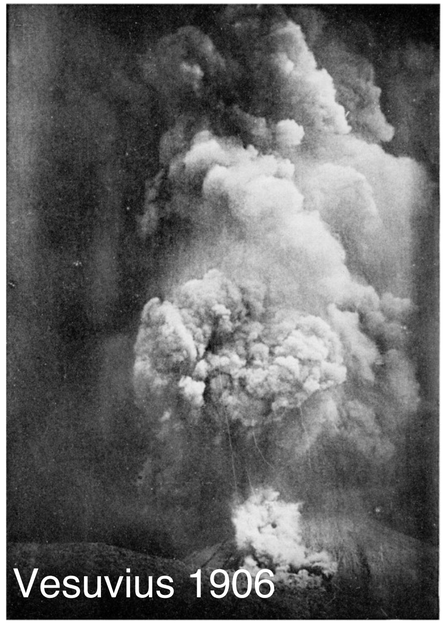
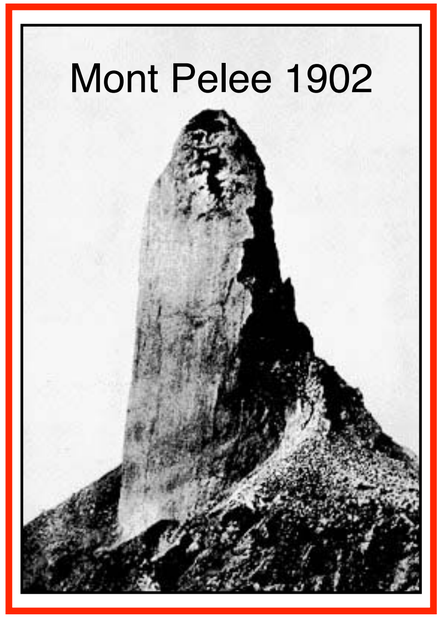
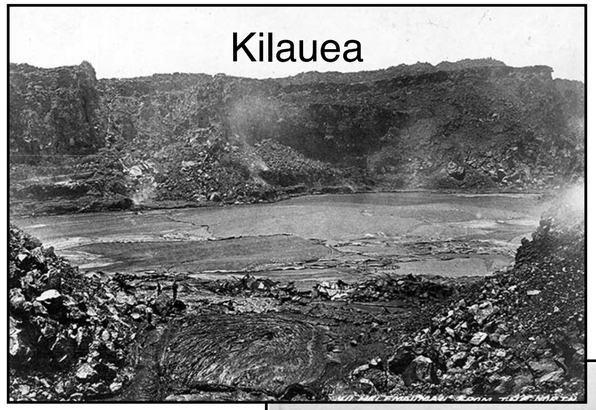
How volcanoes work:
A 100 year perspective

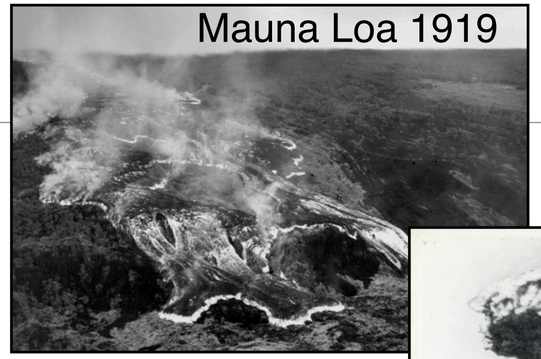
Kathy Cashman
University of Bristol

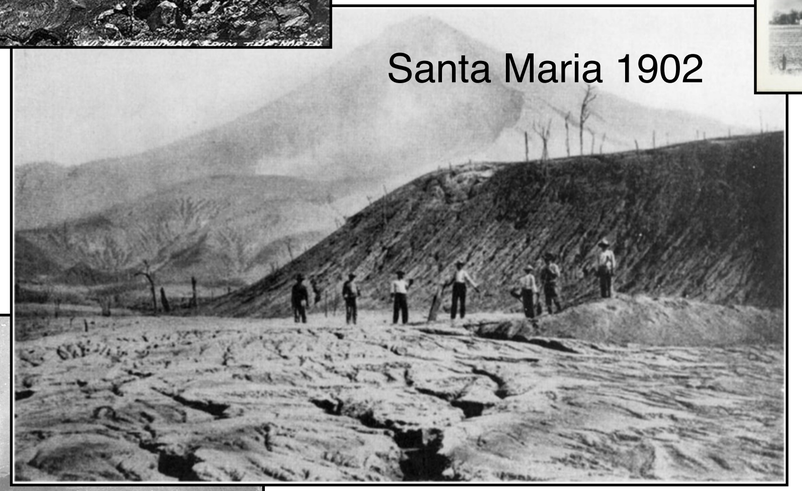
Where were we 100 years ago?

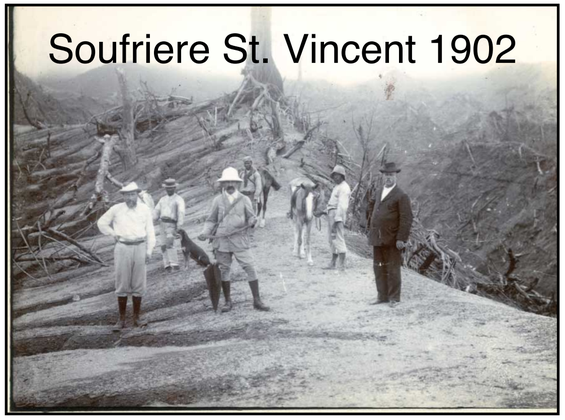


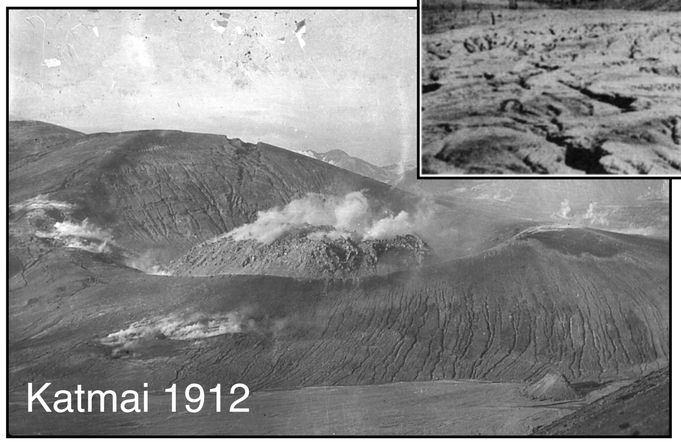




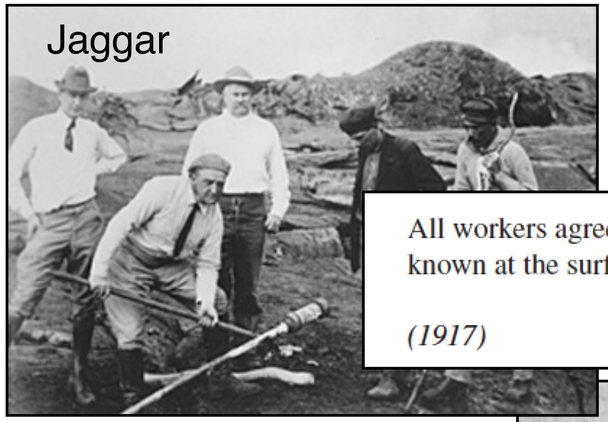








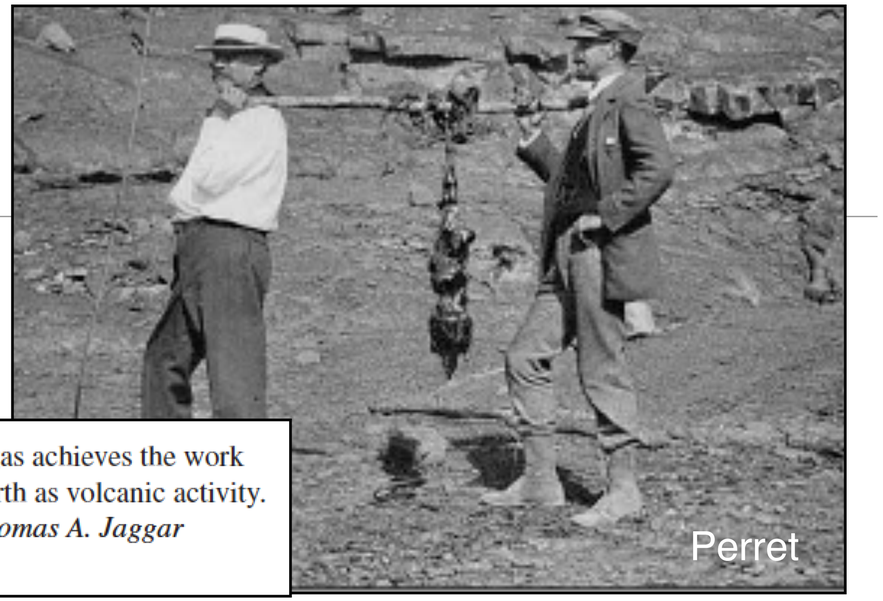
Where were we 100 years ago?

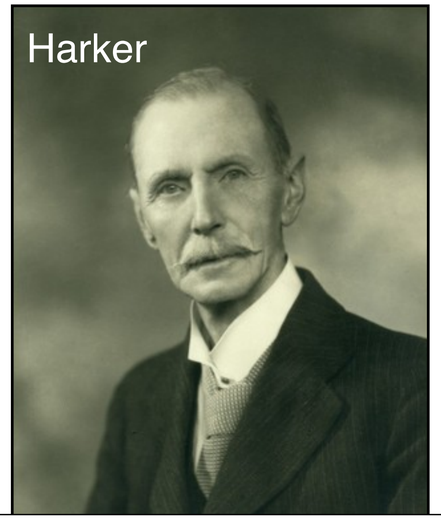


All workers agree that rising gas achieves the work known at the surface of the earth as volcanic activity.

