from the land by wave action; and so a near-shore limit will be set upon the growth of the coral colonies. This is the most simple explanation of the formation of barrier reefs, and since it has been agreed upon by two investigators, who did not advance the action of "sedimentation" as a factor in causing atoll formation, it gains an added weight. The agency that causes barrier-reef formation would seem to be almost certainly the same as that which caused the kindred structure of the atoll, and Darwin recognised this fact, for it would seem absurd that two separate conditions should be involved to account for two such similar structures. At the least, it may be said that it would appear illogical to imagine barrier reefs to be formed by "sedimentation," and the nearly allied atolls to be formed by the directly opposed action of "solution."

I therefore imagine that the workings of "sedimentation" upon the living coral colony, and upon the living coral reef, will account for all the different coral structures that are met with.

The famous theory of "subsidence" also did this, and it did it in a most complete and masterly way; and it is natural to inquire if in a fully developed atoll such as Cocos-Keeling there is any sure sign that subsidence has not taken place or caused its features. It has been said by the supporters of this theory, that subsidence, like a conflagration, destroys its own traces; but in reality it is not so. We have seen, in the course of the development of the atoll, that the first formation, after the reef has come to the surface, is the broad flat layer of the barrier. It has also been insisted, in the description of the barrier, that the breccia stratum is an unbroken layer from the surf edge of the barrier to the breccia rock of the lagoon shore. Too much importance cannot be attached to this fact, which is sometimes forgotten or not appreciated. The islands are mere piles of débris upon this level platform. It is easy to see that the lagoon margin of this platform is the first formed effort of the waves upon the newly risen reef, and that once formed, it has no power to alter its level in any way. The forces that made it are retreating, and as it was when made by the waves at the first gale that met the reef, so it must remain. The extreme seaward edge of the barrier represents the very latest effort of wave-building, and so we have from seaward edge to lagoon shore a platform that represents the sea-building throughout the entire history of the atoll. It is true that the lagoon edge of the platform becomes covered with beach sand, and that the intermediate part becomes covered with the débris pile of the island ; but at any point the breccia stratum may be exposed below its coverings.

Since the breccia platform, when once completed by the waves, and finally deserted by them, can never undergo any further building, it follows that the inner margin of the platform will certainly give the level of the reef, at the time of its very first meeting with the waves. If the whole atoll has sunk, then this inner edge of the platform must occupy a lower plane than its outer edge. The sinking, if it did happen, would not destroy its own traces, but would have a very definite index in this lagoon edge of the breccia platform. As a matter of fact, in this atoll, I have failed to find on levelling across an island any difference between the level of the barrier flats to seaward and the breccia platform exposed on the lagoon shores. I therefore conclude that in the whole long history of this atoll—from the time at which its reef first came within the domain of the breakers to its present advanced condition—no subsidence has taken place. Therefore I reject " subsidence " as an explanation of the features of the Cocos-Keeling atoll.

Since there is no trace of subsidence to be found in this atoll—nothing to be read in its history, or to be found in its



DRAWING TO SHOW THE RAISED STEPS OF BRECCIA PLATFORM ON THE SEAWARD SIDE OF THE EASTERN EXTREMITY OF PULU TIKUS.

structure, to indicate it as a monument raised upon sinking land—it becomes natural to inquire if there is any indication of the opposite movement; whether there is any suggestion of an ultimate hoisting from the ocean-level, as has occurred with its nearest neighbour, Christmas Island. As a result of his examination of the atoll, Dr. Guppy gave it as his opinion "that neither of upheaval nor of subsidence is there any evidence of an unequivocal character." These words were written in 1888, whilst in 1878 Forbes had said: "Between Direction Island and Workhouse Island I observed what seemed to me signs of recent elevation"; and in 1836 Darwin, as has been mentioned, believed that, in the undermining of some coco palms he observed those signs of sinking which he had looked to find.

The evidence of sinking that he found he describes as follows: "At Keeling atoll I observed on all sides of the lagoon old coconut trees undermined and falling; and in one place the foundation posts of a shed, which the inhabitants asserted had stood seven years before just above high-water mark, but now was daily washed by every tide.

There is no real difficulty in accounting for such diverse opinions, given by such highly trained observers. Darwin stayed but ten days in the atoll, and his visit was in April 1836; Forbes remained for three weeks in January and February 1879; and Guppy landed in August 1888, and his visit lasted for about ten weeks.

As the island dry land is undergoing a perpetual cycle of making and unmaking with every set of the local currents, it becomes evident that in order to form any just estimate of the resulting outcome of these forces, the observer must watch the process for a considerable time.

As a result of my prolonged stay I have no doubt that the gain is ultimately to the land, and the opinion of the Governor is that the islands are always winning from the sea; though at any time in some portion of the atoll you may point out spots in which the water is undoubtedly encroaching. The atoll comprises a large strip of land—much larger than any casual visitor can hope to examine with any thoroughness—and it is easy to draw the most diverse conclusions from the inspection of restricted areas; but with time and familiarity with more of the islands, it becomes evident that there is a compensation in the process: but it is more than a mere compensation, for the repair tends over the whole atoll to outweigh the destruction.

Although much importance has been attached to the various indications of land gain and loss of the atoll, I do not think that most of the processes of building and wasting that can be seen daily in progress give any real clue to the actual earth movements to which the land may be subjected. What we really see when we watch a sandy beach piled up, or a strip of shore denuded and the palms uprooted by the waves, is the fluctuating gain and loss of the islands' floating capital. A bank or a spit is made and unmade by a shift of wind or current, it does not indicate a rise or fall of island-level.

We have seen besides that great alterations may be brought about by actual temporary change of ocean-level, for, during periods of several days at a time, the surface of wide tracts of ocean may be raised or lowered locally by the banking-up effects of winds and currents, and there is nothing to distinguish this temporary alteration of water-level from an actual depression or elevation of the land. I do not think that this curious phenomenon of the local variation of ocean-level is sufficiently considered; for it is a very real and a very potent fact; it is only when your extreme elevation above the sea happens to be a few trivial feet that its reality strikes you. For days at a stretch during storms to the westward, the level of the ocean in the neighbourhood of the atoll will be most distinctly raised; and any denudation that may occur during this time will present all the appearances of alteration of land-level. For actual indications of land movements, other things than the shifting sand-banks must be looked for, and evident indices of elevation are furnished in the raised platforms of breccia which may be found in certain portions of the barrier ring. The breccia of the shore platforms is entirely the outcome of subaqueous processes, and it is impossible to conceive a breccia platform to be made *in situ* beyond the reach of the waves; indeed when the composite rock is long exposed to the air, and rain water, it suffers a certain amount of disintegration, and its sub-aerial life is a limited one. Since breccia platforms may to-day be found intact, and exactly in the condition in which they were laid down, beyond the reach of the highest spring tides, it is evident that since the date of their formation they have been elevated by an actual upward movement of the land. Between Pulu Tikus and Pulu Pasir these signs of elevation are striking. A notable fact in their disposition is that they occur in series,one layer above the other; successive land movements being registered by successive steps of breccia, which rise one above the other to a total number of three or four, and to a height of almost as many feet. At that part of Pulu Tikus where these steps are evident, the island rise is thirteen feet above mean tide-level, and is by far the highest land of the island. I can imagine no other explanation for the presence of these raised platforms than that afforded by the supposition that the land on which they were laid down has been raised, as a whole, since their formation, and on the evidence of these raised platforms I presume the Cocos-Keeling atoll to have been subjected, locally, to successive slight waves of elevation.

The positive evidence afforded by raised seaward beaches is not so strong, for gales of abnormal violence may alter the configuration of the débris bank so markedly that a raised field of broken coral may be the work of a few short hours of storm, and the loose fragments may be easily thrown beyond the reach of any subsequent high spring tide. The formation of breccia platforms must of necessity be very slow, and no sudden violence or temporary condition can cause the building of breccia beyond the normal reach of the waves. Wherever, therefore, raised and intact platforms of breccia are found, we may safely argue that actual elevation of land-level has been brought into play; but when raised débris beaches or raised sand beaches are found, then although every appearance of elevation may be present, still it must be remembered that the result seen may be brought about by changed conditions of sea-level or violent storms.

When a raised breccia platform is found upon the seaward barrier, the breccia platforms of the island and of the lagoon shore of course share in the movement. The land undergoes the same slight alteration of level, and the slabs of breccia on the lagoon shore become tilted. At the eastern end of Pulu Tikus these effects are well seen, for the old breccia platform has become undermined by the lagoon wavelets, and has become cracked and broken, and in many places moved from its original site.

I have not included among the possible signs of an upward movement those large blocks of coral rock that are found isolated upon the barrier, and in some atolls have been given the name of "negro heads." There are many enormous "negro heads" upon the windward barrier flats of the southern islands of the Cocos-Keeling atoll, but I never regarded them as being anything else than the tell-tales of the efforts of unusual storms. The experience of living on the atoll during a spell of cyclone weather confirmed this view, and I conceive the storm-driven waves to be capable of tossing up the largest "negro head" that I have ever seen. The power of the waves to move these blocks has been denied by Semper (English Trans., 1883, p. 239) and by Wilks, but the recent work of Hedley on the Great Barrier Reef leaves no doubt that "negro heads" are in reality wave-cast boulders. That the matter should become a subject of theoretical speculation seems almost absurd, for the people who have been born in the atoll, and have lived all their lives upon it, know of these things, and remember the advent of outstanding "negro heads" during the many cyclones which have passed over the islands.

An interesting point is to be noted in connection with some of the elevated rocks of the barrier, and that is the fact that some of them are capable of producing musical sounds. By the action of the sea they become hollowed and tunnelled so that the water rushing into them causes the air to be driven out through holes, with the production of various curious notes.

At the back of Pulu Tikus is a rock which at different levels of the tide and under different conditions of wind and sea emits sounds that range from a deep sigh to a shrill scream.

The point is of interest in connection with the island legend that a spirit voice exists which, calling to people—especially young children—lures them to their fate over the barrier edge.

PART IV

THE FLORA AND FAUNA OF THE GROUP

CHAPTER XXV

THE METHODS OF NATURAL COLONISATION

THE plants and animals which have succeeded is gaining a foothold upon the islands are comparatively few in number, and for the most part the living things of the land are inconspicuous creatures, with but little of that brightness of colouring or luxuriance of growth which one is apt to associate with Nature in the tropics. A great interest, however, attaches itself to the population of a coral atoll, and every living thing, although it may not be attractive to the eye, possesses an added importance from the fact that it has effected a landing, and made a home, in so distant a spot. For this reason I have paid an especial attention to the flora and fauna, and the lists which are added as an appendix to this chapter may be considered as fairly complete for most of the orders.

It is desirable that such a place as Cocos-Keeling should possess a record of the state of its flora and fauna at this time, for, with the increased intercourse with the outer world, changes are always liable to take place; new forms may be introduced and old ones exterminated with great rapidity.

This has already happened in the case of Christmas Island, and were it not for the careful recording of the state of the living things by Dr. C. W. Andrews in 1897, we should now be in ignorance of the extraordinary changes that have taken place so suddenly in the fauna, and we should lack the knowledge of some interesting creatures that have gone for ever.

No good record of the Cocos-Keeling fauna and flora is at present available. The visit of Darwin in 1836 was too short to enable him to make a collection which was at all complete, and during his stay of ten days in April he noted only the rats, the rails and snipe, one small lizard, and 13 species of insects belonging to 8 distinct orders.

Darwin's observations were quoted by Wallace in his "Island Life" (p. 275), and until the visit of Dr. H. O. Forbes they remained our sole guide to the conditions of life upon the islands.

Dr. Forbes visited the islands in 1879, arriving on January 18, and staying till February 9, and he amplified considerably the list made by Darwin; unfortunately his collections were lost in returning to Java, and so the additional species which he observed have not been specifically recorded.*

On August 20, 1885, Mr. E. W. Birch, on behalf of the Straits Government, landed and made inquiries about the islands and their inhabitants; with him, as naturalist, went the Rev. E. C. Spicer. The expedition visited most of the islets, and remained for eight days in the atoll, but in the report (Straits Blue Book, 1885) no light is thrown on the condition of the fauna.

In succeeding Blue Books are scattered notes, made by the Commissioners, on some of the most striking features of the atoll fauna, but most of this information is mere interpretation of local legend, and is of no value.

Dr. H. B. Guppy visited the islands in 1888, and has written an excellent account of their physical features in the *Scottish Geographical Mazagine* (vol. v., 1889, pp. 281, 457, and 569), but he has not, so far as I am aware, published any description of the fauna.

I collected the insects continuously throughout my stay of 15 months, and I am convinced that nothing short of a fairly prolonged residence, even in such a tiny place as is the atoll,

* "A Naturalist's Wanderings in the Eastern Archipelago," 1885.

can yield a collection that is at all representative. A casual visitor, whose stay is limited to a few weeks, cannot hope to meet with the entire insect fauna, and nothing but protracted collecting can give results upon which it is possible to fairly estimate the fauna of even the smallest coral island.

I do not think that the increased number of creatures recorded here indicates an actual increase in the fauna of the place, but only represents a more thorough and prolonged collecting. The Governor is of the opinion that additions have not been made to the fauna within recent years; and those species to be seen to-day have been for long in the islands. Still, changes are increasingly liable to occur as time goes on, and it is very much to be hoped that this census-taking of the fauna will be repeated from time to time.

It is obvious that there are only two routes for emigrants to such a place as Cocos-Keeling; a creature must either come by water, or by flying through the air; and the entire population may be separated into water-borne and wind-borne waifs. The water-borne division comprises two very different sets of colonists: the one party of those who made the voyage by chance, and with much hardihood, at the mercy of the sea-drifts; and the other whose members came as passengers in ships, in company with that greatest distributor of animal types—the merchant sailorman. The first party is the most worthy of study. In order to reconstruct a history of the methods of their transit, some idea must be formed of the ocean flotsam at their disposal, and of the oceanic drifts which carry the flotsam. No better method can be followed than the examination of the wave-cast material of the seaward beaches; and a daily tour of a stretch of barrier reef, for a period of several months, will lead to the discovery of many potential passenger vessels. The trunks of trees are naturally the most abundant of all the flotsam that might serve for the colonist, and it must be remembered that a single tree-trunk may be the only remnant of what was once a real floating island. The very name "floating island" creates the suspicion of romance, and yet floating islands are realities. Many of the trees that fringe tropical shores (and one of the most notable features of tropical shores is the presence of dense vegetation right down to the lap of ocean waves) have complicated root systems, so that, above ground and below, the trees tangle this way and that, and form inseparable masses. The mangrove is a good example of this type of growth, for a clump of trees will grow in so great a confusion of entanglement that the separation of individuals may be impossible; and, moreover, the whole will be firmly braced together by creeping plants, which run from branch to branch like cordage to the masts of ships.

A scour of the sea-coast, or a river in flood by heavy rain, may undermine such a clump, tear it away, and set it adrift to sea, with all the earth still held in the meshes of the roots, all the trees standing—a perfect "floating island." Such things happen, and the floating island is a not uncommon phenomenon in the straits and seas of the Malay Archipelago. I know of a case, where, far out to sea, a submarine cable, on being hauled to the surface, brought up with it banana trees and portions of native houses, which had obviously gone to sea as a floating island and had encountered shipwreck.

It is easily seen that such an island might serve for the transport of a very large number of colonists. It is possible even that it carried human occupants. Such islands could not be expected to long survive the waves of the Southern Ocean, and disaster would surely overtake them when they had left the calmer landlocked seas of the Archipelago. But some portion of them, crowded with the survivors of the wreck, may float for long, and carry its living burden to new homes.

The trunks of trees are common on the seaward beaches and each may have carried its passenger to the atoll from some distant coast-line where its voyage was started. There is one peculiarity about many of these trees which makes them well adapted to the carrying of Nature's colonists. This peculiarity is the shape of the lower portions of their trunks. Most of the tropical trees, whose wood is not especially hard, and which often grow to a great height, have very strong buttresses thrown out about the bottoms of their trunks. These buttresses are in the form of large thin wings, which taper to the trunk above, and below form a series of compartments, like stalls in a circular stable. Within these stalls much earth is held fast by the interlacing of smaller roots, and when such a tree is uprooted, and set adrift to sea, it carries its earth with it. It may carry it for very great distances, and I have seen a "buttressed" tree come ashore in the atoll, from whose base a wheelbarrow-load of fine red earth might have been collected. It must be remembered that such an incident is notable in a place where there is no "earth," save coral reduced to sand, and decomposed vegetation in very small quantities. From the roots of such a tree I have taken small stones, and these are rarities in a land where no stones exist. It is certain that such a tree would have many tenants when it started on its voyage, and it is not unlikely that some would have the good fortune to survive the passage. Its advent offers an explanation for the presence of *Typhlops braminus*—a small snake with an underground habit—in the atoll.

Many other sea-cast objects are stranded on the barrier. The hard seeds of many plants are washed up on the beaches, and these are potential colonists of the vegetable world. Gum resins float to the islands in large masses, and in the heat of the sun they melt upon the barrier rocks. Timbers of ships, often with copper nails still held fast, tell the tale of wrecks, and the ships that do not come to port. Pumice, in all sizes and shapes, is for ever touring these seas, and in parts of the islands it forms a considerable portion of the beaches; most of the pumice that comes to the atoll to-day is still the remains of that great upheaval of 1883, when the eruption of Krakatua altered the whole of the topography of the Sunda Straits. This pumice has been touring the ocean for over twenty years, and still, in the Sunda Straits, some set of current will send whole masses to sea, and a ship will steam for half an hour through the bobbing white balls of pumice which are launched upon an indefinite, and an irresponsible, journey.

In the islands there is a pumice more ancient than this

KRAKATUA AS IT APPEARS TO-DAY.

relic of Krakatua: it is not so clean or white, and it is found farther inland from the present sea beaches. This is most probably the pumice set adrift in the April of 1815, when the unparalleled eruption of Tomboro—the great volcano of Sumbawa—took place.

It is difficult to-day to form any conception of the vastness of these eruptions, for tropical vegetation is so quick to obliterate the traces of destruction. Half a dozen times have I sailed under the towering height of Krakatua, and failed to see, in the jungle-clad coast-line of the Straits, the evidences of the great tragedy that buried the town of Anjer and all its inhabitants for ever. On July 9, 1883, Dr. H. O. Forbes steamed past the mountain, and described its "blazing crater." But little more than a month after, it had buried Anjer, slain an incalculable number of people, swept vast coast-lines with an all-devouring tidal wave, and altered its own appearance so profoundly that a hundred fathoms of water marked the site of part of a previously towering island. The crater has ceased to blaze, and the wonderful luxuriance of tropical vegetation has healed over all the dreadful destruction of twenty years ago. Krakatua is now a slumbering giant that towers above a peaceful stretch of water. Terrible as was the eruption of Krakatua, it was trivial compared with that of Tomboro, although time has almost effaced that event from short-lived Eastern memory. At Bangoewanghie, in the eastern end of Java, the ashes covered all the land to a depth of eight inches, although that beautiful Javanese town is two hundred and forty miles distant from the volcano. For twelve days Tomboro was active, and in that short time 12,000 persons were buried beneath the burning ashes, and 200,000 more fell victims to starvation and exposure.

The blocks of pumice set adrift by these eruptions have been navigating the Eastern seas ever since; they have visited many shores in the course of their travels, and have constituted a mighty fleet of passenger vessels for the use of Nature's colonists.

A floating thing more strange than pumice is coral—coral in the form of large massive rocks which will float buoyantly in the sea. This coral is a species of *Astræa,* the zooid of which is a very large one, and nothing but its dead form is ever seen in the islands. The secret of its presence is the fact that it floats to the atoll, and is in reality an intruder upon the island fauna. The reason of its floating when dead is the presence of the numerous air-spaces, formed in its substance by the growing zooids depositing thin septa at the lower limits of their bodies. Since the zooids are for ever growing upward, they seal off cell after cell, and when they are dead, their mausoleum is a great honeycombed mass of rock, which leaves its old moorings—and after a long life spent in one spot, sets out to sea. It is not likely that this floating coral could be a very useful agent in the colonising of the islands to which it floats, but it might easily increase the coral fauna, for it is a regular thing in coral bionomics that a young colony starts its growth upon an older one.

These floating objects have almost certainly been the means of introducing a portion of the fauna of the atoll—and the group of water-borne colonists, which are not dependent upon man for their transit, is the one upon whose coming some light may be thrown by an attempt to trace their source.

Two methods of investigation are open to the dweller on a coral island. He may try to identify the objects which come ashore, and so determine their place of origin; and he may cast bottles into the water, and try to find out where they go ashore and are picked up. In this way some idea of the ocean drifts which pass the islands may be arrived at; we may find out where they come from, and whither they go.

It might be thought that a determination of the species of those plants, the seeds and trunks of which we find washed up, would give the clue to their native land; but, unfortunately, the information to be derived from this source is not very definite. The distribution of the littoral plants of the tropics is so very wide that even when a seed is definitely diagnosed its exact place of origin cannot, in some cases, be limited even to a continent. It is certain that many of them come from

Australia, and from the islands of the eastern end of the Malayan chain; and most of the plants which have become established in the atoll are represented in Timor, and in Java. It is certain also that the pumice came from Java, and from Sumbawa; for the advent of the Krakatua pumice is well remembered after the eruption. The floating coral has, like all its kind, a wide distribution, and does not help in the determination of the direction of the sea-trend.

One piece of flotsam cast on the beaches of the southern islands tells far more definitely of its origin. A boat came ashore some years ago, which in its lines differed from any that the men of Malay countries build. It was in very perfect condition when it was first found, and the carving on it was so well preserved that the Governor had no doubt at all that it was a war canoe from New Zealand, a craft with which he was familiar.

