



Geology & Meteorology of Hanauma Bay

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Cover Photo: The Koko Rift, southeast O‘ahu. Photo credit: S. Rowland.

Title: **Geology & Meteorology of Hanauma Bay**

Grades: 6-8, modifiable for 3-5, 9-12

Time: 2 - 5 hours

Nā Honua Mauli Ola, Guidelines for Educators, No Nā Kumu: Educators are able to sustain respect for the integrity of one’s own cultural knowledge and provide meaningful opportunities to make new connections among other knowledge systems (NHEC, 2002, p. 37).

Standard: Earth and Space Science 2.A ESS2A: Earth Materials and Systems

All Earth processes are the result of energy flowing and matter cycling within and among Earth’s systems. This energy originates from the sun and from Earth’s interior. Transfers of energy and the movements of matter can cause chemical and physical changes among Earth’s materials and living organisms. Solid rocks, for example, can be formed by the cooling of molten rock, the accumulation and consolidation of sediments, or the alteration of older rocks by heat, pressure, and fluids. These processes occur under different circumstances and produce different types of rock. Weather and climate are driven by interactions of the geosphere, hydrosphere, and atmosphere, with inputs of energy from the sun. The tectonic and volcanic processes that create and build mountains and plateaus, for example, as well as the weathering and erosion processes that break down these structures and transport the products, all involve interactions among the geosphere, hydrosphere, and atmosphere. Earth’s systems are dynamic; they interact over a wide range of temporal and spatial scales and continually react to changing influences, including human activities. Components of Earth’s systems may appear stable, change slowly over long periods of time, or change abruptly, with significant consequences for living organisms. (A Framework for K-12 Science Education, NRC, 2012)

Standard: Earth and Space Science 2.D ESS2D: Weather and Climate

Weather varies day to day and seasonally; it is the condition of the atmosphere at a given place and time. Climate is the range of a region’s weather over one to many years. Both are shaped by complex interactions involving sunlight, ocean, atmosphere, latitude, altitude, ice, living things, and geography that can drive changes over multiple time scales—days, weeks, and months for weather to years, decades, centuries, and beyond for climate. The ocean absorbs and stores large amounts of energy from the sun and releases it slowly, moderating and stabilizing global climates. Sunlight heats the land more rapidly. Heat energy is redistributed through ocean currents and atmospheric circulation, winds. Greenhouse gases absorb and retain the energy radiated from land and ocean surfaces, regulating temperatures and keep Earth habitable. (A Framework for K-12 Science Education, NRC, 2012).

Hawai‘i Content & Performance Standards (HCPS) III

<http://standardstoolkit.k12.hi.us/>

Strand: The Scientific Process	
Standard 1: The Scientific Process: SCIENTIFIC INVESTIGATION: Discover, invent, and investigate using the skills necessary to engage in the scientific process	
Topic: Scientific Inquiry	<p>Benchmarks:</p> <p><u>SC.8.1.1</u> Determine the link(s) between evidence and the conclusion(s) of an investigation.</p> <p><u>SC.8.1.2</u> Communicate the significant components of the experimental design and results of a scientific investigation.</p> <p><u>SC.ES.1.3</u> Defend and support conclusions, explanations, and arguments based on logic, scientific knowledge, and evidence from data</p> <p><u>SC.ES.1.4</u> Determine the connection(s) among hypotheses, scientific evidence, and conclusions</p>
Standard 2: The Scientific Process: NATURE OF SCIENCE: Understand that science, technology, and society are interrelated	
Topic: Science, Technology, and Society	<p>Benchmark:</p> <p><u>SC.8.2.1</u> Describe significant relationships among society, science, and technology and how one impacts the other</p> <p><u>SC.ES.2.1</u> Explain how scientific advancements and emerging technology have influenced society</p>
Topic: Unifying Concepts and Themes	<p>Benchmark</p> <p><u>SC.8.2.2</u> Describe how scale and mathematical models can</p>

be used to support and explain scientific data.

Strand: Physical, Earth, and Space Sciences

Standard 8: Physical, Earth, and Space Sciences: EARTH AND SPACE SCIENCE: Understand the Earth and its processes, the solar system, and the universe and its contents

Topic: Forces that Shape the Earth

Benchmark:

[SC.8.8.4](#) Explain how the sun is the major source of energy influencing climate and weather on Earth

[SC.8.8.6](#) Explain the relationship between density and convection currents in the ocean and atmosphere.

[SC.ES.8.1](#) Describe how elements and water move through solid Earth, the oceans, atmosphere, and living things as part of geochemical cycles

[SC.ES.8.4](#) Describe how heat and energy transfer into and out of the atmosphere and their involvement in global climate.

[SC.ES.8.6](#) Describe how winds and ocean currents are produced on the Earth's surface.

[SC.ES.8.7](#) Describe climate and weather patterns associated with certain geographic locations and features.

[SC.ES.8.8](#) Describe the major internal and external sources of energy on Earth

INTRODUCTION

Hawaiian volcanoes are probably some of the best-studied in the world. One of their aspects that has long been recognized, but which is still not fully understood, is how they evolve from young volcanoes to old seamounts. Geologists noticed that the volcanoes were obviously younger at the SE end of the chain, and older at the NW end. They also noticed that the morphology of the volcanoes differed, even accounting for erosion. And finally, when examining an individual volcano it was clear that older flows and younger flows were not the same. How these changes work, however, was elusive until the early 1980s. Remember also that the early attempts to explain Hawaiian volcano evolution occurred without the benefit of Plate Tectonic theory.

The earliest Western geologists noticed that there were obvious age differences in the islands as one moved from southeast to northwest. They didn't have satellite images, of course, but they could notice

the differences from the surface. Lots of folks made estimates of the order in which the Hawaiian volcanoes had gone extinct, mostly based on the degree to which they were eroded.

Local winds and clouds are the result of the influence of complex terrain and the daily or diurnal heating cycle of the Hawaiian Islands on the large-scale winds and moisture arriving from over the open ocean. Large scale winds here refers to surface winds arising over the open ocean as a result of surface high and low pressure systems that have a scale of ~1000 km, such as the Hadley circulation or Kona lows. Each of the main Hawaiian Islands has many local wind regimes that depend critically on the height of the mountains and the areal size of the islands.

The mountains of Hawai‘i have a profound impact on the weather, both on the wind field and on the climatology of cloud and precipitation. As moist air is forced upslope, it cools and since cool air can hold less moisture, some moisture condenses. As a result clouds and then rain form, which are sometimes referred to as *orographic* clouds and rain.

As the undisturbed flow over the ocean approaches the Hawaiian Islands, the mountains and daily heating cycle over the islands disturbs the flow, resulting in “local” winds. The direction of the flow at large scales interacts with the topography to produce gradients in cloud and rainfall, that in turn help define the local climate; e.g., wet windward and dry leeward slopes. The height of the mountains and the strength of the flow determine if the flow can pass over the top of the mountain or if the flow is forced to split and go around the mountain (see Figs. 8 and 9). Mountains can act both to trigger and anchor thunderstorms that can produce prodigious rainfall rates up to 8 inches (200 mm) per hour.

The fact that topographic features are fixed makes the interaction between large-scale storms systems and mountains somewhat easier to anticipate. The greatest accuracy in weather forecasting is associated with the largest scale systems, so if one has detailed knowledge of topography, it is fairly straightforward to forecast the general character of the topographically forced winds, clouds, and rainfall that will occur with various large-scale weather systems. For example, UH scientists using O‘ahu rainfall data, statistics, and General Circulation Models predict more frequent heavy rainfall events but reduced rainfall intensity through 2040 for the south shoreline of O‘ahu as Earth undergoes unprecedented warming. Heavy rainfall and flash floods have economic and environmental costs: slope and coastal erosion, pollution of marine environment, and damage to coral reefs (<http://www.hawaii.edu/news/article.php?aId=4710>).

CULTURE

Hanauma Bay

Hana-uma can be interpreted as "curved bay," or "hand wrestling bay." There is a story that two men were fighting over a beautiful woman. They decided to settle the match with a type of wrestling called "uma," similar to the arm wrestling we know today. They wrestled and wrestled but there was no winner. They wrestled for so long, they were turned into mo‘o, and they are still wrestling to this day.

Here is a Hawaiian-language newspaper article written by George Poola, who describes Hanauma as a place which the ali‘i resided for a long time. Queen Ka‘ahumanu arrives at Hanauma and is greeted by hula dancers. It is said that people spent whole months playing uma in this area.

