Predicting the Timing and Location of the Next Hawaiian

by Joseph Russo, Stephen Ross Mattox, and Nicole Kildau

The Hawaiian archipelago is the most studied volcanic chain on Earth. In 1963 the linear age progression of the volcanoes along the chain provided significant evidence to support the then-nascent paradigm of plate tectonics (figures 1 and 2). The progression towards younger volcanoes to the southeast is commonly cited as evidence for a hot spot, a place with anomalous volcanism, beneath the island of Hawaii; however, the plume model has recently been called into question (Foulger et al. 2006). Plumes are envisioned as columns of hot rock flowing vertically from shallow, 670 km, or deep, core/mantle boundary, depths. Regardless of the exact mechanism, volcanism has been occurring for over 80 million years, producing at least 94 different shield volcanoes. The youngest active submarine volcano in the chain, Loihi, is a shield 35 km southeast of the island. Earthquake swarms were detected within this volcano as recently as late 2005. Kilauea, the youngest shield volcano on land, has been erupting continuously since 1983. The wealth of geologic data on Hawaiian volcanoes makes them ideal for study by young students. In this paper we will use existing data on the age and location of Hawaiian volcanoes to predict the location of the next Hawaiian volcano and when it will begin to grow on the floor of the Pacific Ocean.

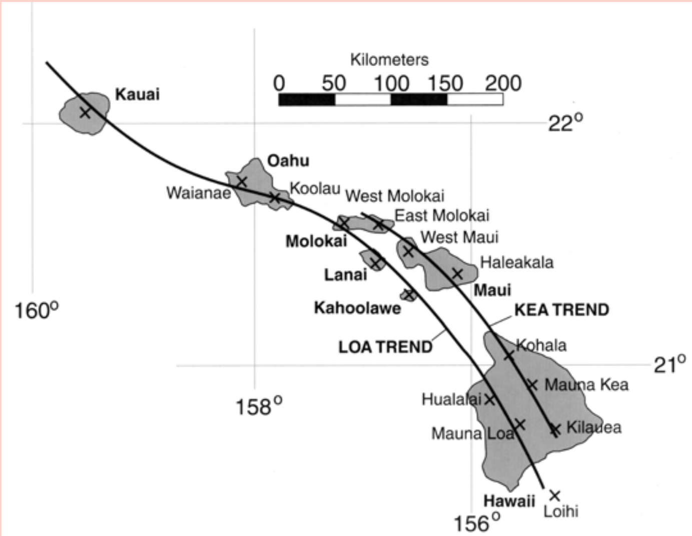
Background

The Hawaii-Emperor seamount chain is defined by a linear pattern of large shield volcanoes that have grown from the seafloor to elevations exceeding 4,000 m. Over time, volcanism wanes and the volcanoes subside and erode, gradually sinking below sea level. An excellent online summary of these classic volcanoes and the role of plate tectonics in forming island chains is provided in *Erup-*

tions of Hawaiian Volcanoes: Past, Present, and Future by the U.S. Geological Survey (*http://pubs.usgs.gov/gip/hawaii/index.html*). James Dana, one of the earliest geologists to visit Hawaii, noticed a pattern to the volcanoes, namely that the volcano summits fall on one of two lines (Figure 1; Jackson et al. 1972). To the north and east, a line of volcanoes trends across east Molokai, Maui, and the east side of the island of Hawaii. He named this the Kea trend, for Mauna Kea on the island of Hawaii. To the south and west, a line of volcanoes trends across Kauai, Oahu, west Molokai, Lanai, Kahoolawe, the west side of the island of Hawaii, and the submarine volcano Loihi. He named this the Loa trend, for Mauna Loa on the island of Hawaii. The spacing along these two trends has been used by geologists to predict the location of future volcanoes (Moore and Clague 1992).

Volcano

FIGURE 1 Volcanoes (x) and islands of Hawaii. Modified from Jackson et al., 1972.



The volcanoes grow on either the Kea or Loa trends.

