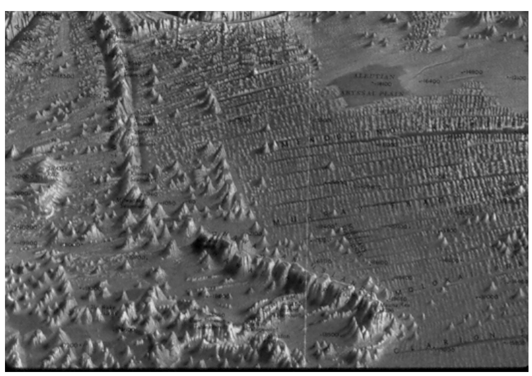
Lecture 24 Hawaii

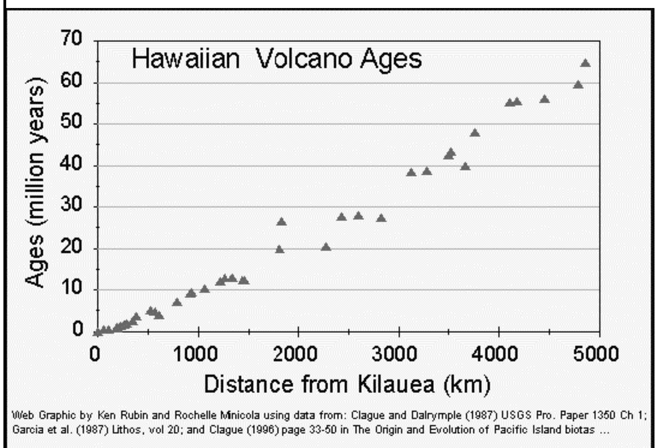
Friday, April 22nd 2005

Hawaii



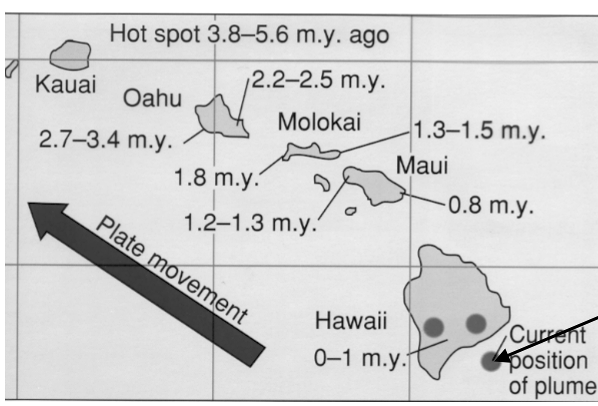
The Hawaiian Islands, in the middle of the Pacific Ocean, are volcanic islands at the end of a long chain of submerged volcanoes.
These volcanoes get progressively older to the north-west (the direction of movement of the Pacific plate).

Age Progression of Hawaiian Volcanoes



The age progression of the volcanoes corresponds to a 9-10 cm/year north-west movement of the Pacific plate over a fixed hotspot.