It is, therefore, safe to conclude that the currents which bring the floating things to the atoll come from the east, and such ocean drifts are, of course, charted. Through Torres Straits the waters of the Pacific Ocean sweep into the Indian Ocean, right to its western limits at the shores of Africa. The waters that wash the northern shores of Australia and the southern shores of the Malayan Islands are, therefore, the carriers of the sea-drift which is likely to be cast up in Cocos-Keeling atoll.

The track of the drift which leaves the islands is more easily followed, and, in order to learn something of it, I set adrift a number of bottles from the lee side of the atoll. In order to make the experiment yield a true index of drift action only, I loaded the bottles so that they floated with none of their surface exposed, on which the winds could act; and as they bobbed about in the waves, only a very small portion of the neck came out of water. Within each bottle I put a note, asking the finder if he would help me by writing to me and telling me of his find. I enclosed a small coin to reward him, and to cover his postage; I sealed the message in a test-tube, put it in the bottle, and launched the whole affair, Many bottles went to sea, being launched a few at a time, during a period of two months. I started the experiment in November 1905, and by June 1906, a reply had come to hand. It was sent by Lieut. G. Piazza, the Resident of Brava, Italian Somaliland, and it told that a bottle, launched on November 15, 1905, had been found at a place called Ras Day, at Brava (1° 06′ 8″ N.; 44° 01′ 52″ E.), on May 27, 1906. My little note came back again none the worse for its sea travel of over three thousand miles. No other reply came in for more than a year, and then, much to my surprise, the Resident of Brava sent me another letter telling me that another bottle had been found, in exactly the same spot as the last, on July 11, 1907; he again enclosed my note, and strangely enough it bore the same date—November 15, 1905—as the first: I was glad to notice that my kind correspondent had meanwhile ceased to be Lieutenant, and was now Captain, Piazza.

No other messages ever came back, and considering the chances of disaster that are likely to overtake a floating bottle—the chances of it breaking in its landing, and the chances of its going ashore where it would not be noticed—it is very wonderful that two ever did survive a passage of almost the whole breadth of the Indian Ocean.

It is a very wonderful thing that, after so long a journey, two of the bottles should have arrived at the very same point on the coast of Africa; and I would dearly love to examine the coast-line of Italian Somaliland, in the region of Ras Day, to see if there was not some waif that had succeeded in making a new home there, and that could tell clearly of a Malayan or an Australian origin. I do not doubt that some such colonist would certainly be found:—some typical Asiatic or Australian intruder on the African fauna and flora. A sea immersion of one hundred and ninety days would still leave seeds fertile and ready to start growth in a new home, and it is possible that some animal waifs might also survive the passage.

The drift that strikes the coast of Africa turns south, and flows down the eastern shores of the continent; and it would appear that there is a southern return current, for a bottle, launched in Mauritius, is said to have reached the atoll. But I do not think that this is a possible route for colonists, for the bottle almost certainly came to the atoll from the eastward, after completing an enormous circuit of the Indian Ocean. The length of this journey would almost certainly prohibit the success of the route as a path for colonisation. Upon the experiment of the drifting bottle, we may base some calculation as to the time which would be occupied by an animal floating from the nearest land to the atoll; and we may reckon that, if the strength of the drifts to the east and to the west of the atoll are at all comparable, a colonist must face a sea journey of some forty days. During a stay of a fortnight in October 1906, in a ship lying on cable ground some twenty miles south of Sumbawa, the current flowed constantly westward at the rate of about one and a half knots; and the waters were carrying all sorts of drift wrack in their stream. If this rate were to be maintained, the time of the journey would be reduced to a half; but the near-shore currents are subject to variations, for the region is one affected by the monsoon. The atoll itself, however, lies without the monsoon area, and the steady westerly drift is apparently constant throughout the year's cycle.

Several creatures must have survived this perilous journey of almost two months of clinging to some floating thing. There are several instances of large snakes having been killed in the atoll, and others have been picked up on the beach, where the waves have cast their vessels. There are, preserved in the Governor's house, the skulls of two crocodiles, shot after successful colonising: and these colonists must have used this route. Of the permanent additions to the island fauna we must probably reckon *Typhlops braminus*, the one earthworm, some of the coleoptera, and perhaps the millepedes which live in rotting wood. Of the flora that has been assisted by flotsam, the fungi are of most interest; and, as throwing some light upon their means of dispersal, it is important to note that every one of the eight species established in the atoll grows upon tree-trunks; not one of them grows upon the ground.

Concerning those plants the seeds of which are hard, and fitted for a sea journey, some very interesting points are to be noted. On the island beaches are many kinds of seeds which may be picked up any day—there are perhaps half a dozen kinds of which one specimen could be found, almost with certainty, in a walk along a hundred yards of beach. Now these seeds will grow with great readiness when picked up and planted in the earth; but as their leaves become recognisable, you are at once astonished to see that they are of a kind of which no representative may be found in all the atoll.

It is a strange chapter in Nature's story, for these seeds have been arriving at the atoll from time immemorial; they have been cast on to its beaches by the waves, all ready to grow, but unable to take root in the broken coral that composes the beaches. A link in the chain is missing, for there is no bird or beast that will move them the very short distance to the resting-place where they could turn centuries of failure into a successful colonising enterprise. The coconut has become the dominant plant of all atolls for the reason that, where the ocean waves toss it, there will it grow; and it sprouts green and fresh within the lap of the waves. The smaller seeds have been aided in their journey by birds or by the wind; but there is nothing that will give a helping hand to the large "Queensland bean," and several others of its kind, and assist it over the foot or two of coral beach which cuts it off for ever from any hope of success.

The colonists that are water-borne, and that have made the passage in ships, are again of two very different companies; for some, man has introduced deliberately into the islands, and some, despite his very best intentions, have accompanied him on his travels.

As a general rule, it may be said that those animals that man has attempted to establish in the atoll have not thriven exceedingly;—whilst those that came with him against his wish have multiplied to an unusual degree.

Whenever man takes a hand at assisting Nature in the process of distribution of living forms, it is to be expected that either his efforts will result in an inconspicuous failure or in a conspicuous disaster. Here, the efforts have been mostly failures.

He has turned down deer—the sambar and the kidang—and at one time quite a numerous herd was preserved with every care. The advent of a British man-o'-war, and the efforts of a regrettable shooting party, ended in driving to sea all those that were not shot—and the fate of those that took to the barrier was no better than that of those which were slain on land, for sharks accounted for all that the crew failed to secure. From Singapore others were reintroduced, but the last of the kidang passed away during my stay on the atoll. In the same island with the deer, a number of rabbits were liberated, but they failed to attain to the wonderful standard of fecundity of their race, and their colony is a very struggling one to-day.

Sheep have been imported, but sheep which, after a prolonged hunt, are shot with great difficulty, and then only yield some twenty-eight pounds of tough mutton, are not reckoned as a success, even by men who welcome anything that does not come from tins. The only influence that the deer and the sheep ever had in the atoll is that the former have created a "browse limit" to the trees—a novel feature in a coral island landscape; and that the latter have left an ever-growing legacy of ticks—and the many mongrel dogs are their legatees. It may be of some interest to the student of parasites to know that these ticks, having lost their proper host, took so readily to the dogs, and that when dogs are not at hand, they have no respect for a far more dignified patron. It may also interest him to know that there is an atoll distribution of parasites, and that the dogs of one island have ticks, but are free from fleas; while the dogs of another island do not possess ticks, but harbour fleas innumerable;—but these things are among the least pleasant members of the atoll fauna.

Pigs thrive exceedingly upon coconuts, and—for pigs—

lead a very clean life upon the dry coral islands:—but pigs are not to be introduced lightly into Mohammedan communities; and though the Chinaman loves the animal in its every phase, and tends with fond care the few that are now kept in the islands, the pig is not destined to extend its domain beyond the limits of its sty. Cats have been introduced, and, cat-like, have become feral, and a nuisance. A somewhat strange incident may be related about cats. On the island on which I lived, no cat had ever been introduced; the settlement was some five years old, and no cat had ever belonged to any of the settlers, so far as is known. A female kitten was brought to the island as a pet, and as she grew up, suspicions concerning her seemed obviously justified, though apparently absurd. The birth of a healthy batch of kittens put all doubts to rest. Their prevailing colour was black, and a great black tom cat ultimately fell to a gun at dead of night, but if he had not called to see his family, he might still be living on that island unknown and happy. This was a lesson to me, for the island was less than a mile long, and about two hundred yards wide at its broadest part; I had been hunting for the fauna of that tiny strip of land for over a year—and twenty-eight men lived on the island—and yet not I, nor any other person, had the least idea that a decent-sized mammal existed on the little stretch of coral land. A monkey and a lemur, which were lost on the island during my stay, also managed to disappear utterly. No one ever saw the lemur again, and, being nocturnal, that is not so strange; but though every man's hand was against the monkey, for he stole our chickens, he was only sighted once in the course of very many months. These facts show how very easy it is to live in the tiniest of restricted areas, and yet, with every interest in your surroundings, to fail to see even fair-sized animals that live around you. While these things are so, we have no necessity to create new species on the strength of their having white whiskers instead of the usual grey.

In some extraordinary fashion, a monkey once effected his own passage to the islands; the manner of his coming is a

NEST OF *MERULA ERYTHROPLEURA*, THE CHRISTMAS ISLAND GROUND-THRUSH.

mystery, and he was not seen again after a cyclone had swept over the group. His coming was mysterious, his going was mysterious, yet his visit is well authenticated, and it was one which lasted many years.

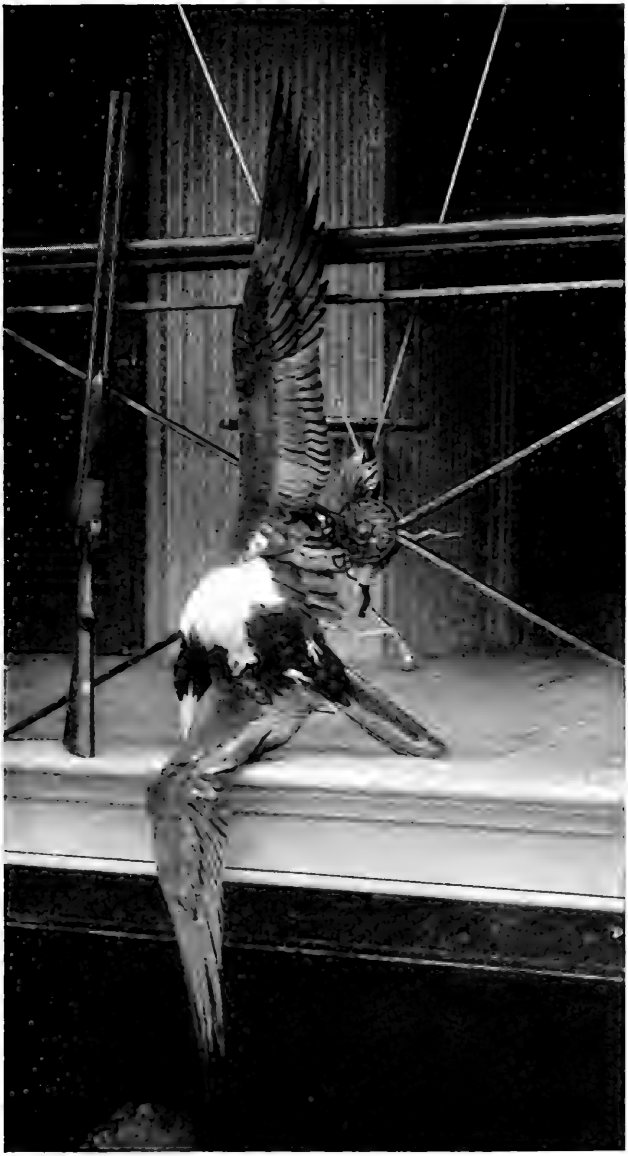
With the introduction of birds, man has been much more successful, and some of his protégés are among the most thriving of all the atoll fauna. Three species have multiplied greatly, and have become quite permanently settled in the islands; one has a somewhat insecure foothold; and one is by now practically extinct as far as this atoll is concerned. Unfortunately it is the most valuable of all the birds that man has attempted to bring to a new home which has now practically ceased to exist—and this is the *Pergâm* (*Carpophaga Whartoni*), the fine fruit pigeon of Christmas Island.

From Christmas Island also came the little "love-bird," *Burung chinta*, and though it exists as numerous little companies upon one island, it has never spread beyond the limits of that island, so that it is easy to live in the atoll and to be unaware of the existence of *Zoesterops natalis*. It is a wonderful thing that, after colonising Christmas Island in the distant past, it has never had the adventure of crossing the mile and a half of sea that separates its home in the atoll from the other islands where suitable food exists in plenty.

The Christmas Island Ground Thrush (*Merula erythropleura*) has, however, shown far more enterprise, and has made itself at home on every island of the atoll ring—but always preferring those in which the vegetation is most varied. It is one of the very tamest and most trusting of birds; it will come quite freely into a bungalow when it wants a drink of water, and it seems to have no fear of man whatever. As it has a song which is reminiscent of the blackbird's and a familiar and attractive way in all its doings, it is a very welcome addition to the live-stock of the atoll.

From Singapore came the familiar Java sparrow—the *Burung glatek*—and he, having all the sturdy insolence of his more homely relations, has become, I should suppose, the most numerous bird of the southern islands. He, too, is a distinct gain to the island community, for he is a gay fellow in appearance, and not unattractive in his habits. In Forbes' account of the atoll, it is said that the Jungle Fowl has been established in the islands; but all the wild fowls to be seen during my stay were domestic fowls run wild. In North Keeling atollon are great numbers of these, and it is a strange thing that of the myriad birds in that vast sea-rookery, the domestic fowls are by far the wildest. In this little island sea-birds breed in thousands; frigate birds of two species, gannets and boobies of three species, and terns of three species, crowd all over the trees and bushes and litter their eggs about the ground. All these birds have to be practically pushed from their eggs, and they simply do not know man, or regard him as in any way a peculiar product of Nature. During my visit to this atollon, I met with no further regard for my presence on the part of the birds than the very solemn vomiting of large quantities of fish by the big Abbott's booby when it was pushed from its solitary egg. There is something rather sad about these birds. Their big black masks give them a pathetic appearance, and when they have vomited their fish, and their egg has been taken from them, they walk away with an air of dejected resignation, as though the affair was no longer of interest to them.

The wonderful tameness of the birds on lonely islands is sometimes difficult to credit, and the charge of exaggeration is easy to make—yet I have myself seen the great frigates—birds nine feet across the wing—picked up from the ground without offering any sort of resistance. These birds were not gorged with food, they were not sleeping, and they were not unwell;—they simply did not mind us walking about among them. Yet you are lucky if you may get within thirty yards of an old cock rooster who shows Plymouth Rock, and Dorking, and many other familiar strains in his varied plumage. He is in the company of three or four hens of the same variegated hues, and in thorough farmyard style he scratches over the turtle-grass which lies along the lagoon shore; but you have no sooner sighted him than he is away



THE SMALLER FRIGATE-BIRD
(*FREGATA ARIEL*).

with his hens, over the tops of the coconut palms, or through the dense undergrowth.

Migrant birds also come to this atollon. Golden plover walk in the shallow lagoon flats, but even the air of peace which the place holds, and the general trust displayed by the resident birds, cannot quite make them forget the fears which they have learned of man in their travels—and they give him a wide berth. It is not flattering to mankind to realise that every animal that really knows him always takes care to avoid him; parasites form the sole exception.

CHAPTER XXVI

SHIP-BORNE AND WIND-BORNE COLONISTS

The creatures that have come in ships, as hangers-on to human enterprise, are perhaps the largest contribution to the islands' colonists;—they are certainly by far the most economically important.

It is not right, always, to regard these creatures as passengers; for as a rule they are residents on the ship, and they came ashore, maybe, quite against their will. It is not that a cockroach joins a ship in Singapore, and steps ashore in the atoll; for the ship is his home, and he was born there, and probably he only left his home by being passed ashore in a packing-case. When a ship has traded for long in Far Eastern waters she has a very considerable fauna of her own, a fauna almost as rich as that of a coral island itself; and, in the case of some ships, it is a question as to which would gain by the exchange, if she were moored alongside a coral island for any length of time. Rats and mice; cockroaches, of perhaps two or three species; ants in varied armies; a scorpion or two; some centipedes, and a host of spiders are the dwellers on practically every ship that floats in Far Eastern waters. Even there is such a thing as distribution on a ship, and in the ship that I came to know best, the cockroaches and the ants had very fairly defined areas of distribution, beyond which they did not greatly transgress. Some creatures, which are not permanent residents upon the ship, make their passage in different forms of merchandise: many beetles, some moths, and a variety of crickets are passengers of this class;—there is one species of cricket that appears to be the invariable accompanier of every straw-stuffed soda-water crate that lands.

By far the most important items in the atoll fauna are the rats, and they undoubtedly came through human agency. The rats have this distinction, that they were firmly established in the atoll before the original settlement was made by man, some eighty years ago. Exactly how the original rats came is of course unknown, but people had occasionally landed in the atoll previous to 1827, and, judging from the after-history, many unfortunates had been wrecked upon its barrier. When the settlers arrived, they found these rats confined to one island, and this island they named Pulu Tikus, or Rat Island, in consequence. It was upon this island that the original rats landed from the wreck, or were brought by man, and there they stayed; for the channel that separates Pulu Tikus from its neighbour is deep and very swiftly running. A man may swim the channel at all tides, but he will have to make a long course, for the current carries him rapidly down; and a rat would surely go to sea in any attempt at making the passage.

After the advent of the settlers, the rats of Pulu Tikus remained the sole representatives of their family in the atoll for very many years. They were not permitted to extend their domain beyond the limits of their own island, for a strict examination was made of all the boats that went between the different islands. They were not exterminated, for the simple reason that the extermination of rats, by any ordinary means, even on so tiny a strip of land, is quite impossible.

Theoretical authorities on tropical public health are apt to talk somewhat lightly about exterminating two disease-carrying pests—the rat and the mosquito. It is repeatedly stated that wonderful good would come of its entire accomplishment, as though it were a practical possibility;—and in a great many cases very wonderful results have been attained. If any one has a fancy that he can exterminate rats or mosquitoes, he might fittingly try his hand in this atoll, for it is an ideal spot for its attempting.

Mosquitoes he will never get rid of, for they pass their larval stages quite comfortably in salt water, and though he may render all his fresh water nasty with petroleum, or copper sulphate, or anything else that he chooses—he cannot hope to poison the Indian Ocean, or even that small portion of it that lies within the lagoon.

Rats may be killed in thousands—this has been done for years and years, and special gangs of the natives have no other employment than rat-catching. Rats may be trapped in astonishing numbers, they may be hunted with dogs, preyed on by cats, shot, poisoned, and routed out, but they will not be exterminated. Trapping merely consists of a wearying repetition of baiting traps overnight and emptying them in the morning, dogs and cats become lazy, and prefer to hunt the land-rail; and, at the best, it is an altogether exceptional dog that will organise a rat-hunt on his own account, and in my experience a dog that can at any time catch a rat by walking a few paces soon tires of the occupation. Shooting becomes expensive, and is but a feeble method. Poison leads to disastrous suicide in drinking-water tanks, to untimely deaths amidst provisions, to horrid death scenes in your bathroom, to beastly sounds in your bedroom by night, and to deaths of other and more valued animals, and is not to be recommended. Immense numbers may be killed by turning over the piles of coconut husks, and murdering all that bolt—but next day the pile will have its tenants again. Danysz virus is quite inert by the time that it can reach the atoll, the journey is too long, and the temperatures of the voyage too varied;—and those rats that were fed on it, and inoculated with it, whilst kept in cages, only exhibited a more than normal fecundity.

If other forms of virus will succeed any better I do not know; but the experiment is being made.

In 1878 the islands received a fresh accession of rats.

The ship *Robert Portner* was wrecked in that year, and from this wreck the atoll derived the greatest curse that has ever fallen to its lot. Cyclones have visited the islands from time to time, and have done incalculable damage; but the steady depredations of the rats cause far more loss than the occasional visits of cyclones; their numbers are legion, and their work is continuous.

The *Robert Portner* rats settled on most of the islands to the south of Pulu Tikus, but on Pulu Tikus itself they never gained a footing, and the "original" rats of that island remain quite distinct from the new-comers. The bad habits of the invaders rapidly became notorious, and, unlike the "original" rat, which did very little damage, they soon became the source of the most real economical loss to the islands.

The rats of Pulu Tikus have always been in the habit of climbing the coconut palms, and in some cases their offspring are reared in the crown of a palm some seventy feet from the ground; and they have learned to open the ripe nuts which have dropped from the palms—for coconut constitutes practically the whole of their dietary.

But the *Robert Portner* rats were not content with this, and when they had become accustomed to climbing the palms, they learned to attack the nuts whilst they were still green. To-day, thousands of nuts must be ruined daily by being nibbled, just where the stalk joins the husk, and a nut that is attacked in this way falls from the palm, and is quite useless for any purpose. It seems a strange thing that these new rats should so quickly have learned this mischievous practice, when the members of the older colony still remain contented with the nuts that fall naturally.

On one of the islands of the atoll ring the whole colony of rats consists of black rats, and stragglers of this species are found in some of the other islands; but the *Robert Portner* rat is the common brown rat, and the Pulu Tikus colony is probably composed of a variety of the same species.

Mice have become fairly abundant in some islands, and they do a considerable amount of damage to the stores, but, although they have no great struggle against enemies, they do not appear to increase much, and their importance, when compared with that of the rats, is practically nil.

The next most conspicuous additions to the fauna made accidentally by ships and merchandise, are the centipedes and scorpions.

The great centipedes have become exceedingly numerous, and they have spread to all the islands; and the scorpions exist in very fair numbers. The wounds inflicted by both these creatures are painful, and a good deal dreaded, but I do not think that they are ever fatal, and all the cases that I have seen have done very well. Both are common species which are widely distributed in the topics, and are the invariable accompaniers of man's enterprise in ships.

