# The Galápagos for University Students

# The Galápagos for University Students:

*A Comprehensive Exploration*

By

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and Avelina Espinosa

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To the college and university students who visit the Galápagos to explore an unparalleled archipelago; to learn about its natural wonders and rich human history, from its discovery by Tomás de Berlanga in 1535 to Charles Darwin's arrival in 1835, Herman Melville's presence as a whaler in 1841, and World War II during the 1940s, when the United States established a military base in Baltra Island; to witness its breathtaking volcanoes, lava flows, and caves; to reflect on the origins of the enormous prickly-pear *Opuntia* or the *Scalesia* forests in the islands' highlands; to swim with amusing sea lions, fur seals, and penguins; to scuba dive among sharks, dolphins, orcas, giant mantas, and sea turtles; to hike on rocky shores covered in thousands of marine iguanas; to take close-up shots of giant tortoises, land iguanas, lava lizards, and albatrosses; to see up-close flamingos, boobies, frigatebirds, hawks, owls, finches, vermilion flycatchers, or carpenter bees; and to have one of the most thrilling experiences a World Heritage Site—the Galápagos—can offer.

To the university students of Ecuador and Galápagos—*ecuatorianos galapagueños*—who possess the archipelago as their own and have the forever responsibility of protecting.

To the college and university instructors—from all over the world—who motivate their students to travel to Galápagos and see, with their youthful yet inquisitive eyes, the "little world within itself", as Charles Darwin characterized it in *Journal of Researchers* (1839). Darwin himself was quite young—26 years old—when visiting the islands from September 15 to October 20, 1835.

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# ACKNOWLEDGEMENTS

We thank the Galápagos National Park (GNP) for leading and facilitating the conservation, research, and outreach programs in the Galápagos Archipelago and its Marine Reserve (GMR). The park officials and rangers, as well as the naturalist guides [licensed by GNP], are essential to the administration, preservation, and management of the fragile terrestrial and aquatic ecosystems. GNP's work is central to seeking harmony between environmental protection and sustainable human development, a constant challenge. The 60-year partnership between the GNP Directorate (GNPD) and the Charles Darwin Foundation (CDF, an international non-profit) has been vital to the scientific work, design, and implementation of management plans and conservation programs in Galápagos.

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Funding for our academic development and research programs can be traced back to the 1980s and up to 2020s, chronologically: Jersey Zoo, Jersey Wildlife Preservation Trust (=Durrell Wildlife Conservation Trust) and Wildlife Preservation Trust International; Wildlife Conservation Society; International Center for Tropical Ecology [current Harris World Ecology Center] and Compton Foundation (via UM-St. Louis); MERCK-AAAS USRA (American Association for the Advancement of Science); American Society of Microbiology URF; Rhode Island INBRE and National Institutes of Health (NIH-NIGMS #2P20GM103430); Rhode Island National Science Foundation NSF EPSCoR (EPS-1004057); Rhode Island Inclusive Network for Excellence in Science & Technology (NSF RII-NEST #2433276); and the RWU Foundation to Promote Scholarship.

We value the work conducted by the New Bedford Whaling Museum; its exhibits highlight the relevance of world whaling over centuries. Most of the images included in Chapter Four (*What Happened in Galápagos Before and After Darwin?*), in which we discuss the industry of whaling (from pursuing whales to hunting them and processing their parts) and its past environmental impacts on the Galápagos, were taken at the museum. On various occasions, Bob Rocha, former head of Education and Science Programs and current Associate Curator of Science and Research, introduced our students to the museum's displays and shared fascinating stories about whaling, whalers, and whales.

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We thank the hundreds of scientists, conservation biologists, and wildlife managers who authored the peer-reviewed articles cited in this book (496 total references). We relied on their work to synthesize, integrate, and conceptualize (1) the most recent natural history research being conducted in the Galápagos' terrestrial and aquatic environments and (2) the conflicts resulting from human interactions with nature, including local population growth and tourism practices in the context of short- and long-term conservation efforts. We also (3) make predictions about the destiny of the Galápagos' unique biodiversity and landscapes under various scenarios of climate change impacts, urbanization trends, diversification of tourism, and conservation investments.

We thank Francisco Dousdebés for sharing with us the photo of Tomás de Berlanga's statue (Chapter Two, *How Were the y$^{a}$s de galapagos Discovered?*). The Syndics of Cambridge University Library for allowing us to reproduce two images (the leather cover and page number 36) from Charles Darwin's 1837-8 Notebook B: Transmutation (Chapter Three, *Why Was Charles Darwin's Visit to Galápagos Significant?*). Photographer Ian Wiese for the aerial image of "Blue Whale Releasing a Fecal Plume" (Chapter Four, *What Happened in Galápagos Before and After Darwin?*)! Gustavo Jiménez-Uzcátegui, Ecuadorian wildlife veterinarian and researcher at the Charles Darwin Foundation, helped us identify checklists and studies on the endemic species of the Galápagos (Chapter Eight, *What Is the Conservation Value of the Galápagos?*). Alex Hearn shared with us information about the 2021 proposal for the expansion of the Galápagos Marine Reserve (Chapter Eleven, *What Can You Do to Help Galápagos?*). Arturo Izurieta, former Director of the Galápagos National Park, responded to our queries about the future of conservation efforts in the Galápagos; his perspective helped us shape a more comprehensive view of the challenges of managing the National Park and its Marine Reserve (Chapter Twelve, *Can the "Little World Within Itself" Be Saved Forever?*).

Several of the historic photographs in Chapter Five (*Why Did the United States Establish a Military Base in Galápagos During World War II?*) are broadly available online at multiple depositories, as we provide links in Appendix A. We highlight that book author and historian John Woram compiled a great initial collection of these images on his Galápagos website (www.galapagos.to), unfortunately no longer available.

We acknowledge the significance of having interacted with thousands of students in our science courses (fieldwork, laboratories, and classrooms). We are proud that many of them, graduate and undergraduate, are now researchers in academia at world-renowned institutions.

During the first year of the COVID-19 pandemic, in 2020, caused by coronavirus SARS-CoV-2, we spent much time at our home in Rhode Island, social distancing and working intensely on our "Galápagos books". We followed the daily statistics on global cases, fatalities, recovered patients, and financial sequels of the disease; we shared that information on social media and discussed it with our colleagues and friends. Looking back, SARS-CoV-2 transformed our communities, and Galápagos was no exception. Tourism, the main or only source of income for thousands of galapagueños, ceased [visitors dropped from 271,000 in 2019 to 73,000 in 2020; ≈80% of the local economy depended on tourism at that time, with $356 US million/year generated by tourism alone]; airports and ports closed, except for transporting essentials; islanders became even more isolated; and visiting scientists, students, and tourists were trapped for months in the islands. From February 2020 to September 2021, 1,485 cases of coronavirus were accounted for in the archipelago and 17 deaths (Ecuador's total cases were 503,767 and 32,351 deaths). Galápagos' tourism recovered by 2022 and reached record-high numbers in 2023.