Instructions to the teacher

This activity can be done by students individually, in pairs, or in small groups. Students will benefit from having Figure 1 enlarged to fill a full page. Figures 3 and 4 could be handouts or projected in class. Based on your students' abilities you might want to do the activity as a class and discuss their answers as they progress or have the students work individually or in small groups and ask the teacher for guidance at any difficult point. If needed, review basic map skills, such as measuring distance using a map scale or measuring compass angles, at the start of the lesson or as they progress through the activity. Depending on students' abilities the teacher may decide to lead the final part of the activity that uses ratios to predict when the new volcano will form. Students can be assessed on their math skills, ability to accurately glean data from the maps, ability to interpret their results, and the quality of their justifications for conclusions.

FIGURE 2 Age and distance trends of Hawaiian volcanoes of the Loa and Kea trends

Loa	Age	Distance	Kea	Age	Distance
Kauai	4.6 Ma		East Molokai	1.7 Ma	
Waianae	3.7 Ma		West Maui	1.5 Ma	
West Molokai	1.7 Ma		Haleakala	0.9 Ma	
Lanai	1.2 Ma		Kohala	0.5 Ma	
Kahoolawe	~1.1 Ma		Mauna Kea	0.4 Ma	
Hualalai	0.3 Ma		Kilauea	0.1 Ma	0 km
Mauna Loa	0.2 Ma	0 km			
Loihi	0				

With correct distances filled in:

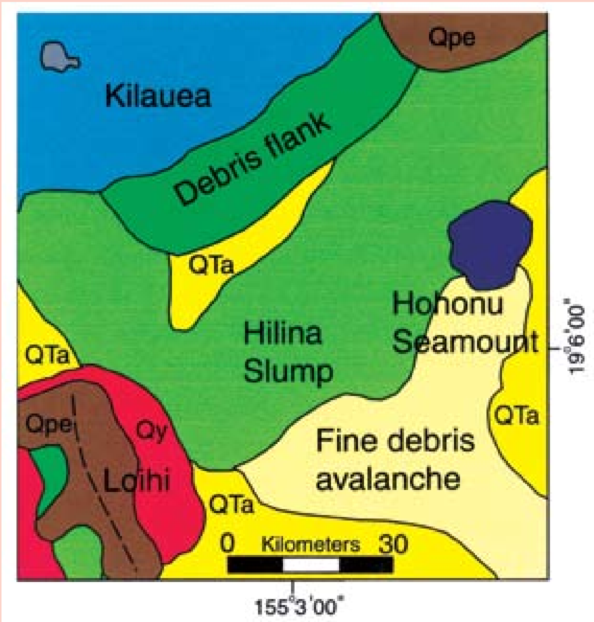
Loa	Age	Distance	Kea	Age	Distance
Kauai	4.6 Ma	505 km	East Molokai	1.7 Ma	256 km
Waianae	3.7 Ma	395 km	West Maui	1.5 Ma	221 km
Koolau	2.2 Ma	305 km	Haleakala	0.9 Ma	182 km
West Molokai	1.7 Ma	280 km	Kohala	0.5 Ma	100 km
Lanai	1.2 Ma	230 km	Mauna Kea	0.4 Ma	54 km
Kahoolawe	~1.1 Ma	180 km	Kilauea	0.1 Ma	0 km
Hualalai	0.3 Ma	60 km			
Mauna Loa	0.2 Ma	0			
Loihi	0				

Determining volcano spacing

What is the average distance between the major Hawaiian volcanoes? Students can gain important insights with some basic map-reading skills and a few calculations by determining the average spacing of each of the volcanoes on the Loa trend. The youngest subaerial (above sea level) volcano, Mauna Loa, will be used as the starting point because it currently sits above the hot spot. Students will examine the Loa trend to check their calculations against the position of Loihi, a submarine volcano, which is the youngest volcano on the Loa trend.

First, students measure the distances from Mauna Loa to each of the respective volcanoes on the Loa trend (Hualalai, Kahoolawe, Lanai, West Molokai, Ko'olau, Waianae, and Kauai) using a map of the Hawaiian Islands (Figure 1). Next, students place this information in a chart (Figure 2) that also shows the ages of these respective volcanoes.