Spiders of several varieties have become abundant, and although some are of obscure species which are at present unnamed, it is likely that they are all of a wide tropical distribution. The larger species are well known as being the hangers-on to man in all his wanderings, and the big *Heteropoda venatoria* has even made attempts to colonise England. Probably nearly all came to the atoll in ships, but without ship intercourse spiders very easily colonise distant pieces of land, and the spider fauna of the neighbouring Christmas Island contained, ten years ago, none of the common ship species, but a variety of kinds peculiar to the island.

The cockroach is another of the creatures which have almost certainly taken advantage of commerce to effect their settlement, and its success has been very great. No less than seven species have become well established in the atoll, and most of them exist in very large numbers. Crickets certainly come in packing-cases, and are always to be found in numbers after a ship has discharged her cargo of stores, but they make themselves quite at home on the atoll, and may be found all over the islands.

Ants are found on every ship, and their spread is easy. Their numbers are very great in individuals, but by no means an astonishing variety of species has made its home in the atoll. Ants are among the most useful of tropical insects, and their introduction is in no way to be regretted; their thread-like journeyings are always a source of quiet entertainment, and as scavengers they cannot be overrated. It is difficult to say which of the sixteen species of beetles have come by accidental tree-trunks, and which have accompanied man; but the widespread *Dermestes felinus* is a follower of trade, and the Copra beetle — *Corynetes rufipes* — owes its truly marvellous abundance to the copra industry. Others have probably used this route, but beetles have a far more varied manner of colonising than is open to many orders of insects.

It is impossible to say if the two species of Geckos came by ships, but the Gecko is no lover of ship life, and as the egg is laid securely beneath the bark of a tree, and two months may elapse before its hatching, it is obvious that the more independent route is open to it. Both the species that have made their home in the islands are widely distributed in tropical countries.

It may be said, on the whole, that the creatures which have accompanied man in his wanderings, and have made their landing unbidden, are a very undesirable set. The rats and the copra beetles are the most harmful of all the atoll's fauna; and the centipede and the scorpion are the most unpleasant. The highly desirable animals which he would have to live around him have ceased to thrive, and the very undesirable ruffians which have taken advantage of his enterprise have thriven exceedingly.

The colonists that have come to the atoll by flying through the air compose by far the most numerous group of all the island fauna; and they are a class of the very greatest interest.

So many of the difficulties which lie in the path of these wind-borne creatures are commonly forgotten, or not appreciated, that their presence upon the atoll often does not create the admiration which it deserves. Two cases may be told of wind-blown waifs in the Cocos-Keeling Islands that will serve to make real some of the problems surrounding this method of colonisation.

At certain times in the year—generally after the rare north winds—the whole atoll will be swarming with dragonflies: the commonest species of them all is the widely distributed *Pantula flavescens*, but *Tramea Rosenbergii* and *Anax guttatus* are mostly to be found on such occasions. They come to the islands in thousands. They hawk for flies over the surface of the lagoon, and are to be met with sailing up and down every quiet glade of coconut palms, with all the accustomed air of settled residents. Yet of all these thousands not one is born or bred in the islands, and not one is ever able to start a permanent race of settlers:—for there is no open fresh water anywhere in which they may pass their larval stages.

They are quite alive to their responsibilities as pioneers, and they do not merely spend their time in a butterfly fashion during their somewhat short life of sunshine;—on all sides they may be seen making every attempt to carry on their race. When rain falls heavily, and collects in puddles on the asphalt tennis court of the cable-station, the puddles are at once exploited as likely places for laying eggs, and numerous females will be seen busily preparing for a new generation. But half an hour of sunshine and all their efforts are vain, for the puddles dry up as quickly as they came.

Even salt water tempts them to lay their eggs, and the females of *T. Rosenbergii* were to be seen daily depositing useless eggs in the salt-water fish-pond on Pulu Tikus.

This case gives some idea of the colossal waste of Nature's methods of colonising. Considering the fact that the atoll is the only dry land spot in all this part of the Indian Ocean, and that it is only eight miles across, some notion may be gained of the extraordinary numbers of these insects which are journeying aimlessly to a certain death. Of all the thousands that do happen to arrive in the atoll, not one can ever hope to carry on its race—and their fate is as useless, and their journey as purposeless, as that of those myriads which drift to nothing save a limitless sea.

The case is a very interesting one, for it is usually assumed that all colonists that set off from their home, and arrive in distant spots, are blown by winds from their native shores;—but this is not the case. These dragonflies go to sea of their own accord, they are not blown from shore, and in absolute calms of long duration, *Pantala flavescens* may be seen hawking about over the sea twenty miles and more from the nearest land. I have seen numbers of this species almost daily in a journey through dead calms all the way from Singapore to

Thursday Island. I have seen them too at almost every point between Java Head and Cocos-Keeling. They are merely flying over the sea instead of flying over the land, and they are certainly not in any way to be regarded as unfortunate storm-driven exiles. Butterflies that are members of strongly flying families do the same; they fly away from the land in a perfectly irresponsible way. Moths come nightly to a ship's lights when she is lying twenty miles from the shore.

I do not for one moment suggest that any of these insects are voluntary colonists, but I am quite sure that it is wrong to regard all insects that are met with when far from land as being wind-borne strays, swept from their homes by gales. Many of them start the journey of their own free will—an aimless and irresponsible journey it is true, but not by any means invariably an involuntary one. When once at sea, without shelter or resting-place, they do become true waifs, and then the wind disposes of them as it will.

The case of these dragonflies, which come in such numbers and are so conspicuous, is certainly only an easily recognised example of what is happening perpetually to an infinity of other creatures, and it makes real the most important fact in Nature's colonising—that the number of her failures must be enormous.

In the first place, either both sexes must arrive at the same time, or the one be ready waiting ashore for the other; or else a pregnant female must come prepared to undertake the responsibilities of maternity in a new land. Vast numbers of waifs must arrive in vain—stray solitary individuals, unmated females, or members of one sex only. Then every creature that has, after a perilous journey, the good fortune to effect a landing on the atoll, still has its fate undecided, for no suitable environment may be at hand for it and its progeny. The dragonflies have no fresh water, and therefore cannot propagate their kind. Countless other waifs, when they had made a successful landing, all ready to carry on the reproduction of their species, must have sought in vain for any plant which would serve as the food for their larvæ, or for any nidus which would have been suitable for their earlier stages. The failures from this cause must be beyond estimate.

The case of the dragonflies gives one aspect of the picture of Nature's methods, her absolute prodigality, her countless failures, and her implicit reliance upon chance. But there is another aspect, and this is the absolute success of her methods. My other case illustrates this.

Some while before I left the atoll we introduced tomatoes into our garden, and the tomatoes came as seeds in packets from England. With the first crop of plants a swarm of the larvæ of a moth, new to the atoll fauna, began to devour the tomato leaves. No examples of this insect had been seen before, and yet the suitable food plant, within a very short time of its appearing above the ground, had received its proper tenants. There can be no question that the insect was certainly not introduced as eggs among the seeds, for, apart from the general improbability of such an occurrence, it is a species which is not found in England, although it is widely distributed over the world. With peas the same story was repeated, and the moth made abundant by their introduction is again a very widely distributed one.

The history of the tomato and the pea is probably one of universal application, for it is almost true to say that of all the vegetable waifs which have arrived in the islands, every one has been appropriated by the insect whose particular choice it happens to be.

We have seen, in the case of the "Queensland bean," how uncertain are Nature's ways of vegetable colonising, and we have seen, in the case of the dragonflies, the enormous chances against successful insect invasion;—it then becomes a matter of very real wonder that almost every chance vegetable colonist has received, by chance, its appropriate animal client.

The question of finding a suitable food plant does not affect all insects equally, for some are far easier to accommodate than others. The larvæ of such moths as *Prodenia littoralis* will eat almost any low-growing plant, and will make themselves at home practically wherever vegetation of any kind exists. Such insects are the most successful of all the pioneers of the animal world, and exist in large numbers on this isolated spot.

But some are by no means so easily satisfied, and a particular vegetable species—or at least a particular genus—is absolutely essential for the nourishment of their larvæ.

These facts give the problem a somewhat different aspect from that which it first wears when we casually remark the colonists and think only of the distance that they have come, and the hardihood of their journey. Those creatures that are settled and established are the elect, and they are appointed out of a countless host of competitors, all of whom have had equal adventure but have gone under in the struggle, through no fault of their own. They are the actual colonists, the survivors of a vast army of immigrants, every one of which was a potential colonist.

It is impossible to conceive the numbers of the lost things perpetually flying about over the ocean, looking for some chance resting-place; it is impossible to conceive the perpetual waste going on among the flying things that have lost touch with land. These are the waifs that come aboard ships when far out at sea, and, considering the chances against an insect boarding a ship in mid-ocean, it is very astonishing how many may be picked up by any one who cares to watch the ship lights by night, and keep his eyes open by day.

From Suez to Penang is an unbroken steamship run of some 15 days, for many Far Eastern boats do not touch at Colombo; and this run gives a very favourable opportunity for collecting any ocean strays.

Upon this tract of ocean, in January 1905, eleven insects came aboard the ship on which I travelled. These eleven insects represented nine different species of five different orders. There were seven specimens of five species of Lepidoptera, one specimen represented the Diptera, one the Coleoptera, one the Orthoptera, and one the Homoptera. Out of the total of eleven insects, seven came aboard at night, and were found flying round the ship's lights.

An extended series of such observations would enormously amplify this list, and it would give us some idea of the resources of Nature in her distribution of potential colonists.

Of the orders which have probably arrived by flying to the atoll Lepidoptera is by far the best represented, and no less than thirty-three species of butterflies and moths have made their home in the islands. Three species of winged Hymenoptera, and eleven of Diptera, have also become settled, and probably most were wind-borne.

The four species of Neuroptera, and several of the Orthoptera have also followed the same route.

Besides the insect fauna, other and higher orders of animals have come to the atoll by flying.

Of the mammals only the bats may use this route, and the Pipistrell peculiar to Christmas Island has found its way to the Cocos-Keeling atoll, but it has never become an established resident. Forbes has reported that the large fruit-eating bats have been blown to the atoll—also probably from Christmas Island—but no memory of their occurrence remains, so far as I could ascertain. It is quite likely that these large creatures should come as colonists, for they commonly make journeys to sea among the Malayan Islands, and across the Sunda and the Bali Straits they flap every evening of their lives as they pass to their feeding-grounds. It is strange that, if these bats have ever come into the islands in any numbers, they have not become settled; but the supply of wild fruit is perhaps too limited, for the Papaia is practically the only fruit that grows outside the limits of the gardens, and its supply is very precarious, and its season is very short. Yet it would not be surprising to learn that these powerful fliers cross the sea from Christmas Island, or from Java, and live upon the bananas and saohs cultivated in the gardens of Cocos.

There is practically only one resident species of land bird that has not been introduced by man, and this is the Philippine land-rail, whose apparently feeble powers of flight make its advent all the more remarkable. It is difficult even

THE NEST AND EGGS OF THE PHILIPPINE LAND-RAIL.

to make this bird rise from the ground, and, unless it is hard pressed, it never attempts to fly; yet, after the fashion of its family, it has become a pioneer.

A widely distributed species of heron, *Demiegretta sacra*, breeds in fair numbers in the islands, and a few wind-blown migrants, swallows, wagtails, snipe and plover, occasionally land, always in very poor condition. The bulk of the avifauna of the islands of course consists of the sea-birds pure and simple;—the frigates, boobies, bo'swain birds and terns: and it is remarkable that the three species of terns, which breed in such numbers on the atoll, are not represented in the Christmas Island fauna.

Since the atoll lies in the south-east Trade zone, and the wind blows from the S.E., E.S.E., or E. for three hundred days in every year, it might be thought that the place of origin of the greater part of the fauna of the atoll would be a very easy thing to determine. It would be presumed at once that Australia was the fatherland of the bulk of all the living things of the islands—and very many of the forms are Australian. But it is a well-known fact, to which I believe Wallace first called attention, that it is the abnormal rather than the normal winds which are the most important in bringing waifs to distant tracts of land. The dragonflies show the truth of this, for their advent certainly follows the rare northerly and north-easterly winds.

The terrestrial fauna is therefore not entirely Australian, or even Austro-Malayan, for it contains a very considerable admixture of Indo-Malayan forms, just as does that of its neighbour Christmas Island.

CHAPTER XXVII

THE LITTORAL AND MARINE FAUNA'

There is another group of settlers in the atoll which has neither come by flying nor by chance flotsam in the ocean drifts, and this is the large army of crabs that has invaded the land so successfully. The crabs of the atoll show a series of transitions between those forms that live entirely in the waters around the group and those that, living always on the land, seek, so far as I have observed, those parts of the islands farthest removed from their ancestral home.

Around the sandy beaches of the lagoon live several species of the genus *Ocypoda*, and they are interesting and rather beautiful crabs of a pale olive-grey colour, and of excessively active habits. They run sideways on the extremities of their long legs, and their two wonderful eyes are held above them as watch-towers, for ever turning this way and that as danger threatens. These crabs live in spiral burrows along the sandy margins of the lagoon, and digging one out of his burrow is a rather difficult proceeding, for the holes are deep and winding. Concerning the spiral nature of the burrows a point of interest arises, for is it always possible to tell from without which way the spiral is wound within. At the mouth of each burrow is a little shoot of sand, cast out by the crab in his excavations; at times the sand-heap is to the right, and at times to the left of the hole, and the tailing out of the shoot leads to the hole in a curve which commences the spiral of the whole boring.

There is no mere chance concerning the winding of these tunnels, for the right-handedness or left-handedness of their spiral depends upon which of the chelæ of the individual is the most developed. If the crabs are watched, it will be noticed that some carry a large right claw in front of their bodies—as a boxer waiting to parry a blow—while others carry a well-developed left claw instead. These holes are excavated anew with every fall of tide, and so the crabs are always busy; indeed, their lives are passed in surprising activity, and the rapidity with which one will decide whether to run for the water or for the shelter of his hole, when danger threatens him, shows a most extraordinary aptitude for taking in a situation at a glance. Nothing escapes the watch-tower eyes, and their range of vision appears to be particularly long, for they are aware of the presence of a man at a surprisingly great distance; and when one has found safety in his hole, he soon learns when danger has passed, for the two great eyes slowly protrude from the hole and take an observation of everything going on outside.

The crabs that have made the next step towards the land are the quaint little "fiddlers" (native name, *Kapeting delima*) of the genus *Gelasmus*, tiny greenish creatures with one great pink claw as large as all the rest of the animal. The pink claw is carried in front of the body in a most grotesque fashion, and is practically all that is seen of the animal as one walks over the muddy flats in which they live, for they are very shy, and they rapidly disappear into their holes as an intruder approaches. The melting from sight of the great army of pink-clawed "fiddlers" is very curious, for, at about the same distance all round, these quaint creatures disappear, and one becomes the centre of a moving circle whose fringe is made up of vanishing pink claws and tiny greenish bodies. In the same mud flats—and practically all over some of the islands—are the large burrows of the *Kapeting balong* (*Cardisoma hirtipes*), a large and powerful crab whose back is dull purple and whose legs are pale yellow. This crab is a very important item in the economy of the islands, for it has a habit of burying the husks of the coconut, and so helping to produce the surface layer of vegetable mould which clothes the more densely vegetated islets.

It has not completely cut itself off from the sea, and large numbers may be seen at certain times marching in armies along the lagoon shores, some wholly in the water and some in the wash; and they are there doubtless for the purpose of depositing their ova.

Its burrows, too, are always made down through the loose débris to the water-level, so that the crab when residing even in the centre of an island is always able to get into the water at the bottom of its burrow when it wishes to moisten its gills.

The other land crabs of the order *Brachyura*, such as the handsome red *Gecarcoidea lalandei*, and the members of the genus *Geograpsus*, live for the most part beneath the loose coral boulders and the roots of trees, and *Gecarcoidea lalandei* seems to have cut itself off from the water very completely at all times of the year save that in which it goes to the beach for the purpose of depositing its ova.

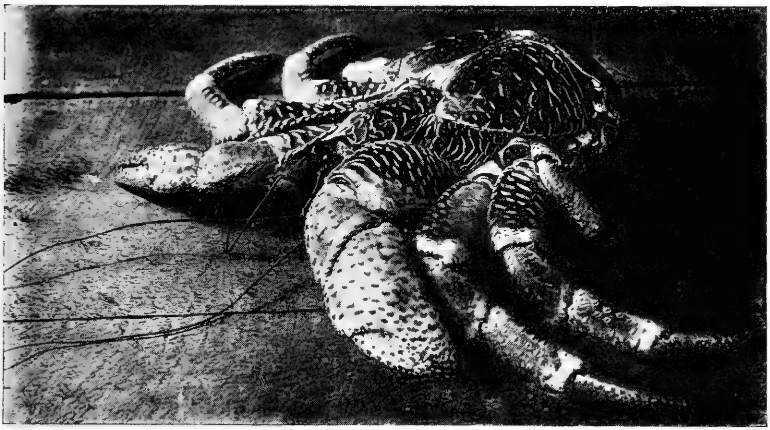
It is the members of the order *Anomura* that have most successfully become land animals, and the great "robber crab" (*Birgus latro*), whose native name is *Udung darat*, is the most completely terrestrial of them all.

The "robber crab" is becoming rare in the Cocos atoll, and I only succeeded in getting possession of five in the fifteen months I lived in Pulu Tikus: but in Keeling atollon it still lives in abundance. It is a very remarkable creature in every way, and no notion of its uncanny cleverness would be imagined from a mere inspection of the animal; but the *Birgus* is one of the cleverest animals living. Its strength is quite incredible. It can nip through wire netting as easily as can a man with cutting pliers. It can tear up tin with ease, and break with its great pinchers the wooden bars of a cage that would serve to imprison a large wild animal. Added to this, it possesses an extraordinary quickness of movement, so that the sudden and well-aimed grabs that it will make are far more reminiscent of the actions of a great spider than of a crab.

So far as I observed, in regard to those that I kept in captivity, the *Birgus* is far more fond of dead rats or meat than of coconut in any form, and it was difficult to persuade them to eat pieces of coconut when there was any animal food to be had.

I have never seen the *Birgus* crab go near the water, nor did those that I had in my possession show any desire to

FIG. 69.



THE "ROBBER CRAB."

(*Birgus latro.*)

get into the water that was provided for them; in fact, the creature seems to prefer the driest parts of the islands for its home. The crab has a wonderful power of climbing, and can clamber up anything that affords the least foothold. It climbs trees with ease, and it could escape from any cage that I ever tried, except an old oil-drum, the metal sides of which afforded no foothold for its claws.

This power of climbing trees it shares with the hermit crabs of the genus *Cœnobita* (native name, *Umpan*), of which two species—the one bright red, and the other dull blue—swarm everywhere in the atoll. These too are interesting creatures, and the way they will march and march—ever leaving behind them a curious sand-print of their trailing shell

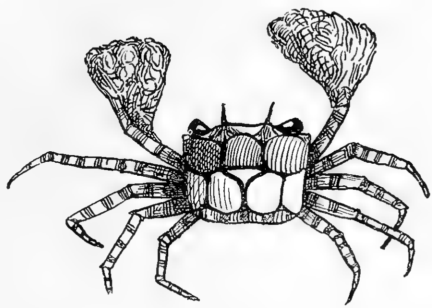
—making an ever-increasing army, the nearer they get to some piece of sea-tossed carrion, is something to watch on tedious coral island days. Very often in the early morning an army will be seen on the beaches, drawn up in a circle, all beginning to turn homewards from the feast upon the body of some fish that has been cast ashore, for a dead shark will collect around it half the hermit crab population of the island. None of these crabs is used for food except the *Kapeting balong* and the Birgus, and at the present time so few of this latter species are to be found that its dietetic importance has ceased. The hermit crabs are, however, extensively used for bait, and the big *Kapeting balong,* put whole upon the hook, makes the best and most attractive bait for the green-fish.

One crab, named *Kapeting trelek,* a member of the genus *Leptograpsus,* is very good eating indeed, and, as it is an abundant species upon the seaward side of the islands, it is to be ranked among the useful animals of the atoll.

In the calm waters of the lagoon, and in the rock pools of the barrier, are a myriad forms of crabs, strange and grotesque in shape and often of very beautiful colours, each marvellously fitted to the environment in which it finds itself. In every colony of coral is some tiny crab, always adapted most wonderfully to its place of residence, and often it is almost impossible to distinguish these coral crabs from the branches of the type of coral upon which they dwell. Many of them bore holes in the coral rock, and these are very difficult to see, for they are small and coloured like the surface of the rock which they inhabit, and one is generally not aware of their presence until they have withdrawn into their holes. Some that live in the soft lagoon sand, as *Calappa hepatica,* are strangely like a fragment of coral conglomerate, for, as they lie in the ooze, their legs are pressed firmly against their shell and not a joint in their whole body is to be seen.

The whole crab fauna of the lagoon and barrier is too numerous to discuss in detail, and the names of only a very few of the army are recorded in the appendix to this chapter; but one rock-pool crab deserves an especial notice. This crab is a minute creature and is very similar to *Melia tessellata,* described by Mr. Borradaile as living in the Male atoll and elsewhere. The crab is rather conspicuously marked, but it has adopted the curious habit of carrying a bouquet of green algæ in its claws, and behind this bouquet it hides its boldly marked body. In the cases which I have examined the alga had actually taken root upon the claw, for it had been held so long in position; but there seems to be no doubt that in the first place the crab plucks the alga and carries it in front of its body as a kind of stalking-horse, and as a shelter from its enemies.

Fig. 70.



Small Crab that holds in its Claws two small Bouquets of Living Algæ.

