The hazards - and benefits - of volcanic eruptions on oceanic islands

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I. Eruption styles/hazards
- Explosive eruptions
  • Magmatic
  • Phreatomagmatic
- Effusive eruptions
  • How lava flows
  • Real-time measurements

II. How volcanic processes relate to magmatic processes

Surface processes
- Geomorphology
- Hydrology
- Soil development
- Biology

Magmatic processes
- Geometry
- P,T conditions
- Magma supply rate
- Magma evolution
Explosive eruptions

**Magmatic** - driven by exsolution of dissolved volatiles

**Phreatomagmatic** - rising magma interacts with external water source
What drives magmatic eruptions? **BUBBLES!**

If bubbles grow fast enough, the fluid breaks into fragments or drops

- Acceleration of fluid up to the surface
- Magma/soda water volume increase
- Bubble nucleation and growth
- Pressure decrease
Fragmentation mechanisms

PUMICE & ASH

brittle fragmentation

Plinian

High viscosity rhyolite

FOAM DISINTEGRATION

liquid instabilities

Hawaiian

Low viscosity basalt

SCORIA
Why do we care? It’s all about the ash

Data from Chouet et al. (1974); Rose et al. (1974); Carey & Sigurdsson (1989); Parfitt (1995); Bonadonna & Houghton (2006); Mannen (2006); Rose and Durant (2009)

Rust & Cashman (in revision)
Ash hazards

Problems with health & airplanes

Data from Chouet et al. (1974); Rose et al. (1974); Carey & Sigurdsson (1989); Parfitt (1995); Bonadonna & Houghton (2006); Mannen (2006); Rose and Durant (2009)

Rust & Cashman (in revision)
Plinian eruptions on volcanic islands

Rare on hot spot oceanic islands BUT there are exceptions, including Alcedo, where a silicic Plinian eruption caused a bottleneck in tortoise evolution)

Beheregaray et al. (2003)
Plinian eruptions on volcanic islands

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Common on arc-related island volcanoes; when they occur they can be disastrous

Santorini c. 3600 ybp - demise of the Minoans

Toba c. 75,000 ybp - bottleneck in human evolution
Other ways to produce fine ash?

Eyjafjallajokull 2010

Intermediate

Phreatomagmatic
Intermediate ("Violent Strombolian") eruptions

- Type example is 1943-1952 eruption of Parícutin, Mexico
- Produce scoria (cinder cones and ash sheets) AND lava flows
Krauskopf (1948)

Vesicular tephra

Degassed lava
Requires gas segregation
(efficiency controlled by magma ascent rate)

Pioli et al. (2009)
How common are these eruptions in non-arc settings?

Not widely recognized BUT (for example) the onset of Sierra Negra 1979 & 2005 eruptions were explosive - was this the result of accumulated volatiles?
Or was it phreatomagmatic?

PHREATOMAGMATIC ERUPTIONS

Interaction of magma with water (groundwater or surface water)

Adding water:

- Increases explosive energy
- Increases amount of ash
- Promote explosive over effusive eruption conditions

“Flying to Europe”
Phreatomagmatic eruptions

Phreatomagmatic eruption was produced by magma interaction with lake water during caldera collapse... generated an ash cloud that reached 20-25 km
Phreatomagmatic eruptions in Hawaii

Inferred eruptions through a crater lake at Kilauea Volcano have produced extensive ash deposits... inferred to be caused by withdrawal of magma, possibly associated with caldera collapse.
Galapagos

- Why do these craters accumulate water?
- What is the potential for (explosive) eruptions through crater lakes, standing water, groundwater reservoirs, or the ocean?
- What are the impacts of these eruptions?

Cerro Azul and Fernandina have crater lakes and tuff cones; Sierra Negra has phreatomagmatic deposits on the crater rim.
Other types of water interaction

Rootless cones - formed when lava flows into areas of standing water
Magma-ocean interactions... Hawaii

Koko Crater

Kilauea

Mauna Loa SWRZ
Kilauea Volcano

 Explosive lava-water interaction requires confinement

Mattox & Mangan 1993
This cone, at the lower terminus of the channel was built by the steam explosions resulting from the incandescent torrent rushing into water, a crater being there formed, surrounded by a heap of black sand. This horse shoe heap was 75 feet high above sea level, and the front of it had broken down on the ocean side, revealing a section of bedded sands over a rock wall beneath... The material was black and rather fine lava sand...Everywhere the sand was coated with a thin film of crystalline white salt, common sea salt, to judge by the taste, and this made the cone white as seen at a distance.

Jaggar (1919)
Tuff Cones

Formed by offshore vents - eruptions through sea water
Surtsey

Type example: Surtsey 1963

Primary hazard: tsunamis

At Myojinsho, 50 tsunamis were recorded at a station 130 km north of the volcano over a two-week period... there could have been hundreds over the course of the eruption.
There are numerous tuff cones in the Galapagos, including these spectacular cones on the coast of Volcan Darwin.
Surtseyan eruptions

Darwin recognized that tuff cones were produced by interaction of magma with sea water, the origin of accretionary lapilli, and the origin of surge bedding...