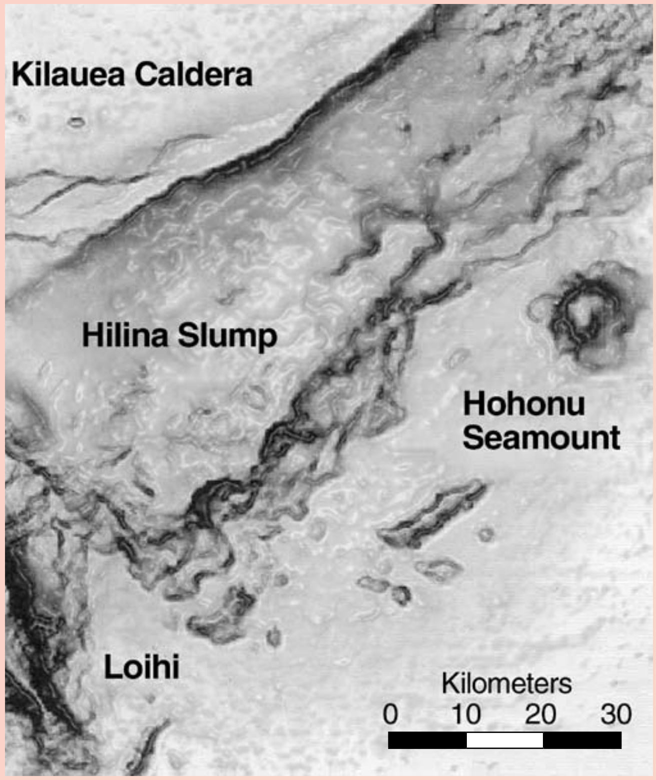
FIGURE 3 Geologic map of the south flank of Kilauea volcano



Modified from Holcomb and Robinson (2004).

The Hilina Slump is a large landslide caused by lateral spreading of the volcano. Loihi is the youngest volcano on the Loa trend. Hohonu seamount is a Cretaceous-age volcano. QTa is a thin apron of nearly flat sediment. Qpe is the undisturbed submarine lava flows on the flanks of the volcanoes. Qy is lava fields.

FIGURE 4 Digital elevation model of the south flank of Kilauea volcano. The same area is shown as in Figure 3



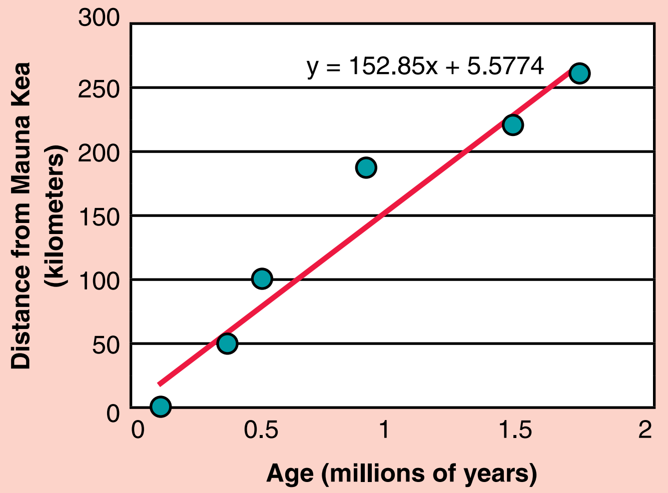
Modified from Moore and Chadwick (1995).

Seven older volcanoes spread over a distance of 505 km define the Loa trend, from Mauna Loa to Kauai. This provides an average spacing between volcanoes of 72 km. Is volcano spacing a good way to predict the location of the youngest volcano on a trend? Ask students to return to the map (Figure 1) and measure the distance from Mauna Loa to Loihi. The actual distance is 77 km, very close to what we would expect from the average spacing of all volcanoes along the trend. This simple calculation supports the idea that average volcano spacing appears to be a useful way to predict the future location of the next Hawaiian volcano.

Where is the next new volcano on the Kea trend?

Students next focus their attention on the volcanoes of the Kea trend and repeat the same procedures. The

FIGURE 5 Age and distance data for volcanoes of the Kea trend



youngest subaerial volcano, Kilauea, will be used as the starting point because it currently sits near the center of the hot spot. Students will first measure the distances from Kilauea to the respective volcanoes on the Kea trend (Mauna Kea, Kohala, Haleakala, West Maui, and East Molokai) using a map of the Hawaiian Islands (Figure 1). They will then place this information in a chart (Figure 2) that also shows the ages of these respective volcanoes.

