(U.S. Geological Survey graphics)

Chapter 3

Kūkulu-o-ka-honua

Pillars of Earth

Volcanism Among the Islands

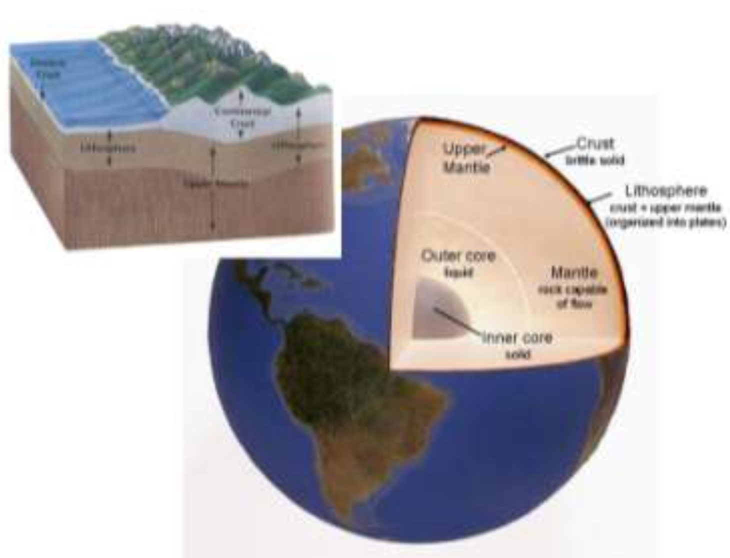
Humans live in a border area between the land, the sky, and the sea. We are vulnerable to hazards from all three of these environments but it is the land we live on that is closest to the home we make, the job we hold, and the places our children go. Earthquakes, volcanic eruptions, tsunamis, and other geologic hazards are earthly events that may kill people and destroy livelihoods. When they occur, the world becomes a terrible place: the solid ground we trust is suddenly no longer trustworthy, as if the very pillars of Earth were crumbling.

In European culture it was once thought that Vulcan, blacksmith of the Roman gods, had a subterranean forge and its chimney was the tiny island of Vulcano in the Mediterranean Sea north of Sicily. Vulcano's hot lava fragments and dark ash clouds were thought to come from Vulcan's furnace as he beat out thunderbolts for Jupiter, the king of gods, and weapons for Mars, the god of war. The English word "volcano" comes from this island. Today we know that the lava on Vulcano actually comes from molten rock generated in Earth's interior below the Mediterranean seafloor.

The 132 outcroppings of land recognized as "Hawaiʻi" are merely the tips of a long ridge of volcanoes, known as the Hawaiʻi-Emperor Chain, extending 3,000 miles from the Big Island of Hawaiʻi to the Aleutian Trench in the north Pacific. Pele's steppingstones across the Pacific are also the highlights of an eighty million year long geologic story.

Plate Tectonics

To understand Hawai‘i, we must understand the workings of the whole Earth. The solid, outer layer of Earth that consists of the *crust*, and the rigid upper part of the *mantle*, together form the *lithosphere*. The lithosphere, ranging from about 25 to 125 miles thick under the continents and 30 to 60 miles thick under the oceans, is broken into massive pieces called *plates*. Lithospheric plates move relative to one another and restlessly shift across the planet surface. Like a piece of toast afloat on a layer of peanut butter, these rigid slabs of rock float on the rest of the mantle, which reaches more than 1,800 miles to the *core* at Earth’s center.