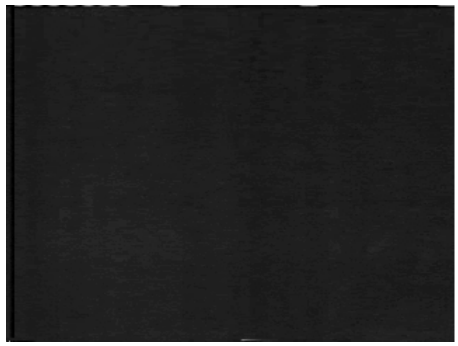
Hawaii

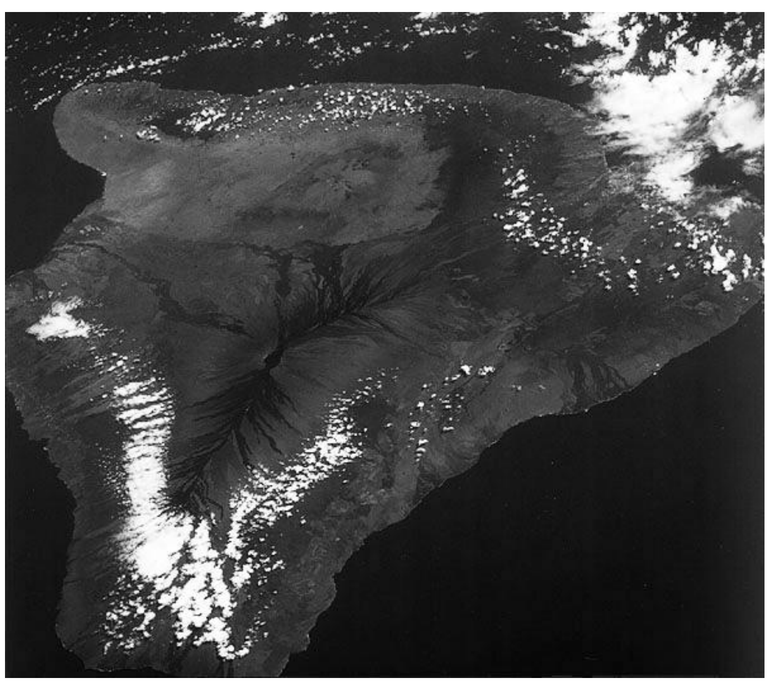


Nonsense!

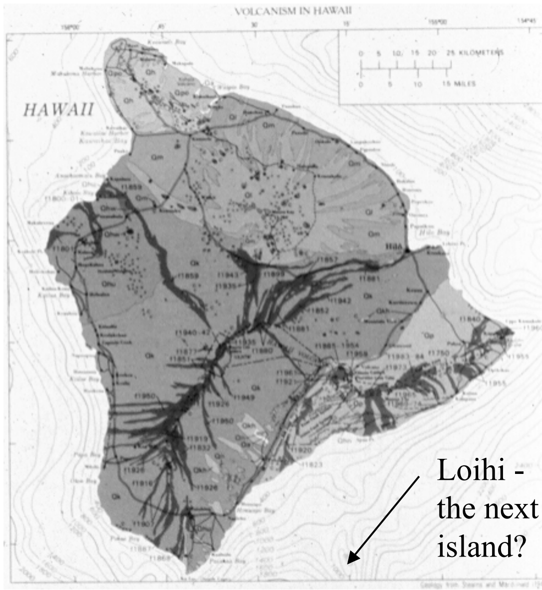
The age progression even applies to the Hawaiian Islands themselves.

Video showing origin of Hotspots





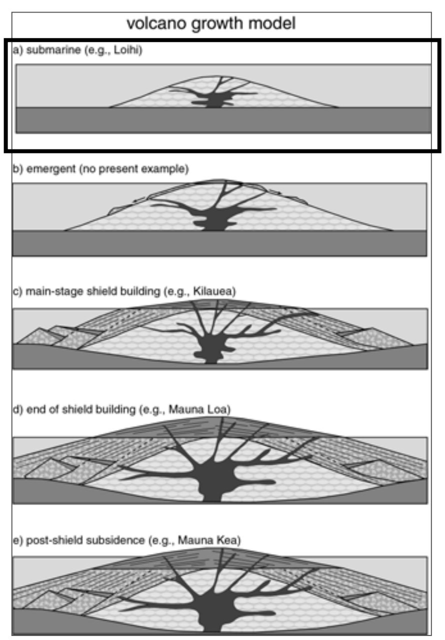
The Island of Hawaii



Loihi - the next island?