The Kea trend, from Kilauea to East Molokai, is defined by five older volcanoes spread over a distance of 256 km. This provides an average spacing between volcanoes of 42.6 km. Ask students to return to the map (Figure 1) and plot this distance from Kilauea to the southeast along the Kea trend. This location, on the ocean floor, is students' prediction of where the next Hawaiian volcano will form. Is the volcano already there and undiscovered? If, not, can we estimate when the seafloor will split open and lava will start to erupt?

Exploring the ocean floor for a new volcano

Is a new volcano on the ocean floor? By plotting the appropriate distance (42.6 km) down the Kea trend students can identify where on the ocean floor to look. Start by having students draw a dashed line to the southeast from Kilauea to project the Kea trend offshore. Next, measure a distance of 42.6 km from Kilauea's summit to the southeast along the Kea trend. This provides an approximate location of a possibly young Hawaiian volcano. But is it there? The submarine flanks of Hawaiian volcanoes have been explored in great detail. For example, Holcomb and Robinson (2004) used GLORIA sidescan-sonar imagery to make a geologic map up to 320 km from the Hawaiian coast (Figure 3). Moore and Chadwick (1995) produced beautiful digital elevation models that show the details of the submarine slopes of Hawaii (Figure 4). Your students can use these maps to explore the ocean floor for the volcano.

Ask students to transfer their compass bearing of the Kea trend from Figure 1 to Figures 3 and 4. Depending on how your students measure the angle it should be about 150° from north, or 60° south of east, or 30° east of south. On the geologic map (Figure 3), when students plot a distance of 42.6 km down the Kea trend from Kilauea's summit at an angle of 150° from north, their volcano location should be in Pleistocene slump deposits. Pleistocene refers to the time period between 10,000 to 1.8 million years; a slump is a block of rock that is sliding out from the submarine base of the volcano. On this map, young volcanoes only 5 km in diameter are shown. There is no such young volcanic feature at the suspected location (155°3'00" longitude, 19°6'00" latitude). Based on the geologic map (which is only a few years old) our newest Kea volcano is yet to arrive.

What does the digital elevation model, a representation of the ocean floor, show? Repeat the transfer of the trend and distance data to Figure 4. The digital elevation models resemble black-and-white photographs of the volcanoes, their submarine flanks, and the adjacent ocean floor. The dark areas show the steepest slopes and the light areas show the gentlest slopes. The suspected location plots in an area of light color, implying gentle slopes. The existing volcanoes in this image have steep slopes. For example, Loihi trends north-south with steep slopes on its east and west flanks. Hohonu seamount is a steep-sided, round cone about 50 km east of our suspected location. Based on the digital elevation map, our newest Kea volcano is yet to arrive.

ACTIVITIY WORKSHEET

Material

- copies of figures
- protractors.

Procedure

Hawaiian volcanoes fall on two distinct trends. Use Figure 1 to find the trends.

1. What are the names of the two trends?
2. Which active volcano is at the southeast end of each trend?

Determining volcano spacing

1. Measure the distances from Mauna Loa to the respective volcanoes on the Loa trend (Hualalai, Kahoolawe, Lanai, West Molokai, Ko'olau, Wai'anae, and Kauai) using a map of the Hawaiian Islands (Figure 1), and place this information in a chart (Figure 2).
2. For the Loa trend, from Mauna Loa to Kauai, divide the total distance by the number of older volcanoes. Return to the map (Figure 1) and measure the distance from Mauna Loa to Loihi. Compare the two estimates. Does using the spacing of the older volcanoes appear to be a useful way to estimate the distance to the youngest volcano, Loihi, in the Loa trend?

Where is the next new volcano on the Kea trend?

1. Measure the distances from Kilauea to the respective volcanoes on the Kea trend (Mauna Kea, Kohala, Haleakala, West Maui and East Molokai) using a map of the Hawaiian Islands (Figure 1). Place this information in a chart (Figure 2).
2. For the Kea trend, from Kilauea to East Molokai, divide the total distance by the number of older volcanoes. Return to the map (Figure 1) and plot this distance from Kilauea to the southeast along the Kea trend. Is the volcano already there and undiscovered?

