THE FIERY BIRTH OF HAWAII

BY

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Abstract

With the advent of the scientific revolution started by Alfred Wegener's proposal of continental drift, and the acceptance of the theory of plate tectonics, there has been a dramatic shift in the understanding of the processes that have shaped and are still shaping the Earth. The hot spot hypothesis offers a theory on how the Big Island of Hawaii came into existence. A fiery birth that started on the floor of the Pacific Ocean almost a million years ago and still continues to this day.

The Fiery Birth of Hawaii

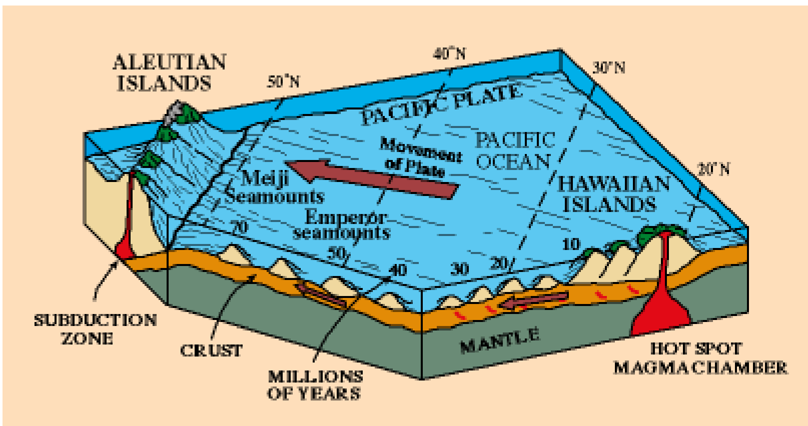

Fig.1: Block diagram of the Hawaiian-Emperor volcanic chain showing the movement of the Pacific Plate (Bradshaw & Weaver, 1993)

Hawaii – also known as The Big Island – is the largest and youngest of the Hawaiian Islands. It is also the youngest of the many volcanic islands that make up the Hawaiian-Emperor chain that extends almost 6000 kilometers in the Pacific Ocean (Tarbuck & Lutgens, 2008). The oldest of these islands are now seamounts or submerged volcanoes. From the main island of Hawaii which lies at a latitude of approximately 20°N (Woods Hole Oceanographic Institution, 1998), the islands extend in a northwest direction and then head almost due north. The hot spot hypothesis has been used to explain the generation of these seamounts and islands. (Tarbuck & Lutgens, 2008)

The earth is made up of different layers: the crust, mantle, and core. The earth's crust is made up of oceanic crust which is a relatively thin layer about 7 kilometers thick; and continental crust that has an average measurement of 35 to 40 kilometers. The crust rests on the lithosphere which is the uppermost mantle. The lithosphere is made up of plates that float over the mobile asthenosphere that makes up the middle layer of the upper mantle. These plates move slowly either toward, away from, or grinding past adjacent plates due to convection currents in the earths interior; resulting in convergent boundaries, divergent boundaries, and transform fault boundaries. However, the volcanic origin of the Hawaiian-Emperor chain was a mystery since they did not lie near any of these boundaries. Scientists came up with the hot spot hypothesis to explain the origin of these seamounts and islands. (Tarbuck & Lutgens, 2008)

According to the hot spot hypothesis, convection currents deep within the earth cause a solid mantle plume rising slowly from the lower mantle to undergo decompression melting. The resulting magma flows upward and forms a hot spot at the base of the lithosphere. The magma forces its way through the lithosphere, pushes apart the oceanic crust, and flows onto the ocean floor. As the Pacific plate moves in a northwesterly direction these lava flows from the stationary hot spot build successive volcanoes on the bottom of the ocean (see Fig. 1). As the outer surface of the lava cools quickly on contact with water it hardens on the outside, while the molten lava on the inside continues to flow. This forms layers of rounded interconnected shapes known as pillow lava. Oceanic crust is composed of basaltic lava. This type of lava is said to have a mafic composition, since it contains a higher proportion of magnesium and iron. Mafic lava is less viscous and tends to produce gently-sloping broad volcanoes that extend long distances called shield volcanoes. The lava cools and solidifies to form the igneous rock basalt. As the lava builds up in layers on the ocean floor over hundreds of thousands of years, the volcano grows and eventually breaks through the ocean surface forming an island. (Tarbuck & Lutgens, 2008)