Thomas A. Jaggar

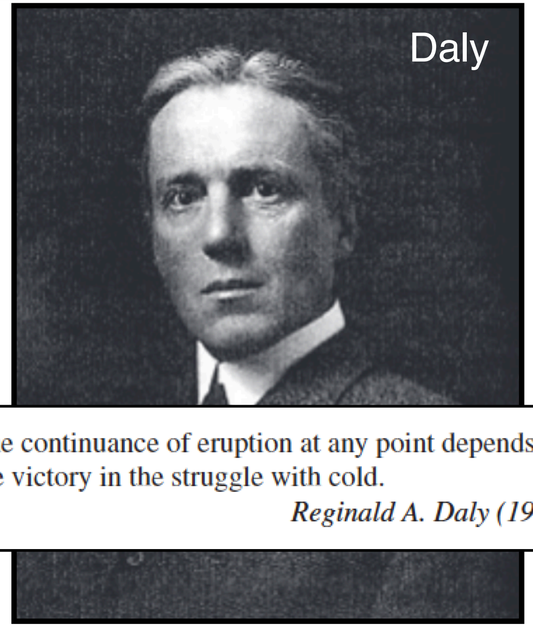
(1917)





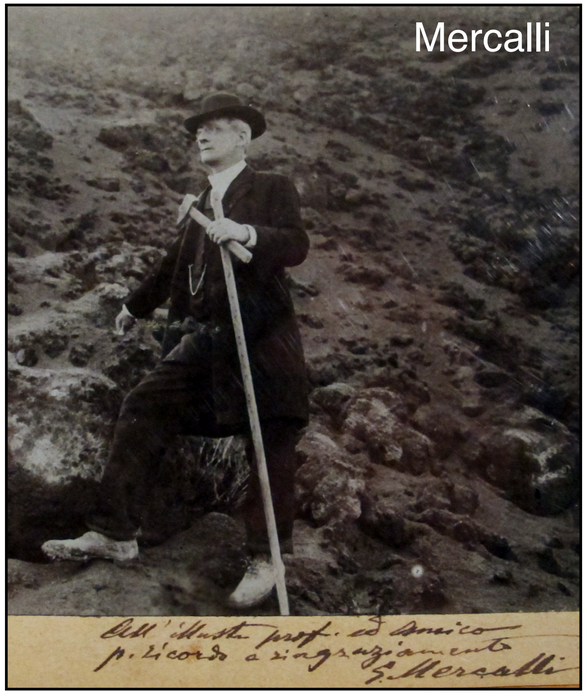
"…we must seek the immediate cause of igneous action, not in the generation of heat, but chiefly in ***relief of pressure***

Harker (1909)



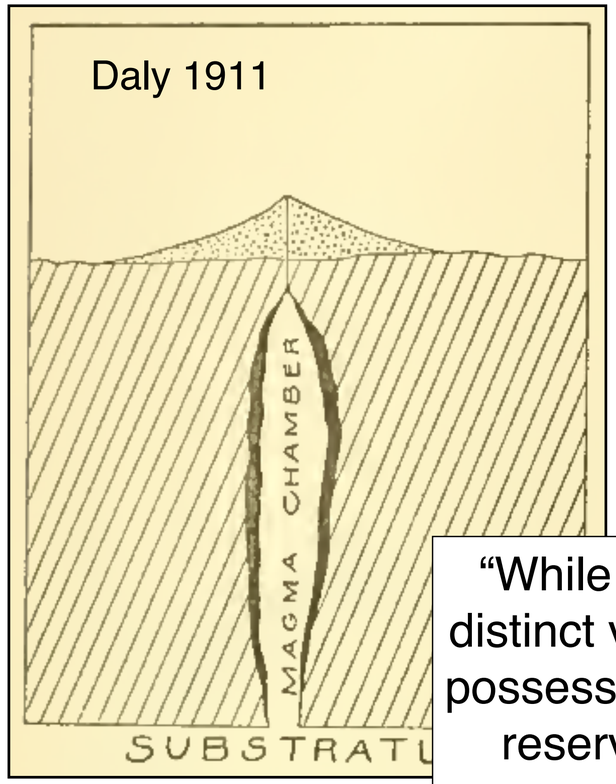
The continuance of eruption at any point depends on the victory in the struggle with cold.

Reginald A. Daly (1911)



Fundamentals of volcanology

Fractionation and Mixing



"Any differentiation which depends on sinking of crystals under gravity ***belongs necessarily to a somewhat early stage of crystallization, when the bulk of the magma was still in a liquid condition***. At a later stage, when the crystals formed are so numerous or large as to touch an support one another, the ***condition may be likened to that of a sponge full of water***…

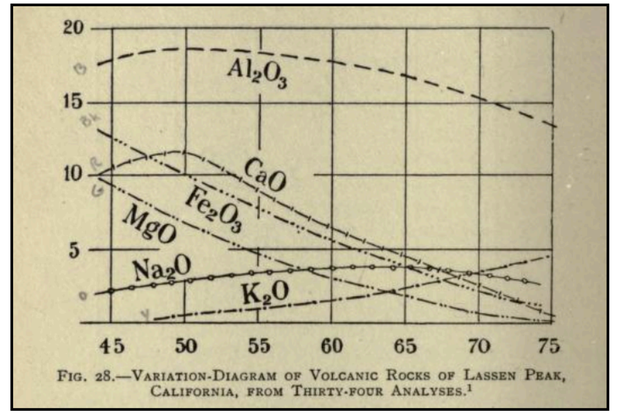
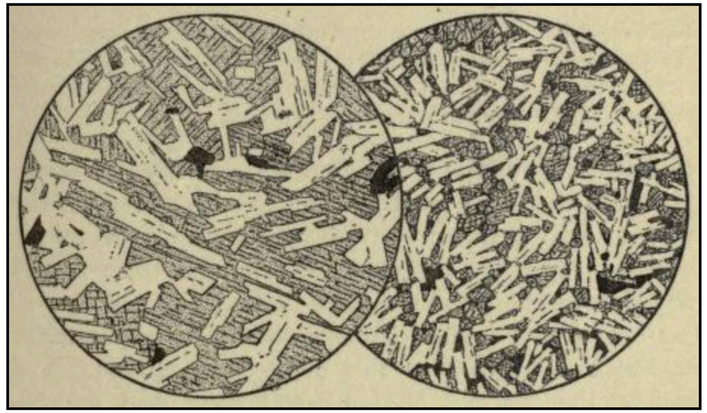


FIG. 28.—VARIATION-DIAGRAM OF VOLCANIC ROCKS OF LASSEN PEAK, CALIFORNIA, FROM THIRTY-FOUR ANALYSES.[1]

"While we picture each distinct volcanic centre as possessing its own proper reservoir of lava, it is necessary to suppose that such reservoir is of ***relatively small dimensions and of temporary status***"



Harker 1909

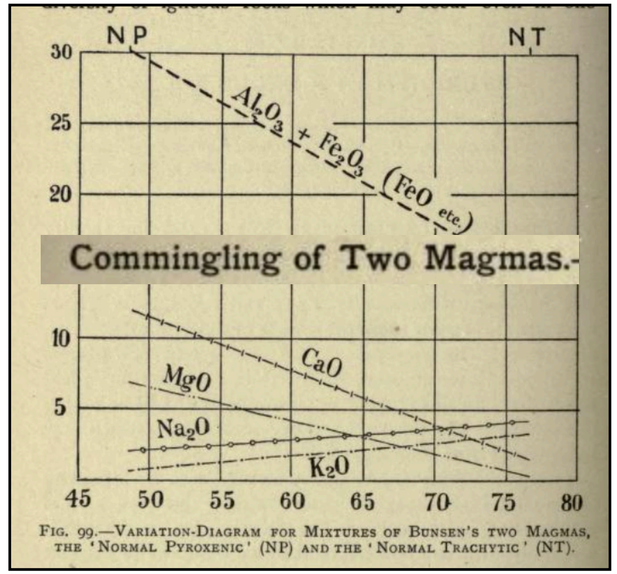


FIG. 99.—VARIATION-DIAGRAM FOR MIXTURES OF BUNSEN'S TWO MAGMAS, THE 'NORMAL PYROXENIC' (NP) AND THE 'NORMAL TRACHYTIC' (NT).