From *Ka Hoku o Hawaii*, February 11, 1930.
(Adapted from a translation in *Sites of Oahu*, p. 267)

**NA ANOAI
O OAHU NEI**
Kakau ia o Geo. Poola

**News of O‘ahu.
Written by Geo. Poola.**

[...]

Ua lohi no ‘a noho ana o na ali‘i
ia mau kalaea sina. Ke ali‘i Mo:—
wahine Kaahumanu, ua helo maluna
e na waa a kipa se ma Hanauma
a Mr. Pahi ke konohiki sina e
noho ana ia wa, a o ke Aliiwahine
Ihilihilaakea ame ke Aliiwahine
Kauanonoia ame na poe hula Mrs.
Alapai wahine, Mr. Hewahewa,
Mr. Ahukai a he mea nei ia labou
ka hui aloha pu ana a e malama ia
na haneli e se alo ali‘i, a he uma
ka hana a na kane o ka lima o ke—
kahi kane aroo kon lima puliki a
paa kula a hina Hale, a he ui ia
pau pu me ka wahine ia alabele ia
mau mahina o ka noho ana.

Pela i kahen ia heia inoa Hana—
uma e kaiaua nei ma kona moolelo

[...]

The period during which the ali‘i resided
in these places was indeed a long span. Queen
Ka‘ahumanu came by canoe and went to
Hanauma, where Pākī was the konohiki at the
time and which was an area of the (legendary)
chiefesses, ‘Ihi‘ihilauākea and Kauanono‘ula
and of the hula dancers, Mrs. Alapai, Mr.
Hewahewa and Mr. Ahukai. It was important to
them to gather together in a welcoming manner,
to maintain the pleasure of the royal courts. The
men played the game of Uma, wrestling, where
one man gripped the hand of the other and
pushed to knock him down. It would build
excitement and women joined in on that track
where whole months were spent in residence.
That was why the place was called Hana-uma,
wrestling, and was renowned in the stories about
it.

Hanauma is also where the beautiful chiefesses ‘Ihi‘ihilauākea and Kauanono‘ula resided. They were very kind to the people of Makapu‘u. They would go to the beach and fish with the people, for that was a common occupation, or ‘oihana, in this region. Perhaps one of them was the maiden the two mo‘o wrestle for. ‘Ihi‘ihilauākea is a small, native fern found in this area, and a name of a local wind as seen on the wind map from *The Wind Gourd of La‘amao* (Fig. 7). Here is an article describing the two chiefesses as such.

From *Ka Hoku o Hawaii*, December 31, 1929.
(Adapted from a translation in *Sites of Oahu*, p. 268)

NA ANOAI O OAHU NEI

News of O‘ahu

[...]

[...]

Ke aliiwahine Ihihilauea a me
ke aliiwahine Kauanonoia he mau
wahine ei laua a uloula imes o na
makaianua e noho ana ma Maha-
pua, a o Mrs. Alapai wahine, Mr.

The chiefesses ‘Ihi‘ihilauākea and
Kauanono‘ula were beautiful women and kind
to the people of Makapu‘u.

[...]

[...]

A o ka mea huaoli man a kei
mau aliiwahine o ka hele pu me na
makaianua i kahakai o lawaia ei,
a he mau mau ia uo keia aue, a o

These chiefesses always delighted in going to
the beach with the people to fish, a customary
occupation of this land.

John Papa ‘Īī also writes that Hanauma is a good place to watch and wait for the winds to become favorable for sailing to Moloka‘i. That is what the wind observers would do, climbing up Kuamo‘okāne and ‘Ihi‘ihilauākea, on the western side of Hanauma.

From *Ka Nupepa Kuokoa*, January 15, 1870.
(Adapted from a translation in *Sites of Oahu*, p. 267)

NA HUNAHUNA
— NO KA —
MOOLELO HAWAII.

[...]

hoi aohē auwaa holo e ae mamua. A pela ka haalele ana iho ia Honolulu, a pae ana i Hanauma, oiai he wahi kupono ia i ke kali ana i ka maikai mai o ka makani, i hiki ai ke holo aku a pae i Molokai. Pela hoi na mea nana makani i pii ae ai mai laila ne ma Kuamookane a me Ihihi-lauakeae, mamua iho o Kuamookane, ma ka aoao komohana o Hanauma. A o ua awa la, he wahi ia e hamama pono ana i ka aoao hikina heua. Ua lulu maikai ia wahi, a he aue kohola mai uka a ke one, a ua puni ia i na kukaipali a koe ae ke awa, a he kuono ia wahi. Ua nui hoi na

Fragments of Hawaiian History.

[...]

Thus they departed Honolulu, landing at Hanauma, for it was a good place to wait for fair winds in order to sail to Moloka‘i. So those who studied the winds climbed upon Kuamo‘okāne (Mo‘okuaokāne‘āpua) and ‘Ihi‘ihilauākea which stood in front of Kuamo‘okāne on the west side of Hanauma. And this bay opens directly to the south-east. This is a nice, calm place. It is almost entirely reef flats from the uplands to the sandy shore. It is surrounded by a circle of cliffs, except for the channel, which makes a cove.

GEOLOGY

Hawaiian Volcanoes

The Hawaiian hot spot is one of the most productive hot spots on Earth, and has produced an impressive chain of almost 200 volcanoes. It includes the major Hawaiian volcanoes (on the islands of Hawai‘i to Ni‘ihau), volcanic remnants and the bases of atolls in the NW Hawaiian islands (Papahānaumokuākea), and the emperor seamounts.

The hot “spot” as a hot “column”

A "hotspot", as we know it, is an upward-moving cylinder of solid mantle material.

The material in the center moves the fastest, is out of equilibrium the most, and melts to the greatest degree. Volcanoes fed by this part of the hot column erupt tholeiite basalt and often. The outer part moves the slowest and only melts a little bit. Volcanoes fed by the outer region of the hot column erupt alkalic basalt and infrequently. Figure 1 depicts the hot “spot” as a hot “column”. It is a hot column of mantle rock that is rising through the adjacent mantle because it is hotter and therefore buoyant.

The entire column does not rise at the same rate. Instead, the central, hotter, more buoyant portion rises faster than the outer, cooler, less buoyant portion. Additionally, the outer portion is dragging against the surrounding mantle. Recall that one way to induce melting is to decompress a hot solid, and this is exactly what occurs at the uppermost part of the hot column. The faster that rocks decompress, the more they melt. When you compare the outer and inner portions of the melt region, there will be differences in both the composition of the melt and its volume. Specifically, the center will produce large volumes of tholeiitic basalt whereas the outer portion will produce smaller volumes of alkalic basalt.

The size of the column is quite speculative, but based on the area of uplifted lithosphere around Hawai‘i, it is probably around 250 km across. If, as some have suggested, the entire mantle convects, then the height is about 3000 km. It is a pretty long, skinny column.

Tectonic plate movement over the hot “column”

Imagine a portion of the Pacific plate moving over the top of this hot column. The inner and outer melting portions will be stretched downstream, but there will still be a pattern similar to that of a bulls-eye (Fig. 1). If you were to follow an individual location on the over-riding plate, it would initially not know there was a hot column at all. Next, it would move over the outer portion of the column, and small volumes of alkalic basalt would start to work their way through to feed a small, young, undersea volcano. After a while, the point that we are following will move over the interior portion of the column, and larger volumes of tholeiitic magma will erupt, building the greatest proportion of the volcano. Eventually, the point will move off the central portion, and over a cooler region of low-supply alkalic magma. When it erupts, it will produce a small amount of alkalic basalt on top of the massive tholeiitic shield. Finally, the location will move off the hot column all together, and the volcano will die.