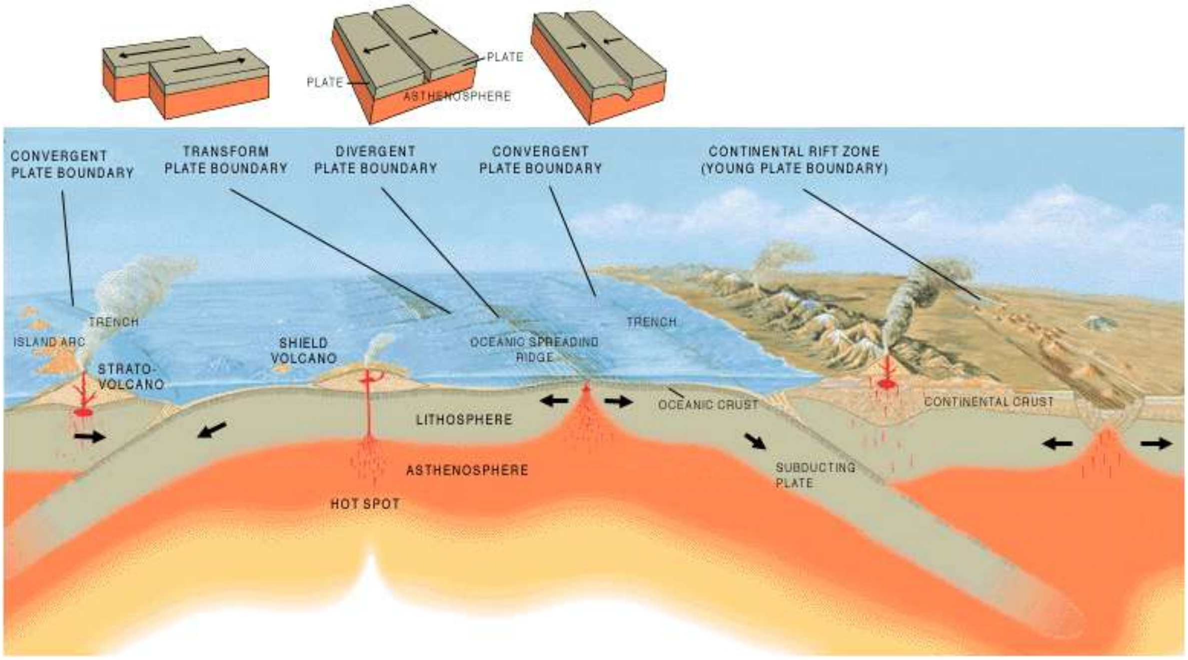
Earth is organized into four layers: the inner core, the outer core, the mantle, and the crust. The uppermost mantle and the crust together form the lithosphere.

The mantle is composed of solid rock that is very hot and able to slowly, plastically deform. Over tens of millions of years the mantle convects or mixes like a great lava lamp. Geologists hypothesize that massive plumes of hot rock rise through the mantle toward the lithosphere. Melting occurs along the upper margin of a plume as it reaches the lower pressure at the base of a plate. The resulting *magma* (molten rock) can rise into the crust and generate active volcanism; such a point on Earth’s surface is known as a *hotspot*.

Hawai‘i is the site of such a plume, a quasi-stationary hotspot that brings magma to the surface. It is this *hotspot volcanism* that produced *Mauna Kea*, which stands more than 31,000 feet from the seafloor to summit, taller than any other mountain on Earth from base to peak, and *Mauna Loa*, the most massive topographic feature on the planet.[1] Indeed, this one hotspot has prodigiously given birth to every island in the Hawai‘i-Emperor Chain as the Pacific Plate slowly passes across. Pele’s home at *Kilauea*, and the undersea volcano *Lo‘ihi*[2], are the focus of effort by the Hawaiian hotspot in recent centuries.

There are two other geologic settings (not found among the Hawaiian Islands) where volcanism is prolific. One type, *subduction zone volcanism*, is produced when two plates collide and one of them dives below the other and is subducted (recycled) into the mantle. As the plate being recycled descends into the mantle it releases water into the hot rock at the base of the overlying plate, lowering its melting point and generating magma. This molten rock rises to the surface and forms a line of volcanoes above the zone where the two plates meet. The active volcanoes of the Cascade Range in Oregon and Washington, and the Indonesian Island Arc are examples of this type of volcanic action.