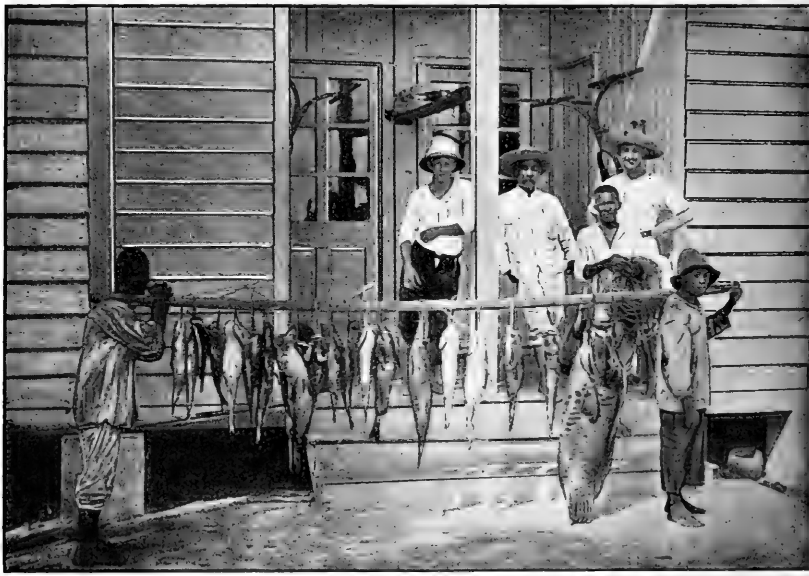
(Enlarged to twice natural size.)

It must not be forgotten that the creatures that live in the waters of the lagoon, no less than those that have invaded the land, are properly a part of the peculiar fauna of the group. For those animals which spend their lives in the shallow waters of the coral beds there is no feeding-ground nearer than the coast of Java, or the shores of Christmas Island, five hundred miles away. The greater part of all the fish about the atoll in all probability spend the whole of their lives in its immediate vicinity, and the many beautiful little coral-haunting species of the lagoon belong peculiarly to the local fauna.

The fish are necessarily among the most economically important animals of all the fauna of coral atolls, for they furnish an abundant supply of fresh food in these places in which it is otherwise very scarce. It is fortunate that of all the quaintly shaped and gaudily coloured atoll fish, there is only one which is poisonous when used for food, and even that one may be safely eaten when properly prepared. All the fish which live in the warm waters about the islands are not, however, either useful for food or at all desirable from any point of view; and chief among the undesirables are the sharks.

Sharks exist in great numbers; a large brown species, which

FIG. 71.



A MIXED CATCH OF COCOS-KEELING FISH.

grows 10 or 12 feet long, inhabits the lagoon; a smaller black and white species comes to the barrier in armies at certain times of the year; and a yellow "dog-fish," some 4 or 5 feet in length, lives everywhere. It is a strange fact that though these fish are so very abundant, and so ready to seize a bait or a fish that has been hooked, no instance of their taking a man has ever occurred, and their only victim that I know of was a boy who, though lacerated severely in an encounter, recovered from it perfectly. Notwithstanding their abundance it is the custom to bathe in the lagoon regardless of their presence, and even the dogs of Pulu Tikus are accustomed to swim about quite unmolested. It was once my misfortune to be

FIG. 72.

LANDING A SMALL BLACK AND WHITE SHARK ON THE SEAWARD BEACH OF PULU TIKUS.

upset in the middle of the lagoon, but the sharks did not avail themselves of the opportunity. Yet, only a few days before, and in the very same spot, they had been so bold in their quest of the body of a speared devil-fish, that they seized the blades of the oars when an attempt was made to tow the carcass beyond their reach. The black sharks afford good sport when gear strong enough to hold them can be used from the shore, and on the occasions of the killing of a pig, they, and the dog-fish, may be easily shot or speared, for they will dash into a few inches of water to secure a tit-bit thrown into the wash. Although the sharks appear to be but very little threat to life, they are in every way a nuisance, for they spoil the fishing, and not only do they take bait and break up fishing-tackle, but they will seize a fish that has been hooked, before it can be drawn into the boat. All this they do without even thinking to turn on their backs in order to bite.

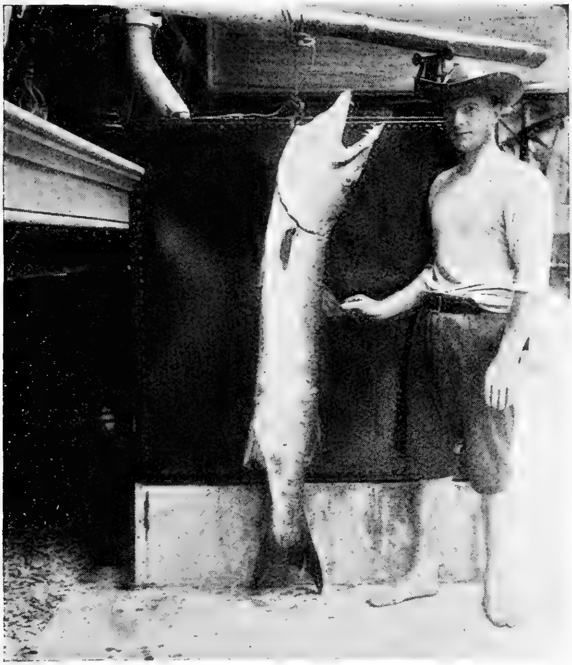
Another fish that may be a real danger is the beautiful sword-fish—*Histiophorous gladius*—for it dashes through the water with great speed, and on more than one occasion has made a sudden rush among a party of bathers. It is coloured a vivid purple when alive, and presents a very different appearance from the dried leathery specimens seen in museums.

The sword-fish has been known to transfix thick wood with his prolonged snout, and the Governor has found upon the beaches a stout bamboo run through by the sharp sword of one of these creatures, but I have never heard of a case in which a man had been speared, although the narrow escapes have been many. The baracouta has, however, left its mark upon at least one man, and I have seen a Cocos native, the whole of whose calf muscles had been torn away by the cruel teeth of this large relation of the pike. The baracouta is an ugly and a dangerous fish, for it is of all sea-creatures the most difficult to see, and it has a habit of dashing upon whatever stirs in the water. Another fish with the same habit is the *Sambar*, whose name is given to it in consequence of this habit, for it signifies the swoop as of a bird of prey upon its victim. So quick is the *Sambar* that it will dash among a shoal of smaller fish, and with the impetus of its rush be carried clean ashore, and I have seen a *Sambar* in chase of mullet dash up the beach at a man's feet, and be kicked high and dry beyond the reach of the water before it had recovered from its surprise.

THE *IKAN P'DANG*, A SWORD-FISH NAMED *HISTIOPHORUS GLADIUS*, TAKEN ON A TROLLING LINE.

The largest of all the atoll fish is the *Ikan pareh*, or "devil-fish" (*Diccrobatis eregoodoo*), and it is to a certain extent a useful fish, for a quantity of oil can be prepared from its liver, and

Fig. 73.



A Baracouta taken on a Trolling Line in the Lagoon.

its skin makes excellent sand-paper. The Pareh is the royal game of the islands, and the spearing of one which measured 13 feet across was the most exciting fishing expedition that I have been privileged to take part in. The Pareh is a curious fish, which comes to the lagoon only at certain times of the year, and generally on a rising evening tide. At such times I have seen as many as twenty in the sail between Pulu Tikus and Pulu

Selma; but for long periods not one will be seen anywhere in the neighbourhood of the islands.

Fig. 74.

The *Ikan Pareh* (*Dicerobatis eregoodoo*), a Giant Skate measuring 13 Feet across its Body.

Among the fish which are useful for food, the "Green fish" is one of the most important, as it is excellent of flavour and grows to a great size. It is a fish of remarkable appearance, being covered with a thick armour of very large and beautiful green scales, but its armour is useless as protection against the spear of the Cocos-born Malay. It may be either speared or taken on the line, and in the latter case it is usually killed in about 6 or 8 fathoms of water with a *Kapeting balong* as the bait. In the stomachs of those Green fish that I have opened, there have been, in addition to the legs and shells of crabs, large numbers of the spikes of sea-urchins; and for the proper mastication of these hard objects the fish is provided with a remarkable grinding-mill situated far back in its gullet. The teeth that are set round the jaws of the Green fish are peg-top teeth, used only for picking up its food from the crevices in the rocks; all the grinding of the hard parts of its spiny victims is carried on by the gullet mill, which consists of knobs of bone studded over with enamel-covered bosses.

The Green fish grows to a great size, one of 200 pounds in weight not being a very exceptional fish, and with increasing size the delicacy of the flesh as an article of food does not diminish, but rather improves.

There are several relations of the Green fish, the *Dongol* being the finest of them, but this fish is not to be taken on the line, for it lives in the tumble of the roughest barrier water. Great shoals of them swim along the barrier rocks and feed upon the Nullipores which clothe the boulders, and though the natives can spear them in the breakers, I was never successful in stopping one with a rifle bullet. The *Kakatua*, however (of which there are several species all belonging to the genus *Scarus*), may be shot with cased bullets with comparative ease, and fish-shooting in the tumbling surf of the barrier was one of my most delightful occupations in the atoll. The many *Kakatua* are fine fish, splendidly coloured, and while some species are bright blue or green, some are blue and yellow, some blue and pink, and some are vivid red in various combinations. Some that inhabit the lagoon may be taken upon a line, but most must be speared or shot, for although it is possible to fish at times upon the barrier, the loss of fishing-tackle among the rocks makes the process an expensive one. Some fish may even be killed with a shot-gun, and the Garfish (native name *Talang-talang*) and

FIG. 75.

THE "GREEN FISH," *Ikan Ijou* (*Pseudoscarus*), WEIGHING 112 POUNDS.

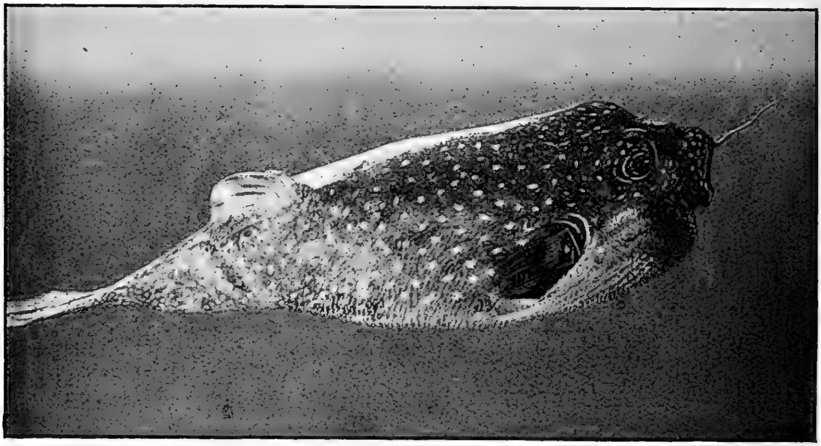
mullet, which swim at the surface, are those that fall the most easy victims. At times when the tide is out upon the barrier very fine fish may be shot as they bolt across a shallow pool to the deeper water beyond. These barrier pools are the homes of some of the most wonderful of all the atoll fish, and it is impossible to describe the splendid colouring, vivid blue and intense purple, of the myriad tiny fish that spend their lives among the branching growths of coral. The Pig-fish (*Balistes*) and a host of others have wonderful patterns picked out in boldly contrasted colours, and there are many very curious points in connection with the mode of coloration of these bright tropical fish.

It is not uncommon for the two ends of a fish to be entirely different in coloration and pattern, so that an appearance is presented as though two fish had been cut in half, and the head end of one joined to the tail end of the other. Another very common design is for a fish to possess one patch of colour that presents a glaring contrast to all the rest of its body; and in such a case a vivid spot is seen moving through the water as the fish swims, but the whole body of the creature becomes very difficult to define.

There is no doubt that these strange freaks of coloration serve a very definite purpose, but we know so little of the elements that enter into the factors of the lives of these fish, and so little of the appearance that these things present when viewed by other creatures in the water, that they appear to us rather as strange and fantastic efforts of Nature than as the useful defensive and offensive aids that they undoubtedly are. There is much to be learned about these creatures, and no better place than Cocos-Keeling could be chosen for studying the reasons for their strange ornamentations, for, in the clear water of the barrier pools and in the lagoon, observations may be made upon them in their natural environment under the very best conditions.

Strange methods of defence of more obvious utility than coloration are to be seen in the many fantastic forms of fish which carry armour-plate, and spikes around their bodies. The Tetradonts show some of these modifications in their most exaggerated forms, as some are shaped like little hard boxes with thick spikes projecting fore and aft, others are one mass of prickles like hedgehogs, and some have only a few cruel spikes situated so that they are sure to wound any animal that attempts to seize them. One of the strangest of the Tetradonts is the *Ikan Buntal*, that can inflate its whole body at will, and so float lightly on the surface of the water, a

Fig. 76.



The *Ikan Buntal* (*Tetrodon patoca*).

bobbing air-ball clothed with prickles. The method of inflation is truly marvellous, for a *Buntal* when irritated can inflate itself in a very few seconds, and from being a creature not much larger than your fist, swells up to the size of a football: and all this is done when the fish is lying calmly under water. It can inflate and deflate itself many times in rapid succession, and can go through the whole performance on land as easily as it can when in the water.

The *Buntal* is the one poisonous fish of the atoll, and the whole of its poison is concentrated in its gall-bladder, so that if the gall-bladder be removed whole, the fish is said to be excellent eating; but I never tried it. I have kept these fish in ponds and tanks, and they rank among the most remarkable of all living creatures, and certainly among the most tenacious of life, for they can stand an extraordinary amount of exposure to the sun and air.

Some fish that seem to have no special method of protection in the matter of coloration or armour-plate, are those that spend their lives in the shelter of the irregular coral masses of the deeper parts of the lagoon and island slopes; and they evidently depend for their preservation upon their power to lurk among the rocks. One such fish is the " rock cod " or *Grapu*, a fine fish which offers good sport, as it is a most voracious feeder, and is excellent eating. The rock cod is mostly remarkable for the enormous size of its mouth ; it can swallow any bait which even a good-sized shark could take in, and the gape of its jaws is wonderful. In some measure it seems to depend upon this enormous gape to resist being pulled from its rocky haunts, for when hooked it invariably comes up with its mouth wide open, and a fish of only a few pounds can offer a very stubborn resistance in this way.

Around the slopes of the island ring, various fine fish may be taken on days when it is possible to go out into the open ocean in a small boat, and snapper, albicore, and " king fish," are among the best to be had in this way, but the success of the fisher is frequently marred by the presence of the sharks, which steal his victim from the hook before it can be pulled aboard the boat.

Large numbers of strange eels live around the rocky shores. They are of many species, of which the commonest is a large grey creature that may often be seen coiled up on the surf-washed edge of the barrier.

The animals are named *Lendong* by the Malays, and are justly held in some dread, for their bite is very severe and they are dangerous creatures to deal with. One species is even credited with possessing poisonous properties, and I think that it is not unlikely that its character is a true one; and certainly its appearance is so really repulsive that it naturally suggests the possession of evil powers. This eel (*Ophichthys colubrinus*, var. *annulata*), which is called *Ular tana* by the natives, is boldly banded with black and white, and it lives in the sand of the lagoon: it does not appear to be a very common species in Cocos, and I only obtained one specimen during my residence in the atoll. A small grey eel that is very common among the holes in the barrier rocks is an interesting creature to watch, for it preys upon the crab named *Kapeting trelek*, and the swiftness with which it will pounce upon one of these crabs and withdraw with it into its hole is quite astonishing. Besides eating the *Kapeting trelek*, these eels destroy a far more valuable creature, for they are particularly fond of young turtles, and turtles are none too common in the lagoon to-day.

Of the myriad other creatures that live in the clear waters of the atoll, some have already been mentioned because of the importance of their actual influence upon the structure of the atoll, and the Bêche-de-mer are the most important of these. Bêche-de-mer live in extraordinary numbers in this atoll for the reason that their exportation is wisely prohibited; they form a very valuable asset to the islands, and one which could be easily exploited in the event of a sudden failure of the crop of coconuts. Bêche-de-mer when dried are called *trepang*, and they are extensively used in China and elsewhere in the preparation of a soup that is nearest akin to turtle soup, and is very excellent. The demand for them is great, and very few of the Chinese servants who come to the atoll can resist the temptation to try to smuggle some away when they leave the place.

The temptation is very easy to understand, for the sea-slugs may be picked up by the thousand without any trouble, and they need no preparation for the market save simple drying in the sun.

Many beautiful star-fish (native name, *Ular bintang*)—one being a very vivid blue—lie scattered about the rock pools; and a great number of very quaint and beautiful sea-urchins (native name, *Terongan*) are to be found about the crevices of the barrier rocks. The shells to be found both in the lagoon and on the barrier are extremely fine, and one of the most pleasant occupations of coral island life is walking at low tide along the flats in the hunt for the fine polished cowries which are to be found beneath any loose boulder that may be turned over.

It is a delightful quest, and one of which the interest never flags, for beneath every stone that is moved there are a hundred forms of life, and most are of brilliant colour and strange in shape. Splendid Nullipores clothe the rocks, bright and delicate Nudibranchs and shining cowries (native names, *Dakon* and *Groos*) live in the crevices; crabs and fish dart this way and that as their home is moved from its foundations.

Octopuses (native name, *Gorita*) also live among these rocks, and they are among the most wonderfully protected of animals, for in the twinkling of an eye they assume perfectly the colour of the boulder to which they cling. They are fairly easily speared, and are by no means bad to eat when properly prepared and cooked. Their curious defensive method of expelling their ink into the water is a very effective one as far, at any rate, as man is concerned, for when one has been hunted from rock to rock, and has finally obscured all the water for many yards around with the dark brown stain, it is as well to give up the chase, for he will not likely be found when at length the water clears. Portions of the tentacles of Octopuses of phenomenal size have been washed ashore upon the atoll beaches, but none of those that I have seen alive about the islands have been of alarming proportions. Jelly-fishes (native name, *Obor obor*) come to the lagoon at certain seasons only, and then they are to be found in great numbers, but for many months on end not one will be seen anywhere about the whole of that part of the ocean. The Portuguese man-o'-war (*Physalia*), however, knows no season, and some are generally to be found in rock pools damaged by the breakers which cast them up. They are also at times encountered when bathing, and the sting of their long tentacles is a very severe one. The sailing of these curious creatures is often to be witnessed, and the queer bubble-like vessels may be seen almost any day proudly navigating the ocean, or wrecked, a blue and white mass, thrown on the shores. Besides the Portuguese man-o'-war, there is one other harmful creature to be met with in rock pools, and that is a worm whose sides are fringed with an array of hairs that look as though they were composed of fine spun glass. The hairs of this worm, upon the very least handling, run deep into the flesh, producing an intense irritation; and their removal is apt to be a matter of some difficulty.

The majority of the creatures to be found any day on a walk along the barrier at low tide are objects of pure delight, and nothing that I know is quite so good, or quite such a perfect pleasure to a lover of Nature, as the hunting for the many beautiful tropical sea-products in the warm waters about the atoll.

APPENDICES

APPENDIX I

LIST OF THE FAUNA

MAMMALIA.

(1) THE PULU TIKUS RACE OF *Mus decumanus*.

During Darwin's visit the only rat in the islands was the Pulu Tikus race, and of it he says: "These rats are considered by Mr. Waterhouse as identical with the English kind, but they are smaller and more brightly coloured" ("Naturalist's Voyage," p. 461); and Wallace ("Island Life," p. 275) adds: "We have here an illustration of how soon a difference of race is established under a constant and uniform difference of conditions."

In the seventy years that have passed since Mr. Waterhouse described the rat, the difference appears to have become more marked, and a description of the race is justified for the reason that the modern introduction of rat virus into the atoll may possibly exterminate it.

External Appearance.—The rat is a slenderly built and sleek-looking animal; its general colour is a warm russet-brown. The fur of the back is coarser, and some hairs stand out which are almost black, and are 30 mm. in length; these long dark hairs are more numerous over the hind end of the body than over the shoulders. The general colour of the body is a rather rich brown, the belly being but little lighter than the back in most specimens. The shorter hairs are grey at the base and bright red-brown at the tips; the longer hairs are dark brown to black. The fore limbs are somewhat lighter than the rest of the body, but the hind limbs are of the general rich red-brown. The under surface is only slightly lighter than the back, and is a light warm brown, not grey; the chin and throat are somewhat lighter. The under surface of the scrotum of the male is covered with long bright red-brown hairs, brighter than those of any other part of the body; the distal extremity of the scrotum is bald, the naked skin being a dark purplish brown.

The vibrissæ—many of them more than 60 mm. long—are numerous and dark-coloured. The ears are almost naked, they are oval and prominent and average 22 by 15 mm. The hind feet are large and long, their soles are dark, almost purple in colour; the digits are slender, the claws are long and much curved. The tail very slightly exceeds the length of the head and body, it is darker than the body colour; it is finely scaled, 12 rows to the centimetre, and sprinkled with numerous fine black hairs. There are two pairs of pectoral mammæ, and three inguinal pairs, 2–3 = 10. The tibiæ are almost straight, having practically no "bow" forwards.

The Skull.—The skull is long and narrow, and is delicately built. The nasals, which extend posteriorly to the anterior margin of the orbit, are 15·5 mm. long, and 2·8 mm. wide at their broadest part. Basal length of skull 35–38 mm.; greatest breadth 18 mm. Interorbital constriction, least breadth 6 mm. Interparietal, length 5 mm., breadth 10 mm. Length of base of anterior root of zygoma 6 mm. Palate, length 20 mm.; breadth, outside m^1 9 mm., inside m^1 4 mm. Palatine foramina 8 mm., *extending 1 mm. behind the anterior edge of* m^1—this is a constant feature. Alveoli (back of incisors to m^1) 12 mm. Upper molar series 6·5 mm. Incisors pale yellow in the lower jaw, orange in the upper jaw.

