

An Amphibious Being: How Maritime Surveying Reshaped Darwin's Approach to Natural History

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Abstract: This essay argues that Charles Darwin's distinctive approach to studying distribution and diversity was shaped by his face-to-face interactions with maritime surveyors during the voyage of H.M.S. *Beagle* (1831–1836). Introducing their hydrographic surveying methods into natural history enabled him to compare fossil and living marine organisms, to compare sedimentary rocks to present-day marine sediments, and to compare landscapes to submarine topology, thereby realizing Charles Lyell's fanciful ambition for a superior form of geology that might be practiced by an "amphibious being." Darwin's theories of continental uplift, coral reef formation, and the origin of species all depended on his amphibious natural history. This essay contributes to our understanding of theorizing in nineteenth-century natural history by illustrating that specific techniques of observing and collecting could themselves help to generate a particular theoretical orientation and, indeed, that such practical experiences were a more proximate source of Darwin's "Humboldtian" interest in distribution and diversity than Alexander von Humboldt's writings themselves. Darwin's debt to the hydrographers became obscured in two ways: through the "funneling" of credit produced by single-authorship publication in natural history and the "telescoping" of memory by which Darwin's new theories made him recall his former researches *as though* he had originally undertaken them for the very purpose of producing the later theory.

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An amphibious being, who should possess our faculties, would . . . more easily arrive at sound theoretical opinions in geology. . . . [He] might mark, on the one hand, the growth of the forest, and on the other that of the coral reef.

—Charles Lyell, *Principles of Geology*, Volume 1 (1830)

Charles Darwin's intimate familiarity with the seafloor distinguished him from other naturalists of his day. He gained this knowledge through exposure to the activities of the maritime surveyors—hydrographers—with whom he circumnavigated the globe on H.M.S. *Beagle* from 1831 to 1836. The hydrographers furnished him with techniques for visualizing underwater topology and for taking samples from the bottom of the sea, and this in turn allowed his forays onto dry land to become opportunities for undertaking just the types of comparisons between terrestrial and submarine processes that the geologist Charles Lyell imagined being accomplished by an amphibious being. And indeed this method of comparison, when combined with the precise geographical knowledge yielded by the surveyors' work, became for Darwin a fruitful source of what Lyell called "sound theoretical opinions." In time this amphibious approach to natural history helped to generate Darwin's theory of compensatory geological uplift and subsidence, his theory of coral reef formation, and his theories of descent-with-modification.¹

It was significant not simply that hydrographers gave Darwin a chance to study the zoology, botany, mineralogy, and geology of the seafloor, but that their specific technique of sounding the depths predisposed him to study submarine animals, plants, rocks, and terrain *together* and to pay attention to their interrelations. The implement the hydrographers used, the sounding lead, captured samples in a fashion that went against the grain of ordinary natural history practice. Using the sounding lead meant gathering whatever was to be found in a particular location on the seafloor, rather than setting out to collect organisms belonging to a particular group. Decades before inventorying a patch of ground became the standard practice of a new science called ecology, Darwin was doing this on the spots of seafloor that had been touched by the sounding lead. Because this sampling of the seafloor was done in the course of a geographical survey, moreover, those specimens were enhanced from the beginning by data about the spatial location they inhabited and their depth below sea level. Those features of the underwater realm that Darwin was able to study through hydrography became his preoccupations on land as well: the interrelations between animals, vegetables, and minerals and their geographical distribution across space and altitude. And because most of the dry land he studied showed evidence of having formerly been under water, the ability to envision landscapes in their past submarine state turned into Darwin's most reliable method of thinking about change over time.

The matrix of practices and concepts I have just described as being a product of Darwin's exposure to the hydrographers' work resembles something Susan Faye Cannon named "Humboldtian science." Alexander von Humboldt was indeed a hero of Darwin's, and the geographical sensibility that underlay so much of Darwin's work is often seen as a consequence of his

¹ Darwin became a transmutationist before he developed the specific idea of natural selection in 1838. He initially viewed geographical change as the causal mechanism for the origin of new species. His understanding of the nature and history of this "geologico-geographical" change was derived from the amphibious program of natural history analyzed here. On Darwin's first evolutionary theory see Janet Browne, *The Secular Ark: Studies in the History of Biogeography* (New Haven, Conn.: Yale Univ. Press, 1983), pp. 182–194; Jane R. Camerini, "Darwin, Wallace, and Maps" (Ph.D. diss., Univ. Wisconsin, 1987); Sandra Herbert, *Charles Darwin, Geologist* (Ithaca, N.Y.: Cornell Univ. Press, 2005); Frank H. T. Rhodes, "Darwin's Search for a Theory of the Earth: Symmetry, Simplicity, and Speculation," *British Journal for the History of Science*, 1991, 24:193–229; and Alistair Sponsel, *Darwin's First Theory* (Chicago: Univ. Chicago Press, forthcoming).

admiration for Humboldt's *Personal Narrative* of his 1799–1804 travels in the Americas.² As is well known, Humboldt focused on the geographical distribution of plants and other phenomena—in altitude as well as across horizontal space—in several works that Darwin devoured before and during the voyage. I aim to show, however, that Darwin's orientation toward distribution (in three dimensions, no less) need not have emerged from reading Humboldt's books. As scholars in science studies have argued in emphasizing the importance of face-to-face interactions in the production of knowledge, it is difficult if not impossible to learn everything one needs to know about replicating an experiment or constructing an instrument merely by reading an instruction manual.³ Likewise, this essay illustrates that the face-to-face practical training available on the ship provided an impetus for Darwin's geographical orientation, which might otherwise be seen as the mere consequence of his reading. Rather, it was daily life aboard a survey ship, abounding in opportunities that Darwin could only have seized directly from working hydrographers, that disposed him to think and behave in ways that have retrospectively been dubbed “Humboldtian.”

In this essay's five sections, which follow the *Beagle* on its westward circumnavigation of the globe, I show how hydrography proved crucial to Darwin's work and came increasingly to underpin not only his observing but also the theories he developed. The locations or regions numbered on the accompanying map (see Figure 1) correspond to these five sections, and it will be useful now to summarize the development of my argument with reference to this geographical/chronological sequence.

Darwin discovered early in the voyage (Sect. I) that the everyday soundings aboard the ship provided an opportunity to procure small animal and plant specimens from the seafloor. This helped to convince him that the study of such “zoophytes” should be a major focus of his attention during the voyage, and it proved eventually to have profound implications for answering theoretical questions. Darwin's resulting familiarity with submarine organisms, rocks, and topology was decisive in shaping his influential interpretations of the geology of South America (Sect. II). He was to argue that the entire continent had been elevated from the ocean, describing the great terraces of Patagonia as former seabeds upraised by a series of gradual elevations. He did this, I demonstrate, not by reference to conjectural seabeds but by comparing those terraces to the actual seafloor he had studied through hydrography.

These ideas in turn made his amphibious gaze more acute, making possible the moment of insight that yielded his first well-known theory, a new explanation of coral reef formation (Sect. III). I argue (in contrast to the current prevailing wisdom, as I will explain in the conclusion of the essay) that Darwin conceived the theory for the first time at Tahiti in November 1835. The growth of coral reefs, so hazardous to navigation, was already a problem of such practical concern that the *Beagle*'s captain, Robert FitzRoy, had himself been instructed by

² On Darwin's relation to Humboldt see Susan Faye Cannon, *Science in Culture: The Early Victorian Period* (New York: Science History, 1978), Ch. 3; Camerini, “Darwin, Wallace, and Maps”; Robert J. Richards, *The Romantic Conception of Life: Science and Philosophy in the Age of Goethe* (Chicago: Univ. Chicago Press, 2002), Ch. 14; and Herbert, *Charles Darwin, Geologist*, pp. 12–17.

³ I am referring to scholarship on the importance of tacit knowledge in various types of scientific replication, as well as to the work of historians who have emphasized the inadequacy of textbooks as a means of inculcating a trainee with the values and competencies required to contribute to a scientific community. Among the former studies, my thinking has been shaped most heavily by H. M. Collins, *Changing Order: Replication and Induction in Scientific Practice* (London: Sage, 1985), Ch. 3; and Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, N.J.: Princeton Univ. Press, 1985), Ch. 6 (see esp. p. 281: “No one built a pump from written instructions alone.”). My strongest debts to the latter (allied) tradition of scholarship are to Andrew Warwick, *Masters of Theory: Cambridge and the Rise of Mathematical Physics* (Chicago: Univ. Chicago Press, 2003); and Gerald L. Geison and Frederic Lawrence Holmes, eds., *Research Schools: Historical Reappraisals, Osiris*, 1993, N.S., 8.

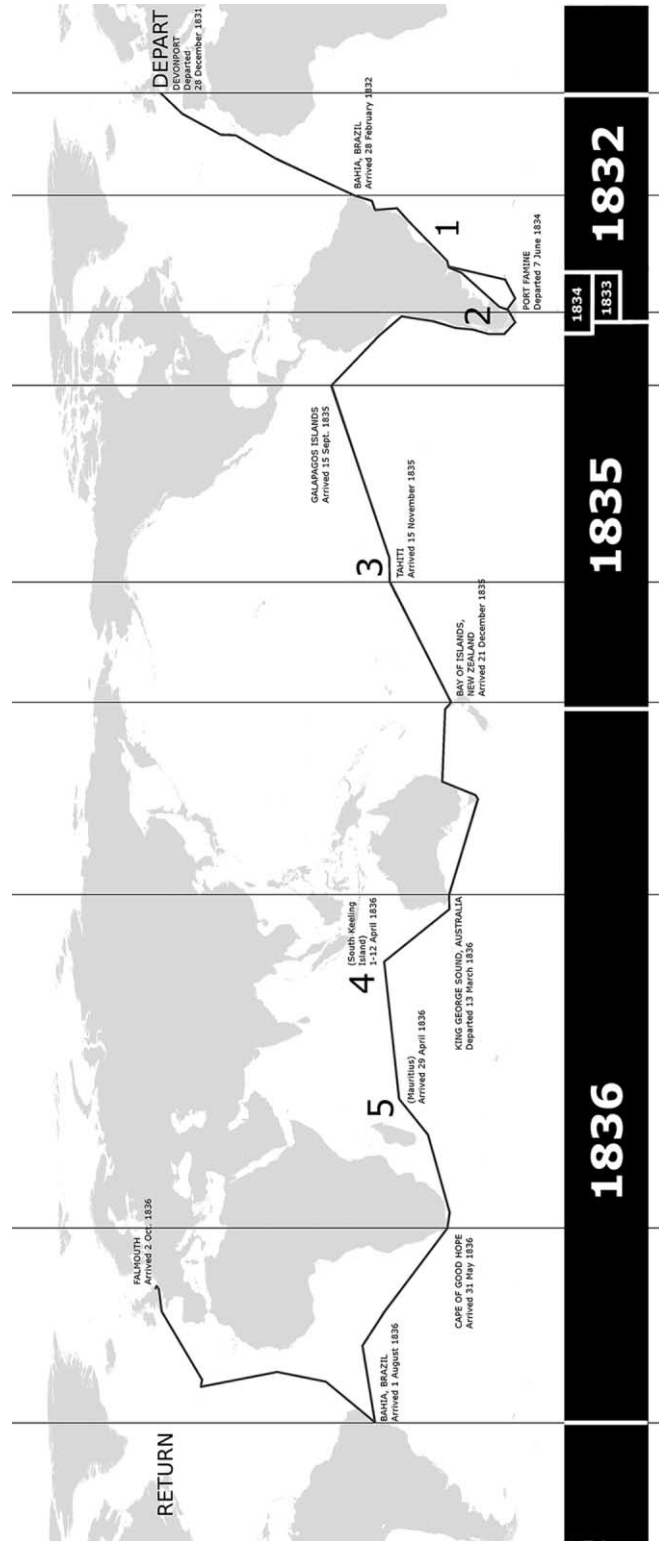


Figure 1. Track chart of H.M.S. *Beagle*'s 1831–1836 voyage. The Atlantic Ocean is shown twice on this chart so that the (simplified) track may be read as a continuous line from right to left. The numbers 1–5 correspond to the locations discussed in this essay. (Chart created by the author.)

the Admiralty to evaluate previous theories of reef formation during the voyage. Thus, as a consequence of Darwin's new coral theory he and the surveyors came to share not only a set of techniques and interests but even a specific rationale for their labors.

