Darwin's *Voyage of the Beagle* as natural history writing.

Darwin's book is an informal account for non-specialist naturalists of his observations on the *Beagle* circumnavigation. He published it in 1845 after many of the more technical books and papers based on his collection had been published (mostly by others). He had already formulated an early version of his theory of evolution by natural selection and drops little hints reflecting that theory here and there. The first publication of the theory of Natural Selection was his joint paper with Wallace in 1858.

In the *Voyage*, Darwin often illustrates how the naturalist's observations lead to a theory which then provokes a serious scientific effort. In one case, he leads his readers through the formation and testing of his theory of the formation of coral atolls. Coral atolls are rings of coral islands with no other geological formations than coral. How they could form was something of a mystery at the time. His observations were based on walking out upon coral reefs, observing how they grow, how storms tear up the reef to make islets that stand above the reef itself. Corals can only grow a little above the low tide line, but they are essentially plants because the significant reef formers all depend for their growth upon symbiotic photosynthetic algae. Coral atolls could not grow up from deep ocean waters. These observations led Darwin to a subsidence hypothesis for atoll formation. High volcanic islands in the tropics have fringing reefs. He visualized such an island slowly sinking. As the island sank its corals would grow upward. As the volcano sank beneath the surface, the reef would keep

growing upward, eventually comprising a roughly circular chain of small islands with a lagoon in the center, an atoll. The coral reef grows most actively at its edges because nutrients from the open sea are supplied there. Hence the circle if islands surrounding a lagoon where coral growth is slower. Coring into reefs in the 1960s eventually proved this picture beyond any reasonable doubt.

The writing of Darwin is the model for your field trip reports. You want to make theory driven observations from which you can draw plausible hypotheses for future testing. I don't expect you to come up anything so grand as Darwin's theory of atolls based on one weekend field trip. But do remember that Darwin's formal training as a naturalist was quite skimpy. It was based on a love of shooting that got him outdoors observing plants and animals as a young man, plus a few field trips with geologists, botanists, and entomologists. He was only 23 when the *Beagle* sailed. He largely taught himself by reading and observing on the *Beagle* voyage. From little first steps like your field trips all the great naturalists have been born!

A few passages from the coral reef chapter are attached to give you some flavor of how naturalists work and write. Your reports should follow this style as best you can. If you have time, read more of the *Voyage of the Beagle*.

selves so delicious that they almost equal those dearer ones at home, to which we are bound by each best feeling of the mind.

The next day I employed myself in examining the very interesting yet simple structure and origin of these islands. The water being unusually smooth, I waded over the outer flat of dead rock as far as the living mounds of coral, on which the swell of the open sea breaks. In some of the gullies and hollows there were beautiful green and other colored fishes, and the forms and tints of many of the zoophytes were admirable. It is excusable to grow enthusiastic over the infinite numbers of organic beings with which the sea of the tropics, so prodigal of life, teems; yet I must confess I think those naturalists who have described, in well-known words, the submarine grottoes decked with a

thousand beauties, have indulged in rather exuberant language.

April 6th.—I accompanied Captain Fitz Roy to an island at the head of the lagoon: the channel was exceedingly intricate, winding through fields of delicately branched corals. We saw several turtle, and two boats were then employed in catching them. The water was so clear and shallow, that although at first a turtle quickly dives out of sight, yet in a canoe or boat under sail the pursuers after no very long chase come up to it. A man standing ready in the bow at this moment dashes through the water upon the turtle's back; then clinging with both hands by the shell of its neck he is carried away till the animal becomes exhausted and is secured. It was quite an interesting chase to see the two boats thus doubling about, and the men dashing headforemost into the water trying to seize their prey. Captain Moresby informs me that in the Chagos Archipelago, in this same ocean, the natives by a horrible process take the shell from the back of the living turtle. "It is covered with burning charcoal, which causes the outer shell to curl upward; it is then forced off with a knife, and before it becomes cold flattened between boards. After this barbarous process the animal is suffered to regain its native element, where, after a certain time, a new shell is formed; it is, however, too thin to be of any service, and the animal always appears languishing and sickly."