The measurements in millimetres of a series of specimens are as follow:

	Head and Body.	Tail.	Hind Foot.	Leg (Tibia).	Front Foot.	Forearm.	Sex.
1	190	190	40	50	20	35	♂
2	207	208	40	45	20	33	♂
3	195	200	40	50	20	30	♂
4	195	191	38	42	22	25	♂
5	205	215	40	52	19	34	♂
6	187	185	40	50	18	32	♂
7	192	215	40	50	19	34	♂
8	200	205	40	45	20	30	♀
9	180	185	40	45	20	30	♀
10	163	158	39	40	22	29	♀
11	150	155	38	39	22	27	♀
12	147	149	36	38	18	24	♀
13	215	230	42	45	22	36	♀
14	198	202	39	48	20	32	♀
15	187	190	39	48	18	32	♀
16	170	160	35	42	20	38	♀
17	120	130	35	35	17	32	♀

(2) Mus decumanus, typ.

This is the pest of the atoll, and does incalculable damage to the coconut plantations.

(3) Mus rattus, typ.

Is common on Pulu Gangsa and some of the small southern islets, and I have had one specimen from Pulu Selma, where it is not nearly so common as *M. decumanus*.

(4) Mus musculus, Linn., is not uncommon on Pulu Tikus.

A herd of feral deer lived for long in Pulu Luar. The animals were introduced from Java and from Singapore, and consisted of two species, the Sambar (*Cervus hippelaphus*) and the Kedang (*Cervus muntjac*). All were dead when I left the islands in 1906.

Waifs and strays include bats of some small species which did not appear during my stay in the atoll, and which are said to be the *Pipistrellus murrayi*, Andrews, from Christmas Island.

AVES.

Colubriformes.

(1) Carpophaga Whartoni, Sharpe.

Native name, *Pergám.*

Introduced from Christmas Island, but by 1906 it was practically extinct in the atoll.

Ralliformes.

(2) Rallus philippiensis, Linn.

Native name, *Ayam utan.*

Very abundant on all the islands, and is everywhere very tame, it being a matter of some difficulty to make it take wing. It feeds on the shore when the tide is out, but it may also be seen perched high in papaia trees eating the ripe fruit, and it has a bad name for eating the eggs of domestic fowls. It nests in September, in tufts of grass, about a foot from the ground; it lays from two to six eggs, very like the English corncrake's. The young are all black when hatched, and can run directly they are out of the egg. The call-note is a shrill grating sound, and in the breeding-season the cock adds a deep croak not unlike the noise made by frogs. This species is not found in Christmas Island.

Lariformes.

(3) Sterna fuliginosa, Gmel.

Native name, *Burung dali.*

Breeds in Keeling Island but not in very great numbers. It keeps very much to itself on the breeding-grounds, and lays one egg in the sand above the beach rise, on the western side of the island. By sailors it is called the whale-bird. Although not uncommon, and often seen at sea, far from the atoll, it does not occur on Christmas Island.

(4) Anous stolidus, Linn.

Native name, *Burung krok.*

Not resident in the Southern atoll, but a frequent visitor to the lagoon. In Keeling atollon it breeds in great numbers. In June the breeding-season has almost come to an end. The nests are made about a foot above the ground, on little collections of sea-tossed wrack. In the atollon all the "noddies" build close together in a rather limited area. Only one egg was found in each nest.

(5) Gygis candida, Wagler, *Isis,* 1832, p. 1223.

Native name, *Burung chuit-chuit* (onomatopœic).

Darwin noted the bird in 1836 ("Naturalist's Voyage," p. 462), and H. O. Forbes gave an account of it in 1879 ("Naturalist's Wanderings," p. 34). The bird agrees with the description of Wagler: "Irides nigro-cæruleæ: rostrum nigrum, basi cæruleum; lingua sublata rostro brevior; pedes cærulei, palma alba, ungues nigri."

In a good description of this bird (Cassin, "U.S. Explor. Exped.," p. 389) the feet are said to be "pale blue, having a deeply indented yellow membrane." In Gould's "Birds of Australia," vol. vii., the feet are described as orange, and are figured of that colour in the accompanying plate. In other accounts it is stated that the feet are yellow or brown. The bird, as I have seen it in the Cocos-Keeling group, invariably has the feet entirely blue, the web being slightly lighter than the toes.

The bird is a common one, and occurs in all the islands. It breeds in the Southern group as well as in Keeling Island.

Although the bird feeds mostly on fish, it may often be seen hovering around the papaia trees and eating the soft fruit. It is quite arboreal in its habits, and its one egg is laid sometimes at a height of 40 feet from the ground. Most of the eggs were found in September, but on visiting Keeling Island in June two eggs were found after very little searching. The egg is almost perfectly oval (40–43 mm. in its long axis, 21–22 mm. in its short axis); it is cream-coloured, mettled and streaked with olive-brown. It is laid on the branch of a tree (*Pisonia inermis, Cordia subcordata, Guettarda speciosa*) wherever a slight irregularity in the bark suffices to hold it steady. In all the cases that I have seen the egg was

Fig. 77.

Egg of *Gygis candida*, laid on the Branch of a Grongang Tree (*Cordia subcordata*).

laid in the long axis of the branch, and the parent bird sat across the branch in the process of incubation. From the fact that three nesting sites were used twice over, it would seem as though the suitable branches for balancing the egg were somewhat limited. The birds take it in turn to sit, or rather stand, on the egg, and they invariably leave it by falling backwards off the branch, in order not to disturb it with their feet; great caution is taken in getting into position on the egg again. Incubation lasts 36 days; the newly hatched young is buff-brown, and it does not move from the tree until it has assumed its white feathers. A bird hatched on September 3, 1905, did not move from the site of its hatch-

FIG. 78.

Gygis candida SITTING ON ITS EGG.

This is the same egg as is shown in Fig. 77.

ing till October 22; it then moved higher up the branch, and remained, with slight changes of position, till November 12, when it took its first flight. Many eggs were watched, and in no case did any accident befall them, but a young bird, hatched on November 17, fell from its insecure position on the fourth day, and was killed. This bird does not occur on Christmas Island, and is not seen far from the atoll—it is, in fact, a sign that the atoll is near when one is seen on the voyage from Java.

ARDEIFORMES.

(6) DEMIEGRETTA SACRA, Sharpe.

Native name, *Blakok*.

Exists in fair numbers, especially in Pulu Atas, where as

FIG. 79.

YOUNG *Gygis candida*, SOON ABOUT TO TAKE ITS FIRST FLIGHT.
The plumage is still mottled with buff-coloured feathers.

many as twenty may be seen fishing together. Birds in the white phase and in the grey phase mix freely together; though it is said in the islands that white pair with white, and grey with grey. The nest is made in the *Pisonia* trees, and two pale blue eggs are laid. I obtained specimens in January.

In Pulu Atas I have also seen a solitary individual of a larger species of Heron, which, in the distance, appears to be pure white; this individual was well known to the natives of the atoll.

PELECANIFORMES.

Suborder FREGATI.

(7) FREGATA AQUILA, Linn.

Native name, *Burung itam.*

Does not breed in the main atoll, but nests in large numbers in Keeling Island. The nest is a slight collection of twigs, stolen from the nesting Gannets, and placed on the flat tops of the *Pemphis* bushes. The nests are crowded together in thousands; one egg only is laid, which is pure white and its surface is shining; eggs were abundant in June. The bird is so tame in Keeling that it has to be driven from the egg, and those birds that are sitting in the hot sun, with their wings half spread, may easily be approached and lifted from the ground.

(8) FREGATA ARIEL, Gould.

This species is more common than the last. Its habits are similar, and it nests freely with the larger species. It is also called *Burung itam* by the natives.

Suborder SULÆ.

(9) SULA SULA, Linn.

Native name, *Burung bebek.*

I have never seen this bird in the main atoll, and its numbers are somewhat limited in Keeling Island. It lays one or two dirty white eggs on the bare ground, at the top of the western sand-beaches.

(10) SULA ABBOTTI, Ridgw.

Native name, *Burung gangsa.*

Is not common in Keeling, and, so far as I have observed, does not come to the Southern group. The face is black, and the bird is considerably larger than the other two species. One or two eggs are laid on the bare ground. The black mask gives the sitting bird a very curious appearance, and it leaves its egg only after having, with great solemnity, vomited large quantities of fish ; it makes no attempt to resist being pushed from the egg, and when the egg is taken, and the fish has been vomited, it quietly walks away. No skin was obtained.

(11) Sula piscatrix, Linn.

Native name, *Burung main main.*

The commonest of the three species, and generally called "Booby" by sailors in these seas. Exists in very great numbers, and is seen in all the many age changes of plumage, from a uniform light brown to white. It lays one egg, in a nest placed, as a rule, high up in trees ; but numbers build on *Pemphis* bushes in Keeling. The birds commonly perch on trees, and are often taken from the rigging of ships.

Suborder Phaethontes.

(12) Phaethon rubricauda, Bodd.

Native name, *Burung buntut.*

Does not exist in great numbers, but still breeds in Pulu Atas. This species, as well as *P. fulvus,* is to be seen everywhere between the atoll and Java Heads.

Passeriformes.

Fam. Ploceidæ.

Dr. H. O. Forbes mentions *Ploceus hypoxanthus* as one of the nesting species of the atoll; but no examples of it exist to-day.

(13) Munia oryzivora, Bp.

Native name, *Burung glatek.*

Introduced, and has multiplied greatly; it is now one of the commonest birds of the atoll.

Fam. TURDIDÆ.

(14) MERULA ERYTHROPLEURA, Lister.

Introduced from Christmas Island, and now very common, especially on Pulu Tikus. The bird is remarkably tame, coming freely into rooms to obtain water. Has a rather pleasing song, which it utters in September and October. The nest is built in November, and the egg is very like that of the European Redwing.

Fam. ZOSTEROPIDÆ.

(15) ZOSTEROPS NATALIS, Lister.

Introduced from Christmas Island. Confined to Pulu Luar, where it exists in some numbers. In Christmas Island it is known as *Burung waringin*, but in Cocos-Keeling it has earned the name of *Burung chinta* or "love-bird."

Golden plover, native name *Burung blebis*, and Curlew are said to breed on some of the islands, but I never found the eggs, nor did I ever obtain a bird for identification. A flock of ducks is resident on Pulu Panjang, and on the same island I have seen many small waders, but the wise policy of the islands is that these birds shall not be interfered with and I cannot name the species. I have, however, shot a stray Snipe (*Scolopax gallinago*, Linn.) from a small flock on Pulu Tikus, and on the same island obtained a Swallow, *Hirundo gutturalis*, Scop. These, and a wagtail, are the only visitors that came to the islands in my stay of fifteen months, and the atoll would seem to be altogether out of the track of any, save very wind-blown, migrants.

In North Keeling atollon are large warrens, the nesting sites of "Mutton Birds"; during my visit to the atollon these birds were not present, but they evidently visit the place, for the purpose of breeding, in very large numbers.

In all probability they are *Puffinus brevicaudus* or *P. sphenurus*.

REPTILIA.

Species determined by G. A. BOULENGER, F.R.S., V.P.Z.S.

(A) LACERTILIA.

Fam. GECKONIDÆ.

LEPIDODACTYLUS LUGUSTRIS, D. & B.

Native name, *Cheechak.*

A very abundant species, inhabiting dwelling-houses, and also living beneath the loose bark of coconut palms. Six or seven eggs are laid at a time—as a rule beneath some convenient chink of bark. It has the characteristic voice of its family, which has given rise to its name.

(2) GEHYRA MUTILATA, Wiegm. (Plate XXI. Fig. 1.)

Not nearly so common as the first species, and lives exclusively out of doors, being always found beneath the bark of the coconut palms. It is at once distinguished from No. 1 by its flattened tail. It lays from three to four eggs, and the incubation period is as long as two months (June to August).

(B) OPHIDIA.

Fam. TYPHLOPIDÆ.

(3) TYPHLOPS BRAMINUS, Daud.

Native name, *Ular minyah.*

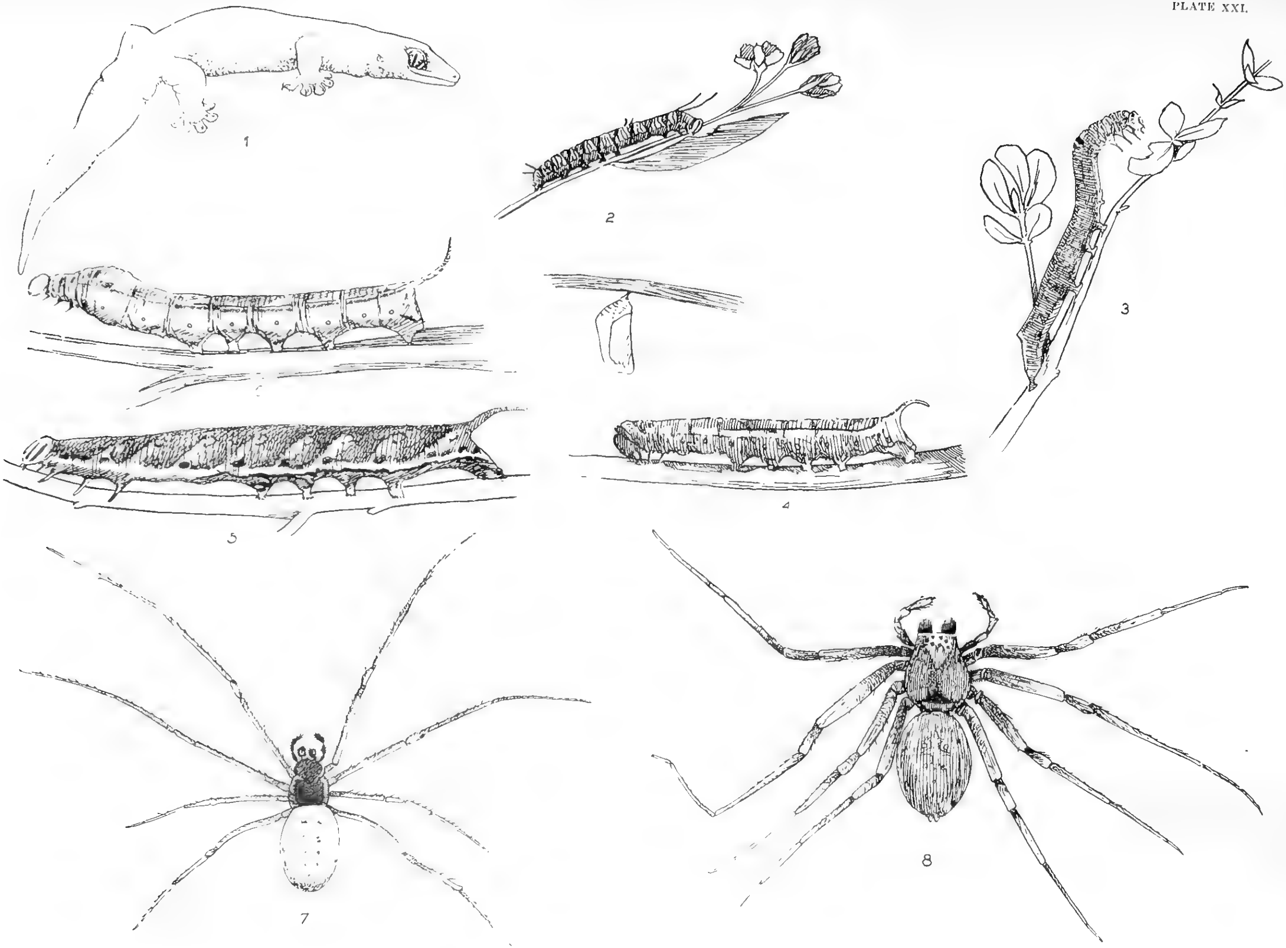
This is not a common species in the islands, and its habits lead to its being very rarely seen. It is most commonly found beneath large coral boulders, and it is extremely active. It is found on practically all the islands in the atoll. The average length is 150 millimetres.

None of these species is found in Christmas Island.

PLATE XXI.

3

(35) Ikan-trompet.


1
2
3
4
5
7
8

(C) Chelonia.

Two species of Turtles are frequently speared in the lagoon. They are *Chelone imbricata*, L., native name *Pinnew sisih*, and *C. mydas*, L., native name *Pinnew betul*. Both have ceased to use the main atoll as a breeding-place, for the native demand for them is too great; but on Keeling atollon their nests are common on the sandy beaches.

PISCES.

The fish of the group were not collected, and no doubt a rich harvest awaits the investigator of the myriad smaller coral-haunting species. The native names of those that are of the most economical importance only are given here; and no specific determination is possible in most cases.

(1) Ikan babi = pig-fish, *Balistes*, sp. (2) Ikan buntal = inflated fish, *Tetrodon patoca*. (3) Ikan buntal besagi = square-shaped inflated fish, *Tetrodon*, sp. (4) Ikan blanah. (5, 6) Ikan bandang and Ikan bandang laut. (7) Ikan buntut burih = spotted tail. (8) Ikan chuchut, generic name for the numerous Sharks. (9) Ikan dongol, *Scarus*, sp., grows to a great size. (10) Ikan grâpu. (11) Ikan iju = green fish, *Pseudoscarus*, sp. (12) Ikan jengot = bearded fish. (13) Ikan jengot karang (karang = coral). (14) Ikan kakap. (15) Ikan kakap kuning = yellow kakap. (16) Ikan kakatua iju, *Scarus*, sp. (17) Ikan kakatua merah = red kakatua, also a *Scarus*. (18) Ikan merah = red fish. (19) Ikan malam = night fish. (20) Ikan menyrat. (21) Ikan padang döeh, the albicore. (22) Ikan p'dang, *Histiophorus gladius*. (23) Ikan pareh, *Dicerobatis eregoodoo*, grows to a great size, being upwards of 13 feet across the back. (24, 25) Ikan peteh, and Ikan peteh kuning. (26) Ikan puti = white fish. (27) Ikan palo. (28) Ikan sambar. (29) Ikan samsi. (30) Ikan skagnol. (31) Ikan talam talam. (32) Ikan talang. (33) Ikan tangiri, the king fish. (34) Ikan todak, the baracouta. (35) Ikan trompet.

MOLLUSCA.

Species determined by E. A. SMITH, F.Z.S.

(1) CYPRÆA HIRUNDO, Linn.
(2) CYPRÆA ANNULUS, Linn.
(3) CYPRÆA MONETA, Linn.
(4) CYPRÆA CAPUT-SERPENTIS, Linn.
(5) CYPRÆA ARABICA, Linn.
(6) CYPRÆA LYNX, Linn.
(7) CYPRÆA CAURICA, Linn.
(8) CYPRÆA ISABELLA, Linn.
(9) CYPRÆA VITELLUS, Linn.
(10) CYPRÆA MAURITIANA, Linn.
(11) CYPRÆA TIGRIS, Linn.
(12) CPYRÆA GLOBULUS, Linn.
(13) NASSA GRANIFERA, Kiener.
(14) NERITA POLITA, Linn.
(15) NERITA ALBICILLA, Linn.
(16) TURBO PETHOLATUS, Linn.
(17) TURBO LAJONKAIRII, Deshayes.
(18) LAMPROSTOMA, sp. (young).
(19) FOSSAR TROCHLEARIS, A. Adams.
(20) MELAMPUS LUTEUS, Quoy and Gaimard.
(21) MELAMPUS CASTANEUS, Muhlfeldt.
(22) MELAMPUS CAFFAR, Kürler.
(23) AURICULA TORNATELLIFORMIS, Petit.
(24) MELEAGRINA MARGARITIFERA, Linn.
(25) PINNA NIGRA, Chemnitz.

The collection of the Mollusca was by no means a representative one, for it comprised only the most conspicuous and more abundant forms.

LEPIDOPTERA.

Lepidoptera Rhopalocera.

(Native family name, *Kupu kupu.*)

Species determined by Mr. F. A. Heron.

(1) Precis villida, Fabr.

This is the commonest butterfly in the atoll. It is most abundant in July and September, and again in March and April. The larva is black, and is covered with spines: food-plant is *Asystasia coromandeliana.* The pupa is suspended by the tail from the branches of its food-plant, it is mottled brown and has no metallic markings. The pupal stage lasts for a fortnight or three weeks.

(2) Hypolimnas bolina, Linn.

(3) Hypolimnas bolina, form nerina, Fabr.

An uncommon species, on the wing in April and August. Specimens are in perfect condition, and the species is evidently resident.

(4) Hypolimnas misippus, Linn.

A common species on all the islands of the group. One worn specimen was taken on Christmas Island by Dr. Andrews. The males and females of this species are very rarely seen together; the males flying high in the shade of the thickly growing cocopalms, and the female being generally seen flying low over the herbage in open spaces. It is abundant from July to October, and again from the end of February to April. The larva is brown and spiny, the head is reddish and bears two spines. It feeds on a succulent weed that grows all over the open spaces in the atoll. The pupa is brown and has no metallic markings; it is suspended by the tail. Six days are passed in the pupal stage. The female mimics *Danais* (*Limnas*) *chrysippus petilia*, Stoll, and is nearly always seen flying in company with that species, whose habits of fluttering over the herbage it has closely imitated. The male, on the other hand, flies strongly and is not often seen fluttering near to the ground.

(5) Vanessa Kershawi, McCoy. (Australian.)

Only four examples of this species were met with in fifteen months, and since all were observed between May 15 and 17, 1906, it is probable that they were waifs. Two rather worn specimens only were captured on Pulu Tikus.

(6) Danais (Limnas) chrysippus petilia, Stoll. (Australian and Christmas Island.) (Plate xxi. Fig. 2.)

Common on Pulu Luar and Pulu Tikus, but not so often met with on the other islands. The larva is pale green, banded with yellow and black. The food-plant is *Asclepias curassavica.* The pupa is suspended by the tail, and is pale green or buff with small golden dots. The average stay in the pupa is only 135 hours.

Lepidoptera Heterocera.

Species determined by Sir George F. Hampson, Bart., F.Z.S.

