REASSESSING CHARLES DARWIN'S CONTRIBUTION TO GEOLOGICAL SCIENCE: A NEW PERSPECTIVE FROM THE GALAPAGOS

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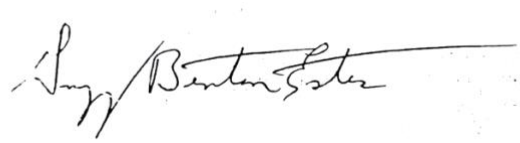
Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree, and does not incorporate any material submitted for a degree.



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Abstract

Charles Darwin is one of the most celebrated figures in the history of science, whose work in organic evolution has revolutionized the way we think about ourselves and the living world. He is widely recognized for his seminal 1859 work *On the Origin of Species*. However, despite devoting much of his early career to geological science, Darwin's geology – and in particular his geology of the Galápagos Islands – has been overlooked. The aim of this thesis is to demonstrate how the author's work has provided a new perspective on Darwin's contribution to geology, through an in-depth analysis of Darwin's accounts of his research in the Galápagos and by geolocating the sites that were central to Darwin's geological theories.

The thesis introduces Darwin's work on geology, outlines the publications to be considered, and details the methodology used in both the author's research and in the thesis. Two substantive chapters then chronicle the author's contribution to knowledge, through (i) a critical examination of leading biographies and other works on Charles Darwin, and (ii) the identification of geological sites in the Galápagos Islands visited and surveyed by Darwin. The thesis closes with a brief conclusion, including possible directions for future research.

The author's contributions come not only through the geographic focus of his research, but from the unusual combination of historical source analysis and fieldwork used to underpin this life-work. Darwin's scientific notes on the Galápagos are primarily on the geology, rather than the biodiversity, of the islands. These notes (his *Geological Diary*), which are in the Darwin Archive at Cambridge University Library, have been almost completely overlooked by biographers. The author made available online the first full transcription of the *Geological Diary* and, through the meticulous scrutiny and critical analysis of these notes and other primary manuscripts, was able to identify the sites that were central to Darwin's theories.

By identifying the key sites visited by Darwin, the author's work has filled a significant knowledge gap. His publications have provided a new narrative on Darwin's visit to Galápagos, not only through an examination of all Darwin's writings on the islands but also by the unusual approach of scaling and exploring the volcanic craters he described to gain a new understanding of what influenced his scientific thinking. The only time Darwin referred to himself as a scientist during the historic voyage of the *Beagle*, he used the word 'geologist'. As the author's work indicates, it is time that Darwin's geological discoveries were recognized to the same degree as his contributions to evolutionary science.

Acknowledgements

I would like to thank my supervisor, Professor David Nash, for his skillful guidance to whom I owe a debt of gratitude for his encouragement and constructive feedback. I thank Richard Darwin Keynes, Keith Thomson, Frank Sulloway and Duncan Porter for directing me towards the Darwin Archive at the University of Cambridge and the staff of the Cambridge University Library, the Sedgwick Museum of Earth Sciences, the Public Record Office of London, and the UK Hydrographic Office for providing access to Darwin's Manuscripts and specimens and to FitzRoy's logs and maps of Galápagos. I am grateful to the Charles Darwin Research Station and the Galápagos National Park Service for their invaluable logistical support and advice. I would also like to mention my co-authors and fellow expedition members for their contributions to this research. In particular, I am eternally thankful to my partner and co-author, Thalia Grant, for her love, support and patience during this journey. And finally, I thank Charles Darwin for providing the footsteps through Galápagos.

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Chapter 1 Introduction

1.1 Positioning Darwin in the History of Science

Charles Darwin (1809-1882 CE) is one of the most celebrated figures in the history of science (Figure 1.1), whose work revolutionized the way we think about ourselves and the living world. Although he is most remembered for his seminal work on evolution, *On the Origin of Species* (Darwin, 1859), Darwin's many publications demonstrate the durability of his influence on a wide range of subjects (Jones, 2009); e.g. insectivorous plants (Darwin, 1992b), plant hormones (Darwin, 1992c), sexual selection (Darwin, 1992d), and the evolution of humans (Darwin, 1992d) and barnacles (Darwin, 1992e). His most lasting contribution to science is identifying the mechanism for evolution known as natural selection.

Darwin's work took place during a key period for modern science. During the years of the Enlightenment (1685-1815 CE) natural philosophers began to move away from a static, dogmatic view of nature as the Creator's design; superstition was replaced by reason (Porter, 1977, Gribbin, 2019). Scripture had been treated like history by most 17th century scientists (Laudan, 1987). By the end of the 18th century a more empirical approach to the study of the natural environment had taken hold as the world was opening up for exploration. As new discoveries were made, old ideas that had been based on ancient philosophers such as Aristotle (384-322 BCE) and Dioscorides (c. 40-90 CE) began to be supplanted by new theories.

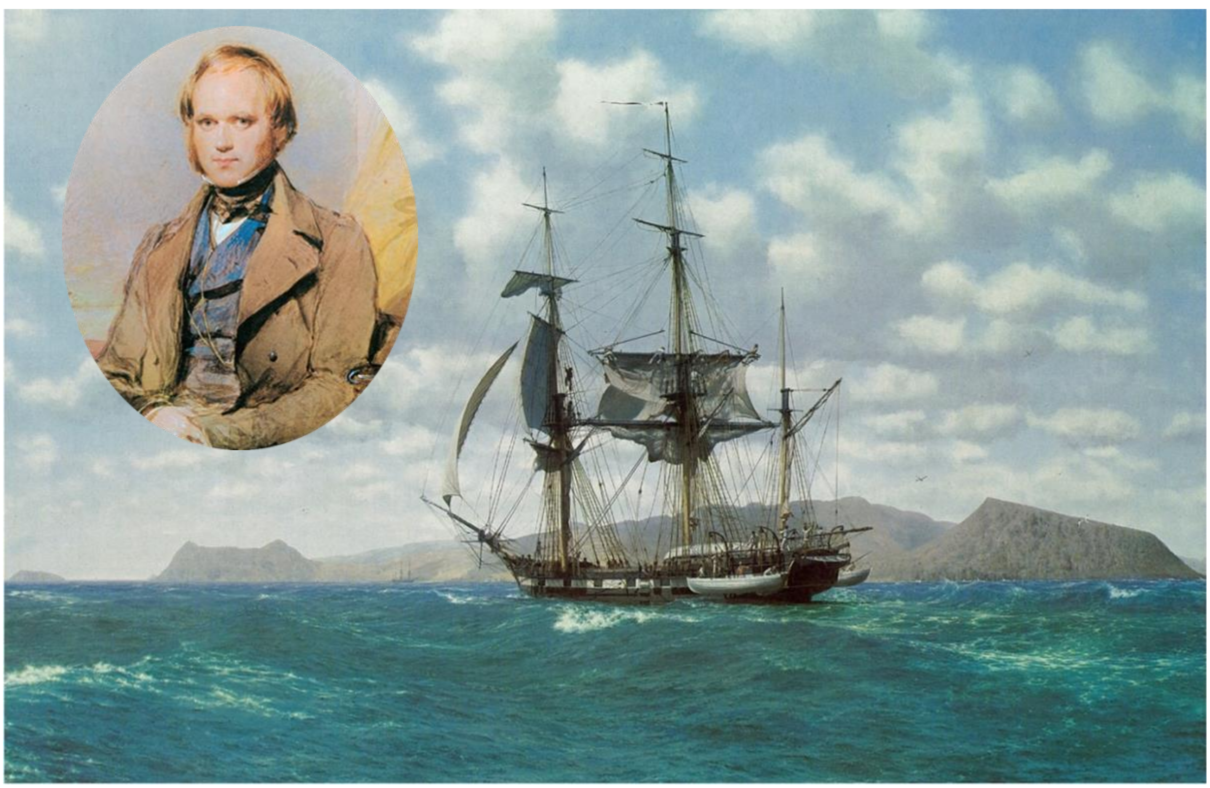


Figure 1.1 HMS *Beagle* in the Galápagos. By courtesy of the trustees of John Chancellor. Charles Darwin c. 1840 by George Richmond © English Heritage Photo Library, Kent. By kind permission of Darwin Heirlooms Trust.

Global travel, mapping and surveying were fundamental for the emergence of modern science (Williams, 2013). This was made possible by improved designs of ships and the use of chronometers and the lunar almanac to determine longitude (Sobel, 2005, Fitzpatrick, 2009). New techniques and hardware made measurements possible in remote parts of the planet. The measurement of the transit of Venus and the collection of species new to science on Captain James Cook's voyage on HMS *Endeavour* (1768-1771) began a tradition of scientific work for naval voyages (Woolf, 1959, Weaver, 2015). The aims of voyages developed from being merely geographic and commercial to including science and natural history. In the early 1800s a burgeoning scientific community in England formed various learned societies, which discussed these new discoveries (Gribbin, 2002). Charles Darwin, "a man of enlarged curiosity" (Wedgwood II, 1985), was born at an auspicious time, which provided him with an opportunity to make his name in this brave new world of scientific exploration and discovery.

Many of Darwin's most celebrated scientific contributions stem from research undertaken during and after his circumnavigation of the globe on HMS *Beagle* (1831-1836; see Figure 1.2). Darwin said that "the voyage of the *Beagle* has been by far the most important event in my life and has determined my whole career" (Barlow, 1958). The first place Darwin visited on the *Beagle* was Cape Verde where he decided to write a book on the geology of the voyage.

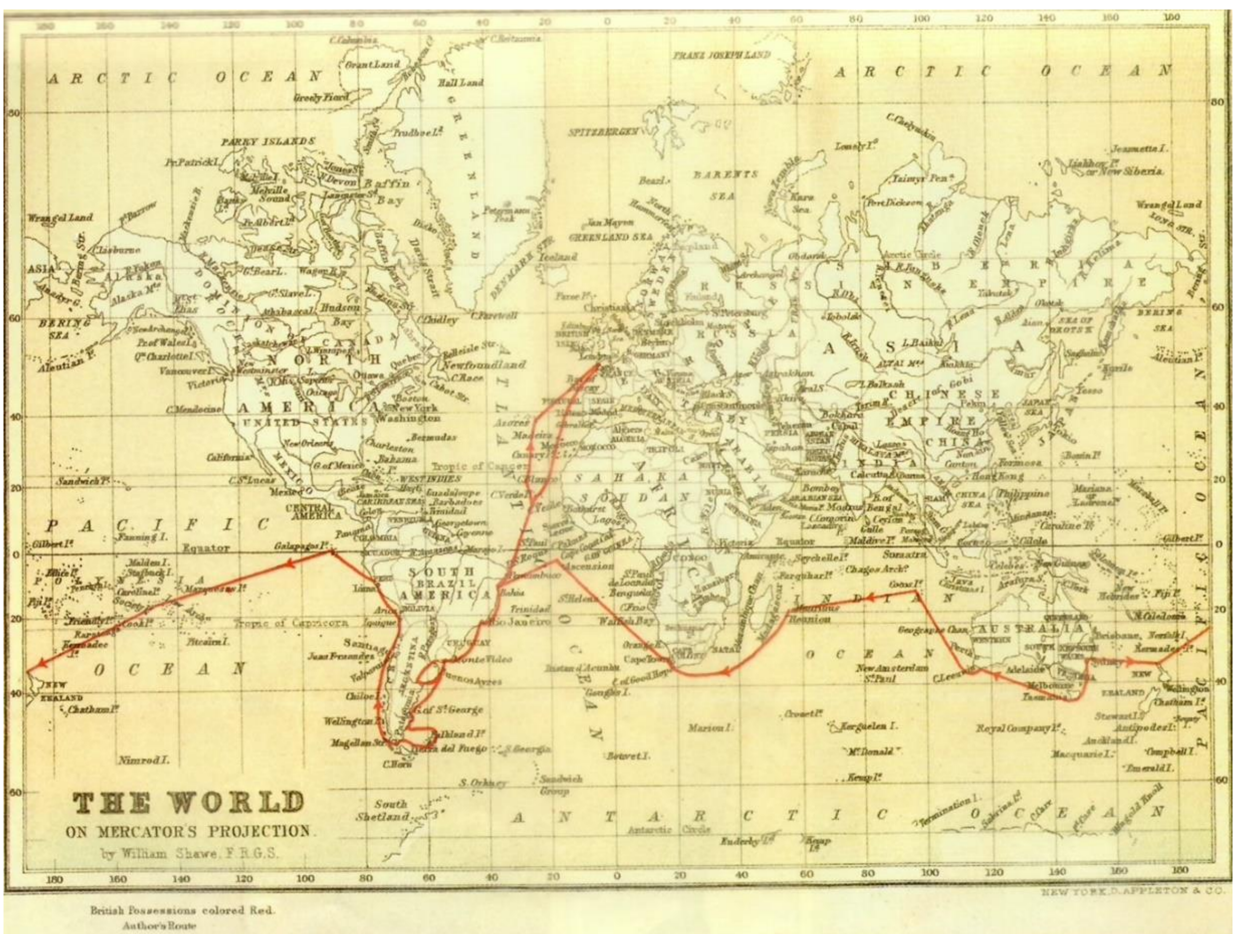


Figure 1.2 Route of HMS *Beagle* on its surveying voyage around the world (December 27, 1831 – October 2, 1836) John Murray, London, 1890. (Authors' collection)

When Darwin returned to England in 1836 he was regarded as an expert on South American geology (Desmond and Moore, 1991). He also came up with an explanation of how coral atolls formed from the subsidence of a volcano. These discoveries gained him entry to the Geological Society of London on November 20, 1836, aged 27 (Desmond and Moore, 1991, Browne, 1995). The voyage of the *Beagle* established Darwin's credibility as a respected scientist, initially as a geologist and later for his work on species. Tellingly, the only time Darwin referred to himself as a scientist during the voyage, he used the word 'geologist' (Porter, 1985).

1.2 Darwin's Early Geology

Although it is recognized that geology predominated Darwin's work during the voyage of the *Beagle* (Porter, 1985), the author has demonstrated through his various publications – the focus of this thesis (see Section 2.1) – that Darwin's geology of the Galápagos Islands has been overlooked. As discussed in Chapter 3, Darwin wrote more manuscript pages (and field notes) on geology than he did on zoology during the voyage (Porter, 1985, Sulloway, 1988). Throughout the voyage the dominant role of geology is apparent from his diary (Keynes, 1988), correspondence (Burkhardt et al., 1985-2023) and his autobiography (Barlow, 1958). Table 1.1 summarizes Darwin's landmark geological discoveries on the *Beagle*.

Table 1.1 Landmark geological discoveries by Charles Darwin on the voyage of the *Beagle*. A complete chronology of the voyage can be found in volume 1 of The Correspondence of Charles Darwin (Burkhardt et al., 1985-2023).

Date	Site	Discovery	Importance
February 1832 & 1836	Cape Verde Islands	Discovers uplifted shoreline	Evidence for vertical movements of Earth's crust
September 1832	Punta Alta, Argentina	Discovers fossils of giant mammals e.g., Glyptodon and Megatherium	Evidence for transmutation from relationships between living and extinct species
October 1833	Rio Carcavána, Chile	Discovers fossil of giant mammal, Toxodon	Evidence for transmutation from temporal relationships of living and extinct species
January 1834	Port St. Julian, Patagonia	Discovers fossil of giant mammal, Macrauchenia	Evidence for transmutation from relationships between living and extinct species
January 1834	Port St. Julian, Patagonia	Discovers fossil marine shells	Evidence for vertical movements of the Earth's crust
January 1835	Mount Osorno, Chile	Observes eruption	Evidence for connection between eruptions, earthquakes & vertical movements
February - March 1835	Valdivia, Chile	Discovers uplifted shoreline associated with earthquake	Evidence for connection between eruptions, earthquakes & uplift
April 1835	Uspallata Pass, Chile	Discovers petrified forest	Evidence for vertical movements of Earth's crust
March 1835	Puequenes ridge and Portilo ridge, Cordillera, Chile	Discovers fossil marine shells	Evidence for vertical movements of Earth's crust
1835	On the Galápagos Islands (see Chapter 4 for chronology)		
1836	Cocos Keeling Islands	Examines coral atolls	Evidence for vertical movements of Earth's crust

1.2.1 Darwin's Geology before the Voyage of the *Beagle*

Prior to the voyage of the *Beagle*, Darwin's grounding in geology was primarily through lectures by Robert Jameson (1774-1854) and Thomas Charles Hope (1766-1844) at the University of Edinburgh and later by John Stevens Henslow (1796-1861) and Adam Sedgwick (1785-1873) at the University of Cambridge (Secord, 1991, Herbert, 2005) (see Table 1.2 for a chronology of Darwin's early geological education). At the time, there were two theories about how Earth's crust formed. The uniformitarian theory of gradual change, promoted by Charles Lyell (1797-1875), contrasted with Neptunist theories that described Earth's surface being formed from the deposition of sediment from water through floods (in some cases biblical, as in Noah's flood).

Darwin was skeptical of Neptunist theories espoused by Jameson at Edinburgh and was more inclined to the uniformitarian views of Lyell. Nevertheless, he gleaned much from Neptunists like Sedgwick, who invited him on a geological field trip to document the Cambrian deposits in north Wales in August 1831. This field trip with an experienced practitioner was instrumental in teaching Darwin how to collect geological samples and make observations using a compass, clinometer and goniometer (Roberts, 2001). Darwin's offer to join the *Beagle* came at the end of this field trip.

Table 1.2. Darwin's early intellectual life before the *Beagle* voyage (Secord, 1991)

Date	Location	Instruction
1825-26	University of Edinburgh	Attends Thomas Charles Hope's chemistry course
1826-27	University of Edinburgh	Attends Robert Jameson's course on geology and mineralogy
1831	University of Cambridge	Reads Alexander von Humboldt's Personal Narrative and John F.W. Herschel's Preliminary Discourse
Winter term 1831	University of Cambridge	Henslow recommends Darwin take up geology for proposed trip to the Canary Islands
July 1831	Llanymynech Hill near Shrewsbury	Geology fieldtrip, Darwin begins to use clinometer
July 1831	Shropshire	Attempts to make a geological map of Shropshire
August 1831	North Wales	Adam Sedgwick instructs Darwin on field geology during fieldtrip to make a geological map
September 1831	Shrewsbury	Darwin accepts offer to join HMS *Beagle* as naturalist and geologist
September 1831	Cambridge	Henslow recommends Darwin reads the first volume of Charles Lyell's Principles of Geology

1.2.2 Darwin's Geology during the Voyage of the *Beagle*

Much of what Darwin learned about geology came during the voyage. The library on HMS *Beagle* included books by Lyell, Charles Giles Bridle Daubeny (1795-1867), George Julius Poulett Scrope (1797-1896), Jean-François d'Aubuisson de Voisins (1769-1841), Alexander von Humboldt (1769-1859) and Christian Leopold von Buch (1774-1853) (Burkhardt, 1985). The most important book for Darwin was Lyell's *Principles of Geology* (Lyell, 1830). Darwin's work on vertical Earth movements in South America and on coral atolls, and his discovery of marine and terrestrial fossils, supported Lyell's theory of steady uniform changes in the Earth's crust and influenced his thinking on the descent of species with modification (Herbert and Norman, 2008). The gradual vertical movements of uplift and subsidence demonstrated to Darwin that Earth was much older than what he had learnt as a student at Edinburgh and Cambridge. An older Earth provided the time needed for species to become modified. Furthermore his discovery of fossils of extinct giant mammals and their relationships to smaller extant forms demonstrated to Darwin a temporal relationship between species (Desmond and Moore, 1991, Eldredge, 2005).

1.2.3 Darwin's Scientific Development on the Voyage

Frank Sulloway has clearly shown that while Darwin's scientific development as a theorizer came through his geological work during the voyage of the *Beagle*, his theories on transmutation of species were formulated primarily after he returned to England (Sulloway, 1988). The year 1835, the same that Darwin visited the Galápagos Islands, was particularly significant in this process of scientific maturity (Table 1.1). That year he discovered marine fossils in the Andes, experienced an earthquake in Valdivia, Chile, and observed the eruption of Mount Osorno in Patagonia. By the time he reached the Galápagos, he was immersed in finding explanations for the origin and composition of Earth. He drew a link between eruptions, earthquakes and vertical movements of Earth's crust on a global scale. His search for more evidence to support his views continued in the Galápagos. However, as the author has shown (and as discussed in Chapter 3), his contributions to geology from his work in Galápagos are almost entirely absent from leading biographies.

1.3 Darwin's Geology of the Galápagos

1.3.1 Galápagos Before the *Beagle*'s Visit

The Admiralty instructed Robert FitzRoy, captain of HMS *Beagle,* to survey the Galápagos Islands. Few naturalists had visited before Darwin as most naval ships bypassed the islands due to their barren volcanic landscape, paucity of freshwater and the absence of indigenous people (Jackson, 1993, Nicholls, 2014). No geologists had visited. The relatively pristine nature of the Galápagos set them apart from other volcanic islands visited by Darwin. The potential for a young naturalist to make his name through describing a new geological landscape inhabited with new species was endless.

1.3.2 Surveying the Galápagos

FitzRoy's meticulous 5-week hydrographic survey afforded Darwin the time to make the first geological survey of the Galápagos. The hydrographic survey provided him with information about the geology of 11 major islands (and their neighbouring islets): Abingdon (Pinta), Albemarle (Isabela), Barrington (Santa Fe), Bindloe (Marchena), Charles (Floreana), Chatham (San Cristobal), Hood (Española), Indefatigable (Santa Cruz), James (Santiago), Narborough (Fernandina) and Tower (Genovesa). The author used FitzRoy's charts and the log of the *Beagle* to track Darwin's movements in the islands (Chapters 2 and 4; see Figures 1.3 and 4.5).

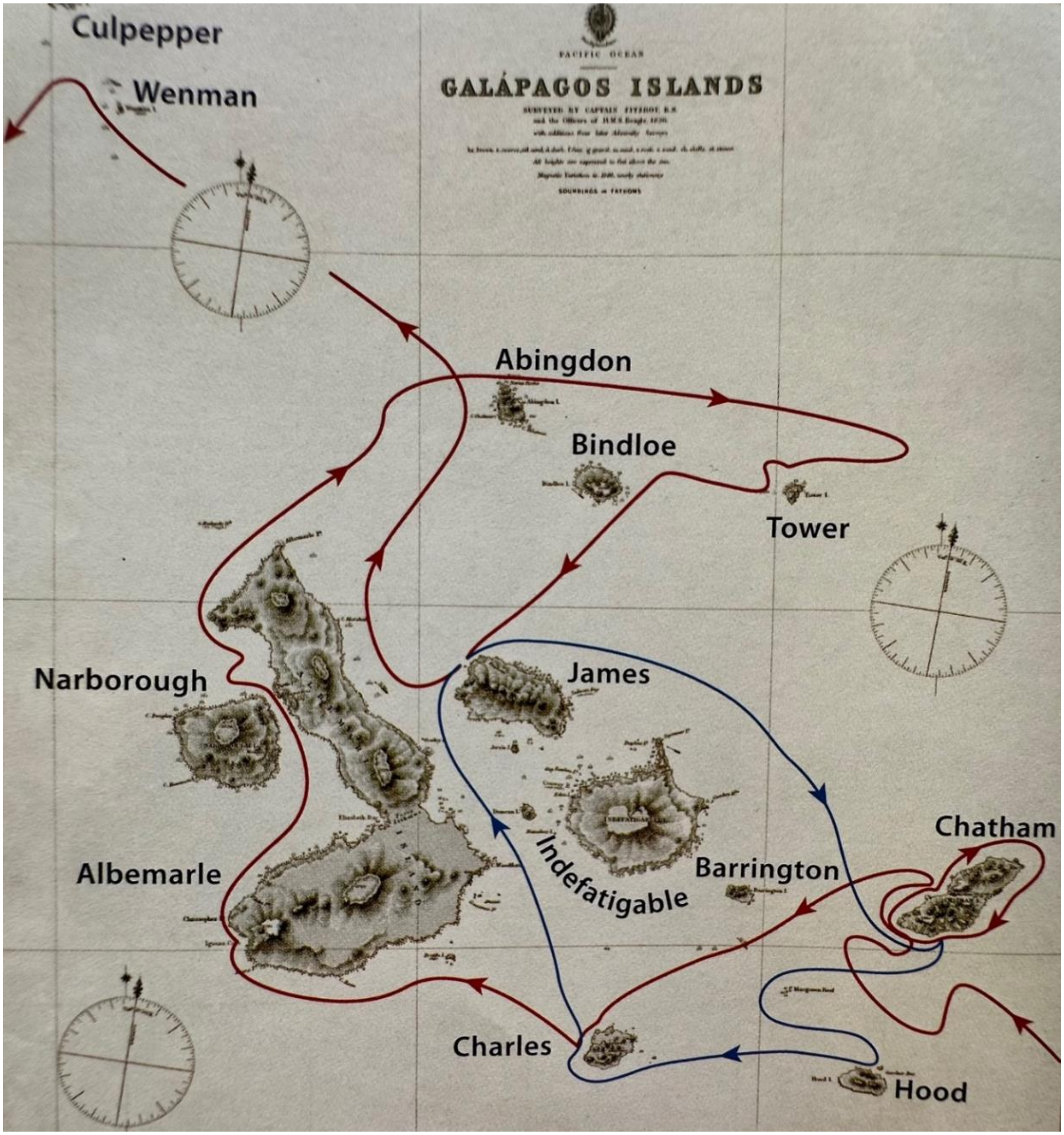


Figure 1.3 Route of HMS *Beagle* through Galápagos. Darwin's route is shown in red. The *Beagle*'s route while Darwin was camped on James Island is marked in blue. *Galápagos Islands, surveyed by Captain FitzRoy, R.N., and the Officers of HMS* Beagle *with additions from later Admiralty Surveys*. Published at the Admiralty 9th August, 1886, under the Superintendence of Captain W. J. L. Wharton, R.N: F.R.S. Hydrographer. Courtesy of Library of Congress. Route of HMS *Beagle* added by the author.

1.3.3 What Darwin Saw

To Darwin the 'most striking' feature of the Galápagos landscape was a varied assemblage of volcanic craters, particularly tuff cones (Darwin, 1844). Darwin was the first to explain how tuff was formed from the interaction of magma with seawater (Simkin, 1984b), and, through the analysis of rock samples from James (Santiago) Island, developed a theory of magmatic differentiation through gravity settling (Pearson, 1996). He was particularly interested in seeing the process by which different types of igneous rocks were formed. He had a compass clinometer to measure angles of strata, a hammer to collect specimens and a blowpipe to identify elements in the rocks. The marine fossils Darwin described and collected, documented in his *Geological Diary*, represent the first paleontological record from the Galápagos (Lipps et al., 1990, Johnson et al., 2010).

1.4 Aims and Objectives

As this chapter has illustrated, whilst Darwin is best known as a naturalist, his pioneering contributions to geology – and specifically his observations of the geology of the Galápagos Islands – have been largely overlooked. The aim of this thesis is to demonstrate how the author's collective work has provided a new perspective on Darwin's contribution to geology through the unusual approach of combining meticulous scrutiny and critical analysis of Darwin's manuscripts with multiple fieldtrips to geolocate the sites that were central to his geological theories. The author was the first to accurately identify all of the historic landmark sites that Darwin visited in the islands (see Chapter 4). These sites include: islands, islets, shield volcanoes, craters, remains of craters, volcanic dykes, spatter cones, tuff cones, scoria cones, kipukas, lava flows, and evidence of uplift. Darwin's geological research is conspicuously missing from accounts of his work in the islands (see Chapter 3). As this thesis shows, the author's contributions have provided a new narrative on Darwin's visit to Galápagos and a new understanding of what influenced his scientific thinking.

1.5 Organization of the thesis

The thesis is organized into five chapters. Having introduced Darwin's work on geology in Chapter 1, Chapter 2 addresses the publications considered in the thesis, and the methodology used in both the author's research and in the thesis. Chapters 3 and 4 evidence the author's unique contribution through a critical examination of leading biographies of Darwin (Chapter 3) and the identification of geological sites in the Galápagos Islands visited and surveyed by Darwin (Chapter 4). The thesis closes with a brief conclusion (Chapter 5), including possible directions for future research. Note that, in general, place names in Galápagos used in the thesis are those used at the time of Darwin's visit, with the modern variant given in parentheses.

Chapter 2 Materials and Methods

Having introduced Charles Darwin, his influence on geological thought, and the aims of this thesis in Chapter 1, this chapter summarizes (i) the publications considered in the thesis (see Table 2.1), (ii) the methods used in their development, and (iii) the processes underpinning the reflective analysis of their contribution to knowledge.

2.1 Publications considered in this thesis

The contribution of the author's five major publications is considered in this thesis (Table 2.1). The publications include the first transcription of Charles Darwin's *Geological Diary* (with accompanying *Introduction*), the definitive volume describing Darwin's movements through the Galápagos, and two journal articles. See Table 2.1 for details of author attributions on multi-authored publications.

2.2 Research methods used during the development of the selected publications

The evolution of the methods used to underpin the publications outlined in Section 2.1 is described sequentially here. The methodology took a relatively unconventional approach by combining archival research and fieldwork. A handful of other Darwin scholars have adopted a similar approach; e.g. Armstrong on the Cocos Keeling Islands (Armstrong, 1991), Pearson and Nicholas on the Cape Verde Islands (Pearson and Nicholas, 2007) and Wesson on Santa Maria Island (Wesson, 2017). However, an important difference between these studies and the author's work is the author's firsthand experience and knowledge of the geology of the Galápagos gained from living and working as a naturalist guide for over 12 years before the research began.

2.2.1 Initial journey

In April 1982, as part of a commemoration marking the centenary of Charles Darwin's death, the author led an expedition to the Galápagos to study the feeding ecology of the Galápagos marine iguana (Estes et al., 1982). Afterwards he began to investigate Darwin's movements, scientific thinking, and observations in the Galápagos. Although the Galápagos Islands and Darwin are inextricably linked through his work on species, there was scanty information in the academic literature on his movements and his scientific research while in the islands. In a search for more information the author went on a journey in 1995 to meet various scholars and scientists who had published on Darwin's voyage on HMS *Beagle*. These included the following who gave helpful advice on where to find manuscripts pertaining to Darwin's visit to the Galápagos Islands:

- Frank J. Sulloway, Dibner Research Fellow, Dibner Institute for the History of Science and Technology, Massachusetts Institute of Technology
- Duncan Porter, Professor of Biological Sciences, College of Science, Virginia Tech
- Keith Thomson, President of the Academy of Natural Sciences Philadelphia
- Richard Darwin Keynes (Charles Darwin's great grandson), Professor of Physiology, University of Cambridge

Table 2.1 Publications considered in this thesis. Hyperlinks to, and copies of, these publications are presented in Appendix I.

Publication Number	Publication	Brief Commentary
1	Darwin, C. R. (1835c) *Geological diary: Galápagos. CUL-DAR37.716-795A Transcribed by K. Thalia Grant and Gregory B. Estes.* [Online].	The first ever full transcription of Darwin's *Geological Diary* (121 pages including 37 sketches and diagrams), part of the largest scientific document composed by Darwin during the voyage of the *Beagle*. Estes was responsible for identifying geological sites described by Darwin and Grant for deciphering Darwin's handwriting.
2	GRANT, K. T., and ESTES G. B. (2002) *Darwin's notes on the geology of Galápagos; An introduction by K. Thalia Grant and Gregory B. Estes* [Online].	The transcription was executed in 1996 and published with the accompanying introduction as part of Wyhe, John van (ed.) (2002) *The Complete Work of Charles Darwin Online* (http://darwin-online.org.uk/). Estes was responsible for the synopsis of Darwin's Galápagos itinerary and locality for Darwin's specimens, and Grant for work on pagination and orthography.
3	ESTES, G., GRANT, K. T. & GRANT, P. R. (2000) Darwin in the Galápagos: his footsteps through the archipelago. *Notes and records of the Royal Society of London,* 54, 343-368. https://doi.org/10.1098/rsnr.2000.0117	This paper documents research led by the author to retrace Darwin's steps in the Galápagos and identify the key sites where he made geological observations. Estes was responsible for Darwin's work on geology, K.T. Grant for his general study of the fauna and flora and P.R. Grant for Darwin's finches.
4	GRANT, K. T. & ESTES, G. B. (2009) *Darwin in Galápagos: Footsteps to a New World,* Princeton, Princeton University Press.	This book represents the "definitive account" (Chancellor, 2002b) of Darwin's seminal visit to the Galápagos. This thesis considers nine chapters (Chapters I - IX), focusing closely on Chapters IV, VI and VII that reveal Darwin's work on the geology of the Galápagos. Both authors worked on the chapters over the 10 years it took to complete the book. Estes led on sections that address geology.
5	HERBERT, S., GIBSON, S., NORMAN, D., GEIST, D., ESTES, G., GRANT, T. & MILES, A. (2009). Into the field again: Re-examining Charles Darwin's 1835 geological work on Isla Santiago (James Island) in the Galápagos archipelago. *Earth Sciences History,* 28, 1-31. https://doi.org/10.17704/eshi.28.1.mjt982717p162323	This publication details an expedition in 2007 to retrace Darwin's steps on James (Santiago) Island. The author's role was to lead co-authors to field sites previously identified by Estes et al. (2000)

2.2.2 Archival Research

There is a wealth of information on Darwin's activities during the voyage of the *Beagle* thanks to his meticulous note-taking and correspondence and the preservation of these writings by his family. Most of Darwin's writings are now available online. The author played a key role in this endeavor by transcribing Darwin's *Geological Diary* (see Table 2.1). The manuscript was examined at the Darwin Archive in the University of Cambridge Library. Photocopies were obtained from the Archive but there were sections where Darwin's handwriting was difficult to decipher without the original, so a full transcription required multiple visits to Cambridge. Editorial comments, indicated by square brackets ([ ]) and page numbers were noted in red. The words recto and verso were used to indicate the front and back of a page. Darwin did not number the verso pages. Those few words and letters that were illegible or uncertain were marked in italicized square brackets (*[ ]*), marginal notes defined by angular brackets (< >) and insertions by double angular brackets (<< >>). Annotations were added as footnotes. Darwin's orthography and symbols are addressed in the author's introduction (Grant and Estes, 2002).

As part of the underpinning research for the publications detailed in Table 2.1 the author critically analyzed all Darwin's writings on geology and other relevant manuscripts (see Table 2.2) to geolocate landmark sites from Darwin's geological survey of the Galápagos (see Figures 4.5 and 4.8a for examples of pages from selected manuscripts).

2.2.3 Fieldwork

The archive work described in Section 2.2.2 was supported by fieldwork to determine the exact sites on the Galápagos visited by Darwin. Initial fieldwork (six field excursions) was conducted between 19 October and 14 December 1996, shortly after the transcription of the *Geological Diary*. The author's original plan was to conduct fieldwork over the same dates that Darwin had visited Galápagos (15 September – 20 October). However, fieldwork could not start until 19 October 1996 as there was a delay in obtaining a permit from the Galápagos National Park Service (GNPS). Islands were visited in the order Darwin visited them (Figure 1.3) apart from Charles (Floreana) Island.

Four further field excursions were undertaken between 1997 and 2009 (under separate GNPS research permits) to check that sites had been correctly identified and to retake GPS readings (see Chapter 4). As only five of the Galápagos Islands are inhabited much of this fieldwork was in remote terrain, involving approximately 300 km travel on foot and 1000 km by boat. Upon completion of each field excursion, reports by Estes and Grant (1996a, 1996b, 1996c, 1997a, 1997b, 1997c, 2003, 2004, 2007, 2009) were submitted to the GNPS (see Appendix II).

By examining notes in Darwin's *Geological Diary* (Darwin, 1835c) and his *Field Notebook* (Darwin, 1835a) (Table 2.2), the author was able to identify the sites Darwin visited and where he collected his geological specimens. Photographs were taken of craters and outcrops in the field to compare with illustrations and descriptions by Darwin in the *Geological Diary* (Darwin, 1835c) (see examples in Figure 4.9 and 4.16), alongside measurements of craters to compare with Darwin's measurements (Figure 4.16e). Examples of the procedures to identify selected sites are provided in Chapter 4.

Table 2.2 Archival material analyzed (Darwin's writings that include geology of Galápagos in bold).

Archival Material	Summary Description
Field Notebook (Darwin, 1835a)	**38 pages of text on the Galápagos Islands.**
***Geological Diary* (Darwin, 1835c)**	**121 pages of text with 37 sketches/diagrams of the geology of Galápagos. The author transcribed the original *Geological Diary* from the Darwin Archive at Cambridge University Library.**
***Beagle Diary* (Keynes, 1988)**	**Darwin's Personal Diary**
Darwin's Correspondence (Burkhardt et al., 1985-2023)	**Transcriptions of Darwin's correspondence**
Darwin's Notebooks 1836-1844 (Barrett et al., 1987)	**Darwin notebooks after the *Beagle* voyage 1836-1844**
***Voyage of the Beagle* 1st edition (Darwin, 1839b)**	**Journal of Researches on Geology and Natural History during the *Beagle* voyage.**
***Voyage of the Beagle* 2nd edition (Darwin, 1845)**	**Journal of Researches on Geology and Natural History during the *Beagle* voyage.**
***Volcanic Islands* (Darwin, 1844)**	**Geological observations on the volcanic islands visited during the *Beagle* voyage**
Darwin's Specimens (Darwin, 1835b, Harker, 1907)	Catalogues of 40 rock specimens and three "fossil" marine shells from Galápagos. (Specimen numbers 3220-3226, 3234-3239, 3247-3250, 3265-3283 3286-3292)
Accounts by Captain & Officers of the *Beagle* (FitzRoy, 1831-1836), (FitzRoy, 1835)	Ship's Log of the *Beagle* ADM 53/236, FitzRoy's Remarks
Charts (FitzRoy, 1836)	British Admiralty Charts L945, L946, L947, L948, L949, L950, 1375
Books on the *Beagle* (Burkhardt, 1985)	Four volumes on the the Galápagos Islands and five volumes on the geology of volcanoes.

2.3 Assessing the Contribution to Knowledge of the Selected Publications

In the remainder of this thesis, two approaches are used to evaluate the contribution of the selected publications (Table 2.1). The first (Chapter 3) is a systematic analysis of major scholarly biographies and other studies of Charles Darwin that incorporate accounts of his geological work. This analysis is used to demonstrate that, by exploring new research themes and focussing on previously unanalyzed sources (most notably Darwin's *Geological Diary*), the author has provided a new perspective on Darwin's contribution to science. The second (Chapter 4) is a systematic account of how the author has combined archival analysis and fieldwork to identify specific sites and even outcrops described by Darwin. This account is used to demonstrate how the author has revealed new insights into Darwin's movements on the Galápagos and the practices underpinning his geological work. Chapter 4 also describes how the identification of specific sites has led to subsequent advances in geological knowledge, and how such information can be used to correct errors and/or misunderstandings in scholarly biographies of Darwin's work in the Galápagos.

Methodologies similar to that used by the author have been implemented in other works that have retraced the movements of scientists and explorers (Stenton et al., 2010, Calhoun, 2015, Brumm et al., 2019, Wang et al., 2021), including Darwin (Armstrong, 1991, Roberts, 2001, Pearson and Nicholas, 2007, Wesson, 2017, Chancellor, 2023). What sets the author's work apart is the combination of rigorous fieldwork with meticulous archival research.

In addition to the analyses presented in Chapters 3 and 4, the author has critically examined reviews and endorsements of his work (Appendix III), citations using Google Scholar (Appendix IV), print runs and web traffic related to the selected publications. Reviews and endorsements were collated by conducting a search online through (i) the University of British Columbia Library (search refined using the limiter 'scholarly and peer-reviewed'), (ii) book retailers (e.g., Amazon), (iii) library catalogues and (iv) Princeton University Press. Information on the print run (7,500 copies) of Grant and Estes (2009) was kindly provided by the publisher, Princeton University Press. The annotated transcription of Darwin's *Geological Diary* (Darwin, 1835c) and accompanying introduction (Grant and Estes, 2002) is published on the website Darwin Online (van Wyhe, 2002a) together with the number of times each has been accessed (76,154 times and 2,735 times respectively, on the date of thesis submission [12 January 2024]). This website is "the largest Darwin resource/publication in the world—and probably the most comprehensive scholarly website on any historical person" (van Wyhe, 2002a). The author is listed as one of the 15 contributors of introductions (van Wyhe, 2002b)

2.4 Conclusion

This chapter has outlined the publications to be considered in this thesis, the methodologies used by the author to produce them and the approaches used to evaluate their contribution to knowledge. Chapters 3 and 4 will address the author's contribution through a critical analysis of leading biographies and other studies of Charles Darwin, and an account of the discovery, examination, and identification of key localities foundational to Darwin's geological theories.

Chapter 3 Critical Analysis of Scholarly Biographies and Other Studies of Charles Darwin

Having outlined the publications to be considered as part of this thesis in Chapter 2, this chapter presents a critical analysis of scholarly biographies and other studies of Darwin's life and research, to demonstrate how the author's work offers a new and unique perspective on Darwin's contribution to science. It does so by (i) examining the coverage of Darwin's scientific discoveries in scholarly biographies, and, for those that discuss Darwin's geology, (ii) exploring the coverage of his major geological contributions and analyzing the primary sources used. This analysis is followed by a separate scrutiny of those journal articles and book sections that address Darwin's geology.

3.1 Introduction

Charles Darwin's life and his many achievements have been chronicled by numerous biographies. Fifty-three of the most important volumes, published between 1887 and 2022, are listed in Table 3.1 (compiled using Google Scholar). The earliest was written by Darwin's son, Sir Francis Darwin, and published five years after his death (Darwin and Darwin, 1887). Biographies vary in their scope and emphasis. Early biographers relied primarily on Darwin's published journals (Darwin, 1839a, Darwin, 1839b, Darwin, 1845) and used his autobiography, personal diary and especially his correspondence as primary sources. Colp (1989) documents the evolution of Darwin biographies up until 1989. More recent accounts of Darwin's scientific work have been facilitated by the comprehensive transcription and digitization of his many notebooks and correspondence (van Wyhe, 2002a) including the author's transcription of Darwin's *Geological Diary*. Consequently, biographies and journal articles are now able to incorporate more of Darwin's scientific writings, contributing to a broader understanding of his intellectual development.