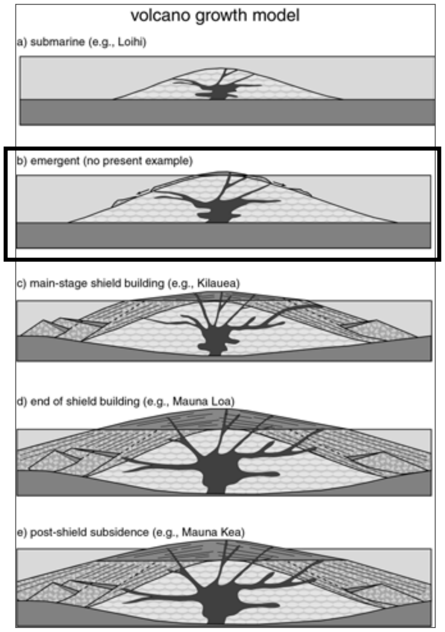
The Volcanoes

- Kohala
- Mauna Kea
- Hualalai
- Mauna Loa
- Kilauea
- Loihi



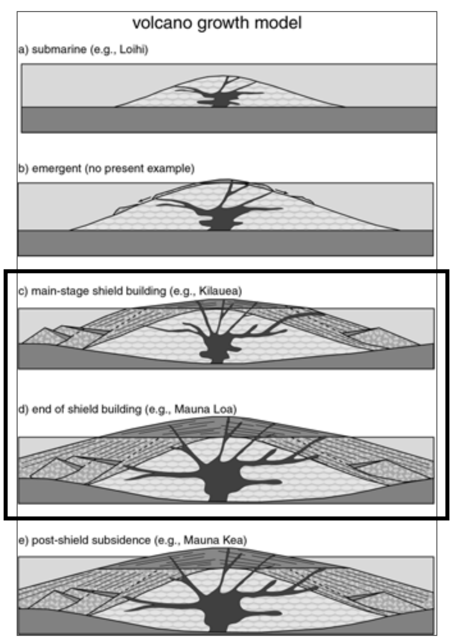
Submarine Stage

Eruption of pillow lavas on the ocean floor producing a submarine volcano. Initial lavas are alkaline followed by a mix of alkaline and tholeiitic lavas and then mostly tholeiites.
e.g Loihi



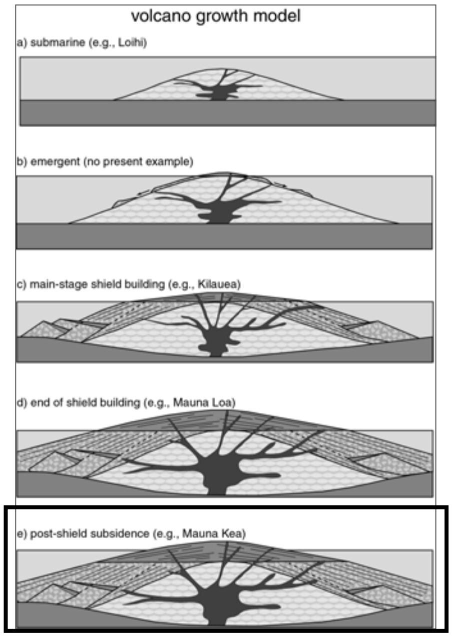
Emergent Stage

The volcano grows to sea level where eruptions become explosive (due to volatile expansion) producing mantling layers of hyalloclastites.
There is no current example of this stage



Shield Building Stage

High magma supply results in voluminous outpouring of tholeiitic basalt to build large shield volcanoes. This constitutes about 95-98% of the volume of a Hawaiian volcano (e.g. Mauna Loa is estimated at 80,000 km^3 and is the earth's largest active volcano).
e.g Kilauea, Mauna Loa

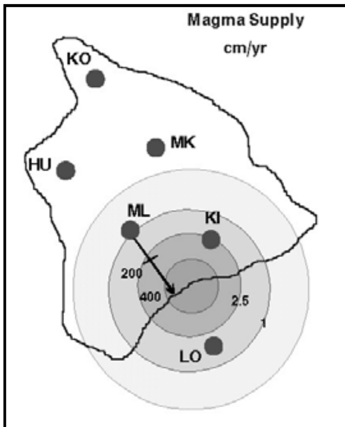


Post-Shield Stage

Magma supplies decrease, changing from tholeiitic to alkalic and forming a thin veneer over the shield stage tholeiites. Lavas are more diverse with a larger proportion of evolved lavas. Eruptions are sometimes explosive. Lava accumulation does not keep up with subsidence. e.g. Mauna Kea, Hualalai

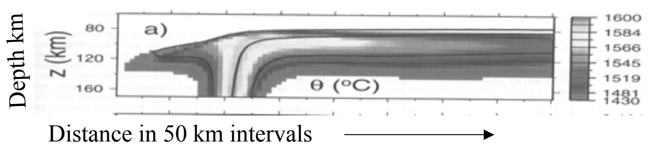
Post-Erosional Stage

Following the post-shield stage is a long dormant period (up to 1 million years?) during which time the volcanoes sink and are deeply eroded. This dormancy is followed by re-juvenated volcanism involving highly alkaline basalts such as basanites and nephelenites. The volume is very small. e.g. Haleakala on Maui, Honolulu Volcanics on Oahu.