When we arrived at the head of the lagoon, we crossed a narrow islet, and found a great surf breaking on the windward coast. I can hardly explain the reason, but there is to my mind much grandeur in the view of the outer shores of these lagoon-islands. There is a simplicity in the barrier-like beach, the margin of green bushes and tall cocoanuts, the solid flat of dead coral-rock, strewed here and there with great loose fragments, and the line of furious breakers, all rounding away toward either hand. The ocean throwing its waters over the broad reef appears an invincible, all-powerful enemy; yet we see it resisted and even conquered by means

which, at first, seem most weak and inefficient. It is not that the ocean spares the rock of coral; the great fragments scattered over the reef, and heaped on the beach, whence the tall cocoanut springs, plainly bespeak the unrelenting power of the waves. Nor are any periods of repose granted. The long swell caused by the gentle but steady action of the trade-wind, always blowing in one direction over a wide area, causes breakers, almost equalling in force those during a gale of wind in the temperate regions, and which never cease to rage. It is impossible to behold these waves without feeling a conviction that an island, though built of the hardest rock, let it be porphyry, granite or quartz, would ultimately yield and be demolished by such an irresistible power. Yet these low, insignificant coral-islets stand and are victorious: for here another power, as an antagonist, takes part in the contest. The organic forces separate the atoms of carbonate of lime, one by one, from the foaming breakers, and unite them into a symmetrical structure. Let the hurricane tear up its thousand huge fragments; yet what will that tell against the accumulated labor of myriads of architects at work night and day, month after month? Thus do we see the soft and gelatinous body of a polypus, through the agency of the vital laws, conquering the great mechanical power of the waves of an ocean which neither the art of man nor the inanimate works of nature could successfully resist.

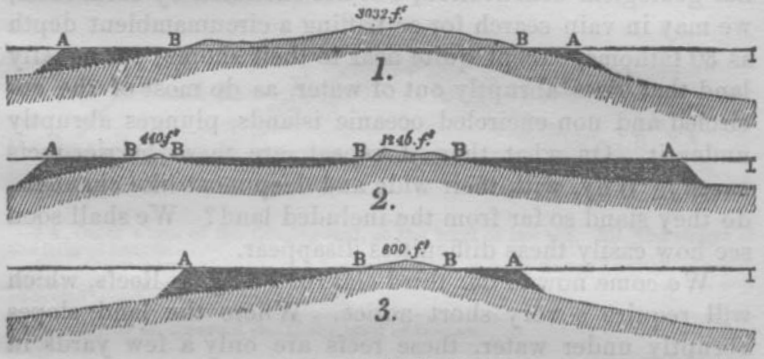
We did not return on board till late in the evening, for we stayed a long time in the lagoon, examining the fields of coral and the gigantic shells of the chama, into which, if a man were to put his hand, he would not, as long as the animal lived, be able to withdraw it. Near the head of the lagoon, I was much surprised to find a wide area, considerably more than a mile square, covered with a forest of delicately branching corals, which, though standing upright, were all dead and rotten. At first I was quite at a loss to understand the cause; afterward it occurred to me that it was owing to the following rather curious combination of

circumstances. It should, however, first be stated that corals are not able to survive even a short exposure in the air to the sun's rays, so that their upward limit of growth is determined by that of lowest water at spring tides. It appears, from some old charts, that the long island to windward was formerly separated by wide channels into several islets; this fact is likewise indicated by the trees being younger on these portions. Under the former condition of the reef, a strong breeze, by throwing more water over the barrier, would tend to raise the level of the lagoon. Now it acts in a directly contrary manner; for the water within the lagoon not only is not increased by currents from the outside, but is itself blown outward by the force of the wind. Hence it is observed that the tide near the head of the lagoon does not rise so high during a strong breeze as it does when it is calm. This difference of level, although no doubt very small, has, I believe, caused the death of those coral-groves which, under the former and more open condition of the outer reef, had attained the utmost possible limit of upward growth.