3.2 Selection of Biographies

In order to explore the author's contribution to knowledge, an in-depth analysis of the content of, and primary sources used within, scholarly biographies of Darwin was undertaken. The first stage of this analysis was to identify those biographies in Table 3.1 that (a) mentioned Darwin's geology and (b) evidenced which of Darwin's writings were used as information sources. Only biographies that clearly display academic rigour, evidenced by the presence of citations and endnotes, and that cover the period of Darwin's life devoted to geology (1831-1848) were included for detailed examination. This whittled the list down to 17 titles. The following 36 biographies were excluded from the analysis:

- early epistolary biographies (Darwin and Darwin, 1887, Allen, 1888, Poulton, 1896, Bradford, 1926, Huxley, 1927, Ward, 1927, Dorsey, 1928, West, 1938, Keith, 1955) that had little to draw on for sources other than publications describing Darwin's voyage of the *Beagle*, his autobiography and his correspondence;
- brief biographies (Olby, 1967, Stevens, 1978, Howard, 1982, Stefoff, 1996, Patent, 2001, Aydon, 2002, Desmond et al., 2007, Berra, 2009);

Table 3.1 Biographies of Charles Darwin in chronological order (biographies selected for analysis in bold)

Author/Year	Title
Darwin and Darwin (1887)	*The life and letters of Charles Darwin: including an autobiographical chapter*
Allen (1888)	*Charles Darwin*
Poulton (1896)	*Charles Darwin and the theory of natural selection*
Bradford (1926)	*Darwin*
Huxley (1927)	*Charles Darwin*
Ward (1927)	*Charles Darwin: the man and his warfare*
Dorsey (1928)	*The evolution of Charles Darwin*
West (1938)	*Charles Darwin: a portrait*
Barlow (1945)	*Charles Darwin and the Voyage of the Beagle*
Barzun (1947)	*Darwin, Marx, Wagner: critique of a heritage*
Irvine (1955)	*Apes, angels, and Victorians: a joint biography of Darwin and Huxley*
Keith (1955)	*Darwin revalued*
Eiseley (1958)	*Darwin's century: evolution and the men who discovered it*
Himmelfarb (1959)	***Darwin and the Darwinian revolution***
De Beer (1965)	***Charles Darwin: a scientific biography***
Huxley and Kettlewell (1965)	*Charles Darwin and his world*
Olby (1967)	*Charles Darwin*
Moorehead (1969)	*Darwin and the Beagle*
Chancellor (1973)	*Charles Darwin*
Colp (1977)	*To be an invalid: the illness of Charles Darwin*
Stanbury (1977)	*A Narrative of the Voyage of HMS Beagle*
Stevens (1978)	*Charles Darwin*
Keynes (1979)	*The Beagle record: selections from the original pictorial records and written accounts of the voyage of H.M.S. Beagle*
Stone (1980)	*The origin: a biographical novel of Charles Darwin*
Brent (1981)	***Charles Darwin: "A man of enlarged curiosity"***
George (1982)	*Darwin*
Howard (1982)	*Darwin*
Clark (1984)	*The survival of Charles Darwin: a biography of a man and an idea*
Bowlby (1990)	***Charles Darwin: A new life***
Bowler (1990)	***Charles Darwin: the man and his influence***
Desmond and Moore (1991)	***Darwin***
Weiner (1994)	*The beak of the finch: evolution in real time*
Browne (Vol. I 1995, Vol. II 2002)	***Charles Darwin: Voyaging (Volume 1)*** ***Charles Darwin: The Power of Place (Volume 2)***
White and Gribbin (1995)	***Darwin: A Life in Science***
Stefoff (1996)	*Charles Darwin: And the evolution revolution*
Patent (2001)	*Charles Darwin: The life of a revolutionary thinker*
Aydon (2002)	*A Brief Guide to Charles Darwin His Life and Times*
Keynes, R. (2002)	*Darwin, his daughter, and human evolution*
Keynes, R. D. (2002)	***Fossils, finches and fuegians: Charles Darwin's adventures and discoveries on the Beagle***
Larson (2004)	*Evolution: the remarkable history of a scientific theory*
Eldredge (2005)	***Darwin: discovering the tree of life***
Herbert (2005)	***Charles Darwin, geologist***
Quammen (2006)	***The reluctant Mr. Darwin: an intimate portrait of Charles Darwin and the making of his theory of evolution***
Desmond et al. (2007)	*Charles Darwin*
Ruse (2008)	*Charles Darwin*
Berra (2009)	*Charles Darwin: the concise story of an extraordinary man*
McCalman (2009)	*Darwin's armada: four voyages and the battle for the theory of evolution*
Thomson (2009)	***The young Charles Darwin***
Porter and Graham (2015)	*Darwin's sciences*
Strager (2016)	***A Modest Genius: The Story of Darwin's Life and how His Ideas Changed Everything***
Wesson (2017)	***Darwin's first theory: exploring Darwin's quest to find a theory of the earth***
Chaffin (2022)	***Odyssey: Young Charles Darwin, the Beagle, and the Voyage that Changed the World***
Preston (2022)	***The Evolution of Charles Darwin: The Epic Voyage of the Beagle that Forever Changed Our View of Life on Earth***

- heavily illustrated 'coffee-table' biographies (Huxley and Kettlewell, 1965, Moorehead, 1969, Chancellor, 1973); compilations of Darwin's writings with relatively little additional text (Barlow, 1945, Stanbury, 1977, Keynes, 1979);
- biographies that include biographical accounts of other historical figures (Barzun, 1947, Irvine, 1955, McCalman, 2009);
- biographies that focus almost exclusively on Darwinism and evolution (Eiseley, 1958, George, 1982, Clark, 1984, Weiner, 1994, Larson, 2004, Ruse, 2008, Porter and Graham, 2015);
- fictionalized biographies (Stone, 1980);
- biographies that focus on Darwin's family and/or health (Colp, 1977, Keynes, R., 2002).

Another criterion for selection was the number of citations on Google Scholar. Most biographies selected have a relatively high number of citations, with nine of the 17 selected titles having been cited over 100 times. The two most cited, with over 1,000 citations each, are by Adrian Desmond & James Moore (1991) and Janet Browne (Vol. I 1995, Vol. II 2002). Selected biographies with few citations but incorporating endnotes, including recent works (Strager, 2016, Wesson, 2017, Chaffin, 2022, Preston, 2022), were also included in the analysis.

3.3 Analysis of Scientific Themes in Selected Biographies

Selected biographies were examined thematically, with each theme corresponding to a period that Darwin devoted to a specific scientific subject (see Table 3.2). Each period ends with a seminal publication: (i) on the *Beagle* voyage (Darwin, 1839a), (ii) on geology (Darwin, 1846), (iii) on barnacles (Darwin, 1854), (iv) on variation of plants and animals under domestication (Darwin, 1868), (v) on evolution and natural selection (Darwin, 1859), (vi) on human evolution (Darwin, 1871) and (vii) on botany and earthworms (Darwin, 1880, Darwin, 1881). Themes such as Darwin's personal life, family and views on politics and religion were excluded.

Key words in the indices and chapter headings, together with textual analysis, were employed to determine the relative proportion devoted to each theme in each biography. For the coverage of a theme to be deemed 'frequent' (F), the theme needs to be the subject of more than two chapters. 'Occasional' (O) coverage is reserved for themes that occur in one or two chapters but are written about in depth, while 'rare' (R) is used where a theme is referred to briefly in only one chapter.

Table 3.2 shows that the most common theme covered by scholarly biographies of Darwin is, unsurprisingly, evolution and natural selection. Other common themes are the voyage of the *Beagle* and Darwin's geological work (the primary focus of Grant and Estes, 2009). Uncommon themes include barnacles, botany and earthworms. Variation of plants and animals under domestication and human evolution have intermediate coverage.

Table 3.2 Relative proportion that each scholarly biography selected from Table 3.1 devotes to specific scientific themes within Darwin's work: (i) frequent (F), (ii) occasional (O), and (iii) rare (R). The coverage included in Grant and Estes (2009) is shown for comparison. Note that the range of years shown is approximate as Darwin's work on specific themes extends beyond time frames.

Biography	Voyage of the *Beagle* 1832-1839	Geology 1826-1846	Barnacles 1846-1854	Evolution & Natural Selection 1836-1859	Variation of domesticated plants and animals 1836-1868)	Human Evolution 1859-1871	Botany & Earthworms 1859-1881	TOTAL PAGES
Bowlby (1990)	O	O	R	O	R	R	R	511
Bowler (1990)	O	O	R	F	O	O	R	250
Brent (1981)	O	F	R	F	R	O	R	536
Browne (Vol. I 1995, Vol. II 2002)	F	F	R	F	O	O	R	1196
Chaffin (2022)	F	O	R	O	R	R	R	362
De Beer (1965)	F	O	R	F	O	O	O	295
Desmond and Moore (1991)	O	O	R	F	O	O	R	808
Eldredge (2005)	O	O	R	F	O	O	R	256
Herbert (2005)	F	F	R	O	R	R	R	485
Himmelfarb (1959)	O	O	R	F	O	O	R	422
Keynes, R. D. (2002)	F	F	R	O	R	R	R	428
Preston (2022)	F	O	R	O	R	O	R	501
Quammen (2006)	O	O	O	F	O	R	R	304
Strager (2016)	O	O	R	F	O	O	R	218
Thomson (2009)	O	O	R	F	O	O	R	276
Wesson (2017)	F	F	R	O	R	R	R	457
White and Gribbin (1995)	O	O	R	F	R	R	R	322
Grant and Estes (2009)	**F**	**F**	**R**	**O**	**O**	**R**	**R**	**362**

3.4 Darwin's Geology 1832-1838 in Selected Biographies

Having determined that the 17 selected scholarly biographies commonly address Darwin's geology, each was analyzed further to establish which of Darwin's landmark geological discoveries during the voyage of the *Beagle* (as discussed in Chapter 1, Table 1.1) were covered. For this analysis, simple presence/absence was recorded (see Table 3.3).

Inspection of Table 3.3 reveals that, of the 17 selected biographies, all include accounts of at least one of Darwin's landmark geological sites, 13 address over half and six cover all except for Galápagos. Aside from Grant and Estes (2009), Herbert's biography, which focusses exclusively on Darwin's geology, is the only one that examines Darwin's geological investigations in Galápagos. Herbert's biography does not, however, include accounts of Darwin's fieldwork in Galápagos and is limited to an examination of just four of Darwin's 43 specimens of rocks and fossils collected on only one of the four islands he visited. Grant and Estes (2009), in contrast, is unique in its comprehensive coverage of Darwin's geological work in Galápagos.

Table 3.3 Coverage of Darwin's landmark geological discoveries during the voyage of the *Beagle* within selected biographies (✓ covered, x not covered)

Biography	Cape Verde Islands Feb 1832 & Sept 1836	Punta Alta & Monte Hermoso, Argentina Sept/ Oct 1832 & Aug 1833	Port St. Julian, Patagonia Jan 1834	Rio Santa Cruz, Argentina Apr/May 1834	Mount Osorno, Chile Nov 1834, Jan 1835	Validivia & Concepcion , Chile Feb/Mar 1835	Peuquenes ridge and Portillo ridge, Chile March 1835	Uspallata Pass, Chile April 1835	Galápagos Islands Sept/Oct 1835	Cocos Keeling Islands April 1836
Bowlby (1990)	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
Bowler (1990)	✓	✓	✓	x	x	✓	x	x	x	✓
Brent (Brent, 1981)	✓	✓	x	✓	x	✓	x	✓	x	✓
Browne (Vol. I 1995, Vol. II 2002)	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
Chaffin (2022)	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
De Beer (1965)	✓	✓	✓	✓	x	✓	✓	✓	x	✓
Desmond and Moore (1991)	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
Eldredge (2005)	x	x	x	✓	x	✓	x	x	x	x
Herbert (2005)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Himmelfarb (1959)	✓	✓	x	x	x	✓	x	x	x	✓
Keynes, R. D. (2002)	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
Preston (2022)	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
Quammen (2006)	✓	x	x	x	x	x	x	x	x	x
Strager (2016)	✓	✓	x	x	x	✓	x	x	x	x
Thomeson (2009)	✓	✓	x	✓	x	✓	x	x	x	✓
Wesson (2017)	✓	✓	✓	✓	✓	✓	✓	✓	x	✓
White and Gribbin (1995)	✓	✓	x	✓	✓	✓	x	✓	x	✓
Grant and Estes (2009)	✓	✓	✓	**x**	✓	✓	✓	✓	✓	✓

3.5 Primary Sources for Darwin and Galápagos.

Having established that the thematic coverage and attention to geology within Grant and Estes (2009) is unique amongst the scholarly biographies analyzed, inspection of the primary sources cited in each biography was conducted to understand why this might be the case. This involved two stages. First, the primary sources themselves were analyzed to ascertain the proportion of information they contained about the geology and zoology of Galápagos. Second, the 17 selected biographies, plus Grant and Estes (2009), were examined for their use of these sources.

3.5.1 Word Counts and Illustrations of Darwin's writings on the geology of Galápagos within primary sources

Each of the eight main primary sources written by Darwin (highlighted in bold in Table 2.2) were analyzed for accounts of his scientific work on the Galápagos Islands to determine the proportion devoted to (i) geology and zoology in general and (ii) geology only. This was assessed using word counts (Table 3.4) and the identification of the thematic focus of all illustrations (Table 3.5).

Table 3.4 Relative word count devoted to the geology and zoology of Galápagos in primary sources written by Darwin (at the time of his visit to the islands or soon after). Word count is approximate, with an error of ~20.

Source	Total word count on the geology and zoology of the Galápagos Islands	Word count on geology of Galápagos	% on geology
Field Notebook (Darwin, 1835a)	1315	771	59
Geological Diary (Darwin, 1835c)	15672	15672	100
Beagle Diary (Keynes, 1988)	4164	947	20
Darwin's Correspondence (Burkhardt et al., 1985-2023)	322	230*	71
Darwin's Notebooks 1836-1844 (Barrett et al., 1987)	1065	250	25
Voyage of the Beagle 1st edition (Darwin, 1839b)	9185	948	10
Voyage of the Beagle 2nd edition (Darwin, 1845)	12042	1076	9
Volcanic Islands (Darwin, 1844)	7851	7851	100

*Note: Darwin wrote 9 letters during the voyage of the *Beagle* that mention the Galápagos. Three of these letters were written about a month before reaching the archipelago in which he noted that he was looking forward to exploring the geology of the islands. The only letter sent from the Galápagos has gone missing. After visiting Galápagos, while still on the *Beagle*, Darwin wrote two letters that mention the geology of the islands, one of which refers to the islands as "that land of Craters" (Darwin, 1985). Another seven letters containing c. 605 words on the geology of Galápagos were written by Darwin after the voyage.

Table 3.5 Illustrations of Galápagos in primary sources written by Darwin.

Source	Illustration
Field Notebook (Darwin, 1835a)	4 sketches of geology
Geological Diary (Darwin, 1835c)	37 sketches of geology
Beagle Diary (Keynes, 1988)	one sketch of cactus
Darwin's Correspondence (Burkhardt et al., 1985-2023)	none
Darwin's Notebooks *1836-1844* (Barrett et al., 1987)	1 sketch of geology
Voyage of the Beagle 1st edition (Darwin, 1839b)	none
Voyage of the Beagle 2nd edition (Darwin, 1845)	1 map of archipelago 1 drawing of Darwin finches 1 drawing of marine iguana
Volcanic Islands (Darwin, 1844)	1 map of archipelago 3 drawings of geology

From the relative word counts in Table 3.4 it is evident that the *Geological Diary* and *Volcanic Islands* (Darwin, 1835c, Darwin, 1844) are the only two sources that solely address geology. It is also clear from Table 3.4 that Darwin's *Geological Diary* is the principal primary source for information about Darwin's observations of the geology of the Galápagos. Table 3.5 demonstrates that the main source for illustrations by Darwin of the geology of Galápagos is also the *Geological Diary*.

3.5.2 Primary Sources for accounts of Darwin's scientific work in Galápagos in selected biographies

Having established that the *Geological Diary* is the principal source for Darwin's observations of the geology of the Galápagos, all 17 selected biographies (plus Grant and Estes, 2009) were analyzed for their use of each primary source. This involved the meticulous analysis of the bibliographies and endnotes in each selected biography. The results of this analysis are shown in Table 3.6, organized according to whether a source was written primarily during or after the voyage of the *Beagle*.

Table 3.6 Citations of Primary Sources within selected biographies for Darwin's scientific work in Galápagos.

	Written During the Voyage of the *Beagle*					Written After the Voyage			Total Citations
Author & Year	*Beagle* Diary	Correspon-dence	*Darwin's Field* Notebooks	*Geological Diary*	Zoology Notes (*Zoological Diary* & *Ornithological Notes*)	*Volcanic Islands*[1]	1836-1844 Notebooks	Voyage of the *Beagle*	
Bowlby (1990)	6	2	0	0	1	0	0	1	10
Bowler (1990)	3	0	1	0	0	0	1	2	7
Brent (1981)	6	4	0	0	1	0	0	2	13
Browne **(Vol. I 1995, Vol. II 2002)**	3	2	0	0	1	0	0	3	9
Chaffin (2022)	9	3	0	0	1	0	0	1	14
(De Beer, 1965)	3	0	1	0	1	0	2	2	9
Desmond and Moore (1991)	7	2	0	0	3	0	0	11	23
Eldredge (2005)	0	0	0	0	3	0	3	3	9
Herbert (2005)	4	8	1	8	6	6	3	9	45
Himmelfarb (1959)	3	4	0	0	1	0	3	8	19
Keynes, R. D. (2002)	4	0	0	0	1	0	0	0	5
Preston (2022)	0	1	1	0	7	0	0	0	9
Quammen (2006)	1	3	0	0	1	0	0	1	6
Strager (2016)	2	2	0	0	2	0	0	5	11
Thomson (2009)	1	2	0	0	3	0	0	7	13
Wesson (2017)	0	0	0	0	0	0	0	0	0
White and Gribbin (1995)	0	0	0	0	0	0	0	0	0
Total for all biographies	**52 26%**	**33 16%**	**4 2%**	**8 4%**	**32 16%**	**6 3%**	**12 6%**	**55 27%**	**202**
Grant and Estes (2009) Chapters 4,5,6,7 (in Galápagos)	**88 23%**	**32 8%**	**23 6%**	**93 24%**	**66 17%**	**12 3%**	**2 1%**	**64 17%**	**380**
Grant and Estes (2009) Chapters 1,2,3,8,9 (before and after Galápagos	**49 43%**	**118 56%**	**1 <1%**	**3 1%**	**9 4%**	**1 <1%**	**1 <1%**	**28 8%**	**210**
Grant and Estes (2009) Total for all chapters	**137 24%**	**150 26%**	**24 4%**	**96 17%**	**75 13%**	**13 2%**	**3 1%**	**92 13%**	**590**

[1] Darwin used his notes from the *Geological Diary* to write *Volcanic Islands* (Darwin, 1844) after the voyage on the *Beagle*. Percentages are rounded.

From Table 3.6, it is clear that, with the exception of Darwin's 1836-1844 Notebooks, Grant and Estes (2009) evidence more use of Darwin's primary writings than all of the other selected biographies. Of all the biographies Herbert (2005) draws most heavily from primary sources with 45 citations. It is noteworthy that Grant and Estes (2009) far exceeds this number in their biography with 590 citations. The most cited primary sources within the selected biographies are the *Voyage of the Beagle* (primarily those passages that describe the zoology of the Galápagos) and Darwin's *Beagle Diary*. In contrast, Grant and Estes (2009) draws most heavily on Darwin's Correspondence and his *Beagle Diary.*

It is also clear from Table 3.6 that, of the selected biographies, none apart from Herbert (2005) and Grant and Estes (2009), cite the *Geological Diary* or *Volcanic Islands* in their accounts of Darwin's scientific work in Galápagos. While Grant and Estes (2009) cites the *Geological Diary* 96 times, Herbert only includes 8 citations. This demonstrates that the selected biographies have focussed on Darwin's zoology rather than his principal scientific work in the Galápagos, studies of its geology.

Most of the selected biographies include images (sketches, maps, photos) to illustrate Darwin's scientific work. These images were examined to identify biographies that had illustrated Darwin's geology of the voyage (Table 3.7). Inspection of Table 3.7 shows that although images of Darwin's geology were used by 11 of the 13 illustrated biographies, only two (Brent, 1981, Herbert, 2005) depict his geology of Galápagos, with a total of three illustrations. Grant and Estes (2009) is unique in that it includes 29 illustrations of Darwin's geology of Galápagos

Table 3.7 Illustrations in biographies (✓ included, x not included)

Author & Year	Geology of Voyage	Geology of Galápagos	Wildlife of Galápagos	Image of Islands	Map of Islands in Galápagos visited by Darwin	Map of Voyage
Bowlby (1990)	✓	x	✓	x	✓	✓
Bowler (1990)	x	x	✓	x	x	✓
Brent (1981)	✓	✓[1]	✓	x	x	✓
Browne (Vol. I 1995, Vol. II 2002)	✓	x	✓	✓	✓	✓
Chaffin (2022)	✓	x	✓	x	x	✓
De Beer (1965)	✓	x	✓	x	✓	✓
Desmond and Moore (1991)	✓	x	x	x	x	✓
Eldredge (2005)	✓	x	✓	✓	✓	✓
Herbert (2005)	✓	✓[2]	x	x	✓	✓
Himmelfarb (1959)	x	x	x	x	x	✓
Keynes, R. D. (2002)	✓	x	✓	✓	✓	✓
Quammen (2006)	not illustrated					
Preston (2022)	✓	x	✓	✓	x	✓
Strager (2016)	not illustrated					
Thomson (2009)	not illustrated					
Wesson (2017)	✓	x	x	x	x	✓
White and Gribbin (1995)	not illustrated					
Grant and Estes (2009)	✓	✓[3]	✓	✓	✓	✓

1. Brent: one illustration
2. Herbert: two illustrations
3. Grant and Estes: 29 illustrations

3.6 Journal Articles and Book Chapters on Darwin's Geology of Galápagos

Having analyzed primary sources and illustrations cited in biographies, other publications that focus on Darwin's geology (specifically journal articles and book sections) were scrutinized to determine (i) what aspects of Darwin's work had been addressed and (ii) which primary sources were used to underpin the research. A list of 68 journal articles and book sections was compiled (see Appendix V) from Google Scholar and relevant bibliographies (e.g. Herbert (2005) and Wesson (2017)). Selection was made by identifying titles of articles or chapters that contain the word geology and or related terms (e.g., fossil, uplift, crater, igneous) and/or names of sites where Darwin studied the geology. Sites included those he visited during the voyage of the *Beagle* (see Table 3.3) as well as places he visited before and after. These 68 publications were then whittled down to nine whose authors had researched the geology of Galápagos and or Darwin's geology. The analysis of these articles and book sections (Table 3.8) displays coverage of each paper and, if applicable, their usage of the *Geological Diary* and if/why the author's work was cited. For comparison similar analysis was made of Estes et al. (2000) and Herbert et al. (2009), the two journal articles considered within this thesis.

Table 3.8 Focus of journal articles and book sections on Darwin's geology of the Galápagos Islands. (x = not cited). Author's work in bold.

Publication	Title	*Geological Diary* (Darwin, 1835c)	Geological Content	Estes's work cited
Allmon (2016)	Darwin and palaeontology: a re-evaluation of his interpretation of the fossil record	1 citation	palaeontology on the voyage of the *Beagle*	Grant and Estes (2009) for location of sites Darwin collected fossils
Chubb and Richardson (1933)	Geology of Galapagos, Cocos, and Easter Islands	x	Geology of Galápagos, Cocos, and Easter Islands	x
Gibson (2009)	Early settler-Darwin the geologist in the Galápagos	x	petrology on James Island	x
Gibson (2010)	Darwin the geologist in Galápagos: An early insight into sub-volcanic magmatic processes	13 citations	petrology on James Island	
Herbert (2010)	" A Universal Collector": Charles Darwin's Extraction of Meaning from His Galápagos Experience	x	petrology on James Island	(Estes et al., 2000, Grant and Estes, 2009) for location of sites visited by Darwin on James Island and transcription of *Geological Diary*
Johnson and Baarli (2015)	Charles Darwin in the Cape Verde and Galapágos Archipelagos: the role of serendipity in development of theories on the ups and downs of oceanic islands	x	Uplift on Cape Verde Islands and Galápagos	(Grant and Estes, 2009) for locating where Darwin went and what he did whilst in Galapagos
McBirney and Williams (1969)	Geology and petrology of the Galápagos islands	x	Geology of Galápagos	x
Pearson (1996)	Charles Darwin on the origin and diversity of igneous rocks	6 citations	petrology on James Island	x
Simkin (1984b)	Geology of Galápagos Islands	x	Geology of Galápagos	x
Herbert et al. (2009)*	**Into the field again: Re-examining Charles Darwin's 1835 geological work on Isla Santiago (James Island) in the Galápagos archipelago**	**14 citations**	**petrology on James Island**	**(Estes et al., 2000) for geolocation of geological sites visited by Darwin on James Island**
Estes et al. (2000)	**Darwin in the Galápagos: his footsteps through the archipelago**	74 citations	**Darwin's geology of Galápagos Archipelago**	

* Estes is a coauthor on Herbert et al. (2009) (see Chapter 2). Herbert's biography (Herbert, 2005), which was analyzed in Sections 3.3, 3.4 and 3.5, was published before this paper.

It is clear from Table 3.8 that the *Geological Diary* is cited by only four of the ten selected publications and only three cite it more than once. An analysis of these citations show that they are limited to accounts of Darwin's work on only one of four islands he visited in Galápagos. Gibson (2010) has the highest number of citations of the *Geological Diary* (13) but these pale in comparison with Estes et al. (2000) who cite the *Geological Diary* 74 times. Furthermore, Estes et al. (2000) cover Darwin's geology on 18 islands and islets.

3.7 Analysis

Having described the results of the analysis of selected biographies and other studies in Sections 3.5 and 3.6, this section provides a more nuanced analysis of these findings. The analysis of selected biographies in Section 3.5 shows that, while all address Darwin's geology during the voyage of the *Beagle*, each either omits or downplays Darwin's principal scientific work in the Galápagos by not referring to information contained within his *Geological Diary*, the most fertile source for insight into his scientific theories on the geology of the islands.

Only two biographies (Herbert, 2005, Wesson, 2017) focus specifically on Darwin's geology during the voyage of the *Beagle* (see Table 3.6). Wesson does not mention Darwin's geology of the Galápagos even though he writes about Darwin's geological investigations on other islands visited during the voyage (Cape Verde and the Cocos Keeling Islands). Herbert is the only biographer (other than Grant and Estes, 2009) to have addressed Darwin's geology of the Galápagos, focussing on Darwin's specimens collected from James Island. Herbert cites Estes et al. (2000), crediting them with "the precise tracing of Darwin's route" in the Galápagos and, with "their local knowledge" of the islands, using "Darwin's original notes to restudy these sites" (Herbert, 2005 pp. 311, 158). Scrutiny of Herbert shows that only 8 folio pages of the *Geological Diary* on Galápagos are cited in her work. By contrast, Grant and Estes (2009) cite 53 folio pages in *Darwin in Galápagos: footsteps to a new world* with 40 folio pages in *Darwin in Galápagos: his footsteps through the archipelago* (Estes et al., 2000). Unlike Herbert, Grant and Estes (2009) also made extensive use of Darwin's sketches to geolocate geological formations on the islands that he visited (see Chapter 4).

The absence of accounts of Darwin's observations in Galápagos within biographies of his geological work during the voyage of the *Beagle* (see Tables 3.2 and 3.3) are at odds with Darwin himself, who wrote three times more on the geology of the islands than the zoology in his scientific notes. The primary sources most cited by biographies on Darwin and Galápagos (Table 3.6) are the Voyage of the *Beagle* and Darwin's *Beagle Diary*. However, these sources cover a small fraction of what Darwin wrote about the geology of Galápagos (Table 3.4). The textual analysis of biographical accounts of Darwin's visit to Galápagos in Section 3.5 reflects that all centre on his zoology rather than geology; e.g. the most highly cited biography (Vol. I Browne, 1995, Vol. II Browne, 2002) devotes over four times more to Darwin's zoology than his geology. By contrast, the primary source most cited by Grant and Estes (2009) on Darwin's time in Galápagos (Chapters 4, 5, 6 and 7) is the *Geological Diary* (93 times) and more text is devoted to Darwin's geology than his zoology.

It is significant that six of the biographies cite the *Geological Diary* for other places visited by Darwin during the voyage of the *Beagle*, but by focussing on Darwin's zoology in Galápagos, have overlooked his principal scientific work in the islands. It is also noteworthy that Grant and

Estes (2009) is the only work to fully interpret Darwin's geology of Galápagos through the use of his illustrations.

The analysis of selected journal articles and book sections in Section 3.6 show that, while each addresses the geology of the Galápagos, they either omit Darwin's geological observations of the archipelago or understate his contributions. In contrast to Estes et al. (2000), general works on the geology of Galápagos (Chubb and Richardson, 1933, McBirney and Williams, 1969, Simkin, 1984a) do not cite Darwin's *Geological Diary* and provide only cursory accounts of Darwin's observations. The papers on the petrology of James Island (Pearson, 1996, Gibson, 2010, Herbert, 2010) cite the *Geological Diary* sparingly (up to 13 times) in comparison with the author's considered contributions (Estes et al., 2000, Herbert et al., 2009) (up to 74 times). Furthermore, Estes et al. (2000) examines Darwin's geological observations of the whole archipelago whereas Pearson, Gibson and Herbert only address one island. Johnson and Baarli (2015) focus on Darwin's research in the Cape Verde Islands with little on Darwin's work in Galápagos and, unlike Estes et al. (2000), do not cite the *Geological Diary.* Allmon (2016) similarly only briefly references Darwin's geology and only once cites the *Geological Diary*. Three publications (Herbert, 2010, Johnson and Baarli, 2015, Allmon, 2016) recognize the author's contribution by citing Estes et al. (2000) and/or Grant and Estes (2009) for geolocating sites that were important to Darwin's scientific theories on geology.

3.8 Conclusion

This chapter has critically analyzed 53 biographies on Charles Darwin alongside 68 journal articles and book chapters that focus on specific aspects of Darwin's scientific work. It has shown that Grant and Estes's (2009) *Darwin in Galápagos: footsteps to a new world* contrasts dramatically with the biographies in demonstrating that Darwin's principal focus during his time in the Galápagos Islands was geology rather than zoology. Biographies portray geology as playing a secondary role in his scientific work on the Galápagos. However, as this chapter shows, Darwin wrote three times more on the geology of the Galápagos than the zoology. This underplaying of Darwin's geology in Galápagos is also shown through the critical analysis of journal articles and book chapters about Darwin's scientific work. Through this analysis the author's submitted contributions (Estes et al., 2000, Herbert et al., 2009) are shown to be the most comprehensive in assessing Darwin's geological observations across the full Galápagos archipelago.

The *Geological Diary*, which was central to Darwin's scientific work in Galápagos, was fully transcribed and annotated by the author (Darwin, 1835c, Grant and Estes, 2002). It proved to be indispensable during Estes and Grant's rigorous fieldwork (1996a, 1996b, 1996c, 1997a, 1997b, 2003, 2004, 2007, 2009) to geolocate the sites that Darwin visited. These contributions to knowledge are discussed further in Chapter 4.

Chapter 4 Following in Darwin's Footsteps: Combining Archive Work with Fieldwork on the Galápagos

Having critically analyzed leading biographies and other scholarly works on Darwin in Chapter 3 and established that geology, his principal scientific work in Galápagos, has been overlooked, this chapter (i) documents the author's work in geolocating the sites Darwin studied and (ii) explores the contributions this has made to research on Darwin's scientific thinking and theories on geology. It starts by illustrating the author's approach to site identification through two case study examples, and then explores how this work has enabled further geological discovery and offers the potential to correct geolocational errors in several leading biographies, journal articles and book sections.

4.1 Introduction

There is a tradition of scholarly research that has focussed on retracing the steps of scientific explorers by analyzing both their published works and unpublished journals, diaries, and maps. Many of these studies have taken a geological approach as descriptions of prominent geological structures and types of rock facilitate locality identification. Brumm et al. (2019), for example, examined Alfred Russell Wallace's account of three volcanic hills in the Maros karst region of Sulawesi to identify the locality of the hut that became his collection centre and where he probably wrote his first surviving letter to Charles Darwin. Stenton et al. (2010) analyzed catalogue labels found with geological specimens to identify Hans K.E. Krüger's movements during his "ill fated" 1930 German Arctic Expedition. Wang et al. (2021) combined archival research of accounts and collections made by 19th century explorers in the Zanda Basin at the foothills of the Himalaya with geological fieldwork to provide type localities for some of the earliest fossil discoveries.

Many of these studies relied on incomplete and in some cases misleading archival material. Brumm et al. (2019, p. 637), for example, states that Wallace's "travel accounts are inconsistent with regards to details about his activities at given points in his journeys, especially in relation to the whereabouts of the many temporary abodes (e.g. huts) he used in the field". Wang et al. (2021, p. 2221) state that there is "very little information on the exact geographic location of the early fossil finds from the Zanda Basin", while Stenton et al. (2010) encountered missing information from catalogue labels.

The author's work (Estes et al., 2000, Grant and Estes, 2009) stands apart in that he relied on well preserved legible manuscripts written by Darwin that include a wealth of detailed descriptions and sketches of localities. Unlike other works that have attempted to retrace Darwin's movements during the voyage of the *Beagle* (Armstrong, 1991, Pearson and Nicholas, 2007, Dott and Dalziel, 2016, Wesson, 2017, Chancellor, 2023), the author had made a full transcription of Darwin's principal scientific work in Galápagos, his *Geological Diary* (Darwin, 1835b, Grant and Estes, 2002), before conducting diligent analysis of this and other primary sources (see Table 2.2). This was followed by extensive fieldwork in the islands over a period of 13 years to locate the sites Darwin studied. Chapter 2 introduced the methodology used by the author for geolocating these geological sites. Section 4.2 will expatiate on this work.

4.2 Case studies: Geolocation of sites visited by Darwin

As noted in Chapter 1, Darwin conducted the first geological survey of the Galápagos. The survey focussed on four features: (i) sandstone (tuff) craters; (ii) rock variation; (iii) lava flows and craterized (spatter cone) districts; and (iv) evidence of uplifts and fossil shells (Figure 4.1). The author was the first to document all the sites where Darwin studied these features on the major islands he visited. In total between 1996 and 2009 the author identified all 70 sites described by Darwin in Galápagos that featured in his scientific thinking on the geology of the islands. These include lava flows, shield volcanoes, craters, remains of craters, tuff cones, scoria cones, kipukas, dikes, evidence of uplift, islands, and islets. While, ostensibly, some islands and islets could be identified from their original names they have been confused with one name referring to two different islands or islets (Woram, 2005, pp. 371-72).

Case studies on Chatham (San Cristóbal) Island and James (Santiago) Island are presented in the following sections to demonstrate how the analysis of Darwin's manuscripts and other primary sources, and fieldwork, were combined to identify sites on these islands. Fieldwork was conducted between 1996 and 2009. The first step required to locate the geological sites visited by Darwin was the identification of initial landing sites from archival materials (see Sections 4.2.1 and 4.2.2). Having established these sites, the author set up six base camps from where fieldwork was conducted to find the specific locations Darwin described in his geological writings.

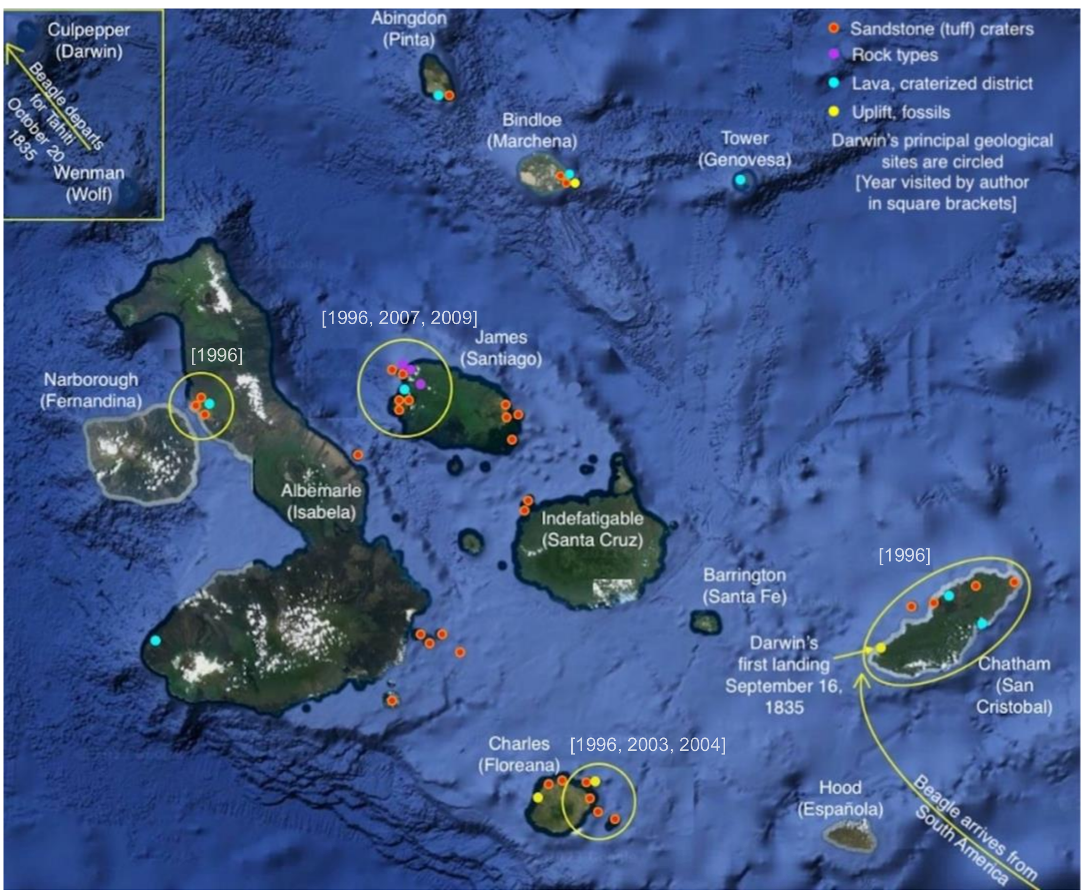


Figure 4.1 Geological sites in Galápagos described by Darwin's in his Geological Diary that featured in his scientific theories. (Image from Google Earth)

4.2.1 Case Study 1: Chatham (San Cristóbal) Island

Darwin spent five days on Chatham (San Cristóbal) Island. It was the only island he circumnavigated on the *Beagle*. He landed at five places where he explored, made notes and drew sketches of the volcanic craters. The author geolocated all the sites he described (see Figures 4.2 and 4.3) on Chatham and nearby islets.