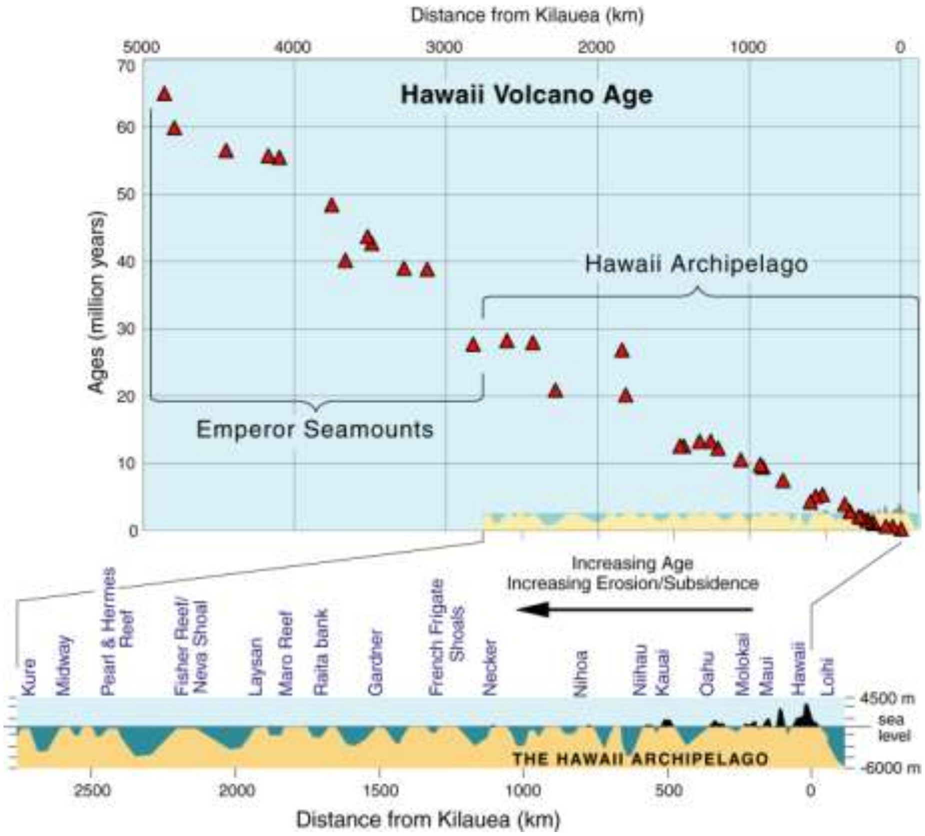
The other type is *rift zone volcanism*, where two plates split apart and magma wells up from the underlying mantle. Rift zone volcanism typically makes new sea floor (oceanic crust) and is recognized by a long valley on the ocean floor where heat and magma escape the upper mantle. In the Pacific the rift zone is named the East Pacific Rise, and in the Atlantic it is called the Mid-Atlantic Ridge.



Earth's lithosphere is broken into plates that interact with one another along their edges. Two plates may diverge, converge, or move past one another in opposite directions. This leads to three types of volcanic action: subduction zone volcanism (formed at certain types of convergent margins), rift zone volcanism (formed at divergent margins), and hotspot volcanism (formed where a plate moves across a stable mantle plume).

Island Evolution

In traditional teachings the demigod *Māui*, navigating beneath the sacred fishhook constellation *Manaiakalani*, raised (navigated to) the Hawaiian Islands one-by-one from the sea. He did this in sequence from the oldest to the youngest, demonstrating an ancient recognition of the islands' age gradient foretelling the modern theory of plate tectonics.[3]



The series of shield volcanoes, atolls, and seamounts that comprise the Hawai'i-Emperor Chain are the product of Pacific Plate movement over the Hawai'i hotspot during eighty million years of Earth history. (Ken Rubin)

As molten rock pours out of Earth's crust at the Hawaiian hotspot, it piles upon itself on the deep seafloor and solidifies under the cooling influence of the surrounding ocean waters. Slowly over hundreds of thousands of years, volcanic rock accumulates under more than a mile of seawater, eventually breaching the sea surface to become a high volcanic island composed of one or a number of *shield volcanoes*, named after its long low profile like a warrior's shield.

On the seafloor, the volcano does not grow as a neat layer-cake of lava beds. Rather, submarine eruptions break into boulders of glass and ash that accumulate as a great pile of broken volcanic rock called *talus*. As the volcano erupts, it accretes steep aprons of glassy talus forming approximately 90% of the edifice, a fundamentally unstable foundation for such a monolith. Later, after the volcanic rock breaks above the ocean surface, layers of *a'a* and *pāhoehoe* lava build upon one another constructing the massive shield. Most of a volcano's growth takes place in this shield-building stage as huge amounts of lava pour out over long spans of time. These young volcanoes are marked by the development of *calderas*, the immense summit depressions that form when lava drains out of a subterranean chamber and the surface collapses into the hollow cavity.

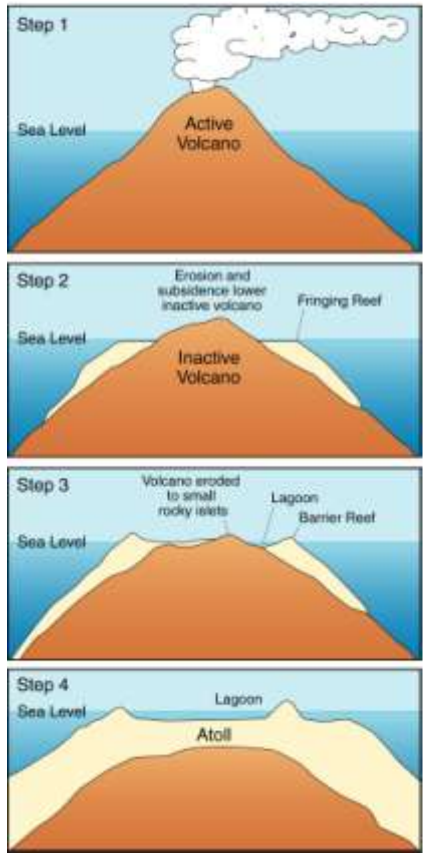
When a volcano enters the *post-caldera stage*, it is still active, but no longer tapping deep magma chambers. Interacting with groundwater and charged with gas, post-caldera eruptions become more explosive in behavior with the formation of subsidiary cinder cones by high fire fountains of gas-charged magma. On O‘ahu, Diamond Head, Koko Crater, Punchbowl and others are left as the legacy of these violent exhalations of the hotspot.