A few miles north of Keeling there is another small atoll, the lagoon of which is nearly filled up with coral-mud. Captain Ross found imbedded in the conglomerate on the outer coast a well-rounded fragment of greenstone, rather larger than a man's head: he and the men with him were so much surprised at this that they brought it away and preserved it as a curiosity. The occurrence of this one stone, where every other particle of matter is calcareous, certainly is very puzzling. The island has scarcely ever been visited, nor is it probable that a ship had been wrecked there. From the absence of any better explanation, I came to the conclusion that it must have come entangled in the roots of some large tree: when, however, I considered the great distance from the nearest land, the combination of chances against a stone thus being entangled, the tree washed into the sea, floated so far, then landed safely, and the stone finally so imbedded as to allow of its discovery, I was almost afraid of imagining

taken in north and south lines, through the islands with their barrier-reefs, of Vanikoro, Gambier, and Maurua; and they are laid down, both vertically and horizontally, on the same scale of a quarter of an inch to a mile.

It should be observed that the sections might have been taken in any direction through these islands, or through many other encircled islands, and the general features would have been the same. Now bearing in mind that reef-building coral cannot live at a greater depth than from 20 to 30 fathoms, and that the scale is so small that the plummets on the right hand show a depth of 200 fathoms, on what are these barrier-reefs based? Are we to suppose that each



1. Vanikoro. 2. Gambier Islands. 3. Maurua.
The horizontal shading shows the barrier-reefs and lagoon-channels. The inclined shading above the level of the sea (AA) shows the actual form of the land; the inclined shading below this line shows its probable prolongation under water.

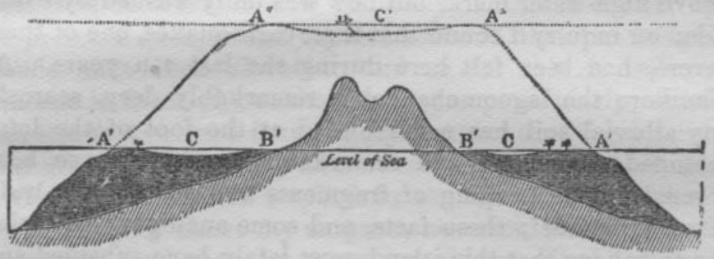
island is surrounded by a collar-like submarine ledge of rock, or by a great bank of sediment, ending abruptly where the reef ends? If the sea had formerly eaten deeply into the islands, before they were protected by the reefs, thus having left a shallow ledge round them under water, the present shores would have been invariably bounded by great precipices; but this is most rarely the case. Moreover, on this notion, it is not possible to explain why the corals should have sprung up, like a wall, from the extreme outer margin of the ledge, often leaving a broad space of water within,

by little on the shore, the island becoming lower and smaller and the space between the inner edge of the reef and the beach proportionally broader. A section of the reef and island in this state, after a subsidence of several hundred feet, is given by the dotted lines. Coral islets are supposed to have been formed on the reef; and a ship is anchored in the lagoon-channel. This channel will be more or less deep, according to the rate of subsidence, to the amount of sediment accumulated in it, and to the growth of the delicately branched corals which can live there. The section in this state resembles in every respect one drawn through an encircled island: in fact, it is a real section (on the scale of ·517 of an inch to a mile) through Bolabola in the Pacific. We can now at once see why encircling barrier-reefs stand so far from the shores which they front. We can also perceive, that a line drawn perpendicularly down from the outer edge of the new reef, to the foundation of solid rock beneath the old fringing-reef, will exceed, by as many feet as there have been feet of subsidence, that small limit of depth at which the effective corals can live: the little architects having built up their great wall-like mass, as the whole sank down, upon a basis formed of other corals and their consolidated fragments. Thus the difficulty on this head, which appeared so great, disappears.