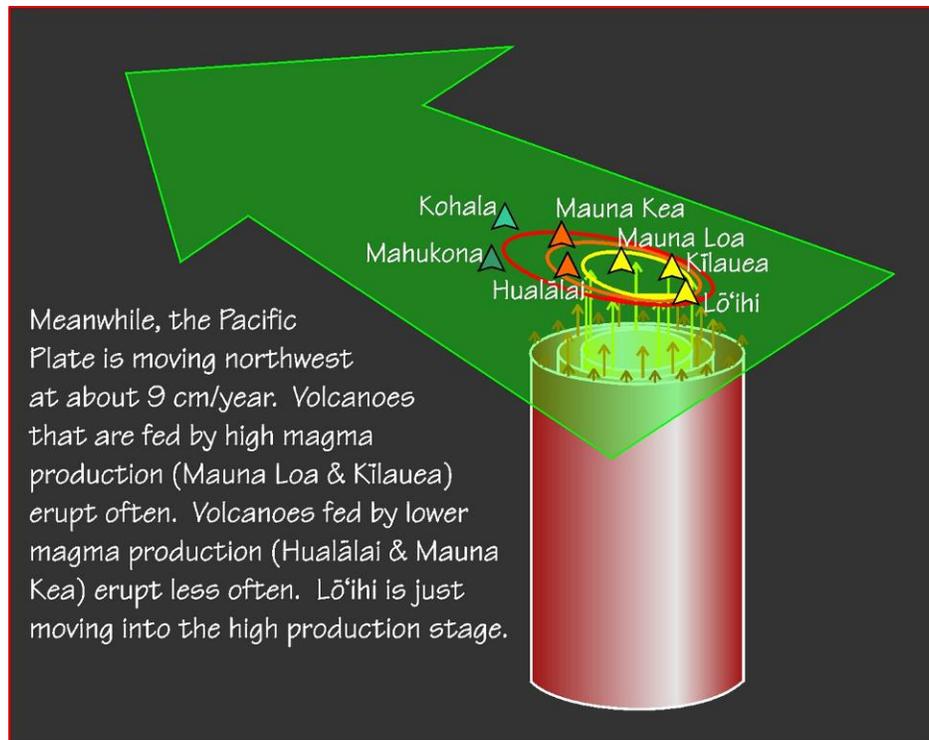


Figure 1: This diagram provides an explanation for how a Hawaiian volcano evolves throughout most of its life. Produced by S. Rowland based on discussions with K. Rubin.

Life Stages of a Hawaiian Volcano

With or without the plate-tectonic/hot spot understanding and connection, the typical order of events on a Hawaiian volcano has been derived. It is important to remember that these are human-defined steps – the volcanoes couldn't care less about them. Some volcanoes skip certain steps, some stay in a particular step for a long time whereas others only briefly. In fact, it is the variability that makes studying this process so interesting. As is diagrammed here (Fig. 2), a typical Hawaiian volcano starts its life as a small seamount, and ends its life as a small seamount. Along the way it grows, becomes very active, then slowly dies off. A few briefly rejuvenate, but all eventually stop erupting, and erode and subside below sea level. Table 1 provides brief descriptions of what occurs in each step of the Volcano's lifetime.

Table 1: Descriptions of the life stages of a Hawaiian volcano.

Stage #	Stage Name	Description
1	<i>Submarine Alkalics</i>	The very first stage in a Hawaiian volcano’s life is somewhat conjectural. We know from the hot-column model that the first melts that a point on the lithosphere encounters (i.e., from the periphery of the hot column) will be alkalic (sodium- and potassium-rich), and we also know that the magma-production rate will be small.
2	<i>Submarine Tholeiite</i>	As the now-established volcano moves closer to the center of the hot column, the magma composition changes and magma supply rate increases. Tholeiite (more silica-rich) lavas are erupted, and they bury the earlier alkalic lavas. On Lō‘ihi, the only Hawaiian example currently in this stage, lavas sampled from the summit and upper flanks are tholeiite whereas those sampled from the lower flanks are alkalic. Lō‘ihi, therefore, hasn’t yet completely buried its early alkalic base. Almost all eruptions in deep ocean water are non-explosive because of the high water pressure.
3	<i>Shallow-water Hyaloclastites</i>	When the summit of the volcano reaches to about 200 m below the surface, the water pressure is no longer sufficient to prevent explosive lava-water interactions, and the eruptions change from passive effusion of pillow lavas to strong steam explosions. These explosions occur every time the volcano erupts as it builds itself from ~200 m below sea level to above sea level. Once it has built above sea level, it erupts lavas again. There is therefore a ~200 m-thick layer of hyaloclastite (volcanic sand and rubble) sandwiched between pillow lavas below and subaerial lavas above.
4	<i>Main Tholeiite Shield</i>	Eventually the volcano gets moves over the center of the hot column, and thereby starts erupting large volumes of tholeiite basalt. This is the stage during which the great majority of the volcano’s volume is produced. This is also the eruptive stage that we understand the best because both Mauna Loa and Kīlauea are in this stage, and they have each erupted many times.
5	<i>Post-Shield Alkalics</i>	Eventually the volcano moves off the central part of the hot column and into the down-stream portion where low volumes of alkalic magmas are produced. The total volume of these lavas is small compared to the volcano as a whole, and it is often likened to a “cap” of alkalics, in older texts, it was in fact referred to as the alkalic “cap.”

		Nowadays, we refer to it as post-shield alkalis.
6	<i>Erosion, Reef-building</i>	At some point the volcano moves far enough off the hot spot so that it is not supplied by magma at all. Erosion, which started as soon as the volcano reached sea level, becomes the dominant geologic process, and extensive reefs are able to develop because they are no longer being buried by lava entering the ocean.
7	<i>Rejuvenation</i>	For reasons that we don't completely understand, some Hawaiian volcanoes come back to life long after they have moved off the hotspot. This rejuvenation activity, which used to be referred to as "secondary" or "post-erosional" occurs 500,000 to >2,000,000 after the volcano was over the hotspot, corresponding to distances of 45 to >180 km from the center of the hot column. The volume of magma that erupts is very small, and it has a very alkalic composition. Not every Hawaiian volcano goes through this stage.
8	<i>Atoll</i>	As soon as material starts accumulating on the ocean floor, its weight causes the lithosphere to begin subsiding. As the volcano grows this subsidence increases, and even as the volcano begins to erode, it continues. Additionally, wind and waves continually wear a volcano down, eventually to below sea level. Coral reefs, however, are able to grow fast enough to keep up with subsidence, so the final morphology is a more or less ring-shaped reef surrounding a shallow lagoon centered on where the old volcano once was. Coral reefs only grow to just below sea level, but waves can break them into sediment which occasionally builds up above sea level as a shallow coral island. If vegetation gets established, these low islands can become semi-permanent, and are known as atolls.
9	<i>Old Seamount</i>	Eventually, because the Pacific plate is moving north, the ocean water temperature is too cold to support reef growth that is fast enough to make up for subsidence. Once a reef subsides below a few tens of meters (gotta check this depth – any oceanographers out there?), it dies, and the resulting reef-capped seamount (called a guyot) continues to subside deeper and deeper.

