ATOLL RESEARCH BULLETIN

No. 88

Coral Islands

by

Charles Darwin

with Introduction, map and remarks

by D. R. Stoddart

Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences--National Research Council

Washington, D. C.

December 15, 1962

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Introduction

Charles Darwin, writing in his Autobiography towards the end of his life, looked back to some of his earliest scientific work associated with the voyage of the Beagle, and was able to"reflect with high satisfaction" on "solving the problem of coral-islands."[1] During the Beagle expedition Darwin had crossed the Pacific Ocean, calling at Tahiti, and then the Indian Ocean, making his famous observations at Cocos-Keeling Island, and on his return home he had given a number of papers to the Geological Society of London. Among them was one announcing his theory of coral reefs, "On certain areas of elevation and subsidence in the Pacific and Indian Oceans, as deduced from the study of coral formations," in which he outlined the scheme whereby fringing reefs were converted into barrier reefs and then into atolls by slow subsidence of the island-foundation. This was the first public announcement of the theory, and it met with a favourable response, especially from Lyell.[2] The substance of this paper was embodied, and greatly extended, in the Journal and Researches 1832-1836, published in 1839 to accompany the official account of the voyage by FitzRoy, and Darwin's ideas were given definitive treatment in the first edition of The structure and distribution of Coral Reefs, published in London in 1842.[3]

In his Autobiography, Darwin has this to say about the formulation of his theory:

> "No other work of mine was begun in so deductive a spirit as this; for the whole theory was thought out on the west coast of S. America before I had seen a true coral reef. I had therefore only to verify and extend my views by a careful examination of living reefs. But it should be observed that I had during the two previous years been incessantly attending to the effects on the shores of S. America of the intermittent elevation of the land, together with the denudation and the deposition of sediment. This necessarily led me to reflect much on the effects of subsidence, and it was easy to replace in imagination the continued deposition of sediment by the upward growth of coral. To do this was to form my theory of the formation of barrier-reefs and atolls."[4]

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[1] All notes pertaining to the Introduction are to be found on p. 4.

The Beagle had been working on the west coast of South America in the earlier part of 1835, and it would therefore be of interest to know when and in what form Darwin first expressed his ideas. In the original Diary of the voyage, he describes the effect of the sight of the reef-encircled Eimeo (Moorea), as seen from Tahiti on 17th November 1835, and on 12th April 1836, in his description of Cocos-Keeling, he plunges into his theory without further ado (this passage was much extended when the Diary was rewritten for publication as Journal and Researches):

> "If the opinion that the rock-making Polypi continue to build upwards as the foundation of the Isd from volcanic agency, after intervals, gradually subsides, is granted to be true; then probably the Coral limestone must be of great thickness. We see certain Isds in the Pacifick, such as Tahiti & Eimeo, mentioned in this journal, which are encircled by a Coral reef separated from the shore by channels & basins of still water. Various causes tend to check the growth of the most efficient kinds of corals in these situations. Hence if we imagine such an Island, after long successive intervals to subside a few feet, in a manner similar, but with a movement opposite to the continent of S. America; the coral would be continued upwards, rising from the foundation of the encircling reef. In time the central land would sink beneath the level of the sea & disappear, but the coral would have completed its circular wall. Should we not then have a lagoon Island? - Under this view, we must look at a Lagoon Island as a monument raised by myriads of tiny architects, to mark the spot where a former land lies buried in the depths of the ocean ..."[5]

The theory was therefore by this time fairly well thought out, and in a letter to his sister, Caroline Darwin, sent from Port Louis, Mauritius, on 29th April 1836, Darwin explained that "The subject of coral formation has for the last half year been a point of particular interest to me. I hope to be able to put some of the facts in a more simple and corrected point of view, than that in which they have hitherto been considered."[6]

Hence, from about November 1835, Darwin had been seriously exercised on the coral reef problem. It was on the 9th November that he first caught sight of "Lagoon Islands" as he called them, in the Low or Dangerous (Tuamotu) Archipelago, and on the 15th he arrived in Tahiti. There he stayed until 3rd December, when the Beagle sailed for New Zealand, arriving on the 21st, and then for Australia. He left Australia on 14th March for Cocos-Keeling, where he spent eleven days in early April, and made his way home by South Africa and South America.

Among the Darwin papers preserved in the University Library at Cambridge, there are two items entitled Coral Islands, one in Darwin's own hand, the other a fair copy with corrections in Darwin's hand. The first is clearly dated 1835, and it includes in the course of the exposition, an account of Darwin's view of Moorea from Tahiti recounted in the Diary for 17th November 1835.[7] There is no mention of the Cocos-Keeling Island. It thus seems very probable that Darwin wrote this outline on the voyage between Tahiti and New Zealand (3rd-21st December 1835), and it

is therefore at least three months earlier, and much longer, than the Diary entry for 12th April 1836, given above.

The original is written on sheets of unlined paper 15.6 x 10.15 inches, folded once to give pages of 7.8 x 10.15 inches. There are twelve such 'sheets' of four pages, and generally the text is written on pages 1 and 3, with the notes to each page of text either on the verso, or in the case of page 3, occasionally opposite on p. 2. In the twelfth sheet, page 4 is also devoted to text. Each page of text, apart from the first, is headed "1835. Coral Islands" and the text-page number. The note-pages are not numbered, and can be referred to as [1a], [2a] ... The detailed composition is as follows:

Sheet 1	Page	1	Text	[1a]	Notes	2	Text	[2a]	Notes
2		3	Text	[3a]	Notes	4	Text	[4a]	-
3		5	Text	[5a]	-	6	Text	[6a]	-
4		7	Text	[7a]	-	8	Text	[8a]	-
5		9	Text	[9a]	Notes	10	Text	[10a]	-
6		11	Text	[11a]	Notes	12	Text	[12a]	Notes
7		13	Text	[13a]	Notes	14	Text	[14a]	-
8		X15	Text	[X15a]	Notes	X15[b]	Text	[X15c]	Text, notes
9		15	Text	[15a]	Diagrams	16	Text	[16a]	Notes
10		17	Text	[17a]	Notes	18	Text	[18a]	-
11		19	Text	[19a]	Notes	20	Text	[20a]	Notes
12		21	Text	[21a]	Notes	22	Text	[22a]	Text

The text has clearly been written in haste: there are many erasures, later cancellations in ink and pencil, and some repetition of notes in the text. This seems to indicate that Coral Islands is Darwin's own first full draft of his theory,[8] and it is quite possible that it was stimulated by his sight of Moorea and its encircling reef,[9] even though the theory had been slowly formulating since the middle of the year.

The Fair Copy is written on feint-ruled foolscap, in units of four pages, each 7.8 x 12.5 inches. As with the original the text is written on pages 1 and 3 of each unit. There are a number of pencilled comments of a critical nature, some erased, in a hand other than Darwin's (possibly FitzRoy's), with brief answers to them in Darwin's hand.