Exploring the ocean floor for a new volcano

1. Draw a dashed line on Figure 1 to the southeast from Kilauea to project the Kea trend offshore. Next, use the bar scale on the map to measure your distance from Kilauea's summit to the southeast along their Kea trend. Place an "X" on the trend line at the appropriate distance from Kilauea. This could mark the location of a new Hawaiian volcano.
2. Use a protractor to measure the angle of your trend line from Kilauea to the southeast. You can measure from north (0°) or another reference. Transfer your bearing of the Kea trend from Figure 1 to Figures 3 and 4. On Figure 3, the geologic map, is there a volcano at the location you plotted? What map unit is at your location? On Figure 4, the digital elevation model, is there a volcanic cone at the location you plotted? Do you see any evidence of a volcano at your location?
3. Visit the U.S. Geological Survey's website for Hawaii earthquake data (*http://hvo.wr.usgs.gov/earthquakes/seismicity/table.html*) and select a map with data for a specific year. Transfer your compass bearing of the Kea trend to the earthquake map. Do you see a cluster of earthquakes at your suspected location that would provide evidence for magma moving in a volcano?

When will the next volcano on the Kea trend start forming?

1. Use a graphing calculator to plot the "age" and "distance from Kilauea" for each volcano along the Kea trend (Figure 2). Determine the slope of the line along the Kea trend (in distance per million years). This is the average rate of migration of volcanoes along the Kea trend.
2. To determine approximately how many years it will take for us to see a new large shield volcano, solve for x in this ratio:

$$\frac{1{,}000{,}000 \text{ years}}{153 \text{ km}} = \frac{x \text{ years}}{43 \text{ km}}$$

How soon after Kilauea started forming should we see the new volcano?

1. If Kilauea is 400,000 years old, should the new volcano already be on the ocean floor?
2. If Kilauea is 100,000 years old, should the new volcano already be on the ocean floor?

Synthesis

1. What types of data did you use to explore the ocean floor for an existing or new volcano? What sources of error might be involved? What additional data or observations might better improve your study?
2. Did you discover a new Hawaiian volcano on the ocean floor? If yes, provide a location and age. If no, predict where and when in the future will lava erupt on the ocean floor.

Another way to search for a volcano is to look for the earthquakes that indicate magma is moving toward the surface. Earthquake swarms have been detected in Loihi, the youngest submarine volcano on the Loa trend. Perhaps earthquake data will indicate a volcano forming at our suspected location on the Kea trend. The U.S. Geological Survey presents compilations of earthquake data for Hawaii online (see *http://hvo.wr.usgs.gov/earthquakes/seismicity/table.html*

Students can visit the website and select a seismicity map for any year

Once again, students then transfer their data on trend and distance to an earthquake map. Regardless of the map they choose their suspected location lacks any earthquake activity. Note: The 1996 earthquake map shows a concentration of earthquakes at Loihi. Based on the recent earthquake data, the newest Kea volcano is yet to arrive.

When is the next new volcano on the Kea trend going to start forming?

Is the next volcano going to form during our students' lifetimes, in the next millennium, or should we be thinking in geologic time? Students can take the age of a volcano and its distance from Kilauea and plot these points on a graph. Using a graphing calculator students will then calculate the linear regression of this data set (Figure 5). If a graphing calculator is not available or if students do not know how to use one Figure 5 can be projected to the class or provided a copy to each student or working group. The slope of this data provides the average rate of migration for volcanoes along the Kea trend (distance per million years). The slope of the line is 153 km/million years, indicating that the focus of volcanism migrates down the Kea trend about 150 km every million years. Students will then use their calculations to predict when the next volcano on the Kea trend should appear.

To determine approximately how many years it will take to see a new large shield volcano (not yet discovered) on the Kea trend, students will use ratios. It is known that every 1 million years the volcanoes in the Kea trend migrate 153 km, and that another volcano is expected to appear approximately 43 km away from Kilauea. Creating a ratio for this provides the following equation:

$$\frac{1{,}000{,}000 \text{ years}}{153 \text{ km}} = \frac{x \text{ years}}{43 \text{ km}}$$

$$x = 281{,}000 \text{ years.}$$

Possible extensions

Students can use the data they calculated for Figure 2 to estimate the location of the next volcano on the Loa trend, southeast of Loihi. Alternatively, students could investigate and apply this method to other linear chains of volcanoes, such as the Tuamoto or Austral groups of islands in the south Pacific. ■

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