Arctiadæ.

(1) Utethesa pulchelloides, Hmpsn.

A very abundant insect on all the islands. It mostly frequents the seaward side, for there the food-plant, *Tournefortia argentea,* Linn., lives most luxuriantly. The perfect insect, and the larvæ, are to be seen at all times of the year, and season appears to make no difference to its numbers.

Noctuidæ.

(2) Chloridea obsoleta, Fabr.

No specimens were taken during 1905, and the insect only became at all plentiful in June 1906.

(3) Chloridea assulta, Guen.

Appeared at the same time as the last species, and was not seen in any numbers.

(4) Cirphis loreyi, Dup.

Not an abundant insect, and strictly confined to a seasonal appearance. Taken in June 1905, and not again until the same month in 1906.

(5) Prodenia littoralis, Boisd.

Abundant on all the islands, on the wing most plentifully in May and June. The larva feeds on a multitude of low-growing plants. This very widely distributed species is found on Christmas Island.

(6) Spodoptera mauritia, Boisd.

Several specimens were taken in June 1905, but in June 1906 it did not appear again.

(7) Leocyma sericeata, Hmpsn.

Not abundant; appears in June and again in November. The larva is pale green and bears a few scattered hairs; it feeds on the leaves of the *Waru* (*Hibiscus tiliaceus,* Linn.). Not on Christmas Island, though its genus is represented by *L. tibialis,* Fabr.

(8) Ophiusa coronata, Fabr.

Only one specimen taken, and a few more seen, in June 1905. Occurs on Christmas Island.

(9) Ophiusa melicerta, Dru. (Plate xxi. Fig. 3.)

This is one of the most plentiful of the atoll insects, being found wherever the bushes of *Pemphis acidula* (native name *Kayu burung*) are growing. It is on the wing practically all the year round, but is most common from June to September. The larva bears a wonderful resemblance to the twigs of the *Pemphis acidula* or the *Ricinus* on which it feeds. It has a habit of dropping from its twig when disturbed, but it always manages to get a fresh hold of a lower twig, on the way down, although it appears to be falling to the earth. It pupates in a few leaves spun together at the ends of the twigs; the pupa is covered with a fine bloom. Fourteen days are passed in the pupal state.

(10) Remigia frugalis, Fabr.

Most abundant in May, and a few stragglers again in September. It flies by day, and is not uncommon in the grassy spaces, where the undergrowth is kept cleared.

(11) Plusia chalyctes, Esp.

The development of a garden on Pulu Tikus appeared to be the cause of the abundance of this species; but since the garden plants were introduced as seed, there appears but little chance of their having been the agent for its introduction. It swarmed in June 1906, and the green larva was abundant on peas, tomatoes, and almost every plant that was grown in the garden. The pupal stage lasts only a week.

(12) Hypena strigata, Fabr.

One example only taken.

(13) Cateptria, sp.

This is a handsome insect, boldly marked with black and white. It appears on the wing in September. The larva feeds on the leaves of *Pemphis acidula,* in company with *Ophiusa melicerta,* to which larvæ it bears a considerable rough resemblance. It is mottled grey on the back, and the belly is velvety black; at the anal extremity is an upwardly directed tubercle with a bifid tip. A collar of magenta colour surrounds the larva behind the head, but in all ordinary attitudes this is hidden by a skin-fold. It pupates among the little leaves of its food-plant; the pupa has no bloom, and the pupal stage lasts for twenty days. I never saw an example of the perfect insect, save those that I reared from larvæ; and, so far as I could find out, no one on the island was acquainted with the moth. The larvæ were by no means uncommon on a few bushes in Pulu Tikus, but I did not meet with them on any other islands.

Sphingidæ.

(14) Macroglossa passalus, Dru.

By no means common, and more frequently seen as a larva than as an imago. On the wing in September. Larva green, with fine bright pink side-stripes; feeds on *Morinda citrifolia*, Linn., native name *M'ngkudu*. The pupa is a mottled yellowish brown.

(15) Cephonodes hylas, Linn. (Plate xxi. Fig. 4.)

Common on Pulu Tikus, but not often seen on the Southern islands. Frequents the flowers of the Papaia by day, and is evidently the source of the error that bees are common in the islets. When hovering in front of the food-plant, in the act of laying its eggs on the leaves, the long hairs of the extremity of the body stand out like a fan. Most abundant in June and September, but stragglers may be taken in almost any month. Larva feeds on the leaves of *Guettarda speciosa*, Linn., native name *Melati*. When first hatched they are quite black, and they only become green in their penultimate and ultimate skins. They are subject to endless variation, and if bred in the dark, very striking larvæ, coloured yellow and black, can be produced; the imagines resulting from these larvæ are normal. This insect occurs on Christmas Island.

(16) Herse convolvuli, Linn. (Plate xxi. Fig. 5.)

Not a very common insect. Found most plentifully on Pulu Selma. The larva is either green or brown, and it feeds on *Convolvulus parviflorus*, Vahl. In the atoll this is the moth specially named *Rama rama*, although in the Straits that word is the general name for all moths.

(17) Chærocampa vigil, Guer. (Plate xxi. Fig. 6.)

The perfect insect is rarely seen, but the larva is very abundant in September. It feeds on the leaves of *Pisonia* *inermis,* native name, *Ampol;* it is green, but in its last skin it frequently becomes putty-coloured. When fed in the dark the last skin is almost invariably brown. A month is passed in the pupa. This species occurs on Christmas Island.

GEOMETRIDÆ.

(18) CHLOROCLYSTIS TENUILINEA, Warr.

Not uncommon in June and August. The larva is green, with darker markings, and is slightly hairy. Feeds on the sticky flowers of *Pisonia,* and pupates among them.

PYRALIDÆ.

(19) PYRALIS MANIHOTALIS, Guer.

Not at all plentiful.

(20) MELISSOBLAPTES, sp.

Very abundant on all the islands of the group.

(21) ZINCKERNIA FASCIALIS, Cram.

Always common. This widely distributed species also occurs on Christmas Island.

(22) MARASMIA VENIHALIS, Walk.

One of the commonest insects. Appears in June, and is always to be found about the station lamps.

(23) CROCIDOLOMIA BINOTALIS, Zell.

Only a few examples met with in June.

(24) PACHYZANCLA LICARSISALIS, Walk.

Abundant from June to August. The larva is green, with minute black spots; it feeds on the leaves and flowers of *Dicliptera burmanni,* Nees. It pupates in the spun-up leaves, and the pupal stage lasts for fourteen days.

(25) PACHYZANCLA STULTALIS, Walk.

Abundant in June on all the islands.

(26) Glyphodes indica, Saund.

Not abundant.

Pterophoridæ.

(27) A brownish coloured Plume is very common in all the islands. The larva feeds on *Boerhavia diffusa*, W., which grows everywhere in the atoll.

Tineina.

(28) The solitary species collected was a very common one; there are probably at least two others that are distinct.

There are therefore practically thirty species of Heterocera on the Cocos-Keeling atoll, and there are more than twice as many species in the fauna of Christmas Island; yet only five, very widely distributed species, are common to the two places.

HYMENOPTERA.

Species determined by the late Col. C. T. Bingham, F.Z.S.

Formicidæ.

(Native family name, *Samut.*)

(1) Odontomachus hæmatodes, Linn. ☿.

(2) Plagiolepis longipes, Jerdon. ♀.

Unfortunately this does not represent the whole of the species of ants found on the atoll. The natives distinguish at least three species: (1) *Samut saman*; (2) *Samut arpi*; (3) *Samut alus*. The other representatives of the family are unfortunately mislaid.

Fossores.

(3) Stizus, sp. (very near *reversus*, Smith). ♀.

(4) Pison hospes, Smith. ♂.

(5) Notogonia subtessellata, Smith. ♂ ♀.

The Fossores are not at all numerous, and only very careful collecting produced the very few specimens obtained in the course of fifteen months.

These five species are not represented in the fauna of Christmas Island.

DIPTERA.

Species determined by E. E. Austen, F.Z.S.

Asilidæ.

(1) Philodicus javanus, Wied.

A common insect of very voracious habits. It is generally een sitting on the coral boulders in the hottest sunshine. It lies in wait for smaller diptera, and it will attack and kill even butterflies as large as *Precis villida*.

Bombylidæ.

(2) Anthrax, sp. Only a very few examples met with.

Dolichopodidæ.

(3) New genus and species (No. I.), near *Psilopus*.

(4) New genus and species (No. II.), near *Psilopus*.

Both of these are common insects, but owing to their green colour and small size, they are not at all conspicuous. They are shining green flies that are most commonly seen running on the leaves of the *Hibiscus*. They are extremely active, and are generally found during the hottest hours of the day.

Muscidæ.

(5) Sarcophaga, sp. No. I.

(6) SARCOPHAGA, sp. No. II.

Both are common species, frequenting the dead bodies of rats.

(7) RHINIA TESTACEA, Rob.-Desv.

Few examples seen, mostly upon the herbage of the seaward side of the islands.

(8) PYCNOSOMA FLAVICEPS, Macq.

The commonest fly in the atoll.

(9) OPHYRA CHALCOGASTER, Wied.

MICROPEZIDÆ.

(10) NERIUS LINEOLATUS, Wied.

HIPPOBOSCIDÆ.

(11) PSEUDOLFERSIA SPINIFERA, Leach.

Usually swarming over the plumage of the Frigate-birds. On Keeling atollon, where these birds breed in thousands, the fly is often seen crawling about the nesting bushes.

CULICIDÆ.

(12) The Mosquito of the islands is a species of *Stegomyia* and it exists in great numbers.

COLEOPTERA.

Species determined by C. O. WATERHOUSE, P.E.S.; C. J. GAHAN, M.A., F.E.S.; and G. J. ARROW, F.E.S.

BRACHELYTRA.

(1) ALEOCHARA, sp. This genus is not represented on Christmas Island.

Clavicornia.

(2) Dermestes felinus, Fabr.

A common species, found mostly in the dead bodies of rats. Universal distribution, and common on Christmas Island.

(3) Coccinella transversalis, Fabr.

A very abundant insect; not present on Christmas Island.

(4) Trochoideus desjardinsi, Guer.

Not present on Christmas Island.

Lamellicornia.

(5) Onthophagus, sp.

Genus not represented on Christmas Island.

(6) Anomala, sp.

An abundant species that lives on the iron-wood (*Cordia subcordata*). Freely attracted to light and most commonly found in the lamps of the Telegraph Station. Not found on Christmas Island.

(7) Potatia acuminata.

The largest beetle found on the atoll. It is by no means common, and not more than a dozen specimens were taken in fifteen months. Not present on Christmas Island.

Malacodermata.

(8) Corynetes rufipes, De Geer.

Native name, *Kutu copra.*

The most important insect of the atoll, from an economical point of view. Called by Europeans the "Copra beetle." Exists in myriads near to the sheds where the copra is stored. It will swarm to anything oily, and was killed in thousands on the refrigerator engines. It is very active, it flies by day, and has a habit of creeping beneath the clothing and biting rather sharply. It does not occur on Christmas Island.

SERRICORNIA.

(9) MEGAPENTHES, sp.

Not a common insect. It does not occur on Christmas Island, where *M. Andrewsi*, Waterh., is the representative of the genus.

(10) MELANOXANTHUS MELANOCEPHALUS, Fabr.

One specimen only, flying in the sunshine, on March 2, 1906. Does not occur on Christmas Island, but the genus is represented there by *M. dolosus*, Cdz., and *M. litura*, Cdz.

HETEROMERA.

(11) OPATRUM, sp. (near *simplex*, Fabr.).

A common insect, found mostly under the bark of the coconut palms. Does not occur on Christmas Island, where the genus is represented by *O. dubium*, Arrow.

(12) CEROPRIA INDUTA, Wied.

Very abundant on all the islands. Lives in rotting wood. The genus is not present on Christmas Island.

(13) SESSINIA, sp.

Native name, *Madú*.

A very common insect. Found on all the islands, and freely attracted to light. It is the subject of great variations in size.

Well known to the inhabitants, Malay and European, as producing an acute dermatitis.

This species would appear to be very similar to, if not identical with, *S. Andrewsi*, Arrow, from Christmas Island; and of that insect Dr. Andrews says that it exudes an oily liquid, "which is considered by the residents to have most injurious properties" ("Monograph of Christmas Island," p. 107).

Longicornia.

(14) Ceresium simplex, Gyll.

Rare. Not found on Christmas Island, but two representatives of the genus—*C. quadrimaculatum*, Gahan, and *C. nigrum*, Gahan—were taken there by Dr. Andrews.

(15) Calocyclus annularis, Fabr.

Only one specimen taken, flying in the sunshine, on March 1, 1906. Does not occur on Christmas Island.

(16) Rhopica honesta, Pasc.

(17) Rhopica binotata, Gahan.

Both unique specimens. The genus is not represented on Christmas Island.

Seventeen species of beetles therefore occur on the Cocos-Keeling group, and only one—a cosmopolitan species—is definitely known to be also an inhabitant of Christmas Island, although the coleopterous fauna of that island embraces ninety-five species.

RHYNCHOTA.

By W. L. Distant, F.E.S.

Suborder Heteroptera.

Fam. Pentatomidæ.

Subfam. Cydninæ.

(1) Geotomus pygmæus.

Æthus pygmæus, Dall. List Hem. i. p. 120 (1851).

Geotomus pygmæus, Sign. Ann. Soc. Ent. Fr. (6), iii. p. 51, t. iii. f. 160 (1883); Dist. Faun. B. I., Rhynch. i. p. 98, f. 49 (1902).

Hab.—Widely distributed: recorded from Ceylon, Bombay, Burma, Andaman Islands, and generally distributed throughout the Malayan Archipelago; found in China and Japan, and recorded from New Caledonia and Hawaii.

Subfam. Pentatominæ.

(2) Nezara viridula.

Cimex viridula, Linn. Syst. Nat. ed. 10, p. 444 (1758).

For full synonymy *cf.* Dist. Biol. Centr.-Am., Rhynch. i. p. 78 (1880).

This species is distributed throughout the Palæarctic, Nearctic, and Ethiopian regions, and over a large portion of the Neotropical, Oriental, and Australian regions.

Subfam. Asopinæ.

(3) Œchalia consocialis.

Pentalatoma consocialis, Boisd. Voy. Astrol., Ent. ii. p. 630, t. xi. f. 9 (1835).

Œchalia consocialis, Stål, Enum. Hem. i. p. 59 (1870); Schont. in Wytsm. Gen. Insect., Fasc. 52, p. 75, t. v. f. 12 (1907).

This species is recorded from, and not uncommon in, Australia, New Zealand, and Tasmania. It is a well-known species in Queensland.

Fam. Aradidæ.

(4) Brachyrhynchus membranaceus.

Aradus membranaceus, Fabr. Syst. Rhyng. p. 118 (1803).

Brachyrhynchus membranaceus, Stål, Hem. Fabr. i. p. 96 (1868); Dist. Faun. B. I., Rhync. ii. p. 160 (1904).

Found throughout British India, Malay Peninsula, and Malayan Archipelago.

Fam. Reduviidæ.

Subfam. Nabidinæ.

(5) Nabis capsiformis.

Nabis capsiformis, Germ. in Selb. Rev. Ent. v. p. 132 (1837); Dist. Faun. B. I., Rhynch. ii. p. 400, f. 256 (1904).

Distributed in the Nearctic, Palæarctic, Ethiopian, Oriental, and Australian regions.

Fam. Capsidæ.

(6) Lygus, sp.?

Two specimens of a species of this widely distributed genus.

[None of these species can be described as at all abundant on the atoll, and only *Nezara viridula* is commonly met with; the others are, for the most part, very seldom found. The whole of the order collected on Christmas Island by Dr. Andrews was not worked over at the time of publication of his Monograph; but of the four species described by Mr. Kirby, there is not one that is common to Christmas Island and the Cocos-Keeling atoll. So far as I know, none of these species has earned a distinct native name, but the domestic representative of the family, which is common in native houses, is called *kutu basuk* = stinking insect.—F. W. J.]

Suborder Homoptera.

Fam. Fulgoridæ.

Subfam. Ricaniinæ.

(1) Nogodina bohemani.

Ricania bohemani, Stål, Freg. Eugen. Resa, p. 280 (1858).

Nogodina bohemani, Melich. Ann. Hofmus. Wien, xiii. p. 305, t. xiv. f. 9 *a* (1898).

Originally described from the Keeling Islands.

[This is not a common insect, and only a few examples were taken, all from the leaves of the Hibiscus trees on the seaward side of Pulu Tikus.—F. W. J.]

NEUROPTERA.

Species determined by W. F. Kirby, F.L.S., F.E.S.

Odonata.

(Native family name, *Kachapong.*)

(1) Pantula flavescens, Fabr.

A very abundant insect; it flies about all over the lagoon, and is present on all the islands. In April and May of 1906 the whole atoll swarmed with dragonflies, but for some time previous to that it had been very rare to meet with a single specimen. In the early months of 1905 these insects were entirely absent from the atoll.

(2) Tramea Rosenbergii, Brauer.

First seen on May 16, 1906, and during the following week it became abundant; but for nearly a year previous to this it had not been seen, and its numbers soon diminished afterwards.

(3) Anax guttatus, Burm.

This species also came first to the atoll in May 1906, and then only about a dozen examples were seen.

Planipennia.

(4) Hemerobius ? sp.

Native name, *Lalar ijou* = green fly.

This is a very abundant insect; it occurs on all the islands, and is certainly resident. When alive it is bright green, and its eyes are remarkably brilliant. On account of its very offensive smell when crushed, it is very well known. It is common at all seasons of the year.

(5) Isoptera.

Native name, *Gegat.*

One species of "white ant" is very abundant in the woodwork of dwelling-houses. It is noteworthy that the natives never include this insect under the title of *Samut*—the family name for ants.

ORTHOPTERA.

Species determined by W. F. Kirby, F.L.S., F.E.S.

Forficulidæ.

(1) Anisolabis annulipes, Luc.

A common species found upon all the islands. It does not occur on Christmas Island.

Blattidæ.

(Native generic name, *Kerklak.*)

(2) Blatella germanica, Linn.

(3) Allacta noctulata, Stål.

(4) Allacta obtusata, Brünn.

(5) Loboptera, sp.

(6) Molytria, sp. (young larva).

(7) Leucophœa surinamensis, Linn.

All these species are common, and are mostly found beneath the bark of trees, or in the dwelling-houses. Only *Leucophœa surinamensis* occurs on Christmas Island.

(8) Periplaneta americana, Linn.

Common in store-houses; introduced by ships.

ACHETIDÆ.

(9) GRYLLODES SIGILLATUS, Walk.

Native name, *Orong orong.*

Most commonly taken near to dwelling-houses; not very abundant.

(10) ORNEBIUS, sp.

A very abundant species. It lives in the bushes of iron-wood (*Cordia subcordata*), and passes its early stages in a rolled-up leaf.

Neither of these species occurs on Christmas Island.

(11) GRYLLACRIS, sp. near *signifera,* Stål.

Native name, *Chingkrek.*

This species also passes its early stages in the leaves of the *Cordia.* When adult it appears to be carnivorous; it has exceedingly powerful jaws, and is credited with waging war on the large centipedes. When put in a box with a centipede it certainly fights with great vigour, and though it bites the centipede, the fights that I have arranged ended fatally for the *Gryllacris*—but I believe that this is by no means invariable. This species does not occur on Christmas Island, but the allied *G. rufovaria* takes its place. The antennæ are 150 mm. long.

(12) PHISIS PECTINATA, Guer.

A fairly common species, usually found in the *Cordia* bushes. It is a bright green when living. It is not found on Christmas Island, but *P. listeri,* which occurs there, is very nearly allied to it.

(13) CONOCEPHALOIDES SOBRINUS, Bol.

The male is buff-coloured, and the female green during life. The species is abundant, and commonly lives in bushes. It is very musical. Does not occur on Christmas Island.

Locustidæ.

(Native name, *Blalang blalang.*)

(14) Acrydium, sp. near japonicum, Sauss.

Very abundant on all the islands. Feeds on the fronds of the coconut palm. It varies greatly in size when adult, and is the subject of great seasonal changes of abundance and rarity.

It is not found on Christmas Island.

Although fourteen species of Orthoptera are found on the Cocos-Keeling atoll, and twenty-three occur on Christmas Island, there is only one species—*Leucophœa surinamensis*—which is common to both places. Of this species Dr. Andrews took only a single specimen.

ARACHNIDA and MYRIAPODA.

By A. S. Hirst, F.Z.S.

Scorpions.

(1) Isometrus maculatus, De Geer.

Native name, *Klajingking.*

Cosmopolitan.

Spiders.

(Native family name, *Laba laba.*)

(2) Smeringopus elongatus, Vinson.

Cosmopolitan.

(3) Physocyclus globosus, Taczaon Taczanowski.

Widely distributed in the tropical regions of the world.

(4) Nephila imperatrix, C. K. (Plate xxi. Fig. 7.)

An adult female example which apparently belongs to this species. It differs from Koch's description of the species in having the abdomen marked ventrally with two dark medium patches, the anterior one being square and separated from the smaller posterior patch by a whitish line. The British Museum possesses examples of this form from Buitenzorg, Java, and from Australia (Keyserling Coll.).

(5) Heteropoda venatoria, Linn. (Plate xxi. Fig. 8.) Cosmopolitan.

(6) Lycosa, n. sp.

(7) Bavia, n. sp.

Millepedes.

(Native name, *Kaki ribu.*)

(8) Trigoniulus, n. sp.

(9) Orthomorpha coarctata, Saussure.

(10) There is also a large Centipede—native name *Alipan* —no specimen of which reached England.—F. W. J.

CRUSTACEA.

(Native family name, *Kapeting.*)

The collection of this order was not at all a representative one; such specimens as were brought home have been determined by Dr. W. T. Calman, F.Z.S.