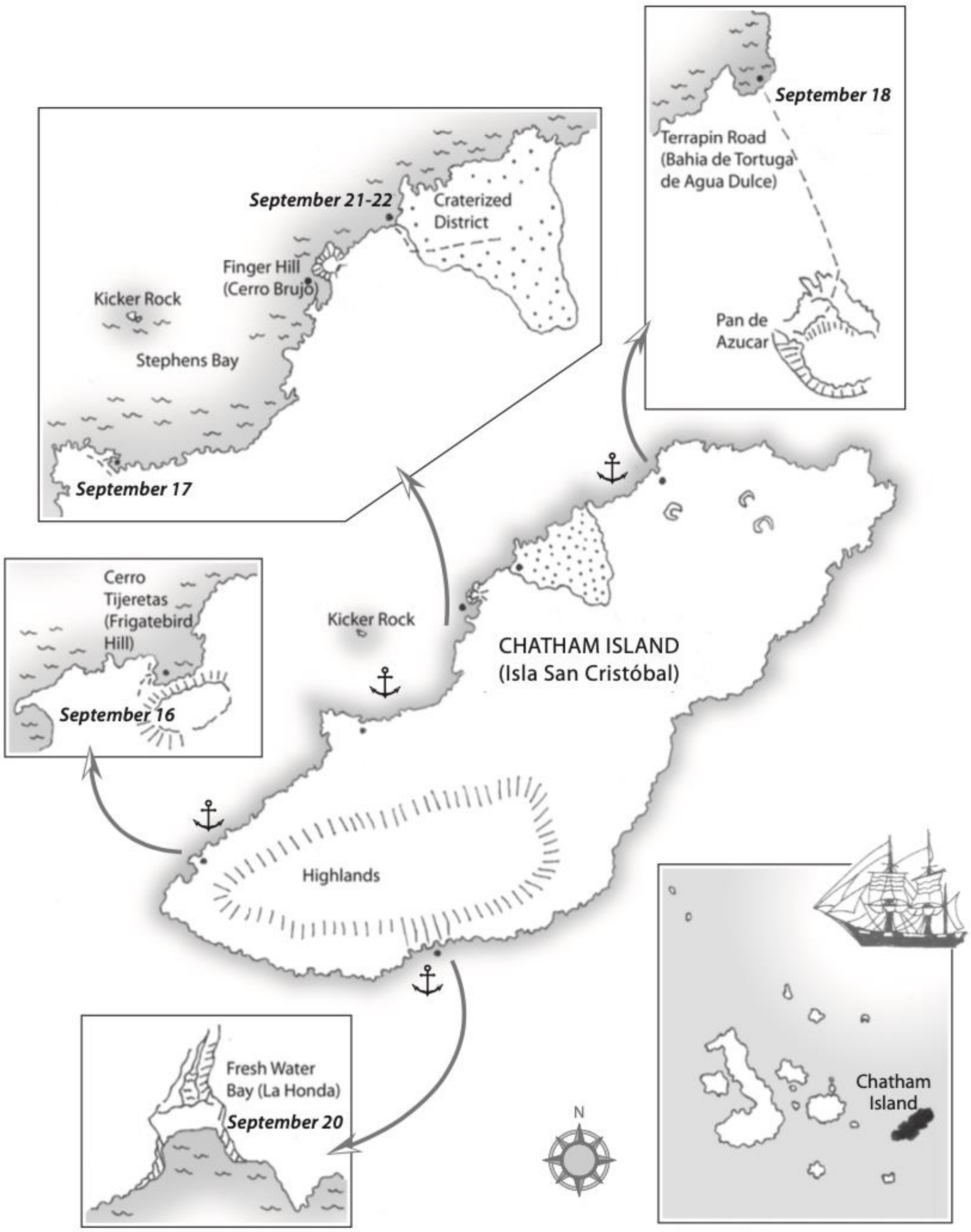


Figure 4.2 Map of Chatham (San Cristóbal) Island showing *Beagle* anchorages and localities visited by Charles Darwin. Drawing by K. Thalia Grant (Grant and Estes, 2009d)

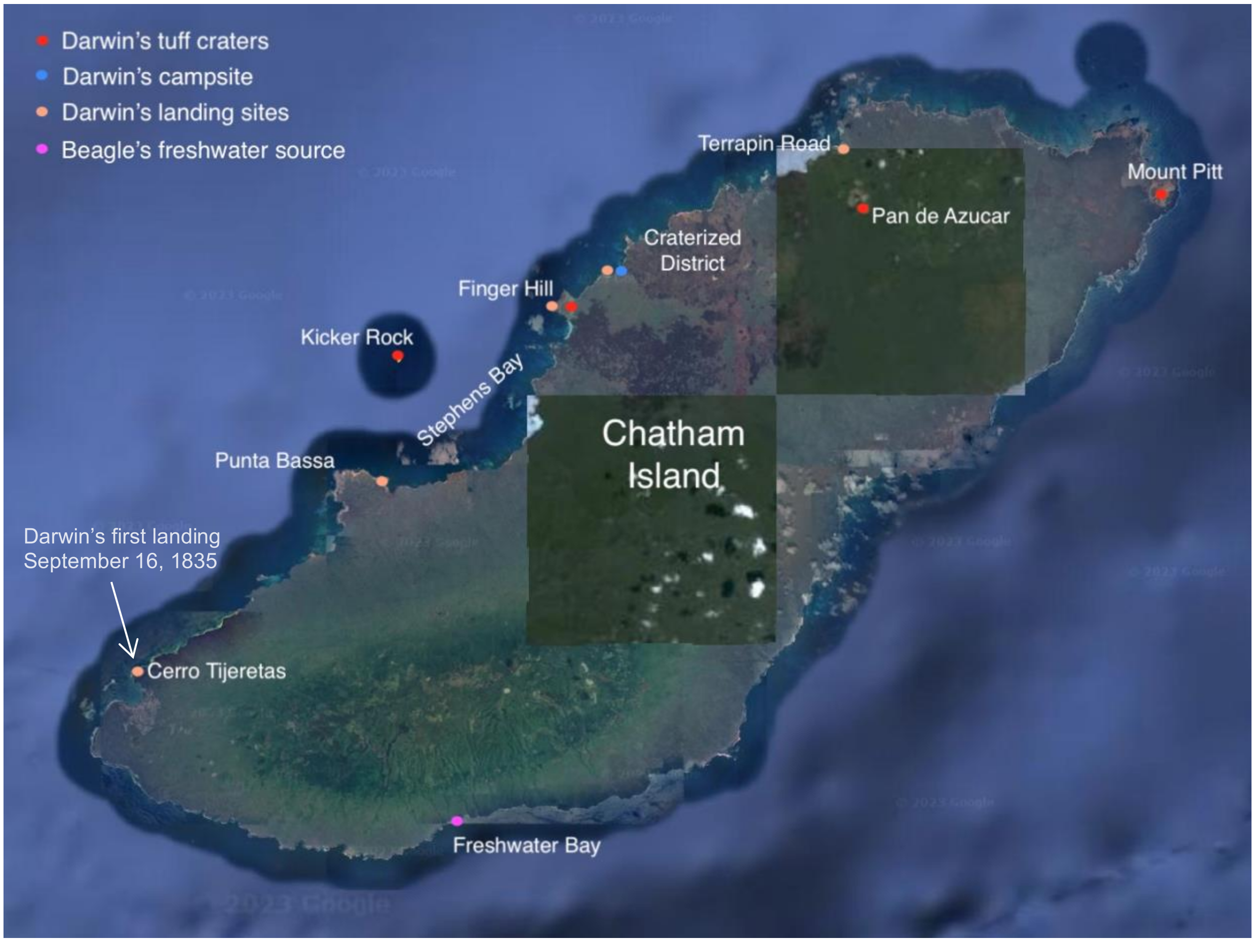


Figure 4.3 Chatham (San Cristóbal) Island showing Darwin's tuff craters, landing sites and campsite geolocated by the author. (image from Google Earth with names of sites visited by Darwin added by the author)

4.2.1.1 Darwin's first landing in Galápagos at Cerro Tijeretas (Frigatebird Hill) on Chatham (San Cristóbal) Island.

One of the sites the author was able to pinpoint from transcribing Darwin's *Geological Diary* is Cerro Tijeretas (Frigatebird Hill). This was the first place Darwin and Captain FitzRoy landed in Galápagos (Figures 4.2 and 4.3) on 16 September 1835. Darwin found "a proof of elevation" here where he "extracted the <3290> [specimen 3290] common fissurella, arca, & plates of a Chiton" that were embedded in the lava (Darwin, 1835c, folio 758). From this description, Estes et al. (2000, p. 345) determined "Cerro Tijeretas is the only place in the vicinity of the *Beagle*'s anchorage with a cliff that has the calcareous rock referred to by Darwin" (see Figure 4.4). The author ascertained the *Beagle's* anchorage for 16 September by examining FitzRoy's log (FitzRoy, 1831-1836) (see Figure 4.5), FitzRoy's surveying charts of Galápagos (FitzRoy, 1836, L945 & 1375) (see Figure 4.6) and FitzRoy's narrative of the voyage of the *Beagle* (FitzRoy, 1839). The author also ascended the hill described by FitzRoy and examined the coastline. There are no other hills and uplifted shorelines in the vicinity, which confirms that this was the site where Darwin and FitzRoy landed.

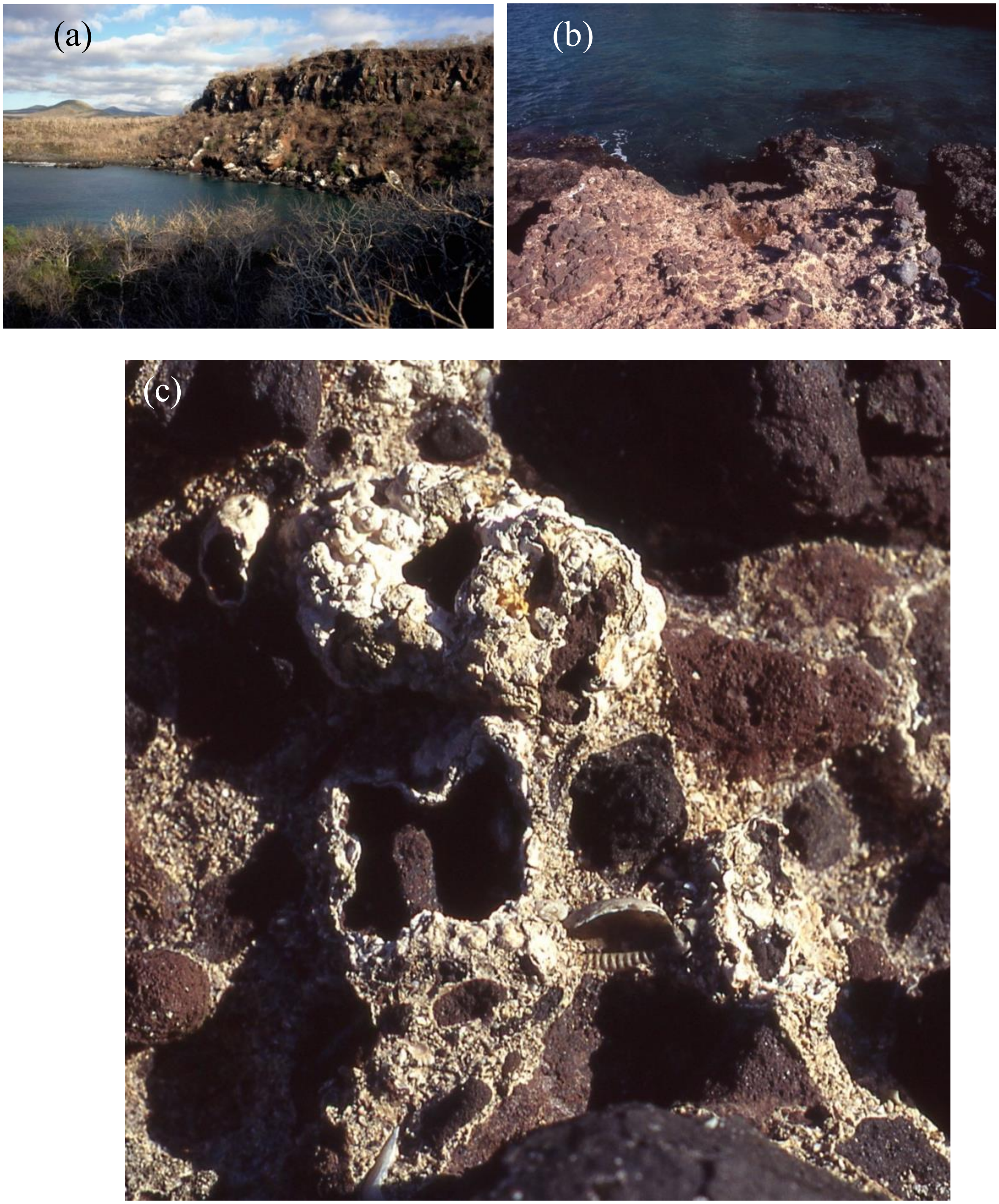
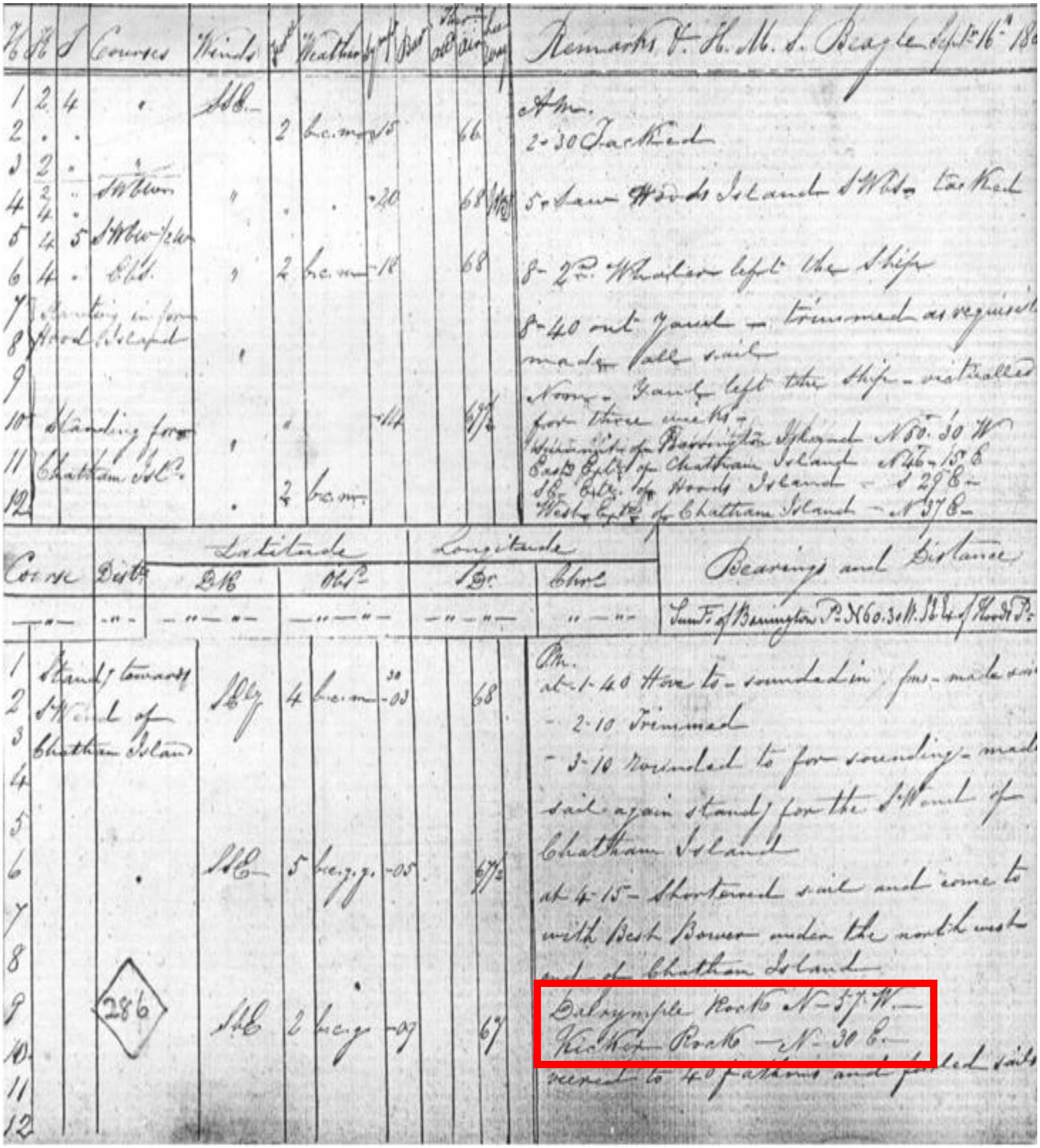


Figure 4.4 (a) Cerro Tijeretas (Frigatebird Hill) where Darwin first went ashore in the Galápagos Islands; (b) Darwin's landing site at Cerro Tijeretas; (c) calcareous material and marine shells embedded in the lava as described by Darwin in his Geological Diary (photos by the author) (This site is now a heavily visited site of the Galápagos National Park. A Darwin monument was erected at Cerro Tijeretas after the author identified it as where Darwin first stepped ashore in the archipelago).



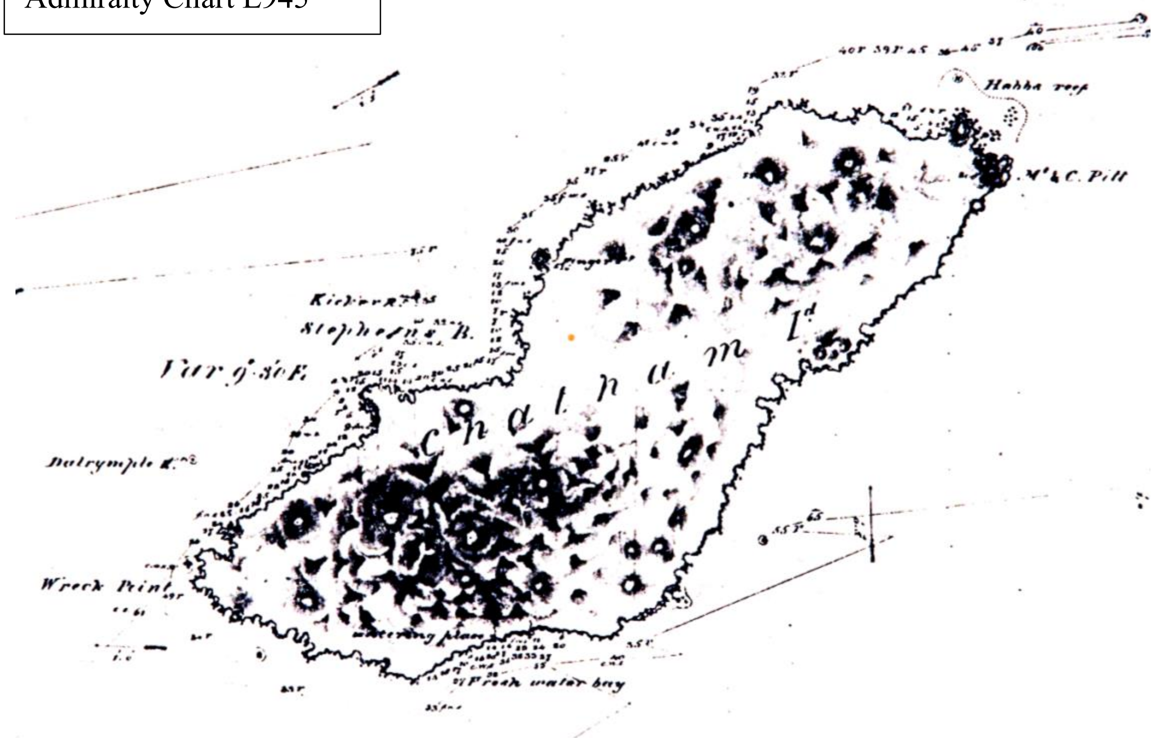
Remarks &c. H. M. S. Beagle Sept 16th
A.M.
2-30 Tacked
5 - saw Hoods Island SWbS - Tacked
8 - 2nd Whaler left the Ship
8-40 out Yawl - trimmed as requisite
made all sail
Noon - Yawl left the Ship - victualled
for three weeks -
of Barrington Island N 50. 30 W
East Extr of Chatham Island N 46 - 15 E
SE Extr of Hoods Island - S 29 E -
West Extr of Chatham Island - N 37 E -

Bearings and Distance

P.M.
at 1-40 Hove to - sounded in
- 2-10 Trimmed
- 3-10 Rounded to for sounding - made
sail again stand for the SW end of
Chatham Island
at 4-15 - Shortened sail and come to
with Best Bower under the north west
end of Chatham Island
Dalrymple Rock N - 57 W -
Kicker Rock - N - 30 E -
veered to 40 fathoms and furled sails

Figure 4.5 Entry for September 16, 1835, in Ship's Log of the *Beagle* (1831-1836). ADM53/236 Part 2. Public Records Office, Kew. This was the first day Darwin stepped ashore in the Galápagos Islands. Bearings were taken on Dalrymple Rock and Kicker Rock (enclosed in red). These bearings helped the author identify the uplifted shoreline where Darwin first landed in Galápagos. Darwin made a sketch of Dalrymple Rock (calling it an "outlying rock") in his *Geological Diary* (Darwin, 1835c, folio 726r) and there is a drawing of Kicker Rock in *Volcanic Islands* (see Figure 4.9a)

Admiralty Chart L945



Admiralty Chart 1375

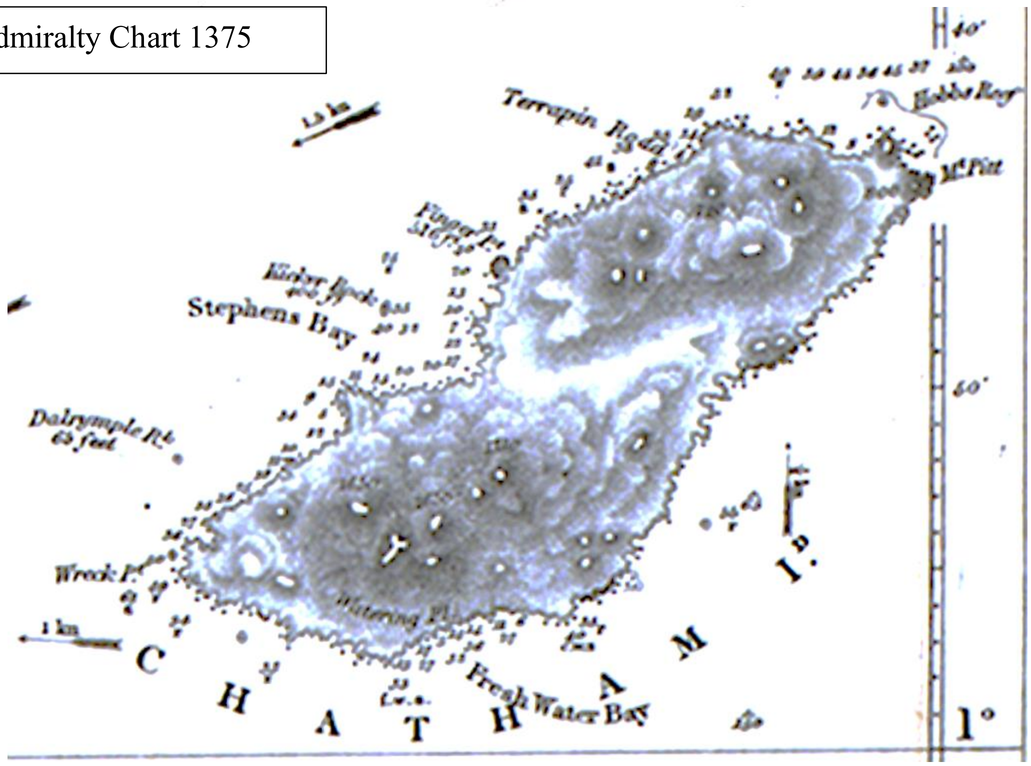


Figure 4.6 FitzRoy’s charts of Chatham (San Cristóbal) Island (FitzRoy, 1836, L945 & 1375) showing soundings taken around the island during the *Beagle’*s hydrographic survey of Galápagos. Dalrymple Rock, Kicker Rock, Stephens Bay, Finger Point, Terrapin Road, Mount Pitt and Fresh Water Bay are sites described by Darwin and FitzRoy.

4.2.1.2 Darwin’s sandstone (tuff craters) and craterized (spatter cone) district on Chatham (San Cristóbal) Island

The volcanic rock of Chatham (San Cristóbal) Island that particularly drew Darwin’s attention was the sandstone (tuff) at Finger Hill (Cerro Brujo), Pan de Azucar, Mount Pitt and Kicker Rock. He described these hills as “the highest points in the neighboring country” (Darwin, 1835c, folio 731^{r}) and collected rock specimens from two of these craters. The fact that these are the highest sandstone (tuff) cones along the northern side of Chatham, the area Darwin explored, supports the author’s contention that they are the ones that Darwin describes in his *Geological Diary*. The author was able to geolocate them by scrutinizing Darwin’s notes and sketches (see Figures 4.7 and 4.8), and by taking comparator photos in the field (see Figure 4.9). He also examined the lithology and morphology of these hills by viewing them from all sides. Seaward slopes were studied by boat as they were otherwise inaccessible due to steep cliffs. The author climbed three of the four hills (Mount Pitt, Pan de Azucar and Finger Hill). Although he did not climb Kicker Rock due to its precipitous sides, he made repeated examinations of it by boat and has compared his observations and photographs with Darwin’s descriptions in the *Geological Diary* and illustration in *Volcanic Islands* (Darwin, 1844) (see Figure 4.9a).

Five of Darwin’s six sketches of Chatham are of the sandstone (tuff) crater at Finger Hill (Figure 4.7). This hill predominates his geological notes for Chatham. It is the only hill with a pool of basaltic lava exposed at the base of the crater as described in the *Geological Diary*. Darwin notes “The sea has nearly cut the mountain in two, on the present inland side. — We see, a funnel shaped mass of black *[* Augitic Crystaline*]* compact Basalt. <<with (red Olivine?)>> (3235) compact, owing to its subaqueous origin, — covered by thick stratum of more vesicular nature: The edges of the funnel spread out & cover on each side the sandstone: the lower part being vesicular & coarse, nearly like the upper part” (Darwin, 1835c, folio 730^{r}). From Darwin’s sketches and notes it is clear that he made these drawings from the craterized district, which is to the northeast of Finger Hill. Darwin described the craterized district in his *Geological Diary*, *Beagle Diary* and *Journal of Researches* likening it to the iron foundries of Staffordshire. Darwin’s account of the chimney cones (spatter cones) in the craterized district was the first time spatter cones were described in Galápagos. The author was able to identify the spatter cones by examining the coastline of Chatham to the northeast of Finger Hill, where there is only one site that fits Darwin’s description.

According to Simkin (1984b) Darwin was the first geologist to explain why the lowest part of the rim of Galápagos tuff craters is always on the southern side, and was the first to show that tuff forms from an interaction of magma with seawater. The author identified Finger Hill as one of the first tuff craters Darwin saw in Galápagos and one of the principal tuff craters that featured in his theories. Darwin collected specimens of tuff at Finger Hill. The author was able to locate where Darwin collected his specimens from the specimen numbers noted in his *Geological Diary* (see Figure 4.8 for specimen 3235 from Finger Hill).

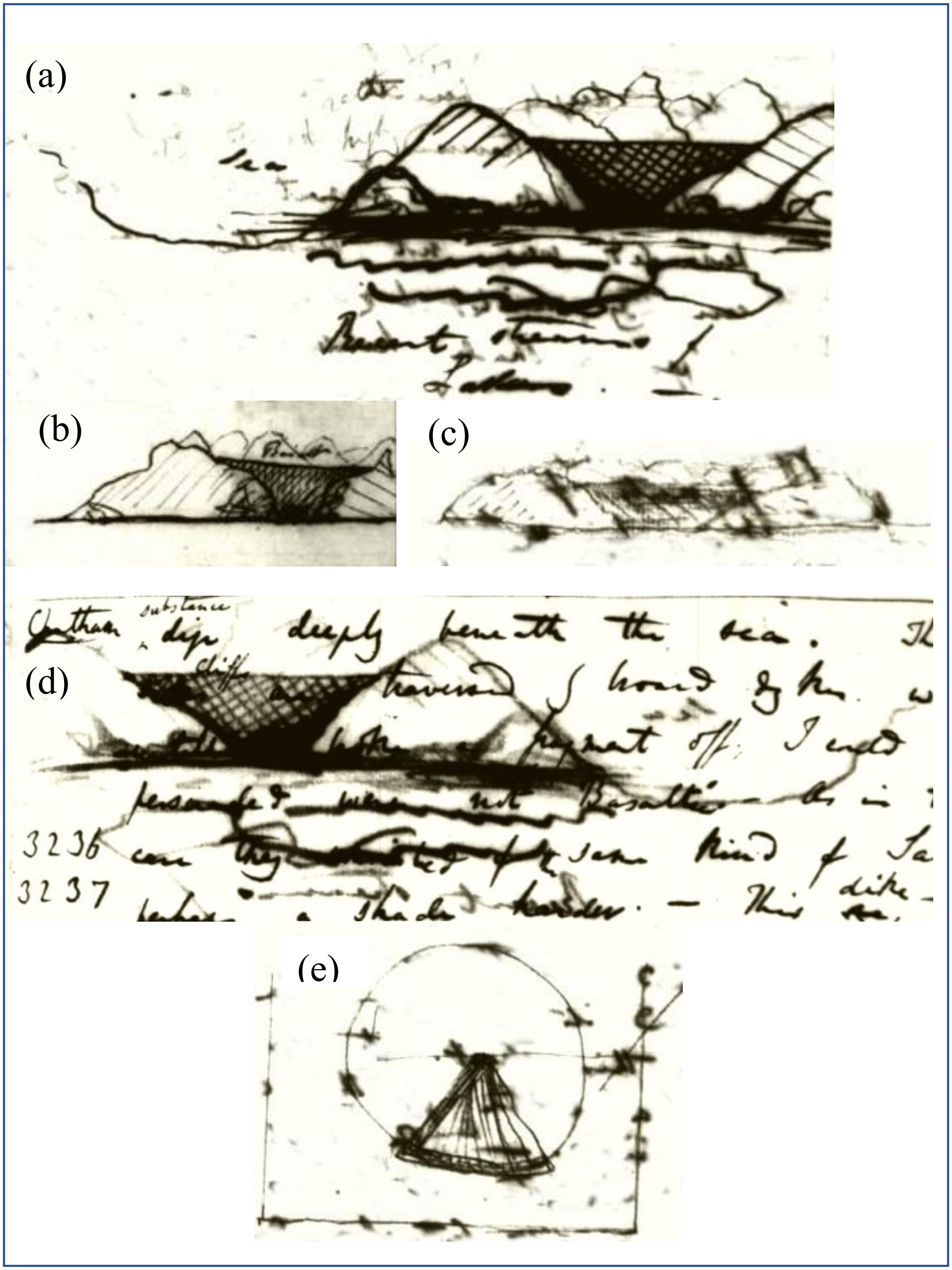
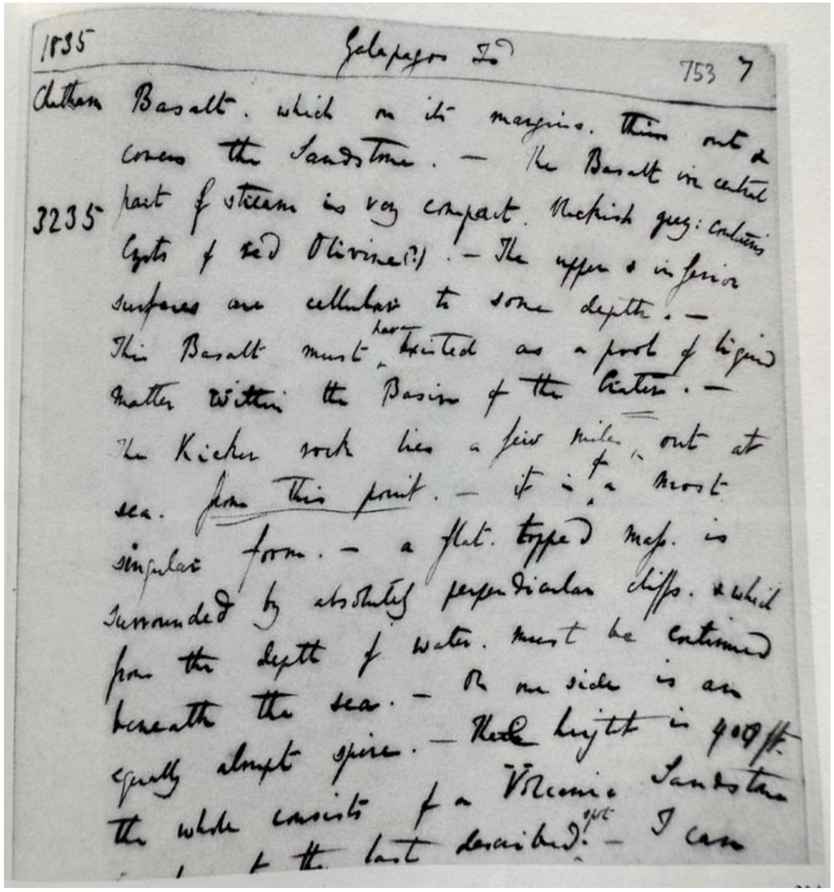


Figure 4.7 Sketches (a, b, c, d) and diagram (e) of Finger Hill (Cerro Brujo), Chatham (San Cristóbal) Island (one of the 28 tuff craters described by Darwin in his *Geological Diary*).

(a)


1835 Galapagos Isd 753 7

Chatham Basalt. which on its margins, thins out &
covers the Sandstone. — The Basalt in central
3235 part of stream is very compact. blackish grey: containing
Crysts of red Olivine (?) — The upper & inferior
surfaces are cellular to some depth. —
This Basalt must have existed as a pool of liquid
matter within the Basin of the Crater. —
The Kicker rock lies a few miles out at
sea. from this point. — it is of a most
singular form. — a flat topped mass. is
surrounded by absolutely perpendicular cliffs. & which
from the depth of water. must be continued
beneath the sea. — On one side is an
equally abrupt spire. — Whole height is 400 ft.
the whole consists of a Volcanic Sandstone
of the last described! grit — I can

(b)

Figure 4.8 (a) Excerpt from Darwin's *Geological Diary* listing specimen 3235 with his description of Finger Hill (Cerro Brujo), Chatham (San Cristóbal Island (Darwin, 1835c, folio 753); (b) Specimen 3235 from Finger Hill (Cerro Brujo) Chatham (San Cristóbal) Island (Photo by the author at the Sedgwick Museum of Earth Sciences, University of Cambridge).

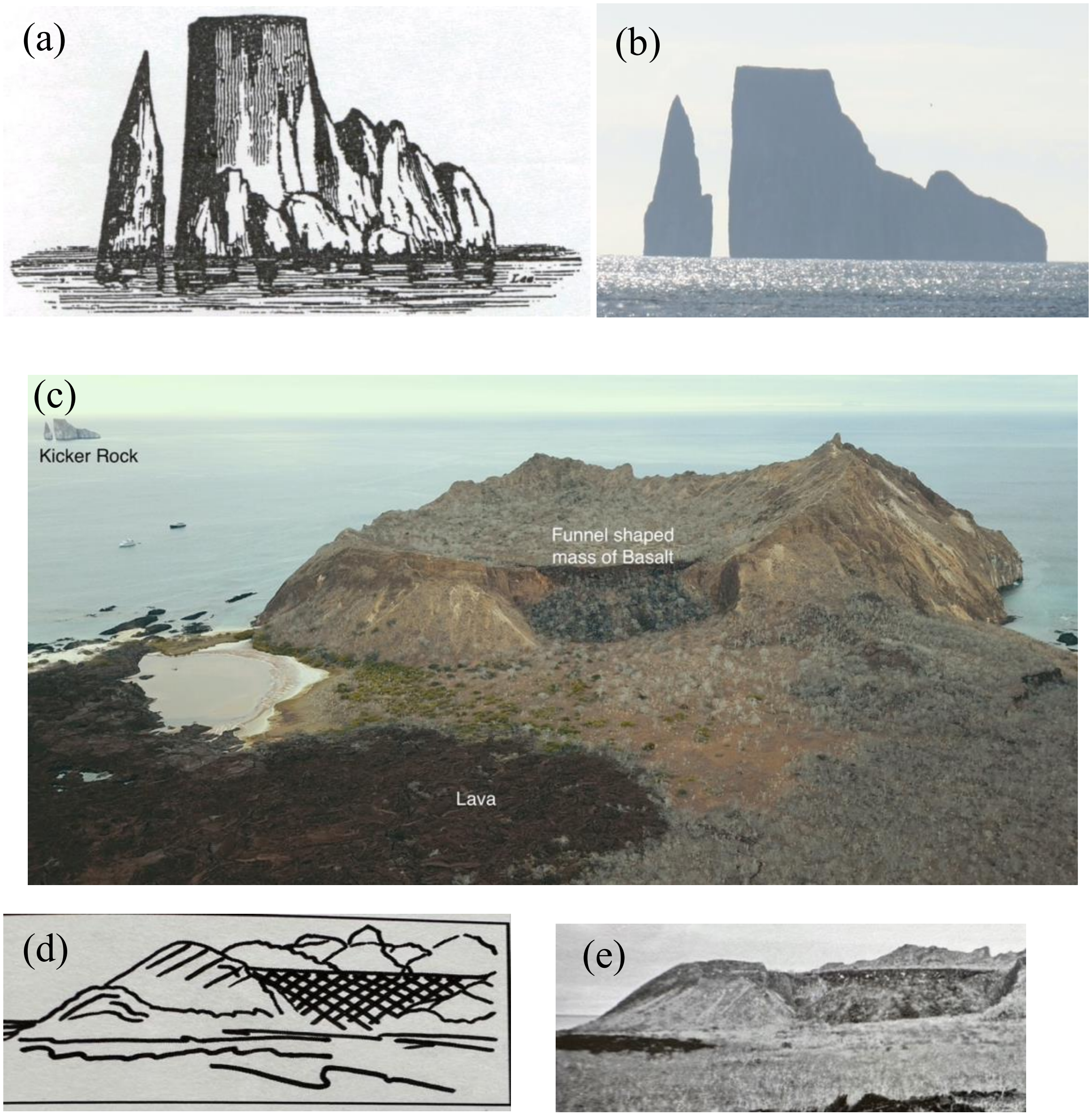


Figure 4.9 (a) Illustration of Kicker Rock from *Volcanic Islands* (Darwin, 1844); (b) Comparator photograph of Kicker Rock (photo by the author); (c) Eastern side of Finger Hill (oblique aerial photo by the author); (d) Sketch redrawn by K. Thalia Grant from original in Charles Darwin's *Geological Diary* (1835c, folio 752^{v}) (Figure 4.7a); (e) Comparator photograph of Finger Hill (photo by the author).

4.2.2 Case Study 2: James (Santiago) Island

Darwin spent nine days on James (Santiago) Island. FitzRoy landed him and four crew members on the 8th of October at Buccaneer Cove, where they camped until the *Beagle* returned on the 17th of October. As well as examining the craters around Buccaneer Cove he also hiked up 3,000 feet to the highlands of James, and across the James Bay lava flow, where he discovered other craters to study. The author geolocated Darwin's campsite and all the volcanic sites he described on James and nearby islets that were key to his scientific thinking (Figure 4.11). These included sandstone (tuff), scoria craters and lava flows, where Darwin collected a diversity of samples.

4.2.2.1 Darwin's sandstone (tuff) craters, lava flow and kipuka on James (Santiago) Island

There are eight sandstone (tuff) cones on James and nearby islets (see Figures 4.11 and 4.12) that featured in Darwin's thinking on how tuff forms through the interaction of magma with seawater. These eight volcanic cones are: Salt Mine (Salina) (Figure 4.13b), Cerro Cowan (Figure 4.13), Salina Escondida (Figure 4.14a), Sugarloaf (Figure 4.14a), one of the Bainbridge Rocks (Figure 4.15a&b), Bartholomew (Figure 4.15c, Cerro Inn (Figure 4.15c) and Mount Tim.

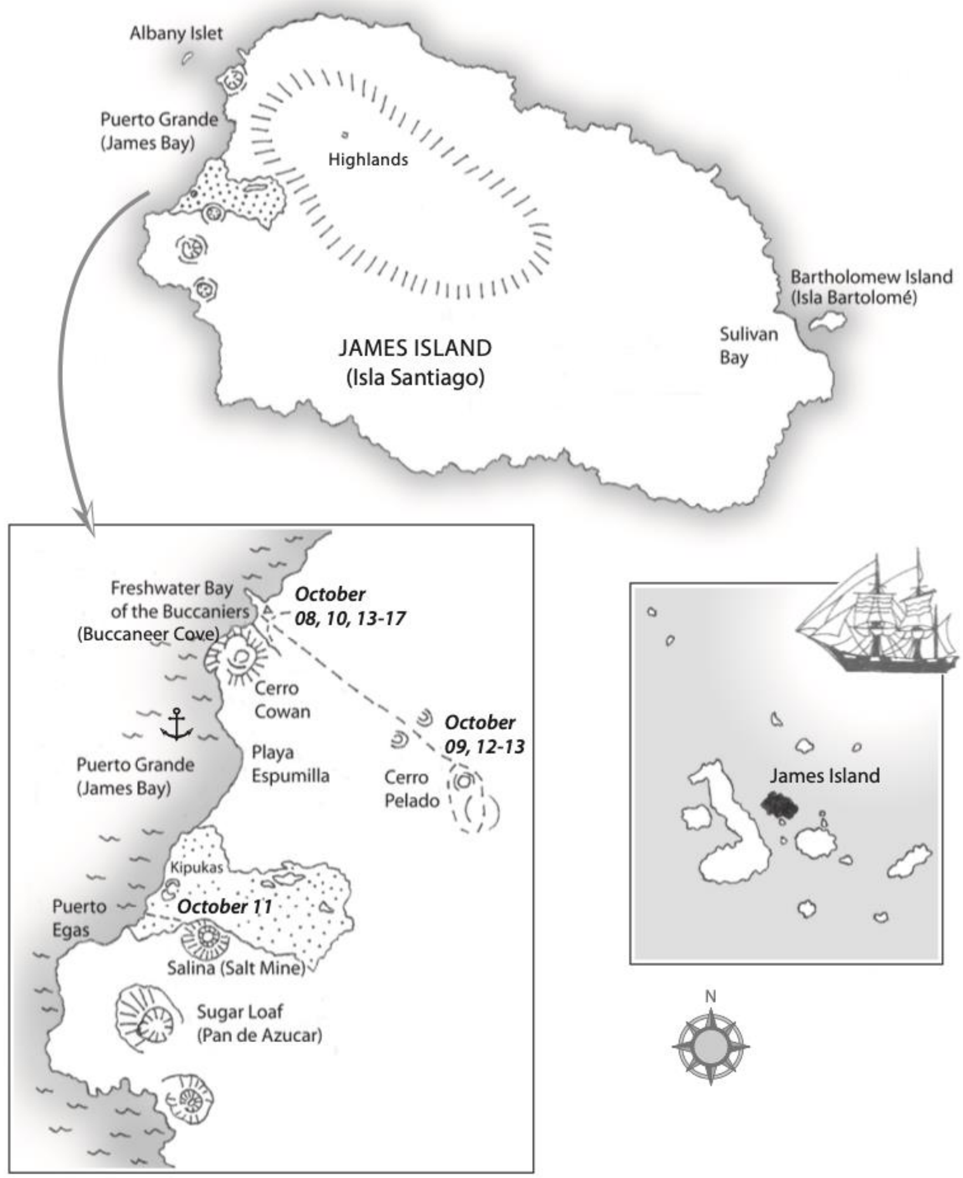


Figure 4.10 Map of James (Santiago Island showing *Beagle* anchorage and localities visited by Charles Darwin. Drawing by K. Thalia Grant (Grant and Estes, 2009g)

Figure 4.11 (a) Sandstone (tuff) craters identified as those described by Darwin on James (Santiago) Island and nearby islets; (b) Northwest side of James (Santiago) Island where Darwin examined volcanic craters, rock types and the kipuka in the James Bay lava flow.