The text presented here* is a transcript of the original paper in Darwin's hand, retaining his spelling and punctuation. In the absence of any earlier manuscript on his coral reef theory, it is thought to be the first full statement he ever wrote. The original and Fair Copy are contained in Volume 41 of the Darwin manuscripts at Cambridge.**

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* Two text-pages of the Darwin manuscript, with their running-heads and marginal notes, and with the notes referring to them, are included in one Bulletin page. The numbers in [] refer to the note-pages, as above. Remarks, or other editorial details, furnished by Mr. Stoddart are also in []. Eds.

** The three sample pages reproduced here, actual size, are from the original manuscript (photos furnished by the University Library, Cambridge).

Acknowledgments

I am indebted to Sir Charles Darwin for permission to publish this paper, to the Library of the University of Cambridge for access to the manuscripts, and to Mr. P. J. Gautrey for his assistance. Dr. Sydney Smith kindly gave me further information on the manuscript and other collections; and Lady Nora Barlow has read the manuscript and given me much encouragement.

Notes

1. The Autobiography of Charles Darwin 1809-1882. With original omissions restored. Edited by Lady N. Barlow. London, 1958, 253 p. (written in 1876). See p. 80.

2. Charles Darwin: On certain areas of elevation and subsidence in the Pacific and Indian Oceans, as deduced from the study of coral formations. Proc. Geol. Soc. London, 2, 1837, 552-554. On Lyell's response to the theory, Autobiography, 1958, pp. 83-84, and 100, and letter from Lyell to Sir J. Herschel, May 24th, 1837, in: K. M. Lyell (editor): Life, letters and journals of Sir Charles Lyell, Bart. London, 2 vols,1881, see Vol. 2, p. 12-13. Compare C. Lyell, Principles of Geology, 1st edition, Chapter XVIII, Corals and coral reefs, 1832 (Vol. 2, p. 283-301) (and similar accounts in editions 2, 3, 4, and 5) with Chapter XVIII, Formation of coral reefs, in Principles, 6th edition, Vol. 3, 1840, p. 366-406.

3. Charles Darwin: Journal and Researches 1832-1836. (Narrative of the surveying voyages of His Majesty's Ships Adventure and Beagle, between the years 1826 and 1836 ..., Vol. 3). London, 1839, 615 p. Charles Darwin: The structure and distribution of coral reefs. London, 1842, 214 p.

4. Autobiography, 1958, p. 98-99. See also Professor C. M. Yonge's essay "Darwin and coral reefs," in: S. A. Barnett, editor, A Century of Darwin. London, 1958, p. 245-266.

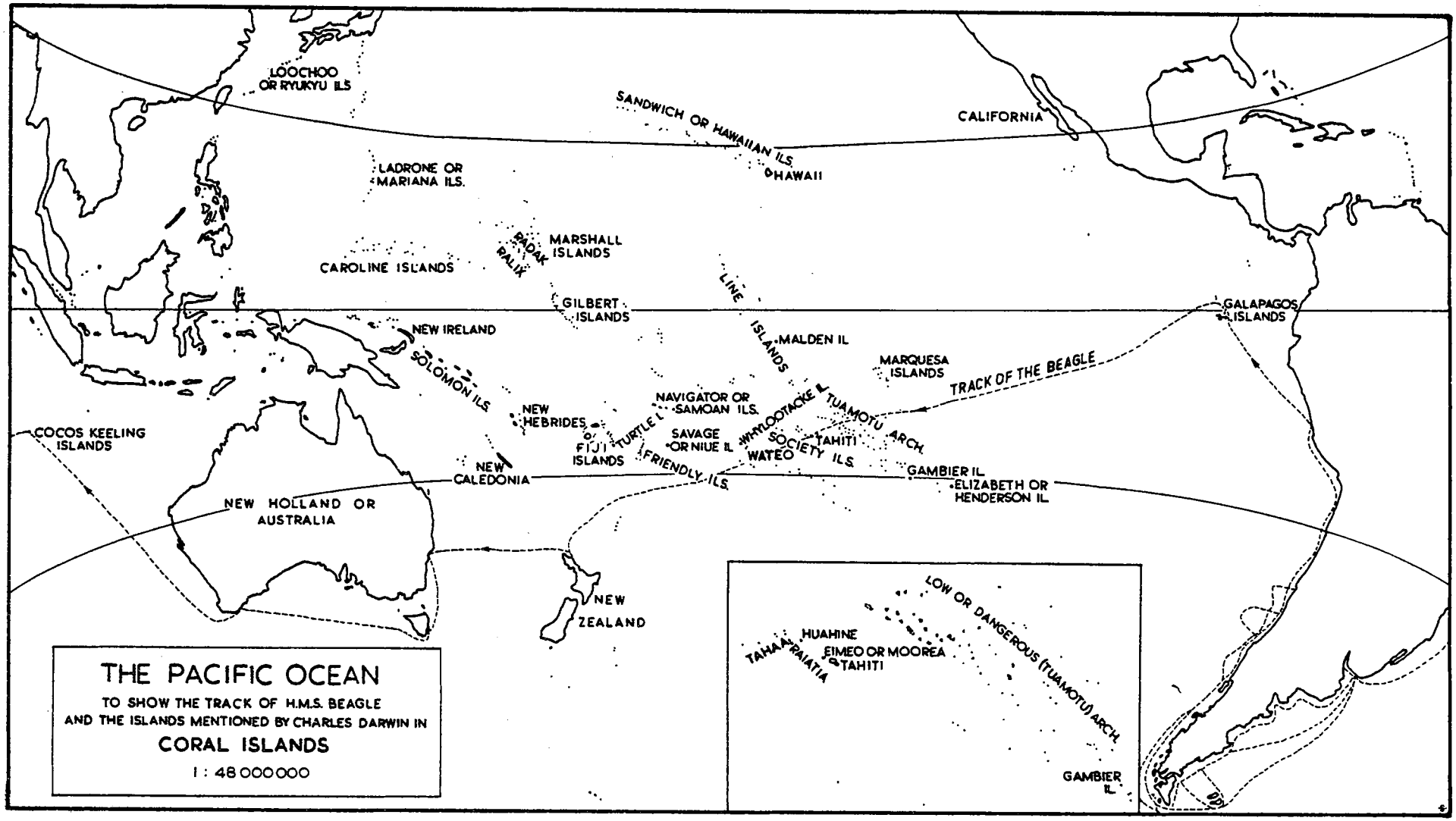
5. Charles Darwin's Diary of the voyage of HMS Beagle. Edited from the MS by Lady N. Barlow. Cambridge, 1933, 541 p. See p. 400.