Overview

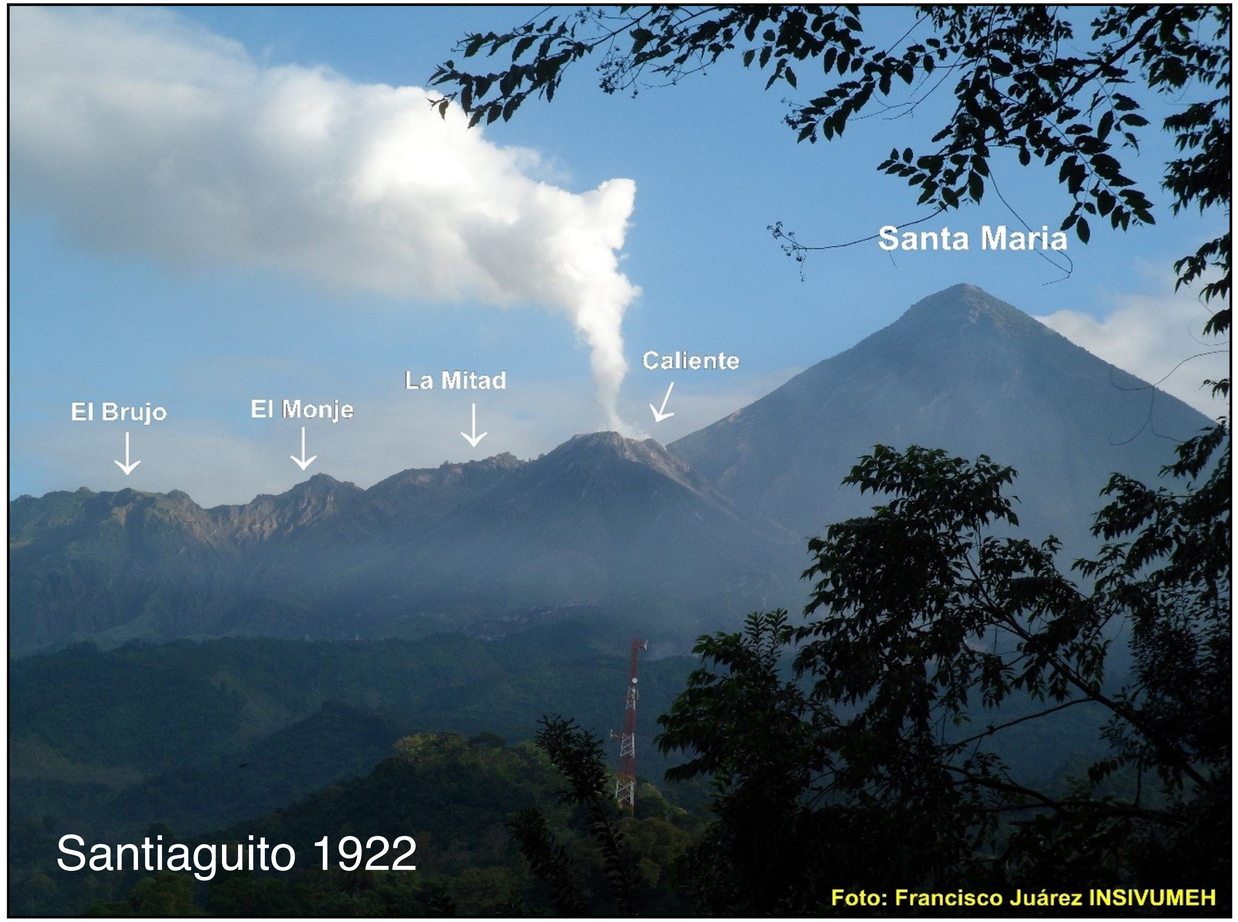
The fundamentals of volcano science were in place 100 years ago, driven by a combination of:

- Key eruptions
- Advances in technology
- Development of conceptual models

The same combination has continued to propel our science forward

1920s and 1930s

Start of protracted dome extrusion

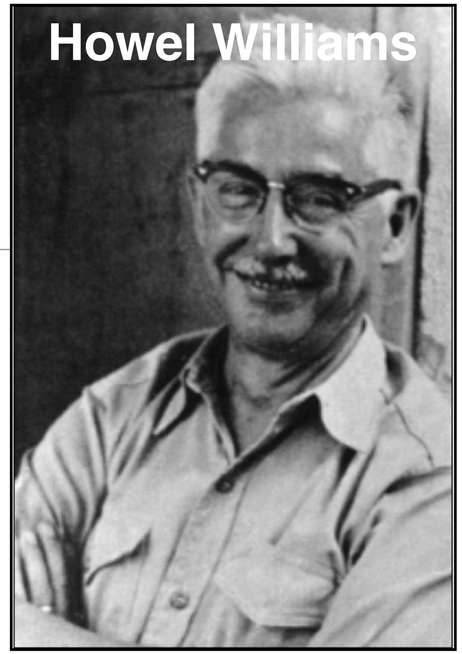


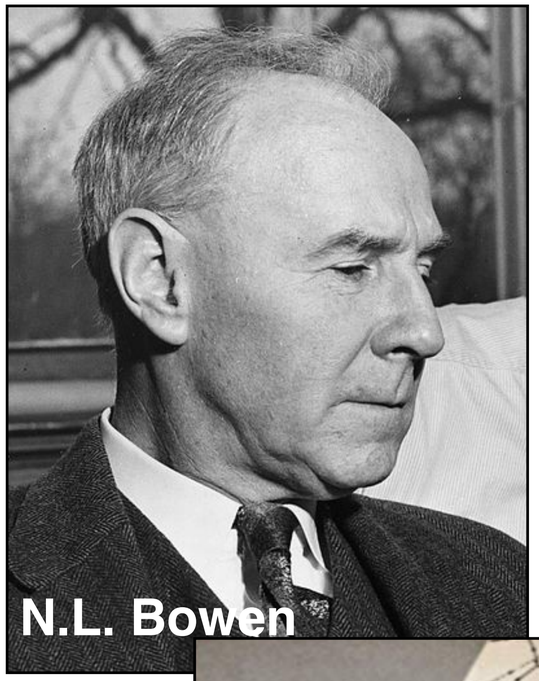
Conceptual advances

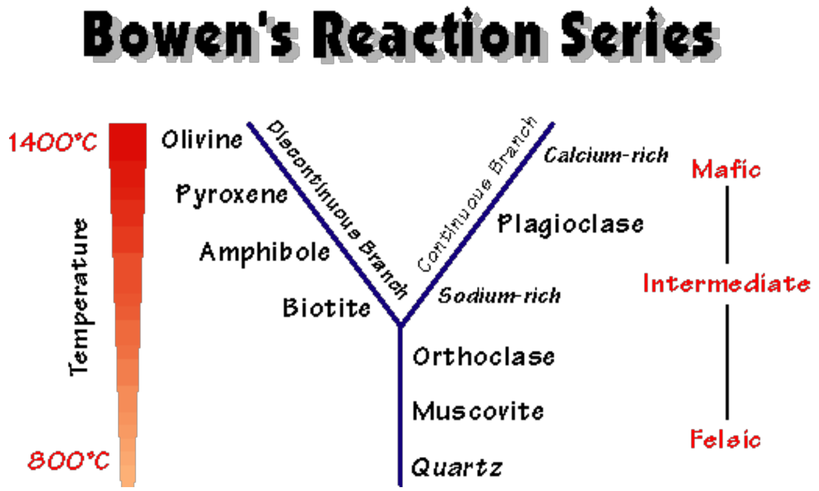
A VOLCANO UNDER AN ICE-CAP. VATNAJÖKULL, ICELAND, 1934–36

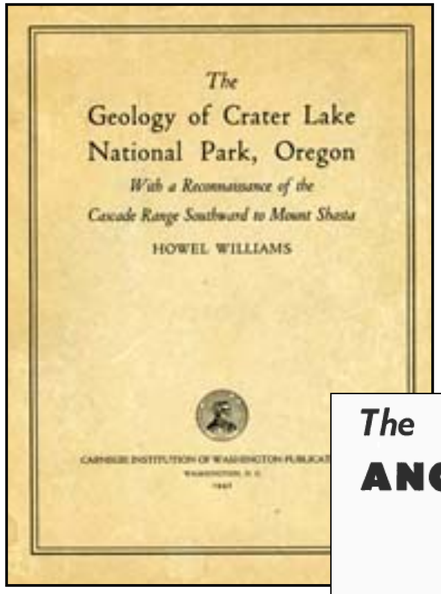
NIELS NIELSEN

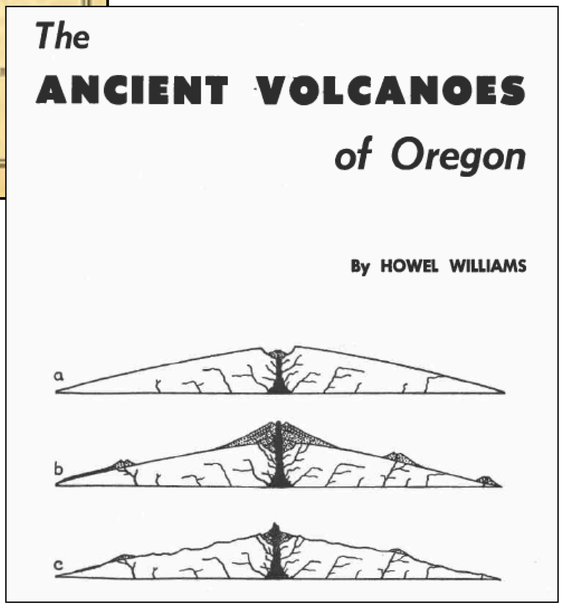
Evening Meeting of the Society, 8 February 1937

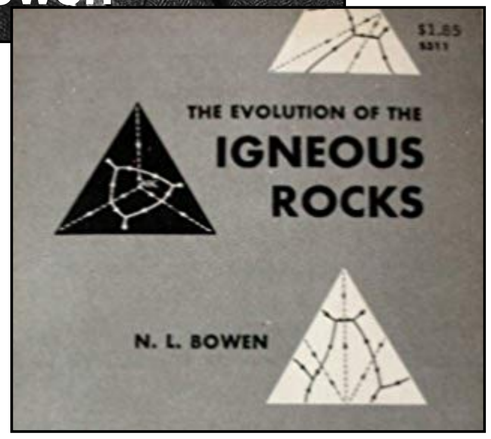












Preliminary Note on the Occurrence of Pigeonite as Phenocrysts in Some Pyroxene-andesite from Hakone Volcano.

By

Hisashi Kuno, *Rigakusi*,
Geological Institute,
Faculty of Science,
Imperial University of Tôkyô.