Darwin closely examined and drew sketches (see Figure 4.12) of two of these cones (Salt Mine and Cerro Cowan) and received reports from the surveying officers on the others. He incorporated these reports in his *Geological Diary*. For example, Darwin states “M^{r} Sulivan informs me that there is a small Is^{d} on the S East end of James Is^{d} which consists of <<a mere circular ridge>> Volcanic Sandstone its diameter is 1/3 of mile. — is very low towards the South but not fairly broken through; it contains a shallow lake of water which appears to rest on Salt. This water appears to be on same level with the Sea” (Darwin, 1835c, folio 783^{v}). From this description the author identified the island as one of the Bainbridge Rocks (see Figure 4.15a&b).

The author identified all eight tuff craters from Darwin’s notes and sketches and found that these craters all show rims broken down on the southern side as described by Darwin: “all the Craters are open or have the low part of their circumference on the South side. <<have their Southern side either much entirely broken down & removed or much lower than the remaining other parts of the circumference.>>” (Darwin, 1835c, folio 787) A good example of this is seen in Sugarloaf (Pan de Azucar) and Salina Escondida (see Figure 4.14a). Darwin hiked across the James Bay lava flow and described seeing “singular ringed & twisted forms which resemble cables, folds in thick drapery & rugged bark” (Darwin, 1835c, folio 780). In one place he encountered “a small Crater of glassy red Scoriæ & Greystone has been overwhelmed & almost concealed beneath the flood of stone” (Darwin, 1835c, folio 781^{r}). This was the first time a kipuka (an area of land surrounded by fresh lava) had been described in Galápagos. The author located it and the twisted forms of lava (see Figure 4.14b), as described by Darwin, by traversing and examining the James Bay lava flow. There is only one kipuka fitting Darwin’s description in this lava flow (see Figures 4.13b and 4.14c).

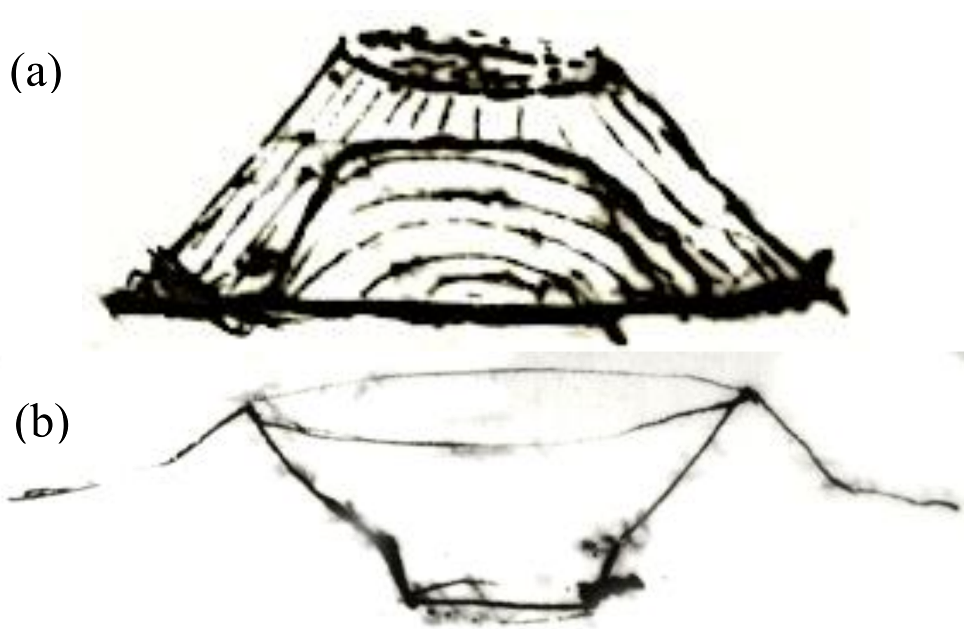


Figure 4.12 Sketches of two sandstone (tuff) craters from Darwin’s *Geological Diary* on James (Santiago) Island (a) Cerro Cowan; (b) Salt Mine crater.

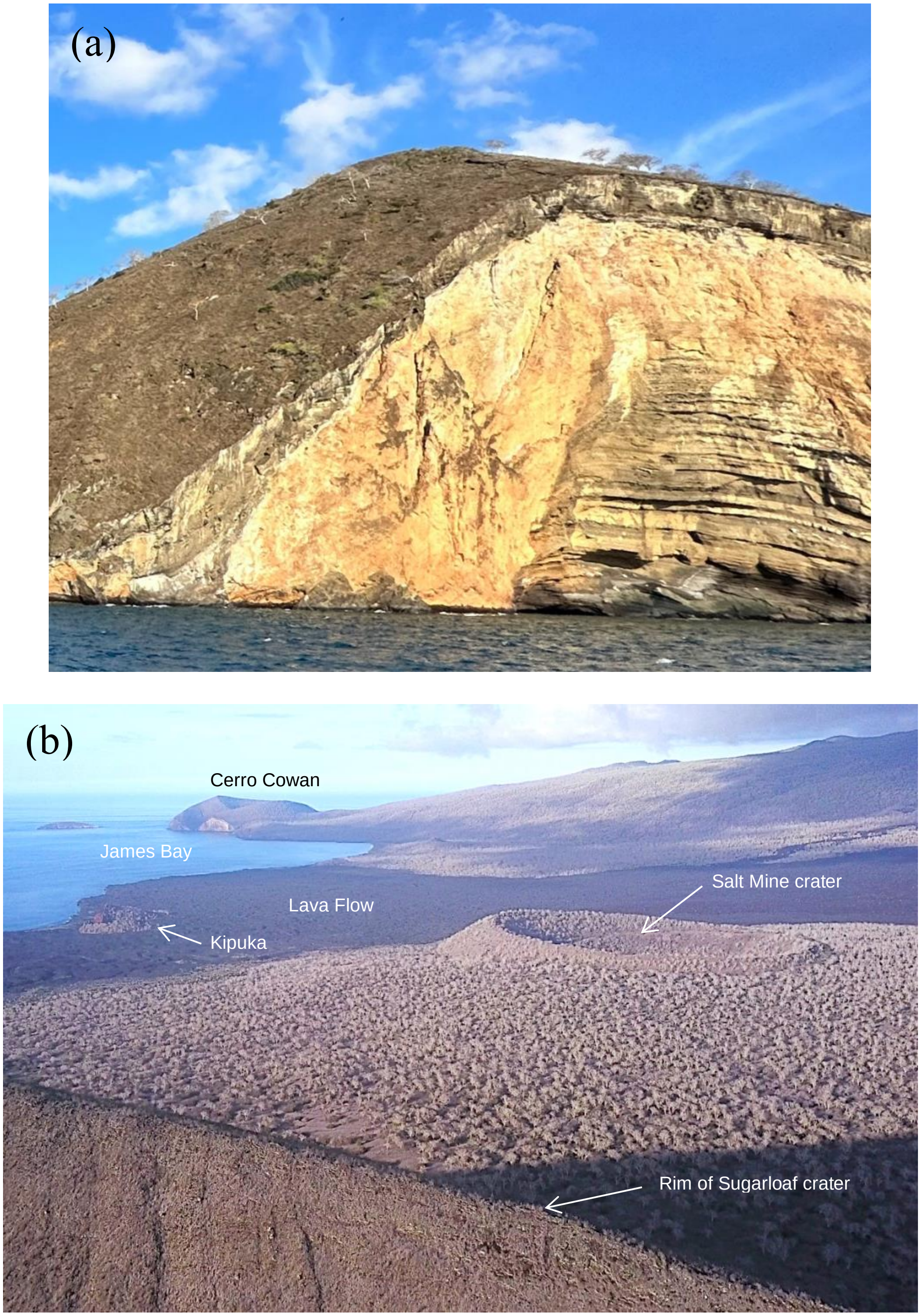


Figure 4.13 Sandstone Craters on James (Santiago) Island (a) Layers of volcanic ash in Cerro Cowan as depicted in Darwin's sketch (see Figure 4.12) (photo by the author); (b) Salt Mine crater viewed from the top of Sugarloaf with James Bay lava flow, kipuka, and Cerro Cowan behind and to the left of the crater (oblique aerial photo by the author). Darwin correctly estimated the distance of the Salt Mine from the beach to be 1½ mile and the diameter of the crater as a third of a mile.

Figure 4.14 Volcanic features described in Darwin's Geological Diary at James Bay on James (Santiago) Island. (a) The sandstone (tuff) craters of Salina Escondida and Sugarloaf viewed from the northwest showing the lower part of the crater rim on the southern side. The James Bay lava flow can be seen in the foreground. (photo by the author); (b) Twisted forms of pahoehoe lava. (Photo by the author); (c) Kipuka (scoria cone) engulfed by a recent flow of pahoehoe lava in the James Bay lava flow (see also Figure 4.13b). (oblique aerial photo by the author)

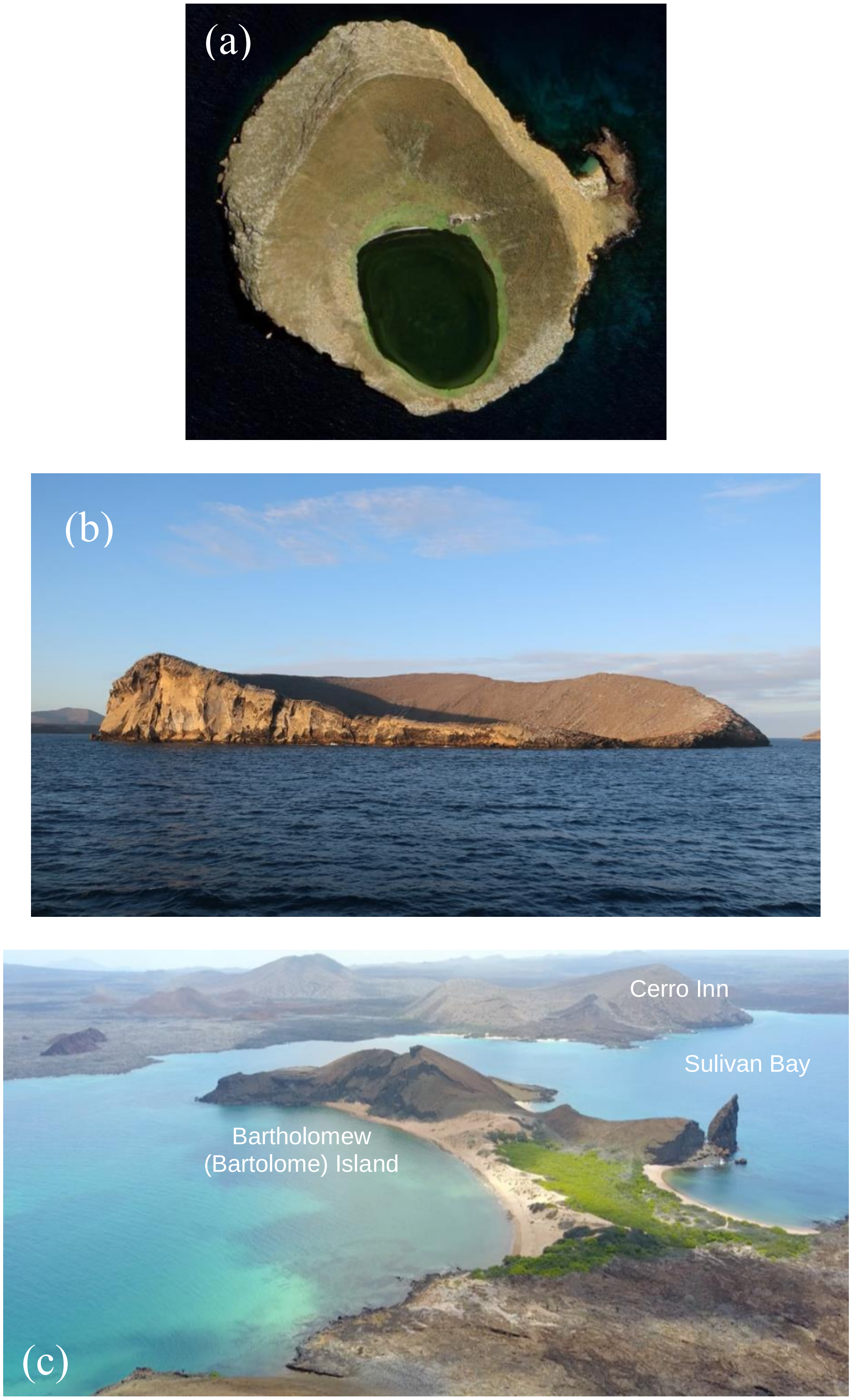


Figure 4.15 Three of Darwin's eight sandstone (tuff) craters on James (Santiago) Island and nearby islets. (a) and (b) One of the Bainbridge Rocks (image (a) from Google Earth and (b) by author); (c) Bartholomew (Bartolome) Island and Cerro Inn on James Island (oblique aerial photo by author). Sulivan Bay and Bartholomew Island were named by FitzRoy after Bartholomew Sulivan, one of the officers of HMS *Beagle*

4.2.2.2 Darwin's rock diversity at Buccaneer Cove and Cerro Pelado

There are three principal sites that played an important role in Darwin's theory on magmatic differentiation through gravity settling of crystals. These are the Promontory and 'Darwin's Layer Cake' at Buccaneer Cove (Figures 4.11b, 4.16), and Cerro Pelado at Jaboncillos in the highlands of James (Santiago) Island (see Figures 4.11b, 4.17). As with Chatham Island, the author geolocated these sites using the *Geological Diary* and other primary sources. Darwin's sketch of 'Darwin's Layer Cake' in the *Geological Diary* was compared with contemporary photos taken by the author (see Figure 4.16). In the sketch the words *ravine* and *sea beach* helped to locate the site at the northern end of the beach at Buccaneer Cove, where there is a ravine next to layers of scoria and lava.

Darwin made measurements of the thickness of these layers and the length of the layers exposed along the beach: "I measured one stream, of which the Trachytic dark part was 8 inches, to which may be added 6 inches for the superficial red cindery matter giving 14 inches for that thickness, & this for whole extent" (Darwin, 1835c, folio 774^{r}). These measurements corresponded with those taken by the author (see Figure 4.16e), which supported that this was the site Darwin examined, particularly as there were no other examples of this layering exposed along the beach.

The specimens Darwin collected at 'Darwin's Layer Cake' (see Figure 4.18c), the promontory, and at Cerro Pelado (see Figure 4.18b) in the highlands were particularly important to his thinking on how different types of rocks can originate from the same source (see Section 4.3). Darwin described Cerro Pelado as: "a large & perfect Crater, circular, sides very precipitous <<& bottom walk wooded>>. In the vicinity nothing but Trachytic Lava is found: the channels by which the Lava has flowed over the rim are yet visible. — The walls of the Crater are chiefly composed of bright red & very glassy red scoriæ united together" (Darwin, 1835c, folio 770). For a detailed explanation of how this crater was identified by the author see Grant and Estes (2009, p. 183-85). The geological specimen #3268 (see Figure 4.18b) that Darwin collected closely matches an outcrop of trachytic lava located near Cerro Pelado (see Figure 4.17).

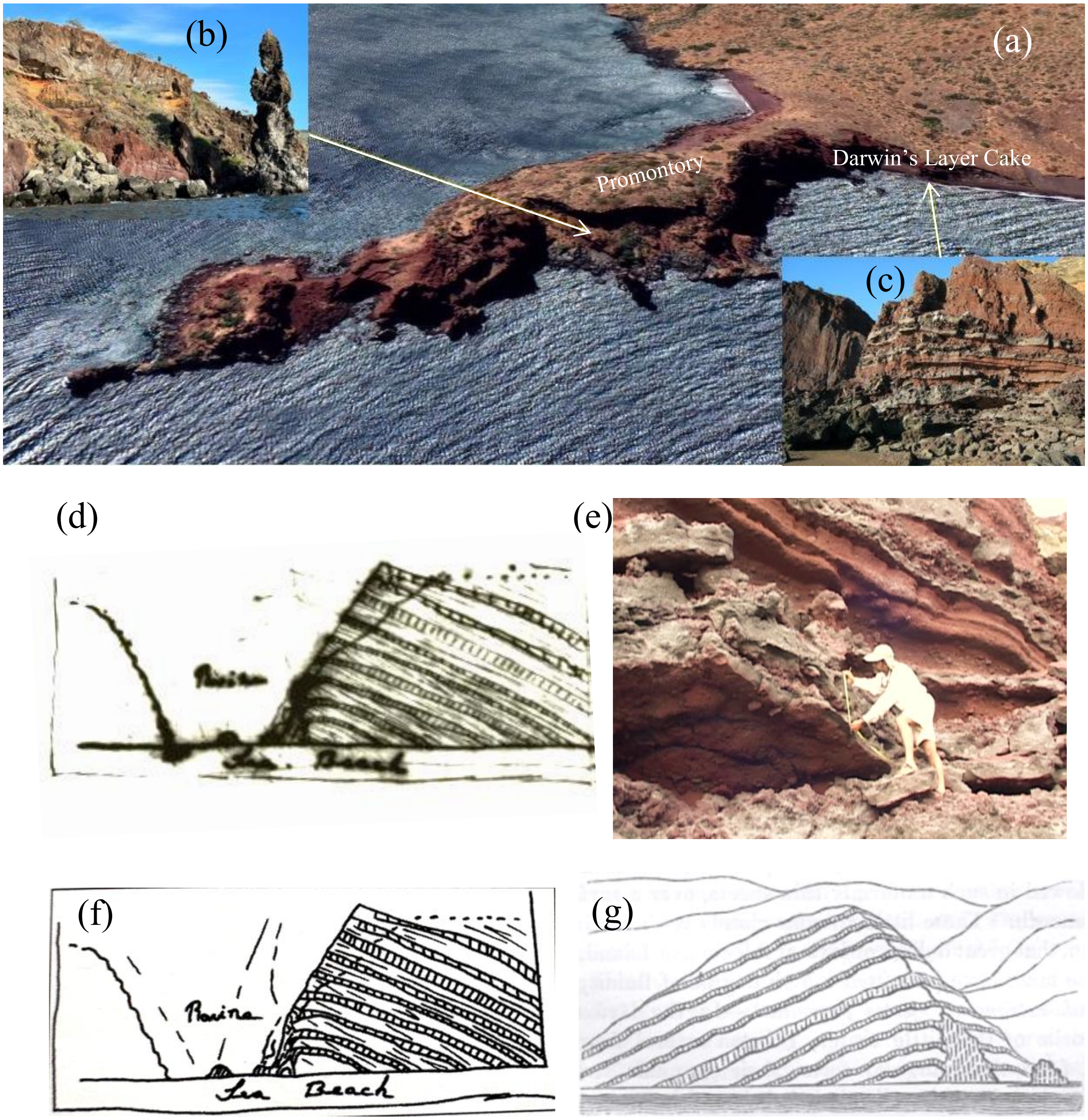


Figure 4.16 Freshwater cove of the Buccaniers (Buccaneer Cove), James (Santiago) Island. (a) Promontory (image from Google Earth) with insert (b) showing promontory with the horizontal bed of lava, volcanic dike and (c) 'Darwin's Layer Cake' (photos by the author); (d) 'Darwin Layer Cake' as sketched by Darwin in his Geological Diary. The words Ravine and Sea Beach are visible; (e) The author measuring layers in 'Darwin's Layer Cake' (photo by K. Thalia Grant); (f) Darwin's sketch of 'Darwin's Layer Cake' (redrawn from Darwin's sketch by K. Thalia Grant); (g) illustration (inverted) of 'Darwin's Layer Cake' in Volcanic Islands (Darwin, 1844).

Figure 4.17 Cerro Pelado at Jabonicllos in the highlands of James (Santiago) Island (860 m elevation). The lava flow that had flowed over the crater described by Darwin, can be seen in these images (Photos by the author).

4.3 Reconstructing Charles Darwin's 1835 Geological Expedition on Isla Santiago in the Light of 21st Century Science

In addition to identifying the primary sites visited by Darwin in the Galápagos, the primary archive- and field-based research illustrated in Section 4.2 has enabled new discoveries about Darwin's contributions to petrology. In 2005, after geolocating all of Darwin's sites in Galápagos and publishing the results in Estes et al. (2000), the author was approached by Dr. Sandra Herbert, Professor in the Department of History at the University of Maryland (Baltimore County) to discuss a proposal for an expedition to examine Darwin's geological sites and collect samples on James (Santiago) Island. This led to a fieldtrip to James Island in 2007 with an international group of geologists and historian. The results were displayed in the Sedgwick Museum as part of a major exhibition in 2009 to celebrate the bicentenary of Charles Darwin's birth and the sesquicentenary of the publication of *On the Origin of Species*. The expedition led to a publication (Herbert et al., 2009), on which the author is a co-author.

The 2007 fieldtrip "proved to be a seedbed for several follow up studies" (personal communication S. Gibson) leading to the publication of three other papers (Gibson, 2009, Gibson, 2010, Herbert, 2010). Another paper including observations from the 2007 fieldwork is in press (personal communication S. Herbert). During this fieldtrip eight days were spent revisiting the sites Darwin studied. The author was a key team member as he had done previous fieldwork (Estes and Grant, 1996c, Estes and Grant, 2007) on the island (see Sections 2.2.3 and 4.2.2). He led the team to the sites where Darwin had collected his specimens at the promontory, 'Darwin's Layer Cake' in Buccaneer Cove (see Figure 4.16), to Cerro Pelado (see Figure 4.19) and to the James Bay lava flow (see Figure 4.14). Herbert (2010) cites the author (Estes et al., 2000, Grant and Estes, 2009) for geolocating Darwin's geological sites on James.

Papers citing Herbert et al. (2009) include: (i) a study that enhances our understanding of Darwin as a collector (Herbert, 2010), (ii) an analysis of seafloor petrogenesis that sheds light on the relationship between geomorphology and the composition of rocks (Schwartz et al., 2018), (iii) research providing insight on the isotopic composition of mantle plumes (Gibson et al., 2012), (iv) an examination of Darwin's geological work on volcanic islands during the voyage of the *Beagle* that contributes to our understanding of his global theory of Earth (Johnson et al., 2018), (v) a study that reveals the importance of historical geology collections (Chalk, 2013) and (vi) an analysis providing a better understanding of Darwin's geological research in southern South America (Dott and Dalziel, 2016).

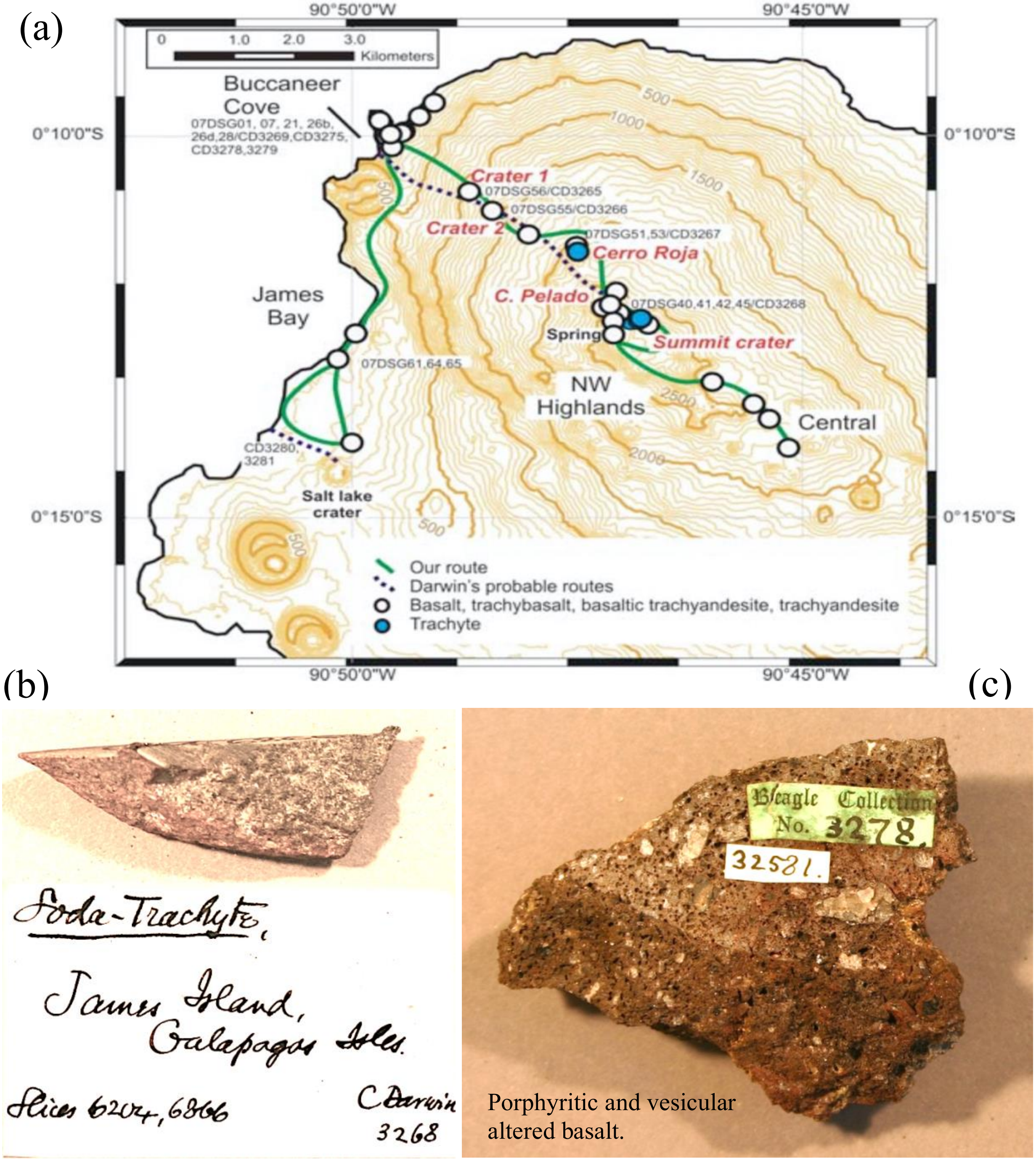


Figure 4.18 (a) Topographic map of northwest James Island showing the locations of samples collected during the 2007 field trip (Reconstructing Charles Darwin's 1835 Geological Expedition on Isla Santiago in the Light of 21st Century Science); (b) and (c) Specimens Darwin collected on James from (a) #3268 at Cerro Pelado and (b) #3278 beneath 'Darwin's Layer Cake' (Photos by the author at the Sedgwick Museum of Earth Sciences, University of Cambridge).

(a)

Figure 4.19 Images from the 2007 expedition (Reconstructing Charles Darwin's 1835 Geological Expedition on Isla Santiago in the Light of 21st Century Science) on James (Santiago) Island (a) The author at Cerro Pelado (photo by Andrew Thurman); (b) Dr. Sally Gibson (petrologist) with author at the base of Cerro Pelado (photo by Andrew Thurman); (c) Gibson holding a piece of trachyte where Darwin collected his specimen at Cerro Pelado (photo by author).

4.4 Corrections of published works on Darwin's geology.

Having identified all the sites Darwin surveyed, scrutiny of leading biographies and journals enabled the author to identify significant geographic errors in four biographies, journal articles and book sections. Examples are outlined here in chronological order.

- McBirney and Williams (1969, p. 3) incorrectly claim that Darwin first landed on Hood Island. However, it was not known where Darwin first landed until the author geolocated the site from Darwin's description of an uplift in the *Geological Diary* (see Section 4.2.1.1).

- McBirney and Williams (1969, p. 54) suggest that Darwin did not collect one of his geological specimens (soda trachyte # 3268) in Galápagos and that it was mislabelled for being from James Island as no soda trachyte had been found during their survey of the island. The author contributed to showing that Darwin did in fact obtain the specimen from James by geolocating the specific crater (Cerro Pelado) where it was collected (see Section 4.2.2.2) and leading a team of geologists to the site to confirm the location (Herbert et al., 2009) (Section 4.3). This was an important specimen for Darwin's theory on magmatic differentiation.

- Several studies (Chubb and Richardson, 1933, p. 23, McBirney and Williams, 1969, p. 101, Allmon, 2016, p. 686 and 701 n. 21) identify a tuff cone on Chatham Island as a source of Darwin's fossil collection of marine shells. The author established that these shells were collected from tuff cones on other islands (Enderby Islet near Charles Island and Bindloe Island) from analysing Darwin's *Geological Diary*.

- Pearson (1996, p. 58) misquoted a key locality in Darwin's *Geological Diary* as "a small bay close to Albemarle I^{sd}". The author correctly transcribed the locality as being "a small bay close to Albanie I^{sd} [sic Albany]" (Darwin, 1835c, folio 770). Albany Island is only one mile from this bay whereas Albemarle is 20 miles. This bay was a significant site for Darwin as his observations of an eroded crater impacted his thinking on magmatic differentiation (Pearson, 1996, Herbert et al., 2009).

4.5 Conclusion

This chapter has demonstrated how the author's work has contributed to transforming our view of Darwin in Galápagos. The predominant role of geology, missing from leading works on Darwin, is displayed through combining analysis of Darwin's *Geological Diary* with fieldwork to identify the geological sites he visited. This has enabled further discoveries on Darwin and geology, and a correction of geographic errors in leading biographical works. The author's contributions will be summarized in Chapter 5 with possible directions for future research.

Chapter 5 Conclusions and Next Steps

5.1 Conclusions from the thesis

In both popular and academic wisdom, the words ‘Darwin’ and ‘Galápagos’ are inextricably linked with the word ‘evolution’, to the extent that it is almost universally accepted that Darwin’s principal work in the Galápagos Islands was on species. As this thesis demonstrates, the author’s work (Estes et al., 2000, Grant and Estes, 2009) has shown this to be a false narrative. By making the first annotated transcription of Darwin’s *Geological Diary* (Darwin, 1835c, Grant and Estes, 2002) and analyzing this manuscript alongside everything else Darwin wrote about the islands, the author has shown that geology was instead Darwin’s principal scientific work. Indeed, analysis of Darwin’s surviving writings (Chapter 3) has demonstrated that he wrote three times more on the geology of the islands than the zoology in his scientific notes.

The aim of this thesis was to demonstrate how the author’s collective works have played a key role in shifting our perception of Darwin as a scientist focussed on species to a surveyor, practitioner, and theorizer of geology. Through the meticulous analysis of everything that has been written about Darwin and Galápagos in leading biographies and journal articles (Chapter 3), the author has demonstrated that Darwin’s geology has been almost completely overlooked and consequently his important contributions to the field of geology have been neglected.

The author’s local first-hand knowledge sets his study apart from other works that have retraced the steps of scientists and explorers. Drawing on 30 years’ experience as a naturalist guide and scientist in the Galápagos, the author was able to combine extensive fieldwork with a critical analysis of primary sources, including original manuscripts, to geolocate the sites Darwin described in his *Geological Diary* (Chapter 4). Estes et al. (2000) and Grant and Estes (2009) document these sites. This work led the author to organize and participate in an international expedition in 2007 to examine sites that featured in Darwin’s thinking on the origin of rock diversity. The expedition resulted in four publications, including one co-authored by Estes (Herbert et al., 2009), with an additional publication in press.

The author has presented his contributions to a new perspective on Darwin and Galápagos at academic meetings including a symposium on Galápagos at San Francisco State University in California in 1999 and gave the Geology and Society Distinguished Lecture at the annual meeting of the Geological Society of America in Seattle, Washington in 2017. The author’s publications will be an important source for any future biographical works and journal articles on Darwin’s scientific work in the Galápagos Islands. They will be particularly relevant for the upcoming bicentennial commemoration of the voyage of the *Beagle*.

5.2 Directions for Future Research

The author’s plans for future studies include the following:

- There is uncertainty about the locality of a horizontal bed of lava that played a key role in Darwin’s thinking on magmatic differentiation. It would be valuable to revisit two localities (Cerro Brujo on Chatham (San Cristóbal) Island and Buccaneer Cove on James (Santiago) Island) to determine which is the correct site.

- Debates exist regarding the precise location where the first marine fossils were collected in the Galápagos. A follow up study of sites where Darwin collected fossil shells on Bindloe (Marchena) Island and Enderby Islet near Charles (Floreana) Island is needed.
- While Darwin's work on the evolution of species in Galápagos is generally known by visitors to the islands, his principal scientific work on geology is unrecognized. The author proposes to set up an interpretive Darwin Trail on James (Santiago) Island to provide information on Darwin's geological work to visitors and naturalist guides of the Galápagos National Park. The author's work in identifying where Darwin first landed in Galápagos has already contributed to the creation of a visitors trail on Chatham (San Cristóbal) Island where a Darwin monument has been erected.
- The 200th anniversary of the Voyage of the *Beagle* will be commemorated in 2031. The author proposes to put together an expedition to revisit and photograph all the sites and particularly volcanic craters Darwin visited in the Galápagos to mark the occasion.
- The author discussed Darwin and the impact of climate change on the Galápagos with Peter Molnar, a leading climatologist, during a trip that Estes led in the islands in 2022. It would be valuable to make a comparative study of FitzRoy's log on weather and sea surface temperatures in Galápagos with current data for the same dates the *Beagle* was in the islands and at the same sites that they visited.

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Appendices

APPENDIX I

Publications Considered in This Thesis (with hyperlinks)

1. Annotated transcription of Charles Darwin's *Geological Diary* on the Galápagos Islands by GRANT, K. T., and ESTES G. B. (2002):
Darwin, C. R. (1835c) *Geological diary: Galápagos. CUL-DAR37.716-795A Transcribed by K. Thalia Grant and Gregory B. Estes.* [Online]. Available at: http://darwin-online.org.uk/content/frameset?pageseq=1&itemID=CUL-DAR37.716-795A&viewtype=text

2. Introduction to annotated transcription of Charles Darwin's *Geological Diary* on the Galápagos Islands:
GRANT, K. T., and ESTES G. B. (2002) *Darwin's notes on the geology of Galápagos; An introduction by K. Thalia Grant and Gregory B. Estes* [Online]. Available at: http://darwin-online.org.uk/EditorialIntroductions/Grant_Estes_GeologicalDiaryGalápagos.html

3. Journal publication on expedition to retrace Darwin' steps in the Galápagos Islands
ESTES, G., GRANT, K. T. & GRANT, P. R. (2000) Darwin in the Galápagos: his footsteps through the archipelago. *Notes and records of the Royal Society of London,* 54**,** 343-368. Available at):
https://doi.org/10.1098/rsnr.2000.0117

4. Book on Charles Darwin and the Galápagos Islands
GRANT, K. T. & ESTES, G. B. (2009) *Darwin in Galápagos: Footsteps to a New World,* Princeton, Princeton University Press. Available for borrowing at Internet Archive: https://archive.org/details/darwiningalapago0000gran
Instructions for borrowing the book:
i) click on 'Log In and Borrow'.
ii) Log in (if you don't have an account with Internet Archive you can sign up for free).
iii) Once you have logged in you have the option of borrowing the book for 1 hour or 14 days. More information on borrowing can be found at https://help.archive.org/help/borrowing-from-the-lending-library/)

5. HERBERT, S., GIBSON, S., NORMAN, D., GEIST, D., ESTES, G., GRANT, T. & MILES, A. 2009. Into the field again: Re-examining Charles Darwin's 1835 geological work on Isla Santiago (James Island) in the Galápagos archipelago. *Earth Sciences History,* 28**,** 1-31: https://doi.org/10.17704/eshi.28.1.mjt982717p162323

Journal publications 3 and 5 are behind publisher paywalls and therefore not open access. Copies of each are included in this appendix.

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DARWIN IN GALÁPAGOS: HIS FOOTSTEPS THROUGH THE ARCHIPELAGO

by

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INTRODUCTION

Charles Darwin visited Galápagos for five weeks, from 15 September to 20 October, in 1835. This is a small fraction of the total of 248 weeks he spent on the voyage of the HMS *Beagle* (27 December 1831 to 2 October 1836), yet his experiences in Galápagos were of disproportionate importance in the development of his scientific thinking. As he wrote in his autobiography,[1] he was deeply influenced by his discovery of the similarity of Galápagos plants and animals to those on mainland South America, and especially 'by the manner in which they differ slightly on each island in the group'. But while in Galápagos, Darwin was primarily a geologist.[2,3] He repeatedly attempted to explain the geomorphology he observed in terms of processes he could only infer: uplift, the direction of lava flows, their terrestrial or subaqueous origin and the eroding effects of seas. He also developed a theory of magmatic differentiation from looking at crystals embedded in the volcanic rock.[4]

Where was Darwin in Galápagos and what did he see? Much has been written about him on his visit to the islands,[5–7] but there is still confusion about exactly where Darwin set foot upon the four islands he visited: Chatham (San Cristóbal), Charles (Floreana), Albemarle (Isabela) and James (Santiago). Only one study has attempted to elucidate his whereabouts,[8] but it lacked information from the most revealing manuscripts[9,10] and so was incomplete and incorrect on points of detail. We attempted to answer these questions by first conducting an extensive search in bibliographic material for relevant information,[11,12] and then by retracing his steps as best as we could from 19 October to 14 December 1996,[13] that is at approximately the same time of year and season (dry) as Darwin's visit.[14] Here we describe the route he took, several of his key geological observations, and changes that have taken place to the fauna and flora since his visit 165 years ago. By visiting the places he visited we were able to appreciate what caught Darwin's attention, and why. The geological features seen and noted by Darwin are still extant today. The living world is in sad contrast, for it is no longer possible to see several components of the fauna and flora he observed.[15,16] Thus the information presented here is of potential value to scholars wishing to revisit his sites for historical or for scientific purposes (figure 1; see table 1 for GPS readings).

Table 1. Locations of sites as determined by GPS readings

island	name of site	south	west
Chatham	Cerro Tijeretas	0°53′26.7′′	89°36′29.0′′
Chatham	Fresh Water Bay, Honda Pond	0°51′29.0′′	89°37′36.7′′
Chatham	Dalrymple, 200 ft offshore	0°49′30.4′′	89°31′25.3′′
Chatham	Puerto Grande Beach	0°45′31.1′′	89°27′29.4′′
Chatham	Cerro Brujo, 50 ft below highest rim	0°45′39.2′′	89°27′25.0′′
Chatham	Cerro Brujo rim, near mouth	0°56′33.9′′	89°29′25.6′′
Chatham	High Crater, 1 mile in Craterized District	0°45′12.7′′	89°25′19.9′′
Chatham	beach at south edge of Craterized District	0°44′51.6′′	89°26′22.5′′
Chatham	landing site of Sulloway; tourist marker	0°43′19.0′′	89°23′30.9′′
Chatham	Cerro Brujo, group of seven dykes	0°45′43.0′′	89°27′53.3′′
Chatham	Pan de Azucar landing beach	0°41′53.5′′	89°21′45.4′′
Chatham	Pan de Azucar beach, where gully starts	0°42′11.4′′	89°21′42.9′′
Chatham	Pan de Azucar, 100 ft from summit	0°43′27.2′′	89°21′11.9′′
Charles	Black Beach	1°16′38.1′′	90°29′17.6′′
Charles	road to highlands near Black Beach	1°16′42.9′′	90°28′40.8′′
Charles	trail junction to Cerro Pajas	1°18′07.4′′	90°27′09.6′′
Charles	Cerro Pajas summit	1°17′43.5′′	90°27′26.8′′
Charles	behind south end of Post Office Beach	1°14′25.8′′	90°26′57.3′′
Charles	spring at base of hill	1°18′51.7′′	90°27′17.8′′
Charles	spring and pirate caves	1°18′57.6′′	90°27′12.3′′
Charles	spring at Cruz Farm	1°17′08.3′′	90°28′12.4′′
Charles	double cliff, facing Cerro Ballena	1°15′22.4′′	90°29′18.0′′
Charles	Champion	1°14′07.0′′	90°23′08.0′′
Albemarle	north Beagle Crater rim; Darwin's descent	0°16′19.0′′	91°21′06.3′′
Albemarle	Beagle Lake shore; Darwin's descent	0°16′29.8′′	91°21′04.3′′
Albemarle	freshwater ravine mouth by sea	0°16′27.6′′	91°21′59.3′′
Albemarle	Punta Cristóbal	0°52′55.1′′	91°30′37.4′′
Albemarle	cement dock at Caleta Iguana	0°58′48.0′′	91°26′45.4′′
Albemarle	Isla Tortuga summit, at climb point	1°00′44.8′′	90°52′15.8′′
James	Buccaneer Cove, camp	0°10′07.3′′	90°49′28.9′′
James	Buccaneer Cove, mid north beach	0°10′05.2′′	90°49′28.8′′
James	Buccaneer Cove, mid south beach	0°10′15.8′′	90°49′36.5′′
James	Buccaneer Cove, Pinnacle	0°10′07.7′′	90°49′33.7′′
James	Cerro Cowan, west side climb point	0°11′04.9′′	90°49′51.9′′
James	freshwater trickle	0°10′53.9′′	90°50′12.1′′
James	red hill in lava flow	0°13′51.7′′	90°50′43.2′′
James	vegetation in front of brown lava aa flow	0°14′09.4′′	90°50′03.1′′
James	northeast rim of salt crater lake	0°14′26.4′′	90°49′59.4′′
James	south shore of salt crater lake	0°14′32.6′′	90°50′09.7′′
James	northwest rim of Salina Escondida	0°16′26.6′′	90°50′30.6′′
James	southernmost pebble beach on lava flow	0°14′09.0′′	90°50′54.9′′
James	Buccaneer Cove, tip of promontory	0°09′57.1′′	90°49′37.8′′
James	tortoise pools	0°13′55.1′′	90°47′01.2′′
James	above Jaboncillos	0°12′43.0′′	90°47′00.3′′
James	Jaboncillos; trees and pottery area	0°12′24.8′′	90°47′06.2′′
James	Jaboncillos; bowl area near Scalesia fence	0°12′46.3′′	90°46′56.2′′
James	near top of island	0°13′06.2′′	90°46′29.9′′
James	Caseta at Central	0°14′29.1′′	90°45′04.4′′

CHATHAM (SAN CRISTOBAL)

Cliff at NW end of Chatham (Cerro Tijeretas)

At 4.15 pm on 16 September 1835 the *Beagle* anchored off the northwestern end of Chatham (Dalrymple Rock N57W, Kicker Rock N30E)[17] and Darwin landed for an hour. We now know that his first venture on to Galápagos soil was at Cerro Tijeretas, the present visitor site of the Galápagos National Park just northeast of Puerto Baquerizo Moreno. FitzRoy mentioned climbing a little hill here.[18] In his geological notes[19 [758]] Darwin described a cliff, in which:

> at a height of several ft above high water mark a breccia of huge fragments of vesicular & compact Basalt were united by a hard calcareous sandstone. In this were fragments of recent shells.