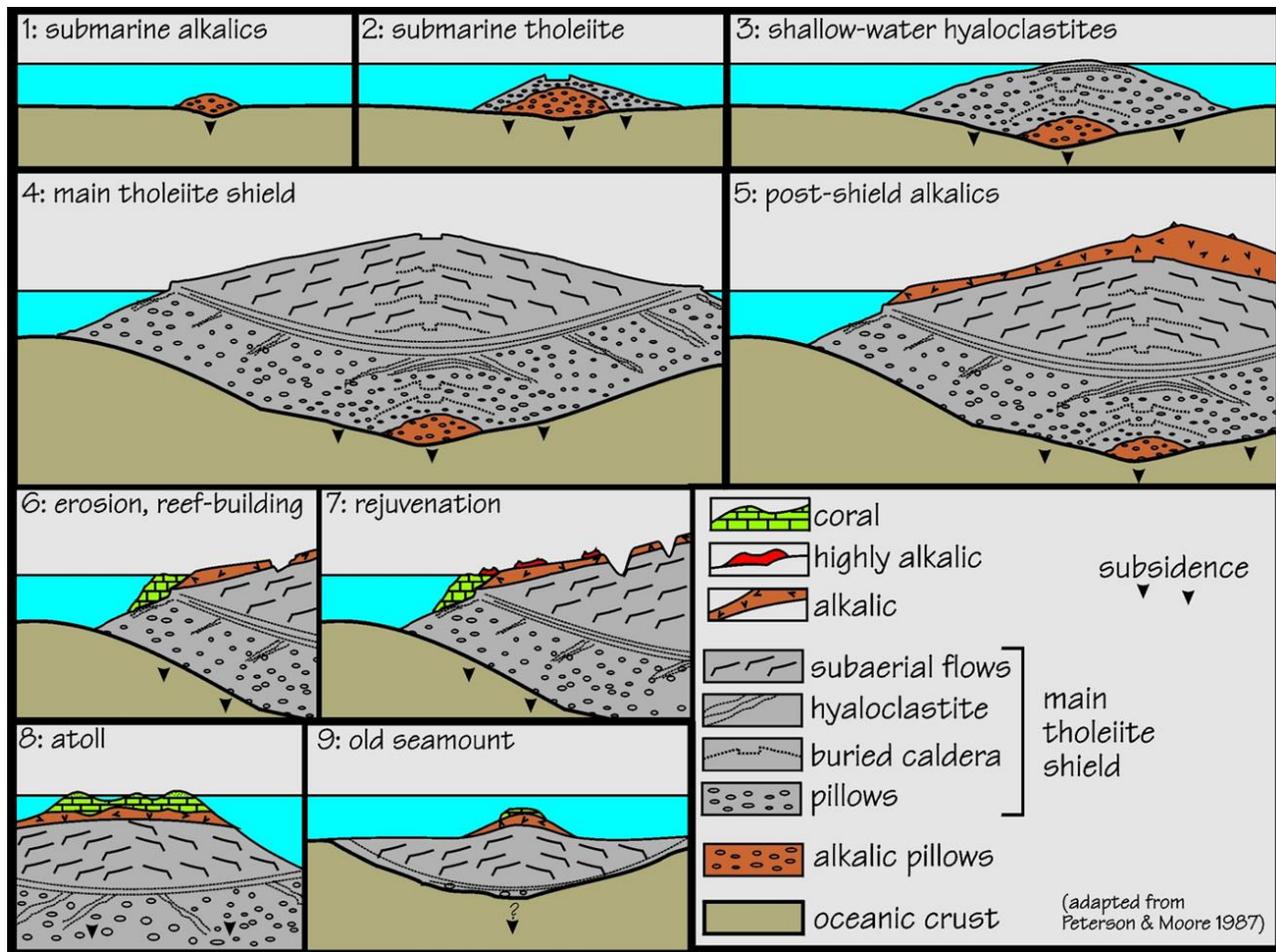


Figure 2: The life stages of a Hawaiian volcano, adapted from Peterson & Moore, 1987.

Stage 7: Rejuvenation

Rejuvenation and Pele’s Travels

Many people have noted that plate tectonics tells us that Hawaiian volcanoes are older from the NW to SE, and the story of Pele involves her moving from NW to SE. Were early Hawaiians explaining the different ages of the islands by Pele producing volcanoes from NW to SE? We consider that a better connection is between Pele’s travels and rejuvenation (or late post-shield alkalic) eruptions. For one thing, Pele is often referred to as Pele Honuamea (Pele, the hewer of the land). She isn’t Pele, the creator of the land; there has to be something there already for her to hew. Second, in those versions of the Kumulipo that mention the birth of the Hawaiian Islands, their birth order starts at Hawai‘i and ends at Kaua‘i, the opposite of what plate tectonics would tell us. Finally, and most interestingly, many (but not all) of the places that Pele visited during her journey from NW to SE, and importantly many where she and her sister Nāmakaokaha‘i fought each other, are rejuvenation-stage vents (particularly on Ni‘ihau, Kaua‘i, and O‘ahu).

In *The Epic Tale of Hi‘iakaikapoliopele*, Pele and her family first come to the Hawaiian islands at the tiny island of Ka‘ula, adjacent to Ni‘ihau. As they work their way down the island chain to Hawai‘i, Pele digs into the earth, searching for the fire that she can make her home in. When they reached O‘ahu, "Pele dug the crater of Āliapa‘akai at Moanalua, but soon reached sea water and left there. She also dug atop Pūowaina, Lē‘ahi, and some other sites on O‘ahu, and because the earth was shallow in those places, sea water was again soon encountered, so they departed from O‘ahu and proceeded on to Moloka‘i. Eventually, Pele finds the fire she is seeking when she digs Halema‘uma‘u Crater, and makes her home there (Nogelmeier, 2008).

The craters that Pele dug before reaching Kīlauea, such as Pūowaina (Punchbowl) and Lē‘ahi (Diamond Head), are all examples of rejuvenation stage volcanism. Their inclusion in the Pele tradition shows that ancient Hawaiians were aware of the volcanic history at these sites, even though all eruption activity had ceased well before any Polynesian explorers set foot on the islands.

Mantle plume modeling

One attempt to explain rejuvenation depends on a complicated computer model of the motion, temperature, density, and other physical characteristics of the hot spot plume. Basically, by modeling all the processes that are understood to be going on, one result is that they figured out the direction that the mantle plume will be flowing. Anywhere that the motion is upward, decompression melting is likely to take place. In the main plume stem, the upward motion is obviously driven by buoyancy, and this is where the majority of melting occurs. This melt is what builds the great majority of a Hawaiian volcano. As the plume material moves off the main plume stem, it sinks back a little bit, and the pressure will increase, countering melting. About 300 km past the main plume axis, however, the material starts to spread laterally as well as downstream. In order to conserve mass, lateral spreading is accompanied by thinning against the base of the lithosphere. Thinning means the lower part of the plume material is moving upward, and because upward motion induces melting, a second zone of melting is created; the tiny bit of melt would fuel rejuvenation volcanism.

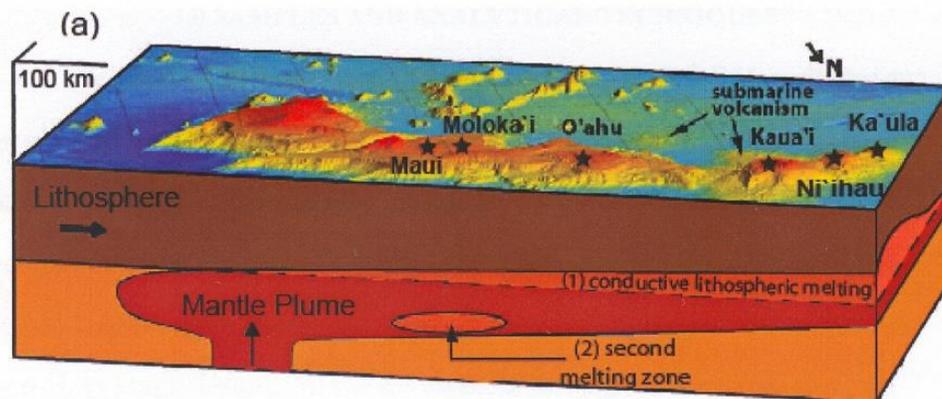


Figure 3: The Dean of the School of Ocean and Earth Science and Technology (SOEST) at the University of Hawai‘i at Mānoa, produced this diagram to illustrate a second scenario for melting away from the hotspot. Drawing by B. Taylor,

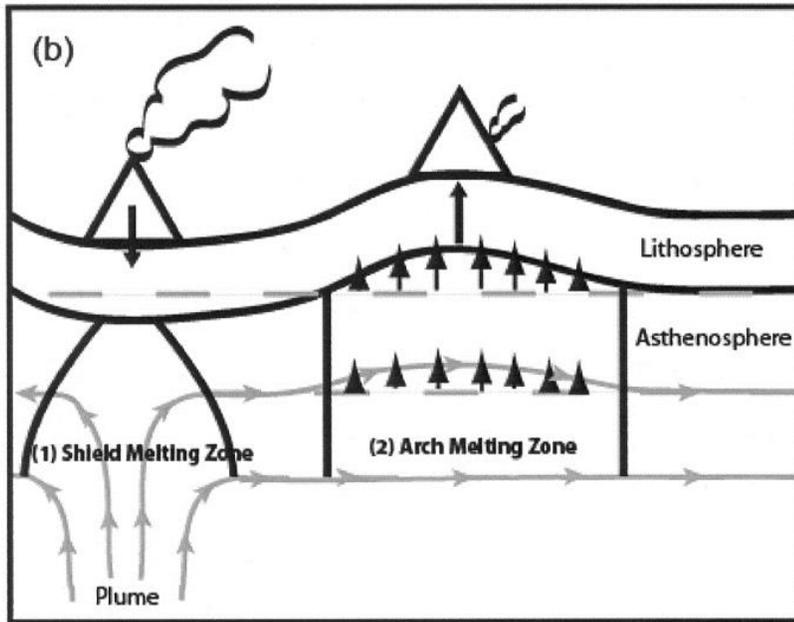


Figure 4: The most recent model was proposed by Todd Bianco and Garrett Ito (Bianco et al., 2005).

strength parameters, and mantle viscosity parameters that you feed into the model (and lots of other things), it is possible to have the lithosphere bow upward at a distance appropriate to where we find rejuvenation volcanism. If the asthenosphere and lithosphere both move upward, there is no pressure loss from less rock above. There is pressure loss from less water above, however, and whether that is sufficient to allow melting, is not entirely sure.