It is no mere coincidence that the coral reef theory Darwin developed through his hydrographic knowledge produced new hydrographic questions. Darwin's methods for underwater observing and collecting had helped to produce a theory that could only be tested by deeper observing and collecting of the same type. When the *Beagle* reached the coral island of South Keeling in the Indian Ocean (Sect. IV), Darwin's geological knowledge and zoological skill illuminated the surveyors' work, while their access to the watery deep provided a firmer foundation for his speculations. Soon afterward, however, when encountering the coral reefs of Mauritius, Darwin's desire to work was stymied by the fact that FitzRoy had no reason to do any surveying at this well-charted port of call (Sect. V). In order to resolve the questions that his theory could not yet answer, Darwin was forced to borrow the hydrographic equipment, take to a boat, and conduct a survey of his own. His wielding of the sounding lead at Mauritius confirms that hydrography had become indispensable to his work as a naturalist, serving as a basis for observing *and* theorizing.

If hydrography was so important to Darwin, why are surveying practices scarcely mentioned either in the general record of how Darwin spent his time during the voyage or in his own stories about the origin of particular ideas such as the coral reef theory? I will conclude this essay by arguing that there were two chief reasons why Darwin's specific, and considerable, debts to the surveyors' work have been overlooked. The first is the funneling of credit that occurred when collective activity yielded single-authored publications, whether they were hydrographic charts or scientific treatises. The second is what might be called the telescoping of memory that a theory produced—or that produced a theory. Thus my account contains arguments about both the social and the cognitive elements of theorizing by nineteenth-century naturalists.

This essay is part of my larger program of research analyzing the status of theory within natural history.⁴ Our understanding of theorizing as an activity has been enhanced in recent years by innovative work in the history of physics by Andrew Warwick and others.⁵ By examining the history of “theoretical physics” using a set of science-studies approaches that had been used to illuminate laboratory life and the history of experiment, these scholars demonstrated the degree to which even apparently abstract sciences depended on material culture, training, and technique. Taking a similar approach to the history of theorizing in natural history, however, raises distinct challenges, because natural history involved no explicit vocational division between experimentalists and theorists of the sort that emerged in the physical sciences.⁶ For Warwick and his colleagues, studying theorizing meant studying whatever it was that “theoretical physicists” actually spent their time doing. In contrast, as Sandra Herbert observed

⁴ I also pursue this question in Sponsel, *Darwin's First Theory* (cit. n. 1); and Alistair Sponsel, “From Specialization to Generalizations: Natural History Fieldwork and the Problem of Theorizing on the U.S. Exploring Expedition,” in *Soundings and Crossings*, ed. Katharine Anderson and Helen M. Rozwadowski (Sagamore Beach, Mass.: Science History, in press).

⁵ My thinking has been shaped by face-to-face interaction with the authors of the following works: Peter Galison and Andrew Warwick, “Introduction: Cultures of Theory,” *Studies in History and Philosophy of Modern Physics*, 1998, 29:287–294; Warwick, *Masters of Theory* (cit. n. 3); David Kaiser, *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives* (Cambridge, Mass.: MIT Press, 2005); and Suman Seth, *Crafting the Quantum: Arnold Sommerfeld and the Practice of Theory, 1890–1926* (Cambridge, Mass.: MIT Press, 2010).

⁶ To the extent that “theoretical” was synonymous with “mathematical,” the Cambridge mathematician William Hopkins came the closest at this time to participating in British natural history exclusively as a theorist. Lyell and Darwin were both indebted to Hopkins's modeling of the mechanical effects of a subterranean fluid on the overlying crust of the earth. See Herbert, *Charles Darwin, Geologist* (cit. n. 1), pp. 210–215.

some years ago, naturalists may have “had” theories but none defined themselves exclusively as “theorists.”⁷

In this essay I aim to offer an account of the everyday activities that led to “having” a theory, while acknowledging that to describe a nineteenth-century naturalist as a “theorist” would be both reductionistic and anachronistic. Rather, what I wish to show is the way in which theorizing was wrapped up in the other practices of natural history, such as collecting, observing, and comparing. This may seem merely to recapitulate the concept of “theory-laden observation,” but what I describe in this case would more aptly be called “observation-laden theory.” By this I do not simply mean “inductive reasoning,” or generalizing from particulars. What I mean is that certain *ways* of observing and collecting—certain specific natural history *techniques*—predisposed their practitioners to “have” theories that were oriented toward certain types of explanations. In Darwin’s case, the modes of observing and collecting he acquired from his hydrographic companions predisposed him to see—as he so famously did—the explanatory power that lay in attention to diversity and distribution.

I. THE SOUNDING LEAD AS A NEW TOOL FOR CONDUCTING NATURAL HISTORY: THE ATLANTIC

The formal purpose of the 1831–1836 voyage of the *Beagle* was to produce improved charts of the southeast and southwest coasts of South America, where revolutions against Spanish control in the 1810s and 1820s had opened new markets to British trade.⁸ The *Beagle*’s young commander, Robert FitzRoy, also carried a set of secondary instructions that would require him to continue from South America into the Pacific and Indian oceans in order to complete a circumnavigation. For example, he was ordered to investigate the treacherous type of coral reefs that we now call atolls, which had been terrifying European navigators for more than a century. FitzRoy was told to exert “every means . . . that ingenuity can devise” to determine the origin of the “circularly formed Coral Islands in the Pacific.” Recent voyagers had declared these ring-shaped reefs to be created by shallow-water corals that could live no deeper than 30 feet below sea level. Somehow, though, such reefs existed in parts of the ocean that were so deep as to be literally unfathomable with the lengths of rope usually carried by explorers. This apparent paradox had a solution that was endorsed by everyone from the geologist Charles Lyell to the navy’s chief hydrographer, Francis Beaufort: these so-called lagoon islands, or atolls, must be formed atop volcano craters lying at depths of less than 30 feet. Beaufort’s instructions to FitzRoy called this a “modern and very plausible theory.” Yet by the end of the voyage, Darwin had rejected it as “a monstrous hypothesis.”⁹ In its stead he developed a new theory that

⁷ Sandra Herbert, “The Place of Man in the Development of Darwin’s Theory of Transmutation, Part II,” *Journal of the History of Biology*, 1977, 10:155–227.

⁸ For an outstanding brief discussion of these issues see the editors’ introduction to Janet Browne and Michael Neve, eds., *Voyage of the Beagle: Charles Darwin’s Journal of Researches* (London: Penguin, 1989).

⁹ Francis Beaufort’s original instructions to FitzRoy, “Memoranda for Commander Fitzroy’s orders,” are recorded in Minute Book 2, 1831–1837, of the U.K. Hydrographic Office Archive, Taunton, on pp. 2–24. I will cite the version printed in Robert FitzRoy, *Narrative of the Surveying Voyages of His Majesty’s Ships Adventure and Beagle between the Years 1826 and 1836*, Vol. 2 (London: Henry Colburn, 1839) (hereafter cited as **FitzRoy, Narrative of the Surveying Voyages of His Majesty’s Ships Adventure and Beagle between the Years 1826 and 1836**), pp. 22–40 (the quotation here is from p. 38). For the remark about the “monstrous hypothesis” see Charles Darwin to Caroline Darwin, 29 Apr. 1836, in *The Correspondence of Charles Darwin*, ed. Frederick Burkhardt, 22 vols. to date (Cambridge: Cambridge Univ. Press, 1985–) (hereafter cited as **CCD**). (In citations of correspondence Charles Darwin will be referred to simply as “Darwin”; full names of other family members will be used.) On coral reefs as threats to navigation see Alistair Sponsel, “From Cook to Cousteau: The Many Lives of Coral Reefs,” in *Fluid Frontiers: New Currents in Marine Environmental History*, ed. John Gillis and Franziska Torma (Cambridge: White Horse, 2015), pp. 137–161.

gained him much of his early scientific acclaim (a theory, by the way, that is widely accepted today).¹⁰

At the time of the *Beagle's* departure from England in December 1831, Darwin's greatest scientific expertise lay in the field of marine zoology. He had been inducted into this study several years earlier by Robert Grant at the University of Edinburgh. They shared a particular interest in the zoophytes: small marine organisms straddling the apparent border between the animal and plant kingdoms, including solitary and colonial corals as well as some calcareous algae. Grant and others in Edinburgh at this time were developing a new style of marine zoology in which naturalists adapted the tools and skills of fishermen in order to gather specimens farther from shore and in deeper water.¹¹ Although this set of collecting practices became more strongly associated in the following decade with the work of Edward Forbes, Darwin too had acquired specimens by accompanying oyster dredgers and fishing trawlers from the harbor at Newhaven. Shortly after the *Beagle* put to sea Darwin improvised a means of resuming these activities. "I proved to day," he wrote in his diary on 10 January 1832, "the utility of a contrivance which will afford me many hours of amusement & work. — it is a bag four feet deep, made of bunting, & attached to a semicircular bow [that] is by lines kept upright, & dragged behind the vessel." The contraption yielded an abundant harvest of organisms "exquisite in their forms & rich colours," leaving Darwin to "wonder that so much beauty should be apparently created for so little purpose." This is one of the first known descriptions of a plankton net in use, and it reveals that Darwin boarded the *Beagle* already primed to develop novel methods for collecting marine specimens.¹² Life aboard a working survey vessel would prove to offer another prospect for collecting, however, and Darwin began to exploit this opportunity just a few weeks later.

Given his maritime experiences in Edinburgh, it should be no surprise that Darwin was fascinated to see the officers begin carrying out their survey in Brazilian waters between Bahia (present-day Salvador) and Rio de Janeiro. In March 1832 Darwin recorded in his diary that "the labours of the expedition have commenced. — We have laid down the soundings on parts of the Abrolhos, which were left undone by Baron Roussin." Determining the extent of these offshore shoals was one of Beaufort's official instructions to FitzRoy, and now the systematic accumulation of data caught Darwin's attention.¹³ Ever curious, he began to analyze the surveyors' results, albeit not within the records of his scientific work. Rather, it was on the *back* of a sheet of zoology notes that he began compiling a "table of thermometrical changes during

¹⁰ On the rise, fall, and revival of Darwin's coral theory see David R. Stoddart, "Darwin, Lyell, and the Geological Significance of Coral Reefs," *Brit. J. Hist. Sci.*, 1976, 9:199–218; Stoddart, "Theory and Reality: The Success and Failure of the Deductive Method in Coral Reef Studies—Darwin to Davis," *Earth Sciences History*, 1994, 13:21–34; and Herbert, *Charles Darwin, Geologist* (cit. n. 1). Darwin's theory is widely taken to have been confirmed in 1952, a notion I analyze in Ch. 5 and dispute in the conclusion of Alistair Sponsel, "Coral Reef Formation and the Sciences of Earth, Life, and Sea, c. 1770–1952" (Ph.D. diss., Princeton Univ., 2009).

¹¹ On Darwin's work with Grant see Phillip Sloan, "Darwin's Invertebrate Program, 1826–1836: Preconditions for Transformism," in *The Darwinian Heritage*, ed. David Kohn (Princeton, N.J.: Princeton Univ. Press, 1985), pp. 71–120. On the new style of marine zoology see Philip F. Rehbock, "The Early Dredgers: Naturalizing in British Seas, 1830–1850," *J. Hist. Biol.*, 1979, 12:293–368; and Helen M. Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea* (Cambridge, Mass.: Harvard Univ. Press, 2005), Ch. 4.

¹² Richard Keynes, ed., *Charles Darwin's Beagle Diary* (Cambridge: Cambridge Univ. Press, 1988) (hereafter cited as **Keynes, ed., Charles Darwin's Beagle Diary**), 11 Jan. 1832, p. 21; on the novelty of Darwin's plankton net see *ibid.*, p. 21 n 1.