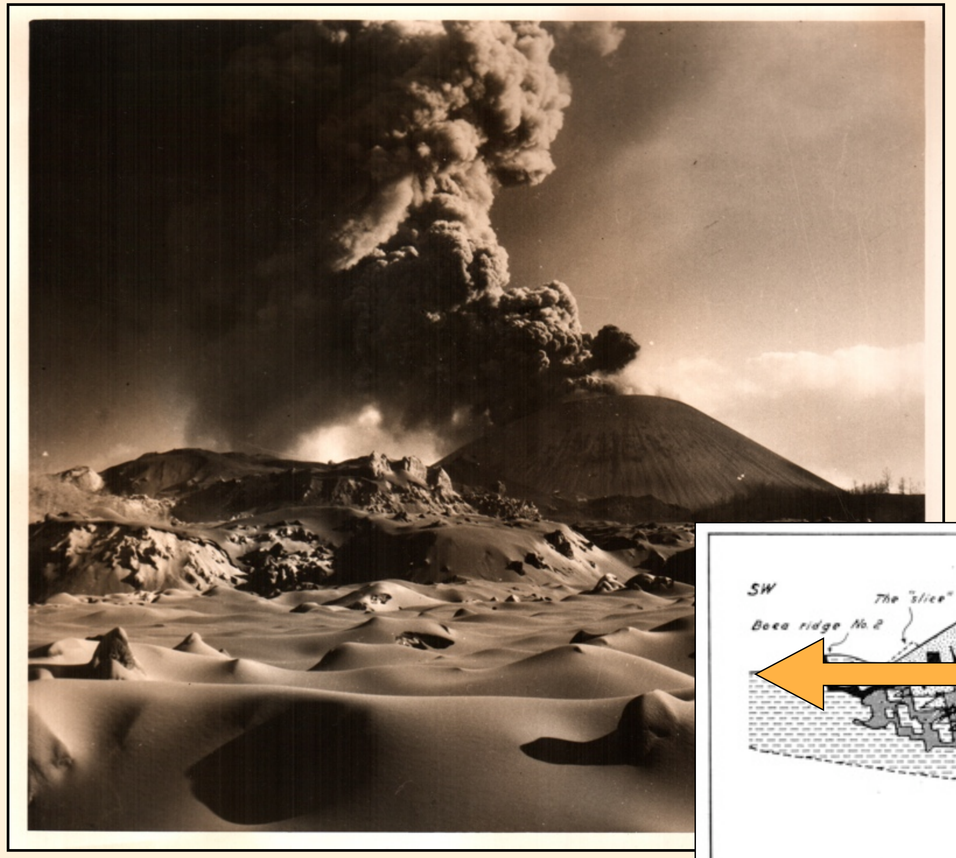
JORULLO

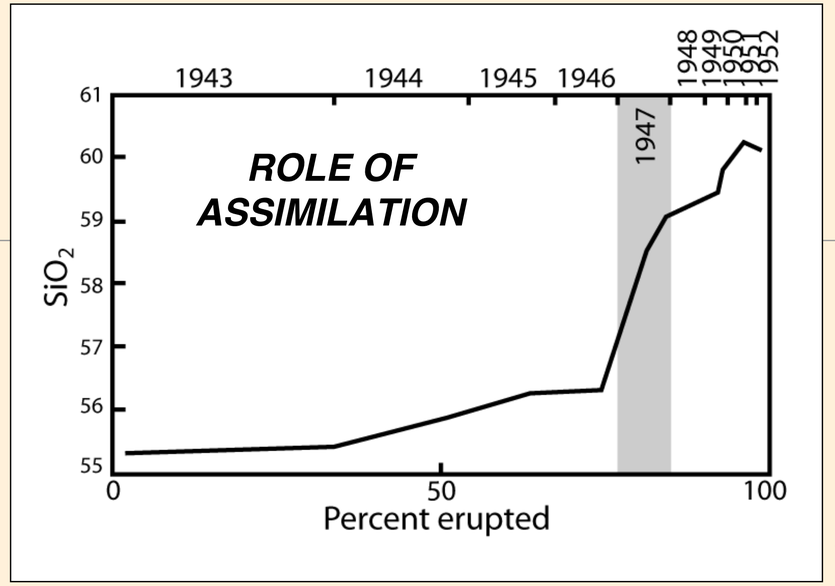
THE HISTORY OF THE VOLCANO OF JORULLO AND THE RECLAMATION OF THE DEVASTATED DISTRICT BY ANIMALS AND PLANTS

By

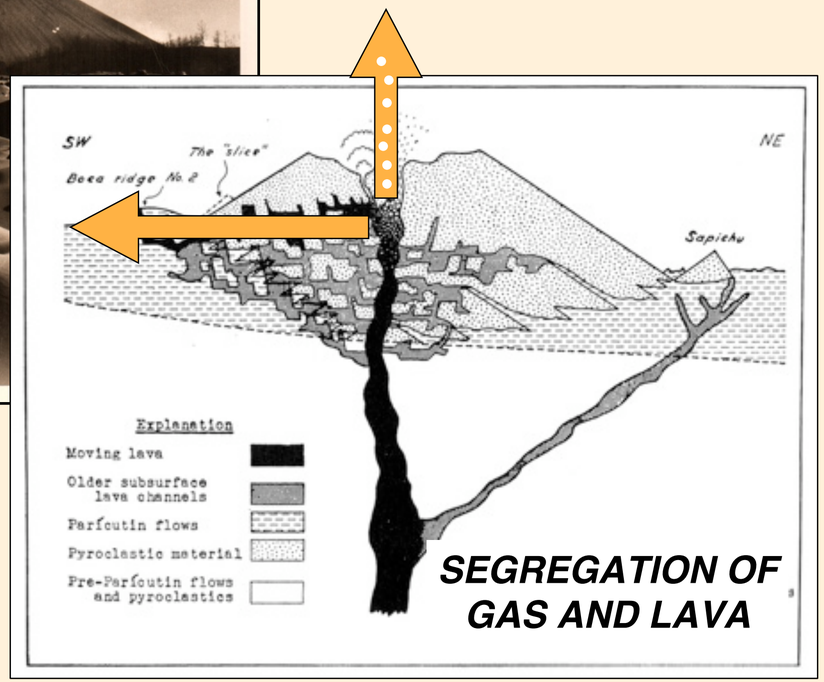
HANS GADOW, M.A., PH.D., F.R.S.
LATE STRICKLAND CURATOR AND READER IN VERTEBRATE MORPHOLOGY IN THE UNIVERSITY OF CAMBRIDGE

Paricutin 1943-1952

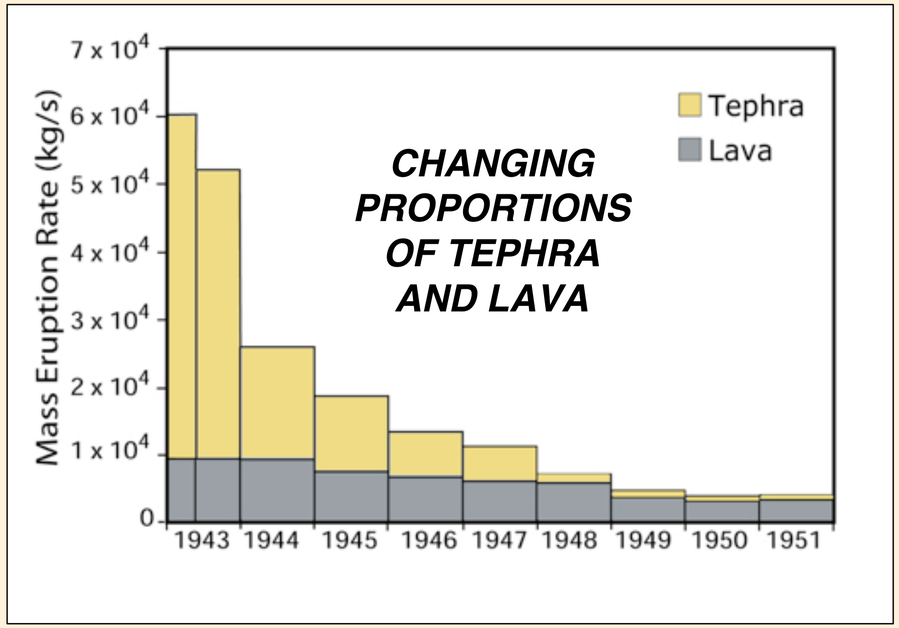




Wilcox (1954)