Honolulu Volcanic Series vents

Probably the best-studied series of rejuvenation-stage vents and flows is the Honolulu volcanic series, which is the rejuvenation stage of Ko'olau volcano. Forty-something vents are scattered about the SE end of Ko'olau, some in obvious lines, others more or less just scattered (Fig. 5).

People have looked hard for patterns related to the structure of the old volcano, but nothing obvious has ever jumped out (Fig. 6). In some cases

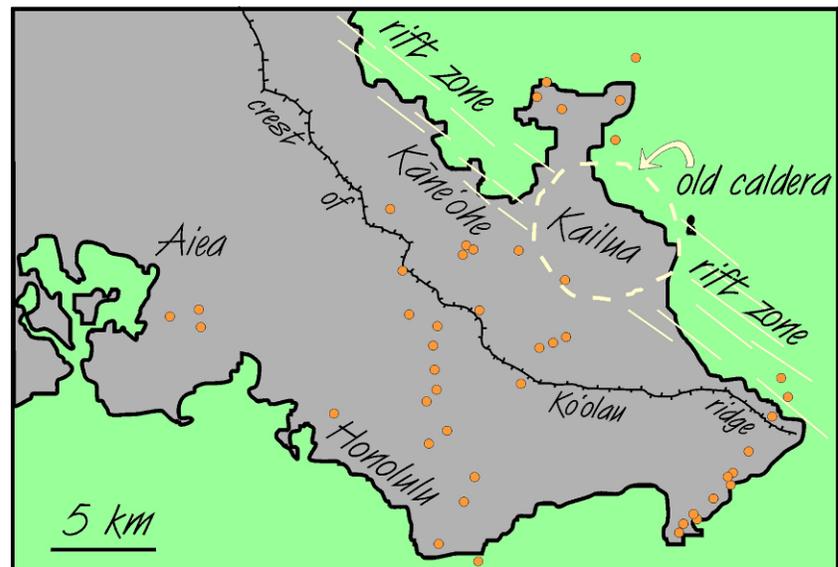


Figure 5: The Honolulu Volcanic Series and its associated vents (orange dots). Adapted from Macdonald et al., 1983.

Melting away from the hot spot

Another scenario for melting away from the hot spot proposes that the mantle plume transmits heat to the overlying lithosphere (Fig. 3). Eventually at some point downstream, enough heat is transferred so that the lithosphere starts to melt a little bit. That little bit would be the rejuvenation-stage volcanism.

The most recent model for rejuvenation-stage volcanism (Fig. 4) describes the process in which the lithosphere is loaded by the weight of a growing volcano (or volcanoes), and the downward motion is partially accommodated by upward motion at a location away from the load.

Depending on the plate thickness,

the vents are in the backs of valleys (Nu‘uanu, Pālolo), in others they are on the ridges between valleys (Kalihi, Tantalus), and in others they are down on the coastal plain (Lē‘ahi, Pūowaina, Mōkapu). They clearly post-date the carving of the valleys, however. Note that the most recent rejuvenation volcanism on Ko‘olau, the Koko rift, is only 40-50 thousand years old, which is quite young. It is definitely statistically possible that another Honolulu volcanic series eruptions could occur, although nobody is predicting it.

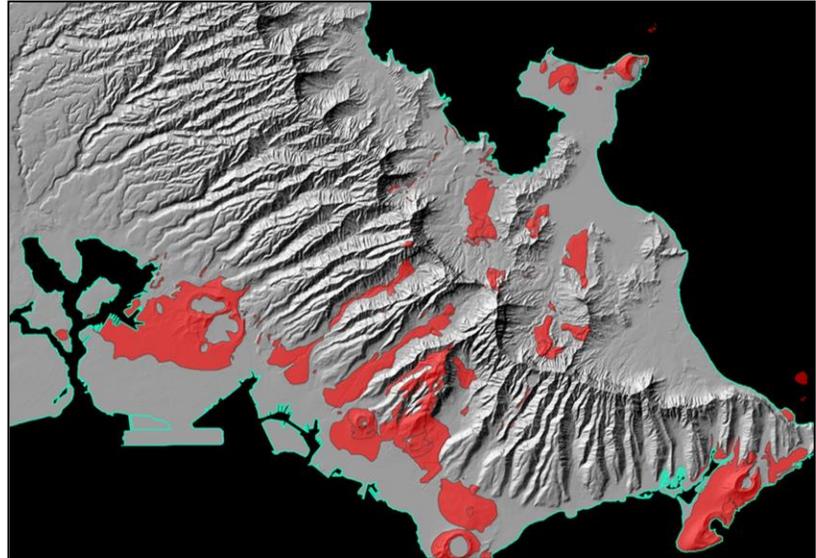


Figure 6: Honolulu Volcanic Series. The red color indicates the Honolulu volcanic series vents and flows. Data from Sherrod et al., 2007.

Hanauma Bay Area

Koko rift

The Koko rift extends from Mānana to the north, past Hanauma Bay, and continues offshore, where there are 2-3 additional vents (Fig. 7). Almost all these eruptions took place offshore of what the island looked like at the time, so there were violent interactions between the erupting magma and shallow ocean water. Mānana and Moku Hope are the northernmost vents of the Koko rift. Other vents and rejuvenation-stage features also include Koko Head, Hanauma, Kahauloa Crater, Koko Crater, Kalama Cinder Cone, and Kaupō Vent (Fig. 7, Macdonald et al., 1983). Table 2 also lists additional place names that are culturally significant to the Hanauma Bay area.



40,000-50,000 year-old vents along the Koko rift

Figure 7: Aerial view of the Koko Rift, southeast O‘ahu. Photo and annotations by S. Rowland.

Table 2: Place names associated with Hanauma Bay, Nā wahi pana o Hanauma. Adapted from: http://hbep.seagrant.soest.hawaii.edu/sites/seagrant.soest.hawaii.edu/files/hbep/hanauma_place_names_poster_6-2011.pdf.

Location Name	English Translation	Cultural Significance
Maunalua	"Two mountains."	Probably named for Koko Head and Koko Crater, the two prominent mountains at the east end of the bay.
Keahupuaomaunalua (Kuapā)	"The shrine of the baby mullet at Maunalua." Also called Kuapā, "fishpond wall."	This 250 acre fishpond was once the largest in Polynesia. Believed to be partly constructed by Menehune.
Kawaihoa	"The companion's water."	The god Kāne brought forth water here. A good spot to watch clouds and predict the weather.
Kuamo‘okāne	"The backbone of Kāne."	642 foot high hill above Hanauma, good place to look for winds to sail to Moloka‘i.
Nono‘ula	"Red sunburned."	Perhaps from Kauanono‘ula, a famous chiefess who lived at Hanauma with ‘Ihi‘ihilauākea. Also said to be named for a mythical creature created by Pele.
‘Ihi‘ihilauākea	Name of the native fern, perhaps meaning "revered broad leaf."	Name of the beautiful maiden of this area, a wind found here, and also refers to the western side of Hanauma.
Pai‘olu‘olu	"Lift gently."	A point on the south side of Hanauma. (Another source says it is a point on the west side.)
Hanauma	"Curved bay," or "hand wrestling bay."	This is where the two hand wrestlers were turned into mo‘o and still wrestle today.
Nāmakaokaha‘i	"The eyes of Kaha‘i."	Named for the older sister of Pele.

Palea	"Brushed aside."	A point on the north side of Hanauma. (Another source says it is the east point of Hanauma Bay.)
Kahauloa	"The tall Hau tree." Also known as Lāna‘i Lookout.	Ka-hau-loa and her brother Kama-a-lau came from Kahiki and overslept after playing the game kilu. They were turned to stones in a stream, she a flat one and he an upright one.
Kohelepelepe	"Vagina labia minor."	Renamed Koko Crater. Pele was being attacked and pursued by Kamapua‘a in Puna. Her sister Kapo threw her vagina to lure away the pig man. He followed it here to Koko on O‘ahu, where it left an imprint and then flew off to Kalihi.