¹³ *Ibid.*, 27–28 Mar. 1832, p. 48. On Beaufort's instruction see FitzRoy, *Narrative of the Surveying Voyages of His Majesty's Ships Adventure and Beagle between the Years 1826 and 1836*, Vol. 2, p. 25.



Figure 2. A sounding lead (pronounced like the metal from which it is made) and line. This hydrographic tool became crucial to Darwin’s work as a naturalist. A “hand lead” such as this one would have been roughly 8–12 inches tall and 6–12 pounds in weight. The base of the lead features a depression known as a “well,” which would be “armed” with soft tallow or wax. By this method a sample from the seafloor (or an impression of the bottom if it were clean) could be recovered. During the *Beagle* voyage Darwin made innovative use of his shipmates’ soundings as a method for acquiring geological, zoological, and botanical specimens from the seafloor. The epistemic value of these specimens was enhanced by the fact that geographical data (about the depth and location at which they had been found) was appended to them as an intrinsic feature of the surveyors’ work. (Image: The Mariner’s Museum.)

crossing and recrossing the bank.”¹⁴ He recorded the time of day when each sounding was taken, the water temperature to the quarter of a degree Fahrenheit, and the depth measured in fathoms (1 fathom = 6 feet). He had already learned to follow the hydrographic convention for indicating that no bottom had been found at a given depth by writing the length of the sounding line in fathoms and placing a dot beneath this number. It was on the third day of paying attention to the surveyors’ work that Darwin discovered something that made him begin to record hydrographic findings on the front side of the page, among his formal zoological notes.

When a sounding was taken, the concave bottom of the sinker, or lead (pronounced like the metal from which the tool was cast), was “armed” with soft tallow that would take an impression and capture a sample of any loose material on the seafloor (see Figure 2).¹⁵ Examining

¹⁴These entries were made on 26–28 Mar. 1832. See Richard Keynes, ed., *Charles Darwin’s Zoology Notes and Specimen Lists from H.M.S. Beagle* (Cambridge: Cambridge Univ. Press, 2000), pp. 31–32.

¹⁵Charles Hutton, *A Philosophical and Mathematical Dictionary* (London, 1815), “Sounding.”

the arming allowed chart makers to include details about the bottom so that navigators could estimate their location, if necessary, by sounding in the same waters. Darwin discovered that such seafloor samples also presented a wealth of information for an opportunistic naturalist.

On 28 March 1832, this time *within* his zoological notes, Darwin recorded that “10 miles West of Abrolhos; there came up with the lead (17 Fathoms) a piece of Fucus.— on which were growing numerous minute tufts of a Conferva.” Under his microscope, the harvest of this one sounding proved to be rich indeed. The filamentous alga he called conferva had “stems simple cylindrical white transparent jointed; end truncate; length 1/10 of inch, diameter 2/3000.” Looking even more closely, he saw that “on this minute plant & on a small coralline were crowded together a forest of numerous species of Bacillareès & Anthrodieès.”¹⁶ This experience showed him that one cast of the lead might produce multiple specimens *and* reveal their interrelations, as in this case diatoms were attached to a plant that was itself growing on another plant. At this moment, ninety days into the voyage, the sounding lead joined the dredge and the microscope among the tools with which Darwin’s scientific knowledge was built.

There were two distinctive things about the sounding lead as a collecting device. The first was that it sampled rocks, animals, and plants together, while preserving their relationships to one another, which helped to establish the links between Darwin’s geology, zoology, and botany that were later set in stone by his more famous land-based study of fossils. Second, the sounding lead drew samples from an identifiable fixed point. Not only that, but when the lead was wielded by hydrographers the geographical location of that fixed point was itself a matter of careful attention. This was much different from collecting marine specimens with an oyster dredge, as Darwin and other Edinburgh naturalists had recently begun to do. Dredges jumbled and disturbed material as they were dragged across the seafloor, rendering unknowable each specimen’s exact point of origin and destroying clues as to the mutual relations between specimens. Specimens from the lead, by contrast, could be attributed to a specific place, geographically and vertically, and to a set of conditions in which plants, animals, and rocks existed in exquisite interrelation.

In other words, collecting by sounding lead meant sampling indiscriminately in a precise location. Such an approach became standard practice for ecologists later in the century, but it stood in stark contrast to other tool-aided methods for collecting in early nineteenth-century natural history, in which a zoologist armed with a butterfly net, or a geologist with a hammer, might wander widely while sampling only insects or minerals, respectively. Here aboard the *Beagle* a new collecting tool was helping Darwin to link geology, botany, and zoology. Thanks to the surveyors’ expertise, he was considering these links geographically as well. It is true that Darwin’s hero, Humboldt, had championed recording just such details of location and vertical distance from sea level in his study of above-water vegetation. But Humboldt had himself previously been a surveyor of sorts. Before going to South America he studied the distribution of vegetation in mines near the Upper Rhine when he was the mining administrator of Freiberg.¹⁷

¹⁶This was recorded as specimen “392 not [in] spirits”; see Keynes, ed., *Charles Darwin’s Zoology Notes and Specimen Lists from H.M.S. Beagle* (cit. n. 14), p. 33. Nearby notes show that Darwin was likely drawing his taxonomic information from what he called the “Dic Class,” the seventeen-volume French natural history reference edited by Bory de Saint-Vincent: Jean Baptiste Genevieve Marcellin Bory de Saint-Vincent, ed., *Dictionnaire classique d’histoire naturelle*, 17 vols. (Paris: Rey & Gravier, 1822). *Bacillaria* and *Arthrodia*—or “Bacillareès & Anthrodieès,” as Darwin called them here—were unicellular algae of the sort now called diatoms.

¹⁷For reasons that will become clear in the conclusion to this essay, I am keen to examine the roots of Humboldt’s phytogeography in his Freiberg surveying work. I speculate that Humboldt’s training and practical work as a mining engineer played a role in generating his “geographical sensibility” similar to the role that I argue hydrography played for Darwin, particularly since Freiberg’s subterranean mines similarly introduced the factor of depth (i.e., negative elevation) to the study of distribution.

And it was the *Beagle's* surveyors who empowered Darwin to collect data like Humboldt, rather than Humboldt's books somehow dictating that Darwin would collect like a surveyor.

II. STUDYING DRY LAND WITH A MARITIME PERSPECTIVE: SOUTH AMERICA

The *Beagle* voyage was almost four years old by the time FitzRoy concluded his labors on the coast of South America and set a course for the Galapagos Islands in September 1835. Darwin had spent a great deal of time studying soundings and even more time rambling inland on a series of geological excursions across the Pampas and into the Andes. Along the way he came up with an idea that proved to be a crucial stimulus for his eventual theory of reef formation—and thus for his rapid ascent in the geological community after the voyage and for his eventual conversion to transmutation. This idea, which he had definitely established by the time he left South America, was that the floor of the Pacific Ocean must be sinking. It grew from his efforts to answer the principal geological question to which he had devoted himself in South America, that of when and how that continent had emerged from the ocean. The question was provoked by his recurring experience of discovering marine fossils well above sea level during a series of inland excursions on the east coast. Many historians have followed Darwin's lead in emphasizing the significant role these fossils played in shaping his interpretations of the continent's geological history.¹⁸

In this section I argue that Darwin's interpretations of these fossils—and, more importantly, of the history of the geological formations in which they were found—were a direct outcome of his attention to the ongoing hydrographic work being carried out on the *Beagle*. Because Darwin's familiarity with hydrography has previously been overlooked (by historians) or unstated (by Darwin in his later writings), his perception of various South American landscapes as former seafloors has been seen largely as an exercise in conjecture. *In fact, these perceptions were based on his intimate knowledge of the actual seafloor.* Because he could compare the physical features of the landscape with the surveyors' descriptions of submarine topology, and compare the sedimentary rocks and fossils he found on dry land with the present-day sediments and organisms collected by the sounding lead, Darwin was able to interpret South America's geological past in the manner of a truly amphibious being.

Darwin knew something about practicing terrestrial geology already. He had taken an interest in the subject after leaving the University of Edinburgh for Cambridge, and indeed he spent part of the summer before the *Beagle's* departure accompanying the Cambridge professor of geology Adam Sedgwick on a field trip.¹⁹ As the *Beagle's* company surveyed southward along the east coast of South America in 1832–1833, Darwin began to learn the geology of the continent during frequent excursions on shore. Northern Patagonia consisted of great terraces of land that appeared level to the naked eye and stretched for hundreds of miles between the Atlantic and the Andes. Though these terraces now stood tens or hundreds of feet above sea level, most of them were characterized by distinctive marine remains. Clearly, those organisms had lived in the sea before becoming embedded in layers of sediment, but in what fashion had the resulting sedimentary rocks come to occupy high, dry land? And how could such large tracts of the earth have been raised up without being deformed by the violence of the elevation?²⁰

Another puzzle was posed by a vast bed of gravel consisting of distinctive porphyry pebbles that seemed to have originated somewhere to the northwest, in the Andes. What agency,

¹⁸ See esp. Alan C. Love, "Darwin and Cirripedia Prior to 1846: Exploring the Origins of the Barnacle Research," *J. Hist. Biol.*, 2002, 35:251–289; and Herbert, *Charles Darwin, Geologist* (cit. n. 1).

¹⁹ James A. Secord, "The Discovery of a Vocation: Darwin's Early Geology," *Brit. J. Hist. Sci.*, 1991, 24:133–157; and Herbert, *Charles Darwin, Geologist*, pp. 39–47.

²⁰ Darwin considered, and rapidly dismissed, the possibility that the world ocean had receded on a massive scale.

Darwin wondered, could have transported a layer of pebbles so evenly across an area that he himself had traced “for more than 700 miles”? In an essay, “Reflection on Reading My Geological Notes,” written around March 1834, he considered the possibility that after a “vigorous elevation” of the seafloor these pebbles had been carried “by the retreating waters” from the “West foot of the Cordilleras [Andes]” to “a deeper sea.” Whatever the exact cause, Darwin felt sure that they had been distributed in a “short period.” Why did he conclude that they had moved rapidly? Because they were not “encrusted by stony small corallines.— (Which I always have noticed to be the case in these seas).”²¹ This statement is clear evidence that Darwin was reasoning by comparing knowledge gained from the sounding lead to that learned through his terrestrial geology.

The specific point of comparison in this case was with pebbles that emerged on the armed sounding lead. Darwin had become very familiar with the pebbles of the seafloor and with the fact that interesting organisms were often attached to them (see Figure 3). In this way, the survey not only provided Darwin with submarine geological and zoological specimens that might be of isolated interest, but also provided a more synthetic view of the seafloor’s physical conditions, its flora, and its fauna.

Thus Darwin was able to write of the Patagonian porphyry pebbles, “Whatever their origin, they mark a great change in the inhabitants of the ocean [for] during a succession of elevations [subsequent to the elevation of the gravel bed, and each producing another, lower plain] such shells as now exist— flourished on the successive lines of beach & were scattered over the bottom.” In other words, a series of elevations had converted new parts of the seafloor into dry land in such a recent geological period that the same organisms alive then could be found at present in the waters beneath the *Beagle*. Indeed, Darwin wrote to his Cambridge mentor John Stevens Henslow, “the most curious fact is that the whole of the East coast of [the] South part of S. America has been elevated from the ocean, since a period during which Muscles [i.e., mussel shells] have not lost their blue color.”²² The remains of sea creatures, some identical to those yet living, became his index of successive elevations.

Darwin’s technique of comparing terrestrial and submarine topology became a way of thinking about change over time, a macroscopic analogue to comparing fossil and living vertebrates. South American landscapes were fossil seafloors. No wonder that the familiarity with the undersea world Darwin had gained from the *Beagle*’s sounding operations gave him an advantage over land-bound geologists. He was becoming Lyell’s amphibious being, and he was able to do so because he had lived and worked aboard a surveying vessel. Uniting geological training with maritime experience was all but unprecedented. As he crowed to his sister Caroline during the voyage, “It is a rare piece of good fortune for me, that of the many errant (in ships) Naturalists, there have been few or rather no geologists. I shall enter the field unopposed.”²³

²¹ Darwin to John Stevens Henslow, 10 Mar. 1834, CCD. For Darwin’s essay see Sandra Herbert, “From Charles Darwin’s Portfolio: An Early Essay on South American Geology and Species,” *Earth Sci. Hist.*, 1995, 14:23–36, esp. pp. 30 (Darwin’s fol. 2), 31 (Darwin’s fols. 5–6); on the date of the manuscript see pp. 25–27. On the pebbles see Oscar A. Martinez, Jorge Rabassa, and Andrea Coronato, “Charles Darwin and the First Scientific Observations on the Patagonian Shingle Formation (Rodados Patagónicos),” *Revista de la Asociación Geológica Argentina*, 2009, 64:90–100.