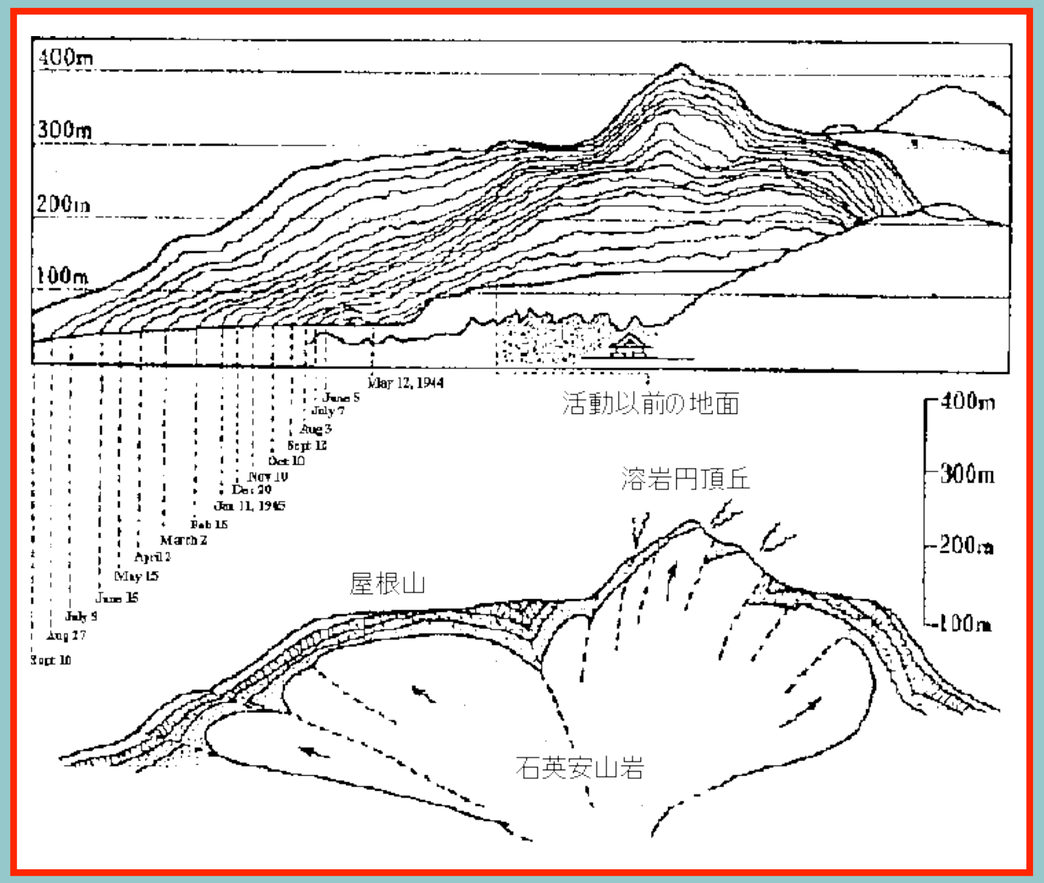
Krauskopf (1948)

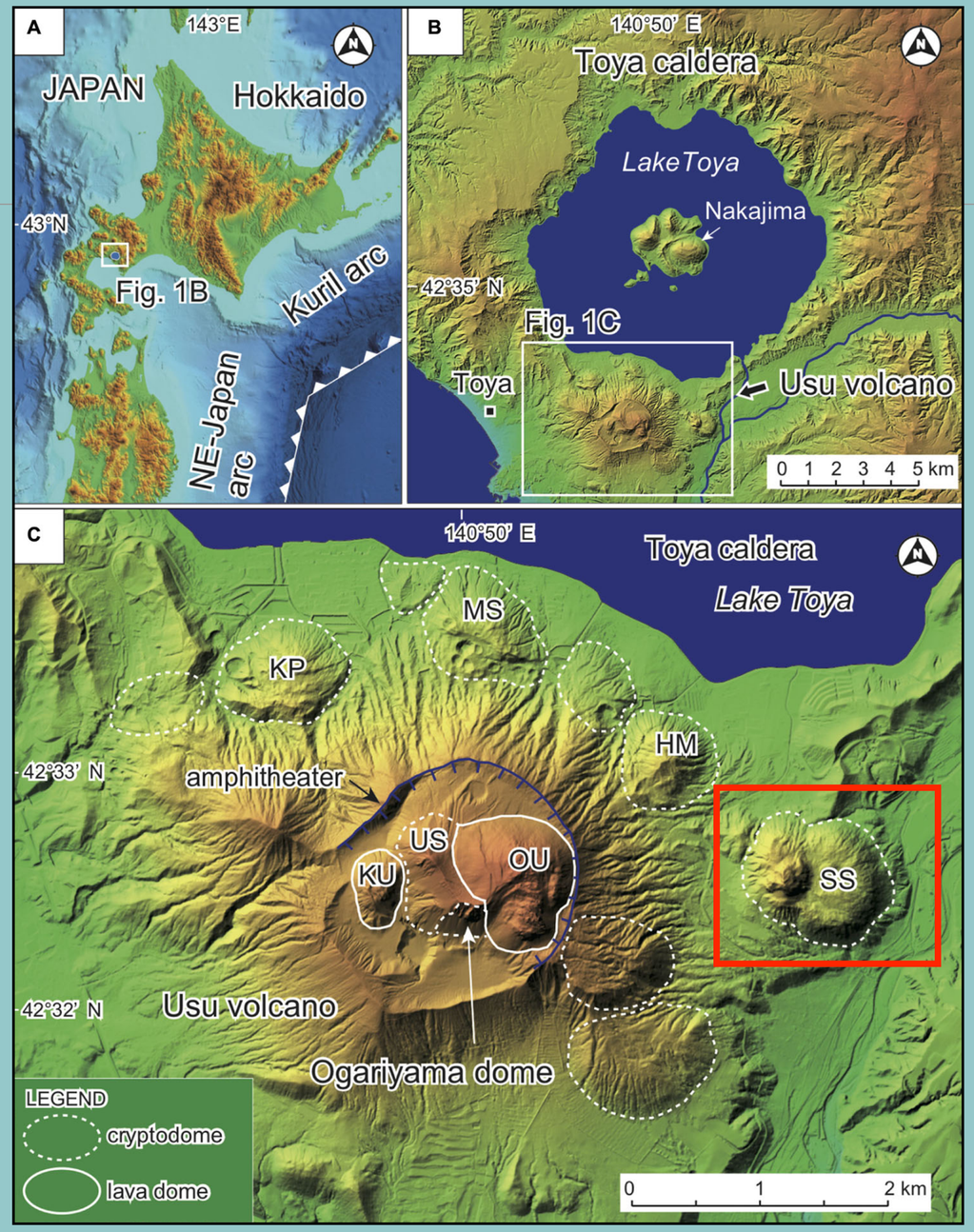


Fries (1953)

