THE GEOLOGY AND VULCANOLOGY OF THE GALAPAGOS ISLANDS

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WHY TALK ABOUT ROCKS WHEN THERE'S MARINE LIFE TO SEE?

Active volcanoes are among the world's ultimate adventure destinations. And they are definitely a destination for those of us who regard ourselves as adventure travelers. Only in the Galapagos marine life is this unique and fragile balance between the exotic and the unusual found. Where else can you risk precipitous falls, hear loud explosions, smell sulfur and dodge lava bombs all near lapping surf and lounging lobos?

A trip to the Galapagos archipelago gives us the opportunity to see a major geologic process at work. And it is one of only four processes that shape the earth's surface; volcanism, erosion, tectionism and meteor impacts. Volcanoes shape not only the earth's surface, but the history of every living thing on the planet. [7]

THE DARWIN CONNECTION

Without the geology of the Galapagos**,** there can be no Galapagos Marine Biology/Ecology. The two are so directly linked that Darwin, in his monumental voyage was at a loss to notice the latter. Sailing from the coast of England in 1831 Charles Darwin, at the age of 22 wrote from the deck of the Beagle, "Geologizing in a volcanic country is most delightful; besides the interest attached to itself, it leads you it leads you into the most beautiful and retired spots." It seems that geology engrossed most of his time aboard ship. Only after his return to England did his friend Professor Judd recall that, "biological speculations began to exercise a more exclusive sway over Darwin's mind."[2]

Darwin first landed on Hood (Espaňola) Island, then Chatham (San Christobal) Island where he found "craters composed of singular kind of tuff, (now called palagonite)" made up of yellowish-brown translucent like resin fragments. Eventually he found them across the archipelago and named them the "most striking feature of the Archipelago." Darwin correctly noted that "much of the greater part of the tuff is originated from the trituration of the grey, basaltic lava in the mouths of creators in standing in the sea." Palagonite is actually caused by basaltic magma coming into contact and rapidly absorbing water in a phreatomagnetic eruption.[2] Darwin was probably the first to suggest such an odd connection between seawater and lava.

BASICS

The Galapagos archipelago consists of 14 main islands and several rocky islets, about 600 miles (970 Km) off the coast of South America. They cover an area of about 3,029 square miles (7,844 square kilometers.) Five of the islands are inhabited and almost certainly the population is greater than the "official" figure of 18,000 people growing. Eco-tourism presents real dollars and a potential real threat to the archipelago. People who get the most out of a trip are those with a sincere interest in natural history or geology and/or biology. [9]

Officially named the Archipelago de Colon (Columbus Archipelago,) they were first discovered by the Bishop of Panama, Toma's de Berlanga on route to Peru in 1535. At the time he named them Las Encantadas "the Enchanted". Several surveys of the islands have yielded Inca pottery fragments. The artifacts provide abundant evidence of pre-Spanish occupation. The area remained unclaimed for over 300 years, used for freebooting, whaling and as a pirate hangout. All of the main islands rise from the western end of the submarine Galapagos Platform, an escarpment at depths of 700 fathoms. There is another important submarine feature called the Galapagos Fracture Zone, marked by high and closely spaced ridges and furrows running westward, about 2° north from near Culpepper (Darwin) Island. In connecting, it cuts across and then offsets the crest of the East Pacific Rise with a total length of about 1600 miles.

The archipelago maintains a climate of relatively low rainfall, low humidity, and low air and water temperatures. In 1935 the government of Ecuador made the Archipelago (in part) a wildlife sanctuary. In 1959 they created the Galapagos National Park, which includes 90 percent of the land surface. In 1986 the surrounding waters became a marine reserve. [6] The striking ruggedness of the Galapagos is accentuated by hardened lava that creates volcanic mountains, craters (calderas) and enormous cliffs.[5]

PETROLOGY AND VOLCANOLOGY OF THE GALAPAGOS

In 1969 A.R. McBriney from the University of Oregon and Howell Williams from the V University of California performed a detailed study of Hood (Espaňola) Island, Baltra (just north of Santa Cruz/ Indefatigable) and Barrington (Santa Fe) Island. The resulting petrology revealed that Hood which was studied intensely is definitely not a volcano, but uplifted block of submarine lavas. Also Indefatigable (Santa Cruz) Barrington and Baltra Islands are comparable as lava uplifts not billowing, rock spewing behemoths.

