Geochemical analysis of the basaltic rocks from volcanoes of the Hawaiian Island: Implications for their evolutionary stage of development

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Abstract

The Island of Hawaii consists of five different volcanoes. These volcanoes have been active over the last million years and erupted predominantly basaltic lavas. These lavas differ in age and chemistry, which is related to their position over a large mantle plume that continually feeds magma to these volcanoes as the oceanic lithosphere moves over this hot spot. The geochemistry of these lavas changes over time and provides insight into the processes operating during their eruption activity.

This project is concerned with analyzing the geochemical signature in basaltic rocks from the five main volcanoes of Hawaii. From north to south these include: Kohala; Hualalai; Mauna Kea; Mauna Loa; and Kilauea. Samples were collected and prepared in the Department of Geological Sciences and analyzed for major oxides and trace elements using X-ray fluorescence techniques. The goal of this project is to investigate the changes in geochemical signature with respect to time and position related to the mantle plume beneath the island of Hawaii.

Project Objectives

- Collect basalt samples five different volcanoes of Hawaii
- Crush and pulverize samples and prepare for whole-rock geochemical analysis
- Perform X-ray fluorescence analysis on whole-rock basalt samples using fusion glass beads for major oxides and press pellets for trace element analysis
- Evaluate and determine the eruptive stage of each volcano based on the geochemical signature

Geologic Setting

The Hawaiian islands are comprised of large shield volcanoes that erupt large volumes of basaltic lava. These large volcanoes and enormous outpourings of lava are a result of the movement of the Pacific tectonic plate moving over a relatively stationary hot spot, or mantle plume.

In Hawaii, there are five major volcanic centers that are in various stages of development depending on their position over the hotspot. Activity beings in a pre-shield building stage as the area moves onto the hotspot. This pre-shield stage is characterized by alkali-rich lavas (termed alkali basalts). As the plate moves directly over the mantle plume, the volcano transitions to the main shield building stage. It is this stage that is responsible for the massive outpourings and significant growth of a volcano. This stage is characterized by less alkali-rich lavas termed tholeiite basalts. As the plate continues to move off the main hotspot the volcano transitions to the post-shield building stage, characterized once again by alkali-rich lavas (alkali basalts). Finally, the volcanic center becomes inactive and enters its erosional stage as it no longer receives magma from the plume.

This projected focused on the five volcanic centers on the Big Island of Hawaii; 1) Kohala; 2) Hualalai; 3) Mauna Kea; 4) Mauna Loa; and 5) Kilauea.

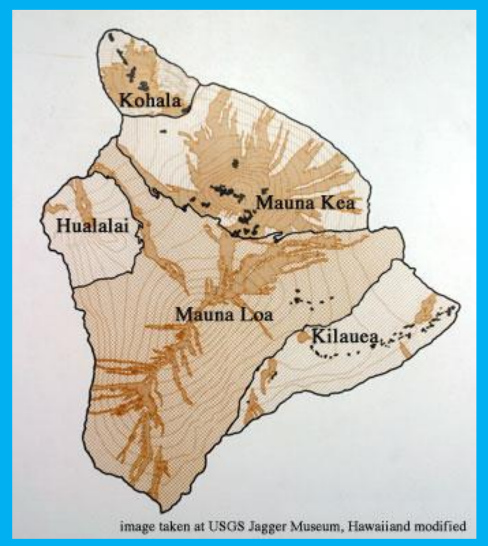


Figure 1. The five volcanoes that make up the Big Island

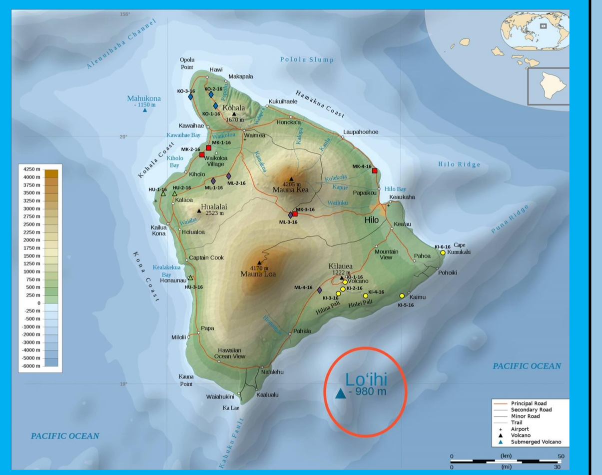


Figure 2. Sample locations of rocks collected from volcanoes of Hawaii

Shield Volcanoes

Sample Preparation & Analytical Methods

X-ray Fluorescence is the emission of x-rays onto a material, and the secondary x-rays that the material produces provides insight into its chemical composition. Two methods were employed for geochemical analysis, fusion glass beads and pressed pellets.

Fusion beads are utilized for major oxide analysis whereas, pressed pellets are used for trace element analysis. The XRF system is fully automated and results typically obtained within a few hours.