6. In Lady N. Barlow, editor: Charles Darwin and the voyage of the Beagle. London, 1945, 279 p. See p. 137.

7. Coral Islands, manuscript, p. 4-5; compare Diary, 1933 p. 348, and Journal, 1839, p. 484-485.

8. Lady Barlow has described jottings outlining the theory in one of Darwin's field note-books, probably written in July 1835; see Charles Darwin and the voyage of the Beagle, 1945, p. 243-244.

9. "I was much struck with this fact [the lack of "essential difference between encircling barrier-reefs and atolls"] when viewing, from the heights of Tahiti, the distant island of Eimeo ..." (Structure and distribution of coral reefs, 1842, p. 46). Also reference in note 7, above.



THE PACIFIC OCEAN

TO SHOW THE TRACK OF H.M.S. BEAGLE
AND THE ISLANDS MENTIONED BY CHARLES DARWIN IN

CORAL ISLANDS

1 : 48 000 000

Although I have personally scarcely seen anything of the Coral Islands in the Pacifick Ocean. I am tempted to make a few observations respecting them.-

In looking at a chart of the East Indian group. it will be seen that a direction within a couple of Points of NW & SE is common to the Western & Eastern Islands.-This line is continued to New Caledonia.-It is fronted
a) by the parallel chains of New Ireland. Solomon & Hebrides Isl^{ds}.- [Perhaps the similar direction of the North part of New Zealand & that part of New Holland, which in its position & barrier of Corall reefs is intimately connected with the South sea, may be more than an accidental coincidence.- [1]] Those small Islands, which stretch in an E.W direction half way across the Pacifick, are frequently described as being a curved part of that Volcanic band of Islands which terminates Southward at the New Hebrides, or more properly in New Zealand.-

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[1. This sentence is deleted in the original, and the following note is given on page 1a:]
(a) Again we see the same fact in the northern part of New Zealand; the constitution of which, like the foregoing Islands, is essentially Volcanic.- The NE coast of Australia which is fronted by the great barrier reef & so intimately connected with the Pacifick, has also a NW & SE direction. The whole shore is believed to consist of Granitic rocks; a little way inland a long chain of hills runs parallel to the coast line.- (Dr Fitton's Appendix to King's Australia)

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But I do not think this is a correct view.-In each separate Archipelago the direction already alluded to is found.- This law prevails even
(a) as far as the Sandwich Is^{ds} (a).- Perhaps the strongest exception will be
(b) discovered in the Friendly Is^{d}? that is if these are taken without reference to the group of the Fidjis. All the Islands ought rather to be considered as so many short parallel lines, than the continuation of the great volcanic band which sweeps round the Eastern shores of Asia.- I have pointed out this fact, as showing a degree of physical connection in the Islands of Polynesia. Forster in his observations in a Voyage round the World. makes three classes for the different kinds:- (1st) High Islands without Coral reefs; he adduces as Examples the Marquesas & Hebrides. & two out of the Friendly Is; to them may be added the Navigators

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[2a] (a) I may even add the peninsula of California & the shores of North America.-
(b) Mem. the Friendly a field of modern disturbance. & therefore the exception of Value.-

as described by Kotzebue. the Sandwich & Galapagos groups & several other smaller ones.- It would be a curious point to ascertain, whether Coral grows abundantly on the shores of any of these Islands, although not forming a reef; or whether as at the Galapagos, it may be considered as absent.- This one fact would alone throw much light on the theoretical structure of all the Coral formations.- We know that in some parts of the World where Corall is abundant, as in the West Indies true Lagoon Islands do not occur. II. High Islands encircled by a reef, as a picture is by a frame.- the singularity of this phenomenon, the beauty & utility of its
(a) effect has scarcely been enough insisted upon by Voyagers.(a)- Forster gives an example in Tahiti, & all the true Society Islands, the higher ones of the Friendly & New Caledonia.- III The low half drowned Islands, composed entirely of Coral

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[3a] (a) It must be borne in mind, that the line of breakers sweeps round, at a considerable distance from the foot of the mountains.- The interval is occupied by the smooth water of the lagoon & the low alluvial land. which has encroached on parts of its former bed.-

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& including a lagoon.- IV. Capt Beechey has described another class, such as Elizabeth. Savage * Wateo Island, (a) which are composed of Coral rock, are of moderate height, & probably before their elevation existed as Low or Lagoon Islands.- Capt. Beechey remarks on the rarity of this class.- I suspect however on a more accurate knowledge. several more will be added to this list. I may perhaps instance Turtle Isd. of Cook. which Forster brings forward as the best example of subterranean elevation in the Pacifick.- With respect to this classification, it appears to me that the distinction between the II & III division, or the high islands with reefs & the Lagoon ones, is artificial.- I believe the reefs and strips of land, which compose the circular Low Islands. are of the very same structure & origin with those reefs which encircle, as with a belt so many of the lofty ones.- Viewing the Ei Meo

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[Marginal note, same page] (a) & Perhaps Malden of Ld. Byron

from the heights of Tahiti I was forcibly struck with this opinion.- The mountains abruptly rise out of a glassy lake, which is separated on all sides, by a narrow defined line of breakers, from the open sea.- Remove the central group of mountains, & there remains a Lagoon Is.d - I ground this opinion from the following facts.- There is a general similarity in the two cases in the form & size of the reefs; their structure appears identical, we have scarcely fathomable water in each case, at a short distance on the outer margin; within is a shallow basin more or less filled up by knolls of growing Corall or converted into dry land.- In the Lagoon Isl.as there are some, which do not deserve this title, for they consist solely of a circular reef, of which scarcely a point projects above the water;(a) whilst others have a more or less complete, but narrow ring of dry land.- In the same

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[Marginal note, same page] (a) Such as the Is.d near Turtle I.