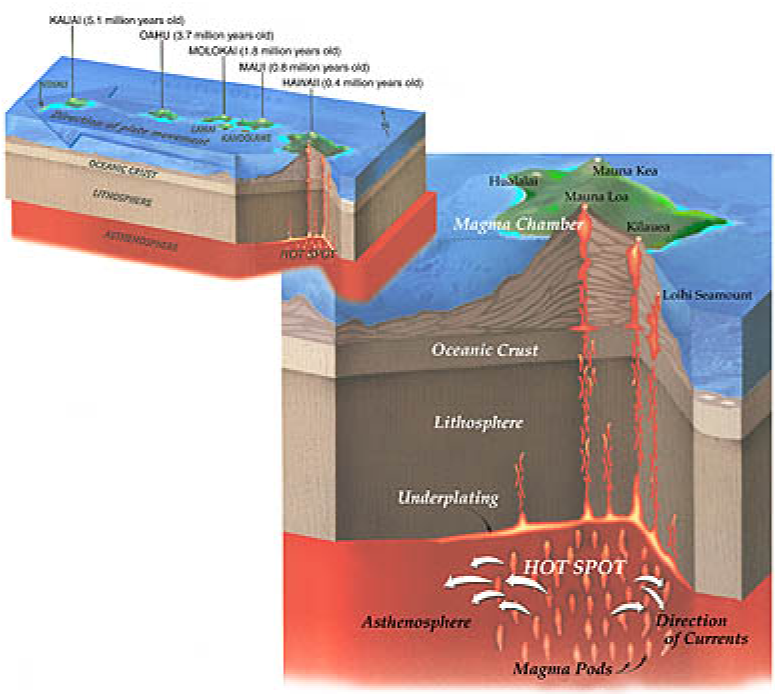

Fig. 2: Magma from a rising mantle plume forming a hotspot. (Hawaii Forest & Trail, Ltd., 2004)

About a million years ago as the Pacific plate continued its north-west movement at the rate of 9 centimeters per year, it carried the older volcanic island Maui past the hot spot and the Big Island started forming in its place (Johnson, 2008). Hawaii is made up of five volcanoes – Mauna Loa, Mauna Kea, Kilauea, Hualalai, and Kohala. Rising higher than

Mt. Everest, Mauna Loa measures over 9 kilometers from its base at the ocean floor. It is the largest active volcano on earth and forms more than half of Hawaii's surface area. (Rubin, 2005).

Mauna Kea is about 0.8 million years old and last erupted about 4000 years ago. It is 4,205m in height and its summit is covered with snow during winter (Rubin, 2008). On its northeastern side erosion by wind and water have carved out deep canyons and valleys. Mauna Kea's steeper summit compared to Mauna Loa shows a difference in the composition of their lava. When a volcano enters the final stage of its growth, its magma supply diminishes and increases in viscosity. This indicates an increase in the silica and feldspar content of the magma and results in brief eruptions of magma that solidify quickly causing a steepening of its slopes (United States Geologic Survey, 2002). Mauna Kea is a very mature volcano and is considered dormant by scientists, so much so that an observatory has been built on its summit.