Hanauma as a Recreation Site

Here is an appropriate article from 1926 about an excursion for schoolchildren out to Hanauma Bay, much like we are doing today. It seems that this was the time when Hanauma was just beginning to become a popular site for recreation, for the article notes that, "Hanauma is a great place to fish and swim, and from now on it will become a place filled with sightseers and people wishing to relax." The complete article follows, both in the original Hawaiian and translated into English.

From *Ka Nupepa Kuokoa*, October 26, 1926.

**KA HUAKAI MAKAIKAI A NA
KEIKI KULA NO HANAUMA MA
NA KAA KALAKA**

Ua haawiiā ae he kono i na keiki o na halekuai apau amo ko na kahua paani. ka poe e hiki ana, e holo makaikai i ke Kaikuono o Hanauma maluna o na kaa kalaka nunui ma ka auwina la o keia Poaono iho, he huakai makaikai i hoolalaia e ke komite hooahuoli i na kamalii no kela ame keia mahina, a e hoomaka ana ka haalelo ana i ka Paka Aala ma ka hora 1:15, poe ka hoomaha lili ana ma na kahua paani ma ke alanui Beritania a e akoakoa ana na kaa kalaka apau ma ke kahua o ke Kpitaha ma ka hora 1:30.

O ke Kaikuono o Hanauma kekahi wahi nani loa ma kela huli hikina o ka mokupuni o Oahu, a o ia no hoi kekahi hapa o ka paka ma Koko Head i haawiiā ae e ka Bishop Estate i kahu no ka paka.

Ma Hanauma he wahi maikai loa ia no ka lawaia ana, a no ka auaukai ana, a ee lilo aku ana ia ma uei mua aku i wahi piha mau ia e ka poe makaikai ame ka poe o make make ana e hooiaha. Ma ka hora 6 o ia ahiabi e hoi mai ai na kaa kalaka me na kamalii no ke kaono uei.

No na titiki ukukaa, he 35, e loa aku ana i na keiki mahuna o na kahua paani mai ka poe aku no lakou na inoa malalo nei: Ma Aala, mai ia Mrs. Ben Oliveria aku; Mrs. aLug Akana, ma ke kiekiena Alewa; mai ia Miss Margaret Waldron aku. ma ka Paka Atkinson; ma ke alanui Beritania, mai ia Mrs. Rose Trevenon aku; a mui ka poe e ea i kohoia e loa aku ai na titiki ma na kahua like ole.

**EXCURSION OF THE
SCHOOLCHILDREN TO HANAUMA ON
TRUCKS**

An invitation has been given to the children of all the stores and the playgrounds, those who are able, to take a trip to Hanauma Bay aboard large trucks in the afternoon this Saturday. This trip was arranged by the committee providing monthly entertainments for the children. Departure will begin at 'A'ala Park at 1:15, with a short stop at the playgrounds along Beretania Street, and then all the trucks will assemble at the grounds of the Capitol at 1:30.

Hanauma Bay is a very beautiful place on that eastern border of the island of O'ahu. It is also a part of the park at Koko Head that has been donated by the Bishop Estate, who serves as administrator for the park.

Hanauma is a great place to fish and swim, and from now on it will become a place filled with sightseers and people wishing to relax. At 6 o'clock that evening, the trucks with the children will head back to town.

Tickets for the ride, of which there are 35, can be obtained by children on the playgrounds from the following people whose names are listed below: In 'A'ala, from Mrs. Ben Oliveria; Mrs. Lang Akana, in 'Alewa Heights; from Miss Margaret Waldron, in Atkinson Park; on Beretania Street, from Mrs. Rose Trevenon; and from the other chosen people tickets may be obtained at various sites.

METEOROLOGY

Hawai‘i's Local Winds and Rains

The Hawaiian Islands are diverse in terms of topography and geographic extent. Each island has unique combinations of mountains, valleys, coastal shapes, land, and windward and leeward features that influence the local circulation of air and the distribution of rain. The local circulations or “local winds” have very different characteristics from the large-scale wind circulation over the open ocean. The several hundred local Hawaiian wind and rain names result from and reflect the diverse topography, cultural traditions, and ecological settings that have a defining role in how people think and talk about Hawaiian weather.

The oral and written literature of Hawai‘i reveal deep interest in and knowledge of winds, rain, and the water cycle. We can see the cultural importance of knowledge of the weather in the following tradition. To be considered a local or *kama ‘āina* (child of the land), you may be called upon to recite the winds or rains of that place. If you could name them, you were then deemed to be a *kama ‘āina*; if not, you would be considered a *malihini*, a stranger. The chants listing winds and rains were often published in the newspapers as part of stories, or to simply inform the public about the nature of the winds in a certain area. At times these would even be challenged and disputed, with a reply such as, "No, that person was wrong, for they are only a *malihini*. I am the true *kama ‘āina*, and these are the correct winds of this area." Our ancestors valued this information, as it was crucial in the everyday lives of a sea-faring and farming people.

Many names of local winds can be found in the story of the *Wind Gourd of La‘amaomao*, (Nāku‘ina, 1902, 2005) which tells of a boy named Pāka‘a, whose mother gives him a gourd that contains the bones of his grandmother, La‘amaomao (Fig. 8). With this gourd, and the chants of wind names that his mother teaches him, Pāka‘a is able to control the winds. Pāka‘a then passes on this knowledge to his son, Kūapāka‘a, and a key moment of the story is when Kūapāka‘a chants to impress the chief Keawenuia‘umi, naming winds from Hawai‘i island to the tiny island of Ka‘ula, out past Kaua‘i. (A calabash named the Wind Gourd of La‘amaomao is in the Bishop Museum.)

There were over 300 names for the different winds and breezes that blow near and over the islands. These names are important because they reflect our ancestors' emphasis on keen observations and their deep knowledge of the local topography, for the wind names describe their nature and often convey natural and cultural information specific to the place. People shared knowledge about weather in more than 100 Hawaiian language newspapers published between 1834 and 1948 (<http://seagrant.soest.hawaii.edu/hawaiian-language-newspaper-translation-project>).

The articles reveal the names of local winds often also provide information on characteristics, direction, origin, force, and timing. These are key because they allow us to tie in traditional knowledge to our modern understanding of winds.

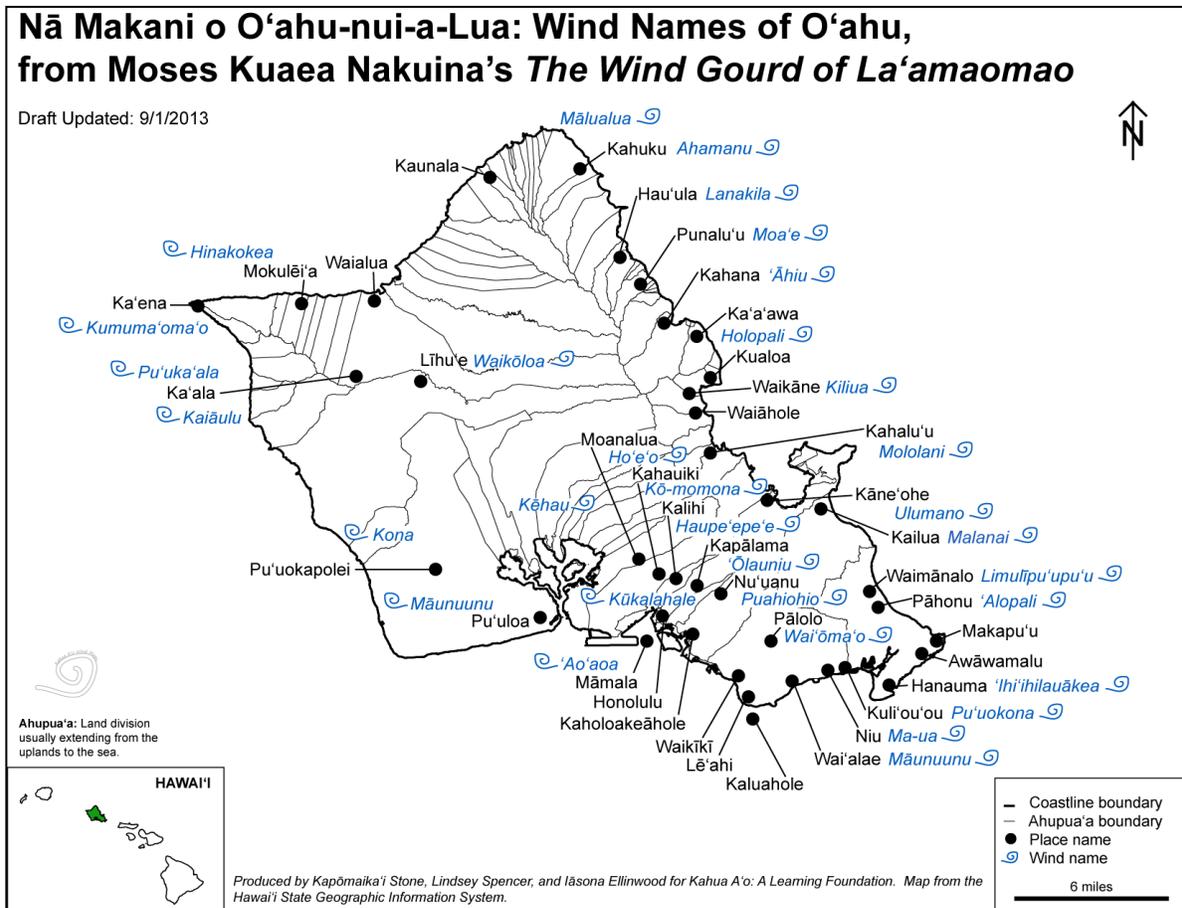


Figure 8: Wind Map of O’ahu, produced by members of the Kahua A’o team.