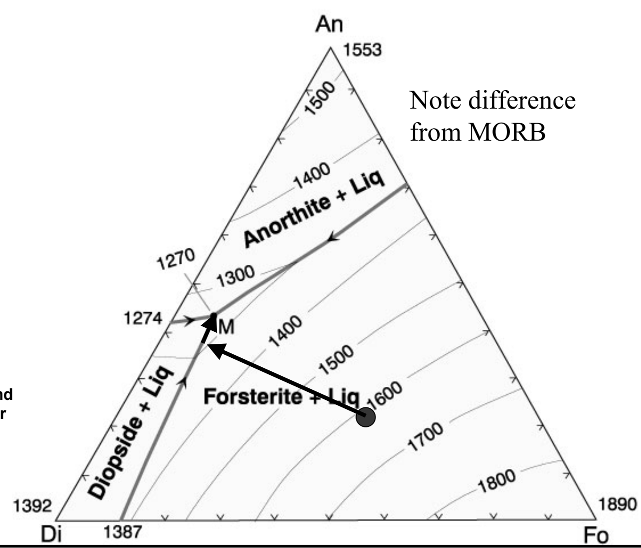
The evolutionary stages of Hawaiian volcanoes are consistent with a thermally zoned plume that is hotter and producing more melt in the plume center than at the margins.

Cartoon showing position of plume relative to volcanoes. Caution – we have no idea where it is actually located or what its shape and radius are!



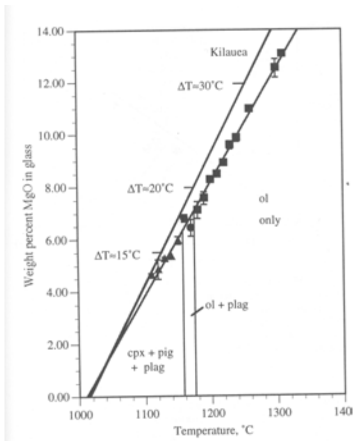
Thermal model of a mantle plume
(Ribe & Christensen, 1991)

- The common crystallization sequence is: olivine (± Mg-Cr spinel), olivine + clinopyroxene (± Mg-Cr spinel), olivine + plagioclase + clinopyroxene



Note difference from MORB

Figure 7-2. After Bowen (1915), A. J. Sci., and Morse (1994), Basalts and Phase Diagrams. Krieger Publishers.



Relationship between MgO in glass and temperature for Mauna Loa

Note how quickly cpx follows plagioclase

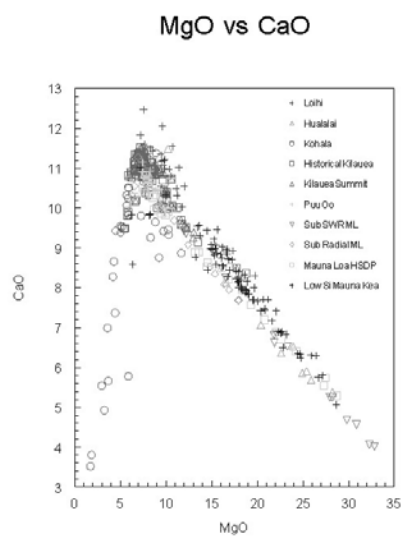
$T(^oC) = 23.0(MgO) + 1012$

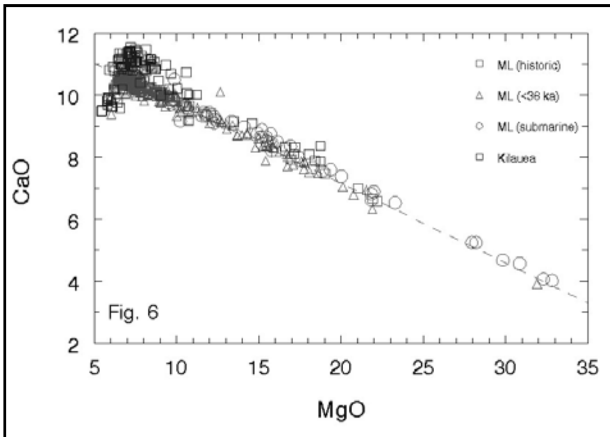
Therefore the temperature of a lava with 7% MgO will be:-

$23.0 \times 7.0 + 1012 = 1174\ ^oC$

The crystallization sequence is clearly shown by the rock chemistry.