He extracted limpets (specimen 3290) and plates of chiton from the rock. From his work in South America, Darwin was particularly interested in uplifts and the 'Cliff' was notable in that he regarded it as 'proof of elevation to a small degree within recent times'.[20[758]] Otherwise Darwin was not impressed by his first visit on shore comparing the country 'to what we might imagine the cultivated parts of the Infernal regions to be'.[21]

Cerro Tijeretas is the only place in the vicinity of the *Beagle*'s anchorage with a cliff that has the calcareous rock referred to by Darwin. Here there are large reddish rock conglomerates containing several species of shells on the southwestern side of the cove at Cerro Tijeretas. The present National Park trail that leads down to the shore at Cerro Tijeretas ends near where Darwin landed.

SW end of Stephen's Bay (Puerto Grande)

On 17 September the *Beagle* weighed anchor at 8.35 am and moved to Stephen's Bay where it anchored at 11 am (Kicker Rock N10E, Finger Peak N45E).[22] Darwin went on shore in the afternoon to collect specimens but he wrote very little about where he landed. Here 'the country was smoother and I believe the lava subaqueous, having flowed into shoal sea'.[23[758]] Puerto Grande is the closest landing site to the *Beagle*'s anchorage and fits Darwin's brief characterization of the place.

While Darwin was on shore, Captain FitzRoy took a boat across Stephen's Bay to Finger Hill (now known as Cerro Brujo) and spent the night there. We are convinced that Darwin did not join FitzRoy. Darwin was keenly interested in geology and if he had gone to Finger Hill he would surely have spent his time examining the unique geology of the crater. Instead, for that day, he wrote in the Beagle Diary 'When on shore I proceeded to botanize …'.[24]

On this day, Darwin saw his first marine iguanas (*Amblyrhynchus cristatus*). In the Beagle Diary he wrote:[25]

> The black Lava rocks on the beach are frequented by large (2–3 ft) most disgusting, clumsy Lizards. They are as black as the porous rocks over which they crawl & seek their prey from the Sea—Somebody calls them 'imps of darkness'.[26,27]

Today, due to predation by feral mammals (cats, dogs and rats) marine iguanas have all but disappeared along the coast of Chatham.[28]

Another animal Darwin mentioned seeing on 17 September, and which can no longer be found on Chatham, is the Galápagos hawk. It was so tame and approachable he was able to push one off a branch with his gun.[29] Tameness was also a feature of the Galápagos dove (*Zenaida galapagoensis*);[30] Midshipman King caught a dove in his hat.[31] Today doves are scarce on Chatham. Mockingbirds (*Nesomimus melanotis*) were also tame and common and, though not abundant on the island today, are still relatively unwary of humans. Darwin collected three of the four species of mockingbirds; he did not see the Hood (Española) Island species (*Nesomimus macdonaldi*). He noted that each island he visited had only one exclusive variety of mockingbird.[32–34] This was important to him later in developing his theory of evolution when he appreciated the significance of geographical isolation.

Terrapin Road (Bahía Tortuga de Agua Dulce)

On 18 September the *Beagle* lifted anchor at 8 am and came to a new anchorage at Terrapin Road at noon (Mt Pitt N76E, Kicker Rocks S50W).[35] Darwin landed here and climbed his first Galápagos tuff crater, which is now called Pan de Azucar. Darwin considered the tuff craters to be 'the most striking feature in the geology of this Archipelago'.[36] As Simkin points out, 'It was Darwin who first recognized how these tuff craters formed from the interaction of lava with water'.[37]

At Terrapin Road Darwin described 'a level district of Basalt & Greystone, smoothed over & the interstices filled up by Calcareous Tufa'.[38[749]] In a shallow stream bed leading from Bahía Tortuga de Agua Dulce inland to Pan de Azucar, we found these flat slabs of lava covered in part with a white calcareous cement, which was studded with shell fragments. Darwin walked inland to 'the broken remains of a low but broard[39] [sic] crater'.[40] He described the site as 'some small hills in parts detached, in others joined to a central mass'.[41[749]] He ascended the tuff cone, measured the angles of strata, described the colour and texture of the tuff, and correctly estimated the height to be about 800 feet.

Darwin first mentions Galápagos tortoises (*Geochelone elephantopus*) on this day, recording that the *Beagle*'s 'hunting party brought back 15 Tortoises: most of them very heavy and large'.[42] We found no tortoises at this site, only some old scats at the base of Pan de Azucar. However, tortoises can still be found a couple of miles to the northeast at a National Park visitors' site called the Galapaguera.

Fresh Water Bay (Bahía de Agua Dulce)

The following day the *Beagle* lifted anchor at 9 am and sailed around the northeastern extremity of Chatham, reaching Freshwater Bay on the southern coast at 1.30 pm on 20 September. It stayed at Fresh Water Bay until 3 pm. We searched for evidence in the literature suggesting that Darwin went ashore, but found no such indication. In the Beagle Diary[43] he wrote: 'At one point there were little rills of water, & one small cascade.—The valleys in the neighbourhead[44] [sic] were coloured a somewhat brighter green'. FitzRoy wrote in much more detail about this place: 'I think it of very great importance, since there is no other natural Watering place [during the dry season] for any number of Ships among the Islands'.[45] Some of the crew landed to determine the feasibility of collecting fresh water and found it to be a very difficult landing. The *Beagle* returned to this place on 11 October while Darwin was camping on James and spent two days taking on water for the ship.[46]

We found three cascades of water and two streams. We landed at La Honda, the largest stream that forms a freshwater pool behind a pebble beach. We had to swim ashore as we were unable to land by boat due to heavy swells. Nonetheless this little cove is the most accessible water source, and from FitzRoy's description[47] it is clearly the place where his men obtained water.

The *Beagle* left Fresh Water Bay and anchored in Stephen's Bay that same evening at 6.20 pm on 20 September. This was the same anchorage they had used on 17 September. Here the *Beagle* crew caught their first Galápagos turtles, most likely the Pacific Green turtle (*Chelonia mydas agassisi*) which is by far the most common species.[48] The *Beagle* stayed in Stephen's Bay until 22 September.

Finger Hill and the 'Craterized District'

According to the Field Notebooks,[49] on Monday 21 September Darwin and his servant Syms Covington were taken by boat '6 miles from the ship' to an area of many volcanic cones (Darwin called it a 'Craterized District'[50[757]]). On the way they passed Finger Hill. Darwin examined it up close from the boat. We know this because he described breaking a fragment off one of the broad dikes in the side of the hill.[51[752]] We thoroughly examined Finger Hill and found that there are ten dikes, they are on the sea side of the volcano, and they can only be observed and reached by boat. Darwin also mentioned Kicker Rock, describing its 'most singular form—a flat topped mass is surrounded by absolutely perpendicular cliffs…. On one side is an equally abrupt spire.—Rock height is 400 ft'.[52[753]]

Darwin depicted the Craterized District as:

> a strange black district, bare of all vegetation & studded over with small Craters, so as to resemble those parts of Staffordshire & Shropshire where Iron Foundries are most common.[53[754]]

He also referred to this region as the 'Phlegrœan fields'.[54[731],55–57] This is clearly the stretch of craters on the northwestern side of Chatham, but it is a vast area. Where exactly did Darwin land and explore?

Darwin and his servant landed at the Craterized District on 21 September and slept on a sand beach that night.[58] There are several small sand beaches along the length of the Craterized District. Darwin described two lava flows: one destitute of vegetation, rough and like 'a sea petrified in its most tempestuous moments',[59[755],60] and the other smoother and 'partially clothed with a stunted vegetation'.[61[755]] Darwin most likely landed and slept on the little beach that borders the southern edge of the Craterized District. This would have placed him at a convenient spot to examine both lava flows, and today at least it is the easiest beach to land at, the others having many submerged rocks at low tide. We know that he did not land at the far northern end of the Craterized District because of its great distance from the *Beagle*'s anchorage (11.25 miles).

Darwin described in great detail the craters in both lava flows,[62[755–757]] noting that their diameters ranged from 30 to 150 yards, that they were elevated from 50 to 100 feet above the surrounding country, that they were generally within one-third of a mile of each other and some were within 30 yards from rim to rim. He also described circular pits about the size of the smaller craters, from 30 to 60 feet deep, and gutters from 2 to 4 feet deep running from the base of the craters. In the Beagle Diary[63] he wrote 'From one point of view I counted 60 of these truncated hillocks…'.

From these descriptions we know that Darwin must have ventured deep into the flow to make his measurements, and to where the craters and pits are dense. This area is much closer to the southern edge than the northern edge of the flow. Furthermore, there is a sketch[64[752]] of a volcanic tuff cone that can only be Finger Hill, viewed from inland. The perspective of the sketch shows that it was not made close to the hill but rather from deep within the Craterized District. He depicted the vegetated lava flow mentioned above as having flowed from the interior of the island around the base of Finger Hill.[65[752]] This is indeed how it appears from the Craterized District. However, the flow does not reach to the base of Finger Hill but only to within *ca*. 300 metres of the volcanic cone. Darwin believed that Finger Hill was once an island and that lava from Chatham flowed around its base thus connecting it to Chatham.

Darwin saw two tortoises on the vegetated lava flow,[66] and recorded that one of the tortoises was eating a prickly pear.[67] Presumably he was referring to *Opuntia* cactus. We found no tortoises or *Opuntia* on either side of the Craterized District, although they both exist elsewhere on the island. The *Opuntia* may have been destroyed by goats introduced after Darwin's visit; there is no evidence of any introduced animals being on Chatham when Darwin was there. We found copious amounts of goat droppings throughout the area, on both lava flows, and frequently heard and saw feral goats. Reference to *Opuntia* cactus is significant for another reason. Darwin collected two, perhaps four, specimens of the now extinct large form of the large ground finch *Geospiza magnirostris* somewhere on this island.[68] According to Sulloway,[69] after he had left the archipelago Darwin apparently remembered seeing these birds for the first time on Chatham. The vegetated lava flow may have been the locality where these finches were encountered because they would probably have depended on the especially large seeds of *Opuntia megasperma* (and *Cordia lutea*) for food in the dry season.[70]

It is also interesting to note that while Darwin says one of the lava flows was destitute of vegetation, we did find candelabra cactus (*Jasminocereus thouarsii* var. *thouarsii*) scattered throughout the craterized flow, exclusively on the precipitous sides of the chimney cones and in the circular pits. We also found a Galápagos tomato plant (*Lycopersicon cheesmanii*) and a cutleaf daisy (*Lecocarpus*), both in flower, in a pit in the centre of the district. Darwin collected both of these plants.

Darwin collected a rice rat (*Oryzomys galapagoensis*) on Chatham.[71,72] The species is now extinct on this island. Rice rats were not collected on any other island, but an introduced rat (*Rattus rattus*) was found on James.

Darwin and Covington returned on board the *Beagle* on the evening of 22 September. The *Beagle* lifted anchor at 6.30 am on 23 September and set sail for Charles.

Charles (Floreana)

At 5.20 pm on the 24 September the *Beagle* anchored at what was then and still is called Post Office Bay. It stayed there until 3 pm on 26 September, then moved to Black Beach (Saddle Pt S11.10W, Round Hill S73E)[73] at 5 pm, where it stayed until 8.05 am on 28 September. Charles was the only inhabited island in Galápagos in Darwin's day. There was a settlement on the island consisting of about 200 political prisoners. Captain FitzRoy described it as 'an oasis in the Desert'.[74] There were many introduced crops growing in the highlands: sweet potato, sugar cane, Indian corn, yucca [cassava], pumpkin, plantain, Quito orange, castor oil plants, melon and bananas. Some of the plants collected by Darwin were later described by the botanist Joseph Dalton Hooker as being introduced.[75] FitzRoy took 'on board live pigs and a quantity of vegetables' from this settlement, and collected a small quantity of water from the highlands, which he conveyed down the hill in bamboo pipes.[76] Although the water was good, the supply was 'quite precarious in 1835'.[77]

Darwin was struck by the 'extreme tameness' of the land birds.[78] He talked about a boy 'Sitting by the side of a Well, with a long stick in his hand, as the doves came to drink he killed as many as he wanted & in half an hour collected them together & carried them to the house'.[79] We saw only one dove on Charles. The scarcity of doves today has been linked to the presence of feral cats.

Mr Nicholas Lawson, acting governor of the settlement, hiked down from the highlands and then accompanied Darwin and FitzRoy on the morning of 25 September back up to the settlement. However, instead of climbing directly to the settlement from Post Office Bay they took a boat to Black Beach and hiked from there along a 'good path'.[80]

We followed the 'old road' to Asilo de Paz, near where the settlement used to be. The 'old road' is now an overgrown path but would have been the trail that Darwin and FitzRoy used. At Asilo de Paz are 'several springs & small pools',[81] including the 'Governors Dripstone', which FitzRoy referred to in the Narrative.[82] Upon reaching the cultivated area they were struck by the lushness of the place: 'the body is cooled by the fine Southerly trade wind & the eye refreshed by a plain green as England in the Spring time'.[83] They returned to the *Beagle* that evening and the next day explored Post Office Bay.

Darwin found the island covered with vegetation and wrote that there appeared to be no recent lava flows. Charles had little interest to him geologically and he wrote scantily about the island.[84] Nonetheless, on 27 September Darwin climbed to the summit, which FitzRoy called Round Hill and which is now known as Cerro Pajas:

> The highest hill is 1800 ft, its summit is formed out of the remains of a Crater, this escarpment consists of red glossy scoria, united together. -From this point I counted in different parts of the Island … from 39–40 hills, in the summit of all of which there is a more or less perfectly circular depression.[85][747]

In following in Darwin's footsteps we hiked to the summit of Cerro Pajas. Darwin wrote that the hill was 'covered in its upper parts with coarse grass and shrubs'.[86] Unfortunately the coarse grass today has been replaced with an introduced *Lantana camara* with vicious thorns. The other shrub, also with vicious thorns but a native plant that Darwin probably saw, is *Zanthoxylum fagara*. There are relatively few of these trees now and none is very large. Formerly the island most likely supported a forest of such trees, occupied by the now extinct sharp-beaked ground finch (*Geospiza difficilis*, originally named *G. nebulosa*[87]). The *Beagle* collection of finches contains two specimens.[88] Today Cerro Pajas supplies the nesting grounds of a species of dark-rumped (Hawaiian) petrel (*Pterodroma phaeopygia*). Darwin made no mention of this bird; however, he was not there during its breeding season.

The Charles tortoise (*Geochelone nigra elephantopus*) is now extinct but in Darwin's day there were still tortoises on Charles. Even then their numbers were diminishing rapidly, and Darwin does not mention seeing any:

> Of course the numbers have been much reduced; not many years since the Ship's company of a Frigate brought down to the Beach in one day more than 200, -where the settlement now is, around the Springs, they formerly swarmed. -Mr. Lawson thinks there is yet left sufficient for 20 years: he has however sent a party to James Island to salt (there is a salt mine there) the meat….[89]

Shells were to be seen lying around the settlement, some used as flower pots.[90]

While in the islands Darwin wrote 'Mr. Lawson states he can on seeing a Tortoise pronounce with certainty from which island it has been brought'.[91] Later on in the voyage Darwin began to recognize this as being important evidence, together with the fact that different species of mockingbird are restricted to different islands, for evolutionary divergence in geographical isolation.[92] Darwin also noted differences in the flora of the different islands:

> For instance the berry-bearing tree, called Guayavita [*Psidium galapageium*], which is common on James Island, certainly is not found on Charles Island, though appearing equally well fitted for it.[93]

The 'double cliff'

Other than Cerro Pajas, Darwin described only one geological feature on Charles. He wrote that the shore of Charles contained evidence of uplift because of the presence of large round boulders above the high tide mark. We think that he examined this coast from the boat as he was travelling between Post Office Bay and Black Beach:

> On the north side of the Island, I noticed in many places a beach of large rounded Rocks, which appeared to me decidedly to be quite beyond the reach of the Surf at the present level. -In one spot, there was a low double cliff, & on the top of the [sic] both a bank of such pebbles. [small sketch] Perhaps this raised beach may be, where highest, 15 ft above the line of any present action.[94][748]

Later in his volume on *Volcanic Islands* Darwin discounted his explanation of an uplift when he was informed by eyewitnesses that 'the rounded boulders, now lying on its summit, are merely the remnant of those which had been rolled up during storms, to their present height'.[95] To find this 'double cliff' we walked along the coast from Black Beach north towards Post Office Bay, and also searched for it by boat. We found the double cliff approximately half a mile north of Black Beach. As Darwin described it, the shore consists of large pebbles and boulders, some of which appear to be above the high tide mark.

Champion

Darwin did not visit the satellite islands around Charles, nevertheless he wrote:

> Mr. Chaffers inform all the small Islands around Charles have all Craters. - Champion Isd is a much weathered Crater, partially composed of Sandstone, containing marine shells.[96[732]]

He mentions that 'Mr. Chaffers … brought me from Champion Is a fossil shell: which he extracted from Volcanic Sandstone at the height of 400–500 ft'.[97[748],98] He then conjectures:

> Has this been a horizontal upheaval. - Everything shows that in place of these Islands being formed by pile of poured out matter, there has been upheaval extending over these different Isd.99[732–733]

Later, however, Darwin wrote that 'Proofs of the rising of the land are scanty and imperfect'.[100]

Champion is biologically interesting because it has populations of mockingbirds and snakes once abundant on Charles but now rare or extinct, and thus represents a remnant of what Charles once was. Mockingbirds were present on Charles during Darwin's visit, but became extinct on Charles at the end of the last century.[101] The status of the Galápagos snake (*Philodryas biseralis*) is unclear but it is rare if present at all. FitzRoy wrote that several snakes were caught on Charles.[102] Champion, unlike Charles, has no introduced mammals.

On 28 September, at 8.05 am, the *Beagle* weighed anchor and set sail for Albemarle.

Brattle (Tortuga)

On 28 September the *Beagle* sailed past Brattle (Tortuga). Darwin did not land here but he described the island's perfect crescent shape.[103[760,788–789]] Brattle was important to Darwin in that it represented the perfect example of a phenomenon that he and the officers of the *Beagle* involved in the survey of the islands had been observing frequently in Galápagos; that many sandstone (tuff) islands and island tuff cones were eroded on the southern side.

He listed 28 instances of this phenomenon, and could find no exception to the rule.[104[788–789]] He noted 12 islands that 'form separate islets, and now exist as mere crescents quite open to the south, with occasionally a few points of rock marking their former circumference', Brattle being the largest and most perfect.[105] The other islands were three of the Crossman's, Cowley, Gardner, Champion and Enderby near Charles Island, two small islets near Indefatigable, an islet near James (possibly Albany) and a small islet described by Lieutenant Sulivan as containing a salt lake which 'has a part of the southern side of the circular ridge not higher than 20 ft, whilst the remainder is perhaps 300 ft above the level of the Sea'.[106[789]] This last islet is clearly one of the Bainbridge Rocks off the southeastern coast of James. Darwin also listed 16 tuff craters, which had the side facing the south much lower than the other parts of the rim. He explains the phenomenon of the cones being broken down on one side as follows:

> Throughout the islands of the archipelago, both the sea, from the tradewind & the long swell of the Great Ocean constantly unite their unwearied forces against Southern shores.[107[790]]

The prevailing winds also give rise to a higher build-up on the leeward rim, as Darwin noted on his visit to Ascension Island.[108]

ALBEMARLE (ISABELA)

Point Christopher (Punta Cristóbal)

On 29 September the *Beagle* rounded the southern end of Albemarle, anchoring from 1 pm to 3 pm, at Iguana Cove (Caleta Iguana).[109] A whale boat was lowered to survey Elizabeth Bay and the western shore of Narborough (Fernandina) Island,[110] but we could find no evidence suggesting that Darwin landed. FitzRoy noted the large numbers of 'hideous iguanas … were quite startling!'.[111] Continuing round the southwestern end of Albemarle, the *Beagle* passed an area similar to the Craterized District of Chatham. This is clearly the area around Point Christopher. Darwin wrote:

> Passed a point studded over with little truncated cones … the Craters were very perfect & generally red-coloured within. - The whole had even a more work-shop appearance than that described at Chatham Island.[112]

Darwin was probably eager to explore this area on foot but 'A calm prevented us from anchoring for the night' and he did not land.[113]

While sailing northwards along the west coast of Albemarle, Darwin was impressed by the island's immense volcanoes, which he conjectured to 'be surmounted by enormous Craters, from which bare & black streams of Lava can be traced down their sides'.[114[759]] Both Darwin and FitzRoy observed an active fumarole on Albemarle. Darwin wrote '…in 2d mound from the south, there was steam issuing from Crater high up'.[115[744–745]] He referred to this mound, now known as Sierra Negra, as Volcano Hill.[116[759]] Darwin did not have the opportunity to climb and examine any of the volcanoes on Albemarle. In a letter to Lyell in 1857,[117] he wrote 'I always regretted that I was not able to examine the great craters on Albemarle Isd, one of the Galapagos'.

Banks (Tagus) Cove

The *Beagle* passed the American Whaler *Science* in the morning of 30 September and at 6.18 that evening she arrived at Banks Cove.[118] Darwin explored Beagle Crater on 1 October. Although he only spent one day there he devoted over a third (36 pages) of his geological notes on Galápagos[119] to descriptions of Beagle and Tagus Craters. Darwin did not give Beagle Crater a name but its identity is clear from his description. Furthermore, he drew a fairly detailed sketch of both craters and the intervening land.[120[745]]

The reason for the *Beagle*'s visit to Tagus Cove was to collect fresh water, although they were disappointed in this respect:

> From different accounts, we had hoped to have found water here. To our disappointment the little pits in the Sandstone contained scarcely a Gallon & that not good - it was however sufficient to draw together all the little birds in the country. - Doves & Finches swarmed around its margin.[121]

Darwin would have landed at this water source in the valley between Banks Cove and Beagle Crater and then scaled Beagle Crater from the northwestern side (figure 2).

The inner slopes of Beagle Crater are very steep but the northern slope is relatively gentle in descending to the lake at the bottom. Darwin did just this:

> The day was overpoweringly hot; & the lake looked blue and clear. - I hurried down the cindery side, choked with dust, to my disgust tasting the water found it Salt as brine.[122]

He noted three islands in the middle of Beagle Crater, one of which had a small

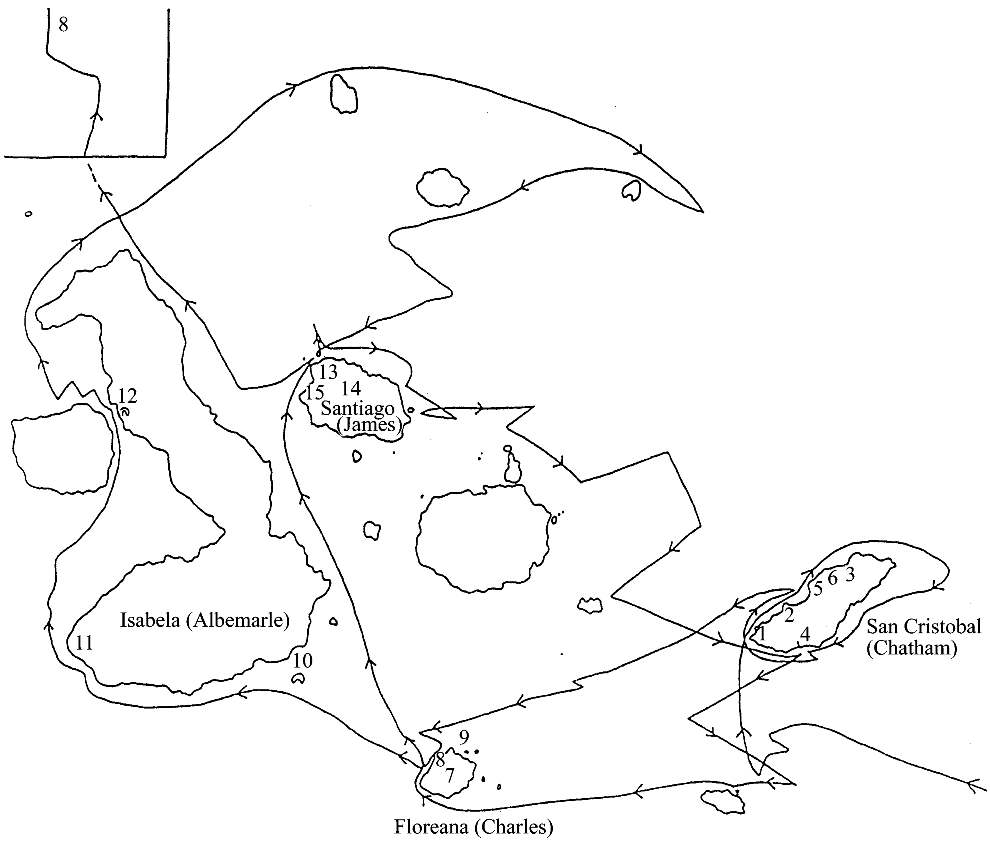

Figure 1. Route of the *Beagle* through Galápagos, and numbered sites visited or observed by Darwin. Number 9 refers to Champion and number 10 refers to Brattle (Tortuga) Island. The broken line indicates Darwin's probable route. The drawing is based on six charts made by FitzRoy (see note 11); see also note 6. The departure of the *Beagle* is not shown correctly; it visited Abingdon, the northernmost island on this map; see also note 209.

crater.[123[734]] There are actually six islands but four of them are very small and two appear to be joined together. They have never been named and so we have named them after crew members on the *Beagle* who helped Darwin with making collections in Galápagos (see figure 2).

At Beagle Crater Darwin made two other salient geological observations. The first was a prevalence of 'a pisolitic structure: the balls [ranging] from size of shot to small bullets, formed of thin concentric layers of the finer particles of the sandstone (margin note 3250).[124[761]] These pisolitic balls were also known as rapilli[125] and are today called accretionary lapilli. We found a profusion of them on the northern rim of the crater. The second feature was an abundance of furrows or 'longitudinal doons

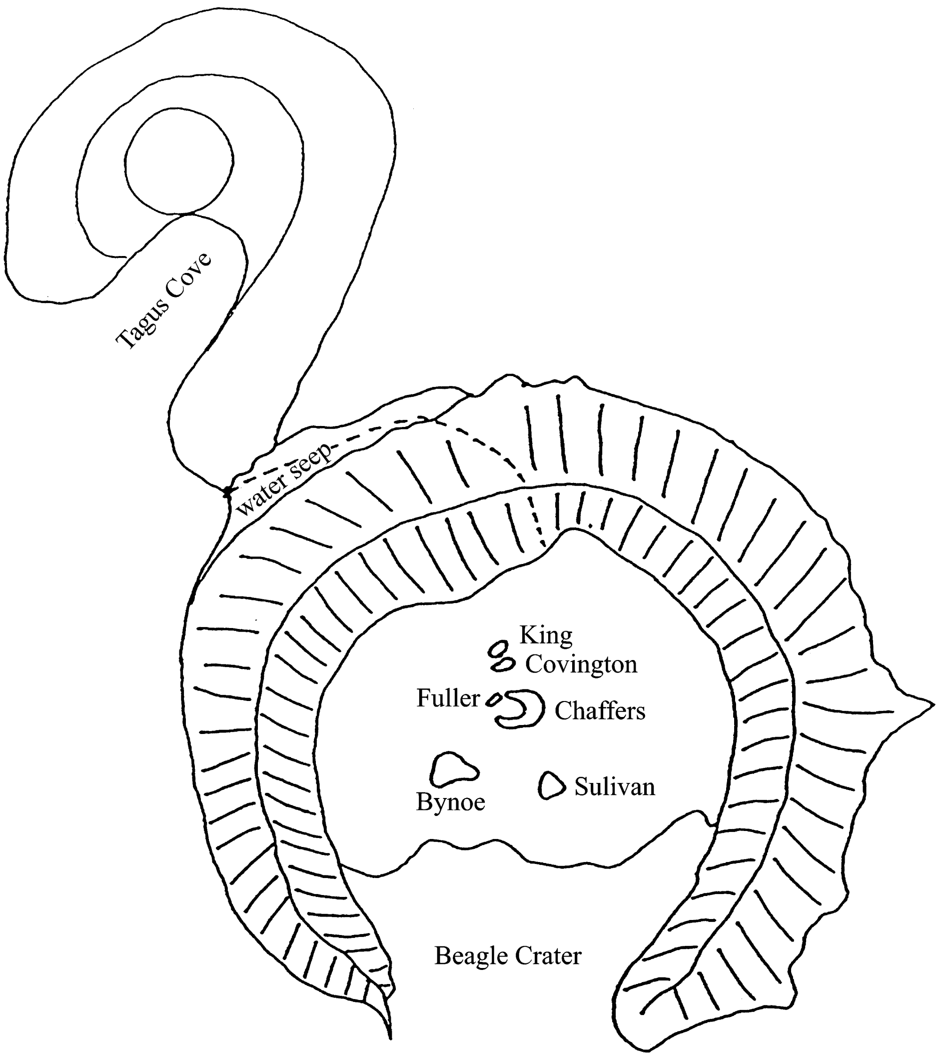

Figure 2. New names for islands in Beagle Crater, Albemarle (Isabela) Island. The map is drawn from aerial photographs in the archives of the Charles Darwin Research Station, Galápagos.

[dunes]'[126[762]] on the external slope of Beagle Crater. He was much struck by them and in a letter to Lyell in 1850 wrote:

> …I think you overlook the cream of my case of tuff-strata at Galápagos, viz that the beds form narrow streams, hollow within from the setting of the outside crust, & therefore no one c[d] here suppose that we had once **horizontal strata** uplifted….[127]

The furrows were 'from 8 to 20 or 40 feet wide, are separated from each other by shallow gullies'.[128[762]] He likened the dunes to the roofs of plastered vaulted passages, cracked into plates.[129] At the rim these dunes sometimes were hollow tunnels and on the north-western lip of the crater they opened into hoods.[130[763]]

Darwin described Banks Cove, although he did not examine it as thoroughly as Beagle Crater. He depicted the cove as being larger than Beagle Crater and in a much more demolished state, with sides 'weathered by the sea into bold cliffs'.[131[766]] He also briefly mentioned another crater with a salt lake at its bottom within the outer ring of Banks Cove; this lake is now known as Darwin Lake. Darwin believed that Beagle Crater was formed above water whereas Banks Cove was probably formed by a marine eruption.[132[745]]

The importance of Beagle Crater and Banks Cove to Darwin lay in their uniqueness:

> I have particularly described these Craters because I do not recollect having read of an exactly parallel case - nor indeed of a large Crater entirely composed of Volcanic Sandstone under any circumstances.[133[767]]

The last feature to be described for this area were the lava flows between Beagle Crater and Banks Cove.[134] These flows emanate from what is now called Darwin Volcano. Darwin observed that 'One enormous stream, many miles broard[135] [sic], almost entirely destitute of vegetation (I believe I must except 2 or 3 plants of a Cactus) interfolds behind & between the Sandstone Craters'.[136[768]] He poetically compares this stream with the lava flow of the Craterized District on Chatham Island:

> The outline of the field of Lava as compared to the Basaltic one of Chatham Is[d] is much smoother - there is not that appearance of huge frozen billows, or nearly so many fissures of contraction. On the contrary the surface itself is excessively rough. I should compare the one to the ocean, the other to a lake violently agitated by a storm.[137[768],138]

He also mentions another more recent and blacker lava flow which crosses the former flow and 'which has flowed from a minute & perfect Crater high up on sides of mountain'.[139[769]] From Beagle Crater this lava flow is easily observed and identified, and the surface resembles the circular pattern of a roughly ploughed field.

As for animal life, Darwin[140] wrote that the rocks abounded with large marine iguanas. He also saw his first land iguanas (*Conolophus subcristatus*) on the slopes of the craters:

> We here have another large Reptile in great numbers - it is a great Lizard, from 10–15 lb in weight & 2–4 ft in length, is in structure closely allied to those imps of darkness[141] which frequent the sea-shore. - This one inhabits burrows to which it hurries when frightened with quick & clumsy gait. They have a ridge & spines along the back; are colored an orange yellow, with the hinder part of back brick red. - They are hideous animals but are considered good food: This day forty were collected.[142]

It would not be possible to collect 40 today. During the expedition we found no land iguanas. However, on a return visit during the wet season we found three on the northern base of the outer slope of Beagle Crater. We also found six tortoises on the return visit. Darwin did not mention finding tortoises here and perhaps they are absent during the dry season. Finches abound at Banks Cove and we found several small ground finches drinking water from seeps in the rock at the water source, as did Darwin.[143–145] However, unlike Darwin, who saw many doves in the area, we only saw two. Doves, which nest on the ground, have probably succumbed to predation by cats, which were introduced after Darwin's visit. Goats are another addition to the island since Darwin's time. In the two days that we were at Beagle Crater and Banks Cove we saw two dozen goats and found their droppings as well as cat scats everywhere.

The *Beagle* left Banks Cove on 2 October at 10 am, rounded the north of Albemarle on 3 October and reached Buccaneer Cove on James Island on the morning of 8 October.

James (Santiago)

Buccaneer Cove

The *Beagle* arrived at Buccaneer Cove[146] on 8 October at 11.20 am. Darwin landed with Covington, the surgeon Bynoe and his assistant Fuller,[147] and the *Beagle* left at 5.30 pm for Chatham to take on water. The men camped in the valley behind Buccaneer Cove. They had difficulty in finding a spot to pitch their tent because of the numerous land iguana burrows.[148] To Darwin, the iguanas had a stupid appearance when they slept with their eyes shut or walked slowly, pausing to shake their heads up and down. He noted[149] that they ate much cactus and 'run away like dogs from one another with pieces'. A finch was observed picking from the same piece, often alighting on the back of an iguana.[150] Other animals noted were the hawk and mockingbird[151] and these can still be seen today. The land iguana, however, has since become extinct on James.

On arriving at Buccaneer Cove they met a party of men, sent from Charles by Mr Lawson to salt fish and tortoise meat.[152] Before lifting anchor, FitzRoy gave these men a 50 lb bag of biscuit, which was received as if it were gold, since they had been living off nothing but tortoise meat.[153] Darwin and his companions employed these men to bring water to them from the 'miserable little Spring of Water'[154] at the foot of the ravine that appears to split Cerro Cowan in half. FitzRoy estimated a yield of about 10 gallons of water an hour from this spring.[155] When we visited the site on 6 November, we managed to collect one litre in half an hour (less than half a gallon in an hour).

Sometime before 13 October the surf broke over the water source and spoiled the pool of fresh water.[156] Fortunately, an American whaler gave them three casks of water.[157] We, too, noted how the surf at high tide contaminated the pool of freshwater.

Darwin described the geology of Buccaneer Cove in much detail, paying particular attention to the 'promontory',[158[770]] which defines the northern side of Buccaneer Cove. A geological formation composed of layers of basalt and scoria stood at the base of the promontory on the beach, a structure that he found 'rather curious'.[159[718]] He measured the streams of lava, described their colour and crystal composition,[160,161] and drew a sketch of the formation.[162] We located this formation on the northern end of Buccaneer Cove on the beach near the base of the promontory. Although Darwin never named the formation, we have called it 'Darwin's Layer Cake'.

Another aspect of the promontory of interest to Darwin was the core or 'bosom' of an eroded crater.[163[720]] This is a mass of a 'quite compact, greenish or blackish grey Trachyte, with few Cryst of glassy feldspar'[164[720–721]] located in the lower centre of the promontory. In the lower surface of this formation Darwin found similar rock 'but containing larger and more abundant crystals of glassy Feldspar'.[165[721]] This important observation was key in developing his ideas on how different types of material could be extruded from the same vents.[166] Darwin also wrote about there being 'grand dykes'[167[773]] and how they formed 'lofty & singular pinnacles'.[168[772]] These black dikes can be found on the southern side of the promontory.

Finally, Darwin described the mass of land on the south side of the cove which is now called Cerro Cowan. He noted that this hill was the

> highest (850 ft) in the neighbourhead [sic]; is surmounted by remains of a large Crater. The whole is composed of Volcanic Sandstone, full of fragments of lava, which abound to such a degree, that some layers are composed of them. - The outside is worn into high & steep cliffs; which are continued deeply beneath the sea.[169[778]]

From the appearance of the unique layers of rock which composed the formation he reasoned that they were of 'subaqueous origin'.[170[778]]

Highlands

Darwin and his companions made two excursions into the highlands, on 9 and 12 October. Their walk was long and at what Darwin estimated to be an elevation of 2000 feet where 'the country begins to show a green color' they came across 'a couple of hovels' where the tortoise hunters lived.[171] At such an elevation the Guayavita tree is and was common (Duncan Porter, personal communication). Darwin wrote that the berries were a principal food of both tortoises and land iguanas. He resided for two days at the hovels, during which time he lived on fried tortoise meat. He ventured a further two miles and an additional 1000 feet in elevation to some springs. Here he found tortoises to 'swarm in the neighbourhead[172] [sic] of the Springs'.[173] The average size of an adult tortoise was almost a yard long and too heavy to lift off the ground but it could easily carry him.[174] He noted that they would lie submerged in the springs and drink great mouthfuls of water ('about 10 gulps in a minute'[175]). Broad paths made by the tortoises extended for miles from the springs.[176] Darwin calculated that they walked at the rate of 30 yards in five minutes. At the time of his visit tortoises were laying their eggs in sandy soil or in hollows in the rocky ground.[177] Unlike turtles, he observed, tortoises cannot be placed on their backs to secure them because they are able to right themselves.

Pools of water and tortoises can be found today in an area called Central in the highlands. However, we think it more likely that he was at another area called Jaboncillos, which is closer to the summit.

While Jaboncillos is now barren and dry due to devastation by introduced goats, when Darwin was there Jaboncillos was probably lush and green, covered with *Scalesia*,[178] *Zanthoxylum fagara* and ferns. Darwin wrote:

> During the greater part of each day clouds hang over the highest land: the vapor condensed by the trees drips down like rain. Hence we have a brightly green and damp Vegetation & muddy soil.[179]

Jaboncillos is near the summit of James, the clouds do hang over this area during the day and the few remaining *Zanthoxylum fagara* trees at Jaboncillos continually drip with moisture collected from the clouds. Jaboncillos is 800 metres high (2624 feet), which is close to the elevation that Darwin estimated the springs to be (3000 feet). In contrast, Central is only 600 metres high (1968 feet).

Another reason for believing that Darwin was at Jaboncillos is the fact that his description of a crater best fits the one we found there:

> …there is a large & perfect Crater, circular, sides very precipitous and bottom well wooded. In the vicinity nothing, but Trachytic lava is found: the channels, by which the lava has flowed over the rim are yet visible. —The walls of the Crater are chiefly composed of bright red & very glossy scoria, united together.[180 [770]]

Darwin made a comparison of rock specimens[181] from different elevations on James and found:

> The Trachytic lavas in the lower parts of the Isd are very cellular & the imbedded Crystals of glassy Feldspar very large & abundant: [whereas] - in the higher central part, the rock generally is more compact, the base blackish grey with scarcely any Crystals, & or they are abundant & small, the base itself being Crystalline.[182 [770]]

Close to the summit of James, Darwin encountered a number of rails which he also called water hens. We saw this bird, which is now known as the Galápagos Rail or Galápagos Crake[183,184] (*Laterallus spilonotus*) and like Darwin we heard it 'uttering loud & peculiar Crys'.[185] Interestingly Darwin stated that there were no tree ferns on James.[186] There are tree ferns but not at Jaboncillos.

The salina

On 11 October Darwin and his companions were taken by the head of the tortoise hunters (the 'Mayór-domo') in a boat down the coast to a salina. This salina is now referred to as the Salt Mine by the Galápagos National Park Service. The 'Mayór-domo' landed Darwin and his men on the lava flow in James Bay or 'Puerto Grande' as Darwin called it.[187[779]] Where exactly he landed on the lava flow is unknown, but it was at one of the several spots where there are large grey boulders full of olivine crystals. Darwin described these boulders as being a few feet above the present level of tides, and was impressed with how they abounded with olivine.[188[780]]

To reach the salina Darwin crossed the bare lava flow, then 'utterly destitute of vegetation',[189[779–780]] but today sparsely covered by several plant species, most commonly the lava cactus (*Brachycereus nesioticus*). Darwin used evocative language to describe the pahoehoe lava flow:

> The surface is smoother than in the Basalt of Chatham Is[d], yet here there are great waves & fissures. The superficies itself has formed singular ringed & twisted forms, which resemble cables, folds in thick drapery and rugged bark.[190 [780]]

Within the surface of the flow: 'The sides of the little Fissures which have acted as Fumaroles are yet white',[191[780]] and these fissures are still visible today. A more recent, darker stream of lava had crossed the greater flow but due to the size of the trees growing in its margin, Darwin reasoned that it was very old.[192[780]] He noted that:

> A Terrapin was caught some years since with its Shell appearing to have been burnt years before. The inhabitants believe this the effect of Volcanic fire. I rather accidental fire in wood.[193 [723]]

Darwin was impressed by the picturesque appearance of the salina:

> At the bottom of this Crater is a Lake, which is only 3 or 4 inches deep & lies on layers of pure & beautifully Crystallized Salt. The Lake is quite circular & fringed with bright green succulent plants; the sides of Crater are steep & wooded; so that the whole has rather a pretty appearance.[194]

The salt was collected from the central parts of the lake because the edge was soft and muddy.[195[783]] Darwin questioned whether the salt was 'a Volcanic exhalation' rather than evaporated seawater which had percolated into the crater.[196[783]] Today there is only a thin layer of impure muddy salt and it is no longer quarried. *Opuntia* trees (*Opuntia galapageia*), once present in the neighbourhood and recorded by Darwin in a sketch,[197] are now scarce, owing to damage by feral animals.