²² Herbert, “From Charles Darwin’s Portfolio” (Darwin’s fol. 6); and Darwin to Henslow, 10 Mar. 1834, CCD. The preservation of the shells’ color was an indication that they had not been long (in geological terms) out of the water.

²³ Darwin to Caroline Darwin, 29 Apr. 1836, CCD. This style of reasoning from present to past was fundamental to the work of all serious geologists at this time, though it has been widely associated with Charles Lyell because of his assertion that present processes *operating at their observed intensities* were sufficient to explain past geological events. More generally, see Martin J. S. Rudwick, *Worlds before Adam: The Reconstruction of Geohistory in the Age of Reform* (Chicago: Univ. Chicago Press, 2008), Ch. 7.

12th May. 1834 118

Am		
10.	34	} sand or minute shingle.
11.	33	
12	41	
1	45	
2	48	
3	48	Shingle (Daphn. almost 1/2 line long. with
4	48	small Coralline shells on (sandy) Glass
5	53	do V 2008. shells
8	50	
12	70	
	15 th	
Am		
8	55	Minute Shingle do
		do
11	70	
12	86	do 1/10 to 20 (tra)
3	7?	do rather finer
		do
3.25	71 1/2	do fine with few pebbles 1/10 to 1/20 Echinus very
6	70	
8	87	Much greater abundance of quartz granules
12	100	all the more even sized. Rather granular &
		& some St. Julian Daph. more like sand:
Am. 14 th		
3.30	76	
8	102	as above + Beneath
12	80	
7 th		
4	80	Fine grey sand. May very minute black
6	48	white transparent quartz rounded granules
8	83	minute shingle. on piece. 3:1 San Juan, common
		for 1/10 to 1/50
Am 15 th		
3	51	minute shingle 1/40 or 1/50 +

Lat: 51. 48'
 Long: 64. 50'

Figure 3. 12 May 1834: "We sailed from S. Cruz. in a SW line to look for the L.Aigle rock. - I attended carefully to the Soundings." This page of Darwin's notes illustrates both the systematic collection of data by the surveyors and the close attention Darwin paid to their work. The entries running down the lefthand side of the page show the time of day when a sounding was made (first column) and the depth found (second column). The corresponding notes describe the type of bottom, the size of granules or pebbles recovered by the arming of the sounding lead, and the nature of any organic matter retrieved. Note the labor that must have been required for the ship's crew to haul up the line after soundings of up to 100 fathoms (600 feet) every two or three hours throughout the day. (Quotation from CUL DAR 34.1:90; pictured table from CUL DAR 34.2:118. This picture is reproduced with kind permission of the Syndics of Cambridge University Library.)

The first half of 1834 was also a crucial time in shaping Darwin's eventual view that the elevation of South America must have been offset by subsidence elsewhere. In "Reflection on Reading My Geological Notes" he posited three possible types of elevatory force: "It becomes a problem. how much the Andes owes its height. to Volcanic matter pouring out?— how much to horizontal strata tilted up.? how much to these horizontal elevations of the surface of continents?" Darwin's approach to answering this question was to depend on the hydrographers' work. "The only method" of solving this puzzle, he wrote, "is to compare the increased height of the plains in the interior between any two points, with the probable slope of the oceans bottom in the same distance."²⁴ Determining the slope of the ocean's bottom was, of course, an everyday task for his companions on the ship. While it was knowledge that only hydrographers could actually produce, Darwin by now took his firsthand access to such knowledge for granted.

Gradually, by 1835, he became convinced of the importance of what, in the quotation above, he called "horizontal elevation," which he also described as elevation "concentric" with the earth. Both terms were slightly misleading; they referred to bulging of the earth's crust on the order of thousands of square miles.²⁵ Unlike more localized injections of molten rock beneath the crust, or tilting of strata, gradual "horizontal" elevation would result in an apparently level uplifting of beds such as he saw in Patagonia. By early 1835 he conceived of the entire continent as having been uplifted in this manner. The Andes themselves, he believed, had been carried upward by this movement. They must have predated the continent and existed formerly as a chain of islands; as they were raised into mountains the surrounding land would have emerged from the sea. When, in February 1835, FitzRoy documented that an earthquake had elevated the coast of Chile by several feet in relation to sea level, Darwin gained confidence that this process was continuing by degrees.

Elevation of this sort must have been offset by subsidence of another part of the earth's crust, Darwin believed.²⁶ Where might this compensatory sinking of the crust be taking place? Darwin's first guess was that it was concealed from the geologist's gaze beneath the vast Pacific Ocean. As he had ranged into the Andes from the west coast in August 1834, Darwin had seen "immense flat valleys" that reminded him of the pebble beds of Patagonia. It seemed obvious that these level-bottomed valleys had once been on the seafloor when the mountains that towered above them had been islands. Thus, he concluded, the basin of the Aconcagua River had once "most clearly [been] marine with Islands."²⁷

In what I believe to be Darwin's first inkling that the bed of the Pacific must have been subsiding, he wrote on 18 August 1834 in his tiny field notebook, "With respect to [the] great valleys," which he saw as uplifted seabeds, "perhaps in Pacific if seen, wonder would be reversed." The words "if seen" could be taken as irony, because there was no direct way to look at the present-day Pacific floor and observe whether it had sunk to compensate for the elevation of these level valleys. There is a chance, though, that Darwin had a notion that he might one day "see" the bed of the Pacific via the same hydrographic practices that had already proved so

²⁴ Herbert, "From Charles Darwin's Portfolio" (cit. n. 21), p. 32 (Darwin's fol. 8); and Cambridge University Library (hereafter CUL), DAR34.1:45.

²⁵ In May 1834 he wrote, "NB When I say concentric. I mean not truly so. — but an enlargement of the curve of the world": CUL DAR34.2:110v.

²⁶ The alternative would be that the whole globe expanded when horizontal elevation occurred, which he found untenable in itself and which would have diverged wildly from the conventional wisdom of continental geologists who interpreted the mountains and valleys of the earth's crust as wrinkles caused by the ongoing *shrinking* of a cooling globe. See Mott T. Greene, *Geology in the Nineteenth Century: Changing Views of a Changing World* (Ithaca, N.Y.: Cornell Univ. Press, 1982), Ch. 2.

²⁷ Down House Notebook 1.15, CUL MS Microfilm 532.

useful off the Atlantic coast. What is beyond doubt is that by 29 May 1835 Darwin had decided to look for evidence that the bottom of the Pacific had subsided. On that day he wrote a letter to a geological acquaintance in Valparaiso named Robert Alison. Darwin's letter is not extant, but Alison's response referred to the *Beagle's* impending departure from South America by saying, "I wish much to hear of your report respecting the islands in the Pacific, and it will be curious if you find a sinking of the land there, & a rising here." Most likely Darwin was not optimistic that he could prove the action of a process whose effects would be hidden beneath the waves. The seafloor might be subsiding, but did he possess the necessary powers of submarine vision? One week after his letter to Alison he wrote to his sister Catherine: "I have lately been reading about the South Sea – I begin to suspect, there will not be much to see."²⁸

Meanwhile, Darwin's ongoing stints aboard the *Beagle* amplified his ambitions in marine zoology. In late 1832 he had begged Henslow to "recollect how great a proportion of time is spent at sea" as he regaled him with descriptions of the "new & curious genera" of pelagic animals caught in the trawl and the "interesting" zoophytes hauled up by the lead. "As for one *Flustra*," he raved, "if I had not the specimen to back me up, nobody would believe in its most anomalous structure." By the time he had immersed himself in the study of South America's geological origin in the summer of 1834, he was reporting to his family that "amongst Animals, on principle I have lately determined to work chiefly amongst the Zoophytes or Coralls: it is an enormous branch of the organized world; very little known or arranged & abounding with most curious, yet simple, forms of structures." To Henslow, a few days later, he claimed to have superseded Lamarck's understanding of coral polyp physiology and asserted that "the present families of Corallines, as arranged by Lamarck, Cuvier &c are highly artificial. – It appears they are in the same state which shells were when Linnaeus left them for Cuvier to rearrange."²⁹

Taking stock of Darwin's progress in his "chief object[s] of pursuit," geology and marine invertebrates, we find that the two activities were highly complementary. What needs emphasis is that they were tightly meshed with the labor and specific objectives of the surveyors. For example, Darwin wanted to know the elevation of every formation he saw; Beaufort had instructed that "it should be considered an essential branch of a nautical survey, to give the perpendicular height of all remarkable hills and headlands." Darwin was eager to compare the inclination of the continent above and below sea level; FitzRoy had been commanded not merely to map undersea terrain, but "to note with accuracy the slope, or regularity, of the depths," along with "the quality of their various materials, and the disposition of the coarse or fine parts, as well as of what species of rock in the neighbourhood they seem to be the detritus."³⁰ And collecting via hydrography had led Darwin to ask questions of terrestrial geology that could be answered only by further knowledge of the seafloor.

III. THE MAKING OF A EUREKA MOMENT: TAHITI

There is no evidence that prior to the *Beagle's* arrival at Tahiti on 15 November 1835 Darwin had conceived any new answer to the questions of how and why ring-shaped coral reefs were formed—or even that he had actively contemplated these questions.³¹ By the time the ship departed eleven days later, he had written a coy note in his diary that reveals that he had gained,

²⁸ *Ibid.*; Robert Alison to Darwin, 25 June 1835, CCD; and Darwin to Catherine Darwin, 31 May 1835, CCD.

²⁹ Darwin to Henslow, 26 Oct.–24 Nov. 1832, CCD; Darwin to Catherine Darwin, 9–20 July 1834, CCD; and Darwin to Henslow, 24 July–7 Nov. 1834, CCD.

³⁰ Darwin to Henslow, 18 May–16 June 1832, CCD; and FitzRoy, *Narrative of the Surveying Voyages of His Majesty's Ships Adventure and Beagle between the Years 1826 and 1836*, Vol. 2, p. 34.

³¹ This statement contradicts the current consensus of Darwin scholarship; see my rebuttal in the conclusion of this essay.

