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Not My Fault: The Galápagos Islands: a unique collision of tectonics, currents, and evolution

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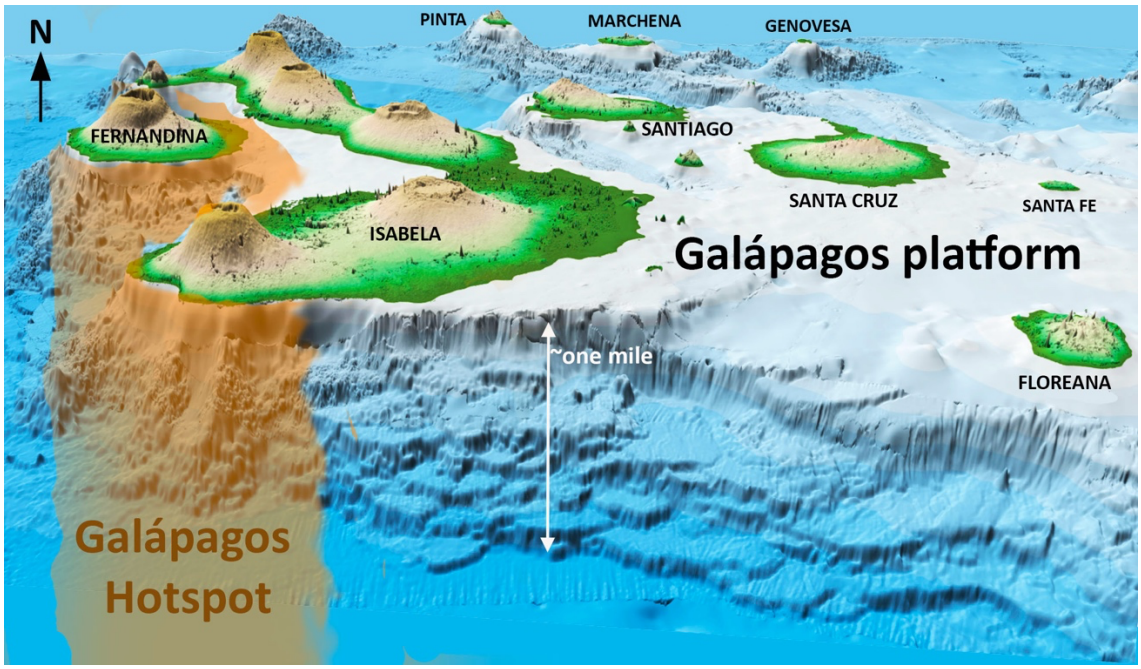

A 3-D sketch of Galápagos platform showing the location and relative heights of the western islands. Shorelines are shown by the dark green shading, and the diffuse orange plume is the approximate position of the hotspot at the present time. (modified from the Galápagos Deep 2023 Expedition https://galapagosdeep2023.com/)

I recently returned from an adventure in Ecuador, the highlight two weeks on a boat exploring the Galápagos Islands. As an earth scientist, there's a geologic story wherever I visit but the Galápagos was a top five bucket list destination for me and many of my geologist friends.

The Galápagos are unique in many ways. Located on the Nazca plate, the islands were formed by a geologic hotspot, a diffuse plume of hotter material originating deep within the earth's mantle and relatively fixed spatially compared to the dynamic motion of plates nearer to the surface. This plume is not molten but its warmth relative to the rock around it allows material to slowly creep upwards. Pressure decreases as the plume nears the surface allowing small amounts of rock to melt, pool up in magma chambers, and occasionally erupt onto the seafloor surface. Over time, the accumulation of lava builds a broad submarine platformsand island archipelagos.

The most well-known geologic hotspot is the Hawaiian Islands where the movement of the Pacific plate has left a chain of islands, atolls, and seamounts more than 3,700 miles long. The

only currently active volcanoes are on the island of Hawaii and the Kamaʻehuakanaloa Seamount off the south coast where the newest Hawaiian island is slowly building. Each island in the chain is a bit older heading to the northwest as plate motion moves it away from the hotspot. The land slowly subsides, erosion eats away it shores, eventually reducing it to a dimple in the seafloor.

The Galápagos Islands show a similar pattern to Hawaii, but the Nazca plate is moving to the east and the newest islands and current focus of volcanic activity are to the west on the islands of Fernandina and Isabela. There are 18 named islands in the archipelago, over 100 smaller ones, and a swath of seamounts that extend east to the Peru-Chile subduction zone where the Nazca plate is consumed beneath the South American plate. Islands get progressively older and more eroded moving to the east towards the mainland Ecuadorian coast.

It's difficult to determine the age each island began to form as the oldest rocks are covered with volumes of younger lava flows and the oldest islands have now vanished down the Peru-Chile subduction zone. Geologic studies have traced the hotspot track back at least 15 million years and some researchers suggest a much longer history and a role in the evolution of land bridges connecting Central and South America when the hotspot was likely located beneath them.

The Galápagos Islands today are located beneath very young oceanic crust. The Galápagos triple junction where the Pacific, Nazca and Cocos plates meet lies roughly 700 miles to the west. Unlike our nearby Mendocino triple junction where two transform faults with side-to-side motion and a subduction zone meet, the Galápagos triple junction marks three diverging boundaries where everything is spreading outwards. The Islands are less than a 100 miles south of the divergent plate boundary between the Cocos and Nazca plate.