There was one other tuff crater that Darwin considered worthy of description on James. FitzRoy called this crater Sugar Loaf (Pan de Azucar).[198] Darwin examined the outer slopes and was struck by the '<u>perfect smoothness</u>' of the layers of tuff.[199 [784]] He likened the lower slope to an immense and cracked plastered floor.[200] Lieutenant Sulivan, one of the officers of the *Beagle*, gave Darwin a description of the interior.[201[783]]

Darwin briefly mentioned a third crater: 'At the distance of 2–3 miles there is another hill of similar appearance, in the Crater of which there is said to be another Salina'.[202[783]] We found this crater immediately to the south of Sugar Loaf. We climbed it and discovered a tiny salina in the bottom, as Darwin had been informed. Since we can find no name for this crater we have named it 'Salina Escondida', as it has remained hidden until now. In the *Beagle* collections are the stomach contents of a flamingo. Although the specimen was not labelled, Darwin notes that flamingos were found in the salinas.[203] We also found flamingos in both of the salinas.

Buccaneer Cove again

From 12–16 October, Darwin and his companions were busy collecting specimens.[204] On 12 October Darwin paid another visit to the hovels and spent the night there, as mentioned earlier. Darwin spent 14 October wandering about bird collecting, and observing the land iguanas.[205] At Buccaneer Cove Darwin measured air and sand temperatures remarking on how high they were:

> During the last two days, the Thermometer within the Tents has stood for some hours at 93º. —In the open air, in the wind & sun, only 85º. —The sand was intensely hot, the Thermometer placed in a brown kind immediately rose to 137, & how much higher it would have done I do not know: for it was not graduated above this. - The black Sand felt far hotter, so that in thick boots it was very disagreeable to pass over it.[206]

We measured similar temperatures.[207]

On 17 October, at 3.50 pm, Darwin and his companions were back on board the *Beagle*.

Surveys and departure[208]

On 8 October, the day Darwin landed on James, Lieutenant Sulivan and a party of men returned from surveying the central islands, having left the *Beagle* on 16 September.[209] While Darwin was on James, the *Beagle* sailed towards Chatham around the north of James and Indefatigable (Santa Cruz). At 11 am on 11 October it anchored at Fresh Water Bay on Chatham,[210] where the crew took on fresh water, wood and 30 tortoises on that afternoon and the next day.[211] Today tortoises are no longer found on this part of the island. They unmoored at 6 am on 13 October and headed towards Hood (Española) Island. On their way they surveyed Macgowen Reef. On the morning of 14 October they anchored on the north side of Hood. They then sailed off towards Charles, anchoring on the west coast at 9 pm. Here they saw an American whaler at anchor. At 5.30 the next morning they headed to Post Office Bay, anchoring at 11 am. There they stayed until 3 pm on 16 October. Although FitzRoy wrote about the post office barrel at Post Office Bay, he said it was no longer used and that letters were left at the settlement. Their next stop was at Black Beach to take on wood, potatoes and pigs. They also picked up mail from a schooner that had just arrived from Guayaquil. On the ship were cattle for the settlement. The *Beagle*, after leaving Charles, navigated up the east coast of Albemarle and at 2.30 pm on 17 October sent a boat to James Island to collect Darwin and his companions.

FitzRoy[212] stressed the danger of getting lost on islands like James. On the day they picked up Darwin from Buccaneer Cove a search was being conducted for a man missing from the American whaling ship that had supplied Darwin with fresh water less than a week earlier.[213] On 18 October the *Beagle* cruised up the northeastern coast of Albemarle. On 19 October they picked up Chaffers, who had been surveying the islands of Tower, Bindloe and Abingdon.[214] Chaffers had collected rock specimens for Darwin from these islands including fossil shells from Bindloe:[215] 'There is a steep Crater also of Volcanic Sandstone; out of which Mr Chaffers procured 3 species of shells, & saw <u>many fragments</u> of an Oyster (3292)',[216][785] At sunset on 20 October, after surveying Wenman (Wolf) and Culpepper (Darwin) Islands, they sailed out of Galápagos waters, headed for Tahiti.

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Office in Taunton, and staff at the Public Record Office in Kew for permission to examine bibliographic material. In Galápagos, we thank Eliecer Cruz, Diego Bonilla and staff of the Galápagos National Parks Service, as well as the staff of the Charles Darwin Research Station for support, encouragement and permission to follow the route Darwin took, and for transport on several occasions.

Notes

1 N. Barlow (ed.), *The autobiography of Charles Darwin, 1809–1882* (Collins, London, 1958).

2 Pearson (see note 3) has shown that while in Galápagos Darwin wrote 'a total of 109 manuscript pages on volcanic observations (in addition to field notes), and only 37 on zoology'.

3 P.N. Pearson, 'Charles Darwin on the origin and diversity of igneous rocks', *Earth Sciences Hist.* **15**, 49–67 (1996).

4 *Op. cit.*, note 3.

5 J. Browne, *Charles Darwin. Voyaging* (Princeton University Press, Princeton, NJ, USA, 1995).

6 F.J. Sulloway, 'Darwin and the Galápagos', *Biol. J. Linn. Soc.* **21**, 29–59 (1984).

7 A. Desmond and J.R. Moore, *Darwin* (Michael Joseph, London, 1992).

8 *Op. cit.*, note 6.

9 Cambridge University Library, Manuscripts Department, DAR 37.2. (folio numbers are indicated in square brackets).

10 R. FitzRoy, *Log of the Voyage of the Beagle 1831–1836* (Admiralty 53/236 Part 2. Public Record Office, Kew) (unpublished manuscript, 1831–1836). We have included in the text FitzRoy's bearings of land formations taken at anchor where the localities of those anchorages are in any way ambiguous (see note 13).

11 Darwin's original manuscripts are kept in the Darwin Archive of Cambridge University Library. We examined and obtained photocopies of his geological notes (note 9) and field notebooks (see note 145) on Galápagos. We obtained a copy of Darwin's zoological diary, section on Galápagos, from Professor Richard Keynes who was in the process of transcribing it for publication. We found Darwin's 90 pages of geological notes (note 9) particularly revealing in that they contained sketches and descriptions of unique geological formations that he examined. They have never been transcribed before. Although there is a published transcription of Darwin's Field Notebooks edited by Nora Barlow (see note 12), it is focused on the biology of the islands and we found that the original notes contained information on the geology of Galápagos that was not included in the published version. At the Hydrographic Office in Taunton we examined and made copies of the Admiralty charts of Galápagos made by Captain FitzRoy. At the Public Record Office in Kew we obtained a copy of the section in Captain FitzRoy's log of HMS *Beagle* (note 10) that pertained to Galápagos. Finally we scrutinized both Darwin's and FitzRoy's published accounts of Galápagos for more information regarding his whereabouts and descriptions of the natural history he observed.

12 N. Barlow (ed.), *Charles Darwin and the voyage of the Beagle* (Pilot Press, London, 1945).

13 In Galápagos we attempted to match descriptions in the literature with identifiable locations and geological features. In the section in Captain FitzRoy's log of HMS *Beagle* (note 10) that pertained to Galápagos, FitzRoy took compass bearings of key land formations when at anchor. For example, when the Beagle was anchored at Black Beach on Charles Island he wrote in his *Log* (note 10) that Saddle Pt was S11.10W and Round Hill (Cerro Pajas) was S73E. Using these bearings, adjusted for the change of degrees in the Earth's polarity

between 1835 and 1996, we were able to approximate the *Beagle*'s anchorage using a Global Positioning System (GPS) and compass. We took a boat to the various positions where we calculated the *Beagle* to have anchored, determined probable landing sites using Darwin's descriptions of land formations, and looked for the geological formations Darwin described. GPS observations were made at all these landing sites and geological formations. We made comparative natural history observations and assessed similarities and differences in the fauna and flora between Darwin's time and today.

14 One of us (P.R.G.) did not participate in the footstep retracing but has visited at other times all four islands and most of the sites visited by Darwin.

15 Darwin wrote (see note 16) 'We may infer…what havoc the introduction of any new beast of prey must cause in a country, before the instincts of the indigenous inhabitants have become adapted to the stranger's craft of power'. Havoc there has been, as much from herbivores as carnivores. Eleven species of mammals have now been introduced to Galápagos (H.N. Hoeck, 'Introduced fauna', in *Key environments. Galápagos* (ed. R. Perry), pp. 233–245 (Pergamon, Oxford, 1984)), and some of them, especially goats and black rats, have been responsible for extinctions of certain finch and mockingbird populations since Darwin's visit (P.R. Grant, *Ecology and evolution of Darwin's finches*, 2nd edn (Princeton University Press, Princeton, NJ, USA, 1999)).

16 C. Darwin, *Journal of Researches into the Natural History and Geology of the Countries visited during the Voyage of H.M.S. Beagle round the World*, 2nd edn (John Murray, London, 1845).

17 *Op. cit.*, note 10.

18 Captain Robert FitzRoy, *Narrative of the Surveying Voyage of His Majesty's Ships Adventure and Beagle between the years 1826–1836 describing their examination and the southern shore of South America and Beagle's Circumnavigation of the globe—in three volumes*, vol. II. (Henry Colburn, London, 1839).

19 *Op. cit.*, note 9 [758].

20 *Ibid.*

21 R.D. Keynes (ed.), *Charles Darwin's Beagle Diary* (Cambridge University Press, 1988).

22 *Op. cit.*, note 10.

23 *Op. cit.*, note 9 [758].

24 *Op. cit.*, note 21.

25 *Ibid*.

26 Darwin most likely took 'imps of darkness' from Byron (see note 18). A copy of his journal was on the *Beagle*.

27 G.A. Byron, 7th Baron, *Voyage of H.M.S. Blonde to the Sandwich Islands, in the years 1824–25*. (London, 1826).

28 While in Galápagos, Darwin and the *Beagle* crew conducted two experiments with marine iguanas (see note 32). A seaman tied a weight to one and sank it. When an hour later they drew up the line the iguana was still alive. Darwin noted that when frightened an iguana would not swim out to sea but would run away over the rocks. He repeatedly threw an iguana into the water and observed that it always swam back to the land. He surmised that its predators were marine rather than terrestrial.

29 *Op. cit.*, note 21.

30 *Op. cit.*, notes 12, 21. Also note 33.

31 *Op. cit.*, note 21.

32 C. Darwin, *Journal of Researches into the Geology and Natural History of the Various Countries Visited by H.M.S.* Beagle (Henry Colburn, London, 1839).

33 R.D. Keynes (ed.), *Charles Darwin's Diary of Observations on Zoology of the Places Visited during the Voyage in 4 volumes* (unpublished manuscript).

34 N. Barlow (ed.), *Bull. Brit. Mus. (Nat. Hist.) Historical Ser.* **2**, 201–278 (1963).

35 *Op. cit.*, note 10.

36 C. Darwin, *Geological Observations on the Volcanic Islands Visited during the Voyage of H.M.S.* Beagle. Part 2 of *The Geology of the Voyage of the* Beagle (Smith, Elder & Co., London, 1844).
37 T. Simkin, 'Geology of Galapagos Islands', in *Key environments. Galápagos* (ed. R. Perry), pp. 15–41 (Pergamon, Oxford, 1984).
38 *Op. cit.*, note 9 [749].
39 Misspellings like these have helped scholars to date Darwin's early writings: F.J. Sulloway, 'Further remarks on Darwin's spelling habits and the dating of *Beagle* voyage manuscripts', *J. Hist. Biol*. **16**, 361–390 (1983).
40 *Op. cit.*, note 21.
41 *Op. cit.*, note 9 [749].
42 *Op. cit.*, note 21.
43 *Ibid*.
44 *Op. cit.*, note 39.
45 Captain Robert FitzRoy, 'Remarks on Galápagos Islands, the NE Coast of Tierra del Fuego, and Magellan Strait—HMS *Beagle* 1835'. (A list of documents sent to the Hydrographer of the Admiralty 16 September 1846 and 14 April 1845. Sailing directions and nautical remarks referring to the coasts of South America, and the Galápagos Islands, intended to be incorporated with the directions and remarks published by the Admiralty on the authority of Captain Phillip Parker King.)
46 *Op. cit.*, note 18.
47 *Ibid.*, *op. cit.*, note 45.
48 *Op. cit.*, note 18.
49 *Op. cit.*, note 12.
50 *Op. cit.*, note 9 [757].
51 *Op. cit.*, note 9 [752].
52 *Op. cit.*, note 9 [753].
53 *Op. cit.*, note 9 [754].
54 *Op. cit.*, note 9 [731].
55 Darwin may have borrowed here from Lyell who refers to a plain in the Val del Bove as 'more uneven than the surface of the most tempestuous sea' (see note 56).
56 C. Lyell, *Principles of Geology*, 3 vols (London, 1830–33). Darwin had a copy on the *Beagle*.
57 The 'Phlegrœan fields' was most likely taken from Lyell, *op. cit*., note 56: 'Instead of inferring, from analogy, that the ancient Vesuvius was always at rest when the craters of the Phlegrœan fields were burning—that each cone rose in succession—and that many years, and often centuries of repose intervened between each eruption—geologists seem to have conjectured that the whole group sprung up from the ground at once'.
58 *Op. cit.*, note 21. See also note 98.
59 *Op. cit.*, note 9 [755].
60 *Op. cit.*, note 55.
61 *Op. cit.*, note 9 [755].
62 *Op. cit.*, note 9 [755–757].
63 *Op. cit.*, note 21.
64 *Op. cit.*, note 9 [752].
65 *Ibid*.
66 *Op. cit.*, note 21.
67 *Op. cit.*, note 12.
68 F.J. Sulloway, 'The *Beagle* collections of Darwin's Finches (Geospizinae)', *Bull. Brit. Mus. (Nat. Hist.), Zool. ser.* **43**, 49–94 (1982). There is a lack of certainty in just how many specimens Darwin collected on Chatham (and Charles and James). Other specimens were collected on this island by FitzRoy, Fuller and Covington, some of them presumably at

another locality. As many specimens of *Geospiza magnirostris* were collected on Chatham (and Charles) as any other species, yet the populations of these extremely large finches became extinct after the *Beagle* visit, for reasons unknown.

69 Sulloway, *op. cit*., note 4, p. 49.

70 B.R. Grant and P.R. Grant, 'Niche shifts and competition in Darwin's finches: *Geospiza conirostris* and congeners', *Evolution* **36,** 637–657 (1982).

71 Darwin noted that 'at least 10 species found near the cultivated ground at Charles Island, have been imported', *op. cit*., note 16.

72 C. Darwin (ed.), *The Zoology of the Voyage of H.M.S.* Beagle *Under the Command of Captain FitzRoy. Part 2. Mammalia. By George Robert Waterhouse. Part 3. Birds. By John Gould. Part 4. Fish. By Leonard Jenyns. Part 5. Reptiles. By Thomas Bell. 3 or 5 volumes.* (Smith, Elder & Co., London, 1838–43).

73 *Op. cit.*, note 10.

74 *Op. cit.*, note 18.

75 *Op. cit.*, note 71.

76 *Op. cit.*, note 18.

77 *Op. cit.*, note 45.

78 *Op. cit.*, note 16.

79 *Op. cit.*, note 21.

80 *Op. cit.*, note 18.

81 *Op. cit.*, note 21.

82 *Op. cit.*, note 18.

83 *Op. cit.*, note 21.

84 *Op. cit.*, note 9.

85 *Op. cit.*, note 9 [747].

86 *Op. cit.*, note 21.

87 *Op. cit.*, notes 6 and 68.

88 A third and final specimen was collected in 1852 by Dr Kinberg on a Swedish expedition: C.J. Sundevall, 'On birds from the Galapagos Islands', *Proc. Sci. Meetings Zool. Soc. Lond.*, pp. 124–130 (1871). That the species was once common is indicated by fossils of at least six individuals: D. Steadman, 'Holocene vertebrate fossils from Isla Floreana, Galápagos', *Smiths. Contr. Zool.* **413**, 1–103 (1986). The large form of *Geospiza magnirostris*, now extinct (see note 68), was apparently the most abundant finch species on the island according to the fossil evidence (229 individuals).

89 *Op. cit.*, note 21.

90 *Op. cit.*, note 18.

91 *Op. cit.*, note 33.

92 In his Ornithological Notes, *op. cit*., note 34, Darwin states 'When I recollect, the fact that the form of the body, shape of scales & general size, the Spaniards can at once pronounce, from which Island any Tortoise may have been brought. When I see these Islands in sight of each other, & possessed of but a scanty stock of animals, tenanted by these birds, but slightly differing in structure & filling the same place in Nature, I must suspect they are only varieties…. If there is the slightest foundation for these remarks the zoology of Archipelagoes—will be well worth examining; for such facts undermine the stability of Species'.

93 *Op. cit.*, note 32.

94 *Op. cit.*, note 9 [748].

95 *Op. cit.*, note 36.

96 *Op. cit.*, note 9 [732].

97 *Ibid*.

98 In *Volcanic Islands*, *op. cit*., note 36, Darwin writes that 'One of the officers gave me some fragments of shells, which he found embedded several hundred feet above the sea, in the tuff of two craters, distant from each other'. These specimens are regarded as the first palaeontological record from the Galápagos Islands: see Jere H. Lipps and C.S. Hickman, 'History of Galapagos geology: Darwin's lost Galapagos fossils', *Geol. Soc. Am., Prog. with Abstracts*, v. **22** (1990). Although Darwin does not specify the name of the officer or the location of the craters in *Volcanic Islands*, *op. cit*., note 36, it is clear from Darwin's geological notes (*op. cit*., note 9) that the officer in question was the master of the *Beagle*, Edward Main Chaffers, and that one of the two craters was Champion island [732, 748], the other being one on Bindloe (Marchena) Island [718, 784–785].
99 *Op. cit.*, note 9 [732–733].
100 *Op. cit.*, note 36.
101 R.L. Curry, 'Whatever happened to the Floreana Mockingbird?', *Noticias de Galápagos* **43**, 13–15 (1986). Had this most distinctive species disappeared before 1835, Darwin would have had much less reason to add mockingbirds to the tortoises as evidence for the geographical replacement of similar species.
102 *Op. cit.*, note 18.
103 *Op. cit.*, note 9 [760, 788–789].
104 *Op. cit.*, note 9 [788–789].
105 *Op. cit.*, note 36.
106 *Op. cit.*, note 9 [789].
107 *Op. cit.*, note 9 [790].
108 In *Volcanic Islands*, *op. cit*., note 36, Darwin describes the cones at Ascension: 'The greater number of them had their truncated summits cut off obliquely, and they all sloped towards the S.E., whence the trade-wind blows. This structure no doubt has been caused, by the ejected fragments and ashes being always blown, during eruptions, in greater quantity towards one side, than towards the other.' And in the Galápagos 'this same power might here, also, aid in making the windward and exposed sides of some of the craters, originally the lowest'.
109 *Op. cit.*, note 10.
110 *Op. cit.*, note 18.
111 *Ibid*.
112 *Op. cit.*, note 21.
113 *Ibid*.
114 *Op. cit.*, note 9 [759].
115 *Op. cit.*, note 9 [744–745].
116 *Op. cit.*, note 9 [759].
117 *The correspondence of Charles Darwin*, vol. 6, *1856–1857* (Cambridge University Press, 1990).
118 *Op. cit.*, notes 10 and 18.
119 *Op. cit.*, note 9.
120 *Op. cit.*, note 9 [745].
121 *Op. cit.*, note 21.
122 *Ibid*.
123 *Op. cit.*, note 9 [734].
124 *Op. cit.*, note 9 [761].
125 P.H. Barret, P.J. Gautrey, S. Herbert, D. Kohn and S. Smith (eds), *Charles Darwin's Notebooks, 1836–1844* (Cambridge: British Museum (Natural History)/Cambridge University Press, 1987).
126 *Op. cit.*, note 9 [762].
127 *The correspondence of Charles Darwin*, vol. 4, *1847–1850* (Cambridge University Press, 1988).
128 *Op. cit.*, note 9 [762].

129 *Op. cit.*, note 9.
130 *Op. cit.*, note 9 [763].
131 *Op. cit.*, note 9 [766].
132 *Op. cit.*, note 9 [745].
133 *Op. cit.*, note 9 [763].
134 *Op. cit.*, note 9.
135 *Op. cit.*, note 39.
136 *Op. cit.*, note 9 [768].
137 *Ibid*.
138 Darwin may have borrowed from Byron, *op. cit*., note 27: 'As far as the eye could reach we saw nothing but rough fields of lava, that seemed to have hardened while the force of the wind had been rippling its liquid surface. In some places we could fancy the fiery sea had been only gently agitated; in others, it seemed as if it had been swept into huge waves'.
139 *Op. cit.*, note 9 [769].
140 *Op. cit.*, note 32.
141 *Op. cit.*, note 26.
142 *Op. cit.*, note 21.
143 *Ibid*.
144 This is only one of only two references to finches made by Darwin in the *Diary*, *op. cit*., note 21, and field notebooks (see note 145).
145 C. Darwin, Down House Notebook 1.17 (field notebooks 1831–36).
146 Darwin called it 'Freshwater Cove of the Buccaniers' in the *Diary*, *op. cit*., note 21, and 'Fresh-water Bay' in *Volcanic Islands*, *op. cit*., note 36. We refer to it as Buccaneer Cove, as it is now called, to avoid confusion with Fresh Water Bay on Chatham Island.
147 It is unclear whether four or five people left the *Beagle* to camp on James. According to Darwin 'Myself, Mr. Bynoe & three men were landed…', *op. cit*., note 21. FitzRoy says Darwin 'was landed, accompanied by Mr. Bynoe, besides his servant and H. Fuller…', *op. cit*., note 18.
148 *Op. cit.*, note 21.
149 *Op. cit.*, note 12.
150 *Op. cit.*, note 144.
151 *Op. cit.*, note 33.
152 *Op. cit.*, note 21.
153 *Op. cit.*, note 18.
154 *Op. cit.*, note 21.
155 *Op. cit.*, note 45.
156 *Op. cit.*, notes 12 and 21.
157 *Op. cit.*, note 21.
158 *Op. cit.*, note 9 [770].
159 *Op. cit.*, note 9 [718].
160 It has been established by McBirney and Williams (see note 161), and Pearson, *op. cit*., note 3, that Darwin's observations on crystals embedded in rock on James helped him to develop and substantiate the theory of magmatic differentiation through gravity settling.
161 A.R. McBirney and H. Williams, 'Geology and petrology of the Galápagos Islands', *Geol. Soc. Am. Memoir,* **118** (1969).
162 *Op. cit.*, notes 9 and 36.
163 *Op. cit.*, note 9 [720].
164 *Op. cit.*, note 9 [720–721].
165 *Op. cit.*, note 9 [721].
166 *Op. cit.*, note 160.
167 *Op. cit.*, note 9 [773].
168 *Op. cit.*, note 9 [772].

169 *Op. cit.*, note 9 [778].
170 *Ibid.*
171 *Op. cit.*, note 21.
172 *Op. cit.*, note 39.
173 *Op. cit.*, note 21.
174 *Ibid.*
175 *Op. cit.*, note 145.
176 *Ibid.*
177 *Op. cit.*, note 32.
178 At Jaboncillos, the only *Scalesia* trees are growing in fenced enclosures. Goat destruction of *Scalesia* is probably the main reason why *Camarhynchus psittacula* (large tree finch) is now apparently very scarce, whereas in Darwin's day it must have been fairly common, as there are as many specimens from James in the *Beagle* collection (5) as there are of any other finch species (five each for *Geospiza scandens* and *G. fuliginosa*). Of the seven finch species collected by members of the *Beagle* on this island it is the only one we did not see in retracing Darwin's visit and on two other visits to the highlands.
179 *Op. cit.*, note 21.
180 *Op. cit.*, note 9 [770].
181 Dr Sandra Herbert has pointed out to us that an expedition (see note 161) to Galápagos in 1964 was unable to find a representative of one of these specimens (No. 3268) on James. We believe that Darwin most likely collected this specimen from the vicinity of the crater at Jaboncillos in the highlands of James and this needs to be verified.
182 *Op. cit.*, notes 9 [770] and 160.
183 Darwin also mentions finding this bird on Charles, *op. cit*., note 33. According to Castro (see note 184), *Laterallus spilonotus* has not been reported from Charles since 1983. However, since her publication, there have been sightings of this bird on Charles reported to the Charles Darwin Research Station.
184 I. Castro and A. Phillips, *A guide to the birds of the Galápagos Islands* (Princeton University Press, Princeton, NJ, USA, 1996).
185 *Op. cit.*, note 33.
186 *Op. cit.*, note 21.
187 *Op. cit.*, note 9 [779].
188 *Op. cit.*, note 9 [780].
189 *Op. cit.*, note 9 [779–780].
190 *Op. cit.*, note 9 [780].
191 *Ibid.*
192 *Ibid.*
193 *Op. cit.*, note 9 [723].
194 *Op. cit.*, note 21.
195 *Op. cit.*, note 9 [783].
196 *Ibid.*
197 *Op. cit.*, note 21.
198 *Op. cit.*, note 10.
199 *Op. cit.*, note 9 [784].
200 *Op. cit.*, note 9.
201 *Op. cit.*, note 9 [783].
202 *Ibid.*
203 *Op. cit.*, note 33.
204 The number of finch specimens assembled by the four *Beagle* collectors—Darwin, FitzRoy, Covington and Fuller—was fairly uniform at one to five per species per island (Chatham, Charles and James) (see note 68). Darwin's own collecting appears to have been consistent with the others' in this regard. This suggests that finches were collected systematically for

variety and not in ignorance of the different types. In fact the only ones missing altogether from the collection that might have been collected in view of the itineraries of the collectors were species that are largely restricted to medium or high elevations; *Camarhynchus pauper* and possibly *C. parvulus* and *C. psittacula* from Charles, and *Cactospiza pallida* on James. Darwin's own collection was the most diverse, comprising all nine of the currently recognized species that were collected. It is possible, however, that some were given to him by Syms Covington, his personal assistant; and uncertainties about the localities must be stressed (see note 68).

205 *Op. cit.*, note 145.

206 *Op. cit.*, note 21.

207 We also measured similar sand and air temperatures, and similar sea temperatures. From 99 measurements in the weather journal kept on board the *Beagle*, the mean temperature of the sea in Galápagos was 68 ºF. These measurements were taken daily at 8 am, noon and 8 pm, from 16 September to 20 October when the *Beagle* was either at anchor or moving from island to island. The lowest temperature measured was 58.5 ºF, at the southwest extremity of Albemarle Island. We took 15 sea temperature measurements at Darwin's landing sites and anchorages and they ranged from 63 to 72.5 ºF, with a mean of 69.3.

208 *Op. cit.*, notes 10 and 18.

209 Lieutenant Sulivan surveyed Sulivan Bay (named after him by Captain FitzRoy) on James Island. The coastline in FitzRoy's map agrees with today's coastline. This brings into question the age of the lava flow that surrounds the 'kipukas' or isolated hills in Sulivan Bay. It is generally thought that the lava flow is only 100 years old, dating from 1897 when a flank eruption was observed on the southern side of James by members of a scientific expedition led by Charles Miller Harris; see A.F. Richards, *Archipélago de Colon* [*Archipiélago de Colón*]*, Isla San Felix and Islas Juan Fernández. Catalog of Active Volcanoes of the World 14.* 50 pp. (IAVCEI, Rome, 1962). However, FitzRoy's charts suggest that the lava flow that forms the coastline is over 165 years old and the more recent eruption, while it may have caused lava to flow over the earlier flow, did not change the shape of the coastline.

210 *Op. cit.*, note 10.

211 *Op. cit.*, notes 10 and 18.

212 *Op. cit.*, notes 18 and 45.

213 *Op. cit.*, note 18.

214 Out of a total of five specimens of *Geospiza scandens* from James two are large enough to have been thought referable to the distinctive form of this species on Bindloe (Marchena; also Abingdon = Pinta), and to have arrived as 'stragglers' (see note 6). The proportion is extraordinarily high in view of the distance from Bindloe (*ca*. 40 km) and the exceptionally low (current) population of the species on that island. Another possibility is that they were collected by someone in the cactus just behind the beach on Abingdon when the *Beagle* picked up Chaffers from his surveying boat: the last opportunity to collect terrestrial bird specimens before leaving Galápagos.

215 *Op. cit.*, note 98.

216 *Op. cit.*, note 9 [785].

INTO THE FIELD AGAIN: RE-EXAMINING CHARLES DARWIN'S 1835 GEOLOGICAL WORK ON ISLA SANTIAGO (JAMES ISLAND) IN THE GALÁPAGOS ARCHIPELAGO[1]

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ABSTRACT

In 1835 Charles Darwin's geological observations on Isla Santiago (James Island) in the Galápagos Islands led him to important insights as to the process by which different varieties of igneous rock might be produced from the same volcanic vent. His work figured in a tradition of interpretation that began with the work of George Poulett Scrope and would end in the twentieth century with the theory of magmatic differentiation of igneous rocks through the process of crystal fractionation. This article reports on the findings of an expedition to Isla Santiago in July 2007 during which we were able to locate samples of igneous rocks similar to those collected by Darwin. We have used these, together with Darwin's original specimens and transcriptions of his field notes, to examine how his understanding of the separation of the trachytic and basaltic series of magmas developed from his initial field observations through to publication of *Volcanic Islands* in 1844.

The mere fact that someone has expressed his thoughts in writing, and that we possess his works, does not enable us to understand his thoughts. In order that we may be able to do so, we must come to the reading of them prepared with an experience sufficiently like his own to make those thoughts organic to it (Collingwood 1962, p. 300).

1. INTRODUCTION

While his work on evolution made him famous, Charles Darwin (1809–1882) contributed to disciplines across a broad spectrum of the natural sciences, including geology (e.g. Herbert 2005). This was particularly true during his service as an unpaid naturalist aboard H. M. S.

[1] The island that is now most commonly called Isla Santiago was known to Darwin as James Island. Another current name for the island is Isla San Salvador.

Beagle (1831–1836). Darwin's collection of fossil mammals from South America received immediate attention from Richard Owen (1804–1892), formed the basis of volume one of *Zoology* from the voyage (Darwin 1840), and contributed to his argument for *Origin of Species* (Herbert 2005, pp. 320–325; Herbert and Norman 2008). His theory of the origin and distribution of coral reefs, which was presented to the Geological Society of London soon after arriving back in England, became the foundation of the first (Darwin 1842) of three books on geology stemming from the *Beagle* voyage. The importance of the remaining two books is less widely appreciated, despite the efforts of Judd (Darwin 1890). The first (Darwin 1844) focused on volcanic islands, while the second (Darwin 1846) summarised the geology of South America. While writing these latter works Darwin had an increasing sense of working in isolation because his deteriorating health meant that he was no longer able to take such an active role in the Geological Society. While writing *Volcanic Islands* he wrote to Charles Lyell (1797–1875): "I hope you will read my volume for if you don't I cannot think of anyone else who will!—".[2] Later he complained to a friend, from his university days, as he was finishing up his geology of South America:

> As for your pretending that you will read anything so dull as my pure geological descriptions lay not such a flattering unction on my soul, for it is incredible—I have long discovered that geologists never read each others works, & that the only object in writing a Book is a proof of earnestness & that you do not form your opinions without undergoing labour of some kind. Geology is at present very oral, & what I say here is to a great extent quite true. But I am giving you a discussion as long as a Chap[r]. in the odious Book itself.[3]

Darwin's assessment of the probable fate of his forthcoming books was exaggerated for effect, but he had a point. *Volcanic Islands* and *Geological Observations on South America* received nothing like the spirited reception of his earlier volumes. Geological ideas were promoted by active debate, and Darwin was no longer regularly present at the Society's meetings to press his case.[4] Since he was a private author, he did not have ready access to followers or students who might promote his ideas and relied instead on his friendship with senior figures in the geological community at large.[5] While admittedly of lesser influence than some of his other works these volumes do, however, deserve attention. Darwin's *Beagle* collections inform and play off each other, such that it is necessary to consider all of the parts in order to gather a sense of the overall enterprise of the voyage. Equally of interest is the insight this provides of Darwin's approach to scientific investigation: how he went about his work in the field, integrated his observations with his collections as he wrote up his field notes, and then moved towards formal publication.

This article focuses on one section of Chapter 6 of *Volcanic Islands* where, under the heading of 'Trachyte and Basalt', Darwin wrote what now seems to be a prescient discussion of aspects of twentieth-century theory regarding the origin of the diversity of igneous rocks. He described how the density difference between crystals and their surrounding melt might account for magmas of different compositions "within the body of the volcanic mountain".

> Lavas are chiefly composed of three varieties of feldspar, varying in specific gravity from 2.4 to 2.74; of hornblende and augite, varying from 3.0 to 3.4; of olivine, varying from 3.3 to 3.4; and lastly, of oxides of iron, with specific gravities from 4.8 to 5.2. Hence crystals of feldspar, enveloped in a mass of liquified, but not highly vesicular lava, would tend to rise to the upper

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2 CD to Charles Lyell, 15 or 22 September 1843, in Burkhardt *et al.* (1985, vol. 2, p. 389).

3 CD to John Maurice Herbert, 3 September [?] 1846 in Burkhardt *et al.* (1985, vol. 3, p. 338.)

4 On the spirited meetings of the Geological Society during this period see Thackray (2003).

5 The geologist John W. Judd [1840–1916], who was Darwin's geological confidant in later life, might be an exception on this point.

> parts; and crystals or granules of the other minerals, thus enveloped, would tend to sink. We ought not, however, to expect any perfect degree of separation in such viscid materials (Darwin 1844, p. 120).

The concept of vesicularity was of importance to Darwin[6] as he believed that this would decrease the overall density of magma and permit the separation by gravity of different phases (*e.g.* feldspars would normally be less dense than the surrounding basaltic magma). He proposed that, from a single volcano, low-density trachytic magma would be erupted from the upper parts of the 'volcanic focus' (edifice). He further suggested that during later eruptions the lower flanks would be 'enveloped by basaltic streams' and that at some volcanoes fluid basaltic magma may be the only eruptive product. Darwin's theory proposed that basalt and trachyte might be erupted more or less contemporaneously from the same volcano. This was in strong contrast with those who associated the formation of trachyte with an earlier period in the Earth's history than the current one in which they believed basaltic magmas form, *e.g.* Alexander von Humboldt (1769–1859). Nevertheless, it was consistent with the views of scientists such as Lyell, George Poulett Scrope (1797–1876) and James Hutton (1726–1797) who believed that the diversity of volcanic rocks was caused by processes operating within and on the Earth, rather than as characteristic of successive parts of its geological history. Scrope (1825), however, believed that basalt and trachyte were both derived from an original granitic source, and that heat and pressure were important in generating the different magma types.

Graham Chinner (formerly Curator of Mineralogy and Petrology at the Sedgwick Museum) emphasized such points in an exhibit of Darwin's geological specimens on display in the Department of Earth Sciences at the University of Cambridge from 1991 until the present. Part of the text notes that "feldspar crystals in porphyritic glassy basalts were concentrated in the lower portions of lava flows. From the density and viscosity data available at the time he showed that the sinking of crystals in basaltic liquid was feasible and suggested it as a mechanism for differentiating trachyte from basalt." Paul Pearson (1996) likewise drew attention to Darwin's interest in the subject and his fieldwork on Isla Santiago in 1835:

> As Darwin rightly suspected, a molten rock is a complex mixture of chemicals in which, over an appreciable temperature range, particular components aggregate into crystals while the remainder stays fluid . . . . Although he did not explicitly make the point such incomplete crystallization amounts to chemical segregation. . . . This phenomenon was the first clue to the problem of the differentiation of the lava. . . . (Pearson 1996, p. 58).

Supplementing Pearson's account, Davis Young has provided the most extensive treatment to date of the context of Darwin's ideas on the differentiation of igneous rocks, which builds on the early and still valuable study of Joseph Paxson Iddings (1857–1920) (Young 2003, Chapter 8; Iddings 1892).

Chinner, Pearson, and Young did not have an opportunity to visit Isla Santiago to see for themselves where Darwin made his observations and collected samples. Two igneous petrologists who did were Alexander R. McBirney and Howel Williams, who travelled in the Galápagos Islands from 19 January to 28 February 1964 as part of the Galápagos International Science Project. Their published study focused on the geology of many of the islands in the archipelago and included maps, detailed petrological descriptions and major-element whole-rock analyses of numerous samples (McBirney and Williams 1969). Darwin's *Volcanic Islands* was a standard reference point in their treatment, although they did not have access to his specimen notebooks or his extensive field notes. But McBirney

6 In addition to the term 'vesicular', Darwin often used the word 'cellular' in his notes.

and Williams did have available a set of petrological descriptions of Darwin's specimens by Constance Richardson (Sister Constance S.S.P. 1907–1989: see Figure 1).[7] She had drawn particular attention to the presence of a sodium-rich trachyte from Isla Santiago, an unusual rock given the generally basaltic nature of other samples from the island; this rock bore Darwin's specimen number CD3268:

> The soda trachyte [3268] from James Island is compact, greenish-grey with a few small crystals of feldspar visible to the naked eye. A thin section shows abundant phenocrysts of feldspar, a few of augite, and also occasionally hornblende, olivine and magnetite set in a trachytic ground mass (Richardson 1933, p. 46).

Figure 1.
Constance Richardson (Sister Constance S.S.P. 1907–1989) who published the first detailed descriptions of thin sections of Darwin's samples from Isla Santiago. While at the University of Cambridge, Richardson served as President of the Sedgwick Club, an organization composed of undergraduates and staff members, and which at that time required members to be elected. Richardson received a first class degree in geology. (Image by courtesy of D. Simons.)

McBirney and Williams attempted to locate the outcrop of this distinctive rock during their fieldwork on Isla Santiago:

> Special effort was made to find the soda trachyte reportedly collected by Darwin from James Island and carefully described by Richardson (1933), but we found nothing remotely resembling this unusual rock. Dr S. O. Agrell furnished us with a thin section of Darwin's specimen, now in the Sedgwick Museum, Cambridge, and this is almost identical with the specimen meticulously described by Richardson. It is, however, quite unlike any rock we found in the entire archipelago; hence, until the presence of trachyte on James Island is confirmed, we cannot exclude the possibility that the specimen described by Richardson was erroneously included in Darwin's collection (McBirney and Williams 1969, p. 54).

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[7] Richardson studied geology at the University of Cambridge at a time when Alfred C. Harker (1859–1939) held the readership in petrology and where Cecil E. Tilley (1894–1973), another distinguished petrologist, was a member of academic staff. From 1927 to 1932, Richardson was a student at Newnham College (Cambridge), which nourished the careers of several women in geology (see Burek 2007). After leaving the University, following a year at Bryn Mawr College in the USA, Richardson taught science in a series of schools; and in 1958 she entered a religious order. The analysis of Darwin's Galápagos rocks is her only publication known to us.

Since McBirney and Williams' observations did not dovetail with Richardson's descriptions of what were believed to be Darwin's specimens from Isla Santiago, there was an obvious anomaly to be addressed. This was significant since Darwin's field work and notes on Isla Santiago prompted him to speculate about the process whereby trachytes and basalts could be produced from the same 'orifice' [vent] (Darwin 1844, p. 120).

The processes by which basalt and trachyte are related are of much more than provincial interest. As detailed above, Darwin used 'trachyte' more generically than petrologists do today; his use included any feldspar-rich intermediate rock, including andesite.[8] The origin of andesite, and the basalt–andesite association, has been one of the most important problems faced by the science of petrology for the past 200 years.[9] Despite the fact that basalt is by far the most frequently erupted lava on Earth, the continental crust has an average composition of andesite, and andesitic magmatism has been the primary mode of continental growth for most of Earth's 4.6 billion year history. Darwin's interpretations were mostly correct: the two subsequent centuries of scientific study have generally concluded that crystal–liquid differentiation is the most important mechanism for the genesis of andesite and trachyte from a melt of basaltic composition. However, as Pearson (1996, p. 51) cautioned, it is "doubtful whether his ideas influenced the subsequent development of the science". Although this is probably too strong a statement, it is clear that Darwin's career bent in a different direction after the mid-1840s, and he was not sufficiently active in the field of petrology to control its direction. His ideas are cited in the nineteenth-century literature, but they are not the driving force.

One of the main questions that we have attempted to address is: are there true trachytes on Isla Santiago? It is clear from Darwin's field notes from *Isla Santiago* and his descriptions of the same rocks in *Volcanic Islands* that there are discrepancies with his use of the terms basalt and trachyte. If Darwin had been mistaken as to the identity of the rocks on the island the strength of his conclusions would be undermined.

2. DARWIN'S VISIT TO ISLA SANTIAGO

While in Lima on August 12th, 1835 Darwin wrote a letter to John Stevens Henslow (1796–1861), his mentor at Cambridge, in which he stated that:

> In a few days time the Beagle will sail for the Galapagos Islands. Is^{ds}.— I look forward with joy and & interest to this, both as being somewhat nearer to England and & for the sake of having a good look at an active Volcano. Although we have seen Lava in abundance, I have never yet beheld the Crater.— (Burkhardt *et al.* 1985, vol. 1, p. 461.