On the other hand, Charles Island (Floreana or Santa Maria), Narborough Island (Fernandina) and many others are among some of the most active volcanoes in the world. Volcanic activity continues today, Charles Island erupted in 1813 as Captian Porter of the U.S.S. Essex reported that in July "a volcano burst out with great furry." Cumbre volcano on Fernandina erupted on 05/ 14/2005. The volcano spewed rivers of lava and sent columns of steam 7km into the air on that Friday. We can hope for more. Cumbre is on the unpopulated island of Fernandina, and is one of the most active volcanoes on the planet.

Charles Island (Floreana or Santa Maria), Chatham (San Christobal) and Hood (Espaňola) Islands are probably the oldest on in the archipelago, it is also the most attractive scenically.

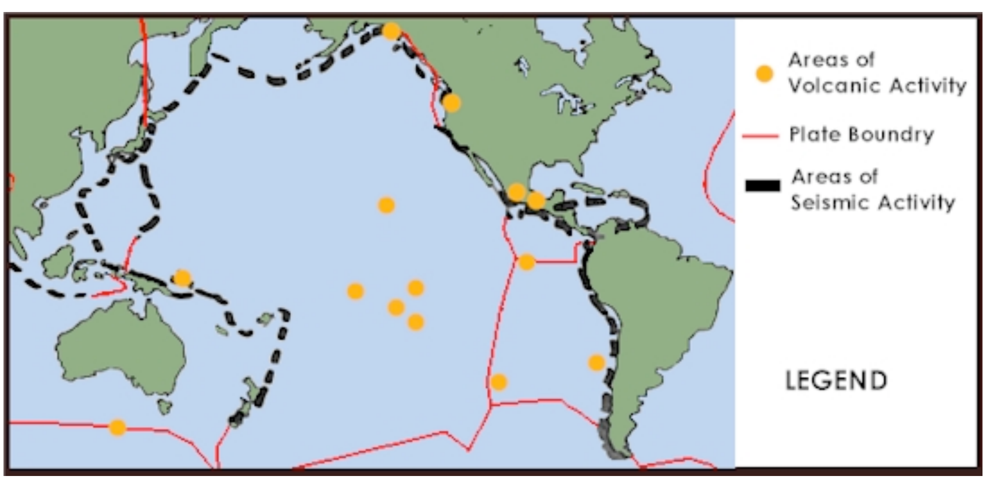
UNIFIED THEORY OF WHY POMPEII IS A BAD REAL-ESTATE BUY

Geology had never formulated a grand unity theory for volcanic activity. Before this last generation, eruptions were thought to be caused by gods, curses, and myriad maladies.

That was until the 1960's brought forth the theory of plate tectonics, the field of earth sciences and seismology struggled for a theoretical foothold to explain a unified theory of how or why earthquakes and volcanic eruptions were related.

After countless earthquake epicenters were plotted on maps, a picture of a grand planetary design began to emerge. One by one plates appeared and clearly showed a new path. It is a planet-wide path upon which the vast majority of all tremors occur. [1]

The outline of this plate formation gave rise to a concept know as the Pacific Ring of Fire, seen from the plotting of volcanoes along or near fault lines running the limits of these plates. Volcanically speaking this is the Earth's busiest side. Over 1,000 volcanoes percolate on this massive Ring of Fire. The Ring runs along the Aleutian Island chain, down the west coast of California, the western side of South America, and back up the New Hebrides, Philippines, Japan and Kamchatka Peninsula. They also include some of the deadliest volcanoes on the planet, such as Pinatubo, Krakatau and Mt. St. Hellens. [7]