Brachyura.

(1) Carupa læviuscula.

(2) Leptodius sanguineus.

(3) Lioxantho punctatus.

(4) Liomera pubescens.

(5) Actæa fossulata ?

(6) Carpilius maculatus.

(7) Euruppellia annulipes.

(8) Pseudozius caystrus.

(9) Eriphia lævimana.

(10) Melia tessellata.

(11) Gelasimus, sp.

(12) Cardisoma hirtipes.

(13) Gecarcoidea lalandei

(14) Liolophus planissimus.

(15) Schizophrys aspera.

(16) Calappa hepatica.

Anomura.

(1) Remipes testudinarius.

(2) Birgus latro.

(3) Cœnobita clypeatus.

(4) Cœnobita rugosus.

(5) Cœnobita perlatus.

(6) Calcinus herbstii.

(7) Clibanarius corallinus.

Caridea.

(1) Alpheus strenuus.

STOMATOPODA.

(1) GONODACTYLUS CHIRAGRA.

VERMES.

There is one species of earthworm found in all the islands, but unfortunately no specimen reached England.

APPENDIX II

LIST OF THE FLORA

The following list of the flora of the atoll is based upon that compiled by Dr. H. O. Forbes from his own observations and from those made previously by Darwin.

To this list I have added several species, and I do not doubt that it still remains far from complete. Where it is possible, I have added the native names of the plants, and noted their distribution and the use to which they are put by the natives. For the naming of the Fungi, which (with the exception of *Polyporus luridus,* which I did not myself observe) are all additions to our knowledge of the flora, I am indebted to Miss A. Lorrain-Smith and Mr. A. Gepp, of the British Museum.

DICOTYLEDONS.

Anonaceæ.

(1) Anona reticulata, Linn.

Cruciferæ.

(2) Sinapis juncea, Linn.
Distribution: Aru Islands, &c.

Capparideæ.

(3) Gynandropsis pentaphylla.
Pedicellaria pentaphylla, Schrank.

GUTTIFERÆ.

(4) CALOPHYLLUM INOPHYLLUM, Linn.

Native name, *Nyamplong.*

Distribution: Widely distributed in tropics; wood useful for furniture.

MALVACEÆ.

(5) HIBISCUS TILIACEUS, Linn.

Native name, *Waru.*

Distribution: Common sea-coast tropical tree; fibre from bark used in islands for cordage, &c.

(6) HIBISCUS ROSA-SINENSIS, Linn.

Introduced.

(7) SIDA CARPINIFOLIA.

TILIACEÆ.

(8) TRIUMFETTA PROCUMBENS, Forst.

LEGUMINOSÆ.

(9) ACACIA FARNESIANA.

Distribution: Timor, &c.

(10) POINCIANA PULCHERRIMA, Linn.

Introduced.

(11) GUIELANDINA BUNDOC, Ait.

Native name, *Klenchi.*

Distribution: Timor.

ROSACEÆ.

(12) ERIOBOTRYA, sp.

Cultivated.

(13) ROSA CENTIFOLIA, Linn.

Cultivated.

NATIVES CLEARING AWAY THE GROWTH OF *KLENCHI* (*GUIELANDINA BUNDOC*) ON PULU TIKUS.

MYRTACEÆ.

(14) BARRINGTONIA RACEMOSA, Blume.

Native name, *Jambu basagi.*
Distribution : Malaya and Polynesia.

LYTHRACEÆ.

(15) PEMPHIS ACIDULA, Forst.

Native name, *Kayu burung.*
Distribution : Tropical coasts of Old World.

PAPAYACEÆ.

(16) CARICA PAPAYA, Linn.

Native name, *Katis.* Useful fruit.

CRASSALACEÆ.

(17) BRYOPHYLLUM CALCINUM, Salisb.

PORTULACEÆ.

(18) PORTULACA OLERACEA, Linn.

Distribution : Timor and Lombok.

RUBIACEÆ.

(19) GUIETTARDA SPECIOSA, Linn.

Native name, *Melati.* Tree with sweet-scented flowers: used by women to decorate their hair.
Distribution : Tropical shores of Old World.

(20) MORINDA CITRIFOLIA, Linn.

Native name, *M'ngkudu.* A useful dye bark.
Distribution: India, Australia, Polynesia, Malay Archipelago.

Compositæ.

(21) Ageratum conyzoides, Cass.
Distribution: All hot countries.

(22) Sonchus oleraceus, Linn.
Distribution: Java, Sumbawa, &c.

Apocynaceæ.

(23) Vinca rosea, Linn.

(24) Orchrosia parviflora, Hensl.

Goodenovieæ.

(25) Scævola Königii, Vahl.
Native name, *Kembang kangkong*.
Distribution: Tropical East Asia, Australia, Polynesia.

Sapotaceæ.

(26) Sideroxylon sundaicum, Burch.
Native name, *Saoh*. A useful fruit.
Distribution: Sunda Islands.

Asclepiadiaceæ.

(27) Asclepias curassavica, Linn.
Native name, *Ujan mas*.
Distribution: Java, &c.

Bignoniaceæ.

(28) Oroxylum indicum, Vent.
Cultivated.

Boragineæ.

(29) Cordia subcordata, Lam.

Native name, *Grongang*. A useful hard wood used for boat-building.

Distribution: S.E. Asia, Australia, Sandwich Islands, Tropical Africa.

(30) Tournefortia argentia, Linn.

Distribution: Ceylon, Australia, Malaya, Mauritius.

Convolvulaceæ.

(31) Ipomœa pes-capræ, Roth.

Distribution: Tropical sea-shores.

(32) Ipomœa grandiflora, Lam.

Distribution: Widely spread in tropics.

Solanaceæ.

(33) Physalis peruviana, Linn.

(34) Physalis alkekengi.

Acanthaceæ.

(35) Asystasia coromandeliana, Nees.

Distribution: India, Malaya, Africa, Arabia.

(36) Dicliptera Burmanni, Nees.

Distribution: Java, Timor, &c.

Labiatæ.

(37) Leonurus sibiricus, Linn.

Verbenaceæ.

(38) Stachytarpheta indica, Linn.

Distribution: Tropical Asia.

Nyctagineæ.

(39) Pisonia grandis.

Native name, *Ampol.*
Distribution: North Australia, Polynesia.

(40) Pisonia excelsa, Bl.

Native name, *Jambu.* A useful fruit.
Distribution: Malay Islands.

(41) Boerhavia diffusa, W., var.

Amarantaceæ.

(42) Amarantus schoflexus.

(43) Achyranthes argentea, Lam., var. villosior.

Laurineæ.

(44) Hernandia peltata, Meissn.

Native name, *K'mador.* A tall forest tree of which not many specimens exist.
Distribution: India, Malaya, Polynesia.

Euphorbiaceæ.

(45) Euphorbia pilulifera, Linn.

Native name, *Cheplok.* Produces an edible berry used in the islands.
Distribution: Tropics and sub-tropics.

(46) Acalypha indica.

(47) Ricinus communis, Linn.

(48) Aleurites moluccana.

Urticaceæ.

(49) Urera gaudichandiana, Hensl.

MONOCOTYLEDONS.

Gramineæ.

(50) Panicum sanguinale, Linn., var.
Distribution: Timor, &c.

(51) Stenotaphrum lepturoide, Hensl.

(52) Lepturus repens, Forst.
Distribution: Timor, &c.

(53) Eragrostis amabilis, Linn.
Distribution: Timor, &c.

(54) Fimbristylus glomeratus, Nees.

Palmaceæ.

(55) Cocos nucifera.

Native name, *Klapa*. Exists in many varieties.

A great number of useful articles are made from the coconut palm and its products, and in the atoll full advantage is taken of all the many uses to which the nuts can be put.

From the husk of the nut (*sabût*) fibre is taken, but in the atoll no coir is manufactured, and the husks are used to spread on the ground and assist in building up the superficial layer of vegetable soil. The shell of the nut is used for fuel, and water-vessels (*batok*) and ladles (*gayong*) are skilfully made from cleaned nuts. From the flesh of the nut itself the *copra* is prepared by simple sun-drying, and the *copra* is used in the preparation of all the grades of coconut oil (*minyah klapa*). Soap (*sabon*) is also made from the oil by admixture of the ashes of burned husks.

The grated nut (*ampas*) is used for a variety of culinary processes, and the expressed juice is used as a very nutritive drink (*santan*).

The nut that has already begun to sprout, or is soon about to do so, provides another excellent article of diet (*tombong*), which consists of a sponge-like mass that occupies the whole of the interior of the mature nut.

An alcoholic drink (*twak*) is prepared from the juice of the wounded spathe (*manchong*), and when the *twak* has turned sour it makes an excellent vinegar (*chukak klapa*).

The central shoot of the palm, while still white and brittle (*umbût*), makes good salad and an extremely pleasant pickle.

The palm itself furnishes the materials for many domestic purposes. Baskets (*kroso*) are made from its interlaced leaves; thatch (*atap*) for house roofs is prepared by tying the leaves into bundles, and the midrib of the leaf (*plĕpa*) when split makes the well-known house wall called *dinding*. The wood of the trunk is used at times for certain parts of houses, and the central wood (*nibong*), which is stronger and tougher than the outer parts, makes useful walking-sticks.

Pandanaceæ.

(56) Pandanus, sp. Though not observed by Darwin or Forbes, is now very abundant on Pulu Selma and the larger Southern islands—one island being actually named Pulu Pandan.

The fibre of the leaves is used to make matting and basket-work.

Musci.

(57) Hypnum rufescens, Hook.

Funagi.

(58) Polyporus luridus.

(59) Marasmius, sp.

(60) Panus connatus, Berk.? This fungus grows generally upon the *ampol* tree, and is good to eat.

(61) Hirneola auriculæ-Judæ, Berk.

Distribution: Europe, W. America, Mexico, Cuba, Tasmania, Borneo, and Christmas Island.

(62) Auricularia mesenterica, Fries.

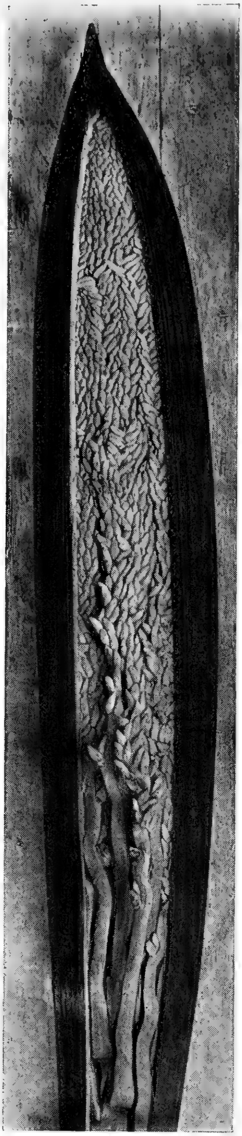
(63) Lenzites nivea, Cooke.

(64) Polystichus rigens, Sacc et Cub.

(65) Poria homæma, Sacc.

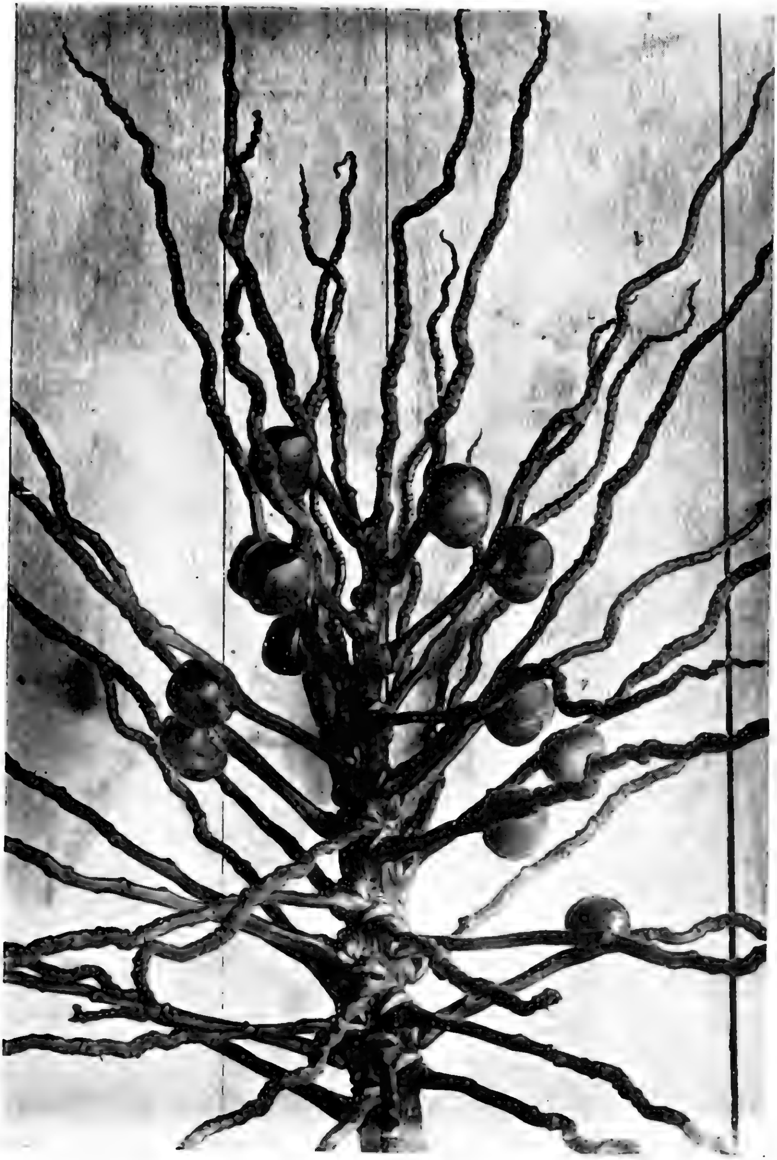
(66) Stereum, sp.

PLATE XXIII.

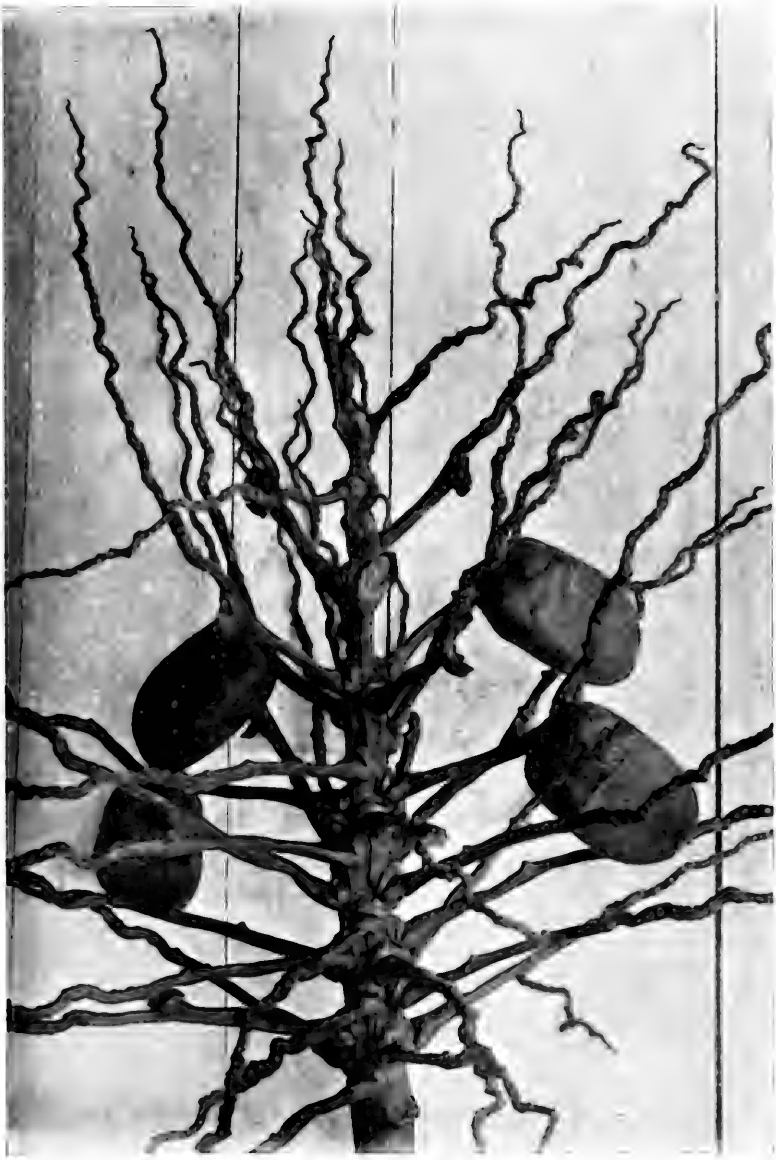


THE SPATHE OF THE COCONUT PALM.

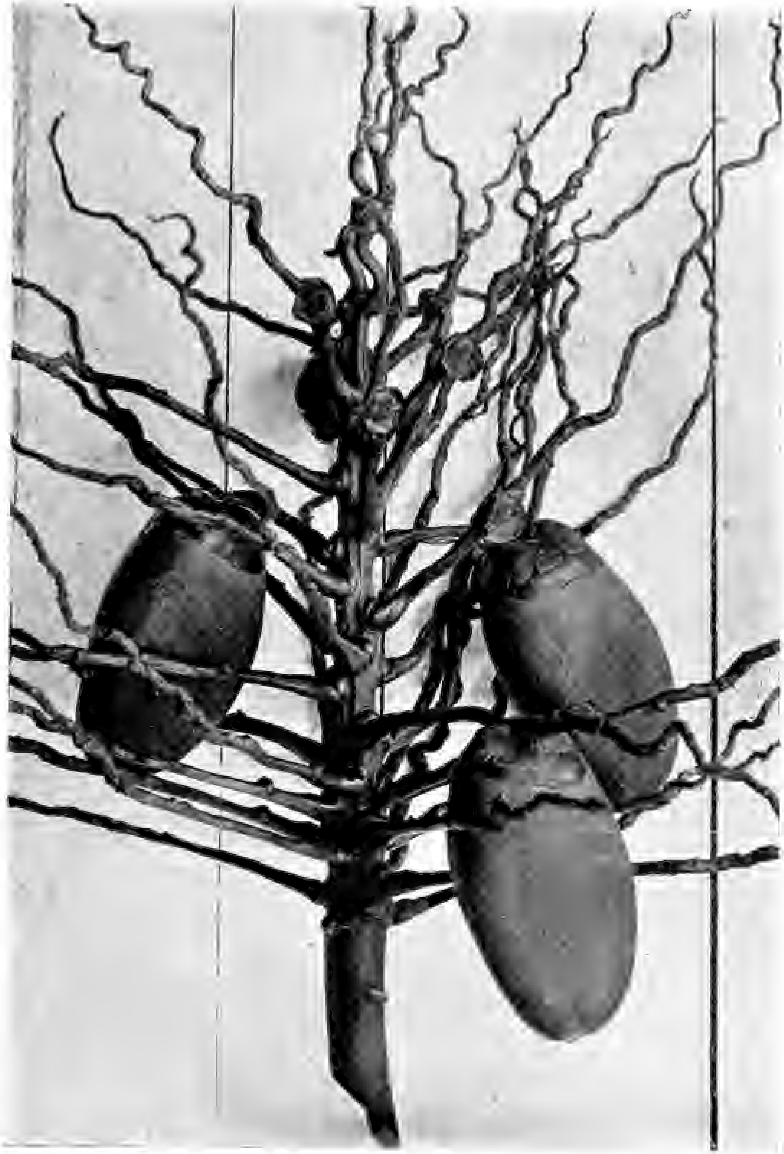
THE FLOWER SPIKE OF THE COCONUT PALM AFTER THE SPATHE HAS BEEN OPENED. SOME NUTS ARE ALREADY FORMED ON THE BASES OF THE STEMS. THIS STAGE IS CALLED *MANGGAR.*



YOUNG NUTS DEVELOPING ON THE FLOWERING STEMS WHEN THE INFERTILE FLOWERS HAVE BEEN SHED. WHEN IN THIS STAGE THE NUT IS KNOWN BY THE NATIVE NAME OF *BLÛLÛK.*



YOUNG COCONUTS IN THE STAGE IN WHICH THE CONTAINED NUT IS BEGINNING TO BECOME HOLLOWED—STAGE CALLED *KLAPA CHINKER.*



GREEN COCONUTS IN THE STAGE IN WHICH BOTH HUSK AND NUT MAY BE CUT WITH A KNIFE, AND THE CAVITY OF THE NUT ALREADY CONTAINS "MILK," *KLAPA MUDA.*

BIBLIOGRAPHY OF SOME OF THE MORE IMPORTANT WORKS REFERRED TO IN THE TEXT

(A) Relating to Cocos-Keeling and the Clunies-Ross Family.

1. Clifford, Hugh, "Heroes of Exile: The Romance of a Scots Family." London, 1906.

2. Darwin, "A Naturalist's Voyage Round the World," chapter xx.

3. Denys, "A Dictionary of British Malaya," article on Cocos-Keeling.

4. Guppy, Dr. H. B., "The Cocos-Keeling Islands," *Scottish Geographical Magazine*, vol. v., 1889, Nos. 6, 9, and 11.

5. Forbes, Dr. H. O., "A Naturalist's Wanderings in the Eastern Archipelago." London, 1885.

6. Straits Settlements: Papers relating to Cocos-Keeling and Christmas Islands, 1897 ("Parliamentary Papers," C. 8367), and

7. "Colonial Reports" annuals since 1897.

(B) Relating to Neighbouring Coral Islands in the Indian Ocean.

8. Alcock, A., "A Naturalist in Indian Seas." London, 1902.

9. Andrews, Dr. C. W., "A Monograph of Christmas Island." British Museum publication. 1900.

10. Andrews, Dr. C. W., *Proc. Zool. Soc.*, 1909, p. 101.

11. Hickson, Prof. S. J., "A Naturalist in North Celebes." London, 1889.

12. Wallace, A. R., "The Malay Archipelago." London, 1869.

(C) Relating to the Coral Problem—The Rate of Growth.