Darwin's expectations of seeing an active volcano in the Galápagos archipelago (see Figure 2) were not realized: the only activity that he reported was a small jet of steam from a crater on Isla Isabela (Albemarle Island, Keynes 1988, p. 338). Nevertheless, during his time in the archipelago, Darwin made important observations on volcanic rocks. Of particular significance were the field observations that he made during the ten days (8–17 October) that he spent in the west of Isla Santiago.

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8 Andesites are the common type of magma erupted by volcanoes at subduction zones whereas trachytes are commonly found in intra-plate volcanic settings, such as ocean-islands and continental rifts.

9 Darwin first encountered the term 'andesite' on his return from the *Beagle* voyage (von Buch 1836, p. 464). He did not employ the term in *Volcanic Islands* but used it routinely in *Geological Observations on South America* (Darwin 1846). See also Wyatt (1986, p. 11), and Young (2003, p. 109).

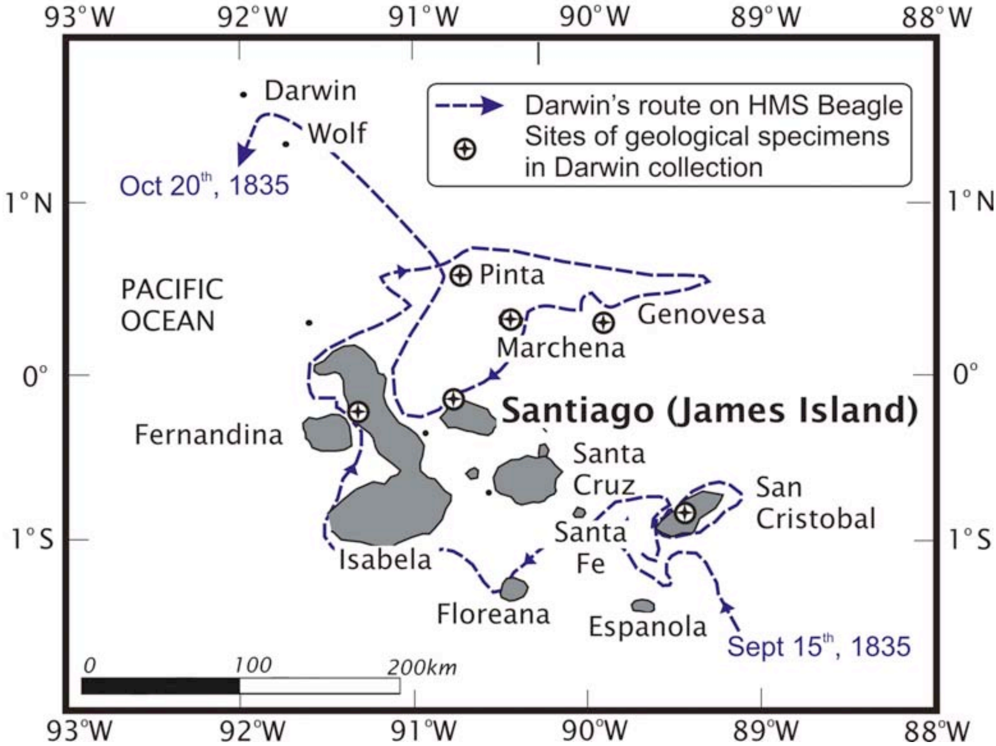

Figure 2. Map of the Galápagos illustrating the location of Isla Santiago and the route of HMS Beagle *(after Estes, Grant and Grant 2000). Sites of geological samples in the Darwin collection at the Sedgwick Museum are shown for reference. Darwin collected rock samples from: Chatham Island (San Cristobal) and Albemarle Island (Isabela). Additional samples were collected by Mr Edward Chaffers (dates unknown), Master of the* Beagle, *from Bindloe Island (Marchena), Abingdon Island (Pinta), and Tower Island (Genovesa) while Darwin was on Isla Santiago. (Figure prepared by S. A. Gibson.)*

Darwin's notes indicate that a party of four or five men landed at Buccaneer Cove on the west coast of Isla Santiago (see Figure 3) in the late morning of 8 October and left in the early afternoon on 17 October 1835. The party included Darwin, his servant Syms Covington (1816?–18661), the *Beagle*'s surgeon Benjamin Bynoe (1804–1865), the surgeon's assistant H. Fuller (dates unknown), and possibly one other man. Table 1 shows a summary of Darwin's activities on the island. His field equipment during the *Beagle* voyage included a two to three pound field hammer, lenses, a contact goniometer, acid bottles, and at least one blowpipe used for geochemical study.[10]

Some of Darwin's biological specimens were preserved in spirits in jars, with metal tags on which numbers were stamped. Dry specimens had paper labels on which a second series of numbers were printed (Keynes 2000, p. 317). Because his numbering related to type of storage, geological specimens were interspersed with other materials that were also stored dry. In his field notes, Darwin used broad terminology as well as physical qualities (hardness, colour and texture) to describe the rocks that he encountered (Harker 1907). From early in the voyage he noted the appearance of the volcanic rocks, such as whether they were 'cellular' or 'vesicular', and also the abundance and grain size of any feldspar that was

[10] On Darwin's recommended field equipment see Darwin (1849). Also see Judd (1909) and Herbert (2005, Chapter 3).

present (DAR 32.1:22v and 27v). He also recorded his on-the-spot observations in telegraphic style in field notebooks, and sometimes in loose notes, and wrote a more formal diary of his geological observations some time later. We assume that, as a general practice, the specimens were numbered sequentially in the same order that they were collected.

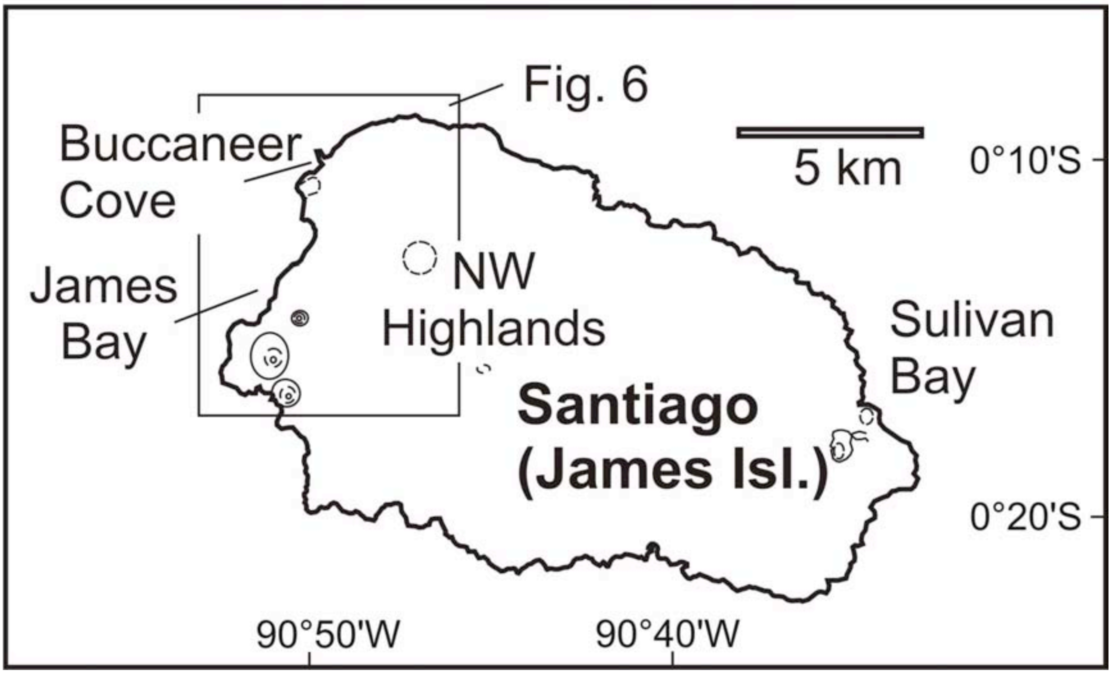

Figure 3. Simplified map of Isla Santiago showing some of the locations mentioned in the text and sites of the largest craters. (Figure prepared by S. A. Gibson.)

2.1. Darwin's geological specimens from Isla Santiago

Darwin collected a total of nineteen geological specimens from Isla Santiago, which are labelled CD3265 to CD3283, consecutively. These are bracketed by Specimen 3264, described as 'Gorgonia', and specimen 3284 described as 'Cactus. Flower yellow' (Geological Specimen Notebook [DAR 236]; Keynes 2000, p. 423). The geological specimens listed for Isla Santiago formed a small portion of the nearly 2,000 geological specimens Darwin collected on the voyage, the majority of which are presently housed at the Sedgwick Museum of Earth Sciences in Cambridge.[11] Of the original nineteen geological specimens collected by Darwin on Isla Santiago, eighteen are currently stored at the Museum and one specimen (3274) is missing. It was catalogued by the Cambridge petrologist Alfred Harker but was not mentioned in his thin-section list or in the work of Richardson (1933).

[11] Harker (1907, p. 102) used the figure of 2,000. The most recent inventory at the Sedgwick Museum recorded 1371 (of 1930) specimens in the collection (Hide 2007). The number given in Herbert (2005, p. 99) is incorrect. The Harker Catalogue of geological specimens (Harker *ca* 1907) is available online at www.darwin-online.org.uk, as is *Volcanic Islands* (Darwin 1844) and DAR 37.2, which contains Darwin's geological field notes from the Galápagos Islands. The transcription of DAR 37.2 was done by Thalia Grant and read by other members of the team.

Table 1. Summary of Darwin's visit to James Island between 8 and 17 October 1835. The quoted remarks are taken from Darwin's Diary (Keynes 1988, pp. 360–363).

Date (1835)	Location on James Island	Darwin's geological sample numbers
8 October	Landed at Buccaneer Cove. "We pitched our tents in a small valley a little way from the Beach.— The little Bay was formed by two old Craters: in this island as in all the others the mouths from which the Lavas have flowed are thickly studded over the country."	
9 October	"Taking with us a guide we proceeded into the interior & higher parts of the Island, where there was a small party employed in hunting the Tortoise.— Our walk was a long one.— At about six miles distance & an elevation of perhaps 2000 ft the country begins to show a green color.— Here there are a couple of hovels where the men reside.—. . . About 2 miles from the Hovels & probably at an additional 1000 ft elevation, the Springs are situated."	CD3265–CD3279
10 October	Darwin wrote the notes contained in DAR 37.2:716–723 on his samples CD 3265 to CD 3279.	
11 October	"The Mayór-domo took us in his boat to the Salina which is situated about 6 miles down the coast.— We crossed a bare & apparently recent stream of Lava which had flowed round an ancient but very perfect Crater.— At the bottom of this Crater is a Lake, which is only 3 or 4 inches deep & lies on layers of pure & beautifully Crystallized Salt." Darwin recorded his findings on samples CD 3280 through CD 3283 in a note dated 11 October (DAR 37.2:723.)	CD3280, CD3281, D3282, CD3283
12 October to 13 October	"On the 12th I paid a second visit to the houses [the 'hovels' in the highlands], bringing with me a blanket bag to sleep in.— I thus enjoyed two days collecting in the fertile region.—"	
14 October to 16 October	"During the last two days, the Thermometer within the Tents has stood for some hours at 93°.—"	
17 October	"In the afternoon the Beagle sent in her boats to take us on board.—"	

Darwin's geological specimens from Isla Santiago include four unconsolidated "volcanic sandstones" (now referred to as tuffs; CD3276, 3277, 3282, 3283) that are stored in specimen jars. The remaining fourteen specimens are rock samples collected from lava flows and dykes. The majority of Darwin's geological specimens were collected at Buccaneer Cove. These are numbered sequentially from CD3269 to CD3279 (Table 2). We believe that they are from the promontory and north end of the beach. The remaining samples were collected during Darwin's trek into the Highlands (CD3265 to 3268) and from a boat trip to James Bay (CD3280–3283). In Darwin's notes from Isla Santiago he refers to a specimen with red earthy spots as 3299 but this is almost certainly a mistake and should read 3279.

Table 2. Summary of petrological descriptions of Darwin's geological samples from Isla Santiago.

1. SE traverse from Buccaneer Cove to Cerro Pelado

Darwin no. (Harker no. in brackets)	Equivalent sample (this work)	Darwin's description in his specimen notebook (abbreviated)	Richardson description (substantially abbreviated)	Description of sample location (Darwin [1835] in italics; and this work)	Description and classification (this work)
CD3265 (32575)	**07DSG56** S0°10.737' W90°48.704'	Base. Blackish grey (few Felspar Cryst) with Olivine rare	Basalt with zoned feldspar phenocrysts of basic labradorite (An_{79-60}, p. 53). Few phenocrysts of pale-greenish augite & colourless olivine.	*Inland, beyond the influence of the sandstone craters.* Crater 1 (300m)	Vesicular, **basalt** flow containing large, rounded, strongly zoned and smaller lath-shaped plagioclase feldspars together with round olivines.
CD3266 (32576)	**07DSG55** S0°11.294' W90°48.042'	Trachytic. cellular lava frequent large Cryst of glassy Feldspar; commonest kind	Differs from 3265 in containing no augite and larger proportion olivine (p. 53)	*Inland, beyond the influence of the sandstone craters.* Flows occur below 200m and also emanate from Crater 2 (500m)	Dark grey, vesicular **basalt** containing large rounded feldspar phenocrysts, olivine and clinopyroxene set in a fine-grained groundmass.
	07DSG53			NW Highlands near Crater 3 (Cerro Roja, >600m)	Dark and non vesicular. Exhibits a flow texture. A few phenocrysts (2mm in length) of plagioclase feldspar (An_{66-35}), olivine (Fo_{75-66}) and clinopyroxene (diopside). **Trachybasalt**
CD3267 (4730, 6865, 32522)	**07DSG51**	Olivine do [ditto—i.e. as 3266] with few glassy Cryst	Blue-green **Oligoclase Andesite** (p. 48). Plagioclase feldspar (oligoclase, An_{28}), augite, brown hornblende, olivine (not obviously fayalitic)	NW Highlands near Crater 3 (Cerro Roja, >600m)	**Trachyandesite**
CD3268 (6204, 6866)	**07DSG42**	Compact greenish grey Lava with many small Cry of glassy Fels	Soda trachyte, compact greenish-grey with small crystals of feldspar (zoned from potash-oligoclase to anorthoclase) visible to the naked eye (pp. 46–47). Phenocrysts of augite, blue-green and also brown hornblende (cossyrite) together with yellow fayalitic olivine. Aegirine-augite present in the groundmass.	NW Highlands (860m) Cerro Pelado	Grey-green colour. Mainly sodic plagioclase and alkali feldspar (Andesine–Anorthoclase, An_{34-13}), yellow fayalitic olivine (Fo_{20}), a blue-green (Ferro-edenite) and also a brown amphibole **Trachyte**
	07DSG40, **41**, **45** S0°12.408' W90°46.905'			NW Highlands near Crater 3 (Cerro Roja, >600m) NW Highlands (860m) Cerro Pelado	Green colouration and non-vesicular. Few feldspar phenocrysts (3 mm in length). Abundant alkali feldspar (Sanidine to Anorthoclase), some blue-green amphibole (Ferro-edenite) and minor olivine. **Trachyte.**

2. Buccaneer Cove

Darwin no. (Harker no. in brackets)	**Equivalent sample (this work)**	**Darwin's description in his specimen notebook (abbreviated)**	**Richardson's description (substantially abbreviated)**	**Description of sample location (Darwin [1835] in italics; and this work)**	**Description and classification (this work)**
	07DSG26b S0°10.033' W90°49.567'			Buccaneer Cove	Fresh Olivine Gabbro xenolith in basalt. Xenolith contains abundant cumulus olivine, olivine (Fo83), intercumulus zoned plagioclase feldspar (Bytownite-Labradorite, An75–62) and clinopyroxene (diopside)
CD3269 (6867 [loc?] 32583)	**07DSG01** **S0º10.033'** **W90º49.567'**	Finely & much cellular Trachyte with much Cryst Gl. Fracture Feld. Outer surface. Red glossy Scoria	Porphyritic scoriaceous olivine-basalt [loc?] Porphyritic vesicular olivine basalt with xenolith	Thin lava flow in red scoria. 'Layer cake' (Estes, Grant and Grant, 2000), Buccaneer Cove	Vesicular **Basalt** bearing xenoliths of gabbro together with large crystals of olivine, clinopyroxene, plagioclase feldspar and an opaque oxide
	07DSG26d S0°10.033' W90°49.567'			Buccaneer Cove	**Leucogabbro** predominantly consisting of plagioclase feldspar (Bytownite–Labradorite, $An_{72–54}$) with clinopyroxene (augite) and olivine (Fo_{77}).
CD3270	**07DSG28** S0°09.58' W90°49.27'	Ditto with fragment of altered Granite	Basalt with dominant feldspar phenocrysts, practically no yellow pyroxene (p. 54). Contains the most olivine	Buccaneer Cove	**Gabbro** mainly composed of plagioclase feldspar (Labradorite, $An_{61–52}$) and clinopyroxene (diopside). Olivine ($Fo_{75–66}$) is partially altered and less common
CD3271 (32587)		Imbedded fragments of ditto [Trachyte]. Varieties coarser & finer grained. Quartz generally visible. Mica changed into glassy minerals. Perhaps some Syenite	Gabbroic xenoliths—but 3271 is a **eucrite** rather than a gabbro, augite and less feldspar than in 3273, whereas 3271 and 3272 have more feldspar	Buccaneer Cove	
CD3272	S0°10.033' W90°49.56'	Ditto	Ditto	Buccaneer Cove	**Gabbro** xenolith with red-brown staining. Coarse grained (~ 5mm) with high modal abundance of plagioclase and pyroxene. Non interlocking framework no obvious olivine
CD3273 (4731)		Ditto	Contains zoned feldspar laths ($An_{72–61}$), pale-brownish green ophitic augite, colourless partially altered olivine (Fo_{71})	Buccaneer Cove	

2. Buccaneer Cove (cont.)

Darwin no. (Harker no. in brackets)	Equivalent sample (this work)	Darwin's description in his specimen notebook (abbreviated)	Richardson's description (substantially abbreviated)	Description of sample location (Darwin [1835] in italics; and this work)	Description and classification (this work)
CD3275 (32584)	**07DSG07**	Red, irregular fracture Claystone base. Very heavy with red earth & Cry. Of Glassy Feld. Generally more of the latter and more cellular	Altered porphyritic olivine-basalt	Buccaneer Cove	Red oxidized vesicular **olivine basalt** containing large crystals of plagioclase feldspar and altered olivine in a very fine-grained groundmass. Alteration of the olivine gives rise to the red specks in hand specimen
CD3278 (32581)	**07DSG01?** S0°10.033' W90°49.567'	Brown, smally cellular Trachyte with blue iridescent patches of Olivine could not measure F.	Specimen has colourless augite with yellow rims; seen as an important mineral, p. 50. Resorbed plagioclase (labradorite, $An_{72–65}$) phenocrysts. Altered olivine	*'Pap' of lava in Buccaneer Cove*, beneath 'layer cake'	Red-brown colouration. Porphyritic and vesicular altered **basalt**. Phenocrysts of pyroxene and plagioclase feldspar (~3mm in length). High phenocryst content (~50 %). Small cognate xenoliths
CD3279 (4732)	**07DSG21?**	Gray. Compact ditto. few Cryst of Gl. Feldspar [added: Olivine (B.P.)	Porphyritic olivine andesite contains feld spar laths, presence of a few large, slightly altered olivine phenocrysts, and having ophitic augite that is strongly zoned and passes locally into a yellow variety	*Dyke at Buccaneer Cove*	**Trachyandesite**

3. James Bay

Darwin no. (Harker no. in brackets)	Equivalent sample (this work)	Darwin's description in his specimen notebook (abbreviated)	Richardson description (substantially abbreviated)	Description of sample location (Darwin 1835, in italics; and this work)	Description and classification (this work)
CD3280 (32524) (346)	**07DSG65** S0°12.927' W90°50.1'	Blackish grey Lava. abounding	Olivine basalt, pp. 48–49. Pale-green olivine phenocrysts enclosed in a groundmass of labradorite ($An_{65–61}$), ophitic purplish augite and olivine.	Older than historic (~1759) *flow at James Bay*	**Olivine basalt.** Small phenocrysts of olivine set in a fine-grained, grey, groundmass containing plagioclase feldspar and ophitic purple-brown clinopyroxene.
CD3281 (4733) (323)	**07DSG61, 64** S0°12.927' W90°50.156'	Ditto. Blacker. more cellular	Glassy olivine basalt, p. 49.	Historic (~1759) pahoehoe *flow at James Bay*	**Vesicular olivine basalt.** Small phenocrysts of olivine ($Fo_{76–62}$) set in a fine-grained, black, glassy groundmass. Small laths of plagioclase (Bytownite, $An_{84–71}$) and clinopyroxene are also present.

Age of James Bay flow is from Simkin and Siebert (1994). Latitudes and longitudes are GPS positions (WGS84 datum).

The fourteen surviving samples of crystalline igneous rocks collected by Darwin from Isla Santiago still bear his original specimen numbers, although his yellow labels are no longer visible. The specimens were donated to the Woodwardian[1] Museum in 1897 and curated by Harker, who had thin-sections made of the rocks (see Figure 4) and recorded brief petrographic descriptions of each one in his meticulous museum catalogues (*ca* 1907). Subsequently, Richardson (1933) provided more detailed descriptions of the hand specimens and thin-sections, as well as for several other samples collected from Isla Santiago by L. J. Chubb in 1924.[2] Richardson used an immersion method to estimate refractive indices and determine, for the first time, the composition of minerals (olivine, feldspar and amphibole) in Darwin's Isla Santiago samples. She also published a whole-rock analysis of one of these samples (the trachyte, CD3268); the analytical work was undertaken by W. H. Herdsman, a commercial analyst based in Glasgow, who used wet chemistry techniques and was one of the principal scientists engaged in this type of work at the time. The analysis of CD3268 required removal of part of the hand specimen and its subsequent reduction to a powder. Apart from the small slivers of rock that were removed for making Harker's thin-sections, all of the remainder of Darwin's samples from Isla Santiago remain intact. No other published information on the mineralogy and petrology of Darwin's samples exists or detailed study of Isla Santiago. There is, however, an unpublished PhD thesis on the petrology and geochemistry of volcanic rocks from Isla Santiago by Hartmut Baitis (1976). He identified trachytes close to the summit of Santiago but, since Darwin's samples were not available to him, no direct comparison was undertaken. We note that Baitis's samples of trachyte, which are currently housed at the University of Idaho, are much coarser-grained than Darwin's trachyte. Furthermore, Baitis made no mention of the presence of amphibole in these rocks.

In the early nineteenth century there were no guidelines in place for the systematic naming of volcanic rocks. An early attempt to classify igneous rocks based, on their mineralogy and textures, was proposed in 1823 by Karl Caesar von Leonhard (1779–1862), a German petrographer (Young 2003, p. 110). This information may not have been available to Darwin whose naming of igneous rocks would essentially have been learnt from lectures at Edinburgh under Robert Jameson (1774–1854), contact with his mentor Henslow at Cambridge, and fieldwork in North Wales with Adam Sedgwick (1785–1873) (Secord 1991). A record has been compiled of the books that Darwin had with him on the voyage, and from this, as well as from the surviving books, a number of which carry his annotations, we know which works he relied on.[3] As one might expect, the works of authors such as Humboldt, Charles Daubeny (1795–1867), Scrope, and Lyell, were useful to him. In addition, from the evidence of his extensive marginal annotations, it is clear that during the voyage he especially relied on a comprehensive two-volume work *Traité de géognosie* by J. F. d'Aubuisson de Voisins (1819)[4] for rock identification, and especially so in the

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1 The Woodwardian Museum was re-named the Sedgwick Memorial Museum of Geology, following the construction and opening of a new purpose-built museum in 1904.

2 These were housed in the British Museum of Natural History in London. The geologist Lawrence Chubb (1887–1971) studied and taught at University College London.

3 See Burkhardt *et al*. 1985, vol. 1: 553–566, Appendix IV ('The books on board the *Beagle*'). Up to the point of his travel aboard H.M.S. *Beagle* Darwin's education in geology had progressed through four stages: (1) childhood collecting of interesting mineral specimens combined with experiences working in a home chemistry laboratory; (2) study under Robert Jameson at the University of Edinburgh; (3) study of natural history, broadly conceived, under John Stevens Henslow at the University of Cambridge; and (4) in the period immediately following completion of coursework at Cambridge, extensive reading of such authors as Alexander von Humboldt and John Herschel, combined with a short course of fieldwork in Wales under Adam Sedgwick. For further background see Secord (1991) and Herbert (2005).

4 The French geologist and mining engineer Jean-François d'Aubuisson de Voisins (1769–1841) studied with Abraham Gottlob Werner at the *Bergakademie* in Freiberg in 1800–1801 but later adopted volcanism as an explanation for the origin of basalts. Adam Sedgwick recommended that Darwin bring d'Aubuisson's

Galápagos. Whilst there, Darwin used the most-widely accepted terms, which simply referred to coarse-grained plutonic rocks as granites or syenites and fine-grained volcanic rocks as basalt, greystone or trachyte. Nevertheless, he was clearly concerned about this terminology and how his use of it compared with that of other geologists. In 1836 he wrote to Henslow "I am anxious to know, whether Prof Sedgwick recommends any particular nomenclature for the rocks" (Burkhardt *et al*. 1985, vol. 1, p. 513). Usage was clearly a major issue, for Darwin needed to adopt a recognized vocabulary in order to make comparisons of his findings with those of other geologists.

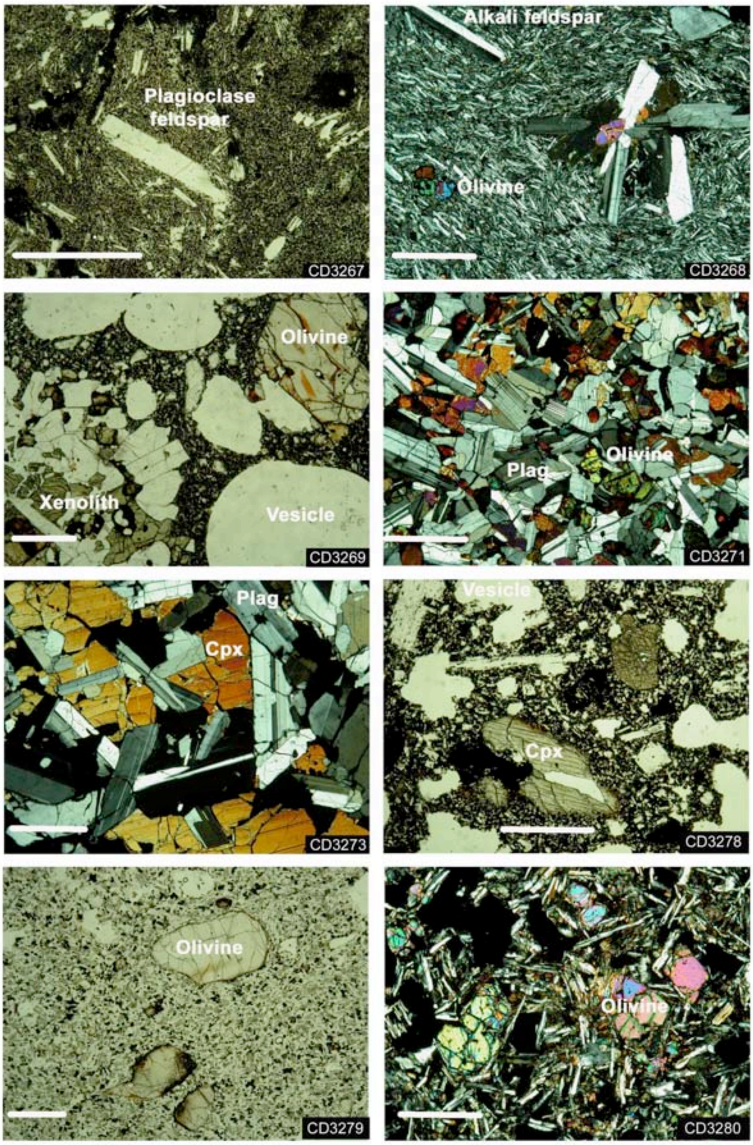

Figure 4. Photomicrographs of thin sections of some of the geological specimens collected by Darwin from the west of Isla Santiago. CD3267 (trachyandesite) and 3268 (trachyte) were collected during Darwin's trek into the Highlands. CD3269 and 3278 are vesicular basalts from Buccaneer Cove. CD3279 is a large feldspar basalt from a dyke at Buccaneer Cove. Specimens CD3271 (troctolite) and 3273 (gabbro) are 'coarse-grained fragments' (xenoliths) from Buccaneer Cove; and CD3280 is an olivine basalt from James Bay. Images of CD3267, 3269, 3278 and 3279 were taken in plane-polarized light. Images of all other samples were taken using cross-polarized light. The scale bar in the bottom left-hand corner of each image is 1 mm. Brief descriptions of the samples are given in Table 2. (Images by courtesy of S.A Gibson.)

Traité on the voyage, which he did. Volume 1 of Darwin's copy of the book is inscribed "C. Darwin HMS Beagle". See also the article by Arthur Birembaut on d'Aubuisson de Voisins in the *Dictionary of Scientific Biography* (vol. 1, pp. 327–328, 1970).

2.2. Darwin's nomenclature for igneous rocks on Isla Santiago

In *Volcanic Islands* Darwin defined his use of the terms trachyte and basalt:

> Trachyte, which consists chiefly of feldspar, with some hornblende and oxide of iron, has a specific gravity of about 2.45; whilst basalt, composed chiefly of augite and feldspar, often with much iron and olivine, has a gravity of about 3.0. (Trachyte from Java was found by Von Buch to be 2.47; from Auvergne, by De la Beche, it was 2.42; from Ascension, by myself, it was 2.42. Jameson and other authors give to basalt a specific gravity of 3.0; but specimens from Auvergne were found, by De la Beche, to be only 2.78; and from the Giant's Causeway, to be 2.91) (Darwin 1844, p. 120).

However, these definitions were not used by Darwin during the *Beagle* voyage. A comparison between his Galápagos field notebook and *Volcanic Islands* reveals that there are several instances where he revised his field classification of rocks from Isla Santiago (Gibson 2009). In his published work Darwin also questioned whether or not there was actually any 'true' trachyte in the northern Galápagos.

> In the northern islands,[5] the basaltic lavas seem generally to contain more albite than they do in the southern half of the Archipelago; but almost all the streams contain some. The albite is not unfrequently associated with olivine. I did not observe in any specimen distinguishable crystals of hornblende or augite; I except the fused grains in the ejected fragments, and in the pinnacle of the little crater, above described**. I did not meet with a single specimen of true trachyte**; though some of the paler lavas, when abounding with large crystals of the harsh and glassy albite, resemble in some degree this rock; but in every case the basis fuses into a black enamel (Darwin 1844, p. 114, emphasis added in bold).

This contrasts with his full manuscript notes (DAR 32–DAR 38 in the Darwin Archive at Cambridge University Library) in which he stated that:

> Considering the Islands in the whole Archipelago, it may be remarked, that the Southern ones appear to be entirely composed of Basalt and Greystone whilst the Northern division is more essentially trachytic (DAR 37.2:786). (*In margin:* Chatham.)

In a description of a traverse from Buccaneer Cove to the NW Highlands (Jaboncillos) Darwin mentioned that:

> Travelling inwards in a SE line, where beyond the influence of the sandstone Craters All the rock is highly cellular blackish grey **Trachyte**, abounding with glassy Feldspar:(3265), parts are more compact (3266).— (Field Notes, DAR 37.2: 723, emphasis added).[6]

Thus we see Darwin using the term 'trachyte' in field notes where later he would alter his identification.

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5 Here, Darwin's writing is somewhat confusing, because it is unclear what he means by the 'northern islands'. In fact, lavas at Genovesa, Pinta, and Marchena (Figure 1) are notably rich in plagioclase (albite according to Darwin). Darwin did not visit these islands, but specimens from each, collected by Chaffers, are included in his collection. Darwin does, however, seem to have been including Santiago in this discussion, by referring to the 'ejected fragments' (xenoliths of Buccaneer Cove) and 'pinnacle'. We suspect that he originally thought some of his plagioclase-phyric rocks from Isla Santiago were trachytes, but he found them to be basalt using the blowpipe test. It is unclear whether he subjected the actual trachyte in his possession to a blowpipe test.

6 Darwin's deleted remarks are not included in the transcriptions from his manuscript notes reproduced in this article.

2.3 Naming volcanic rocks in accordance with present-day international guidelines

The present-day classification of igneous rocks encompasses their chemistry as well as their mineralogy and is based on a scheme proposed by Carl Bernhard von Cotta (1855), which divides 'eruptive' rocks on the basis of their silica content (Young 2003, pp. 116–117). Fine-grained and essentially anhydrous volcanic rocks are now conventionally classified on the basis of their whole-rock chemistry according to the recommendations established by a special sub-commission of the International Union of Geological Sciences (IUGS) on igneous rocks published by Roger W. Le Maitre (1989). One of these classification schemes involves the silica and total alkali content of volcanic rocks and relates these to recommended field boundaries on a bivariate plot.[7] Figure 5 shows how this type of plot can be used for all of the currently available analyses of samples from Isla Santiago (our unpublished data, Baitis 1976, Richardson 1933, Saal *et al.* 2007, White *et al.* 1993).

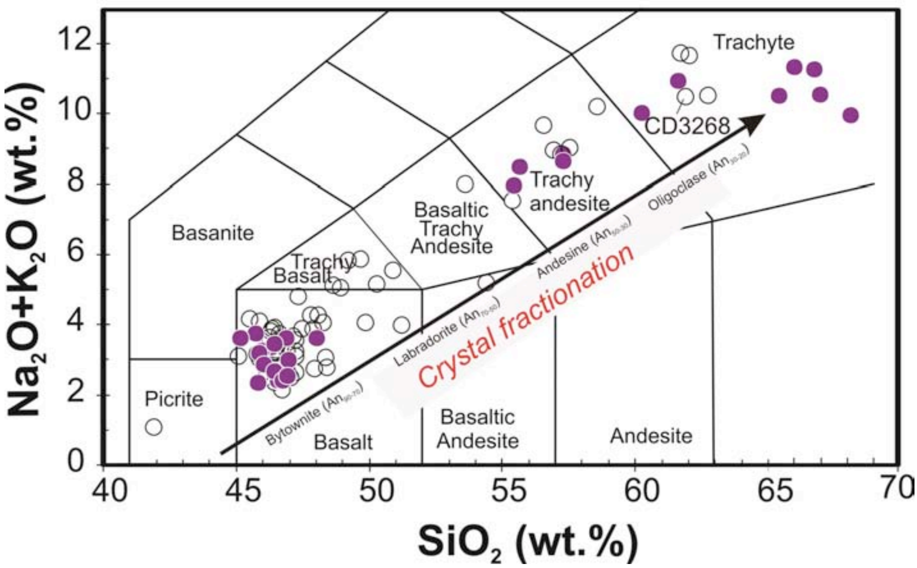


Figure 5. Classification of fine-grained igneous rocks from the northwest of Isla Santiago according to the scheme proposed by an IUGS sub-commission (Le Maitre 1989). The Isla Santiago rocks range in composition from basalt to trachyte. The arrow shows the change in bulk-rock composition with crystal fractionation and how the approximate composition of the plagioclase feldspar changes as the magma composition evolves during this process. Note that the solitary picrite analysis designated E76 (McBirney and Williams 1969; White, McBirney and Duncan 1993) is from a sample collected in a small bay to the north of Buccaneer Cove. This rock is almost certainly a basalt that has accumulated a significant amount of olivine (McBirney pers. comm.; SAG/DG unpublished interpretation). Closed circles are our unpublished analyses and open circles represent samples from previous studies (Baitis 1976; McBirney and Williams 1969; Richardson 1933; White, McBirney and Duncan 1993). (Figure prepared by S. A. Gibson.)

Richardson (1933) determined the chemical composition of CD3268 and noted that it had twice as much sodium as potassium; hence the reference to it as a 'soda' trachyte. In the 1960s, Herdsman's analyses were shown to have poor precision with respect to alkalis (especially Na) and also silica/aluminium ratios (C. H. Emeleus, pers. comm.). Despite this, CD3268 falls well within the 'field of' trachytes. Richardson (1933) also determined the chemistry of minerals (olivine, feldspar and amphibole) in most of Darwin's Isla Santiago

[7] Igneous rock classification is not always rigorously followed by all modern petrologists. Because there is completely continuous variation in rock composition and mineral assemblage, practitioners generally apply rock names that best suit their particular study.

samples on the basis of their refractive indices. We have combined her findings with state-of-the-art electron microprobe analyses of mineral phases present in our own samples (Table 2). The latter were chosen to be representative of the different types of volcanic rocks that we encountered in the west of Isla Santiago. These analyses were undertaken in the Department of Earth Sciences at the University of Cambridge and the results are summarized in Table 2. Details of analytical techniques are presented in Gibson *et al.* (2008).

3. RECONSTRUCTING DARWIN'S FINDINGS

In July 2007 we spent eight days on Isla Santiago, examining rock outcrops and collecting samples with the intent of verifying Darwin's findings (see Appendix for further expedition details). Prior to the fieldwork we re-examined all of Darwin's samples from Isla Santiago. Our goal was to find similar outcrops to those observed by Darwin, and to collect samples that resembled his specimens (Table 2). While it was not the expedition's goal to replicate his full experience on the island (after all he collected in all areas of natural history and his geological collecting came in the first half of his stay [Table 1]), it was necessary to identify his route in order to locate the sites he visited as accurately as possible (see Figure 6). In identifying his route we relied heavily on previous work by Greg Estes and Thalia Grant (Estes, Grant, and Grant 2000).

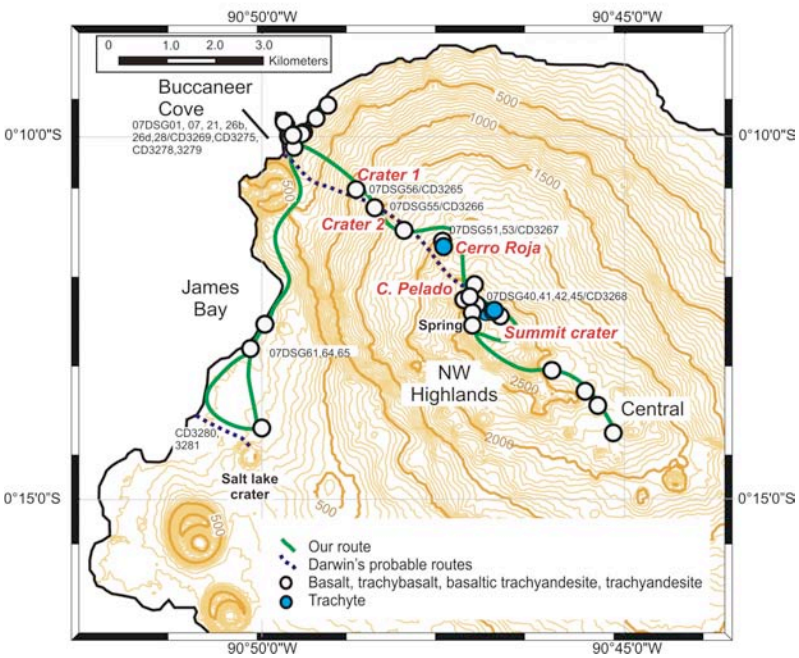


Figure 6. Topographic map of northwest Isla Santiago showing the locations of samples collected during the 7 July expedition (serial code 07DSG–???) and possible correlations with sites of volcanic rock samples collected by Darwin in 1835 (serial code CD32–???). Contours are shown at fifty-foot intervals. (Figure prepared by S. A. Gibson.)

Retracing the localities from which Darwin had collected his geological samples was by no means straight-forward because:

(i) He did not accurately describe his routes in his field notebooks. Transcriptions of his notes reveal that his descriptions of sample locations were quite general and only occasionally mentioned specific landmarks.

(ii) Darwin's samples were small (< 10 cm, with most being < 5 cm; and many have surfaces that are either covered with lichen or are weathered.

(iii) Darwin did not refer to his samples by number in his published work.

(iv) It has been proposed that one of the samples in the Harker Collection at the Sedgwick Museum (CD3268) at the University of Cambridge was not actually collected in the Galápagos (McBirney and Williams 1969) and therefore may not resemble any of the volcanic rocks on the island.

3.1 Association of rock types and volcanic craters in west of Isla Santiago (James Island)

The west of Isla Santiago consists of a major shield volcano with parasitic cones on its flanks (Gibson 2009). Eruptions of basaltic lava have occurred since Darwin's visit but these are confined to the eastern side of the island, such as the 1906 lava flow at Sulivan Bay (Simkin and Siebert 1994). Although Darwin did not provide detailed descriptions of where he collected his samples on Isla Santiago, he stated that:

> James Island. The only part of this Island which I examined is the West side.— The country here gradually slopes upwards to an elevation of about 3000 ft (DAR 37.2: 769).

After describing and collecting samples from Buccaneer Cove, Darwin subsequently referred to two separate excursions that he made inland with resident tortoise hunters. He described how they took a south-east traverse and came across a perfectly-shaped volcanic crater near the summit of the island.

> Travelling inwards in a SE line, when beyond the influence of the Sandstone Craters, All the rock is highly cellular blackish grey Trachyte, abounding with glassy Feldspar: (3265), parts are more compact (3266).— More in the interior compact varieties are common, containing more or less numerous Cryst: of glassy Feldspar.— Here I found a very perfect Crater: well wooded, but entire and large.— Generally it may be remarked that the more cellular Trachyte. contains the largest and perhaps more numerous Cryst of Feldspar.— This is the reason, I do not believe, they preexisted.— Circumstances determine their size & numbers. Specimens of more compact kinds 3267:3268 (DAR 37.2:723).