Showa Shinzan 1944-1945

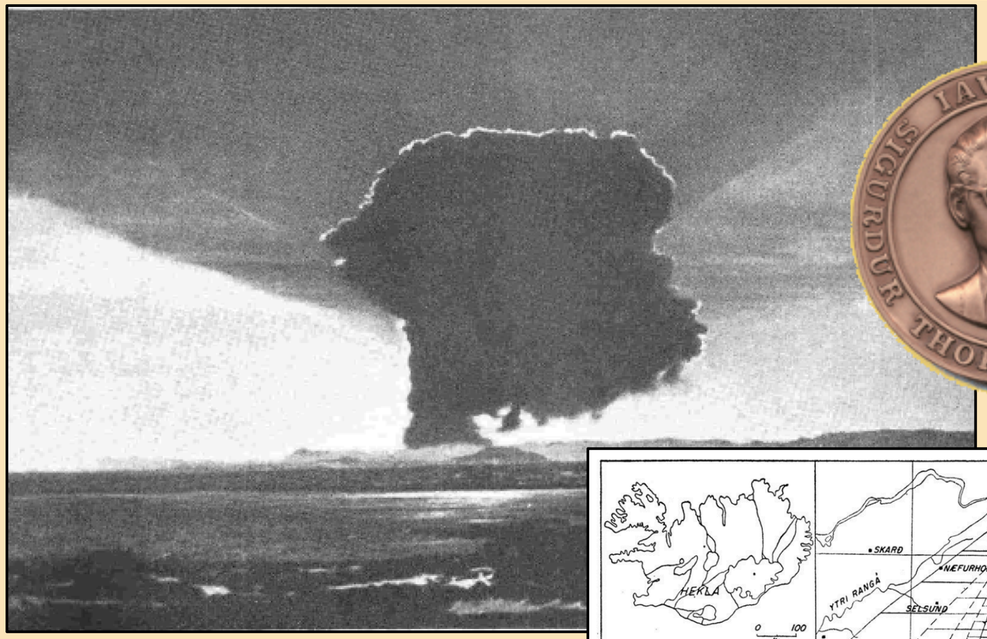
Mimatsu diagram

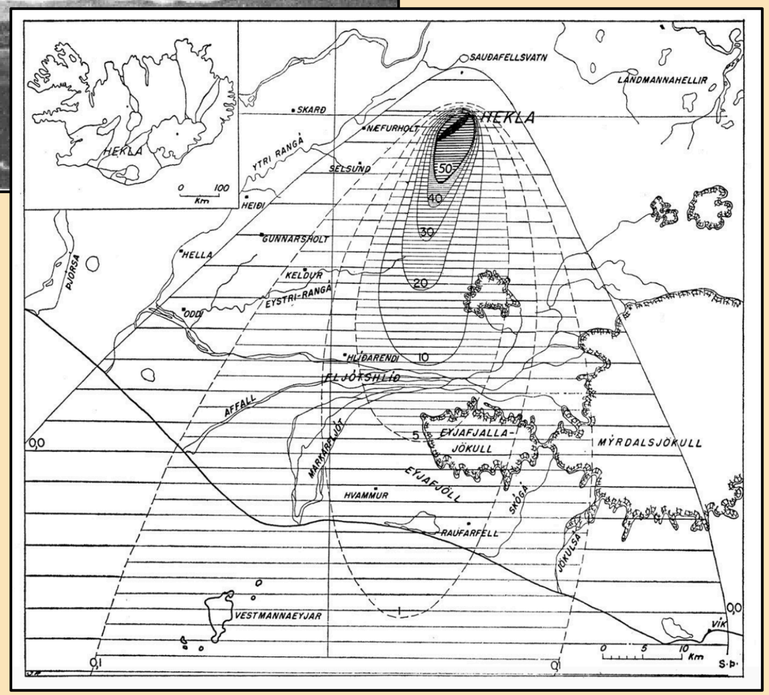




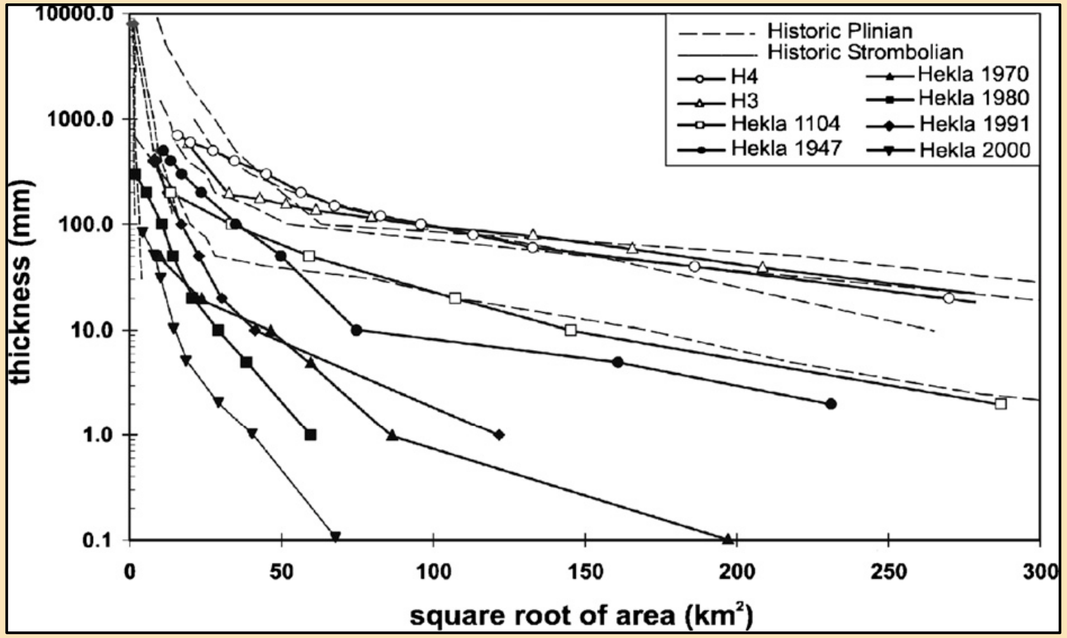
Goto and Tomiya (2019)

Hekla 1947





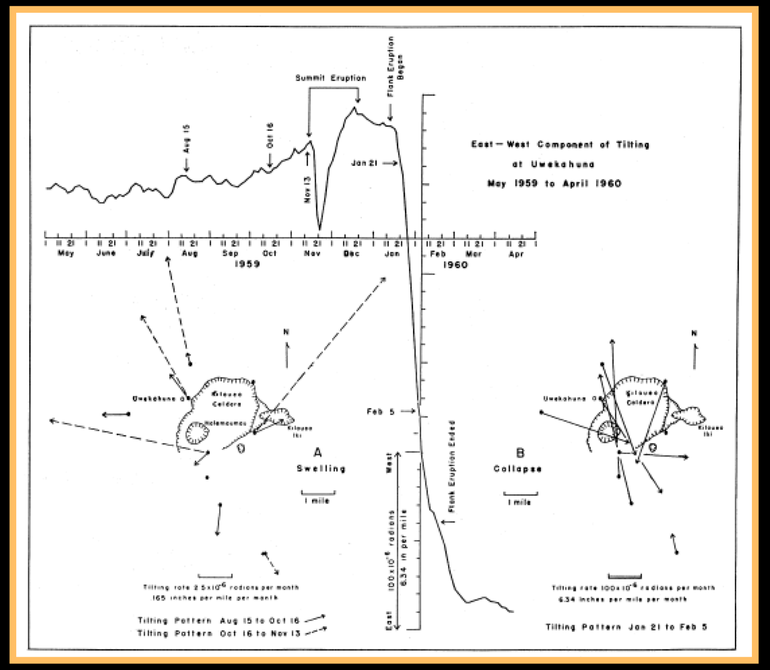
Thorarinsson (1950)



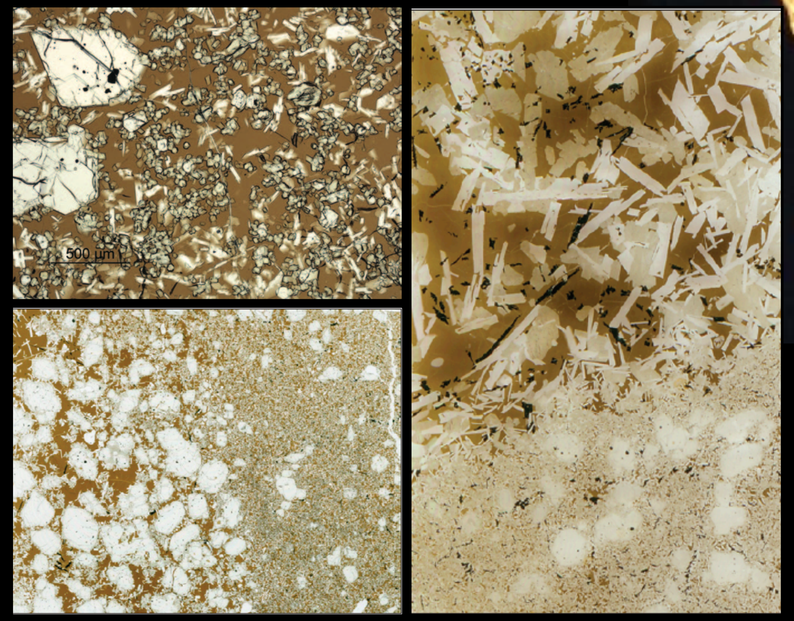
Thordarsson and Larson (2007)

Thorarinsson developed the field of tephra studies, ***including use of √area diagrams for tephra thickness and grain size***

Kilauea lava lakes 1959-65

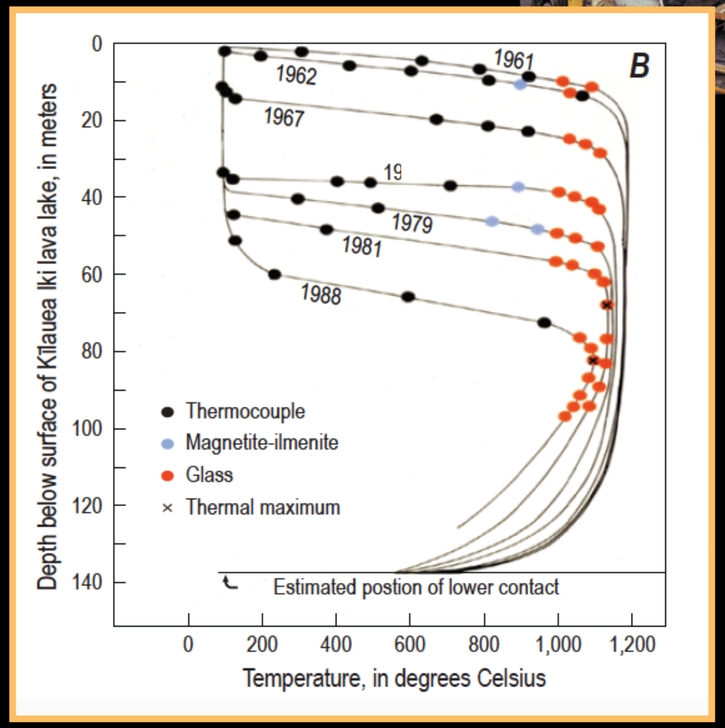


Eaton & Murata (1960)



Kilauea Iki eruption provided first geophysical evidence for lava drainage and collapse

Lava lake drilling projects provided a natural laboratory for studying the chemical and physical evolution of Hawaiian lava during cooling



Helz et al. (2014)

Surtsey 1963-1967: The birth of an island

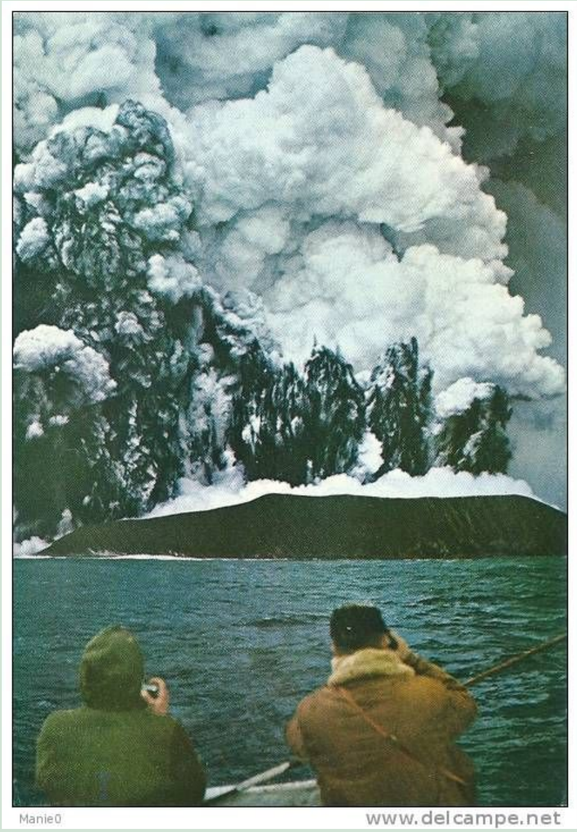
The Submarine Eruption off the Vestmann Islands 1963-64.