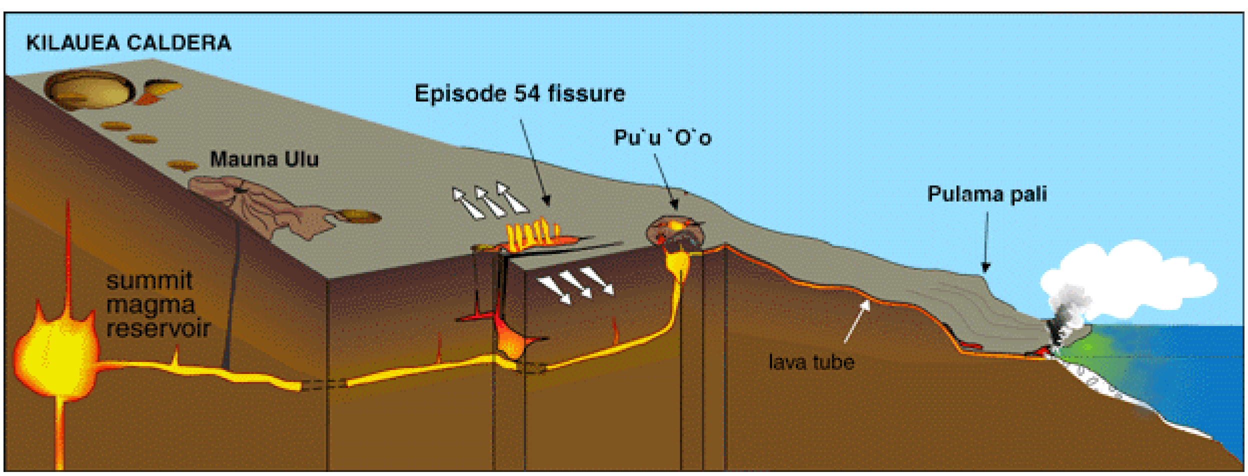

Fig. 3: Cutaway view of the east rift zone of Kilauea volcano (USGS, 2000).

Today Kilauea is the most active volcano on Hawaii. Its east rift zone which forms a distinct ridge is 55 km long and extends under the ocean for another 75 km, while the southwest rift zone is 35 km long. The east rift zone erupts discontinuously along its fissure and dike intrusions have caused the rift zone to widen. Thus, Kilauea is widening internally as well as externally as new layers of lava flow to the surface. (USGS, 2004). Its Pu’u ‘O’ eruption has been the longest-lived rift zone eruption in Kilauea’s history. The eruption started in January 1983, and by June 1983 was spewing lava fountains up to 460 m high. The fallout from the fountains built a 255 m high cone at the Pu’u ‘O’ vent. The average lava production from a Pu’u ‘O’o eruption is about 300,000 to 600,000 m^3/day (Rubin, 2008). A lava tube carries lava 11 km to the sea, building up new land (USGS, 2009). About 4 km uprift from Pu’u’O’o’ an eruption from the Napau Crater on January 30, 1997, termed episode 54, caused the rift zone to widen 1.8 m in Napau and 36 km about 2km uprift (USGS, 2000).

The two main types of lava are pahoehoe and a’a. Pahoehoe lava flows appear very fluid and have a smooth, ropy surface. As the lava flows, the surface cools and forms a skin. Folds develop in the skin as the front of the flow slows down while the incoming lava continues to push forward. As pahoehoe fronts advance they tend to be less than a foot high, but can grow several feet as lava continues to flow into them and gets trapped under the cooled top crust and sides. This solid layer preserves the heat of the lava flow and enables it to advance great distances.

A’a flows look like glowing piles of rubble. The molten core is surrounded by cooler loose jagged pieces that continuously fall off the top and sides. Large slow-moving a’a flows can reach heights of more than 50 feet as the lava continues to pile up.

Pahoehoe lava can turn to a’a as it cools and gas bubbles escape causing breaks in the smooth-flowing lava. Pahoehoe lava can also change to jagged a’a lava when it slows down, then travels over rough terrain and gets broken up. Lava flows on Hawaii can wreak destruction destroying homes and property, and on the other hand it can create new land where no land existed before (Lava Flows and Lava Tubes, 2004).