Benefits?

Palagonitic tuffs produced by these eruptions... palagonite is an alteration product of basaltic glass - has high plant-available Ca and high cation exchange potential

James Bay, Santiago Island
Are there benefits?

Ash from volcanic eruptions can act as mulch in dry climates AND provide “instant soil”

Jorullo Mexico 1759-1774
We see a similar story in the central Oregon Cascades with the help of Lidar which provides both ‘bare earth’ topography AND vegetation topography.
Upper McKenzie River, OR

All flows mapped as 3000 years old BUT...

they have dramatically different vegetation - WHY?
Isopachs estimated from pits and lake cores suggest that the total volume of the tephra deposit was ~ 1 km$^3$.

Clear Lake lies within the 10 cm isopach… suggests that tephra deposited on the previously emplaced southern flow allowed the development of mature forest;

Lack of tephra on the younger flows has prevented revegetation.

McKay and Cashman (in prep)
Lava flows

Kipukas
CHALLENGE: Lava flows are hot, may traverse tens of kilometers and thousands of meters in elevation, and change from liquid to solid.

GOAL: to predict flow paths, flow lengths, and rates of advance.
Lava flow morphologies

Morphology determined by emplacement conditions

Pahoehoe

Blocky

Aa
Surface morphology created by increase in crystal content and/or shear rate

pahoehoe

< ~ 15-20% crystals

`a`a

> 30-35% crystals

What determines the rate and extent of cooling?
Channelized flow - Two regimes

1. Open channel
   - steady, mobile central crust
   - fragmented solid in shear regions

   HIGH EFFUSION RATES; STEEP SLOPES

2. Insulating tube
   - continuous solidified roof
   - efficient delivery of fluid lava

   LOW EFFUSION RATES; LOW SLOPES

Griffiths et al. (2003); Cashman et al. (2006)
Channel velocity
Mauna Loa 1984

Velocity decreases with time (eruption rate) and distance (increasing lava viscosity plus mass loss from overflows and bifurcations).

High vent velocities produce coherent flow structures.

Data from Lipman & Banks (1987)
Flow paths?

Once the vent is established, possible flow paths can be predicted using “lava sheds”.

How accurate do DEMs need to be?

Modeling approach uses cellular automata.

Kauahikaua et al. (2003)
Flow advance rates

Kauahikaua et al. (2003)
Flow advance rates

Kauahikaua et al. (2003)
Branching affects rates of flow advance

data from Wolfe et al. (1988)
Monitoring active flows
Using SAR images to map active lava flows

Satellite-based radar images are collected frequently and are relatively insensitive to clouds
SAR imaging

SAR coherence used to measure post-emplacement subsidence

Stevens et al. (2001)
We can also use SAR images to monitor flow emplacement

Requires a mask for persistently decorrelated ocean and vegetation

H. Dietterich unpublished data
Resulting image corresponds well with USGS maps of flow advance...except for some problems where the flows enter vegetation.

H. Dietterich unpublished data
Persistent Decorrelation July 21, 2007 - October 13, 2010

Initial advance of July 2007 flow before TEB

H. Dietterich unpublished data
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Average days decorrelated

- 102
- 109
- 153
- 204
- 254
- 293
- 381
- 425

Days decorrelated

r = 0.99

H. Dietterich unpublished data
Volcanic Hazards

• Explosive eruptions
  - Plinian eruptions rare (disastrous)
  - ?Ash-producing eruptions? (potential to have impact)
  - Phreatomagmatic activity important

• Effusive eruptions
  - Very common form of activity
  - Emplacement processes complex
  - Can be monitored remotely
What do the Galapagos have to offer?

Volcanic processes

Surface processes

Impact

Magmatic processes

Plumbing
Volcanology and magmatic systems

Maps of vents and flow types can be used to map stress fields and explain the characteristic morphology of Galapagos volcanoes.

Geist et al. (2006)

Geist & Harpp (2009)
Temporal and spatial distribution of flow types provides information on magma plumbing system and volcano construction.
Volcanology and magmatic systems

Extending into the submarine realm allows full reconstruction of magmatic systems...

Geist et al. (2006)
Volcanology and magmatic systems

...and allows us to start asking questions about magma plumbing systems as they affect eruptive processes such as caldera formation.
For example:
What triggers collapse and where does the magma go?

- Slow drainage during prolonged eruptions?
- Intrusion into dike or sill?
- Submarine lava flows?
Summary

• Hazards
  - Explosive eruptions
    Ash abundance and size
    Magmatic or phreatomagmatic
  - Lava flows
    Rate and length of advance
    Vent location

• Benefits
  - Explosive eruptions
    Instant soil?
  - Effusive eruptions
    Hydrology, Isolation drives evolution