This is our fifth academic volume printed at Cambridge Scholars Publishing, United Kingdom. The books are distributed worldwide.

Thanks to all.

# PREFACE

This volume is an abridgement of our academic books, *Arrivals of Life to the Galápagos* and *A Synthesis of the Galápagos*, printed as hardbacks and paperbacks (2024/2025) by Cambridge Scholars Publishing. What is new in the current volume, *Galápagos for University Students*? The abridgment itself, which has been adapted for motivated undergraduates and their instructors, as well as the approach to the book, which relies on questions, answers, discussions, and observation projects. Each chapter begins with a question. The volume offers 280 figures and 733 subfigures, 15 tables, 30 analytical questions, including perspectives from which to answer them, 20 discussion topics (argumentative format), 24 observation projects to be conducted while visiting the islands [always respecting the regulations that protect the Galápagos National Park and its Marine Reserve] or as library-work activities, 9 terminology/content boxes, and 496 references. We have also structured the book for a broad college and university audience, including research undergraduates, graduate students (i.e. master's degrees), their instructors and mentors (professors, lecturers, and postdocs interested in teaching), as well as study-abroad students and international field-trip instructors (i.e. multidisciplinary academic programs) who travel to the Galápagos from all over the world.

The length and chapter organization make the book suitable for seminars and/or laboratory discussions facilitated by a college/university instructor; keep in mind that some chapters are extensive, e.g., Chapter One, *What Are the Galápagos Islands?* (101 pages), or Chapter Eight, *What Is the Conservation Value of the Galápagos?* (149 pages). Because the chapters increase in complexity, we recommend the reader explore them in order. However, we have also organized the material to be read independently by chapter (i.e. by the more experienced reader). For that reason, throughout the book, we deliberately reinforce concepts and summarize content (e.g. meaning of acronyms, synopsis of figures, tables, and data from previous sections) and frequently advise the reader to explore figures in a specific manner. We include dialog boxes to highlight the central message of the figures and/or expedite the interpretation of the statistics (the latter kept to a minimum).

## Structure and Content of the Book

This volume has 12 chapters and 2 appendixes (*Appendix A: Figures' Notes and Sources*, and *Appendix B: Galápagos National Park Rules*). All chapters include a conclusion(s) section followed by questions, answers, discussions, and observation projects. The questions are analytical and challenging to the reader. As we state at the beginning of each **Questions** section, "*the following questions merit generous written answers. You might need to do additional reading or library work to enrich your answers (we suggest exploring...* the following references*)*". In the answers section of each chapter (i.e. **How to Answer the Questions Above**), we indicate, "*The questions above have various possible answers. Here we suggest perspectives from which to address the queries*". In other words, the student reader is encouraged to envision alternative answers to the questions. In the **Discussion Topics** section, we indicate, "*The discussion topics below should be addressed with your peers. We encourage college instructors to facilitate the dialogue*". And in the **Suggested Observation Projects**, we emphasize, "*…The suggested observation projects below take into consideration that you will travel to Ecuador and the Galápagos legally; that you will visit the islands as a tourist [holding a Transit Control Card, a mandatory document issued by Ecuador and specifically by the Governing Council of Galápagos]; and that you will respect the regulations that protect the Galápagos National Park and the Marine Reserve (see complete list of rules in Appendix B). Only accredited scientists, academics, and/or naturalists who have obtained official permits can do research in Galápagos. You can take pictures, but flash photography is not permitted when taking photos of wildlife. Professional photography and videos recorded for commercial purposes must be authorized by the Galápagos National Park Directorate. The ideas below are for enthusiastic college explorers interested in learning about the archipelago*".

We begin the book by asking, *What Are the Galápagos Islands?* (**Chapter One**). The chapter is extensive, and in it we cover seven main topics: (i) Plate tectonics as they relate to the archipelago's formation; subtopics include: *The Origin of the Islands*. *The Galápagos Hotspot*. *The Galápagos Plateau and Its Proximate Ridges*. *Age and Formation of the Current Islands*. (ii) Volcanism; subtopics: *Volcanoes Uplift or Subside*. *Caldera-Volcanoes and Volcanoes without Calderas*. *Underwater Volcanoes, Seamounts, and Guyots*. (iii) Caves' formation and soils; subtopics: *Lava-Tube Caves or "Pyroducts"*. *Soils: Younger vs. Older Islands*. (iv) An overview of the archipelago as seen from space and how to outline it; subtopics: *Zooming Out: Islands Visible from Space*. *Sketching Today's Archipelago*. (v) Features of the surrounding ocean; subtopics: *The Ocean and Its Turbulent Waters*. *The Upwelling*. (vi) Biogeography; subtopics: *Origins of the Galápagos Biota*. And (vii) islands' topography, seasonality, and vegetation; subtopics: *Zooming In: The Islands' Appearance at First Glance*. *The "Hot" and "Cool" Seasons*. *Vegetation Cover*. *A Uniquely Well-Preserved Mangrove Forest*.

In **Chapter Two**, *How Were the y*$^{a}$*s de galapagos Discovered?*, we travel back in time 490 years, to 1535, when Tomás de Berlanga—Bishop of Panama—and his crew arrived adrift in unknown islands. In a colorful letter to Carlos/Charles I King of Spain, dated April 26, 1535, the Bishop wrote: "*IT seemed right to me to let Your Majesty know about the course of my trip since I departed from Panama, on the twenty-third of February of the current year* [1535]... [Our] *ship sailed with very good breezes for seven days, and the pilot kept course near land and* [then] *we had calm for six days; the currents were so strong, and engulfed us in such a way, that on Wednesday the tenth of March we sighted an island* [likely today's Española/Hood]*; and, because on board there was water for only two more days, it was agreed to take down the lifeboat and go on land for water and grass for the horses. And once there, the men found nothing but sea lions, and turtles and galápagos* [gəˈläpəˌgəs=the giant tortoises] *so big that each could carry a man on top, and many iguanas that look like serpents...*" Berlanga's adventure also helps us introduce readers to the Galápagos early cartography, like the "Portolan Chart of the Pacific Coast from Guatemala to Northern Peru" (1565), in which the "*y*$^{a}$*s de galapagos*" or "*isles of galapagos*" [isles of the tortoises] were depicted (*galapagos* = tortoise).