Rigaku ZSX3 X-ray Fluorescencent Instrument

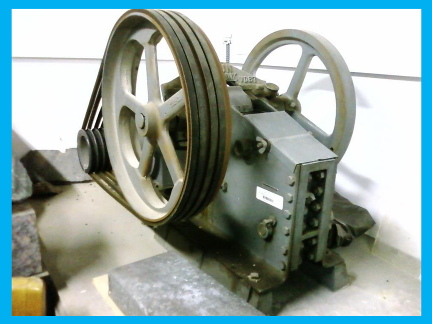
All samples of basalts were crushed and pulverized into gravel size (~4 cm) using the jaw crusher. Crushed material was placed in a ball mill run between 40 to 90 minutes. The resulting fine powder was used to prepare the samples into pressed pellets and fusion beads. (n.b. If the powder was not fine enough, the larger grains would alter the ratio of chemical composition in the rock, which would give an inaccurate analysis of the abundance of certain elements in the rock.)

Pressed pellets were prepared by drying the powder for 1 hour to drive off any water present. Powders were then mixed with an inert binding material. The sample was then compressed, using 20 tons of pressure.

Carver 25 ton press for making pressed pellets for trace element analysis

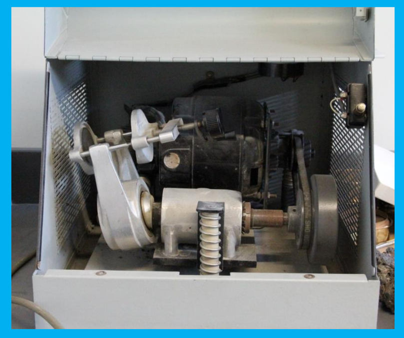
Fusion beads were prepared by mixing the powder with lithium borate in a 1:7 ratio. Then, approximately 0.2500 g was measured to calculate the loss on ignition in the sample, this accounted for any gases, that may have been present in the sample. Both, were put into separate graphite crucibles, and heated in the muffle furnace for 20 minutes. Every 5 minutes, the powder mixed with the lithium borate was taken out, and swirled to promote the complete mixing of the material.

Samples were cooled for an hour, and the result of the powder and lithium borate mixture was a fusion bead, similar in appearance to a small glass disk. Then, the glass was polished prior to placing it into the XRF for analysis.



Jaw crusher

Sample in gravel size



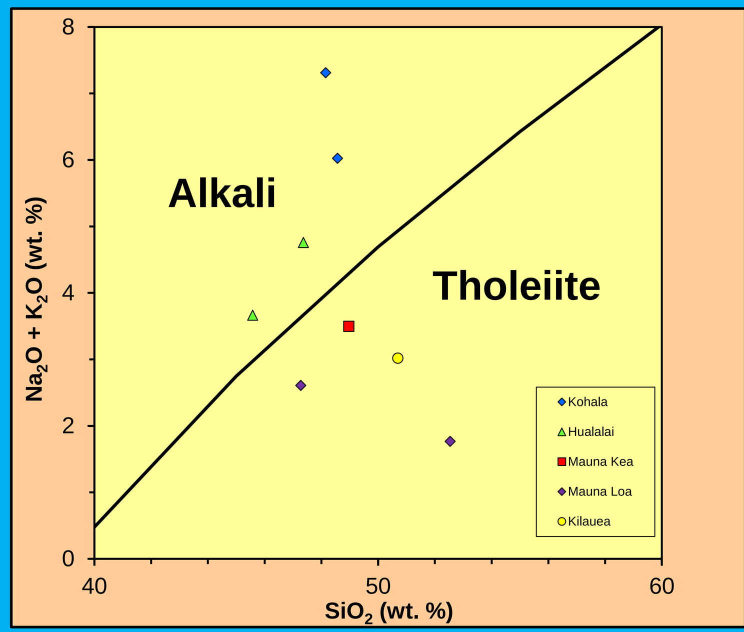
Ball mill pulverizer

Ball mill pulverizing vessel

Melting powders into fusion beads in the muffle furnace

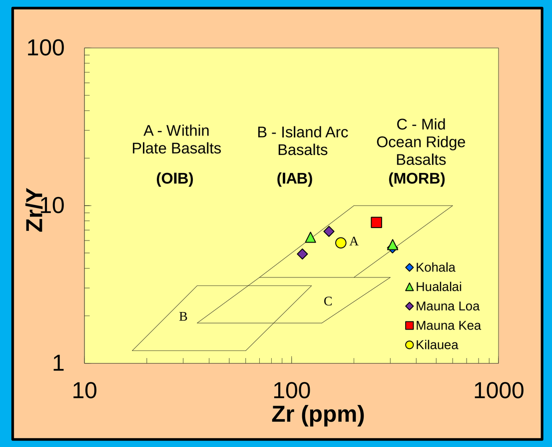
Glass fusion beads and pressed pellets in sample holders waiting analysis