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manner in the encircling reefs, although they generally are only ornamented by a few speck formed Islands, yet at the fine Island of Huahine Ellis states the reef is becoming converted into dry land.- The essential character in the one class, of a large encircled Isld. itself dwindles away & becomes ambiguous.- We have the 2 large Islands of Raiatia & Taha (?) included in one reef.- In such cases, as in Gambier Is.d so well described by Capt Beechey, where a group of small hilly Islands are encircled by one grand reef, or as in Whylootacke. (seen by the Beagle) when one single one is so situated, it becomes a question in which of the two classes they ought to be arranged.- In the Is.d of Caledonia, as drawn on a large scale in Krusenstern's Atlas, the reef will be seen prolonged at each extremity. & encircling the continuation,

beneath the water of the land. It here requires less effort of imagination to remove the central hills & to leave a perfect lagoon Is.d - this change judging from the figure, it might be believed was actually in process.- The last argument which I can adduce is the parallelism between the Archipelagoes of the two orders, for instance the low Island & the Society ones.- Moreover, this parallelism is found in the direction of the longer axis of the oval figure, which is so frequent in the encircling reefs & low Island:- One is tempted to extend still further this similarity & to believe that there is no difference between the reef which encircles an Island, & those extraordinary barriers of Coral, which front for so many leagues the coast of Australia & I believe the Northern shore of Brazil.- The high encircled Isds. are composed of various geological formations: no

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doubt ancient Volcanic rocks are most abundant, but in Tahiti M. Hoffman found Granite. Mr. Ellis states. that in several of the Society Is.ds Granite, Hornblendic rock, Limestone & rock with Garnets is found. Forster in New Caledonia describes the prevalent rock under the name of Gestele stein, which I believe to be Mica Slate.- Hence we may feel secure (if any doubts could have been entertained) that these encircling reefs are not built on the crests of submarine Craters.- If the proofs of the identity in nature of the two kinds of reefs, are considered as conclusive, in a like manner, there is no <u>necessity</u> that the Lagoon Isd. should be based on such Craters. This view will I think, generally be more satisfactory, it removes the difficulty of the immense size of the Lagoons far exceeding any known Crater: & explains the extreme irregularity of figure. exemplified in the Radack

& Ralix groups, described by Kotzebue. Whether we look at these Islands. as having formerly encircled high land, or resting on the brim of a Crater, [1] it appears to me, we must admit, the theory of Mr Lyell, that their present structure is owing to a series of small depressions.- If the ground on which the Lithophytes have built their edifices has not subsided. it must have remained stationary or been elevated. [It being allowed that the Corall animal can flourish only at a small depth. it (a) follows, on the first supposition, that all the submarine mountains within this limit had the same height & that not one raised its head (a) above the level of the sea.[2]] On the second supposition. of a series of elevations; these movements over a large tract of ocean, ceased. & never exceeded the limits already pointed out.- Now, these consequences from the two suppositions, are so very improbable: (for if they are not so,we

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[1. Marginal note:] Vol II Chapt: XVIII
[2. This sentence is deleted in the original, and the following note is given on page 9a:]
(a) On the first of these suppositions. it being allowed. that the Coral animal can only flourish at a small depth, it follows that submarine mountains, on which the Coral is now growing. reached within the limits of such depth, the surface, but yet that not one peak ever raised its head above this level.-

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might expect to find somewhere a tract of country with mountains of an equal height) that to my mind the evidence of subsidence the only remaining supposition is demonstrative.- No doubt the fourth class of Islands, the raised Coral rock, is an argument on the other side; but their acknowledged rarity appears to me a proof that they ought rather to be considered as exceptions or irregularities in the prevailing movement. If a gradual upheaval was in progress here, as on the shores of S. America. the Coral would afford a more palpable and lasting evidence, than could be expected under any other circumstances.- Capt. FitzRoy has discovered an interesting tradition amongst the Low Islanders, that the arrival of the first Ship. was followed not long afterwards by a great inundation which destroyed many people.- Earthquakes are occasionally experienced here; at Tahiti there happened one which was believed to have foretold the arrival of the first Missionaries.

I looked in vain on the shores of Tahiti for any sort of evidence of a consequent rise.- In the Polynesian traditions (Ellises Researches) there are accounts of deluges, which evidently were accompanied by Volcanic phenomena.- The difficulty in understanding the cause of a reef of living Coral, being separated by channels or lakes from the land. has not as yet. been attempted to be removed. The only explanation. which I can offer. is
(a) chiefly conjectural.[a] - when at Tahiti I examined the reef.- I found on
(B) the exterior margin, a solid broard [sic] (30-50 yards?) mound of Coral
(A) rock, strikingly resembling an artificial (but low) breakwater. on which the surf beat with violence.- The surface of the mound is compact &
(C) smooth.- It is slightly curved & dips towards the inside or smooth water of the Harbor. Owing to the surf. I could not examine the outer margin; I am told it consists of

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[11a] (a) It rests on a belief that the species of Coral, most efficient in building a reef, flourish best when immersed in the surf of the outer breakers, & that their growth is checked by sediment & fresh water brought down from the central land.-

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smooth ledges of <u>living Coral</u>, & that its general inclination is great:- It is only on rare occasions, when there happens to be very little surf & a low tide that the living parts can be seen. Not unfrequently after gales of wind, the ledges (probably overhanging) are torn up & in enormous masses thrown far up on the reef: By this means also the Natives know the exterior margin is thus constituted. The central part of the breakwater is entirely dead; on its surface the chief production is an encrusting inarticulate <u>Corallina</u>. The sea, breaking violently on the outer margin, continuouslypumps over in sheets the water of its waves.- hence the surface is worn smooth & gently declines towards the lagoon.- I was assured that on the rare occasions, alluded to, the central part is exposed, uncovered to the rays of the sun, & that this invariably kills
(a) the animal, & leaves the Lithophyte dead rock.

<u>(a)</u>

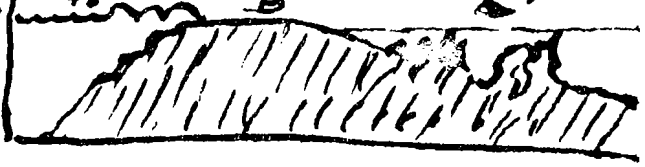
[12a] (a) There must however be some process by which the mound is repaired: if once worn away so deeply as always to be covered by the water, the case becomes at once similar to the outer parts; perhaps the Corallinas & other small Marine productions may protect the surface.-

I looked in vain on the shores of Tahiti for any sort of evidence of a consequent rise. — In the Polynesian traditions (Ellis, Researches) there are accounts of deluges, which evidently were accompanied by Oceanic phenomena. —

The difficulty in understanding the cause of a reef of living Coral, being separated by channels or lakes from the land, has not as yet been attempted to be removed. The only explanation, which I can offer, is chiefly conjectural. — When at Tahiti I examined the reef. — I found on the exterior margin, a solid (30-50 yards?) mound of

(B) Coral rock, sticking (apparently) an artificial (but low) breakwater, on which the surf beat with violence. —

(A) The surface of the mound is compact & smooth. —



It is slightly convex & dips towards the

(C) inside or smooth water of the Harbor. During the surf, I could not examine the outer margin; I am told it consists of

This revised version of the sketch on Darwin's page 11 occurs on a separate piece of paper inserted in the Fair Copy.