In *Why Was Charles Darwin's Visit to Galápagos Significant?* (**Chapter Three**), we examine Darwin's exploration of the Galápagos Archipelago from September 15 to October 20, 1535. But first, we set the record straight: Robert FitzRoy, Captain of Her Majesty's Ship (HMS) Beagle and head of the vessel's surveying voyage around the world (1831 to 1836), which included the exploration of the Galápagos Islands, had requested and been granted by the British Admiralty permission to bring Mr. Darwin—as naturalist—on board. Four years later, Darwin wrote in *Journal of Researchers* (1839) "*The natural history of this archipelago is very remarkable: it seems to be a little world within itself; the greater number of its inhabitants, both vegetable and animal, being found nowhere else*". The Beagle's voyage, FitzRoy's command, Darwin's brilliance, and the uniqueness of the Galápagos Islands all merged in history. The notion of evolution by means of natural selection, which

Darwin conceptualized later in life (*The Origin* 1859), can now be broadly applied to nature. The "*great monsters*" and "*a little world within itself*", as he referred to the giant tortoises and the isles (1839), are now exemplars of natural history. Today, the theory of evolution by means of natural selection is attributed to both Charles Darwin and Alfred Russell Wallace (co-discoverers of natural selection). Ever since Darwin and Wallace, however, our collective understanding of evolution has changed significantly at the molecular, genetic, organismal, ecosystem, global, and cosmic levels.

In **Chapter Four**, What Happened in Galápagos Before and After Darwin?, we remind readers that "[m]uch happened in [the archipelago] before and after Darwin's short visit—as a naturalist on board HMS Beagle under the command of Captain Robert FitzRoy…" For example, "[T]hree hundred years earlier, the islands were accidentally discovered, in 1535, by Tomás de Berlanga and his crew… And just three years prior to the Beagle's arrival, Ecuador claimed possession of the Archipelago of Ecuador (…) on February 12, 1832... During World War II, the United States established a military base on Baltra [Seymour] Island from 1942 to 1946… In 1959, Ecuador created the Galápagos National Park; by 1978, UNESCO declared Galápagos a World Heritage Site… A few decades later, coinciding with the tourism boom (1980s to 2000s), the local population increased significantly, from 5,545 in 1982 to 28,583 in 2024. Tourism grew from 42,000 visitors in 1989 to 276,000 in 2018. The COVID-19 pandemic reduced tourism to 73,000 visitors in 2020, but trends recovered by 2025…" And finally, we state, "There is one distinctive human activity that took place globally and affected the Galápagos' natural history prior to, during, and after Darwin's visit: whaling!" In Chapter Four, "we discuss industrial whaling as it covered the world's oceans ("Global Whaling: 1760s to 1920s") and its impacts on the Galápagos Islands—also known as "Whaling Ground 38".

In **Chapter Five**, we address: *Why Did the United States Establish a Military Base in Galápagos During World War II?* By the end of the 1800s, the Galápagos Archipelago had gained geopolitical value due to its strategic location in the Tropical Eastern Pacific and with respect to the soon-to-be-constructed Panama Canal. Ecuador was approached by England (early 1900s), France (1898), and the United States (1899) to negotiate the islands as either payment for Ecuador's debt with England (after England financed Ecuador's war of independence with Spain), purchase an island for France, or lease one island for the United States. In 1911, the US proposed another lease—for 99 years, which was not accepted by Ecuador. After the Japanese attack on Pearl Harbor in 1941, Ecuador signed an agreement with the United States for the establishment, in 1942, of US military bases on Seymour (Baltra or "The Rock") Island (Galápagos) and Salinas (mainland Ecuador) to protect the Panama Canal and its surroundings. By 1944, the United States had prepared a draft of a "*bilateral agreement for the leasing of* [military] *bases on Ecuadorian territory over a period of 99 years*". The idea was not accepted by Ecuador, and two years later, in 1946, Ecuador requested the US "*withdrawal from Galápagos*". The US officially returned Baltra to Ecuador on July 1, 1946. All American personnel had left Galápagos by 1948. "The Rock" of the 1940s is nowadays a memory of WWII as well as a symbol of sovereignty—for Ecuador—with a complex past. Geopolitically, however, the destiny of the Tropical Eastern Pacific—and its multiple strategic locations, including the Galápagos Archipelago—will remain uncertain. Regional or global interests in this particular geographic space could manifest again in response to circumstantial change.

In **Chapter Six**, Who Lives in Today's Galápagos Islands?, we explain that "The Galápagos human population [has] increased from 17,451 inhabitants in 2001 to 23,046 in 2010 and to 25,244 in 2015. By 2022, it reached 28,583". We also highlight historical trends; for example, "[F]rom 1950 to 2015, the islands' population increased 19-fold. The fastest rate occurred between 1982 (4.0%) and 2001 (6.4%). By 2010, the speed of population growth declined to 3.1% and to 1.8% in 2015. It was 1.6% in 2022. The boost during the 1980s-1990s overlapped with the tourism boom. The decline by 2010/2015 corresponded to enhanced age-cohort-specific emigration (ages 15/17-24), presumably to pursue higher education or jobs elsewhere. Despite the decline in growth rate from 2010 to 2015, the population experienced a net gain of 2,576 individuals during that time. It was driven by higher immigration (3,368 people) than emigration (792 people). Between 2015 and 2022, the population increased by 3,339 individuals". We also state in the chapter that "When humans arrive, transformations of the environment follow", [and that] "[i]n contrast to other island groups discussed in [the chapter], Galápagos remains [relatively] well preserved... But [we alert readers that] just like Galápagos, [other] archipelagos mentioned [in Chapter Six] (Seychelles, Madeira & Selvagens, Azores, Cape Verde, Mascarenes, Canaries, or Hawai'i), once imposing and with matchless wilderness, started their journeys into the Anthropocene with very few human settlers. They were, too, discovered as uninhabited islands, although at different times during history, and gradually became colonized…"