And in notes made after his descent from the highlands to Buccaneer Cove, Darwin mentions that the walls of the crater are composed of bright red glassy scoria:

> In several parts there are old broken down Craters & In the central highest part of Is^{d} —about 8 miles inland— (& between 2–3000 ft high. Estimation) there is a large & perfect Crater. Circular. sides very precipitous & bottom well wooded. In the vicinity. nothing but Trachytic Lava is found: the channels by which the Lava has flowed over the rim are yet visible.— The walls of the Crater are chiefly composed of bright red & very glassy ~~red~~ scoria united together.— (DAR 37.2:770).

Cerro Pelado is a prominent circular, steep-sided crater near the summit of Santiago Island (00°12′21″S, 90°47′3.1″W), at an elevation of about 840 metres (2,750 feet) and has a diameter of 200 metres. (see Figures 6 and 7; Estes, Grant and Grant 2000). It is located six kilometres inland of Buccaneer Cove. These distances are shorter than those reported by Darwin for his "large & perfect Crater", but his estimates (eight miles for the journey inland and one third of a mile for the diameter of the crater) appear to have been recorded in his notebook several days after his return to Buccaneer Cove. Moreover, distances covered in the interior of the islands can be exceedingly difficult to estimate, especially in the heavily vegetated regions.

Figure 7. Cerro Pelado: a perfectly shaped crater located close to the summit of Santiago. It contains bright red scoria and has a prominent lava flow that appears to have flown over the rim of the crater (left of image) and closely matches one described by Darwin in his field notes. (Image by courtesy of A. Thurman.)

Vegetation and wildlife on Santiago has been altered since Darwin's visit, following the introduction of pigs and goats. Pigs dug up tortoise and turtle eggs and also ate the Galápagos petrels that nest in the highlands. Goats damaged the native vegetation, especially in the highlands. But both introductions had been eradicated by 2004, and saplings were already present in the crater floor in 2007. The lavas that emanate from Cerro Pelado contain large laths of plagioclase; in contrast to Darwin's field description, our thin-section investigation confirms that these are basalts rather than trachytes. Red scoria, some of which is glassy, is present in the northern and western walls of crater. We did not encounter this distinctive rock in abundance in any of the other craters and believe that Cerro Pelado is the crater that Darwin described. This is consistent with the description of Darwin's route proposed by Estes, Grant, and Grant (2000). A larger (one km in diameter) bowl-shaped depression lies to the southeast of the summit of the island, and to the southeast of the "perfect crater" at Cerro Pelado (see Figure 6). The geological origin of the bowl is not clear, but it seems to have formed by a ring of separate vents. It is not "very precipitous" and, although Darwin may have visited it (one of the ring vents is the highest point on the island), it is not in his description. A spring (00° 12.611′ S, 90° 47.097′ W) emerges less than 1 km from the southwest rim of the bowl at 865 m elevation. The horizontal position accuracy is ± 8 m. (Measurement made July 2007, WGS 84 datum.) This spring and its environs is likely where Darwin observed tortoises wallowing (Estes, Grant, and Grant 2000).

3.2 Trachytes and trachyandesites in the northwest highlands

On the higher northwest slopes of the main volcano on Isla Santiago (see Figure 6) a wide variety of rock types outcrop, including trachytes, trachyandesites and trachybasalts (Table 3). The most differentiated rocks (trachytes) occur nowhere else in the vicinity of the Isla Santiago highlands (Gibson 2009) and are readily distinguished in the field, on the basis of colour and texture, from the basaltic rocks that form lavas lower down the slopes. Trachytes occur to the east of Cerro Pelado and also at the crater known as Cerro Roja (Crater 3, see Figure 6).

Table 3. Petrographic terms used to define fine-grained volcanic rocks in the west of James Island[8]

Rock type	Criteria for differentiating volcanic rocks in the field and also in thin section
Trachyte	Light coloured, generally porphyritic, fine-grained rock, composed primarily of alkali feldspar, plagioclase, quartz, biotite with minor hornblende and feldspathoids. In general, any mineral grains large enough to be seen will be alkali feldspar but not quartz. These rocks are commonly flow-banded.
Trachyandesite	Little or no free quartz but dominated by equal amounts of alkali feldspar and sodic plagioclase along with one or more of the following mafic minerals: amphibole, biotite or pyroxene. Small amounts of nepheline may be present and apatite is a common accessory mineral.
Basaltic trachyandesite	Intermediate between trachyandesite and trachybasalt. Plagioclase feldspar ranges in composition from labradorite to oligoclase. Ferromagnesian minerals are those more commonly found in basalts (olivine, augite).
Trachybasalt	An extrusive rock intermediate in composition between trachyte and basalt. Characterized by calcic plagioclase (labradorite) and sanidine, with augite and olivine.
Basalt	Dark-coloured, fine-grained may have visible phenocrysts of olivine, plagioclase feldspar and/or clinopyroxene.

The trachyte that we observed near Cerro Pelado (e.g. 07DSG40) forms a prominent north-facing 300m long bluff (see Figure 8), which we interpret as a volcanic dome. The rock that constitutes the lower and middle parts of the bluff has a 'chalky' bright-green appearance but is quite different from Darwin's greenish-grey 'trachyte' (CD3268) which has less alkali feldspar and browner amphibole. CD3268 is slightly less evolved and resembles a slightly more mafic trachyte (07DSG42, Figures 4 and 9) that we collected from the top of the bluff, immediately below the summit ridge. 07DSG42 contains phenocrysts of alkali and plagioclase, yellow fayalitic olivine (Fo_{20}), clinopyroxene together with both a brown and also blue-green amphibole. The petrography and mineral chemistry of 07DSG42 are very nearly identical to CD3268 (Table 2).

8 Note that in both his field notes and *Volcanic Islands* Darwin referred to the 'Mineralogical composition of the rocks'. He is more precise about the compositions of mineral phases, such that plagioclase feldspar is referred to as albite, and alkali feldspar as orthite or potash feldspar and pyroxene as augite.

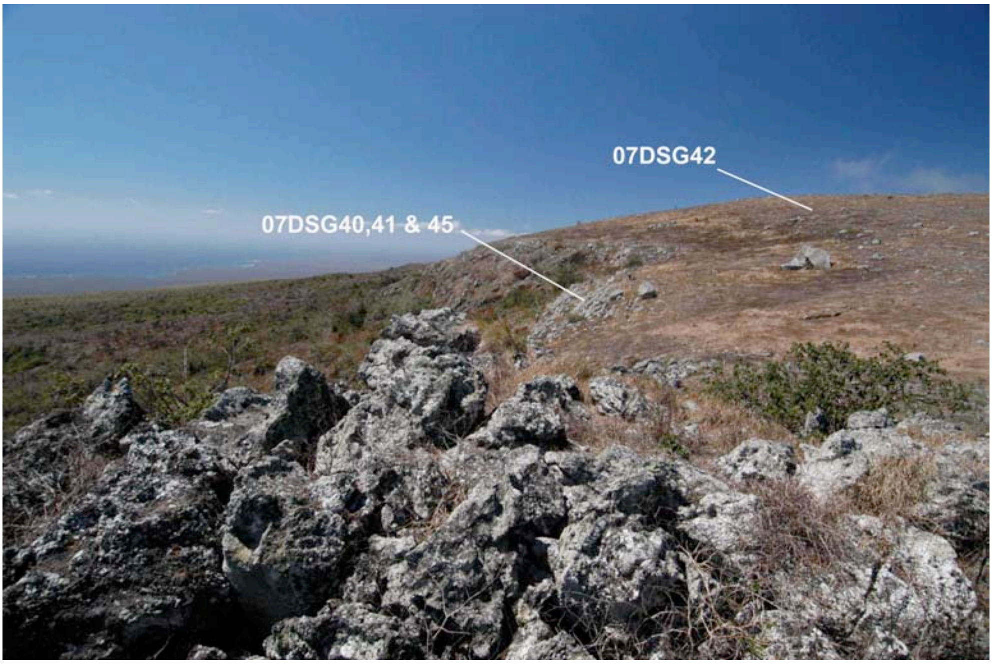


Figure 8. Location of trachytes at an elevation of 860 metres (2,830 feet) and approximately one hundred metres due east of Cerro Pelado, near the summit of Isla Santiago. (Image by courtesy of A. Thurman.)

The trachyandesites (see Figure 9) that we collected from the crater rim of Cerro Roja (07DSG50 and 07DSG51) on the north-west facing slope of Isla Santiago (Figure 6) were from large volcanic bombs, measuring up to 1 metre in length, and differ from CD3268 in that they are finer grained and vesicular. In many respects, 07DSG51 is similar to CD3267; both contain brown amphibole, clinopyroxene and olivine that is not especially fayalitic (Table 2, see Figure 4). We therefore suggest that Darwin may have collected CD3267 in the vicinity of Cerro Roja, as he ascended towards the summit of Isla Santiago.

3.3 Trachybasalts at Buccaneer Cove

Several dykes outcrop on the promontory at Buccaneer Cove, some forming spectacular pinnacles, while others that form a small island off the cove (see Figure 10) are composed of trachybasalts. Darwin reported that:

> The piles of scoriae are traversed in several places by great broad dykes many yards thick, which vertically run for considerable distances.— They consist of a compact Trachyte with only few Crystals of [Fel] the sides and certain spots are cellular.— [*In margin:* 3279] (DAR 37.2:772).

Specimen CD3279, referred to in the above quotation, contains large phenocrysts of olivine set in a groundmass rich in plagioclase and clinopyroxene (see Figure 4). Richardson noted in her thin-section description of CD3279 that the feldspar was more sodic (labradorite) than in the basalts and that it contains a yellow clinopyroxene. She suggested that the rock is an olivine andesite. The high amount of plagioclase in this rock almost certainly prompted Darwin to classify it as trachyte rather than basalt, but using the present-day IUGS classification scheme it would probably fall in the field of trachybasalts or basaltic andesites, *i.e.* intermediate between basalt and trachyte (see Figure 5).

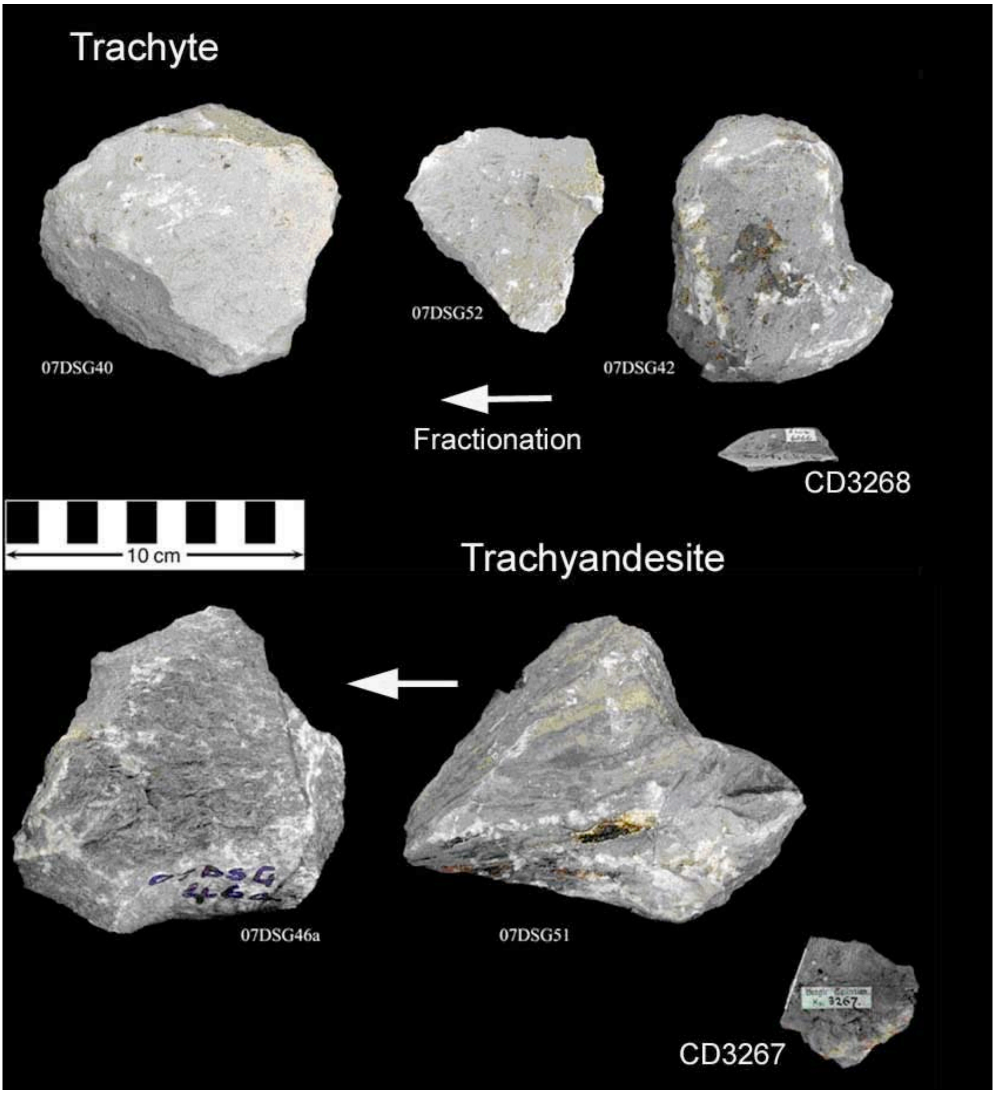


Figure 9. Hand specimens of trachytes (07DSG40, 52, 42, 46a) and trachyandesite (07DSG51) collected from the northwest of Isla Santiago. Darwin's samples (CD3267 and 3268) are placed next to their closest equivalents in our sample collection. Arrows illustrate how the compositions of fine-grained volcanic rocks change with crystal fractionation; fractionation of mafic (iron and magnesium rich) minerals, such as olivine and pyroxene, causes an increase in the silica content of the magma. This increase in silica is often shown by the colour of fine-grained rocks, which changes from black (basalt) to blue/grey (trachybasalt or trachyandesite) to pale-green (trachyte). (Images courtesy of D. Simons.)

Figure 10. Promontory at the north end of Buccaneer Cove. Darwin interpreted this as the wreck of a large crater. (Image courtesy of A. Thurman.)

3.4 Large-feldspar basalts in and around Buccaneer Cove

Darwin was particularly unsure of the terminology (trachyte or basalt) that he should use for the volcanic rocks on Isla Santiago which are rich in large crystals of plagioclase. These are the dominant rock type over much of the northwest of the island, including Buccaneer Cove, Cerro Pelado, and the summit bowl. Concerning the promontory at Buccaneer Cove (Figure 10), Darwin wrote:

> In central & rather lower part of the promontory. which I believe to have been bosom of Crater. There is a mass about 200 ft thick of a quite compact, greenish or blackish grey **Trachyte** with few Cryst of glassy Feldspar: (DAR 37.2: 720–721, emphasis added).

But when referring to the same 200-foot outcrop in *Volcanic Islands* Darwin changed the name of this rock from trachyte to basalt.

> One side of Fresh-water Bay, in James Island, is formed by the wreck of a large crater, mentioned in the last chapter, of which the interior has been filled up by a pool of **basalt**, about two hundred feet in thickness. This basalt is of a grey colour, and contains many crystals of glassy albite, which become much more numerous in the lower, scoriaceous part (Darwin 1844, p. 117; emphasis added).

The reason for the discrepant descriptions is unclear. The origin of the prominent outcrop is straightforward: it was a lava lake that filled the crater of the scoria cone near the end of its eruption. It is closer to fifty feet than 200 feet thick, but massive blocks of it have tumbled to the sea, giving the impression that it could be 200 feet thick. Also, the base is not particularly vesicular (although the top is), and it is not very rich in feldspar phenocrysts (typically 2% by our observation). We note, however, that crystal sorting of feldspar typifies many other Galápagos lava flows and fossil lava lakes.

Darwin's other samples of volcanic rocks from Buccaneer Cove are mostly plagioclase-phyric types (i.e. with phenocrysts of plagioclase). Presumably, CD3275 was collected by Darwin because it contains 'bright red specks' and forms an abundant rock type at Buccaneer Cove. He wrote of this location:

> There were very many large pieces of a harsh red Claystone base, more or less vesicular & containing more or less Cryst^s of glassy Feldspar and small bright red earthy specks.— Specimen Shows the two cases in lesser extreme (3275).— I did not reach any stream of this rock, but it must be very abundant.— (DAR 37.2:720).

Thin-section examination reveals that the red specks in CD3275 are formed of altered olivine and that the rock is a basalt that has undergone hydrothermal alteration. This process frequently affects rocks that are located near volcanic vents and olivine is particularly susceptible to this type of alteration.

The lowest crater (Crater 1, see Figure 6) above Buccaneer Cove occurs at an elevation of 300 metres (~1,000 feet). It contains highly vesicular basalt flows that resemble Darwin's sample CD3266. The rocks contain phenocrysts of rounded olivine and two generations of plagioclase that are set in a fine-grained groundmass. The largest feldspars are rounded, full of glass inclusions, and the sparser smaller crystals are more homogeneous and lath-shaped (Table 2).

Lava flows emanating from Crater 2, and also those that occupy much of the lower slopes below 200 metres (650 feet) around the northwest of Isla Santiago, are exceedingly rich in large (~5 mm) plagioclase phenocrysts and resemble CD3265 (Table 2). In thin-section, the plagioclase crystals show strong compositional zonation and are full of inclusions. Additionally, some of these samples (e.g. 07DSG55) contain phenocrysts of pale green clinopyroxene and olivine.

3.5 Olivine basalt from James Bay

In notes made on 11 October Darwin described how his party took a boat trip from Buccaneer Cove 6 miles south to James Bay (which he referred to as Puerto Grande) with resident tortoise hunters to visit the salina that had formed in a tuff crater. Darwin mentioned that at James Bay:

> Stream.— Have burst from several small Craters at foot of central Trachytic mass of highest hills & Craters.— Consists of <u>Greys</u>tones such as (3280) which abounds in a very remarkable degree, with quantities of olivine. is generally very Vesicular & sometimes rather a Darker color (3281).— The Basin is much the same as in Central Trachytes, the Olivine here replacing glassy Feldspar.— Its surface is smoother than the Basalt of Chatham Isd.— Yet many great fissures.— Surface ringed, (like Cow-dung), which often takes form of <u>cables</u>; folds in a [*illegible*] & branches with rough bark. In this Island we have this Olivine Lava as the latest, whilst in Albemarle, that of Trachyte.— Near to the Sea, it has burst through an ancient crater, (composed of igneo-cemented red glassy Scoriae & greystone Lavas) filled up Crater & left only 2 pieces, which stand in front of each other.— (DAR 37.2:722).

James Bay is a broad (~9.5 kilometres wide) bay located to the south of Buccaneer Cove (see Figure 6). The James Bay flows are olivine-phyric basalt and are distinguished from others in the northwest of the island by the fact that olivine is the only phenocryst phase. A prominent recent (~1759 AD) lava flow fringes the back of the middle part of the bay over a distance of more than three kilometres and erupted from a crater on the flank of the main volcano. The flow is covered by sparse vegetation (mainly cacti: *Brachycereus nesioticus*) and displays spectacular pahoehoe textures, including those resembling ropes, and, as noticed by Darwin, cow dung (Figure 11). This lava resembles specimen CD3281. The olivine grains in this flow are small (~1mm) and range in composition from $Fo_{76–62}$ (see Table 2). Small laths of plagioclase ($An_{84–71}$) and clinopyroxene (diopside) are also present. Below the recent pahoehoe flow at James Bay there is a grey-weathering lava flow that is coarser grained. The sample that we collected from this flow (07DSG65) has a similar appearance in both hand specimen and thin section to CD3280 (see Table 2 and Figure 4).

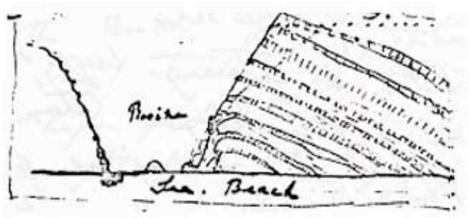
Figure 11. Recent lava flow at James Bay, being examined by G. Estes, D. Geist, and S. A. Gibson. (By courtesy of A. Thurman.)

3.6 Coarse-grained 'fragments' in lavas at Buccaneer Cove

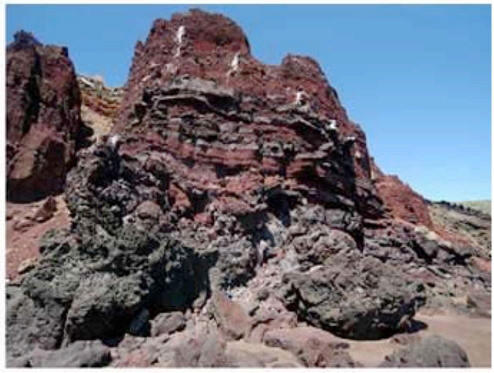
Darwin's fieldwork on Isla Santiago also influenced his ideas on the origin of coarse-grained igneous rocks contained in eruptive rocks. The lava flows at the north end of Buccaneer Cove, especially those that make up 'Darwin's Layer Cake' succession contain xenoliths (Estes, Grant, and Grant, 2000). (See Figures 12 and 13.)

As previously noted by both Richardson (1933) and Pearson (1996), Darwin referred to these inclusions as 'granites' in his field notes. 'Granite' was then defined as beng "composed of three simple minerals, feldspar, quartz and mica" (Lyell 1830–1833, Vol. 3 glossary). While on the voyage, Darwin subscribed to the largely Lyellian view that granite was still in the process of formation within the Earth (Oldroyd 1996, Chapter 9). Darwin wrote of specimens 3270 through 3273:

> This Trachytic Lava is remarkable by containing very many fragments of altered rocks, which clearly have been **Granites** and Syenites (3270:71:72:73) (DAR 37.2: 719, emphasis added).



(a)



(b)

Figure 12. (a) Darwin's field sketch (from DAR 37.2:773) of the thin streams of lava at Buccaneer Cove in which he has labelled the 'sea', 'beach' and 'ravine'. A similar but revised version of this sketch also appears in Volcanic Islands *but is drawn from a different perspective. (b) Present-day outcrop at Buccaneer Cove. Individual 'streams' of lava ~ 40 cm thick are interbedded with bright red scoria. These flows are especially rich in coarse-grained fragments. (Image [b] courtesy of A. Thurman.)*

Figure 13.
Hand specimen of one of Darwin's 'fragments' (CD3272) found at Buccaneer Cove. (We observed similar xenoliths in the thin lava flows at this locality. Some of the large crystals of feldspar that Darwin observed may have been derived from disaggregation of these xenoliths.) (Image by courtesy of D. Simons.)

Darwin's initial description of these xenoliths as granites was influential in his initial interpretation as to how the trachytes formed. In notes made after his departure from Isla Santiago, he proposed that the lavas at Buccaneer Cove had been formed by the melting of material of composition similar to the fragments. Note that he again calls the plagioclase-phyric basalt 'trachyte':

> The Trachyte here is interesting from containing very many small generally angular fragments of altered rocks, which clearly have been Granites & Syenite. — Hand specimens do not impress the idea of their extraneous origin, with the force with which inspection of the bed itself does [*in margin:* 3270:71:72:73]. —The glassy substance into which the Mica has been changed is remarkable.— One piece seems to have been part of a Quartz vein (3274.).— [*in margin:* 3274] The Feldspar is in nearly the same glassy fractured state as is the Trachyte. (Is the form & size similar?). It will be observed that the fragments have not become vesicular. — In a like manner the Crystals of the most vesicular varieties of lava are not thus affected.—

> One is led to suspect that all such Crystals proceed from the Granite & that they are not produced in the liquid Lava.— Inspection of a specimen of a cindery, regularly & highly vesicular Trachyte, brought from Abingdon Is[d] by M[r]. Chaffers [*in margin:* 3288], where the Crystals are very large & perfect, will tell more on this side of the argument than any description.— Yet I am unwilling to take up this opinion: If the Trachyte is melted Granite the quartz & mica has formed the more fusible part.— [*in margin:* which composes the matrix for the glassy Feldspar:—] In the fused mass, when at an intense heat, does not the quartz & a small portion of the other ingredients form the Crystals of glassy Feldspar.— May not these Crystallize at a temperature when the rest of the matter is fluid? This will explain the imbedded & extraneous appearance of the Crystals.—I do not however understand in any [*alternative reading:* every] point of view the observation, which I believe to be exact, viz that the Crystals abound more in the more Vesicular varieties (DAR 37.2: 775–776).

It is clear, however, that by the time Darwin wrote *Volcanic Islands* he realized that there was no quartz in these rocks, and that they could therefore not be granites. Therefore, as is common practice among researchers, he revised his opinion of their proper classification:

> In the lava and in the scoriae of this little crater, I found several fragments, which, from their angular form, their granular structure, their freedom from air-cells, their brittle and burnt condition, closely resembled those fragments of primary rocks which are occasionally ejected, as at Ascension, from volcanoes. These fragments consist of glassy albite, much mackled, and with very imperfect cleavages, mingled with semi-rounded grains, having tarnished, glossy surfaces, of a steel-blue mineral. The crystals of albite are coated by a red oxide of iron, appearing like a residual substance; and their cleavage-planes also are sometimes separated by excessively fine layers of this oxide, giving to the crystals the appearance of being ruled like a glass micrometer. There was **no quartz** (Darwin 1844, pp. 110–111, emphasis added).

Although he initially considered that the xenoliths might have been the source of the trachytes, Darwin arrived at the currently held conclusion that these coarse-grained rocks consist of olivine, feldspar and pyroxene (*i.e.* they are gabbros) and formed from magma that solidified at depth:

> It is interesting thus to trace the steps by which a compact granular rock becomes converted into a vesicular, pseudo-porphyritic lava, and finally into red scoriae. The structure and composition of the embedded fragments show that they are parts either of a mass of primary rock which has undergone considerable change from volcanic action, or more probably of the crust of a body of cooled and crystallised lava, which has afterwards been broken up and re-liquified; the crust being less acted on by the renewed heat and movement (Darwin 1844, p. 112).

The coarse-grained xenoliths at Buccaneer Cove exhibit large variations in abundances of olivine, plagioclase and clinopyroxene. This diversity of rock types is also apparent in Darwin's collection. By far the most abundant are gabbros, which are composed of calcic plagioclase and clinopyroxene with minor olivine and resemble CD3270, 3272 and 3273 (Figure 4). CD3271 is distinctive because of its content of olivine and plagioclase (it is best described as a troctolite, see Figure 4). We also collected rare xenoliths with high proportions of plagioclase (07DSG26d) and of olivine (07DSG26b) from Buccaneer Cove. Their compositions are, however, subtly different to those of CD3271 (Table 2).

Richardson (1933) estimated the compositions of the plagioclases and olivines in the gabbroic xenoliths and the host lavas and established that they were different. She thus concluded that the large feldspars and olivines in the 'basaltic matrix' were not derived from the assimilated xenolithic material. Like McBirney and Williams (1969), we interpret these 'fragments' as the products of partial crystallization that have accumulated in a shallow magma chamber before being erupted in lava flows from a vent in the vicinity of Buccaneer Cove.

4. CONCLUSIONS AND OBSERVATIONS

The volcanic landforms and rock types that Darwin encountered during his ten day visit to Isla Santiago in 1835 are traceable and provide insight into Darwin's thinking while he was in the field. We were able to locate volcanic and plutonic rocks that resemble, if not match, all of Darwin's Isla Santiago specimens now curated in the Sedgwick Museum collection. With the aid of modern petrological and geochemical equipment we have been able to fully characterize rocks identical to those that Darwin collected and confirm the presence of trachytes in the NW Highlands. The trachyte that outcrops close to the summit resembles CD3268, the sample that McBirney and Williams (1969) doubted had been collected by Darwin on this island.

Darwin's characterization of igneous rocks and interpretations of their formation were revised following his return to England, prior to publication of *Volcanic Islands* in 1844. His initial field-based subdivision of fine-grained rocks into basalts and trachytes reflected what he would have been taught during his studies at the Universities of Edinburgh and Cambridge. On his return to England, Darwin re-classified the vesicular volcanic rocks rich in large feldspar phenocrysts as basalts rather than trachytes. Darwin's revised classification is in line with modern-day terminology and presumably a response to his discussions with other authorities, particularly William Hallowes Miller (1801–1880), Professor of Mineralogy at the University of Cambridge.[9] This explains the apparent discrepancy that exists between Darwin's use of the term trachyte in his field notes and in *Volcanic Islands*. This is important when trying to understand, for example, how Darwin used his field evidence from places such as Isla Santiago to make the connection between the spatial and temporal distribution of basalts and trachytes and how he linked these to the depth of magma extraction from beneath individual volcanoes. On the basis of his observations, Darwin proposed that the diversity of igneous rocks was caused by dynamic processes operating underneath volcanoes, rather than being a characteristic of the Earth's changing composition over the course of geological time, which was one of the principal hypotheses of the time.

Given Darwin's fame, it would be easy enough to over-credit his contribution to modern petrology (Merton 1968). Our combined field and laboratory-based study has examined the extent to which Darwin's initial observations align both with his own published conclusions and with present-day understanding of igneous processes. We note that Alfred Harker, who is recognized as one of the founders of modern igneous petrology, devoted much effort to preserve Darwin's specimens. Harker attributed to Darwin the leading role in establishing a new notion of magmatic differentiation, noting that the only practical alternative to the idea was the "doctrine of countless special creations" (Harker 1909, p. 310. For a more nuanced account published in the same year see Judd 1909). Pearson (1996), however, has emphasized the limited impact of Darwin's work on the subsequent development of igneous geology after 1844 (Pearson 1996, Young 2003, Chapter 8). Even with the caveat of the danger of over-crediting Darwin, it is impressive that he drew so boldly from his observations on Isla Santiago.

The final observation we wish to make pertains to the relationship between Darwin's petrological work on Isla Santiago and his zoology and botany. There are several points of

[9] William Hallowes Miller succeeded to the professorship of mineralogy at the University of Cambridge in 1832, after it was vacated by William Whewell. Miller continued Whewell's focus on crystallography. After returning from the *Beagle* voyage, Darwin consulted Miller on a number of the geological specimens that he had collected during his travels.

commonality coming as they did during the later stages of the *Beagle* voyage. Darwin's researches in Galápagos geology, as in zoology and botany, represented a culmination of his South American work and an opportunity for him to test some of his skills of both observation and reasoning. Furthermore, common ideas, drawn particularly from Scrope and Lyell, emphasized the on-going nature of processes operating within the Earth and upon its fauna and flora. For Darwin, as well as for Scrope and Lyell, such processes were seen to affect species as well as rocks (Lyell 1830–1833, vol. 2, chapters 8–11; Scrope 1825, pp. 238–239). Darwin took time to develop his ideas in each of these areas; in all his work on natural history there was an interval of several years between initial observation and formal publication. During that interval he developed his views and reworked them in the light of the then-current science, without losing the originality of his field-based insights. This was as true for his geological work on Isla Santiago as it was for his work with plants and animals at the same location.

APPENDIX: NOTES ON THE JULY 2007 EXPEDITION

The existence of the 'trachyte problem', and some idea of where the outcrop of this rock type might be, was discussed by members of our group in 1999 (Estes, Grant and Grant 2000; Herbert 2005, pp. 120–126). An opportunity to undertake geological fieldwork on James Island arose in July 2007. The timing of this expedition stemmed from the inherent interest relating to the existence of trachyte on James Island and from the circumstance that the Sedgwick Museum of Earth Sciences is in the process of preparing a full-scale exhibit of Darwin's geological specimens to open in 2009, the bicentenary of Darwin's birth. David Norman and Sandra Herbert submitted a successful application to the Charles Darwin Research Station for a study entitled "Reconstructing Charles Darwin's 1835 Geological Expedition on Isla Santiago in the Light of Twenty-First Century Science".

The team that went on James Island included the geologists David Norman, Sally Gibson and Dennis Geist and, as guide and natural historian Greg Estes. Andrew Thurman served as photographer. Melina Neira from Ecuador and Andrew Miles from the UK were student members of the team. José Luis Villa Fuerte from Ecuador served as field assistant. Sandra Herbert, Thalia Grant, and James Herbert remained on Isla Santa Cruz where they facilitated arrangements with the Charles Darwin Research Station and the *Parque Nacional Galápagos*. Interestingly Darwin's own party included about the same numbers on site and was also in effect a multi-national effort. While on James Island, Darwin's group was materially assisted by local, and visiting Spanish-speaking residents and by 'Yankee' whalers who gave them a supply of fresh water, the fresh water of Buccaneer Cove having been contaminated by a surge of salt water. Darwin's group stayed on James Island 8–17 October 1835; the present team stayed on James Island 7–14 July 2007.

Unlike in Darwin's time, Isla Santiago is uninhabited and access is restricted by the *Parque Nacional Galápagos*. The only sources of fresh water used by visitors are rainwater-fed tanks in the highlands. We therefore took all of our own provisions and fresh water. The majority of our time was spent in the west of the island, around James Bay, Buccaneer Cove and in the northwest Highlands (see Figure 6). We set up a base camp behind the beach at Buccaneer Cove in a valley where the promontory intersects the coastline. Darwin is believed to have camped in this same area (Estes, Grant and Grant 2000). In his 'Diary' Darwin referred to this area as 'Freshwater Cove of the Buccaniers' (*sic*), which has now been shortened to Buccaneer Cove (Keynes 1988, p. 361). We camped for a further two nights inland from Buccaneer Cove at an elevation of approximately 650 metres (2,100 feet) just below the altitude at which the dense woodland changes to grassland. The ascent to our second camp took approximately half a day, and we spent two days exploring volcanic craters and lava flows in the NW Highlands (Figure 6). A further day was spent walking to and collecting samples from James Bay. The remainder of our time was spent at Buccaneer Cove. These locations and our route into the NW Highlands are similar to those described in Darwin's field notebook (Estes, Grant and Grant 2000). Almost all of the geological features described by Darwin are still visible on Isla Santiago. An exception may be the northeast-facing cliffs on the promontory at the north end of Buccaneer Cove, where there is evidence of steady on-going erosion and of a considerable recent fall of large blocks. Darwin believed that this outcrop represented the core of an eroded crater.

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ARCHIVES

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APPENDIX II

Field Trip Itinerary Permits and Reports
Historical Study of Charles Darwin's Visit to Galapagos in 1835

Year	Permit no.	Days in Field	Report
1996-1997	No. 015-96 PNG	43	Estes and Grant (1996a, 1996b, 1996c, 1997a, 1997b, 1997c)
2003	No. 033-33 JDT/SPNG 2003	1	(Estes and Grant, 2003)
2004	No. 00446 2004]	1	(Estes and Grant, 2004)
2007	No. PC-15-96 Ext. 02-07	21	(Estes and Grant, 2007)
2009	No. PC-15-96 Ext. 04-07	15	(Estes and Grant, 2009)

Field trip Permits and Reports document the islands and number of sites visited.
In total 81 days were spent in the field between 1996 and 2009.

APPENDIX III

Reviews and Endorsements

Reviews and endorsements of the book *Darwin in Galápagos: Footsteps to a New World* (Grant and Estes 2009) are from recognized scientists, historians and authors of works related to Charles Darwin.

Duncan M. Porter, coeditor of *The Correspondence of Charles Darwin*
"Grant and Estes provide a vivid and accurate account of where Charles Darwin went on his 1835 visit to the Galapagos Islands. This is an important addition to the Darwin literature and to our knowledge of what Darwin did in–and how he was affected by–Galapagos."
Porter, Duncan M. 2009. Cover endorsement. *Darwin in Galápagos; footsteps to a new world*, by K. Thalia Grant and Gregory B. Estes, Princeton: Princeton University Press.

Sandra Herbert, author of *Charles Darwin, Geologist*
"The authors have provided a richly detailed and evocative description of Darwin's route and experiences in the Galapagos Islands. In doing so they have made a significant contribution to Darwin studies"
Herbert, Sandra. 2009. Cover endorsement. *Darwin in Galápagos; footsteps to a new world*, by K. Thalia Grant and Gregory B. Estes, Princeton: Princeton University Press.

Edward J. Larson, author of *Evolution: The Remarkable History of a Scientific Theory*
This book provides the best description yet of Darwin's trip through the islands. The authors have a remarkable familiarity with the places Darwin visited, and ably share that knowledge."
Larson, Edward J. 2009. Cover endorsement. *Darwin in Galápagos; footsteps to a new world*, by K. Thalia Grant and Gregory B. Estes, Princeton: Princeton University Press.

Janet Browne, Aramont Professor of the History of Science, Harvard University, author of *Charles Darwin: The Power of Place*
"This volume provides a timely and interesting account of a key moment in Charles Darwin's life–and, it might be said, in the history of evolutionary biology. It is especially valuable to encounter the deep local knowledge that the authors bring to the locations they describe. The route Darwin took around the islands comes alive in this book"
Browne, Janet. 2009. Cover endorsement. *Darwin in Galápagos; footsteps to a new world*, by K. Thalia Grant and Gregory B. Estes, Princeton: Princeton University Press.

Martin Wikelski, Max Planck Institute for Ornithology and Konstanz University
"Grant and Estes, the world's authorities on Darwin in Galápagos, put readers in young Darwin's mind and meticulously trace his every footstep. They have the most intimate knowledge about this archipelago and a heartfelt friendship with its most famous visitor. Darwin comes alive in this carefully researched book. A book every Galápagos traveler should read, as should anyone who wants to understand how Darwin became the first evolutionary biologist."
Wikelski, Martin. 2009. Cover endorsement. *Darwin in Galápagos; footsteps to a new world*, by K. Thalia Grant and Gregory B. Estes, Princeton: Princeton University Press.

Jonathan Weiner, author of the *The Beak of the Finch*
"This book is a tale of two journeys: Darwin's in the islands, and the authors' as they retraced his steps. Darwin's, of course, was one of the most important series of footsteps in the history of human exploration. And the journey that Thalia Grant and Greg Estes have made is impressive because they have done so much legwork in the islands and the libraries, and have spent so much of their lives working in the archipelago."
Weiner, Jonathan. 2009. Cover endorsement. *Darwin in Galápagos; footsteps to a new world*, by K. Thalia Grant and Gregory B. Estes, Princeton: Princeton University Press.

Frederick R. Davis, associate professor in the Department of History at Florida State University
"The authors were meticulously empirical in their approach to researching and writing Darwin in Galápagos. Rather than speculating what Darwin might have seen upon visiting certain islands (as other historians have done), Grant and Estes ponder Darwin's choices. There is, for example, considerable evidence that some species that abound in the islands today were equally abundant, if not more so, during Darwin's visit, yet he declined to note their presence, despite references to them in other places on his long voyage. The authors note Darwin's preoccupation with the geology of the islands as one explanation for his lack of interest in common organisms, but he was also focused on life that was unique to Galápagos."
Davis, F. R. 2010. Darwin in Galápagos: Footsteps to A New World (review). Cary: Oxford University Press.

Lyall Anderson, Isaac Newton Trust Research Fellow, University of Cambridge
"…the strength of this account lies in the fact that equal weighting is given to Darwin's geological and zoological explorations. Much of what Darwin theorized about geology will probably come as quite a surprise to many. For example, on James Island (Santiago), he collected evidence to support his theory of the generation of different lavas from the same magma through fractional crystallization. Other observations relate to the formation and evolution of tuff cones from subaqueous through to terrestrial settings."
Anderson, L. I. 2010. Darwin in Galápagos: Footsteps to a new world (review) *Palaeontology Newsletter,* 73, 86-88

Rick MacPherson, *Conservation Programs Director for the Coral Reef Alliance*
"A faithful, detailed recreation of Darwin's course once ashore on each island had never before been attempted. The authors went about ascertaining what paths Darwin took by referring to his unpublished geology notes, Captain Robert FitzRoy's log of the *Beagle* and the nautical charts of the area prepared by the crew, and by relying on their own familiarity with the topography, ecology, habitats and distribution of organisms on each of the four islands… With its numerous illustrations, photographs, maps, archival notes and sketches, and its day-by-day, step-by-step, island-by-island retracing of Darwin's Galapagos explorations and thinking, *Darwin in Galapagos* is an important addition to the history of evolutionary thought."
MacPherson, R. 2010. Darwin's Islands. American Scientists. Research Triangle Park: Sigma Xi Scientific Research Society

Richard A. Richards, Professor of Philosophy, University of Alabama and author of *The Species Problem: A Philosophical Analysis*

"Darwin in Galapagos: Footsteps to a New World provides "new insights into an important period of Darwin's life—the five weeks he spent exploring the Galápagos Islands in 1835."
Richards, R. A. 2010. Darwin in Galápagos: Footsteps to a New World (review)
The Quarterly Review of Biology 85. 342-343

Frank W. Nicholas, Emeritus Professor Genetics Laboratory University of Sydney

"We now have a single, detailed reference book for a very important episode in Darwin's life and work. no serious Darwin library or scholar should be without Darwin in Galápagos. "
Nicholas, F. W. 2011. Darwin in Galápagos: Footsteps to a New World (review). Victorian Studies, 54, 145-147

Randy Moore, H.T. Morse-Alumni Distinguished Professor of Biology, University of Minnesota

"Darwin in Galapagos: Footsteps to a New World is a readable, scholarly account of Charles Darwin's adventures in the Galapagos Islands. Unlike some of the other Darwin-related books of the past two years, Darwin in Galapagos covers new ground; it is the only book to meticulously retrace Darwin's five-week tour of Galapagos from 15 September to 20 October 1835."
Moore, R. 2011. Darwin in Galápagos: Footsepts to a New World. (review). University of California Press

APPENDIX IV

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