If, instead of an island, we had taken the shore of a continent fringed with reefs, and had imagined it to have subsided, a great straight barrier, like that of Australia or New Caledonia, separated from the land by a wide and deep channel, would evidently have been the result.

Let us take our new encircling barrier-reef, of which the section is now represented by unbroken lines, and which, as I have said, is a real section through Bolabola, and let it go on subsiding. As the barrier-reef slowly sinks down, the corals will go on vigorously growing upward; but as the island sinks, the water will gain inch by inch on the shore—the separate mountains first forming separate islands within one great reef—and finally, the last and highest pinnacle

disappearing. The instant this takes place, a perfect atoll is formed: I have said, remove the high land from within an encircling barrier-reef, and an atoll is left, and the land has been removed. We can now perceive how it comes that atolls, having sprung from encircling barrier-reefs, resemble them in general size, form, in the manner in which they are grouped together, and in their arrangement in single or double lines; for they may be called rude outline charts of the sunken islands over which they stand. We can further see how it arises that the atolls in the Pacific and Indian



A′A′. Outer edges of the barrier-reef at the level of the sea, with islets on it. B′B′. The shores of the included island. CC. The lagoon-channel.
A″A″. Outer edges of the reef, now converted into an atoll. C′. The lagoon of the new atoll.
N. B.—According to the true scale, the depths of the lagoon-channel and lagoon are much exaggerated.

Oceans extend in lines parallel to the generally prevailing strike of the high islands and great coast-lines of those oceans. I venture, therefore, to affirm, that on the theory of the upward growth of the corals during the sinking of the land,[1] all the leading features in those wonderful structures, the lagoon-islands or atolls, which have so long excited the attention of voyagers, as well as in the no less wonderful barrier-reefs, whether encircling small islands or stretching

[1] It has been highly satisfactory to me to find the following passage in a pamphlet by Mr. Couthouy, one of the naturalists in the great Antarctic Expedition of the United States: "Having personally examined a large number of coral-islands, and resided eight months among the volcanic class having shore and partially encircling reefs, I may be permitted to state that my own observations have impressed a conviction of the correctness of the theory of Mr. Darwin."—The naturalists, however, of this expedition differ with me on some points respecting coral formations.

for hundreds of miles along the shores of a continent, are simply explained.

It may be asked, whether I can offer any direct evidence of the subsidence of barrier-reefs or atolls; but it must be borne in mind how difficult it must ever be to detect a movement, the tendency of which is to hide under water the part affected. Nevertheless, at Keeling atoll I observed on all sides of the lagoon old cocoanut 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: on inquiry I found that three earthquakes, one of them severe, had been felt here during the last ten years. At Vanikoro the lagoon-channel is remarkably deep, scarcely any alluvial soil has accumulated at the foot of the lofty included mountains, and remarkably few islets have been formed by the heaping of fragments and sand on the wall-like barrier-reef; these facts, and some analogous ones, led me to believe that this island must lately have subsided and the reef grown upward: here again earthquakes are frequent and very severe. In the Society Archipelago, on the other hand, where the lagoon-channels are almost choked up, where much low alluvial land has accumulated, and where in some cases long islets have been formed on the barrier-reefs—facts all showing that the islands have not very lately subsided—only feeble shocks are most rarely felt. In these coral formations, where the land and water seem struggling for mastery, it must be ever difficult to decide between the effects of a change in the set of the tides and of a slight subsidence: that many of these reefs and atolls are subject to changes of some kind is certain: on some atolls the islets appear to have increased greatly within a late period; on others they have been partially or wholly washed away. The inhabitants of parts of the Maldiva Archipelago know the date of the first formation of some islets; in other parts, the corals are now flourishing on water-washed reefs, where holes made for graves attest the former existence of inhab-