The whole reef may be described, as consisting of two parts: the outer margin of the Breakwater, the solid part of which is higher than all the rest, & a tract of very shallow water which varys in width from 100 yards to a mile. In this low part there are little narrow twisting channels & holes of deep water, & on the other hand many points. where the Coral reaches to the surface. It is in this still water where an observer as has often been described, may watch the fish gliding amongst groves of variously coloured Corals. This part of the reef seldom or never is directly joined to the shores: but there is left channels & harbors where a Ship can anchor in a fine Sandy bottom.- I imagine it is the fresh water & sediment brought down. which helps to prevent these spaces being filled up & likewise perhaps the cause that these reefs are seldomer
(a) converted into stripes of dry land. than in the Lagoon Is^ds.- In the shallow parts the most abundant kind of Lithophytes, are stony & branching. generas (as). Also Fungia & Caryophillia

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[13a] (a) When such does happen. that part close within the breakwater would from the fragments thrown over it, be soonest changed.- there also the water is pure & fit for the growth of some kinds of Coralls.-

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Showing them to some intelligent natives I was assured that such kinds never grow on the outside of the reef or compose solid reefs.- From their descriptions. I imagined the prevalent kinds, so situated are such as Porites. Millepora. & some Meandrina & Astrea. Anyhow they appeared to consider that there is a wide distinction in the two cases. Analogy. from the habits of all other marine animals would lead one to suppose that the same species would not flourish in two such different localities, as the foam of furious breakers. & shallow placid lakes. If this opinion should be granted. it would be very important; we might infer that those species. which build the external solid wall, the highest & most perfect part of the Corall rock, will only flourish where the waters break
[1] violently. M. Quoy & Gaimard, state, "that the species, which constantly formed the most extensive banks, belong to the genera. Meandrina, Caryophyllia. & Astrea" & that the Saxigenous polypi increase most considerably in shallow & quiet water. I am not aware whether they suppose, these same species form the outer parts of the reefs.

[1. marginal note:] D. L. Beche

With respect to the ratio of increase I have a few remarks to offer.- In the greater number of the Lagoon Is^{ds} from the arguments already used, it is clear no movement of elevation has taken place.- Now Capt. Beechey remarks, that the strips of dry Coral, divested of any loose sandy materials heaped upon them are rarely elevated more than 2 ft above the level of the sea. Now whatever this elevation may be, it is clear, that the highest point of the living Coral rock is in any Is^{d} as high or higher than the dead. Because the dead. lived under similar circumstances & may have suffered degradation.- Now this quantity is so much higher than the level of the ocean & therefore than the waters of the Lagoon, which must afford the nearest approximation to judge by.- Hence the Coral, which has formed the strips of dry land, could not have been cherished by those quiet waters, but rather in the turbulence of the breakers, where a surface above the mean

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level. would never remain uncovered & exposed to the rays of the sun.(x)- In those cases where true Coral rock is above the level of the Lagoon. (a) the land must have increased outwards;(a) but as it appears from the extreme depth. beyond the reef, that this can hardly be a general process. I suspect that Coral rock may often be difficult to be distinguished from a rock of cemented fragments.- Besides the greater absolute height of the Coral which grows in the surf, it must be remembered, that yearly gales of wind, tear off large fragments, some of which are tossed on the reef & others must fall down into the surrounding depths. Yearly the Polypus has to replace this damage.- On the other hand, within the lagoon all detritus accumulates, & if as according to M. Quoy and Gaimard. the Coral grows <u>there also</u> most rapidly; how comes it that the Lagoon is not more commonly filled up? This is the more surprising. if we look at the entire section of a Lagoon Island in Capt. Beechey. & see how trifling the inequality of the foundation

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[X15a:] (x) This conclusion perfectly agrees with what was visible in the reef of Tahiti.

[X15c:](a) as appears to have been the case. on the Is^{d} on which Capt. Beechey found the remains of the wreck of the Matilda so very singularly situated.

[Note on verso of Leaf 11 in Fair Copy:] Insert this as a note stating my previous formed opinion.

Note - May not earthquake waves be occasional agents?- May not the wreck of the Matilda have been thrown inshore by a great wave?- Such an event happening once in a century- as at Lima or Concepcion - would hardly be known to the few Europeans who have yet examined Polynesia.

really is. And we must also bear in mind that arguments can be advanced to show that the subsidences must happen after long intervals.- such as few proportionate numbers of submerged circular reefs; & again the quantity of detritus heaped up on the dry Coral.- The general tenor of the foregoing facts, strongly urges me to believe that the Coral, most effective in forming the solid reef, will only flourish near to the break of the Sea.- I will not pretend to conjecture concerning the cause of this predilictiqn, whether the motion of the fluid, or the quantity of insolved[1] air. is favourable; or whether the light and heat, which must pervade still shoal water is injurious to the growth of their Species.-

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[1. In the Fair Copy, insolved is rendered intangled.]

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[respect to the ratio of increase, it must be remembered, that all the Coral. which grows within the lagoon. accumulates. whereas on the outside yearly large fragments are torn off & carried away. The Polypi have to repair all this damage. On the supposition that the dimensions of the reef or island do not decrease. (which at least will be granted), the polypi must yearly repair this damage.[1]] - If then the two following postulates are allowed, much of the difficulty in understanding the Coral formation. will I think, be removed.- (1^st) That in certain parts of the Pacifick, a series of subsidences have taken place; of which no one exceeded in depth, the number of ft, at which saxigenous polypi will flourish: & of which series, the intervals between the successive steps. were sufficiently long to allow of their growth, always bringing to the same level the upper surface of the reef.- (2^nd) That those species of Lithophytes, which build the outer. solid wall, flourish

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[1. These two sentences deleted in the original, and their substance expanded in the two pages marked X15 and in [X15c], clearly added after this section of the text was written.]

(a) best, where the sea violently breaks.-
Better to explain my views, I will take the case of an Island situated in a part of the ocean. which we will suppose at last becomes favourable to the growth of Corall.- The circumstances which determine the presence or absence of the Saxigenous Polypi are sufficiently obscure, but they do not enter into this discussion.- Let AB represent the slope of an Island so circumstanced & CD the level of the ocean. Then Corall would immediately commence to grow on the shore (D) & would extend Sea-ward as far as the depth of water. would permit its rising from the bottom.- Let this point be (H).- The breadth of the reef (HD) would then depend, on the angle of inclination of the bottom.- This space might either be converted into a piece of Alluvial ground, or even, from the Corall springing up vertically from E & so protecting the inner space, might exist as a Lagoon.-

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[16a] (a) This second Post: is not so necessary as the first: as will be subsequently seen.- Possibly the fact of the Windward side of the low Islands, where the surf <u>generally</u> is most violent, being the highest & most perfect. may be partly explained by such an admission.-