The question, *Why Is Nature Tourism Essential to Galápagos?*, is addressed in **Chapter Seven**. Galápagos' subsistence is powered by tourism. In 2018—a record-high year before the COVID-19 pandemic—275,817 visitors arrived in the archipelago. By 2019, total arrivals dropped to 271,238 visitors. By 2020, arrivals decreased to 72,519 visitors (3.8 times below 2018). By 2021, arrivals had partially recovered to 136,336 visitors (49.4% with respect to 2018). And by 2022, they reached 267,688 visitors (97% with respect to 2018). An expected post-pandemic boost occurred in 2023, with an all-time record high of 329,477 arrivals. During 2024, the numbers decreased to 279,277 visitors, suggesting tourism trends were normalizing after COVID-19. In 2019, the Galápagos National Park alone generated $356 million USD, ≈60% of the profit produced by all protected areas in Ecuador. There was a direct benefit connection between the "entrance fee" [for tourists] to the Galápagos National Park and *in situ* conservation and administration work. In 2024, the fee generated $21.1 million USD; half of it went to the National Park itself (conservation programs, infrastructure, education and outreach activities, and salaries = jobs). In 2018-2019, 63% of Galápagos' tourism-related businesses (*N*=874) were hotels, lodges, and travel agencies; the rest were restaurants and bars (15%), small boats for transportation (12%), boats and ships with on-board stays while exploring/sightseeing the archipelago (9%), and transportation on land (1%). An estimated total of 3,955 jobs were directly created by Galápagos' tourism in 2018-2019, 60% of them at hotels, lodges, and on-board boats and ships. An important component of the tourism workforce was the naturalist guides; about 817 were licensed by the Galápagos National Park by 2019; however, not all were active or employed concurrently. Note that the boats and ships with on-board stays (cruises) employed 394 naturalists (48% of the total licensed ones) during 2019.

Now, the cautionary conservation and sustainability message, in terms of Galápagos' local population growth (Chapter Six) and tourism trends (Chapter Seven), can be summarized as follows: (1) If most of the Galápagos' ecosystems remain legally protected and restoration and reintroduction programs continue, the essence of the archipelago has a chance to make it into the future. (2) If the State of Ecuador continues to own and administer the land under low-impact development ideals, the exceptionally unique Galápagos will be exposed to manageable habitat alteration. (3) If human presence in the islands remains at low numbers and density, Galápagos could persist long-term. (4) If tourism continues to be eco-friendly, small-scale, and respectful of both the fragile terrestrial/marine habitats and the local people, Galápagos could offer for centuries the possibility of being explored by those who love and value nature. But (5) if Galápagos chooses the path of fast unsustainable change, urban crowding leading to occupation of additional land, and eco-unfriendly tourism (amusement, entertainment), or if it is persuaded by local or international investors to mimic or resemble other oceanic, volcanic archipelagos discussed in chapters Six and Seven [e.g. Hawai'i, Cape Verde, Canaries, Madeira & Selvagens, Azores, Seychelles, Mascarenes, including in some cases their mall-shopping, spring-break, or night-life tourism; or their outdoor recreation practices and water sports: windsurfing, kiteboarding, jet-skiing, parasailing, wakeboarding, waterskiing, bumper-tube riding, fly-boarding with hydro-flight aqua-jet propulsion or jet-pack flying], its destiny will be comparable. It will be a matter of time.

The question, *What Is the Conservation Value of the Galápagos?*, is addressed in **Chapter Eight**, the longest of the book. In 1978, the United Nations Educational, Scientific and Cultural Organization (UNESCO) designated Galápagos a World Heritage Site. "…*World Heritage is the designation for places on Earth that are of outstanding universal value to humanity and, as such, have been inscribed on the World Heritage List to be protected for future generations to appreciate and enjoy*…" UNESCO describes Galápagos' "Outstanding Universal Value" as follows: "…*This archipelago and its immense marine reserve is known as the unique 'living museum and showcase of evolution'. Its geographical location at the confluence of... ocean currents makes it one of the richest marine ecosystems in the world. Ongoing seismic and volcanic activity reflects the processes that formed the islands. These processes, together with the… isolation of the islands, led to the development of* [matchless] *plant and animal life—such as marine iguanas, flightless cormorants, giant tortoises, huge cacti, endemic trees and the many different subspecies of mockingbirds and finches*…" The World Heritage Convention (WHC, an international treaty) highlights four criteria (VII, VIII, IX, and X) that warrant Galápagos' designation as a World Heritage Site. Criterion VII is about the spectacular underwater wildlife and seascape features of the Galápagos. Criterion VIII highlights its plate tectonics, volcanism, and ongoing geomorphological processes. Criterion IX focuses on the ecological, evolutionary, and biogeographic [processes and] characteristics of terrestrial and marine environments. And Criterion X underlines the local biodiversity and endemism and the conservation status of the flora and fauna. In the chapter, we integrate all these premises with yet another question: "*By preserving the Galápagos Archipelago and its Marine Reserve, what are we really safeguarding?*" We respond by examining three particular areas: biodiversity, endemism, and ecosystem functions.

*What Are the Main Conservation Problems in Galápagos?* We address this question in **Chapter Nine**. The archipelago has multiple conservationrelated problems, broadly including: The impacts of climate change on the local habitats, the people living on the islands, and their means of subsistence (agriculture, artisanal fishing, and tourism). Large-scale predatory fishing in the vicinity of the Galápagos Marine Reserve (particularly by international fisheries). Macro- and microplastics in the ocean, permeating all trophic levels (globally and in Galápagos). Unmanageable local population growth in the islands of Santa Cruz, San Cristóbal, and Isabela. Increasing eco-unfriendly tourism. Wildlife trade (e.g. baby giant tortoises, which are smuggled for the global market). Illegal drug trafficking in the Tropical Eastern Pacific that has targeted the archipelago as a steppingstone on its way to international consumers. And geopolitical instability in the region (part of it derived from drug trafficking). These problems pose unprecedented threats to the Galápagos and all entail human conflict with nature! In Chapter Nine, we examine, in detail, 12 case studies regarding conservation problems in the islands. Some are local problems; others are regional or global and affect the archipelago directly or indirectly. Their subtitles include: *Introduced Species: 1535 Onwards*. *Invasive Species at World Heritage Sites*. *The Global Decline of Shark Populations*. *The Fu Yuan Yu Leng 999 and the Shark-Fin Market*. *Tuna Fisheries Around the Galápagos Marine Reserve*. *The Decline of Sea Lions and Fur Seals*. *Wildlife Trade: Tortoises and Iguanas for Sale*. *Wildlife Roadkills: Homo the Driver in Galápagos*. *Oceans' Microplastics Reach Galápagos*. *Microplastics in the Guts and Tissues of Marine Life: Coastal Ecuador and Galápagos*. *Macroplastics Present in All Galápagos Islands*. And *Plastics Ingested and Uptaken by All Trophic Levels*.