1. Extensive olivine crystallization (and accumulation)
2. Followed by clinopyroxene and plagioclase crystallization

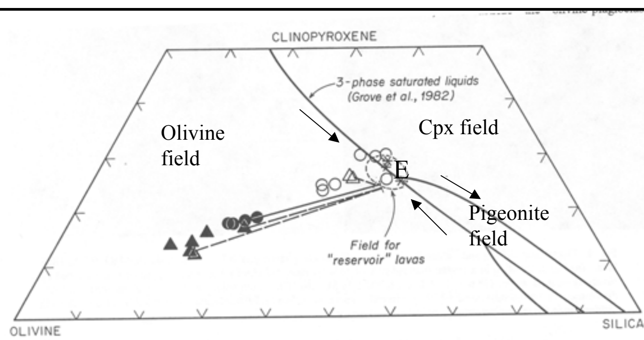




Data for Mauna Loa compared with Kilauea

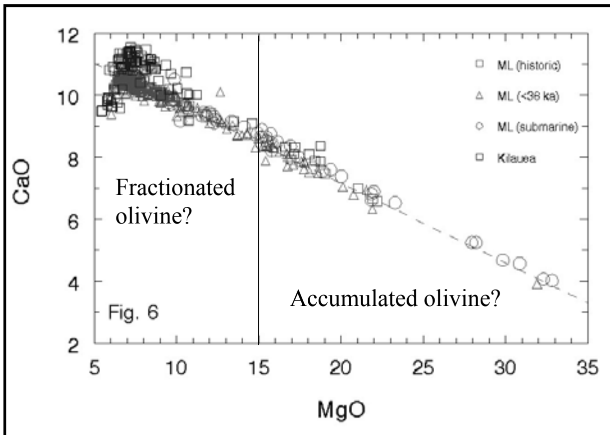
There are three problems:

1. Why does Mauna Loa differ from Kilauea?
2. Why do we only see an olivine fractionation trend for Mauna Loa? Why are there so few fractionated lavas showing cpx and plag crystallization?
3. What is the composition of the parental or primary magma (olivine fractionation vs accumulation)?



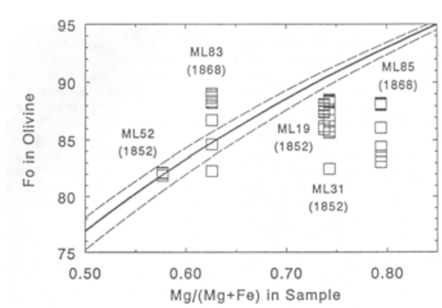
1. Mauna Loa lavas first crystallize olivine
2. At E olivine is joined by Cpx (+ Plag) and pigeonite
3. E is a reaction point where olivine reacts with the melt to produce pigeonite. The magma composition is fixed at E until all olivine is consumed. Only then can the melt evolve further.
4. Recharge and mixing with new parental magma drags the melt composition back into the olivine field
5. The process is repeated over and over again
6. Therefore Mauna Loa rrely erupts fractionated lavas

Note – all crystallization paths from the olivine field (red arrows) lead to E



Where does the parental (primary?) magma plot on this olivine-control line?

1. Most subaerial MgO-rich glassy lavas (true liquids) have a maximum MgO content around 10-11%
2. Submarine glass fragments have been found with MgO = 15%
3. Does this mean that lavas with > 15% MgO have accumulated olivine?

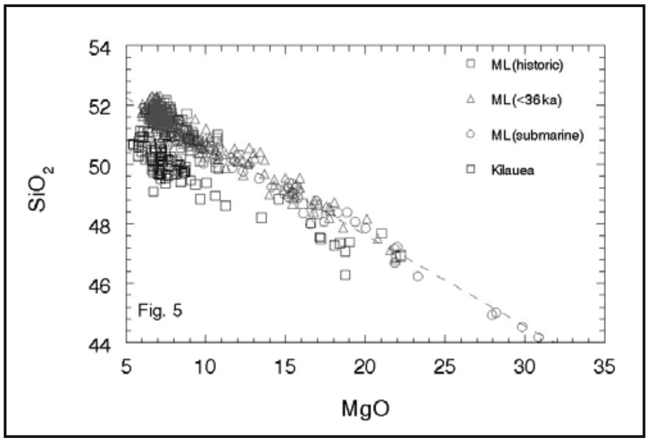


Fo content of olivine vs Mg/(Mg + Fe)