Hawai'i's Sea-Land Breezes

The contrast between the ocean and the island temperatures drives sea-land breeze circulations on each of the Hawaiian Islands. Sea and land breezes exist due to the difference in temperature over land and sea during the day and night. During the day the land heats up more rapidly than the sea, so for the same altitude the temperature over land will be warmer than over the sea. Because air that is warm relative to its surroundings rises, this generates a difference in the pressure between the air over the land and the sea, specifically, with lower pressure over the land and higher pressure over the sea. Therefore, the rising warm air is replaced by cool moist air from over the sea. The influx of air from the sea is called a sea breeze, and it often produces clouds and showers over the mountains.

During the night, especially when there are no clouds, both the land and ocean radiate heat to space, but the land loses its heat much faster than the sea because water has such a high heat capacity (ability to store heat in a given mass of substance) and wind driven motions in the water mix warmer water up from just below the surface. Therefore, the land cools faster than the sea. Pretty soon the relatively warmer air over the ocean begins to rise. Air that is cooled over the land flows downslope toward the ocean to form a land breeze.

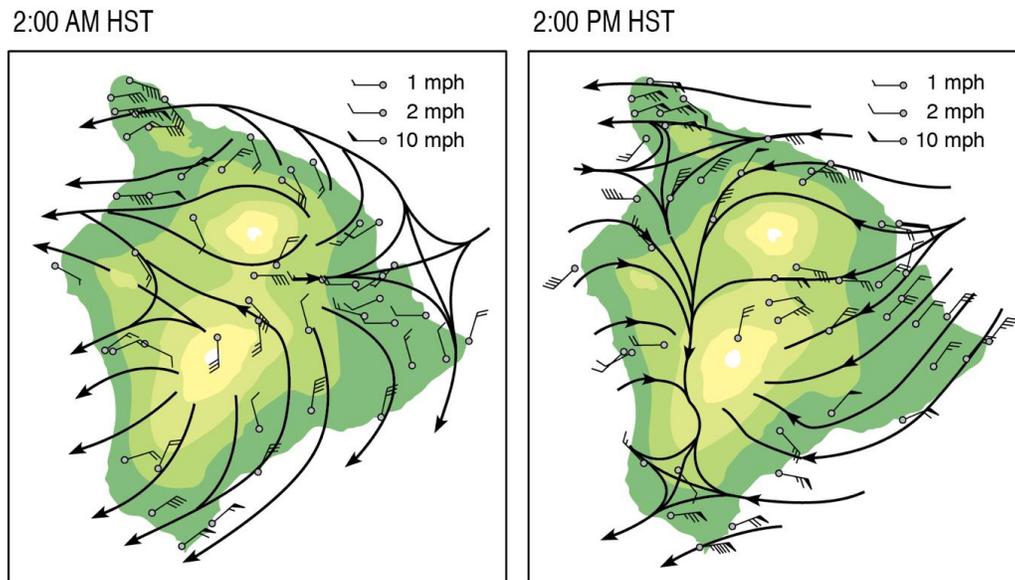


Figure 9: Island of Hawai‘i with color shading indicating elevation (colors change every 3000 ft.) and average winds (mph) during a six-week period during July and August 1990. Produced by S. Businger.

The strength of the sea-land breezes varies from island to island, depending on the height of the island’s mountains and the overall size of the islands, and the strength of the large-scale winds. The taller volcanoes on Maui and the island of Hawai‘i block the large-scale flow, allowing heat to build up on the leeward sides even when the large scale winds are moderately strong and thus increasing the strength of the daily sea breeze over the lee slopes of these islands (Figs. 9 and 10). Conversely, the taller mountains also produce cooler air at altitude and a stronger land breeze at night. Note the flow splitting in Figs. 9 and 10. The smaller islands such as Kaua‘i and O‘ahu have lower mountains that do not block the flow. Therefore, these islands only experience well-developed sea-land breezes under lighter large-scale winds conditions.

If you study the winds at Keāhole Airport, you find there is a daily cycle in wind direction (<http://www.weather.gov/data/obhistory/PHKO.html>) that includes all compass directions! The winds at Keāhole Airport are characteristic for winds in general along the leeward side of the island. The forecast winds for the Island of Hawai‘i can be viewed at <http://weather.hawaii.edu/>. Click on the lower right thumbnail to access WRF model output. Then change field to surface winds and domain to Big Island to get a detailed view the impact of the large volcanoes on the flow and the diurnal sea-land breeze cycle across the island.

Several Hawaiian newspaper articles mention the channel between Moloka‘i and Lahaina, Maui. The channels between the Hawaiian Islands are sometimes dangerous for navigating. This is because the trade winds are funneled through the narrow area between two islands causing the pressure gradient to increase between the entrance and exit of the channel, which in turn causes the wind speed to increase. The waves generated by these higher winds can interact with ambient swells, particularly those coming up from the south, to produce very steep standing waves. This is the reason why many boating accidents occur in the island channels.

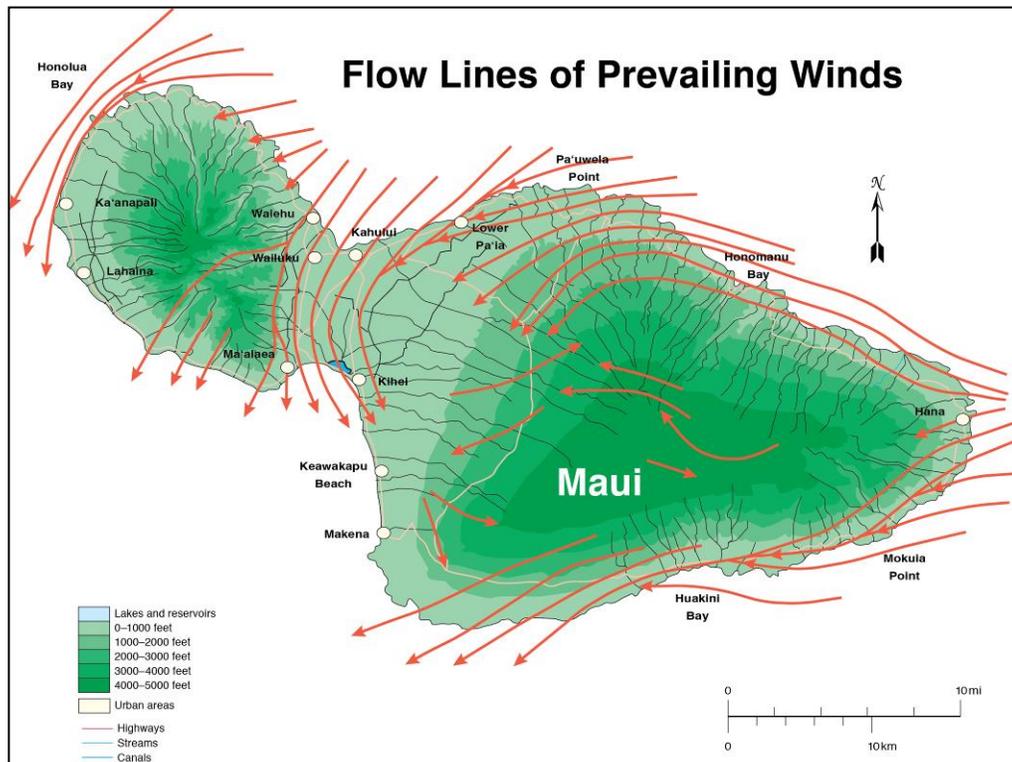


Figure 10: Stream or flow lines (red lines) are drawn everywhere parallel to the local wind direction and show the impact of the mountains on the flow during the afternoon on a typical trade-wind day. Produced by S. Businger.