In **Chapter Ten**, *How Will Climate Change Affect Galápagos?*, we explain that, in Galápagos, climate change will impact almost all aspects of human life and people's interactions with nature. We highlight that the local economy is powered—almost entirely—by nature tourism. Extreme weather (severe hot-rainy and cool-dry seasons) and sea-level rise will bring stress to both natural habitats and human settlements. Frequent rainstorms will affect buildings, harbors, homes, and infrastructure connectivity; sewage pipes will break and lead to further contamination of the drinking water (already a problem in Galápagos). Nature hiking or biking trails in the areas open to visitors will have to be repaired or rebuilt, as will viewing platforms, observation decks, and interpretive signs (additional costs to the Galápagos National Park). Economic losses will impact tour/expedition providers, hotels, restaurants, groceries and fish markets, shops, and cultivated areas. Food supply to the islands, either coming from the continent or being distributed within the archipelago, will be affected by extreme weather (e.g. more turbulent seas will lead to longer journeys, extra use of fuel, and higher market prices for goods and supplies). Depending on the severity of climate change impacts on the human population (e.g. if tourism drops significantly or collapses due to natural disasters, combined with large-scale loss of farmlands to urbanization as well as inflated costs of living), future sizeable emigration back to the continent could result—the eco-exodus or environmental refugees. Climate change will accentuate differential financial stress among dissimilar income groups. Socio-economic inequality and unemployment could grow, as could social tensions and the lack of safety and security for the public and tourists. In Chapter Ten, we also elaborated on two particular topics regarding climate-change impacts on both terrestrial and marine ecosystems in the Galápagos: *Extreme Weather and Its Sequels* and *Impacts of Climate Change on Coral Reefs*. The central point of these topics is that the Galápagos Islands are warming up and—for now—becoming rather dry, but "extreme wet" will prevail long-term. The archipelago appears to be destined to less rain during the cool-dry season (drier archipelago for now), combined with a delay in the onset of the hot-wet season (rains will start later), plus a mix of severe hot-wet seasons during more frequent El Niño years and intense cool-dry seasons during La Niña years. Climate change will bring extreme variation in seasonality to Galápagos and affect both wildlife and humans!

In **Chapter Eleven**, *What Can You Do to Help Galápagos?*, we remind readers that the principle "think globally, act locally" applies to the archipelago and its Marine Reserve. We state *"Now, to be most effective helping the Galápagos, you will need to think and act globally as well as think and act regionally and locally. The global context will be, of course, planet Earth. The regional setting will be the Tropical Eastern Pacific (TEP), where Galápagos is located; TEP will also include the proximate countries, those with jurisdiction over the TEP maritime zones (i.e. territorial waters/sea and exclusive economic zones), like Ecuador, Colombia, Panama, and Costa Rica. And the local scale will correspond to both Galápagos itself, whenever you visit it and explore it as a citizen of the world, and your own community wherever you reside"*. In the chapter, we make specific recommendations under the following subtitles: *Think and Act Globally: Planet Earth*. *Think and Act Regionally: TEP and Proximate Countries*. And *Think and Act Locally: Galápagos and Your Own Community Wherever You Reside*.

We end the book by addressing: *Can the "Little World Within Itself" Be Saved Forever?* (**Chapter Twelve**). And we ask and answer yet again familiar questions to the reader, such as, Will this World Heritage Site be the one that forever-survives? Will Galápagos be different? Will its caretakers and policymakers not mimic the mistakes that nature custodians have made in other volcanic archipelagos, where pristine ecosystems and endemic wildlife have substantially disappeared while being replaced by large towns and cities, conventional tourism resorts, highways, and introduced species? Will the Galápagos' people, Ecuador, and the world commit to safeguarding and managing the archipelago and its marine reserve so that sound sustainable development practices limit human population expansion on the islands, sponsor solely eco-friendly tourism, and secure revenue fairness for the residents? We close by returning to Darwin and stating, "*Regardless of humans surviving the Anthropocene (e.g. the consequences of climate change, mass extinctions, or warfare) or global catastrophic events (e.g. Earth's collisions with asteroids, which will probabilistically happen long-term), ecological and evolutionary processes will continue in future Galápagos archipelagos, of course on a planet already scarred by human presence. But these realities can inspire us to pledge our existence to the health of the Earth"* (…). *As Charles Darwin reflected in the Journal of Researchers (1839), just four years after exploring the Galápagos in 1835,* [t]*he natural history of this archipelago is very remarkable: it seems to be a little world within itself; the greater number of its inhabitants, both vegetable and animal, being found nowhere else* (…). *Indeed, a little world, the only one we have, is worth saving forever*".

Guillermo Paz-y-Miño-C
Avelina Espinosa

# CHAPTER ONE

# WHAT ARE THE GALÁPAGOS ISLANDS?

The Galápagos Islands are a volcanic oceanic archipelago located in the Tropical Eastern Pacific, 900 km (560 mi) off coastal Ecuador, near the equator (latitude 0°), and at longitude 91° West (Fig. 1.1; terminology in Box 1.1). The Republic of Ecuador claimed jurisdiction over the islands in 1832. Galápagos belongs to Ecuador (Paz-y-Miño-C and Espinosa 2024a)!


**Fig. 1-1** Location of the Galápagos Islands with respect to the Tropical Eastern Pacific and the proximate mainland (South and Central America). The volcanic and oceanic archipelago is situated 900 km (560 mi) off coastal Ecuador (latitude 0° and longitude 91° West). Galápagos belongs to Ecuador. Design: GPC.

In Fig. 1.2, we summarize some descriptive distances characteristic of the archipelago and provide both the most common Spanish and English names of the main islands, as follows: (1) East and Southeastern Islands: San Cristóbal (Chatham), Floreana (Charles), and Española (Hood); (2) Central Islands: Santiago or San Salvador (James), Santa Cruz (Indefatigable), Baltra (Seymour South or South Seymour), Seymour (Seymour North or North Seymour), Rábida (Jervis), Pinzón (Duncan), and Santa Fé (Barrington); (3) Western Islands: Isabela (Albemarle) and Fernandina (Narborough); (4) Northern Islands: Marchena (Bindloe), Pinta (Abingdon), and Genovesa (Tower); and (5) Northwestern Islands: Darwin (Culpepper) and Wolf (Wenman; Paz-y-Miño-C and Espinosa 2024a).