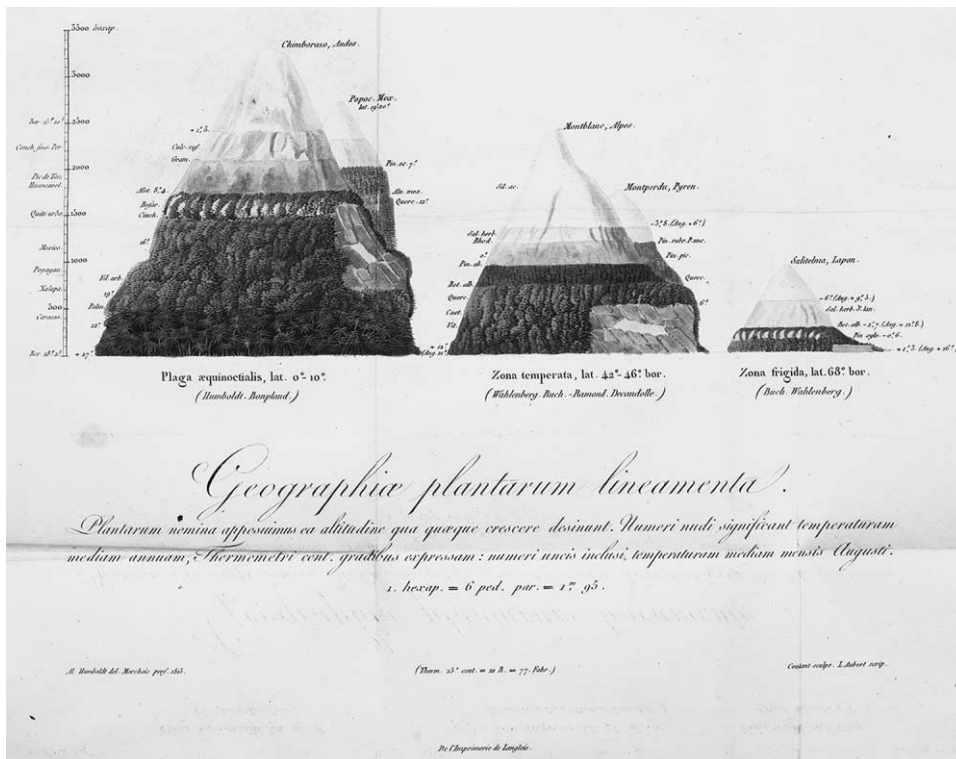


Figure 4. Zonation of vegetation on mountainsides. This 1817 diagram by Alexander von Humboldt illustrates a phenomenon that Darwin encountered when climbing Tahiti: distinctive floras grew in bands around the island, each one characteristic of the climatic conditions at a given elevation. (Image: Linda Hall Library of Science, Engineering, and Technology.)

in addition to his ambitions in coral zoology, a sudden confidence that he could overturn the prevailing theory of reef formation. Then, during the long passage from Tahiti to New Zealand, he drafted an essay in which he described a eureka moment at Tahiti and sketched the outlines of an elegant and breathtakingly original theory that claimed to explain the origin of virtually all the reefs in the Pacific.

I now recreate the circumstances that led to Darwin's moment of insight and argue that the insight itself depended on his ability to envision the underwater terrain and its inhabitants with the eyes of a hydrographer (see Sect. I) and his desire to determine whether the islands of the Pacific appeared to be sinking (see Sect. II). I identify two further factors specific to Tahiti that, when combined with the knowledge and expectations Darwin brought to the island, made his eureka moment possible. The first of these, which was recorded explicitly in Darwin's notes, was the vantage offered on the land- and seascape of the Society Islands by climbing high up Tahiti's mountainous slopes. The second local factor, which Darwin described in his diary but which neither he nor any other scholar has previously linked explicitly to his coral theory, was the striking succession of different types of plants he witnessed while ascending the mountain-side at Tahiti. This was a particularly impressive manifestation of the phenomenon of plant "zonation" according to altitude, which Humboldt had depicted, in iconic diagrams, as distinct rings of vegetation encircling mountains at different elevations (see Figure 4). I argue that Darwin's new account of how rings of shallow-water corals could grow in the deep ocean was

nothing less than the submarine equivalent of Humboldt's celebrated vision of the distribution of land plants (see Figure 5). Darwin was not yet the rabid (and indebted) Lyellian he would become after the voyage; his view of the world still owed much more to Humboldt.³² But his hydrographic perspective had led him unconsciously to the very analogy Lyell imagined might be drawn by a truly amphibious geologist, that between the forest and the coral reef.

Upon arriving at the breathtaking peaks of Tahiti after spending nearly a month as a speck on the seemingly limitless ocean, Darwin sought perspective on his surroundings. Rather than climbing a mast, as he had done earlier in the Pacific passage when straining for a glimpse of coral islands, he hired guides to lead him up the nearest canyon. Ascending to a height of several thousand feet, he realized that he had climbed through a series of discrete zones of vegetation. Moving vertically uphill from sea level gave him the uncanny feeling that he was moving horizontally across great portions of the globe, as though he were moving northward from the equator back toward his home. Halfway up, after coarse grass had succeeded the dwarf ferns below, Tahiti began to look strangely familiar. "The appearance was not very dissimilar from that of some of the hills in North Wales; and this so close above the orchard of Tropical plants on the coast was very surprising." He pressed onward, until "trees again appeared . . . tree ferns having replaced the Cocoa Nut." This was a remarkable experience, but one that he might have expected on such a steep climb, for the first pages of Darwin's favorite book asserted that "each group of plants is placed at the height that nature has assigned." "These regions," Humboldt argued in the *Personal Narrative*, "form the natural divisions of the vegetable empire; and in the same manner as the perpetual snows are found in every climate at a determinate height, [plants] have also their fixed limits."³³ Humboldt's plant geography, like his study of snowlines, famously illustrated that climbing in elevation was equivalent to climbing in latitude.

Darwin had doubtless seen Humboldt's iconic depictions of the succession of flora on the flanks of Chimborazo, which was then believed to be the highest mountain in the world, and he knew of Humboldt's claims to have determined "according to barometrical measurement, in more than 4000 plants of the equinoctial region, the height of each station above the level of the sea."³⁴ However, he had never seen such a vibrant manifestation of this phenomenon until he arrived at Tahiti, where a succession of distinct floras ringed the mountain in a series of living contour lines.³⁵

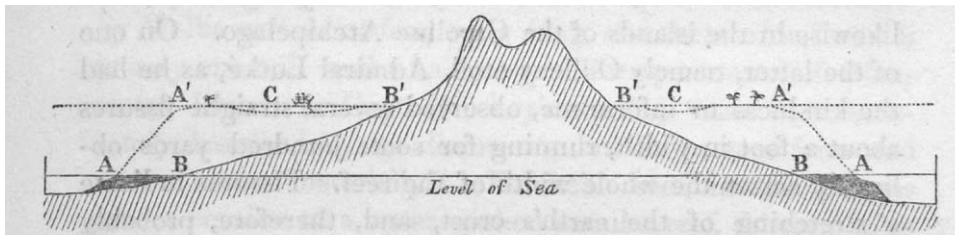
At this moment, as Darwin stood "two or three thousand feet" above Matavai Bay, it suddenly mattered that he had arrived at the Pacific already believing that the seafloor might be sinking. Here, I believe, is where ideas he had formed in South America gained new and unanticipated meaning. Darwin turned west toward the island of Eimeo (present-day Moorea). Lying fifteen miles distant, it was a smaller version of the jagged mountain he had just climbed. Like Tahiti, Eimeo rose up from within an offshore barrier reef. He likened the island to an engraving, which instead of being bordered by a mat within a frame was surrounded by a lagoon within a reef.

³² On Lyell's later intensive private and public fashioning of Darwin into the quintessential advocate for his geological principles see Sponcel, *Darwin's First Theory* (cit. n. 1).

³³ Keynes, ed., *Charles Darwin's Beagle Diary*, 17 Nov. 1835, p. 368; and Alexander von Humboldt and Aimé Bonpland, *Personal Narrative of Travels to the Equinoctial Regions of the New Continent during the Years 1799–1804*, trans. Helen Maria Williams (London: Longman, Hurst, Rees, Orme, & Brown, 1818), p. xxvi (this was the translation read by Darwin).

³⁴ Alexander von Humboldt, "New Inquiries into the Laws Which Are Observed in the Distribution of Vegetable Forms" [anonymous translation], *Edinburgh Philosophical Journal*, 1822, 6:273–279, on p. 279.

³⁵ This was, incidentally, the period when the use of the cartographic convention of the contour line, or isohypse, was becoming common. The use of isobaths (contours of a given depth) in hydrographic charts, on the other hand, was already well established. See Arthur H. Robinson, "The Genealogy of the Isopleth," *Cartographic Journal*, 1 June 1971, 8(1):49–53.



[No. 4]

A A—Outer edge of the reef at the level of the sea.

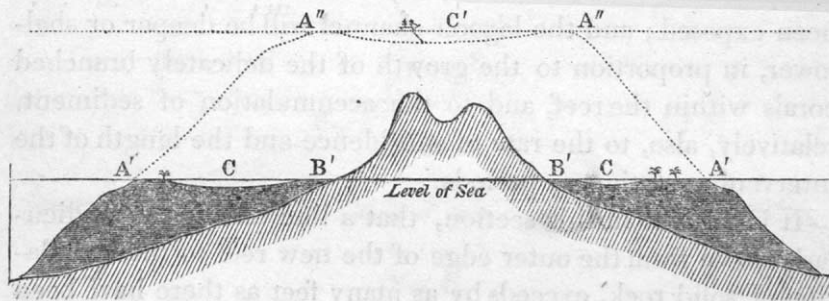
B B—Shores of the island.

A' A'—Outer edge of the reef, after its upward growth during a period of subsidence.

C C—The lagoon-channel between the reef and the shores of the now encircled land.

B' B'—The shores of the encircled island.

N.B. In this, and the following wood-cut, the subsidence of the land could only be represented by an apparent rise in the level of the sea.



[No. 5.]

A' A'—Outer edges of the barrier-reef at the level of the sea. The cocoa-nut trees represent coral-islets formed on the reef.

C C—The lagoon-channel.

B' B'—The shores of the island, generally formed of low alluvial land and of coral detritus from the lagoon-channel.

A'' A''—The outer edges of the reef now forming an atoll.

C'—The lagoon of the newly-formed atoll. According to the scale, the depth of the lagoon and of the lagoon-channel is exaggerated.

Figure 5. Sectional diagrams from Charles Darwin, *The Structure and Distribution of Coral Reefs* (London: Smith, Elder, 1842), pp. 98, 100. The upper diagram shows the proposed transition from fringing reef to barrier reef by the action of coral growth during subsidence. The lower diagram shows the transition from barrier reef to atoll by subsidence. In each diagram the depiction of the barrier reef stage was based on an actual survey of the barrier reef that encircles the island of Bolabola (Bora Bora), and the other stages were conjectural. Note the similarity between these images and the illustration by Humboldt (see Figure 4). In both cases, vegetative growth is shown as occurring within specific elevation (or depth) zones on the side of a mountain. (Images courtesy of the History of Science Collections, University of Oklahoma Libraries; copyright the Board of Regents of the University of Oklahoma.)

The notes he wrote about this moment do not say why he began to ponder the subsidence of the ocean floor—or even that he did so. They mention only the consequence of doing so, of imagining that Eimeo was in the process of sinking out of sight: “Viewing the Ei Meo from the heights of Tahiti I was forcibly struck with this opinion. . . . Remove the central group of mountains, & there remains a Lagoon I[sland].”³⁶ If Eimeo were drawn downward below the sea while the reef around it continued to grow, Darwin realized, all that remained would be a circular reef enclosing an empty lagoon. While staring at a barrier reef, he had perhaps just solved the puzzle of how atolls are formed: not atop submarine volcano craters but as a result of corals growing upward at the circumference of a sinking island.

In order for the reef to remain visible while Eimeo sank out of sight, corals would have to continue to grow in the zone of water just below sea level. It seems no coincidence that Darwin had this idea immediately after pondering the vertical distribution of plants while climbing to this vantage point. I contend that Darwin recognized these rings of coral as equivalent to the bands of flora that were encircling Tahiti above the sea. After all, didn’t corals grow like a turf of vegetation wherever a suitable foundation lay at the appropriate depth? Just as plants would migrate up the mountainside if Eimeo sank, coral “vegetation” would grow upward and remain in the zone just below the surface. Like the snowline that marked a boundary in Humboldt’s diagrams of mountain vegetation, the waterline constituted a fixed limit for the upward growth of corals. Darwin had realized that the same principle constraining the geography of plants on the Andes was applicable to the vegetative growth of zoophytes on the flanks of submarine mountains.