Before this trip I had expected the Galápagos Islands to be similar in shape and volcanic characteristics to Hawaii. Both are caused by hotspots beneath oceanic crusts. There are similarities. Both archipelagos feature basalt, the most common volcanic rock on the planet and the rock that makes up the surface of the sea floor. Basalt is a mafic rock rich in magnesium and iron. It is less sticky and flows more readily than the more acidic rocks that make up Mt. Shasta and most of the Cascades, producing broad shield volcanoes like Mauna Loa.

Galápagos Islands are also composed of shield volcanoes, but they don’t look like Mauna Loa. They aren’t as large and appear a bit blockier with steeper slopes. On closer inspection, many of the layers are ashy, composed of broken up fragments of volcanic rock. Tephra is the term used to describe volcanic rock that is blasted into the air and cools, landing on the ground as solid fragments. The size of the fragments can vary from bombs as large as cars, cinders the size of your fist, to fine dust-sized ash particles.

There are two main ways that volcanoes produce tephra. All magma contains gas. At depth, the great pressure of surrounding rock keeps the gas in solution. When that pressure decreases near the surface, the gas can violently escape propelling particles high into the air. The explosive plume produced in the May 1980 eruption of Mt. Saint Helens was driven by this process. Eruptions can also become explosive when large volumes of water come in contact with magma. That is what helped to propel particles in the 2022 Tonga eruption nearly 20 miles into and through the stratosphere.

There are likely several factors that contribute to the differences in behavior and appearance of the volcanoes in Hawaii and the Galápagos. While both hotspots have built up thick platforms of layered lava flows on the seafloor, the Galápagos platform is atop much younger, thinner ocean crust and the nearby ridge may contribute to the magma. There is a bit more variation in the composition of Galápagos volcanic rocks and, unlike Hawaii where well-developed rift zones provide stable conduits for magma, the volcanoes are more widespread. The younger thinner surrounding oceanic crust may also provide easier access for ocean – magma interactions.

For most visitors to the Galápagos, geology is only a secondary attraction. The main draw is the wildlife. Over 80% of the land birds and almost all of the reptiles are endemic and found nowhere else on the planet. These include the poster worthy giant tortoises, marine and land iguanas. Darwin's finches are not particularly noticeable at first to a non-birder, but they practically land on your lap and it's not hard to notice the distinct difference in beak shape. These small birds helped to cement Charles Darwin's ideas about evolution as they rapidly adapted to the many different land habitats that would be occupied by other bird families on the mainland. One island even features a vampire finch that slashes the backs of seabirds and drinks blood in times of food scarcity,

How did these plants and animals make it to the Galápagos and why are they still here? The islands today are roughly 600 miles off the mainland coast, and most are separated from each other by 15 to 30 miles of water, much too far for a giant tortoise or land iguana to swim. The primary mechanisms of plant dissemination were likely wind, seed transport by birds and insects, and vegetation rafts or mats. Some animals may also have safely floated on these rafts, especially reptiles that can go without eating for months. It's hard to imagine the ancestral tortoises and iguanas swimming or floating those 600 miles but dispersal was likely aided by different island positions 15 million years ago and drastically changing sea levels over the past million years.

Jason Ali and Jonathan Aitchison published a 2014 paper in the Journal of Biogeography examining how differing sea level stands during the Ice Ages may have affected isolation and interconnection of islands. During the last low sea level stand 20,000 years ago, the water level in the Galápagos was almost 500 feet below today's tide level. The sea level was even lower 630,000 years ago at nearly 700 feet below the current shoreline. Ali and Aitchison suggest that tortoises, land iguanas, finches, and other land bound animals were repeatedly able to intermix during times of low sea level and then isolated again as the water levels rose.

One of the main thoughts that stuck with me over my 15 days in the Galápagos is that almost all of the endemic species are still here today and the lack of fresh water on the islands is the reason. Legends suggest the Inca made it to the archipelago but dismissed it as an inhospitable place. There is no evidence Polynesians were ever on the islands but if they had, the lack of water would have prevented permanent settlement. For centuries after a Spanish bishop was blown off course and landed in 1535, the islands were considered of no value and only worth throwing a few tortoises in the hold to provide fresh meat for passing privateers, fishermen, and merchant vessels.

Today visitors to Galápagos provides over 95% of the Ecuador's tourism economy. As a UNESCO World Heritage site there is pressure to preserve the unique environment. But Ecuador is a poor country, and China is making overtures to mine and develop potential resources on the

islands. Overfishing, invasive species, and climate change also put delicate ecosystems at risk. I am so glad I was able to visit the Galápagos. There are few things better than snorkeling with marine iguanas, watching a penguin move at torpedo speed beneath you, or viewing the famous courtship dance of the blue-footed boobies. I want my grandchildren to be able to see this too.

Lori Dengler is an emeritus professor of geology at Cal Poly Humboldt, and an expert in tsunami and earthquake hazards. The opinions expressed are hers and not the Times--Standard's. All Not My Fault columns are archived online at https://kamome.humboldt.edu/taxonomy/term/5 and may be reused for educational purposes. Leave a message at (707) 826-6019 or email Kamome@humboldt.edu for questions and comments about this column or to request copies of the preparedness magazine "Living on Shaky Ground."