Curved lines give equilibrium compositions

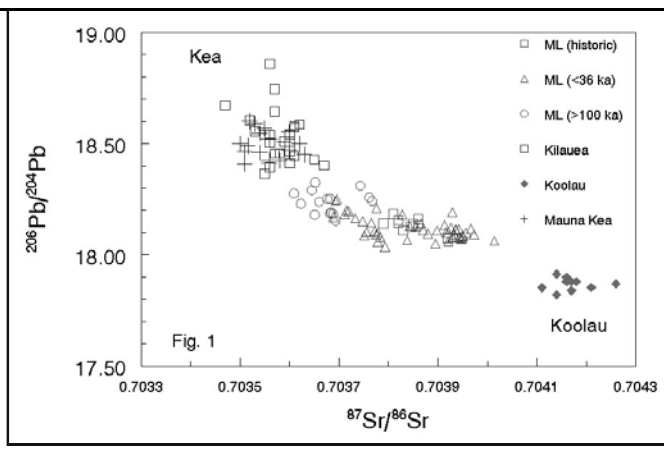
1. Maximum Fo in Mauna Loa olivines is $Fo_{88\text{-}89}$
2. This corresponds to Mg/(Mg + Fe) around 0.70 and an equivalent MgO of 14-15%
3. This is the parental composition from which the most forsteritic olivines crystallized (it may not be primary)
4. Lava with > 15% MgO have accumulated olivine and are not liquid compositions

Why are Mauna Loa lavas different from those of Kilauea?



Lower SiO_2 at a given MgO content in Kilauea lavas relative to Mauna Loa lavas may reflect:

1. Lesser extent of melting
2. Melt segregation at greater depth

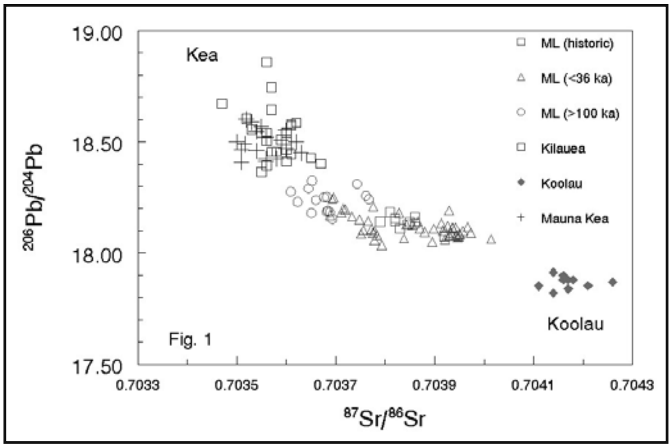


There are also differences in isotopic ratios between Hawaiian volcanoes. They plot on mixing lines between two mantle end-components:-

Kea – possibly primitive plume material (high $^3He/^4He$)

Koolau – possibly entrained lower mantle

(There is a lot of debate and uncertainty!)



Notice how old Mauna Loa (> 100 ka) is closer to Kilauea than young (< 36 ka) Mauna Loa
This implies the plume source for Mauna Loa has changed over time

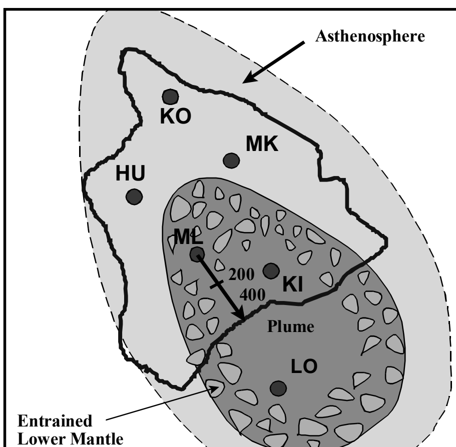


Fig.1

Current models suggest that the Hawaiian plume is zoned both compositionally and thermally

This cartoon illustrates how currently magmas for Mauna Loa may be being produced near the margins of the plume, whereas 200 – 400 ka ago its magmas may have come from closer to the plume center (as do Kilauea and Loihi today?)