As the Pacific Plate shifts, the volcanic island moves away from the heat source and thus ends major eruptive activity.[4] When this happens, a volcano enters the *erosion stage*. A combination of weathering, gravity, rainwater, and waves carve at the volcanic slopes, reducing its elevation and area. Rock and vegetation decay, forming soil. Water, air, and animals add their chemistry, laying a blanket of organic detritus across the sterile volcanic landscape. Shaped by the land and in turn shaping the land, life, air, and water transport the island across an organic threshold as what was once an erupting volcano becomes a living community. Dense forests, thick streams, deep watersheds, and broad fringing reefs stretch their living tendrils and fill every corner of the environment with the tissue of life.

In time, however, the volcanic peaks subside and the land wears down to the level of the sea. Although erosion will ultimately have its way, even in its burial beneath the sea a volcanic corpse sustains a thriving population. Coral reefs broaden their position at the sea surface, forming insular shelves and terraces, as the remnants of the old volcano form an underpinning for the coral and hard algae to construct an *atoll* upon its tomb.

The only visible evidence of a volcano’s ancestry, an atoll rides continuously northwestward on the relentless Pacific Plate. Sometimes a lagoon will shallow and fill with *calcium carbonate* sediments, the skeletal fragments of reefal organisms. But in the majority of cases the lagoon remains an open body of circulating water, protected by the surrounding reef from heavy wave barrage.

The lush marine biomass of an atoll is remarkable; to call them rainforests of the sea is not overreaching. But the northern journey of the Pacific Plate cannot be denied and ultimately the giant stump of a volcanic edifice that is an atoll enters the latitudes of cold water and reduced sunlight that limit the growth of fragile coral polyps and marine algae. Atolls maintain their march to the northwest until they finally subside beneath the waves at the aptly named *Darwin Point*[5]. Today located on the northern edge of Kure Atoll, the Darwin Point marks the limit of reef tolerance for northerly conditions. Beneath the waves, drowned atolls become *seamounts*. The oldest of these is the eighty million year old Meiji at the far end of the 3,000 mile long *Hawai‘i-Emperor Chain*, considered the world’s longest mountain range.[6] Tens of millions of years later the seamount will be subducted into the mantle and recycled beneath the Aleutian Islands from whence lava will erupt, a reminder that Earth is the ultimate recycler.



Atolls are large, ring-shaped reefs with a central lagoon. Most atolls begin as fringing reefs on a subsiding, inactive shield volcano. The reef continues to grow vertically as the volcano subsides and erodes. Eventually, all surface evidence of the volcano disappears and a central lagoon marks the former position of the caldera before it submerged.

Living on a Volcano

In Hawaiian culture, volcanic eruptions are attributed to the restless Pele, goddess of volcanoes. Pele arrived by canoe in Hawai‘i from Kahiki, a mythical land (interpreted by some as Tahiti) that was her birthplace. Originally landing on Ni‘ihau, it was Pele’s task to establish the family home and kindle volcanic fires. Oral history tells that Pele encountered groundwater that put out the volcanic flames she discovered with her powerful digging stick *Pa-oa*.

Digging in the low coastal plains near the ocean, all her fire-pits were so near the water that they burst out in great explosions of steam and sand, and quickly died. Moving from one island to the next, in frustration she at last found Kilauea on the island of Hawai‘i where she built a mighty enduring palace of fire at the summit crater of Halema’uma’u. This location, still considered the house of Pele, is a sacred spot among the Hawaiian Islands and should only be visited with reverence and for a specific purpose for it is dangerous and hallowed. Kilauea is the world’s longest continuously erupting volcano. Since 1952, it has erupted thirty-four times, and since January 1983 the eruption has been continuous.[7]

The current eruption of Kilauea has been relatively calm without notable explosions or particularly violent behavior. But this has not always been the case. Even Kilauea has its dangerous side. When hot internal magma encounters a large body of groundwater the union can be devastating. Sudden conversion of the water into steam can lead to violently explosive eruptions that are quite dangerous. These are known as *phreatomagmatic* eruptions and Kilauea has a history of such violence. On May 10, 1924, a phase of violent eruptions began that sent columns of ash thousands of feet into the sky repeatedly throughout the next eighteen days.[8] Explosions hurled rocks as large as eight tons over half a mile from the main vent. These boulders can be seen today littering the landscape around Halema'uma'u.