As basaltic lava flows it tends to cool and form a crust over the top. As the flow continues over a period of time the top and sides solidify forming lava tubes. The hot lava inside the tube gets insulated and can flow for miles. Some lava tubes get enormous and can form lava tunnels big enough for people to walk through (Topinka, 2002). At times lava travelling through a lava tube can pour into the ocean where it cools and forms pillow lava.

Scientists have discovered that magma temperature can be estimated from the amount of magnesium the lava contains. The higher the magnesium content the higher the temperature of the magma. (USGS, 2008). There is a change in the composition of the magma as it rises into the volcano due to crystallization. Olivine, a mineral that crystallizes at high temperatures, crystallizes first, then pyroxene, which ranges in color from dark green to black, and lastly plagioclase feldspar which is white in color. By noting the composition of the olivine in lava one can get a record of magma composition over time and estimate the period of transition from the core to the rim of the volcano (USGS, 2008). Olivine crystals washed out of an eroded seaside cinder cone has created green sand at Papakolea Beach. The other crystals like pyroxene and feldspar being lighter easily get washed away by the waves while the denser olivine crystals remain (Johnson, 2008).

In order to discover hot-enough rock to produce geothermal energy one may have to drill as much as 5 km deep into the Earth. At Puna, on the eastern part of the Big Island, a geothermal company called Ormat Technologies decided to drill a deep injection well. During the drilling process they encountered molten magma 2.5 km down. Exposure to air caused the top layer of magma to immediately cool and form a layer of glass over the molten magma below. The drill was sunk once more to retrieve cuttings of the newly formed glass. Unlike the inky black glass formed from basaltic magma, the glass cuttings were found to be clear and colorless. On analysis of its chemical composition, the glass was found to be made of dacite, which has a composition that falls between basalt and granite. Continental crust is made up of granite which has a felsic composition. This means it has a high content of feldspar and silica. The magma that was discovered was a going through the process of chemical differentiation in which some minerals in the basaltic magma crystallize as they cool, gradually changing the chemical composition of the magma and taking it towards a more granitic composition. The study of this site at Puna, which contains superhot rock at 1050 degrees Celsius, could yield much insight into the study of the process of chemical differentiation in magma (Gramling, C. 2008).

Giant submarine slides and slumps on the flanks of Hawaii's volcanoes that occurred hundreds of thousands of years ago have been mapped by GLORIA, a long range side-scan sonar that maps the morphology and texture of the seafloor. These are believed to be caused by large earthquakes. Kilauea's south flank is sliding seaward at 10 cm/yr. (Morgan, 2008). These giant submarine debris avalanches occurring about 200,000 and 100,000 years ago, respectively, may have caused tsunamis that deposited coral-bearing marine conglomerates as high as 70 m on Molokai and 325 m on Lanai. (Giant Hawaiian underwater landslides, 1994)

Loihi, the newest seamount in the Hawaiian Island chain has been forming underwater 21 miles from the Big Island. It is 9000 feet tall and 3000 feet from the surface of the ocean. It will emerge from the ocean in a few tens of thousands of years (Parks,1997). Both Loihi and Kilauea have emerged from the flanks of Mauna Loa and all three volcanoes share the Hawaiian hotspot. (Rubin, 2006)

Over millions of years, the force of gravity along with erosion, wear down the volcanic islands until they ultimately get submerged and form seamounts. This is going to be the fate of The Big Island, as it moves away from the hotspot like all the older islands in the Hawaii-Emperor chain, while the youngest volcano Loihi, takes its place over the hot spot.

Hawaii's fiery birth which started almost a million years ago goes on to this day. Like the other islands formed over the Pacific hotspot it will eventually stop erupting as it is carried away by the northwest motion of the Pacific plate, eventually becoming dormant and then extinct. Gravity and erosional processes are going to take their toll on its igneous body as it cools, becomes dense, and subsides, eventually becoming a seamount and getting subducted under the earth's crust due to the inexorable motion of the Pacific plate. Right now The Big Island is very much volcanically active, and continues to fascinate us with its ever changing form as it is fed by the timeless processes taking place deep within the Earth (Johnson, 2008).

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