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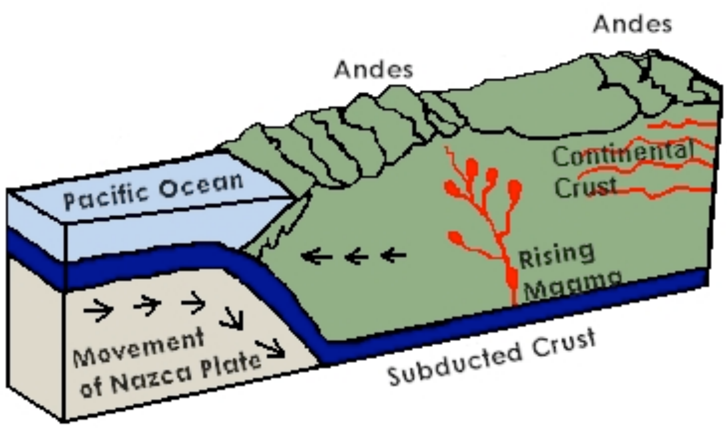
Pacific Ring of Fire

Powered by forces originating in the planet's molten core, these enormous plates float at speeds up to four inches per year. They ride, almost floating on a layer of softer, more malleable rock called the asthenosphere. 1

Seismologists have come to understand that there are three types of plate borders, the first, divergent rifts where new ocean floor is created by basaltic magma rising and spreading out from the earth's interior. Convergent zones are the second instance, where tow plates meet, colliding head on or one diving beneath the other. And finally, shear borders occur where the plates grind slowly past each other evenly matched moving in opposite directions. 1

Many of the exact details of the genesis of earthquakes remain undiscovered, but John Hodgson, a Canadian seismologist sums the mystery up, "Whether we can see the fault break, or whether the earthquake focus is hundreds of miles within the earth, no one now doubts that the origin is tectonic." 1



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For our purposes, the Galapagos archipelago is located on what is now know as the Nazaca plate. And the islands are center around about 20 basaltic volcanoes. For reasons still misunderstood, people often compare the volcanic activity of Hawaii and the Galapagos archipelago in casual conversation (usually at dinner parties when you mention this Galapagos Marine Ecology course.) Unlike the basaltic volcanoes of Hawaii, the islands of the Galapagos do not have well defined rift zones, instead they employ a series of patterned side vents and radial vents further away under the flanks of the volcanoes. Hawaii cracks and the Galapagos basically leak and ooze out the sides. 3 We'll describe more on this strange "leaking" later.

As the Galapagos archipelago floats in an area of unusual seismic activity, it is important to understand the big, planet wide picture. The creation of new ocean floor at remote mid ocean ridges is accompanied by almost constant earthquake activity, magma leaches up to fill fissures, faults and cracks attendant with this continuous movement. Along the jagged crests of the towering undersea ridges islands are formed. Between the peak walls the steep sides of narrow canyons leach material called basaltic magma, which is constantly rising from the underlying asthenosphere. These constant mid ocean earthquakes go largely unnoticed because they are generally low magnitude and cause no harm to humans; however the constant pace of tremors pulses a drumbeat of planetary change.

As new ocean is constructed with the attendant quakes, fresh magma oozes into older faults and cracks building strain until it is relieved by a moderated earthquake or what is often referred to as “swarms” of micro-quakes. These earthquakes take place in imbricate faults-a complex of weak, layered areas in the continental plate. Interestingly, as the newly formed sea floor shifts toward subduction zones far away, it grows harder and heaver. As the slab sinks, it endures more deformation. This area called the Benioff Zone (named for American seismologist Hugo Benioff) is between 70 and 400 miles deep. And compression forces earthquakes even at this level. [1]

Most of the worlds great quakes occur under the trench itself, generating tsunamis, additional quakes, and volcanic eruptions. These ruptures are sometimes no more than 30 miles deep and often touch off lower magnitude tremors.