Darwin had been waiting for four years to get a look at the zoophytes responsible for building coral reefs. He continued for several days to explore Tahiti’s higher altitudes, so it was not until 22 November that he finally fulfilled his wish. He did so in an outrigger canoe paddled by hired men. Farthest from shore he found a “mound of Coral rock, strikingly resembling an artificial (but low) breakwater,” fronting the open ocean. Inside the line of whitecaps marking the reef’s highest point was a broad tract of uneven coral. This inner reef reached anywhere from 100 yards to a mile shoreward from the breakers. It was covered by the calm lagoon waters, which deepened as the reef disappeared toward the island, leaving inner harbors “where a ship can anchor in a fine Sandy bottom.”³⁷

While examining the lagoon at Tahiti, Darwin was especially eager to discern whether different types of organisms created different parts of the reef. The main constituents of the inner reef were “stony & branching generas” and “Fungia & Caryophyllia.” The calm water of the lagoon seemed a haven for “admiring the pretty branching Corals.” He collected a specimen of *Fungia* and kept it alive long enough to study the “considerable powers of contracting & motion” of the polyps under his microscope.³⁸ He hoped to compare these specimens with corals living on the other side of the reef, in the water of the open ocean, but the men were unable to take him there “owing to the surf . . . breaking violently on the outer margin, continuously pump[ing] over in sheets the water of its waves.” Instead he relied on the testimony of the Tahitians themselves. “Showing [lagoon corals] 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 [corals] such as [the genera] Porites. Millepora.

³⁶ David R. Stoddart, ed., “Coral Islands by Charles Darwin,” *Atoll Research Bulletin*, 1962, 88:1–20, on p. 7.

³⁷ Keynes, ed., *Charles Darwin’s Beagle Diary*, 22 Nov. 1835, p. 378; and Stoddart, ed., “Coral Islands by Charles Darwin,” p. 10.

³⁸ Stoddart, ed., “Coral Islands by Charles Darwin,” p. 11; Keynes, ed., *Charles Darwin’s Beagle Diary*, 22 Nov. 1835, p. 378; and “Fungia,” specimen 1334, in Keynes, ed., *Charles Darwin’s Zoology Notes and Specimen Lists from H.M.S. Beagle* (cit. n. 14), p. 301.

& some *Meandrina* & *Astrea*. Anyhow, they considered that there is a wide distinction in the two cases.” All his former experience studying the contents of his dredge and the armings of the sounding lead encouraged him to believe his Tahitian informants. “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 [lagoons].”³⁹ He was convinced that the massive reef builders could only inhabit the outer margin, meaning that they would grow upward, but not inward over the reef flat, if an island they fringed were to sink. This explained why atolls continued to have lagoons rather than becoming covered over by a solid cap of coral rock.

Tahiti was a revelation. The combination of Darwin’s high-altitude eureka moment and his study of the reef from sea level led him to make one of the boldest entries to be found in his entire *Beagle* diary. Upon determining that the up-close details of the reef offered nothing to contradict his speculations from the mountainside, he wrote, “It is my opinion, that besides the avowed ignorance concerning the tiny architects of each individual species, little is yet known, in spite of the much which has been written, of the structure & origin of the Coral Islands & reefs.”⁴⁰ All his ambitions are revealed in this brief note. Earlier in the voyage he had decided to study corals—the “tiny architects,” he called them here—precisely because he relished the opportunity to gain expertise in an area of “avowed ignorance.” Now, unexpectedly, he could also challenge the “much which ha[d] been written” on a glamorous theoretical problem that animated Beaufort and Lyell.

IV. SHARED QUESTIONS: SOUTH KEELING

Four years into his sojourn with the maritime surveyors, Darwin had developed a theory whose key predictions could only be tested by hydrography. In this section and the next, I examine the two opportunities Darwin received to make a close personal study of living coral reefs. These visits took place under very different circumstances and offer contrasting case studies in Darwin’s fieldwork. On both occasions he was eager to understand the distribution of different kinds of corals on different parts of the reef and to determine whether the submarine structure of each reef had the characteristics predicted by his theory. The critical distinction between the two visits was that FitzRoy carried out a survey at one of these locations but not the other. South Keeling was a remote and little-examined outpost, so he and the officers conducted a full hydrographic survey of the reef. Mauritius, on the other hand, was a well-established depot, and there was no reason for FitzRoy to conduct a fresh survey. I argue that comparing Darwin’s activities while studying these two reefs reveals the extent to which he had come to depend on his shipmates’ work. During the course of the voyage, the hydrographic survey had become absolutely indispensable. So when it turned out that FitzRoy would not be surveying the Mauritius reefs, Darwin felt that he had no choice but to take to a boat and play the role of hydrographer himself.

Brimming with confidence after departing the site of his eureka moment, Darwin spent the December 1835 passage from Tahiti to New Zealand writing a detailed statement of the theory, a twenty-page essay entitled “1835 Coral Islands.” The *Beagle* was crossing the very waters in which Beaufort had expected FitzRoy to carry out his coral island surveys. Exhausted by the survey of South America, however, FitzRoy chose to sail on without stopping. Thus when writing out his essay Darwin admitted that he had “scarcely seen anything of the Coral islands

³⁹ Stoddart, ed., “Coral Islands by Charles Darwin,” pp. 10, 11.

⁴⁰ Keynes, ed., *Charles Darwin’s Beagle Diary*, 23 Nov. 1835, p. 378.

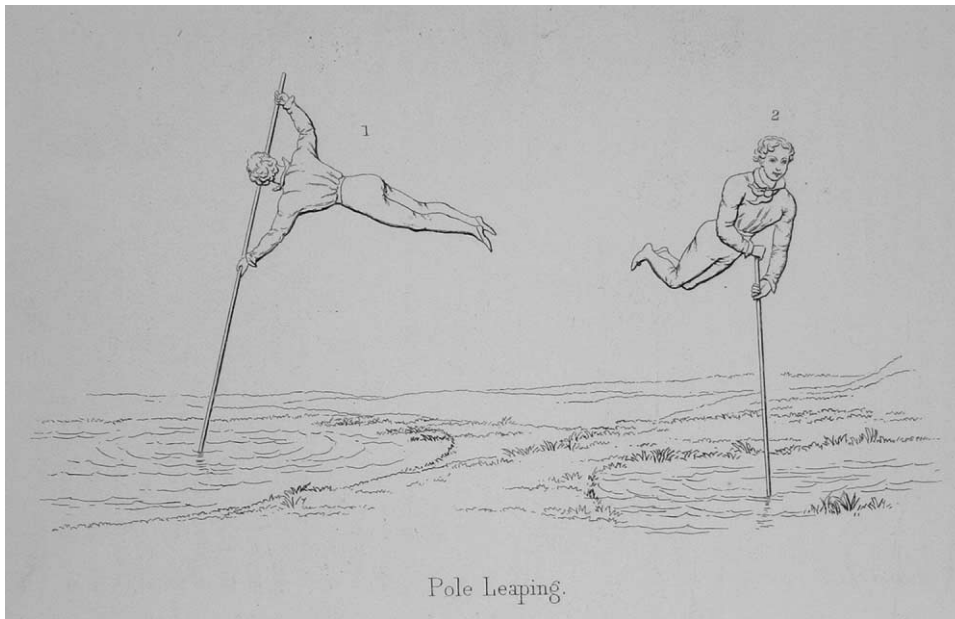


Figure 6. “Pole Leaping.” An illustration demonstrating the use of the leaping-pole, from *Walker’s Manly Exercises* (1860). Darwin originally used leaping-poles in the fashion pictured here, to cross ditches, during his entomological rambles. During the *Beagle* voyage he drew on this experience in order to examine the “furthest mound [of coral at Keeling Island], which I was able to reach by the aid of a leaping-pole, and over which the sea broke with some violence.” (Quotation from Charles Darwin, *The Structure and Distribution of Coral Reefs* [London: Smith, Elder, 1842]. Image reproduced with the permission of the Johns Hopkins University Library.)

in the Pacific Ocean.”⁴¹ Only in the last months of the voyage, once in the Indian Ocean after visiting New Zealand and both eastern and western Australia, did FitzRoy finally take the opportunity to survey a coral island as Beaufort had ordered. He elected to call at the Keeling Islands (which are now an Australian territory known as the Cocos [Keeling] Islands), a pair of ring-shaped reefs situated 700 miles southwest of Java and Sumatra. The *Beagle* sailed into the lagoon of South Keeling through a channel in the reef and remained for ten days. With his new theory of reef formation in mind, Darwin turned his attention toward the points of evidence that might determine whether this structure had taken its shape from an underlying submarine crater (as his contemporaries theorized) or from the subsidence of a reef-fringed island.

Darwin began with traditional, above-water natural history fieldwork while the hydrographers waited for high winds to die down. Proceeding over multiple paths from the breakers to the lagoon, Darwin collected twenty-four zoological and eighteen geological specimens. He desperately wanted to see the strong corals that formed the outermost bulwark of the reef, so he used a “leaping-pole” to vault onto coral heads among the foaming breakers of the Indian Ocean (see Figure 6). Peering down, he continued to find patterns in the distribution of various genera within what FitzRoy called “under-water forests of the Keeling islands,” diverse

⁴¹ The original manuscript is at CUL DAR41:1–12 (Darwin’s pp. 1–22), while CUL DAR41:13–22 is a fair copy probably made by Darwin’s servant, Syms Covington.

reefs whose various builders exhibited “more difference than between a lily of the valley and a gnarled oak.”⁴²

Darwin’s leaping-pole had propelled him to the very limit of the terrestrial world, allowing him to peer into the breakers at the seaward margin of the reef. However, the evidence that could reveal the island’s deeper history lay beyond the reach of the leaping-pole and the geological hammer, beyond the terrestrial way of seeing. As Lyell had argued in the *Principles of Geology*, the ideal observer of a coral reef would be an amphibious being who could see beneath the waves. In the surveyors’ hydrographic work, Darwin found just such an extension of his senses. Beaufort’s instructions to FitzRoy had urged him to use “every means . . . that ingenuity can devise of discovering at what depth the coral formation begins, and of what materials the substratum on which it rests is composed.” Further, “the slope of its sides” was to be “carefully measured . . . by a series of soundings, at very short distances from each other.”⁴³ The effect of sounding in such a systematic manner in radial lines moving away from the reef would be to extend the traverses that Darwin had conducted above water.

Beaufort (and Lyell) had envisioned such coral reef soundings providing the crucial evidence needed in order to gauge the relative merits of the crater-rim theory and an earlier notion, J. F. Eschscholtz’s claim that reefs grew up from deeper foundations.⁴⁴ But the approach would serve even better to evaluate Darwin’s theory. If the foundation of the reef came close to the surface and had the outline of a volcano, or if subaqueous lavas were found at shallow depths, it would offer support for Lyell and for the French naturalists who had originally posited a depth limit for coral growth, J. R. C. Quoy and Joseph Paul Gaimard. Alternatively, because there appeared (according to Humboldt himself) to be a limit on the inclination at which lava could harden into rock on the side of a volcano, a foundation that sloped more steeply than the sides of known volcanic cones would suggest that the reef had been built up by corals. Convinced that reef-building corals could not grow at any significant depth, Darwin seems never to have given serious consideration to Eschscholtz’s older theory. Therefore, if the surveyors were to find a steep inclination of the reef’s foundation, Darwin would consider it strong evidence that corals had grown straight upward from a subsiding foundation in the manner he envisioned. During the previous four years Darwin had found an ever-increasing number of ways to learn from the *Beagle*’s hydrographic enterprise; finally, here at South Keeling, his objectives had become almost indistinguishable from those of the officers.

Darwin’s Keeling field notes reveal a naturalist collaborating intimately with the hydrographers at work. Not only did Darwin record the detailed results of forty-six individual soundings and summarize the findings of several times that many; he quoted more than a dozen comments about the island directly from FitzRoy, who had by this time read and commented on a written draft of Darwin’s coral theory, and Lieutenant B. J. Sullivan (whose name Darwin inevitably misspelled in his notes as the more conventional “Sullivan”).⁴⁵ The full scope of Sullivan’s contributions to the ideas Darwin developed during the voyage is difficult to assess, but it was probably considerable. Still surviving among Darwin’s manuscripts from the voyage are several

⁴² FitzRoy, *Narrative of the Surveying Voyages of His Majesty’s Ships Adventure and Beagle between the Years 1826 and 1836*, Vol. 2, p. 634. On Darwin’s coral specimens from South Keeling see Brian Roy Rosen and Jill Darrell, “A Generalized Historical Trajectory for Charles Darwin’s Specimen Collections, with a Case Study of His Coral Reef Specimen List in the Natural History Museum, London,” in *Darwin tra scienza, storia e società: 150o anniversario della pubblicazione di Origine delle specie*, ed. Francesco Stoppa and Roberto Veraldi (Rome: Edizioni Univ. Romane, 2010), pp. 133–198.