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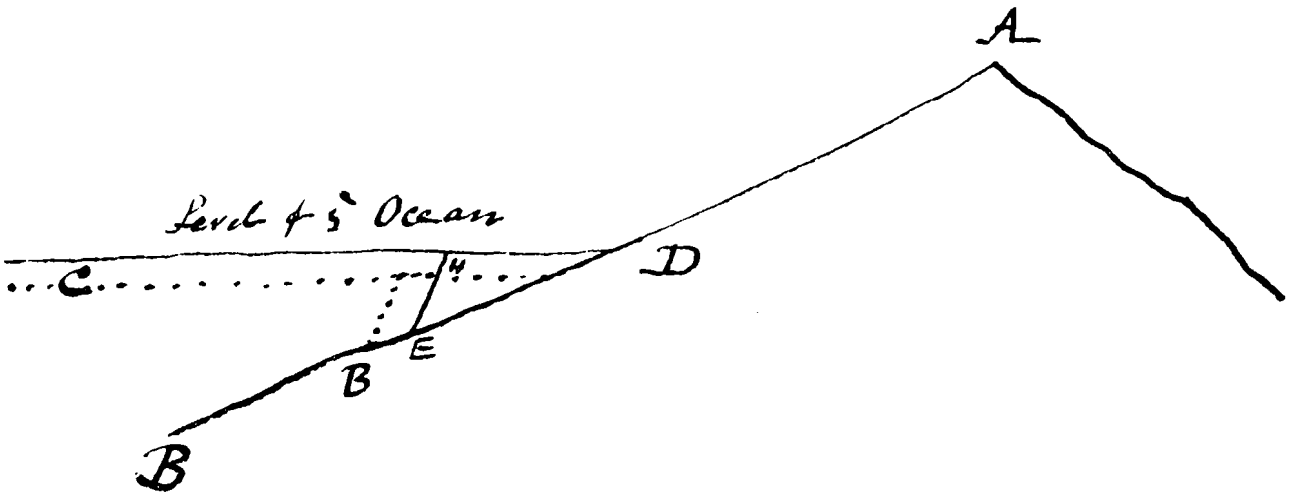
This reef would however essentially differ from those in the South Sea, in the depth of the water. (I exclude any few exceptions) beyond the Wall not suddenly becoming excessive.- If the level of this Island should remain stationary. I cannot imagine any change.- But if the land should be raised. (or sea sink): the outline would be as represented by the dotted line.- And on the shores. a fringe of Dry Coral rock would be left: This circumstance is known to happen in the East & West Indian Is[ds].- Some such fact, may perhaps explain the double reefs found by Capt. Beechey at Loo Choo, <u>one of which was dead & one living</u>.- Now if we suppose the land gradually to subside (See Fig. II. I have represented the water rising; the effect of course is the same) the level of the sea will stand at Cl instead of at CD.- The Coral of the outer wall favoured by the heavy surf.
(a) will soon recover its former level.[(a)]- If this process.

[17a] (a) or the whole may be supposed to have same tendency to grow up & recovers its former level: but that the sediment &c from the land checks its growth.

(a). best, when the sea violently breaks. —
Better to explain my views, I will take
the case of an Island situated in a part
of the ocean which we will suppose at
last becomes favorable to the growth of
Coral. — The circumstances which determine
the presence or abence of the Madreporous
Polypi, are sufficiently obscure, but they
do not enter into this discussion. —
Let AB represent the slope of an Island
so circumstanced & CD the level of the
ocean. Then Coral would immediately commence
to grow on the shore (D) & would extend lat-
ward as far as the depth of water would
permit it to rise from the bottom. —
Let this point be (H). — The breadth of
the reef (HD) would then depend on the
angle of inclination of the bottom. —
This space might either be covered with
a piece of Alluvial ground, or even, from
the Coral springing up vertically from E & so
protecting the inner space, might exist as
a lagoon. —



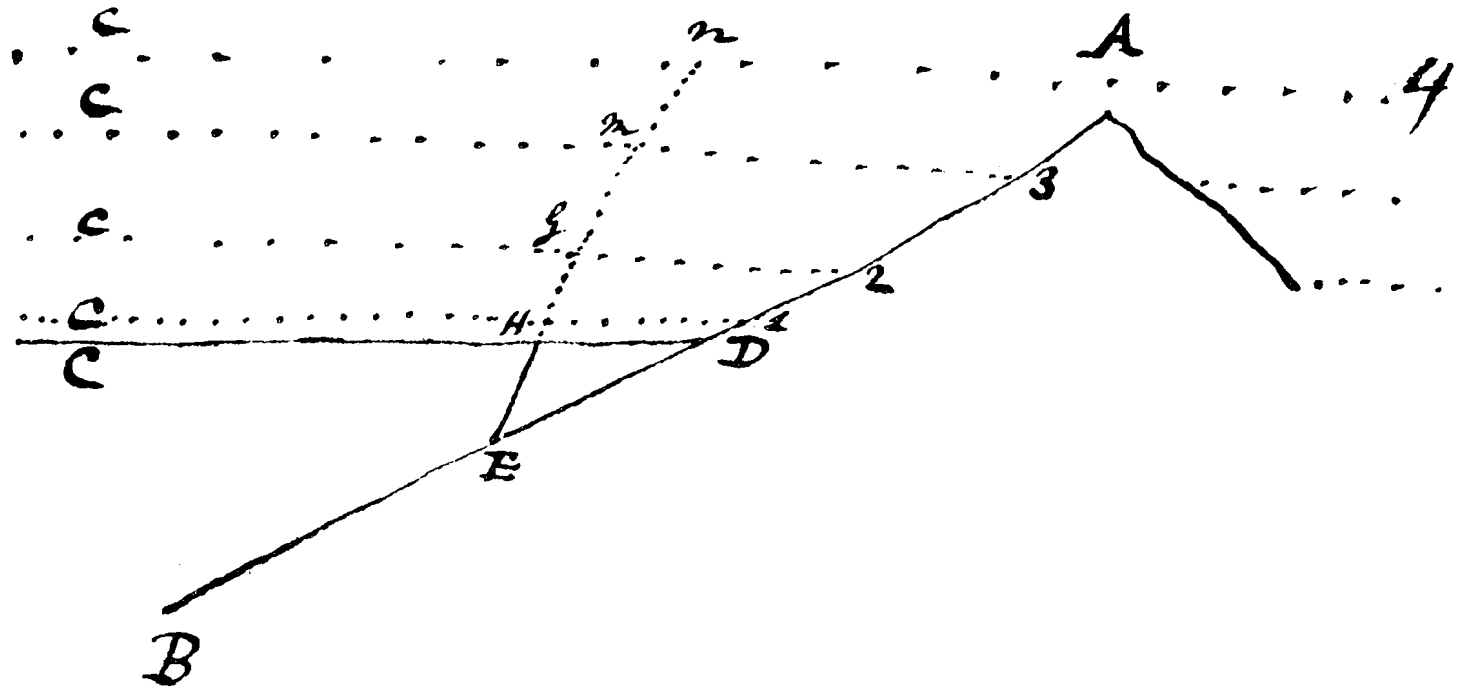


Fig II

is repeated each time the sea will gain on the land while. the reef rises, nearly vertically on its first foundation.- I say nearly vertically, because, any & every small portion removed in front of the lower part & the building being continued upwards before its repair, this must throw backwards the whole of the superstructure. When the level stands at (C3), the space between the reefs & the land, will be more, than twice as broard as at first. This space will probably be occupied by a lake of water. such still water. not being favourable to the growth of the most efficient species of Coral.- I may mention that when at first the reef touched the shore. in the mouth of each stream. there must have been a channel.- such openings. during the longest series of depressions. would be continued & hence would generally