Here is a list of active and potentially active volcanoes in Hawaiʻi provided by the Pacific Disaster Center.

Active and Potentially Active Volcanoes in Hawaiʻi *Pacific Disaster Center website: http://www.pdc.org/index.php*

Volcano	Eruption type	Eruptions in past 200 years	Latest activity	Remarks
Haleakala	Lava, ash	1	1790	In last stage of volcanic cycle. Expected recurrence rate about 200-600 years.
Hualalai	Lava, ash	1	1800-01	High hazard due to unusually fluid lava.
Kilauea	Lava, most common; ash, rare	47	On going from 1983	Explosive eruption at Kilauea summit in 1790 killed approximately 80 Hawaiian warriors. Lava-flow hazard to 4 coastal areas in the 19th century, 5 in the 20th century.
Kohala	Lava, ash	0	120,000 years ago	Volcanic cycle may not be completed, but eruption probability is low.
Loihi	Lava	Not known	Not known	Submarine volcano; seismically active; youngest lava less than 1,000 years old.
Mauna Kea	Lava, ash	0	4,000 years ago	Frequency of activity before latest eruption is estimated to be about 300 years.
Mauna Loa	Lava	30	1984	Lava-flow hazard to 8 coastal areas in the 19th century, 8 in the 20th century.

The words “volcanic eruption” conjures the classic image of a flaming geyser spouting out of a mountaintop with blazing, viscous rivers oozing down its slopes and a column of dark “smoke” rising into the sky. The image is instructive because volcanic rock fragments and lethal gases are common volcanic hazards in Hawaiʻi. The deadly pillar of gas and *pyroclastic particles* (rock fragments formed in a volcanic eruption) rushing from the central vent of a volcano is mostly made of water vapor and glass particles, but can also include toxic gases. The gas plume rising from an active vent on Kilauea consists of about 80% water vapor with lesser amounts of sulfur dioxide, carbon dioxide, and hydrogen. Small quantities of carbon monoxide, hydrogen sulfide, and hydrogen fluoride are also present. Extremely small amounts of mercury and other metals have been detected in gases emitted from vents along the east rift zone of Kilauea. Even in the non-explosive phases of eruptions, these gases are released around the crater or fissure vents and are capable of causing the rare fatality.

The storied history of Kilauea is full of warnings. In 1790, Keoua, Chief of Puna, was leading his small army toward Ka‘u on a route near the Keanakakoi crater on the slopes of Kilauea Volcano, when an explosion occurred. Keoua split his army into three divisions to ensure the whole army would not be harmed in case of catastrophe, and they proceeded after one another down the Ka‘u trail. Roughly six miles from Halema’uma’u the third division found the entire second division lying motionless on the ground. None of the bodies showed signs of being burned or struck by rocks, yet everyone was dead. Apparently, Kilauea’s summit caldera had belched a *pyroclastic surge cloud*, an avalanche of poisonous gas and fine ash that raced down the slopes. These burning clouds are glassy, gassy avalanches moving on a thin cushion of air at high speeds. Eighty Hawaiian warriors were killed by the toxic gas, but their pigs were found wandering unharmed among the corpses because their low height kept them below the deadly cloud.[9]

When pahoehoe lava enters the ocean for extended periods of time, new land is created in the form of a fan-shaped platform known as a *lava bench*. Lava pouring into the ocean from either surface flows or lava tubes cools rapidly, usually shattering in the cold water into sand- to block-size fragments. These accumulate along the shore to form a loose foundation that can support overlying lava flows which build a bench above sea level. However, the bench is deceptive; while it looks like solid land, it will in fact eventually collapse sweeping unwary visitors into the sea. National Park Service personnel usually rope these dangerous areas off to protect the public. Nonetheless, adventurous hikers are seen on these dangerous features, and have been lost when they visited the wrong place at the wrong time.

A lava bench at East Lae`apuki on the south shore of the Big Island collapsed during the night of 13 August, 2007. Photos courtesy of the USGS Hawaiian Volcano Observatory.