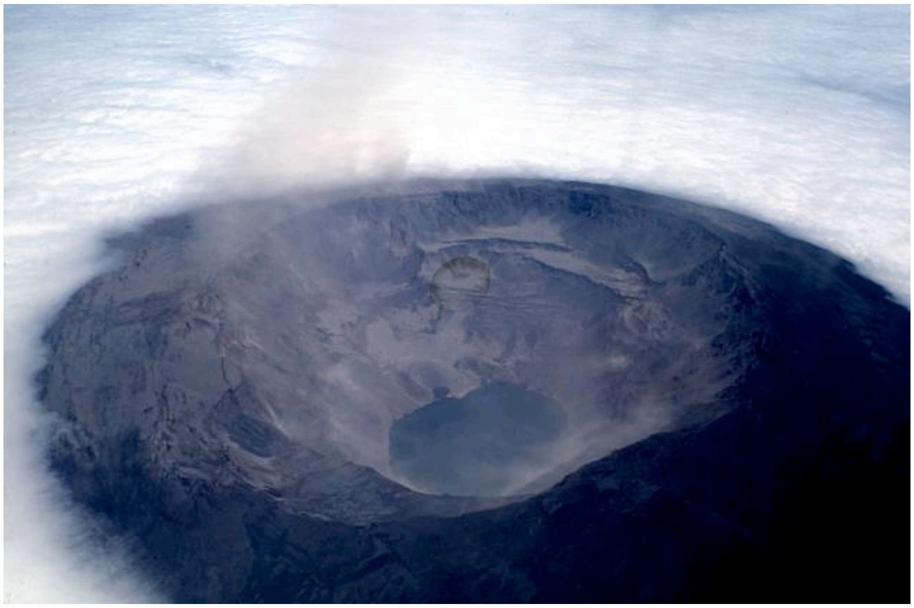
Almost 90 percent of seismic energy is caused by tectonic plate shift.[1]

Ocean ridges where upwelling magma creates ocean floor are frequently offset by a kind of zigzagging pattern of faults. In the Galapagos, unlike collision zones of plates pushing up into mountain ranges, sutured together because of the 20-mile-thick crust of the Earth’s mantle[1], magma wells up within channels of molten lava over eons of time, with sides of the islands themselves eventually retreating back to the sea floor. In fact the Galapagos Islands surface of 100,000 to several million years ago can be found not far off shore, under the lapping sea. In 1967 the seismologoical world was wrapped in discovery of this concept of seafloor drift. At a meeting of the Geophysical Union, over 70 papers were presented on the subject of seafloor spreading, many by skeptics of this new theory who had been spurred to reevaluate the possibility of - today’s Island being tomorrow’s seafloor. Kicker Rock off the coast of Chatham Island suggests just a parting of millions of year old real estate.

Over eons of time, the Galapagos Archipelago was created by the largest and most active groups of oceanic volcanoes. The oldest rocks dated on Barrington, Hood, and Indefatigable (Santa Cruz) Islands date to the Pleistocene age. Chemically the rocks differ from those of Hawaii, they are more typical of igneous rocks of the East Pacific Rise.

More importantly in the 1960’s blossom of interest in tectonic theory, scientists learned that the Galapagos were never connected to the main land of South America. The Archipelago is the result of individual volcanoes and appears to have been controlled by two major fault lines, one trending northward, and the other trending nearly east-west. They in fact, grew from a broad shallow platform near the crest of the East Pacific Rise.

OUR VERSION OF THE VERY “BIG BANG”


[10]

Dust clouds rise from Fernandina caldera on July 4, 1968, about three weeks after a major explosive eruption that was followed by collapse of the caldera floor.

Narborough Island (Fernandina) is a location of tremendous import in the world of vulcanology. In 1968-9 Tom Simkin and K. A. Howard, both of the Smithsonian Institute observed the island which is essentially a single volcano of remarkable profile. It looks like an inverted soup plate with abundant youthful flows descending the steep outer edges. A swarm of fissures ring the outer flank of the caldera making it one of the most outstanding profiles in volcanology. On May 21 there had been a brief eruption of about 700 meters, on the eastern flank of the island. On June 11 and earthquake near Narborough was recorded in Quito. Within an hour, a large white cloud began rising as a column, and then spread at a high of about 20 Km. Members of the fishing boat Urvina Bay, 35 Km east of the Fernandina caldera reported a pink color on the underside of the cloud as it spread quickly. Loud booms and smaller explosions were heard and in fact recorded across the western hemisphere. They were even recorded at Boulder Colorado, with and amplitude equaling that of the largest nuclear explosions.