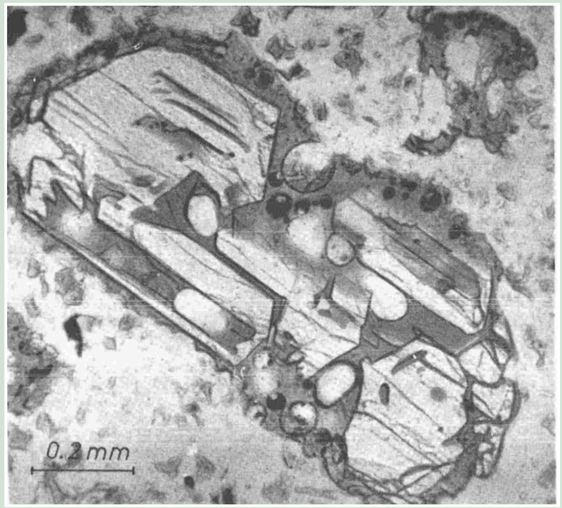
A PRELIMINARY REPORT *

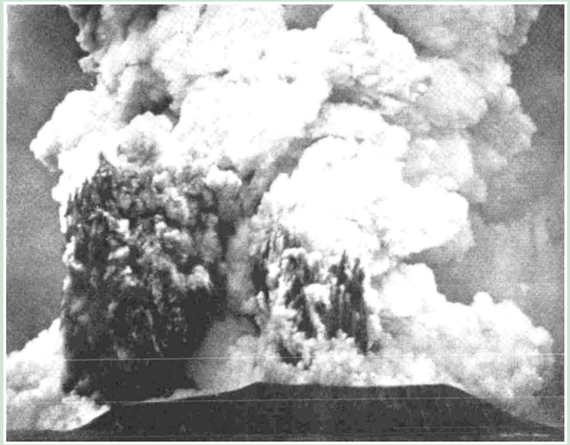
S. THORARINSSON - Th. EINARSSON - G. SIGVALDASON
and G. ELISSON

A now classic image of lightening coursing through a towering Surtsey eruption column late 1963.
Image credit: Sigurgier Jonasson

Surtseyan:
A new eruption style



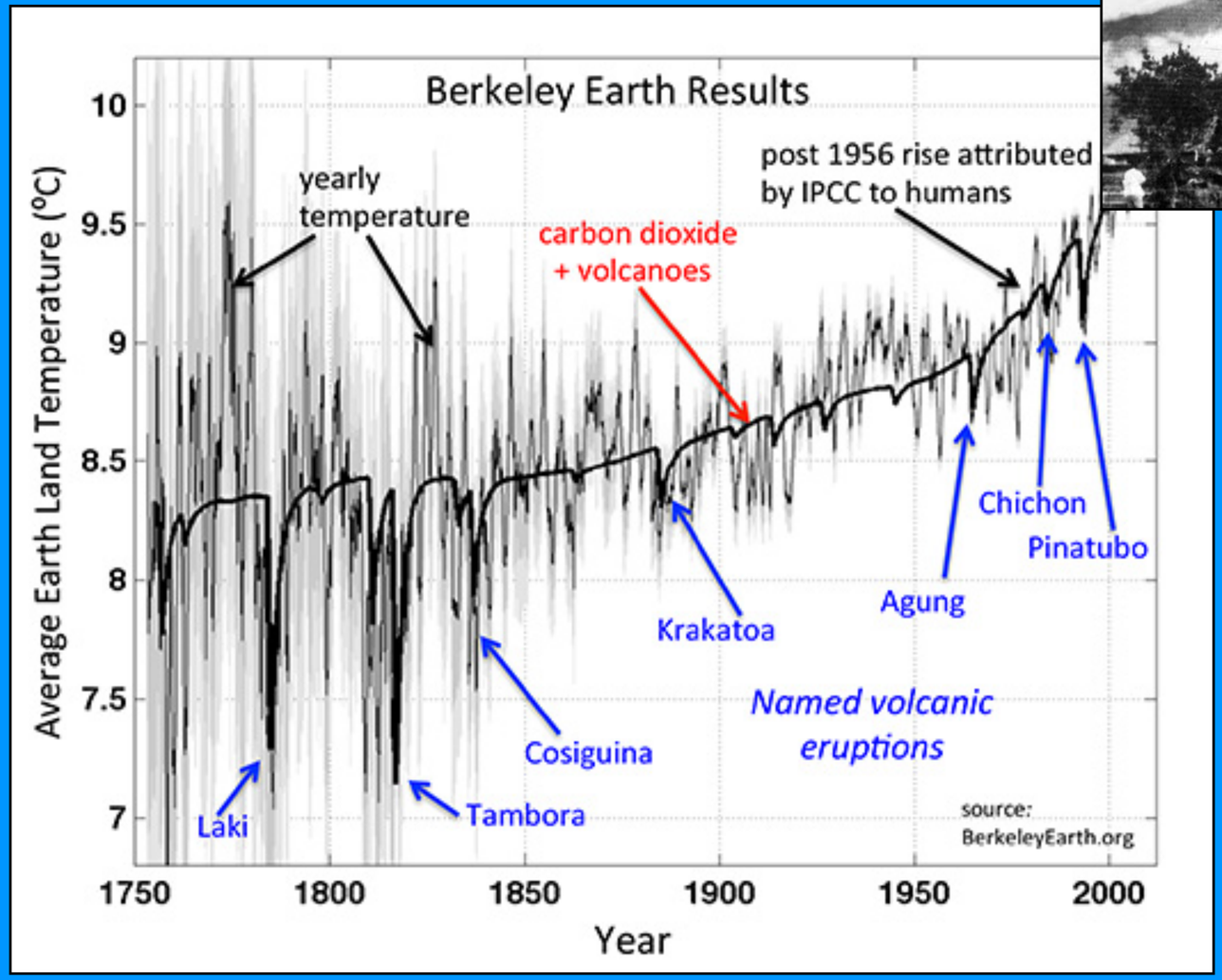




A natural laboratory for geologists and biologists

Agung 1963

Zen and Hadikusumo (1964)



The first 20th century eruption to produce a demonstrable effect on global temperatures

Stratospheric Temperature Change from the Mt. Agung Volcanic Eruption of 1963

REGINALD E. NEWELL

Dept. of Meteorology, Massachusetts Institute of Technology, Cambridge

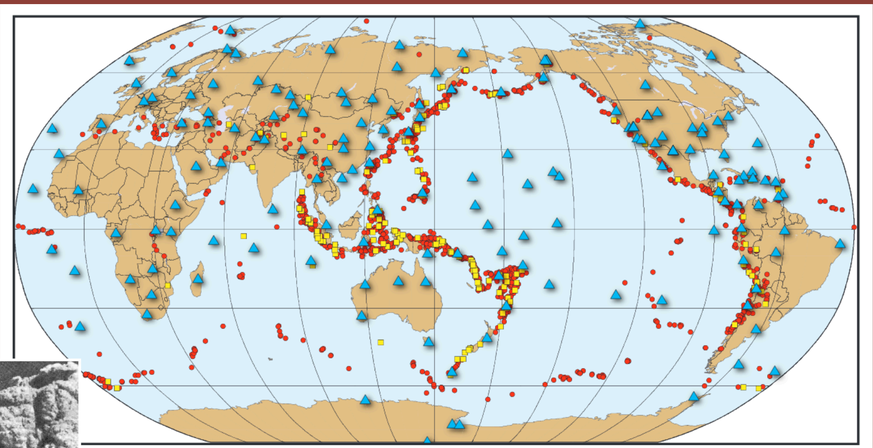
27 March 1970

Atmospheric turbidity after the agung eruption of 1963 and size distribution of the volcanic aerosol

Frederic E. Volz

First published: 20 September 1970 | https://doi.org/10.1029/JC075i027p05185 |

Some technological advances: 1940s-1960s

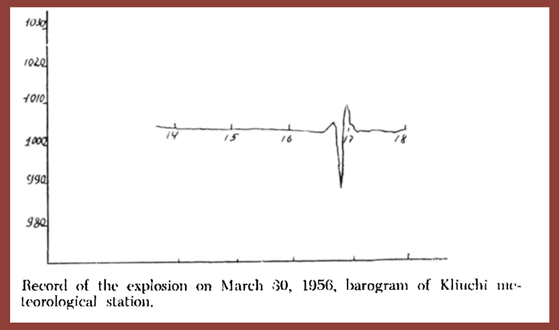


eismographic Network stations (triangles) are shown against a backdrop of large earthquakes
)0–2010 (red circles—magnitude 6–6.9, yellow squares—magnitude 7 and larger earthquakes).

World-Wide Network of Seismograph Stations
(WWNSS)

Developed in the 1960s as part of the limited test ban treaty

Lateral blast documented - Bezymianny 1956



Record of the explosion on March 30, 1956, barogram of Kliuchi meteorological station.

Gorshkov (1959)