Vog (volcanic smog) and *laze* (lava haze) are the most persistent hazards associated with gases. These hybrid words describe two common problems associated with Hawai‘i’s ongoing eruptions. Vog forms around craters and vents when sulfur dioxide (SO_2) gases mix with the atmosphere producing an aerosol of tiny, suspended droplets of sulfuric acid. As this drifts and accumulates downwind, a cloud of natural pollutants forms. In addition to the trace gases noted previously, mercury levels are frequently above normal in vog. The gas isn’t usually threatening over a short period of time, except to persons with respiratory or heart problems. More typically, the acidic vog can produce acid rain that leaches heavy metals such as lead and copper from plumbing. These metals can find their way into our drinking water, a particular hazard for small children to regularly ingest as they grow.

Agriculture is particularly vulnerable to volcanic gas. Since March 12, 2008, sulfur dioxide emissions from a new gas vent in Halema’uma’u Crater have affected residents with respiratory problems, caused voluntary evacuations, and produced significant damage to agricultural farms and ranches[10]. The emissions have also led to concern for the long-term effects on health, water quality and agriculture. The eruptions have produced massive volumes of sulfur-dioxide gas, increasing daily emissions from roughly 100 tons to 1000. This has devastated coffee, macadamia, protea farming, and other growing operations in the Ka’u district, especially in Ocean View region, located downwind of the eruption cloud. This problem has grown so severe that the Governor of Hawai’i convened a special task force of interagency personnel to develop strategies for managing the impacts related to volcanic emissions.

Volcanic smog tends to accumulate during *stagnation* when trade winds fail, locally known as “kona weather”, when air stalls against a mountainside from poor atmospheric circulation. While prevailing northeasterly winds on the Big Island usually carry the smog southwest, it can also be carried across the southern end of the island and up along the Kona (western) coast. In contrast, Kona winds (blowing from the south to west direction) blow the noxious air into the populated areas on the east side of the island, including Hilo (and the rest of the state).

One telling story about the danger of volcanic gases involves a couple in 2002 visiting the stark landscape where lava enters the sea on the south shore of the Big Island. Much of this terrain consists of young, glassy volcanic rock that is precarious for hiking. Near the point where red lava flows into the sea, a dozen feet underground molten rock travels through a network of lava tubes toward the shore. On this sad day, a heavy and sudden rainsquall blew in from the ocean and water that ran through the fractured rock beneath their feet turned to steam when it hit the subterranean lava. The ensuing cloud of scalding water vapor engulfed the hapless couple and killed them.[11]

If you’re growing increasingly concerned for your safety, don’t worry. It’s not difficult to stay safe when you visit Kilauea. Here are some suggestions;

1. Stay clear of vents during any eruptive activity.
2. Avoid topographic low spots in these same areas because heavier gases accumulate in low areas.
3. Try to avoid visiting the region of active lava on windless days. If you have a health problem that is aggravated by smog, relocate until the air clears.
4. Pay heed to information issued by the Hawaiian Vog Authority (HVA), established in 1990 to address associated problems.

5. If you live on the Big Island with a cistern water supply, have it checked for lead levels and other compounds as recommended by the Health Department.

Here is a list of common volcanic hazards provided by the Pacific Disaster Center.

Volcanic Hazards *Pacific Disaster Center website: http://www.pdc.org/index.php*	
Pyroclastic Surges	Gravity-driven, rapidly moving, ground-hugging mixture of hot gases, ash, and glass fragments.
Lahars	Avalanche of water, rock, and mud that rush down hills leading away from a volcano.
Landslides	A rapid downslope movement of rock, snow, and ice.
Lava flows	Molten rock (magma) that pours or oozes onto Earth's surface.
Tephra	Glassy shards that are ejected from a volcano and form a sedimentary deposit.
Volcanic Gas	Dissolved gases released to the atmosphere during an eruption: water vapor, carbon dioxide, carbon monoxide, sulfur oxides, hydrogen sulfide, chlorine, and fluorine.
Tsunamis	Ocean wave generated by a sudden displacement of water. May be caused by earthquake, landslide, or volcanic activity on the sea floor.

Ground Fractures and Subsidence

The body of a volcano is alive and breathing. As magma pours into its belly and later retreats back to Earth's interior, the volcano will expand and contract, tilt and vibrate, and portions will even shift laterally under the push of magma and the pull of gravity. Cracks and fractures in the ground commonly result from the inability of brittle rocks to stretch in compensation for the changing size of the volcano. These features are generally small in size but fractures can occur in larger dimensions of several feet across and vertical offsets in the level ground are common. These cause serious damage to buildings, roads, and services such as water pipes or power lines.