Moloka‘i is considered by Hawaiians to be the island of the winds. This is partly due to the fact that the mountains play a less important role in affecting winds here than on the other islands. The winds can pass easily over the lowest parts of this island without having to split or even rise very far. The western half of Moloka‘i is dry because it lacks orographic rainfall, rainfall that occurs when moist air is forced to rise over mountains, cooling and therefore condensing and precipitating (Fig. 11). The forced ascent by terrain is the reason why the windward sides of all the Hawaiian Islands are lush and green with vegetation in the satellite view in Fig. 11. Conversely, air that has already lost much moisture becomes even drier as it descends and warms along the lee slopes, thus the lee areas of all the islands are relatively dry. The exception is the Kona coast of the Island of Hawai‘i where the trade winds are



Figure 11: True-color satellite image of the Hawaiian Islands showing the influence of the mountains on rainfall and vegetation. Photo credit: NASA.

blocked by Mauna Loa, and a well-developed (and almost daily) sea breeze brings clouds and rainfall upslope there (see Fig. 11).

Poetic Usage of Wind and Rain Names

Kanikau (grief chants) were frequently submitted to the Hawaiian language newspapers in honor of those who had recently passed away, and usually contained references to certain areas that were significant to the deceased. In the following kanikau, composed by Mrs. Kealalaina Ka‘aikaula, several references are made to the Hanauma area, including mentions of the Kā‘eleke‘i shore wind and the Ma‘akua rain at sea. Through the use of these images, she is able to beautifully illustrate her memories of time spent with her late husband.

From *Ka Nupepa Kuokoa*, November 23, 1878.

Welma Puuwai Kumakena.

E KA NUPEPA KUOKOA E; *Aloha oe* :—

Ka opuu pua rose a ko'u manao e anoi mau nei. No ka pilihua kaumaha o ko'u manao, no ko'u koolua, i hele aku i ka hale koo-u ke-wai a ka makamaka ole. Ke waiho aku nei au imua ou, a nau ia e kiani ae, ma na welau o ko kuaa aina kupa, i ike mai ai na kini makamaka ona.

[...]

Aloha kuu kane i ka lulu o ka makani.
 E kiai ana hoi i ka lau lehua o Kaana.
 Aole au e ana i ka paio a ke anu.
 Ua anu macele au i ka hele o kuu koolua.
 Aloha kahi a kuaa e pili ai.
 I ike ai kuaa ma ke kaha i Hanauma.
 E ike i ka onohi o Ihihilaūakea.
 E punia ni maua e ka makani kaelekei o ke kaha.
 Alo aku maua e ike ia Mālei.
 Ka wahine kiai makalae o Makapu'u.
 E noho ana i ke kai o Kawili.
 Auau aku i ka wai o Puha.
 Halapu hewa ana au i ke kino wailua.
 Elua kuaa i ka piina o Keaniani.
 E ani peahi ana i ka lau o ke kawelu.
 Hoolai aku i ka wai o Auwaihahine.
 Luana aku kuaa o ka poli o Kealoha.
 E ike aku ana i ka ua' poaihala o Kahaluu.
 Ua luulua au i ko aloha e noho nei.
 Ua pepe a wali ko'u nui kino.
 I ka hana a ka ua koiawe i na pali.
 Pulu elo au i ka lihilihi o ko aloha.
 E ike aku ai i ka makani ahia.
 Ahia ka onohi piina ia Helekela.
 E hoopili ana ue ke ao poihiwa i ka lewa.
 He hiwahiwa nui oe na kuu kino.
 O kuu kino ka i mehana i ko poli.
 Ia ka ua maakua, e pehi ana i ka ilikai o ka moana.

Auwe kuu kane,—Kuu kane hoi--e.

Mrs. Kealalaina Ka'aikaula.

Expression of the Grieving Heart.

To Ka Nupepa Kuokoa; Greetings to you:—

The rose bud for which my desire forever yearns. Due to the heavy grief of my thoughts concerning my companion who has gone to the damp and misty friendless house, I submit this to you, for you to gently wave it about to the far edges of our native land so that his many friends may see.
 [...]

Affection to my dear husband in the lee of the wind. Watching over the abundant lehua of Kā'ana.

I do not measure the strife of the cold.

I am cold and numb for my dear companion has gone.

Love to the place where we were together.

Where we moved along the shore at Hanauma.

To see the center of 'Ihi'ihilaūakea.

Where we were encircled by the Kā'eleke'i wind of that shore.

Together we looked upon Mālei.

The woman who guards the shore of Makapu'u.

Residing in the sea of Kāwili.

Bathing in the waters of Pūhā.

I am taunted by the spirit.

Just you and I ascended Keaniani.

As the leaves of the kāwelu grass gently waved.

At peace in the waters of 'Auwaihahine.

We two relaxed in the bosom of Kealoha.

Gazing upon the Pō'aihala rain of Kahalu'u.

I am weighed down with sorrow for your abiding love.

My entire being is crushed and weak.

In the way that the ko'iawe rain pelts the cliffs.

I am drenched in the petals of your love.

It brings me a vision of the wild 'Āhiu wind.

The fiery-tempered eye is stirred to wildness by

Helekēlā.

Connecting with the dark, looming cloud in the sky.

You are a precious thing to my person.

My body found its warmth in your embrace.

Even in the Ma'akua rain, as it beat down upon the surface of the sea.

Alas my dear husband,—My dear husband—ē.

Mrs. Kealalaina Ka'aikaula.

Instructional Procedure follows 5 Es:**1. Engage:**

- How do the winds behave as they interact with each island?
- What are the visible clues of wind interaction with the islands?
- What is the wind pattern like at Hanauma Bay

2. Explore:

- Investigate the winds of the area by recording coordinates and characteristics of the wind.

3. Explain:

- Explain the effect of altitude on wind speed.
- Analyze different data sets to explain differences in measurement.

4. Elaborate/Extend:

- Create a class wind map by measuring the winds in various locations.
- Research other local wind patterns observed around the world.

5. Evaluate:

- Teacher evaluates student comprehension and effectiveness of the lesson.
- Students evaluate the cultural significance of local winds in Hawai‘i.

ACTIVITY: Measuring Wind Speed and Direction**HCPS III Std. 1 Scientific Inquiry, [SC.8.1.1](#), [SC.8.1.2](#)**

We use the word *wind* to describe *horizontal movement of air*. An upwards, vertical movement of air is an *updraft*, a *downdraft* is air is moving down. Wind exerts a *force* and like any other force it has *intensity* and *direction*. These two quantities describe the wind itself at any given point and time. We use an *anemometer to measure wind intensity*, and a *wind vane and compass to detect which direction* the wind is blowing from. *Winds are usually described by the direction they are blowing from*, e.g., *NE trade winds, Kona winds*. Winds are the balance between 5 different forces active in the atmosphere: 1) pressure gradient, 2) centrifugal force, 3) Coriolis force, 4) gravitational force and 5) frictional force. The balancing of these forces generates a *wind vector* for that precise location and time.

Let's use a compass, a hand held anemometer, and time piece to record wind direction, speed, and time. We'll compare our observation with those collected at the same time by the National Weather Service (see <http://www.prh.noaa.gov/hnl/pages/obs.php>).

Plot the winds on a map of your island to see how location and time of day affect your results. Repeat this exercise at school and at home several times during the day. Does a pattern emerge to the local winds and does that pattern change with time of day?

Questions: Summarize What You've Learned

1. At which altitude was the wind speed the highest? Explain why altitude might have this effect on wind speed.
2. How do the data collected in this lab compare with the National Weather Service's data? Describe any differences and assess what might cause them.
3. How do you think the winds near the shore at Hanauma Bay would be different at night?
4. Five forces were mentioned as contributors to wind speed and direction. Which of these is most responsible for higher winds in the channels between islands?
5. Why are the windward sides of the Hawaiian Islands characteristically green and lush, while the leeward sides are usually dry?
6. Identify two ways in which knowledge of local winds and rains were culturally significant to Hawaiians in the past.

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