13. Dana, "Corals and Coral Islands," 1875, p. 96 *et seq.*

14. Darwin, "On the Structure and Distribution of Coral Reefs," p. 96 *et seq.*

15. Gardiner, S., "The Maldives and Laccadives," 1903, vol. i, Part III. p. 327.

16. Wood Jones, F., "The Rate of Growth of the Reef-building Corals." London, 1908.

(D) Relating to the Variability of Coral Species.

17. Duerden, J. E., *National Academy of Sciences*, vol. viii. 7th Memoir. Washington.

18. Hickson, Prof. S. J., "On Millepora," *Proc. Zool. Soc.*, April 1898.

19. Hickson, Prof. S. J., *Proc. Zool. Soc.*, Nov. 1898, and other papers by the same author.

(E) Relating to Atolls and Atoll Formation.

20. Agassiz, A., Memoirs, *American Academy of Arts and Sciences*, vol. xi. Part II. No. 1, 1885, p. 107.

21. Agassiz, A., *Bull. Mus. Compar. Zool. Harvard*, vol. xiv., 1888.

22. Agassiz, A., *Roy. Soc.*, 1903. *Nature*, 1903, p. 547.

23. Basset-Smith, *Ann. and Mag. Nat. Hist.*, 1890, p. 353.

24. Bourne, G., "Atoll of Diego Garcia," *Proc. Roy. Soc.*, 1888.

25. British Association, "Discussion on Coral Reefs," 1893.

26. Dana, "Corals and Coral Islands," 1875.

27. Darwin, "On the Structure and Distribution of Coral Reefs."

28. "Funafuti, the Atoll of," *Roy. Soc.*, 1904. Professors Judd, Solas, David, Sweet, Sorby, &c.

29. Gardiner, S., "The Fauna and Geography of the Maldive and Laccadive Archipelagoes," vol. i. Part III., 1902.

30. Gardiner, S., *Nature*, 1904, p. 371.

31. Guppy, Dr. H. B., "Coral Reefs of the Solomon Islands," *Proc. Roy. Soc. Edin.*, July 1886, p. 857.

32. Guppy, Dr. H. B., *Proc. Linn. Soc. N.S.W.*, 1884, vol. ix. Part 4.

33. Guppy, Dr. H. B., various short articles in *Nature*, 1888, &c.

34. Hedley, C., "Coral Reefs of the Great Barrier Reef." 1907.

35. Hedley, C., "The Broadening of Atoll-Islets," *Nat. Science*, vol. xii. No. 73, 1898, p. 174.

36. Hedley, C., *Nature*, August 4, 1904, p. 319, and other papers.

37. Langenbeck, Dr. Von R., *Die Theoriem über die Entstehung der Koralleninseln und Korallenriffe und ihre Bedeutung für Geophysische Fragen*. 1890.

38. Ledenfeld, R. Von, see *Nature*, May 8, 1890.

39. Mann, W., *Korallen und andere gefteinsbildende Tiere*. 1909.

40. Murray, Sir John, "The Structure and Origin of Coral Reefs and Islands," *Proc. Roy. Soc. Edin.*, April 5, 1880.

41. Murray, Sir John, and Irvine, *Nature*, June 12, 1890.

42. Reade, T. Mellard, *Nature*, March 22, 1888.

43. Semper, Prof., "Animal Life." English trans. International Scientific Series, vol. xxi.

44. Wharton, Admiral Sir J. A., *Nature*, June 19, 1890.

45. Wharton, Admiral Sir J. A., *Nature*, Feb. 23, 1888.

INDEX

Abbott's booby, 300, 343
Abu bunchahan, 54
Agar-agar, 122
Agassiz, Prof. A., Darwin's letters to, 217
  on formation of submarine banks, 225
  on volcanic basis of atolls, 216
Age of coral zooids, 105
Alcyonaceæ, 58
Aldrich, Captain, visit to Christmas Island, 42
Alexander Clunies, 7
Algæ, effects of, on coral growth, 113, 122, 125, 194
  effects of, on silting of lagoon, 194
  growth of, in lagoon, 189
Andrew Ross, 38, 42, 286
Annexation of islands to Ceylon, 37
  to Great Britain, 28
  to the Straits Settlements, 40
Ants, 306, 355
Asexual reproduction of corals, 71
Atoll, description of, 135
Atollons, formation of, 269
Atolls, "miniature," in lagoon, 252
Australia, cable route to, 147
Australian horse ships, visits of, 24
Ayesha, wife of George Clunies-Ross, 44

Banchahan, 54
Bands, effects of, when placed round coral branches, 115
Banks, submarine, 221
Baracouta, 322, 347
Barometric readings, 208
Barrier, formation of, 253
  outer edge of, 155
  slope of, 156
  structure of, 151
  windward, 163
Barrier pools, coral growth in, 91 124
Barrier reefs, formation of, 278
Basin-shaped reefs, 251
Basset-Smith on bathymetrical range of corals, 239
  on deep-water corals, 245
Bathymetrical limits of corals, 239
  caused by sedimentation, 242
Bats, 312, 337
Batu Dua, 195
Batu Satu, 195
Beaches, lagoon, 172
  seaward, 168
Beagle, visit of, to atoll, 20
  voyage of, 216
Bêche-de-mer, 330
  as sand-producers, 165
Beetles, 306, 357
Best man, at wedding ceremony, 52
Betrothal, formalities of, 49
Bibliography, 381
Birch, Mr. E. W., visit to atoll, 37
Birds, introduced, 299
  species of, 338
  tameness of, 300
Birgus latro, 316, 368
Birth, customs connected with, 46
Blora, visit of, to atoll, 16

Boat-building in Cocos-Keeling, 38
Booby bird, 300, 343
Boring animals, effects of, on corals, 126
Borneo, Ross's ship, 12
Bottles used to determine currents, 293
Bourne, G. C., on currents, 232
Breccia, formation of, 254
  in lagoon, 173
  sites of formation of, 161
Breccia platform, definition of, 154
  evidences afforded by, 279
  raising of, 282
Brekat, 53
Bridegroom, costume of, 50
British Christmas Island Phosphate Co., 43
Broadening of reefs, 277
Buchanan, J. Y., on deep-water corals, 245
Buntal (fish), 328, 347
Burial customs, 54
Burung chinta (*Zosterops natalis*), 299, 344
Burung glatek (Java sparrow), 299, 344
Butterflies, species of, 349
Button Islands, 262

Cable ships, soundings made by, 145
Cable, submarine, 44
Calappa hepatica, 318, 368
Calm water, influence on coral growth, 90
Calms, in region of atolls, 209
Capel, Admiral, visit of, 8
Cardiosoma, 176, 178, 315, 368
Carpophaga Whartoni, 43, 299, 338
Cats, introduction of, 298
Centipedes, 305, 367
Ceremonies connected with marriage, 50
Challenger, voyage of, 227
Chamisso on atolls, 232
Changes in ideas regarding atolls, 214
  of lagoon shores, 198
  of ocean-level, 199
  periodic, in atoll-building, 169
Charts, early, 5
Chinese blood in natives, 21
Christmas Island, settlement of, 41
Cilia of coral embryos, 64
Circumcision, rite of, 48
Climate of atoll, 201
Clouds over atolls, 204, 211
Cockroaches, 306, 364
Coconut, introduction of, 17
  uses of, 377
Coconut oil, 35
Cœnopsammia, 85
Coleoptera, species of, 357
Colonising routes for fauna, 288
Coloration of corals, 93, 96
  of fish, 327
Comet, H.M.S., visit of, 16
Commerce as distributer of fauna, 302
Conglomerate of beaches, 175
Corallites, form of, 76
  in rough-water types, 90
Corallum, alteration of, in repair, 118
Corals, growth of, in lagoon, 190
  living, 57
Corynetes rufipes, 306, 358
Crabs as producers of vegetable soil, 178, 269
  species of, 314, 367
Crescent shape of islets, 177
Crickets, 306, 365
Crocodiles, 295
Crustacea, species of, 367
Currents, alteration of, 163
  as carriers of fauna and flora, 293
  in lagoon entrance, 198
Currents, oceanic, rate of, 295
Cyclone of 1862, 29

Cyclone of 1876, 35
Cyclones, 205

Dana on "Subsidence," 234
Darkness, corals active during, 241
Darwin on atoll formation, 216
 on fauna, 287
 visit of, 20, 137
Dead corals in lagoon, 193
Death, ceremonies connected with, 54
Death-processes in corals, 121
Deep water, influence on corals, 92
Deep-water corals, pigmentation of, 97
Deer, introduction of, 297, 337
Deformities, superstition regarding, 46
Demiegretta sacra, 313, 342
Dermestes felinus, 306, 358
Desertion of Hare's followers, 18
Destruction of corals in lagoon, 122, 192
Devil-fish, 323
Dew, absence of, 211
Dicerobatis eregoodoo, 323, 347
Dicotyledons, species of, 371
Diptera, species of, 356
Discovery of the islands, 3
Distribution of corals, 68
 in the atoll, 157
Doldrums, 201
Domestic fowls, feral, 300
Dominant apical zooid, 82
Dragonflies, 205, 307, 363
Dredging corals, 191
"Drowned atolls," 230
Duerden, J. E., on coral embryos, 63, 67
 on nocturnal habits of corals, 241
Dutch navigators, visits of, 24
Dymoke, Elizabeth, 13
Dymoke Shoal, 195

Earth, carried on tree-trunks, 290
 disappearance of, on coral *débris*, 180
Earthworms, 179, 369
Eels, 329
Egeria, H.M.S., visit to Christmas Island, 42
Embryos of corals, 63
Environment, changes of, 116
 influence of, on corals, 79, 84
Espoir, H.M.S., visit of, 37, 40
Evil spirits as a cause of infantile death, 47
Experiments on change of environment, 123
Exposure of corals above tide-level, 127

Fallacies of Gardiner's theories, 224
 of Murray's theory, 226
Fauna of the atoll, 286, 335
Feasts, ceremonial, 53
Feeding of corals, 241
Fiddler crabs, 176, 315
Fish eating coral, 130
 of the atoll, 319
 species of, 347
Fish-shooting on the barrier, 325
Fitzroy, Admiral, soundings by, 145
Fixation of coral larvæ, 68
Flat-topped *Porites* colonies, 247
Flies, species of, 356
Flinders on atoll formation, 213
Floating corals, 171, 291
 islands, 288
Flora, list of, 371
 of the group, 286
Forbes, Dr. H. O., on fauna, 287
 on lagoon, 192
 visit of, 36, 137
Foul water, influence on corals, 122
Fremantle, Captain, visit of, 28
Fresh water, presence of, 183
Freshening of salt water, 129
Frigate birds, 300, 342

Fringing reefs, formation of, 279
Fruit pigeon, 299, 338
Funafuti atoll, investigation of, 234
Funerals in the atoll, 55
Fungi, list of species of, 378
of the islands, 295
Fungia, observations on, 243

GARDEN, arrival of insects in, 310
Gardiner, S., on atoll formation, 222
on bathymetrical limits of corals, 241
on *Lithothamnionidæ*, 157
on "reversed atolls," 272
Gecarcoidea lalandei, 316, 368
Geckos, 307, 345
Gelasimus, 176, 315, 368
George Clunies-Ross, 32
Glendinning Shoal, 149
Globigerina ooze, 149
Governor, appointment of Ross II., 29
appointment of Ross III., 34
Gradient of submarine slope, 150
Graham's Island, destruction of, 225
Grass, influence of, on reclamation of land, 177, 187
Graves in Cocos-Keeling, 55
Green fish, 324, 347
Ground thrush, 299, 344
Growth forms of corals, 71
Guppy, Dr., references to work of, 3, 137, 150, 157, 171, 177, 192, 208, 225, 278
Gygis candida, 339

HAGUE, J. H., on Jarvis Island, 210
Hair, superstitions regarding, 55
Hare, Alexander, 10
Hare, John, 12
Hedley, C., on Great Barrier Reef, 235
Height of island-building, 263
Hermit crabs, 317
Hesse, Mr. F., 145
Hickson, Prof. S., on currents, 233
Hippomenes, 14
Histiophorus gladius, 322, 347
Holothurians as sand-producers, 165, 265
Homoptera, species of, 362
Horsburgh, 4
Horseshoe islands, 269
Hymenoptera, species of, 355

ININ, wife of Ross III., 34
death of, 44
Insects flying out to sea, 309
Introduced fauna, 297
Islands, growth of, 259
origin of, 257
structure of, 176
"Itchy corals," 133

J. G. C.-Ross, ship, 37
loss of, 39
Jampei, 55
Jarvis Island, 210
Java, cable route to, 148
Java sparrow, 299, 344
Jelly-fish, 331
Jetsam of reef, 290
John Clunies-Ross, 8
John George Clunies-Ross, 27
Juno, H.M.S., visit of, 28

KAKATUA, 130, 164, 264, 325
Kapeting, 176, 178, 315, 367
Karang gatal, 133
Keeling, Captain William, 3
Keeling Island, 141
development of, 271
Keyser, Mr. A., visit of, 129
Krakatua, eruption of, 290
pumice from, 170
Kramer on atolls, 236
Kunyet, 50

LADDS, Captain, 136
Lagoon, beaches of, 172
description of, 185
silting of, 186

Lagoonlets of atoll islands, 176
Land crabs, 316
movements, 279
Larval forms of corals, 63
Le Conte on barrier reefs, 278
Legal code of Cocos-Keeling, 30
Legend concerning spirit voices, 285
Leisk, 22
Lendenfeld, R. von, on solution theory, 228
Lepidoptera, species of, 349
Leptograpsus, crabs of genus, 318
Level of ocean, variations of, 199
Lifeless areas of lagoon, 193
Light, influence on bathymetrical range of corals, 241
Lime, coral turned into, 191
"Limiting line of sedimentation," 238
Lithothamnionidæ, 157, 270
Littoral fauna, 314
Living corals, study of, 135
Lowness of islets, 139, 182
Luigi Raffo, ship, 39

Maclear Deep, 148
Madrepora, repair of damage in, 111
Maniciana, embryos of, 67
Marine fauna, 314
Marriages, 49
Mas kawen, 49
Meandrine fission, 119, 74
Measurements of growing corals, 69
Melia tessellata, 319
Merula erythropleura, 299, 344
Meteorological records, 201
Mice, 305, 337
Migrant birds, 301
Milleporæ, 132, 179
Mollusca, boring in corals, 110, 126
species of, 348
Monkey, arrival of, in atoll, 298
Monocotyledons, species of, 377
Montipora, repair of damage in, 118
Mosquitoes, 357
breeding in salt water, 303
Moths, species of, 350
Motile coral larvæ, 64
Mourning customs, 56
Murray, Sir John, 150, 221
Mus Macleari, 43
Musical rocks, 285

Name, customs of change of, 48
Native customs, 45
rising, 33
Negro element in natives, 21
"Negro heads," 284
Neh Basir, 20
Neuroptera, species of, 363
Nocturnal habits of corals, 241
Northerly winds, 204
Northern part of lagoon, 195
Nubia, sand formation in, 267
Nulliporæ, importance of, 156

Object of original settlement, 15
Observations on living corals, 60
Obstruction to currents, influence of, 257
Ocean bottom, 149
level, alterations of, 199, 282
Octopuses, 331
Ocypoda, crabs of genus, 314
Ooze, deposition on ocean bottom, 221
Ophichthys colubrinus, 329
Orbulina ooze, 149
Origin of fauna, 313
of marriage ceremonies, 51
Original settlement, 14
Orthoptera, species of, 364
Outer edge of barrier, 160
Outward growth of atolls, 277
of reefs, 263

Papaun blood in natives, 21
Pareh, 323, 347

Pergám, 43, 299, 338
Petition of Ross I., 23
Philippine land-rail, 312, 338
Phosphates, formation of, 210, 180
in Christmas Island, 42
Physalia, 331
Piazza, Captain, 294
Pig-fish, 327, 347
Pigs, introduction of, 297
Plapen, Catherine, 8
Plate forms of coral growth, 80, 86
Pocillopora, colonies on floating log, 100
Poisoning of lagoon corals, 192
Poisonous fish, 328
Porites colonies as miniature atolls, 247
manner of growth, 106
Portuguese man-o'-war, 331
Prevalent winds, 202
Problems involved in atoll-building, 217
Pulu Atas, settlement of, 19
Pulu Bras, Hare's residence on, 19
Pulu Selma, settlement of, 19
Pumice, 170, 290

QUEENSLAND bean, cast up on beaches, 296
Question of basis on which atolls are built, 217

RABBITS, introduction of, 297
Radiolarian ooze, 150
Raffles, Sir Stamford, 10
Rain from cloudless sky, 206
influence on corals, 129
Rain-clouds, splitting of, 210
Rainfall, influence of, 180
of atoll, 206
Raised beaches, evidences of, 283
Rapid growth of corals, 196
Rate of growth of corals, 69
Rats, black, 305, 337
damage done by, 304
description of, 335
Rats, introduction of, 303
Raymond, Joseph, 22
Reade, T. Mellard, 229
Reefs, formation of, 245
Religion of islanders, 45
Reproduction of corals, 61
Reptilia, species of, 345
Resins, cast on beaches, 171
"Reversed atolls," production of, 271
Rhynchota, species of, 360
Robber crab, 316
Robert Portner, wreck of, 304
Rock cod, 329
Rocks cast on barrier, 284
producing sounds, 285
Rodriquez, cable route to, 148
Ross I., death of, 25
Ross II., death of, 31
Rough water, influence on corals, 86
Rujak, 50

SAMBAR, deer, 297, 337
fish, 322, 347
Sand flats, 186
influence of, in lagoon, 188
influence of, on land formation, 264
islands, 181
produced by fish, 164
Sand-banks, development of, 257
Sandstone, beach formation, 175
Scari as sand-producers, 164, 264
habits of, 130
Scorpions, 305, 366
Sea-level, alterations of, 199
Sea-slugs as sand-producers, 165
Sediment, deposition in lagoon, 226, 228
effects of, on corals, 123, 136
effects of, on type of growth, 94
Sedimentation banks, 238
in open ocean, 237
influence on corals and reefs, 249

Seeds cast up by waves, 171, 296
Semper, Prof., Darwin's letters to, 217
    on "Subsidence," 234
Serpent, H.M.S., visit of, 29
Settlers, original, 16
Sharks, 320, 347
Sheep, introduction of, 297
Ships as carriers of fauna, 296
    fauna of, 302
    insects flying aboard, 311
Shoaling of lagoon, 187, 275
Shores of lagoon, 172
Showers, influence of, 183
Silt cast off by corals, 243
    effects of, on corals, 123, 189
Silting of lagoon, 125
S'kada bumi, 53
Slamatan, 53
Slope of lagoon reef, 197
Slopes, submarine, 150
Slowness of coral growth, 193
Snakes, arrival of, in atoll, 295
Solitary corals, 59
    repair of, 104
Solution, theory of, 222
Somaliland, currents to, 294
Soundings of Indian Ocean, 145
Spawning of corals, 62
Specific distinctions of corals, 83
Specific gravity of sea-water, 129
Spherical growth of corals, 72
S'pia Dupong, wife of Ross II., 31
Spicer, Rev. E. C., visit of, 215
Spiders, 306, 366
Spirits, belief in, 45
    offerings to, 53
Stinging corals, 133
Stones carried on floating logs, 290
Storms, influence of, 261, 263, 283
Submarine basis of atoll, 144
    slope of atoll, 146
Subsidence, absence of signs of, 280
    theory of, 216, 218
Surf, influence of, on corals, 158
Sword-fish, 322, 347
Symmetrical zooids, 82
Sympathy between zooids, 106

Talbot, Mr. A. P., visit of, 40
Talus slopes, extension of, 277
Tameness of birds, 300
Telegraph ships, soundings by, 145
    station, 44
Temperature of islands, 207
    of lagoon, 200
Tendencies of coral growth, 86
Tern, the white, 339
Tetradonts, 327, 347
Theories of atoll formation, 212
Thunder and lightning, 211
Ticks left by sheep, 297
Tide excursion, influence on height of islands, 262
    variation of, 199
Tomboro, eruption of, 291
Tombstones, form of, 55
Trade winds, 201
    influence on atoll form, 256
Tree-trunks, floating, 289
Triangular islands, 4, 138
Turk Reef, 195
Types of coral growth, alterations of, 115
    distribution of, 158
    in lagoon, 191
Typhlops braminus, 290, 346

Udung darat, 316
"Undecided" forms of corals, 131
Unreliability of signs of change in atolls, 199
Upward land movements, 281

Vanderwadl, 11
Variability of corals, 101
Vegetable soil, 179
Vegetation, influence of, on land formation, 267
    of islands, 179, 371
    of lagoonlets, 177

Vegetative forms of corals, 71
Volcanic origin of atolls, 215

Water-borne flora and fauna, 288
Waves as sand-producers, 166
  depth at which felt, 238
  force of, 170
Wedding ceremonies, 49
Wells of fresh water, 182, 210
Westerly winds, effects of, 196, 198
Wet days, 207
Whalers, visits of, 22
Wharton, Admiral, on soundings, 144
  on submarine banks, 225
White tern, 339
Wilson on coral larvæ, 67
Wind, influence on land formation, 180, 261, 266
  prevalent, 202
Wind-borne fauna, 307
Worms, boring in corals, 110
Wreck of ship *Robert Portner*, 304
Wrecking of settlement, 36
Writings of Ross I., 24

Zephyr, H.M.S., visit of, 37, 40
Zoantharia, 58
Zooanthellæ in coral larvæ, 66
Zooid, "dominant," 82
Zooids, methods of division of, 71
Zosterops natalis, 299, 344

Printed by Ballantyne & Co. Limited
Tavistock Street, Covent Garden, London