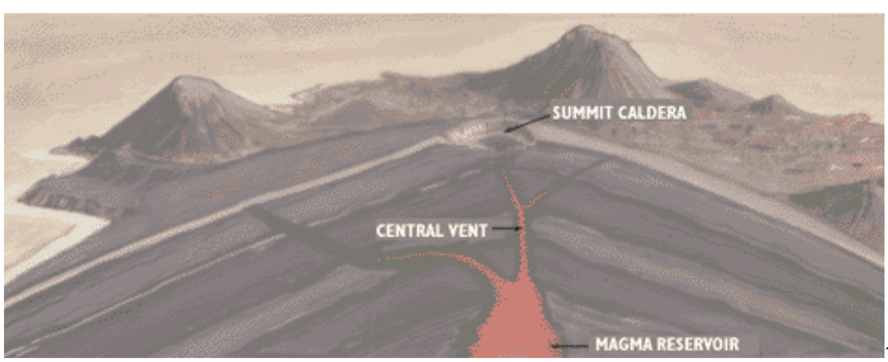
Lighting was observed over the volcano with flashes of violet, green and red light.
By June 18 and 19 the activity increased to about 200 seismic events a day. On the 21st a fly over revealed the floor of the volcano's caldera floor dramatically dropped some 300 meters, asymmetrically. The drop is thought to be a withdrawal of lava as an unknown depth, possibly at the base of the escarpment of the Galapagos Platform just west of the island. [2] This single eruption was the largest historical caldera collapse ever recorded. [3]

Narborough Island (Fernandina), is so active that is has become one of the most studied geophysical features of the planet. Between 1950 and 1998 Fernandina erupted at least 13 times. A shallow-dipping dike of lava fed the 1995 flank eruption, spawning tremendous study. This flank eruption caused lava to leak out underneath the caldera rim, in exactly the way the super-famous (in the world of vulcanologists) caldera floor sinking, described above. [3] The difference was, this eruption was above water, and could be studied.

WHAT MAKE THE GALAPAGOS DIFFERENT?

What makes the Galapagos different from so much of the rest of the world's seismic structures? It has to do with the way molten rock leaks. A detailed study of this 1995 flank eruption (above water on Fernandina) revealed that the normal radial ringing of lava is not found all over these volcanoes. A research team found that unlike normal stress of cooled lava compressional radiant rings, two types of vents could be found at Fernandina. One radiating like a stack of pancakes an another (and unusual) set of stress formations were present, that were vertical. These circumferential dikes were observed to be about a meter thick. The team theorized that what starts out at the top of the rim as sideways, pancake-stack like rings of cooled lava, on the horizontal-plane from the caldera-rim rotates as it sinks. These up and down stress-axis then presents much easier potential opening, from which magma can escape at some future date. Imagine the sides of a wooden ship being lapped up and down instead of sideways. The planet's gravity would quickly sink the ship. Because that same gravitational force presents easy access for liquids out the less supported horizontal opening while the vertical axis presses against itself to retain the flow on one side. [8]

The best-fit model of this 1995 study presented a picture of radial dyke extruding lava with an intrusion far from being horizontal; it was about 34 from horizontal as the lava flow opened under the caldera rim, down the side of Fernandina.[3] By 1995 the team were able to use satellite imagine and much more sophisticated tools than their predecessors. The conclusion was that the volcano creates the traditional cooled molten dykes that radiate out from the center of the caldera rim, but unlike other studied locations, these stress-rings push out over time and twist horizontally as they move away.