⁴³ FitzRoy, *Narrative of the Surveying Voyages of His Majesty’s Ships Adventure and Beagle between the Years 1826 and 1836*, Vol. 2, p. 38.

⁴⁴ Sponsel, “Coral Reef Formation” (cit. n. 10), Ch. 1.

⁴⁵ The fair copy of the essay (see note 41, above) contains annotations by Darwin and FitzRoy.

diagrams of reef structure drawn in Sullivan's fine hand and accompanied by descriptions of areas Darwin had not visited. The friendship they forged during the voyage flourished for the rest of their lives. Their shared hours in the *Beagle's* poop cabin surely included conversations in which Darwin discussed his theories and Sullivan extemporized on the hydrographic work he and his fellow officers had undertaken.

At Keeling the presence of corals made sounding particularly difficult. As Darwin remarked in his notes, FitzRoy's mate Peter Benson Stewart "carried away [i.e., lost] his anchor in 13 [fathoms] & [his] lead in 16. F: The Capt[ain] when sounding in 10 & 12 fathoms frequently had the lead jammed so as not to be without much difficulty to extricate it.— How then rough the bottom must be." FitzRoy himself declared, "I was anxious to ascertain if possible, to what depth the living coral extended, but my efforts were almost in vain, on account of a surf always violent, and because the outer wall is so solid that I could not detach pieces from it lower down than five fathoms." The captain spared no effort, however, as "small anchors, hooks, grappling irons, and chains were all tried—and one after another broken by the swell almost as soon as we 'hove a strain' upon them with a 'purchase' in our largest boats." It devolved upon Darwin to diagnose both the type and the present condition of the deeper corals by the impressions they left in the "tallow hardened with lime" that FitzRoy packed into the bottom of his broadest lead. In his notes Darwin gave a special mark of emphasis to one of FitzRoy's early soundings on the outer margin. From a depth of 8 fathoms (48 feet), the tallow came up "beautifully marked with *Astrea*," the bulwark coral genus that Quoy and Gaimard had claimed must live within 30 feet of the surface. Seeing that it was "probably alive" (because the tallow was "quite clean" and free of the sand that could accumulate freely on a surface of dead coral), this sounding alone demanded a small revision to current zoological knowledge. Gradually Darwin drew broader conclusions about the extent of the living reef: to a depth of 12 fathoms (72 feet) he found the "armings clean [showing] *Millepore* [and] *Astrea*." Beyond the zone of bulky corals he found "a fathom or two of fragments" that occasionally contained smaller bits of animated matter. Below 20 fathoms (120 feet) there was only sand, with "no sign of any thing hard.— in [the] soundings." These observations showed that the reef had a shallow "first inclination" from the breakwater to a depth of about 30 fathoms, with its breadth of 100–200 yards corresponding to a band of "discoloured water" that could be seen beyond the breakers. From the 30-fathom mark, Darwin could see that the bottom "suddenly incline[d]" into darker blue water.⁴⁶

Eager as Darwin was to learn the secrets of the blue deep, it came as a serious disappointment that strong winds "rendered the most important part [of the survey], the deep sea sounding, scarcely practicable." High winds and strong currents made very poor conditions for sounding because an accurate measurement required the lead to drop straight down so that the line remained vertical. To his note about one sounding of 770 fathoms, Darwin added an annotation: "depth doubtful (360 really)."⁴⁷ FitzRoy made the best of the conditions, "eagerly tak[ing] advantage" of "two moderate days . . . to go round the whole group in a boat." Sullivan managed to achieve a small number of measurements between 200 and 300 fathoms. More remarkably, at "only a mile from the southern extreme of the South Keeling" FitzRoy found no bottom at 1,200 fathoms.⁴⁸ With nearly one and a half miles of line played out, it was among the deep-

⁴⁶ CUL DAR41:53; FitzRoy, *Narrative of the Surveying Voyages of His Majesty's Ships Adventure and Beagle*, Vol. 2, p. 634; CUL DAR41:53; CUL DAR41:56; CUL DAR41:55; CUL DAR41:54; and CUL DAR41:57.

⁴⁷ Keynes, ed., *Charles Darwin's Beagle Diary*, 7–11 Apr. 1836, p. 417; and CUL DAR41:55. On the difficulties of keeping the lead line "dead up and down" see Rozwadowski, *Fathoming the Ocean* (cit. n. 11), Ch. 3.

⁴⁸ FitzRoy, *Narrative of the Surveying Voyages of His Majesty's Ships Adventure and Beagle*, Vol. 2, p. 630. For Sullivan's measurements see, e.g., Darwin's list of "Sulivans. outside deep soundings" on CUL DAR41:53.

est soundings that had ever been taken by any navigator. The thought of it boggled Darwin's mind and challenged his mathematical skills. At the bottom of one scrap of Keeling notes are two attempts to multiply 1,200 by 6, with the second yielding 7,200 as the depth of FitzRoy's sounding in feet. Working from a list of deep soundings and their "estimated distance" from shore, Darwin preempted the officers by making his own preliminary calculations of the slope. By obscure methods, Darwin found the angle to be 48° at its steepest inclination.⁴⁹

Darwin sought something like a general theory of reef growth by comparing how the reef sloped on different sides of the island, eventually consulting with officers whose facility with trigonometry far exceeded his own. Considering the shallower slopes out to 30 fathoms, he found "no law about the extension of the discoloured water[, which was] at least not less on the leeward. than windward side." Regarding the deeper water, Darwin found it "clear from Mr. Sullivan's sections" that there was also "no law with respect to [the] Windward & Leeward . . . shape of [the] lower Mountain." This ambition that the accumulation of geographical measurements would produce knowledge of underlying "laws" of distribution and physical geography was reminiscent of Humboldt's approach.⁵⁰ Furthermore, by incorporating measurements by Sullivan and others into what would become single-authored scientific publications, he was also, perhaps unconsciously, exemplifying Humboldt's authorial relationship to those who had helped the Prussian to gather his zoo- and phytogeographical facts.

The reef's foundation was indeed exceptionally steep. Sullivan explained to him that on some attempts the sounding line had been severed between 500 and 600 fathoms, suggesting that it caught the edge of a cliff at that depth. Darwin considered it the "precipice of [an] unfathomable wall" that may have been cut by the "Action of [the] sea." If the cliff had indeed been created at sea level by the action of surface currents, its present situation implied a subsequent subsidence of 500 or 600 fathoms. Darwin noted that the "very great inclination between the 2 soundings on the SE side [is] so steep that it must be rock." He turned again to Humboldt, from whom he learned that "Cones of Volcano[es] have a medium slope from 33° to 40° Even the steepest parts but little exceeding these numbers."⁵¹ FitzRoy's soundings showed the walls of the reef to be steeper than a volcano, and Darwin took confidence from this knowledge even though the survey left many of his original questions unanswered.

On departing Keeling, Darwin wrote his explanation of reef formation into his diary, where he had previously only hinted at the theory's existence. Given that the coral theory had as yet been recorded only in the "Coral Islands" essay, Darwin's decision to add it to his permanent record of the voyage was a sign of new confidence. This version emphasized the results of FitzRoy's recent deep sounding in arguing, "Hence we must consider this Is[land] as the summit of a lofty mountain." While Darwin acknowledged uncertainty as to "how great a depth or thickness the work of the Coral animal extends," he was more convinced than ever that "we must look at a Lagoon Is[land] 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."⁵²

⁴⁹ CUL DAR41:56; CUL DAR41:54; and CULDAR41:51. Darwin tended to labor over arithmetic, and in many cases I cannot see how his slopes could have been produced from the measurements he was working with. When Darwin lived in London after the voyage he commissioned his brother Erasmus to calculate angles of inclination (see notes by Erasmus in CUL DAR39.1:28–30).

⁵⁰ CUL DAR41:57; and CUL DAR41:52. For a concise and useful discussion of Humboldt's expectation that knowledge of underlying laws would emerge from such activity see Michael Dettelbach, "Humboldtian Science," in *Cultures of Natural History*, ed. Nicholas Jardine, James A. Secord, and E. C. Spary (Cambridge: Cambridge Univ. Press, 1996), pp. 286–304.

⁵¹ CUL DAR41:56; CUL DAR41:49; and CUL DAR41:56.

⁵² Keynes, ed., *Charles Darwin's Beagle Diary*, 12 Apr. 1836, p. 418. On Darwin's *Beagle* diary, or "Log Book," see Janet Browne, *Charles Darwin: Voyaging* (Princeton, N.J.: Princeton Univ. Press, 1996), p. 194.

V. DARWIN'S HYDROGRAPHIC INITIATIVE: MAURITIUS

At Mauritius, a volcanic island with a fringing reef, Darwin himself acted as a hydrographer. The occasion of his casting the sounding lead came three weeks after leaving the Keelings and is recorded in his little-noticed Mauritius field notes. Unlike South Keeling, Mauritius was a common way-station. Indeed, FitzRoy's published narrative of the voyage was to contain only a single sentence about the island, and he had stopped there only to comply with Beaufort's instructions to "determine the difference in longitude from [the southwest coast of Australia] to the Mauritius." Darwin still had some very specific questions, however, about the organisms that built the various parts of a coral reef. In order to answer them he would have to take to the water himself. Along with at least one unidentified accomplice, Darwin "pull[ed] out to seaward," where, as he recorded, "I sounded repeatedly with a lead, the face of which was formed like a saucer with a diameter of four inches."⁵³ This was a considerably broader lead than the one illustrated in Figure 2, which has a well approximately one inch in diameter. Indeed, he was innovating: adopting a deep-sea lead for shallow-water work because it afforded a larger sampling area.

Darwin was by now intimately familiar with the reef-building corals of the Indian Ocean. With precision unmatched in his previous accounts, he identified four discrete zones as he moved from the beach out to deep water. From the mounds of coral that formed the break-water out to 8 fathoms (48 feet), the "arming invariably came up deeply cut by the branching Madrepores & marked with the impressions of *Astrea*s; its surface was also, without a single exception perfectly clean. not bringing up a particle of sand." The absence of sand was clear evidence that the corals were alive. "At each cast . . . we pounded the bottom with the lead, & as the sand, if present, would have adhered from any of the blows, I think it is pretty certain, that where coral is most abundant, the bottom is quite clean. . . . This fact would afford a useful aid in ascertaining the depth at which coral flourishes." From 8 to 15 fathoms (48–90 feet), the arming was almost entirely clean of sand and "beautifully marked with impressions of *Astrea*s . . . some species of *Madrepore*, *Seriatopora*, & fragments of branching *Millepora* & I think *Porites* as figured by Lamouroux."⁵⁴ The next zone, to 20 fathoms, contained extensive beds of the *Seriatopora* and was free of the massive reef builder *Astrea*. Finally, from 20 to 33 fathoms (120–198 feet) most of the soundings showed a sandy bottom.

We can see that Darwin was by now confident in his ability to discriminate several genera of corals by the indentations they left in a clean gob of tallow four inches across. What is more, these notes illustrate vividly the way that a particular method of collecting predisposed Darwin to a particular way of thinking: the sounding lead sampled or recorded whatever was to be found on the bottom, across the spectrum from animal to vegetable to mineral. As a consequence, what might have been a narrow exercise in identifying coral genera became, in addition, something like a proto-ecological investigation of the relation between processes of sediment deposition and coral growth.

Armed with the knowledge from his private survey, Darwin gained confidence in his answers to questions on which he had previously been willing only to "conjecture": the depth limit of coral growth, the factors contributing to the existence of gaps between reefs and the shore of high land, the reason why a reef's highest point lay at its outer margin, and the factors that determined the distance of that margin from the shore. He wrote down a set of principles of reef growth, listed, tellingly, in a geographical sequence from shore to deep water. Sounding

⁵³ FitzRoy, *Narrative of the Surveying Voyages of His Majesty's Ships Adventure and Beagle*, Vol. 2, p. 33; and CUL DAR38.2:894.