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(a) face the valleys, as is observed to be the case.[a]- This explanation is referrible to those reefs which front a continent or encircle an Island.- If the subsidences are continued, till by the encroachment of the water an Island is reduced from large to small, & is at last totally submerged; then there will remain a true Lagoon Is^d.- When viewing Ei meo, or the chart of New Caledonia. I talked of removing the central mass of hills, this was the process I was considering. If the above hypothesis, all its
(b) parts considered together, is considered even as partially satisfactory (for I am aware several objections can be raised against it) it will be worth while to follow out some of the more extended consequences. In those parts of the world, where a general movement upwards is in progress, we ought not to find groups of Lagoon Is^d or that class of reefs. which encircles the land at a distance & has very deep water close to the outer wall. How far this is actually the case I have not

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[19a] (a) These channels would generally have about the same depth as the lagoons; their bottoms being filled up with sand or detritus.- The action of currents would prevent their total filling up.-
(b) I must observe that in the early part of the series of subsidences, there can be little doubt that the fresh-water & sediment, brought down from the central land, would be injurious to the growth of the Coral within the reef.- But when a Lagoon Island was once formed, (excepting the prejudice caused by the accumulated sediment, as a slippery foundation) we must look to the other reasons as an explanation of the continuation of the inequality in growth.-

sufficient data to judge. In the West Indies, where proofs of recent elevation are abundant, reefs of these structures are not found. or at least are not common.- Within the East Indian Islands, the shores of which are frequently overlaid with raised Coral rock, I believe likewise they
(a) are not found.- In the Pacifick I may adduce the Sandwich Isd.- It will be interesting to discover. whether those groups (our first class) which are not protected by reefs, but yet have Coral abundant on their shores can
(B) be proved to have been recently elevated.B- If such generally is the case, it will give much probability to the idea, that the direction of the movement determines the structure of the reef.- It is manifest that a Lagoon Isd. might be raised s trifle, by an oscillation in the general movement without its character being lost.- This appears to have happened
[1] at Turtle Isd (Cook), which Forster brings forward as the best instance of subterranean upheaval in the Pacifick.- Plants are described on the reef as growing on the dead Coral, which is raised above the

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[1. marginal note:] (P. 147)
[20a] (a) How are the Ladrones (which have dead Coral on the surface)?
V. Kotzebue II Vol.-
V. some large Chart. Kotzebue gives no information on the subject.- Note
(B) Mr. Bennet informs me that in the New Hebrides, which are thus circumstanced he found dead coral at an elevation of 1500 ft.-
Vide Wanderings in New S. Wales

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reach of high water.- yet this Island appears to have retained its proper figure. If however such movements were continued, no doubt an Isd of our fourth class would be produced.- Now it is remarkable, that out of the few instances of this Class given by Capt. Beechey, two of these Islands are surrounded by reefs of growing Coral, but these are attached to the shore, not being separated by channels or lakes of water. I allude to
(a) Henderson I described by Capt Beechey himself & Wateo by Cook.-

On the opposite supposition of a general progressive subsidence in any part of the World (of course I include only those favourable to the growth
(b) of Coral) we should expect to find either or both Lagoon Isds & the encircling reefs.- The archipelago of the Society Is (which are encircled) & that of the Low Isd occur in the same part of the ocean.- The Friendly Isd in a like manner are divided into the same two sorts of groups.- As decisive evidence of depressions of

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[21a] (a) V. Byron for structure of Malden Isd.-
(b) V. Chart of the Barrier of Eastern Australia, are there in that district any lagoon Isds?-
Note

level. will almost always be deficient: all that we can look to is that there is no evidence of an opposite tendency. Now against this. a flagrant
[1] instance. can be brought up. from Mr. Ellis' account of the true Society Is[d].- He states, that on the mountains of Raiatia, Coral & shells &c are found. I do not clearly understand that he himself has examined into the circumstances. Perhaps they may be interstratified with the Lavas & only point out a very ancient elevation.- From the mineralogical nature of the strata in Tahiti I felt no doubt, but what they had formerly been submerged beneath the Sea.- To all such general views, as these, many exceptions, may always be expected to be found; to ascertain their truth, a far more extended examination of all the phenomena, is absolutely necessary. If the reality of them should ever be proved, it would be important to Geology. For then we might assume that groups of Lagoon Is[d] clearly showed that a chain of Mountains had there sub-
(a) ———

[1: marginal note] V. Ellis Vol. 1 P. 389

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(a) [22a]
-sided.- And, when in any formation there should be found, a great thickness composed of Coral & the genera of which resembled those, which now build the reefs, we might also conclude. that during its successive accumulation, the general movement, was one of depression.-

Before finally concluding this subject, I may remark that the general horizontal uplifting which I have proved has & is now raising upwards the greater part of S. America & as it would appear likewise of N. America, would of necessity be compensated by an equal subsidence in some other part of the world.- Does not the great extent of the Northern & Southern Pacifick include this corresponding Area?- Humboldt carrys a similar idea still further; In the Fragmens Asiatiques, P 95. he says. "Par consequent l'epoque de l'affaisement de l'Asie occidentale coincide plutot avec celle de l'exhaussement du plateau de l'Iran, du plateau de l'Asie centrale, de l'Himalaya, du Kuen Lun, du Thian shan & de tous les anciens systemes de montages diriges de l'est a l'ouest; peut etre aussi celle de l'exhaussement du Caucau, & du noeud de montagnes de l'Armenie & de Erzeroum."[1]

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[1. The following translation, found on a single sheet in Darwin papers, Vol. 42, folio 23, is transcribed in the final paragraph of the Fair Copy:] Humboldt (Fragmens Asiatiques Page 95) in a similar manner considers that the epoch of the sinking down of Western Asia coincides with the elevation of the platforms, of Iran, of central Asia, of the Himalaya, of Kuen Lun, of Thian Chan, and of all the ancient systems of Mountains, directed from East to West.