As the flanks of a volcano inhale and exhale, *ground subsidence*, or sinking of the land, may occur. The scale of subsidence ranges from the entire-island, to parts of a volcano's sides sinking, to the settling of a small area and local collapse of lava benches on the shore. Rapid subsidence is more directly related to volcanic or seismic activity and is a particular threat in coastal areas because of the possible inundation by tsunami. Similarly, ground settling and fractures are also associated with earthquakes.

A particularly large type of ground fracture known as a *rift zone* is found on most Hawaiian volcanoes. Sharing the same name as the rift zone mentioned at the beginning of this chapter in connection with lithospheric plates, rift zones in Hawaiʻi are smaller than the aforementioned features which mark the edges of massive, ocean forming, continent-carrying plates. Rather, rifts in Hawaiʻi are places where the volcanic crust is pulling apart. Often two rifts radiate away from the summit of Hawaiian shield volcanoes. These do not point towards adjacent volcanoes but instead tend to run parallel to volcano-to-volcano boundaries. Because rifts mark openings in the crust they are natural conduits for subterranean magma migration away from the main magma chamber (usually located under the summit caldera). At their surface, rifts are characterized by a seismically active valley, numerous vents, fissures, cracks, cinder cones, pit craters, faulting, and various sources of lava. All of these are indications that magma prefers to intrude (underground) into rift zones and may be stored there for periods up to a few years.

Because rifts are characterized by earthquakes and ground subsidence, they are an especially bad place to build a house. Yet amazingly, an entire subdivision exists in Kilauea's east rift zone where it enters the sea. *Kapoho Vacationlands* subdivision is built in the center of the east rift valley and the subsiding ground has allowed flooding by the sea forming Kapoho Bay. Add marine flooding to the heightened incidence of quakes, tsunami, eruptions and other hazards, and this region deserves the award for all time worst housing project in the Hawaiian Islands![12]

On the scale of an entire island, subsidence is a natural chapter in the evolution of the landscape. Supported by heat from the hot spot and the fresh outpourings of lava, young volcanoes are able to build to great heights. But the mass of the enormous edifice immediately overwhelms the ability of the lithosphere to support its weight and paralleling its growth is a several hundred thousand year long process of bending Earth's lithosphere and slowly settling deeper into the upper mantle. As long as volcanism is active the mountain cheats this process and grows lava layer upon lava layer. But as the plate shifts further from the hotspot, cooling, subsidence, and erosion take over as the main agents controlling the elevation and geography of the land surface.

Volcanic Hazards

At daybreak of March 25, 1984, the second day of the last Mauna Loa eruption, six large vents on the mountain's slopes was feeding numerous lava flows headed eastward down the mountain – straight for Hilo. For over a week, the town of Hilo watched in growing horror as hot rivers flowed towards their homes, one of them halting within a mere 1.2 miles of the local prison. Residents were mesmerized by the smoke from burning vegetation, the lava's glow at night, and the explosions caused by methane gas along the advancing flow front. The river of flames crept closer to Hilo every day for a week. On April 4th, the impending fire hazard changed course four miles from the city's main road; everyone breathed a sigh of relief. On April 15th, the eruption ceased.[13]

While eruptions such as the one in 1984 may be the most vivid hazard, other equally life-threatening dangers loom near any active volcano. As lava streams down the sides of Kilauea Volcano it forms long, thin rivers of burning rock. But as it meets the flat land of the coastal zone, these lava streams slow and fan out often forming lava deltas on the shoreline. As the rock meets the seawater it builds an unstable shoreline feature called a *bench* that is prone to collapse without warning. Tempting to hikers that make the long trek from Chain of Craters Road to the lava entry point on the shore, these benches offer an exciting opportunity to view the sea up close on the otherwise hard, hot hike to the east. Visitors are warned not to make the side trip onto a lava bench but not all heed this message. Bench collapse is not a rare event, and once a new bench forms it is almost guaranteed to collapse in the near future. Lives have been lost when lava shorelines suddenly collapse into the sea. It is best to skirt around low lying benches and enjoy them from a distance.

Thanks to many years of study by scientists at the U.S. Geological Survey Hawaiian Volcano Observatory, various state and county authorities, and the University of Hawai'i, volcanic eruptions are semi-predictable. Accurate predictions rely in large part on data that stream in from state-of-the-art instruments monitoring the rumblings of Kilauea and Mauna Loa. Precursor events such as *earthquake swarms* (hundreds of small earthquakes transpiring in a few days) and patterns of summit swelling and deflating can suggest the onset of a volcanic event. Even though the precise moment or type of eruption cannot be forecast, there is usually ample time to warn residents and take all necessary precautions for reducing the impact of an eruption.