⁵⁴ CUL DAR38.2:894–895.

had become more than a source of specimens and data. The work at Keeling and Mauritius shows that by his fifth year on the *Beagle* the practice and logic of hydrographic surveying quite literally ordered Darwin's understanding of coral reefs. Hydrography had endowed him with an awareness of the undersea environment that primed him in many ways for his insight at Tahiti. It also provided him with a practical way of testing many of his predictions about coral growth and reef structure, to the point that he considered himself simply unable to study coral reefs without access to soundings.

It makes a telling coda to this episode to look at a set of instructions for examining coral reefs that Darwin wrote more than a decade later as part of his contribution to an 1849 book. The Admiralty's *Manual of Scientific Enquiry: Prepared for the Use of Her Majesty's Navy: And Adapted for Travellers in General* was edited by the astronomer John Herschel with encouragement from Beaufort. Darwin wrote the chapter on making geological observations. In it he offered instructions for studying coral reefs; they attest both to his familiarity with the tools and practices of hydrography and to the central role that hydrographic technique played in his view of reef studies.

The most important point with respect to coral reefs, which can be investigated, is, the depth at which the bottom of the sea, *outside the reef*, ceases to be covered with a continuous bed of living corals. This can be ascertained by repeated soundings with a heavy and very broad bell-shaped lead, armed with tallow, which will break off minute portions of the corals or take an exact impression of them. . . . There is reason to suspect that different species of corals grow in different zones of depth; so that in collecting specimens, the depth at which each kind is found, and at which it is most abundant, should be carefully noted. . . . Whenever it is practicable, soundings ought to be taken at short ascertained distances, from *close* to the breakers in a straight line out to sea, so that a sectional outline might be protracted on paper.⁵⁵

It would have been obvious to anyone who had read Darwin's 1842 book, *The Structure and Distribution of Coral Reefs*, that he was seeking information relevant to testing the predictions made by his theory of reef formation. But as the account of his exploits at Mauritius reveals, Darwin was also instructing future travelers to reenact precisely the hydrographic endeavors that had been the basis for his own knowledge of reefs.

CONCLUSION: TELESCOPING AND FUNNELING

I have argued that Darwin's ability to relate the growth of organisms to geological and geographical conditions, present and past, was a product of his unprecedented experience with hydrography. This is how he actually realized Lyell's optimistic promise for an amphibious being: to "mark, on the one hand, the growth of the forest, and on the other that of the coral reef," and thereby to "arrive at sound theoretical opinions in geology." Why, then, has the considerable submarine component of Darwin's fieldwork been overlooked? Answering this question requires attention to the accounts that Darwin and Darwin scholars have offered for how he arrived at those sound theoretical opinions. In concluding, I will point to two processes that played a role in shaping how Darwin's theories have been remembered. For the sake of distinguishing them I borrow the metaphors of telescoping and funneling.

⁵⁵ Charles Darwin, "Geology," in *A Manual of Scientific Enquiry: Prepared for the Use of Her Majesty's Navy: And Adapted for Travellers in General*, ed. J. F. W. Herschel (London: John Murray, 1849), pp. 156–195, on pp. 190–192.

Telescoping

Let's begin with the way Darwin himself remembered the process of theorizing. Of the coral reef theory he wrote, in his autobiographical "Recollections" of 1876, "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[outh] America before I had seen a true coral reef." Thus he claimed that when he had first encountered "living reefs" (i.e., at the locations discussed in Sects. III–V of this essay) he "had therefore only to verify and extend my views." According to these reflections, Darwin had "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," he continued, "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 coral atolls."⁵⁶

The account I have presented contradicts this statement by arguing that only later, at Tahiti (Sect. III), did he first perceive that geological subsidence could explain the origin and shape of coral reefs.⁵⁷ Far from having "thought out" the theory before seeing a living reef, he initially conceived himself as having a new explanation for "the formation of barrier-reefs and coral atolls" only at the very moment when he first got a good view of a living reef. So how did Darwin come to feel that his experiences in South America (discussed here in Sect. II) constituted the "whole" of a theory that he was not even conscious of having until several months after leaving that continent?

The answer is that new theories can change the narratives by which individuals make sense of their scientific careers. I have already shown how Darwin's idea at Tahiti defined a plan of writing and fieldwork through the rest of the voyage, and it is hardly surprising that a new theory would alter the course of his work from that point forward. But the eureka moment in Tahiti imposed *retrospective* coherence on his activities as well. He had discovered unexpectedly that certain ideas dating to his time in South America were relevant to solving the well-known question of the formation of coral reefs.⁵⁸ Once Darwin "had" the theory, he forevermore remembered his investigations into South American elevation and subsidence as *inherently* relevant to the theory (indeed, as constituting the theory), and it became all but impossible to remember that he had ever pursued this line of study for other reasons, independent of the theory he would eventually produce.

This argument applies not only to Darwin's coral reef theory but to his evolutionary theorizing as well. Frank Sulloway, the historian who debunked the myth that Darwin became an evolutionist at the Galapagos Islands, wrote, "Contrary to the legend, Darwin's finches do not appear to have inspired his earliest theoretical views on evolution, even after he finally became an evolutionist in 1837; *rather it was his evolutionary views that allowed him, retrospectively, to understand the complex case of the finches.*" Sulloway went on to rebuke the authors of bad "textbook" histories who had oversimplified Darwin's biography to the point of distortion by "telescoping history around one dramatic moment of insight in the Galapagos Archipelago."⁵⁹ But Sulloway failed to chastise Darwin for being a bad historian of his own work, in the sense

⁵⁶ Nora Barlow, ed., *The Autobiography of Charles Darwin, 1809–1882* (London: Collins, 1958), p. 98.

⁵⁷ The existence of two independent stories about when and where Darwin developed the theory has led to some ambiguity. Herbert, for example, draws from both stories but does not seek to resolve their apparent inconsistency. Compare pages 169 and 171 of *Charles Darwin, Geologist* (cit. n. 1).

⁵⁸ For an extended defense of this claim see Sponsel, "Coral Reef Formation" (cit. n. 10), Ch. 2.

⁵⁹ Frank J. Sulloway, "Darwin and His Finches: The Evolution of a Legend," *J. Hist. Biol.*, 1982, 15:1–53, on pp. 32 (emphasis added), 47.

that Darwin, too, “telescoped” history around certain dramatic moments of insight. It was only his later evolutionary theorizing that made it *seem* to him as though the distribution of certain animals he encountered during the voyage had always determined the theory he would eventually develop. And likewise, to paraphrase Sulloway, geologizing in South America appears not to have sparked Darwin’s thinking about the shape of coral reefs; rather, it was his eventual explanation for reef formation that allowed Darwin, retrospectively, to believe that the key to understanding coral reefs had always lain in studying the geology of South America.

Funneling

Sudden moments of insight may *seem* to have been divinely inspired, but eureka moments can be explained. I have argued for the special significance of hydrographic surveying as a hitherto-underappreciated source of specimens, observations, and even a theoretical perspective during Darwin’s travels. Although Darwin departed Britain with sufficient training in marine zoology and geology to be able to make original observations in both departments of study, the insights gained from hydrography allowed him to develop theories that fused the two pursuits. Through his careful attention to the officers’ hydrographic surveying, any given cast of the sounding lead could provide *both* zoological and geological specimens, interrelated elements characteristic of a particular combination of depth and geographical location. He saw these specimens as the present-day organic and inorganic constituents of *future* sedimentary rocks, and in turn he was able to interpret the upraised sedimentary beds of South America as *former* iterations of the seafloor with which he was now so familiar. Using hydrography in this way encouraged and enabled him to draw the analogies between geographical space and geological time that underpinned his coral reef theory and eventually his evolutionary theories as well.

What is significant is not just that Darwin was interested in hydrography, but that it was virtually unprecedented for a naturalist with decent training in geology and zoology to be so intimately involved in hydrographers’ labor. Helen Rozwadowski has argued that the rise of an “oceanographic” perspective occurred, later in the nineteenth century, precisely through the introduction of hydrographic techniques into natural history.⁶⁰ This essay has shown that Darwin wedded these pursuits in the decade before this synthesis was initiated afresh by such pioneers of British marine science as Edward Forbes in the 1840s and William Carpenter in the 1850s. That this marriage of hydrography and natural history was achieved by Forbes in particular lends considerable support to my argument, for he was—after Darwin—the next naturalist to receive the distinctive Edinburgh training in marine zoology before studying aboard a hydrographic surveying vessel. As with Darwin, this led him not only to do zoology with a geographical perspective but also (to borrow the subtitle of his 1843 report to the British Association for the Advancement of Science) to pursue the study of marine invertebrates’ distribution for its “bearing on geology.”

Darwin never emphasized his debt to hydrographic technique in his scientific writings, and he did not go on to publish in the genres associated with the production of hydrographic knowledge—namely, nautical charts and sailing directions. On the contrary, his publications in geology and zoology generally obscured the surveyors’ contributions. These men, along with the crewmen who executed their orders and Darwin’s servant Syms Covington, were the invisible technicians who allowed him, for example, to imply in print that he had made a sounding of 86 fathoms (516 feet) all by himself. FitzRoy became outraged after the voyage when he saw how scantily Darwin had acknowledged the ship’s company in his volume treating the *Beagle*

⁶⁰ Rozwadowski, *Fathoming the Ocean* (cit. n. 11).

voyage.⁶¹ But in following such a path Darwin was only following a model that had helped to establish Humboldt, for example, as the author of ideas and natural laws stemming from labor-intensive survey-style investigations of the Americas.

Much has been made by historians of “Humboldtian science” and of Darwin’s status as a practitioner thereof.⁶² While I would argue that the amphibious Darwin was even more concerned with distribution and with quantitative measures of elevation (below and above sea level, as provided by the hydrographers) than Susan Faye Cannon herself noticed, we should be wary of the name Cannon affixed to these pursuits. Rather than seeing Darwin as “Humboldtian,” we should view both Darwin and Humboldt (the former mining engineer) as surveyor-naturalists who managed to assume an autocratic position with respect to data created and collected by a variety of people.⁶³ It may be difficult to imagine the intrepid Darwin of the *Beagle* as a consumer rather than a producer of data, but this he was, at least with respect to the voyage’s original conception as a knowledge-producing venture—namely, as a geographical survey. And he went on to become an even more prolific consumer of others’ findings. As Janet Browne’s work reveals so well, Darwin’s stature later in his life enabled him to acquire far more information from his correspondents than he sent out in return.⁶⁴ The gradients in authorial status, from seamen to surveyors to Darwin himself, turn out to be virtually identical to those that characterized Darwin’s later relationships to other practical men and indeed to a number of female naturalists as well. From natural history fieldwork to theories and authorship, interaction with hydrographic surveyors shaped the approaches to science that defined Charles Darwin’s career.

⁶¹ Charles Darwin, *The Structure and Distribution of Coral Reefs* (London: Smith, Elder, 1842), pp. 80–82; and Browne, *Charles Darwin: Voyaging* (cit. n. 52), pp. 370–371 (FitzRoy’s outrage).

⁶² Cannon, *Science in Culture* (cit. n. 2); Dettelbach, “Humboldtian Science” (cit. n. 50); and Michael Dettelbach, “The Face of Nature: Precise Measurement, Mapping, and Sensibility in the Work of Alexander von Humboldt,” *Studies in History and Philosophy of Biological and Biomedical Sciences*, 1999, 30:473–504.

⁶³ I thank my student Patrick Anthony for pointing out the affinities between my idea of Darwin (and Humboldt) as “surveyor-naturalists” and Ursula Klein’s description of Humboldt as a “savant-technician.” Klein emphasizes Humboldt’s role as a mining official and thus his contributions in technical *as well as* scholarly arenas, whereas my emphasis here has been on Darwin’s fashioning of an *exclusively* scholarly persona *despite* his adoption of skills from the technical arena. See Ursula Klein, “The Prussian Mining Official Alexander von Humboldt,” *Annals of Science*, 2012, 69:27–68.

⁶⁴ Janet Browne, *Charles Darwin: The Power of Place* (Princeton, N.J.: Princeton Univ. Press, 2002).