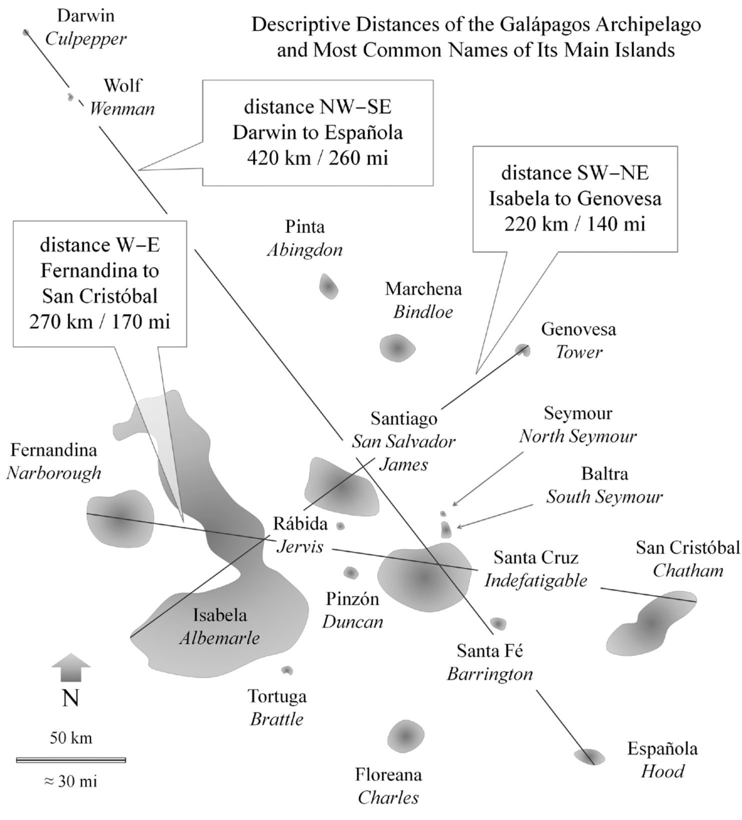


**Fig. 1-2** Descriptive distances of the Galápagos Archipelago and most commonly used Spanish and English (*italics*) names of the main islands. Sketch: GPC.

**Box 1-1** Essential terminology for this chapter.

***Bioregions***. Areas with distinctive biodiversity, biogeography, and ecology. Here we discuss bioregions within the Galápagos Marine Reserve (GMR). Biologists have proposed the existence of five bioregions in GMR, i.e. based on the species composition and abundance of fishes and macro-invertebrates (Far North, North, West, Elizabeth Bay, and Southeast; sketch in Box 1.3).

***Erosional terraces***. Flat or sub flat areas along the slopes of an underwater mountain (seamount) formed after the accumulation of sediments. In Galápagos, underwater mountains (i.e. long-gone islands primarily located to the East of the archipelago) have erosional terraces. Galápagos' seamounts have been exposed to seashore wear [inducer of sedimentation] during millions of years.

***Hydrothermal vents***. Bottom-of-the-ocean cracks [proximate to volcanic areas] through which hot water discharges. As the vent-water ascends, it reacts with magmatic rocks beneath the seabed and mixes up with chemicals (multiple compounds, particles, and gases result). This "hot buoyant mix" rises, often vigorously. Some hydrothermal vents have "chimneys", which are built up from the sedimentation of particles (sketch in Box 1.2).

***Microbes (bacteria, Archaea, and protists) and their viruses***. Unicellular organisms and their specialized viruses. Bacteria and Archaea lack nuclei. They are phylogenetically distinct from one another. Protists are unicells with nuclei. Microbes and their viruses are the foundation of ecological communities.

***Oceanic vs. continental islands***. Oceanic islands like the Galápagos originate from volcanic activity, i.e. a hotspot that pierces the bottom-of-the-ocean crust (Fig. 1.4). These islands have not been part of a continent. By contrast, continental islands form from the fragmentation of a continental landmass (e.g. Tasmania was once part of the Australian continent).

***Pyroducts***. Or lava tubes. Pyroducts form when lava (molten rock) descends the flanks of a volcano (like a "stream" or "river"). If the surface of the lava-flow cools down and crystallizes, a rock "ceiling" would form, while molten rock continues to flow beneath. After the eruption ceases and the pyroduct empties, a "lava cave" will remain (sketches in Figs. 1.14 to 1.16).

***Seamounts and guyots***. Below-the-sea-level mountains [or volcanoes] are often called seamounts. Former volcanic islands now submerged are called guyots.

***Subduction***. Sinking of a tectonic plate [its edge] with respect to another plate [and in the direction of the Earth's mantle]. Plates' edge/edge=subduction zone.

***Tectonic plates***. Or lithospheric plates. Huge slabs of rock (Earth's crust). Each continent or ocean has its own plate (continental or oceanic lithosphere).

## The Origin of the Islands

How did the Galápagos Archipelago originate? As volcanic islands, the Galápagos are product of interactions between tectonic plates (e.g. Nazca, Cocos, South American, Pacific, Antarctic; Fig. 1.3) and a hotspot (i.e. the source of magma that fuels the volcanoes; Fig. 1.4). Examine Fig. 1.3. In it, we offer a close-up look at the location of the Galápagos Archipelago on the Nazca Plate [the islands rest on Nazca] and in relation to the Cocos, South American, Pacific, and Antarctic plates; note the position of the East Pacific Rise (EPR, a submarine volcanic ridge). The Nazca Plate moves East (5.2-7 cm/year or 2-3 in/year); it collides with the South American Plate, which moves in the opposite direction. As Nazca subducts [sinks] under South America, an entire cordillera—nourished by the geological effects of the collision and subduction—rises: the Andes! The interaction with the other plates is less antagonistic. The Cocos Plate travels Northeast, moving away from Nazca, but it does collide with the Caribbean/North American plates in what today is Central America. The Pacific Plate drifts West, away from its boundary with Nazca, the EPR, while the Antarctic Plate slides with Nazca as the former travels East and stumbles upon South America (Paz-y-Miño-C and Espinosa 2024a).