Appendix: Works referred to by Charles Darwin

In 'Coral Islands' Darwin makes reference to some fourteen books and papers, listed below. It is probable that not all of these were carried on the Beagle, and the references derive from other sources. For example, Darwin did not read other languages with ease, and his knowledge of the work of Quoy and Gaimard almost certainly derives from De la Beche's 'Geological Manual.' To trace the books relevant to the coral work which Darwin actually had with him during the voyage, we have the evidence of his own writings, in the 'Autobiography, 'Life and Letters,' and 'More Letters' - which together mention only Humboldt, Lyell and a "small volume" of Milton - together with the books remaining in his library at the time of his death, and listed in the following two publications:

H. W. Rutherford. 1908. Catalogue of the library of Charles Darwin now in the Botany School, Cambridge. Cambridge, University Press, 91.

Books received in the University Library from Down House, March-May 1961. Cambridge, University Library, mimeographed (29 p.).

Two books were pre-eminent in his collection: Lyell's 'Principles of Geology' and Humboldt's 'Personal narrative of travels to the equinoctial regions of the New Continent.' The first edition of the 'Principles,' used on the voyage, is now at Cambridge, together with editions 5, 6, 7, 9, 10 and 11, all from Darwin's library. Volume 1 (1830) is inscribed "Given me by / Capt F. R/ C. Darwin;" Volume 2 (1832), containing the chapter on coral reefs, has on the flyleaf "Charles Darwin / M. Video Novem^{r} 1832." The copy of the 'Personal Narrative' is the English translation by H. M. Williams, London 1819-20, 6 volumes in 7, and is inscribed: "J. S. Henslow to his friend C. Darwin on his departure from England upon a voyage round the world. 21 Sep^{r} 1831." Both volumes are annotated. In the coral reef chapter of Lyell, 'Principles,' Volume 2, it is interesting to see that the paragraph in which "subsidence by earthquakes" is advocated to account for the form of atolls has been scored.

In addition to these works, to which Darwin made frequent appreciative references in his letters and 'Autobiography,' he probably also had with him Humboldt's 'Fragmens de géologie et de climatologie asiatiques' (his admiration for the author overcoming his repugnance for French); Captain Beechey's 'Narrative,' a much annotated copy being preserved in the Cambridge collection; and Forster's 'Observations,' also at Cambridge and quoted in 'Coral Islands.' It is clear from 'Coral Islands' that a number of volumes which are no longer in his library were also taken on the Beagle: chiefly Kotzebue's 'Voyage;' Ellis's 'Polynesian Researches;' Bennett's 'Wanderings in New South Wales;' Byron's 'Voyage;' and King's 'Narrative.' De la Beche's 'Researches in theoretical geology,' 1834, is in the library, but not the 'Geological Manual,' 1831, which was probably used during the voyage. We have the evidence of FitzRoy that a copy of Krusenstern's 'Atlas' was carried on the Beagle.

One further relevant volume in the library, which may have been taken on the voyage, is Playfair's 'Illustrations of the Huttonian Theory,' 1802.

From the point of view of 'Coral Islands,' however, it is clear that Lyell, Beechey, Kotzebue, Forster and De la Beche were Darwin's

main sources, together with a collection of voyages and travels now forgotten. The complete list is as follows:

Beche, H. T. de la. 1831. A geological manual. London, Treuttel and Würtz. 535 p.

Beechey, F. W. 1832. Narrative of a voyage to the Pacific and Beering's Strait, to co-operate with the polar expeditions: performed in His Majesty's Ship Blossom, under the command of Captain F. W. Beechey, R. N., F. R. S. &c. in the years 1825, 26, 27, 28. Philadelphia, Carey and Lea. 493 p. (This edition in Darwin's library, annotated).

Bennett, George. 1834. Wanderings in New South Wales, Batavia, Pedir Coast, Singapore, and China; being the journal of a naturalist in those countries, during 1832, 1833, and 1834. London, R. Bentley. Volume 1, 440 p. Volume 2, 428 p.

Byron, George Anson, 7th Baron. 1826. Voyage of H. M. S. Blonde to the Sandwich Islands, in the years 1824-25. Captain the Right Hon. Lord Byron, Commander. London, John Murray. 260 p.

Chamisso, Adelbert von. 1821. Remarks and opinions of the naturalist of the expedition: in, Kotzebue, Voyage, Volume 2, p. 349-433; Volume 3, p. 1-318, and 331-336.

Ellis, William. 1829. Polynesian researches, during a residence of nearly six years on the South Sea Islands; including descriptions of the natural history and scenery of the islands - with remarks on the history, mythology, traditions, government, arts, manner, and customs of the inhabitants. London, Fisher, Son and Jackson. Volume 1, 536 p. Volume 2, 576 p.

Fitton, W. H. 1827. An account of some geological specimens, collected by Captain P. P. King, in his Survey of the Coasts of Australia, and by Robert Brown, Esq., on the Shores of the Gulf of Carpentaria, during the voyage of Captain Flinders: in, King, Australia, Volume 2, p. 566-630.

Forster, J. R. 1778. Observations made during a voyage round the world, on physical geography, natural history and ethic philosophy. London, G. Robinson, 649 p.

Humboldt, Alexander von. 1831. Fragmens de géologie et de climatologie asiatiques, par A. de Humboldt. Paris, Gide. Volume 1, 309 p. Volume 2, p. 310-640.

King, P. P. 1827. Narrative of a survey of the intertropical and western coasts of Australia. Performed between the years 1818 and 1822. London. Volume 1, 451 p. Volume 2, 637 p.

Kotzebue, Otto von. 1821. A voyage of discovery, into the South Sea and Beering's Straits, for the purpose of exploring a north-east passage, undertaken in the years 1815-1818, at the expense of His Highness the Chancellor of the Empire, Count Romanzoff, in the ship Rurick, under the command of the Lieutenant in the Russian Imperial Navy, Otto von Kotzebue. London, Longman, Hurst. Volume 1, 358 p. Volume 2, 433 p. Volume 3, 442 p.

Krusenstern, A. I. von. 1826-27. Atlas de l'Océan Pacifique dressé par M. de Krusenstern. St. Petersbourg, 34 maps.

Lyell, Charles. 1830-1833. Principles of geology, being an attempt to explain the former changes of the earth's surface, by reference to causes now in operation. London, John Murray. Volume 1, 1830, 511 p. Volume 2, 1832, 330 p. Volume 3, 1833, 398 p. and 109 p.

Quoy, J. R. and Gaimard, J. Paul. 1824. Mémoire sur l'accroissement des Polypes lithophytes considéré géologiquement: in, Voyage autour du monde entrepris par ordre du Roi ... par M. Louis de Freycinet. Zoologie, par MM. Quoy et Gaimard, Médecins de l'Expédition. Paris, Chez Pillet Aîné. 712 p. Chapter XV, p. 658-671. Also reprinted in Annales des Sciences Naturelles, VI, 1825, p. 273-290.