Once a lava flow slithers its fiery form down the mountain, evacuation is usually straightforward and methodical. At the same time, however, volcanologists warn people not to be complacent because if Pele is feeling particularly spirited that day, events like pyroclastic surges or random explosive events may occur without warning. It's also important to remember that volcanic activity cannot be prevented so best to do some research before buying your dream home for a steal in Hilo, Puna, Ka'u, or Kona. The U.S.G.S. provides a volcanic hazards map and guide highlighting the island of Hawai'i's low-risk areas.

The Hawaiian Islands are beautiful, but we should never forget that they are a fleet of volcanoes that are incompletely understood and capable of surprising violence. As they pass from the youth of Kilauea to the middle age of Mauna Kea and Haleakala we should keep in mind that they will be the source of still more eruptions and the cause of earthquakes and tsunamis.

Here are some sources of information for you:

U.S.G.S. Hawai'i volcano Observatory - http://hvo.wr.usgs.gov/

What are volcano hazards? http://pubs.usgs.gov/fs/fs002-97/

VOG: A volcanic hazard http://hvo.wr.usgs.gov/volcanowatch/1996/96_05_29.html

State of Hawai'i Governor's Office VOG information: http://hawaii.gov/gov/vog

Hawai'i State Civil Defense: http://www.scd.state.hi.us/

Pacific Disaster Center: http://www.pdc.org/iweb/pdchome.html

U.S.G.S. Atlas of Natural Hazards in the Hawaiian Coastal Zone: http://pubs.usgs.gov/imap/i2761/

UH Sea Grant Publications:

Purchasing Coastal Real Estate - http://www.soest.hawaii.edu/SEAGRANT/communication/pdf/Purchasing%20Coastal%20Real%20Estate.pdf

Hawai'i Coastal Hazard Mitigation Guidebook - http://www.soest.hawaii.edu/SEAGRANT/communication/HCHMG/hchmg.htm

Homeowners Handbook to Prepare for Natural Hazards - http://www.soest.hawaii.edu/SEAGRANT/communication/NaturalHazardsHandbook/naturalhazardprepbook.htm

[1] U.S. Geological Survey, Hawaiian Volcano Observatory, Mauna Loa: Earth's Largest Volcano, http://hvo.wr.usgs.gov/maunaloa/; and University of Hawai'i, Institute for Astronomy, About Mauna Kea Observatories, http://www.ifa.hawaii.edu/mko/about_maunakea.htm.

[2] For more information on the Hawaiian hotspot, see U.S. Geological Survey, Hawaiian Volcano Observatory, Hotspots, http://hvo.wr.usgs.gov/volcanowatch/1995/95_04_14.html.

[3] For more information on the demigod Maui, see W.D. Westervelt, Legends of Maui (Kessinger Publishing Co 2004).

[4] For a map showing the tectonic motion in the Pacific Basin, see NASA Crustal Dynamics Data Information System, Tectonic Motion in the Pacific Basin, http://cddis.nasa.gov/926/swpactect.html.

[5] R.W. Grigg, Darwin Point: A threshold for atoll formation, Coral Reefs, Vol. 1, No. 1 (June 1982).

[6] R.W. Grigg, Paleoceanography of Coral Reefs in the Hawaiian-Emperor Chain – Revisited, Coral Reefs, Vol. 16, No. 5 (June 1997).

[7] University of Hawai'i, School of Ocean and Earth Science and Technology, Hawai'i Center for Volcanology, Volcanic History of Kilauea, http://www.soest.hawaii.edu/GG/HCV/kil-general.html.

[8] U.S. Geological Survey, Hawaiian Volcano Observatory, The 1924 Explosions of Kilauea, http://hvo.wr.usgs.gov/kilauea/history/1924May18/.

[9] Gordon Andrew Macdonald et al, Volcanoes in the Sea: The Geology of Hawai'i, p 164 (UH Press 1983).

[10] See for instance, Ragnar Carlson, Big Island rocked by cloud of uncertainty, Honolulu Weekly, August 27, 2008. p.6-7.

[11] Interview with Aisha Morris, Geologist, in Honolulu, HI (November, 2000).

[12] For more information on the various issues at Kapoho, see Dennis H. Hwang, Coastal Subsistence in Kapoho, Puna, Island and State of Hawai'i, Report for the Hawai'i County Planning Department (County of Hawai'i January 2007).

[13] U.S. Geological Survey, Hawaiian Volcano Observatory, 1984 Eruption: March 25 – April 15, http://hvo.wr.usgs.gov/maunaloa/history/1984.html.