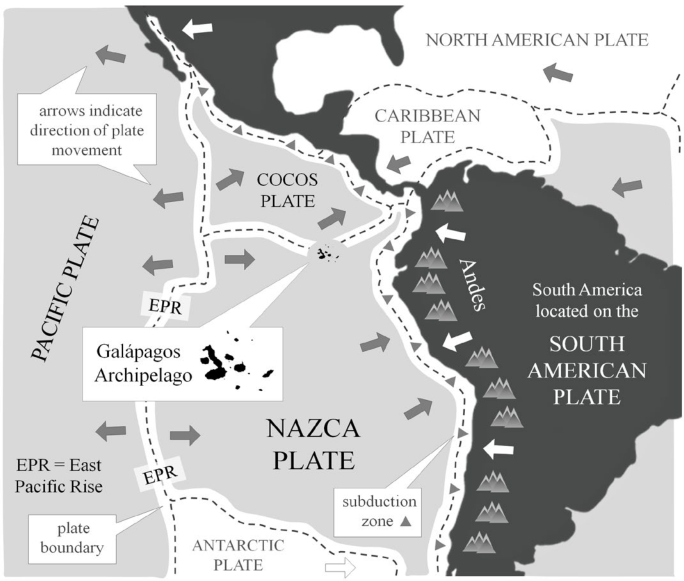


**Fig. 1-3** Location of the Galápagos Archipelago on the Nazca Plate and in relation to the Cocos (N), South American (E), Pacific (W), and Antarctic (S) plates. Arrows=direction of plate movement; triangles=subduction zones. Sketch: GPC.

## The Galápagos Hotspot

Now, bring your attention to Fig. 1.4. In it, we depict a possible mechanism for the origin of the Galápagos hotspot [a hypothesis that applies to other hotspots on Earth, like Hawai'i or the Canaries]. The current islands are young (0.032-4 Ma; =million years), but the hotspot dates to 139 million years. It manifests itself at the crust, although its source of energy is traceable to the planet's mantle-core boundary. The Nazca Plate drifts above the hotspot. The archipelago and hotspot are connected via a heat column—or plume—which expands from the Earth's [outer] core to the upper mantle (after Toulkeridis and Addison 2014; for comprehensive discussion, see Paz-y-Miño-C and Espinosa 2024a).

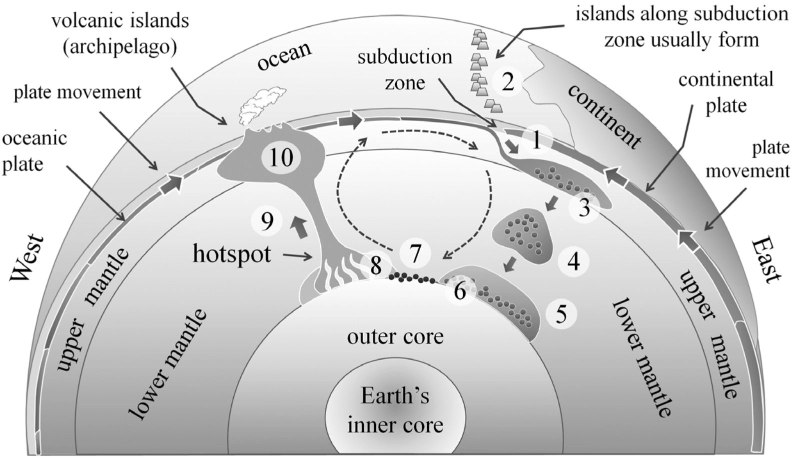


**Fig. 1-4** Possible mechanism for the origin of a hotspot, as applied to the Galápagos Archipelago. (1) an oceanic plate [Nazca] subducts under a neighboring continental plate (gravity takes the oceanic plate down); (2) part of the oceanic plate can form small islands along the subduction zone (proximate to the continent), or (3) it re-melts in the upper mantle; (4) remnants of the plate sink toward the outer core; (5) plate remnants linger at the heat boundary between the lower mantle and the outer core (this takes geological time); (6) heavy elements (e.g. iron) separate as the plate remnants continue to melt; (7) separated heavy elements accumulate at the lower-mantle/outer-core boundary; (8) the lighter, less dense remnants of the former plate rise; (9) the up-rising materials form a heat-column (or plume), anchored at the mantle-core boundary; since the now "hotspot" is hotter than the surrounding mantle, its magma continues to move up; (10) upon contact with the above crust (i.e. the existing plate [Nazca]), the magma perforates it, giving origin to volcanic islands, which are later destined to travel Eastward, erode, sink, and die off as underwater mountains or "seamounts" (this phenomenon can take Ma =

millions of years). Layout: GPC; redrawn and modified after Toulkeridis and Addison (2014). For comprehensive discussion about the geological origin of the Galápagos, see Paz-y-Miño-C and Espinosa (2024a).

## The Galápagos Plateau and Its Proximate Ridges

What does the bottom of the ocean look like in the Galápagos? In Figs. 1.5 and 1.6, we depict the seafloor topography around the archipelago (after Paz-y-Miño-C and Espinosa 2024a). The islands rest on a 1000-m (≈3300-ft) deep platform [plateau], which becomes shallower toward the East (reaching 400-m/≈1300-ft depth; dialog box in Fig. 1.5, center left). We have highlighted contour lines at 500-m to 3000-m depth (≈1600-ft to ≈10,000-ft depth). Keep in mind that the deepest and steepest ocean floor is located to the West and Southwest of the platform (off the plateau), where it reaches >3000 m/10,000 ft depth. Now, focus your attention on the Galápagos Spreading Center, GSC (spreading = diverging, separation between the Nazca and Cocos plates), a mid-ocean ridge apparently formed 23-25 Ma [keep in mind that both GSC and EPR, the latter mentioned above, are submarine geological formations]. GSC expands ≈1400 km (≈900 mi) from longitude 98° to 86° West (full expansion not shown in Fig. 1.5). To its West (at 98° W), the spreading rate of W-GSC is 45 mm/year (1.8 in); and to the East (at 86° W), 63 mm/year (2.5 in). At its midpoint, which bumps into the W 91° Fracture Zone (center top of Fig. 1.5), the spreading rate of GSC is 57 mm/year (2.3 in; review in Sinton et al. 2003). About 10 Ma, the GSC was located closer to the hotspot (roughly where the islands of Fernandina and Isabela rest nowadays; see "hotspot-plume zone" in Fig. 1.6); back then, most of the plume-derived magma was directed to the GSC (Harpp et al. 2003). At present, the magma primarily fuels the young volcanoes—which have calderas—in Fernandina and Isabela islands. But since older islands lack calderas (East of the archipelago), it appears that their process of formation was different because the hotspot was bound to directing magma mainly to the ridge—in a GSC-caused siphon effect (more on the islands' volcanoes below; Harpp and Geist 2018).

Along the Galápagos Spreading Center (West GSC and East GSC), there are numerous deep-sea hydrothermal vents. These vents form out of seabed cracks [located proximate to volcanic areas] through which hot water (350-°C/660-°F and even higher temperature) discharges. In Box 1.2, we sketch an exemplar hydrothermal-vent field with its microbial habitats and some of its macroorganisms. Chemosynthetic microbes [not photosynthetic] are the foundation of deep-ocean hydrothermal-vent ecosystems (full discussion in Paz-y-Miño-C and Espinosa 2024b).