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Basaltic Shield Volcano

A 1992 study of this basaltic shield and these multitudes of eruptions evidenced a trend for lava to distribute along a northwest to southeast direction. This NW-SE preference gives the island an elongated and scalloped outline. The caldera of Fernandina percolates like a coffee pot, set to brew over a hundred of million years. [4]

The "strangest" new world theory

Trachyte pumice which is porous and filled with air pockets comes from some of the volcanoes on the archipelago. This kind of lava forms clumps, worm shaped sections, rafts and blobs. A connection has even been suggested by later teams of scientists that the floating pumice found on the beaches of James, Indefatigable, Bindloe, and Tower Islands may have served as life-rafts to transport animals and plants to and across the Galapagos. Darwin was of the "flotsam and jetsam school" of floating logs, sea grass and debris. H.W. Bates one of the earliest explorers of the Amazon, in 1892 was apparently the first to suggest pumice as a flotation device. [2 p. 113]

Marine dispersal of pumice thought to be from the South Sandwich Islands occurred during an eruption in 1962. Later this "pumice raft" material washed up on the western coast of Australia. It had traveled 8000 miles at an average rate of about 18 miles a day. The larger lumps were reportedly more responsive to wind drift and therefore moved even faster. Everything moved though, including the fine pumice gravel which moved at somewhere between 6 and 7 miles a day. [2 p. 116] Floating pumice is not likely to have carried terrestrial vertebrates to the archipelago, however it seems an interesting candidate to transport vegetation or insects the five hundred miles or so from the mainland.

Conclusion

For a lot of reasons, the Galapagos has been spewing lava for a long time. We think it will keep spewing lava for more time. And we think it is great fun!

THERE'S NO REASON TO INCLUDE THIS BUT WE THOUGHT IT WAS FUN

One of the most unusual connections between Darwin and the volcanoes is the tortoise evacuation of 1998. It was during an eruption of Cerro Azul, on Isabella Island. The eruption created a serious threat to the island's rare tortoises, and the solution was to evacuate them by helicopter. While others (weighing up to 500 pounds) were rescued by humans and were hand carried across rugged terrain. Darwin's interest made the tortoises famous, and worth saving, and also made the islands initial value geological. He even named a volcano after himself; Volcan Darwin also on Isabella. [7]

- Sources -

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Photo by Tom Simkin, 1968 (Smithsonian Institution)

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Fernandina

Abreviated Eruptive History

Start Date: 1813 Jul 14 (on or before)

Stop Date: Unknown

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2

Area of Activity: South flank

Eruptive Characteristics:
- Flank (excentric) vent
- Regional fissure eruption (?)
- Phreatic explosion(s) (?)

Start Date: 1814 Jul

Stop Date: 1814 Aug

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2

Eruptive Characteristics:
- Flank (excentric) vent (?)
- Regional fissure eruption (?)
- Explosive eruption (?)
- Lava flow(s) (?)

Start Date: 1817 (in or before)

Stop Date: Unknown

Location is Uncertain

Volcanic Explosivity Index (VEI): 2

Area of Activity: (western Galápagos)

Eruptive Characteristics:
- Flank (excentric) vent (?)
- Explosive eruption
- Lava flow(s)

Start Date: 1819

Stop Date: Unknown

Dating Technique: Historical Records

Volcanic Explosivity Index

Eruptive Characteristics:
- Flank (excentric) vent (?)
- Explosive eruption
- Lava flow(s)

(VEI): 2

Start Date: 1825 Feb 14	Stop Date: 1825 Oct (in or after)
Dating Technique: Historical Records **Volcanic Explosivity Index (VEI):** 3 **Area of Activity:** East summit and SE flank	**Eruptive Characteristics:** Regional fissure eruption Explosive eruption (?) Lava flow(s)

Start Date: 1846 Nov	Stop Date: Unknown
Dating Technique: Historical Records **Volcanic Explosivity Index (VEI):** 0 **Area of Activity:** East flank	**Eruptive Characteristics:** Flank (excentric) vent (?) Regional fissure eruption (?) Lava flow(s)

Start Date: 1888	Stop Date: Unknown
Dating Technique: Historical Records **Volcanic Explosivity Index (VEI):** 1	**Eruptive Characteristics:** Unknown

Start Date: 1926	Stop Date: Unknown
Dating Technique: Historical Records	**Eruptive Characteristics:** Unknown

Start Date: 1927 Dec 13 (on or before)	Stop Date: Unknown
Dating Technique: Historical	**Eruptive Characteristics:**

Records

Volcanic Explosivity Index (VEI): 0

Area of Activity: South flank near Punta Mangle

Flank (excentric) vent
Lava flow(s)

Start Date: 1937 Mar	Stop Date: 1937 Apr

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 0

Eruptive Characteristics:
Flank (excentric) vent (?)
Lava flow(s) (?)