Geochemical Results

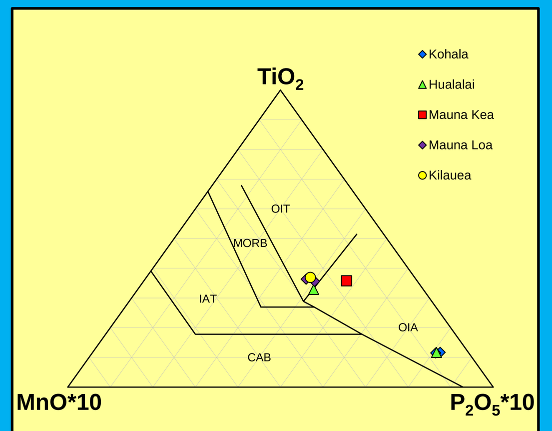


Total alkali vs. SiO_2 graph depicting tholeiitic and alkalic fields based on their chemical composition

	KO-3-16	KO-3-16	HU-2-16	HU-3-16	MK-1-16	ML-1-16	ML-2-16	KI-2-16
OXIDES								
SiO_2	48.15	48.57	45.58	47.36	48.96	52.54	47.27	50.69
TiO_2	3.00	3.17	2.67	3.44	3.75	2.08	2.73	2.63
Al_2O_3	15.51	16.43	13.61	18.85	14.77	12.97	12.04	13.82
Fe_2O_3	12.82	11.56	14.76	12.56	12.03	10.55	12.90	11.85
Na_2O	5.69	4.55	2.66	3.29	2.60	1.46	1.97	2.53
MgO	3.64	4.36	8.48	4.39	5.60	10.72	9.59	6.68
K_2O	1.62	1.47	1.01	1.47	0.90	0.31	0.64	0.49
CaO	7.57	7.37	10.62	5.88	10.67	8.98	12.34	10.82
P_2O_5	2.09	2.23	0.34	2.40	0.50	0.22	0.31	0.28
MnO	0.17	0.22	0.21	0.22	0.17	0.15	0.19	0.18
TOTAL	100.26	99.94	99.93	99.85	99.95	99.97	99.98	99.95
$Na_2O + K_2O$	7.31	6.02	3.66	4.76	3.50	1.77	2.61	3.02
TRACE								
V	76.2		320.0	78.5	364.8	272.5	278.2	331.1
Cr	5.6		427.6	5.6	153.8	757.9	716.6	308.4
Mn	1704.2		1458.5	1806.6	1419.4	1313.3	1329.1	1424.6
Co	20.7		51.8	21.2	38.8	52.9	64.5	59.7
Ni	0.3		221.5	-2.9	83.4	471.7	311.9	103.8
Cu	14.8		81.2	5.9	91.7	91.7	121.6	135.2
Zn	115.2		98.2	121.7	111.1	99.9	92.8	118.5
Rb	24.7		20.9	21.8	18.1	5	10.8	9.5
Sr	1737.8		442.8	1042.2	608.7	264.6	445.1	383.1
Y	56.9		19.6	54.5	32.8	22.9	22.1	29.8
Zr	306.9		123.4	307.6	256.6	112.8	151.6	172.8
Nb	51.9		21.7	51.4	33.9	8.2	19.2	17.8
Mo	-0.1		-0.1	-0.5	0.4	0.4	0.3	0.4
Ba	555.5		291.0	616.6	305.9	71.6	181.1	135.5
Pb	3.4		2.2	2.2	2	1.7	3.2	1.7
Ti	17985.6		16024.64	20622.8	22457.27	12463.61	12463.61	15778.84



Tectonic discrimination diagram of Zr/Y vs. Zr showing the tectonic settings for basalt. Within-plate (OIB) basalts are related to mantle plume activity. Island arc (IAB) are formed in subduction zones. Mid-ocean ridge basalts (MORB are formed at oceanic spreading centers.



Tectonic discrimination diagram further defining tectonic settings of basalt generation. The Hawaii samples all fall in either the OIT (ocean island tholeiite) or the OIA (oceanic island alkali basalts).

Conclusions

There are three developmental stages for volcano evolution on the island of Hawaii. These includes a 1) pre-shield building stage, 2) main shield building stage, 3) and post-shield building stage. The developmental stage is dependent on the position of Hawaii over that mantle plume.

Geochemical analysis shows:

1) Hualalai and Kohala are alkalic and hence are in their post-shield building stage, entering the erosional stage

2) Mauna Kea, Mauna Loa, and Kilauea are tholeiitic and within the main shield building stage

3) Geochemical discrimination diagrams are consist with the geologic setting of the volcanoes with Hualalai and Kohala representing oceanic island alkali basalts (OIA) and Mauna Loa and Kilaeua plotting within the oceanic island tholeiite field. Mauna Kea plots within the OIA field suggesting it may be in the transition from main shield building to post shield building stages

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