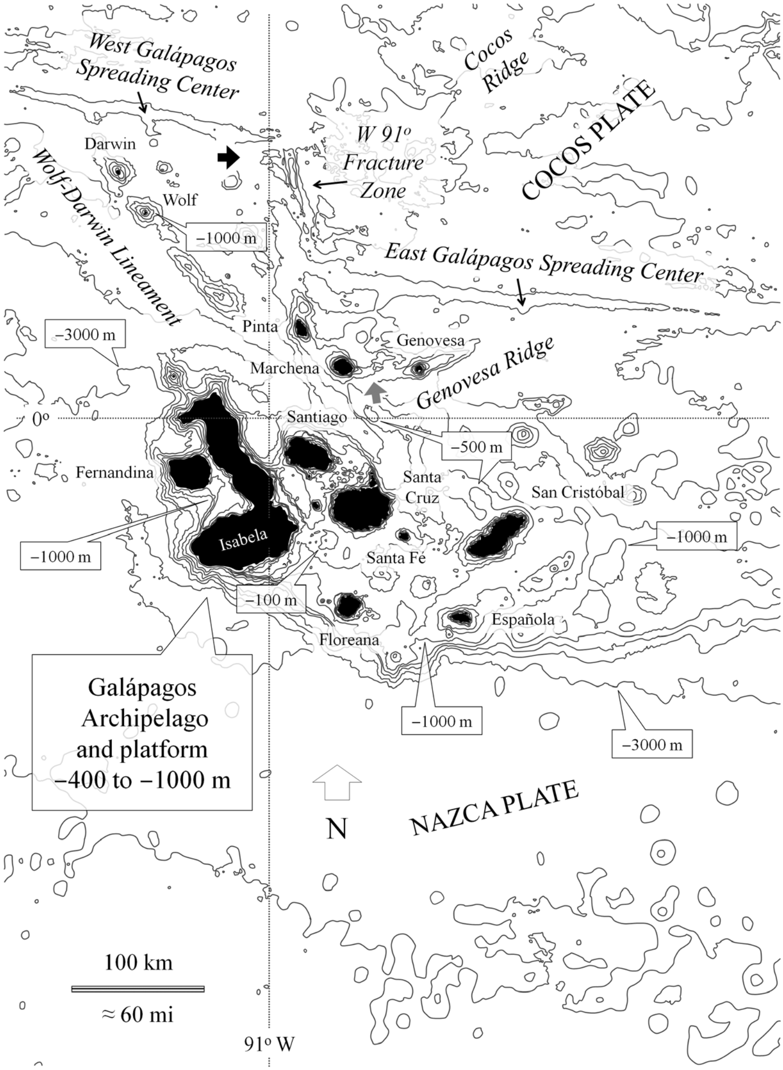


**Fig. 1-5** Seafloor topography around the Galápagos Archipelago. Note the West and East Galápagos Spreading Centers (W/E-GSC); W 91° Fracture Zone/ Galápagos Transform Fault (GTF); Wolf-Darwin Lineament (WDL); and Genovesa Ridge (GR). Thick black arrow=GSC-GTF stress region. Thick gray arrow=extension of GR. Sketch: GPC, after General Bathymetric Chart of the Oceans (GEBCO); NOAA, National Centers for Environmental Information (NCEI), and Charles Darwin Foundation (links in Appendix A).

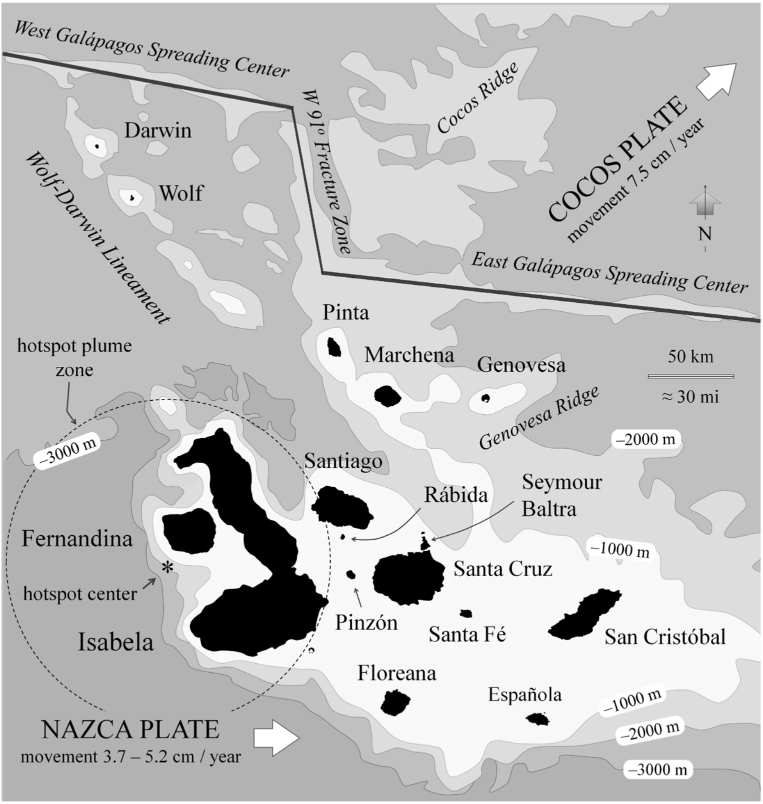


**Fig. 1-6** Close-up of the Galápagos Archipelago with respect to its immediate seafloor and hotspot-plume zone (depths 1000-3000 m or 3300-10,000 ft). Layout GPC, after Villagómez et al. (2007); Graham et al. (2014); Sinton et al. (2017).

**Box 1-2** What are deep-sea hydrothermal vents?

Hydrothermal vents form along ocean ridges. They were confirmed to exist in 1977 when the submersible *Alvin* reached 2,700-m (9,000-ft) depth and its crew spotted numerous vent fields at the Galápagos Rift. After two months of sea-work and 24 dives to five discernible vent fields, the *Alvin* produced >100,000 color images and multiple collections of unknown-to-science specimens, including giant clams, mussels, snails, and worm-like invertebrates, as well as crabs, octopuses, and even fish (Ballard 1977).

Hydrothermal vent fields are full of life forms. Scientists have documented 592 species, and 332 genera of organisms distributed across 63 world-exemplar vent fields (Bachraty et al. 2009).