Start Date: 1958 Sep (?)	Stop Date: 1958 Dec 30 (on or after)

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2

Lava Volume: $> 3.1 \times 10^7$ m^3

Area of Activity: SE, SW and west caldera rim

Eruptive Characteristics:
Radial fissure eruption
Lava flow(s)
Lava lake eruption

Start Date: 1961 Mar 21 ± 1 day	Stop Date: 1961 Sep

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2

Area of Activity: SE flank

Eruptive Characteristics:
Central vent eruption
Radial fissure eruption
Explosive eruption
Lava flow(s)

Start Date: 1968 May 21	Stop Date: 1968 May 23 ± 1 day

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2

Area of Activity: ESE flank (600 m)

Eruptive Characteristics:
Flank (excentric) vent
Radial fissure eruption
Explosive eruption
Lava flow(s)

Start Date: 1968 Jun 11	Stop Date: 1968 Jul 4 (on or before)

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 4

Tephra Volume: > 1 x 10^8 m^3

Area of Activity: West caldera wall

Eruptive Characteristics:
Central vent eruption
Explosive eruption
Pyroclastic flow(s)
Phreatic explosion(s)
Lava flow(s)
Caldera collapse
Debris avalanche(s)

Start Date: 1972 Jun 4 ± 45 days	Stop Date: Unknown

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 0

Area of Activity: SE caldera bench

Eruptive Characteristics:
Central vent eruption
Explosive eruption
Lava flow(s)

Start Date: 1973 Dec 9	Stop Date: 1973 Dec 16 ± 1 day

Dating Technique: Historical Records

Volcanic Explosivity Index

Eruptive Characteristics:
Central vent eruption
Explosive eruption
Lava flow(s)

(VEI): 2

Area of Activity: ESE caldera wall

Start Date: 1977 Mar 23	**Stop Date: 1977 Mar 27**

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 1

Area of Activity: SE caldera bench

Eruptive Characteristics:
- Central vent eruption
- Explosive eruption
- Lava flow(s)

Start Date: 1978 Aug 8	**Stop Date: 1978 Aug 26**

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2

Lava Volume: 9 ? x 10^6 m^3

Area of Activity: NW caldera bench

Eruptive Characteristics:
- Central vent eruption
- Explosive eruption
- Lava flow(s)

Start Date: 1981 Aug 1 ± 270 days	**Stop Date: Unknown**

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 0

Area of Activity: South caldera rim

Eruptive Characteristics:
- Central vent eruption
- Lava flow(s)

Start Date: 1984 Mar 30	Stop Date: Unknown

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 1

Area of Activity: NW corner of caldera

Eruptive Characteristics:
- Central vent eruption
- Explosive eruption
- Lava flow(s)
- Debris avalanche(s)

Start Date: 1988 Sep 14	Stop Date: 1988 Sep 16

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2?

Lava Volume: $7.0 \pm 1.0 \times 10^6$ m^3

Area of Activity: East caldera wall

Eruptive Characteristics:
- Central vent eruption
- Explosive eruption
- Phreatic explosion(s)
- Lava flow(s)
- Debris avalanche(s)

Start Date: 1991 Apr 19	Stop Date: 1991 Apr 24

Dating Technique: Historical Records

Volcanic Explosivity Index (VEI): 2?

Area of Activity: Base of ESE and NW caldera wall

Eruptive Characteristics:
- Central vent eruption
- Explosive eruption
- Lava flow(s)

Start Date: 1995 Jan 25	Stop Date: 1995 Apr 8 (?)

Dating Technique: Historical

Records

Volcanic Explosivity Index (VEI): 2

Lava Volume: $5.6 \pm 1.0 \times 10^7$ m^3

Area of Activity: SW flank

Source:

Smithsonian
National Museum of Natural History

Site Location:

http://www.volcano.si.edu/world/volcano.cfm?vnum=150301=&volpage=erupt&format=expanded