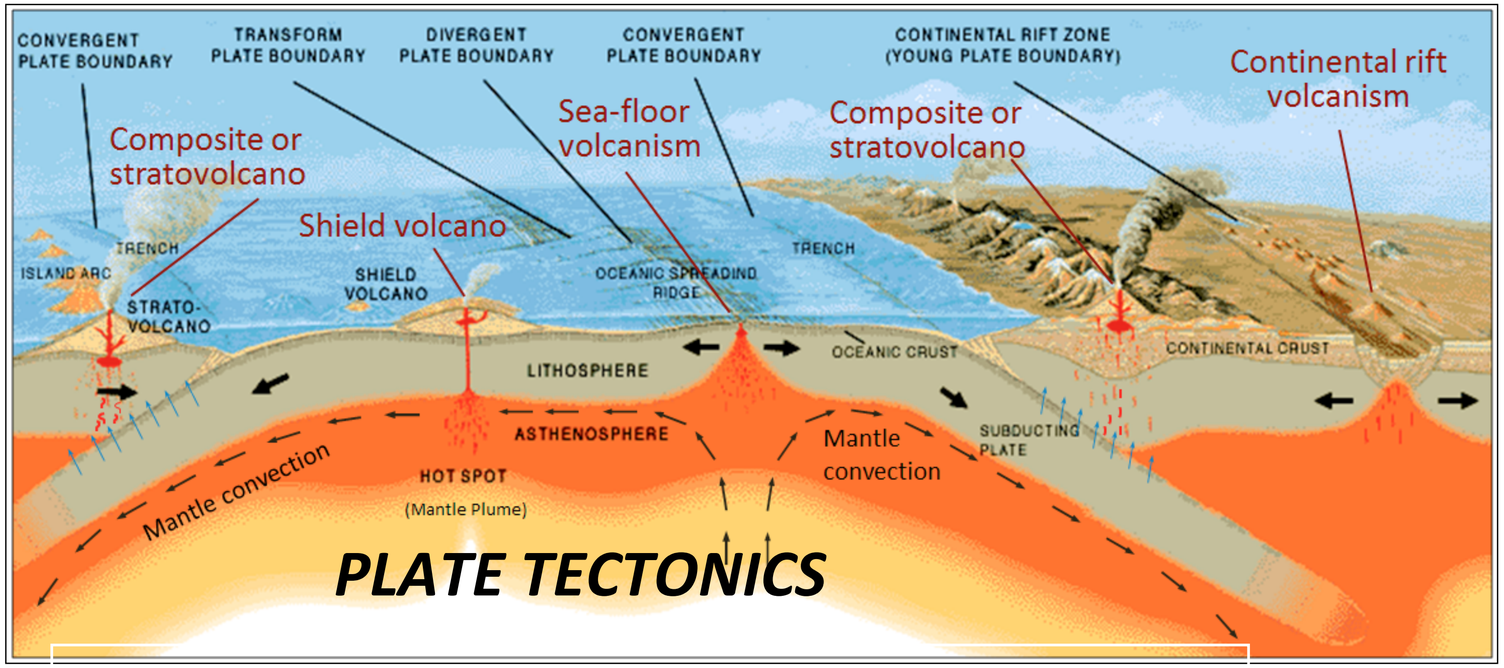
EPMA

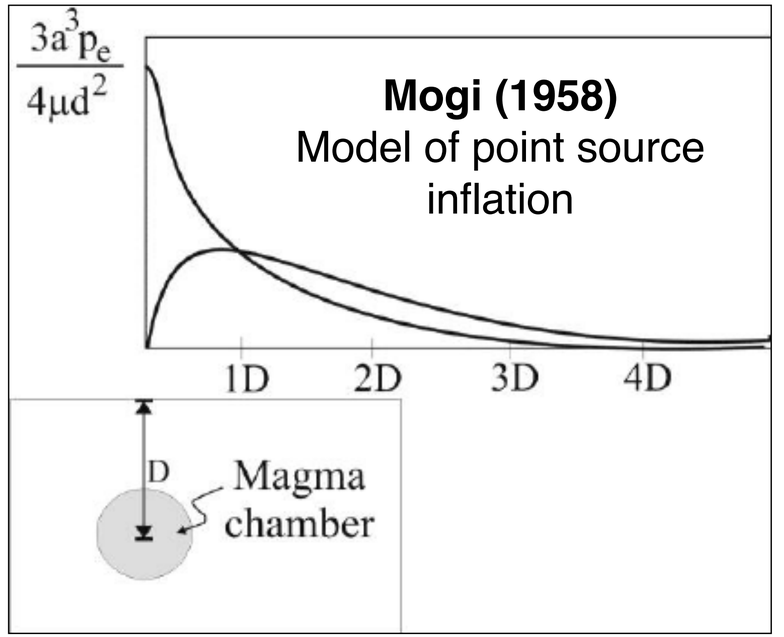
First commercial instrument constructed in 1956

Set the stage for thermobarometry

Surveys of the ocean floor

Some conceptual advances





Mogi (1958)
Model of point source inflation

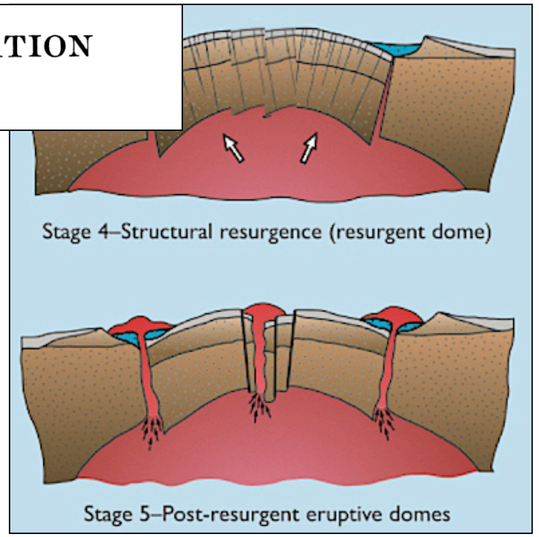
Plate Tectonics explained:

- Age progression of Hawaiian Islands (Macdonald 1953)

Williams (1953):
- Distribution of volcanoes in orogenic belts
- Source of magma
- Source of volatiles

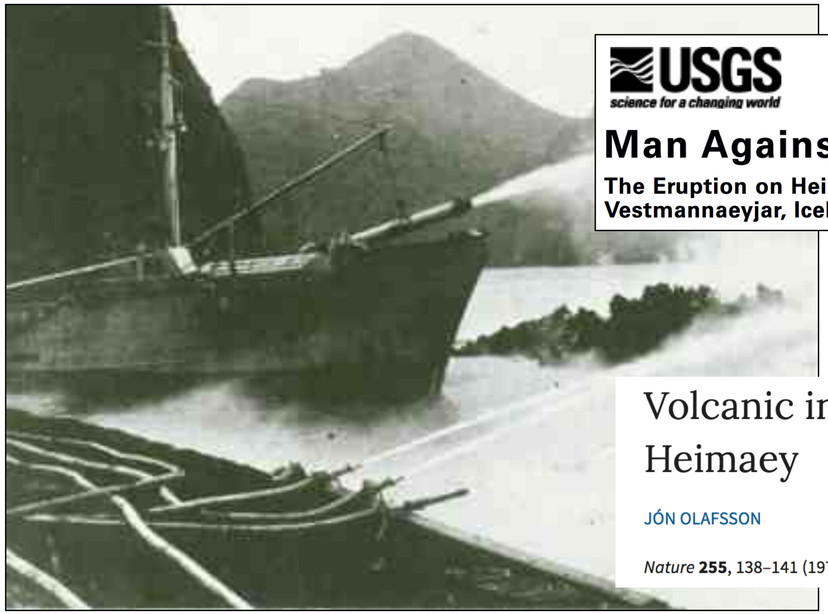
MECHANICS OF ASH FORMATION

J. VERHOOGEN



Smith & Bailey (1968)
Caldera resurgence

Heimaey 1973



USGS
science for a changing world

Man Against Volcano:
The Eruption on Heimaey, Vestmannaeyjar, Iceland

Known primarily for lava flow diversion but also inspired a diverse range of investigations

Volcanic influence on seawater at Heimaey (1975)

JÓN OLAFSSON

Nature **255**, 138–141 (1975) | Download Citation

The 1973 Heimaey Strombolian Scoria deposit, Iceland (1974)

S. Self [a1], R. S. J. Sparks [a2], B. Booth [a2] and G. P. L. Walker [a2]

Strontium Isotopes and Rare Earth Elements in Basalts from the Heimaey and Surtsey Volcanic Eruptions (1973)

R. K. O'NIONS, R. J. PANKHURST, I. B. FRIDLEIFSSON & S. P. JAKOBSSON

Nature **243**, 213–214 (1973) | Download Citation

Composition of Atmospheric Particulate Matter from the Eruption of Heimaey, Iceland

Mroz and Zoller (1975)

Petrology of mugearite-hawaiite: Early extrusives in the 1973 Heimaey eruption, Iceland (1973)

S.P. Jakobsson [a], A.K. Pedersen [b], J.G. Rönsbo [c], L. Melchior Larsen [d]

Fuego 1974

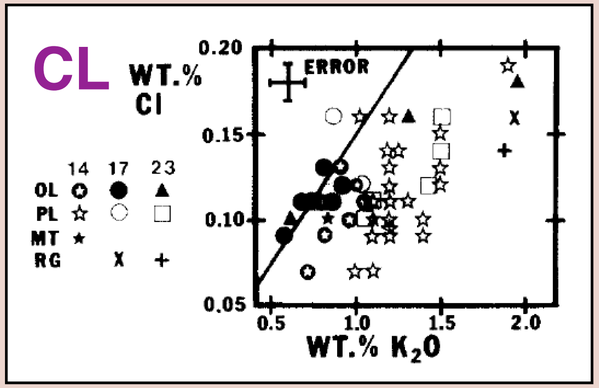
THE OCTOBER 1974 BASALTIC TEPHRA FROM FUEGO VOLCANO: DESCRIPTION AND HISTORY OF THE MAGMA BODY

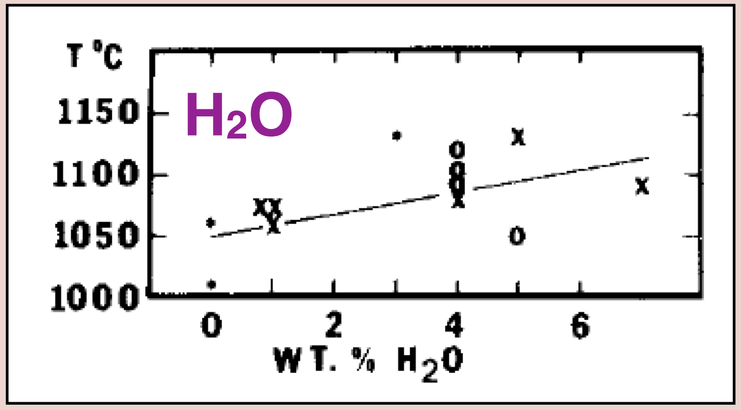
WILLIAM I. ROSE, Jr.[1],*, ALFRED T. ANDERSON, Jr.[2], LAUREL G. WOODRUFF[1],** and SAMUEL B. BONIS[3]

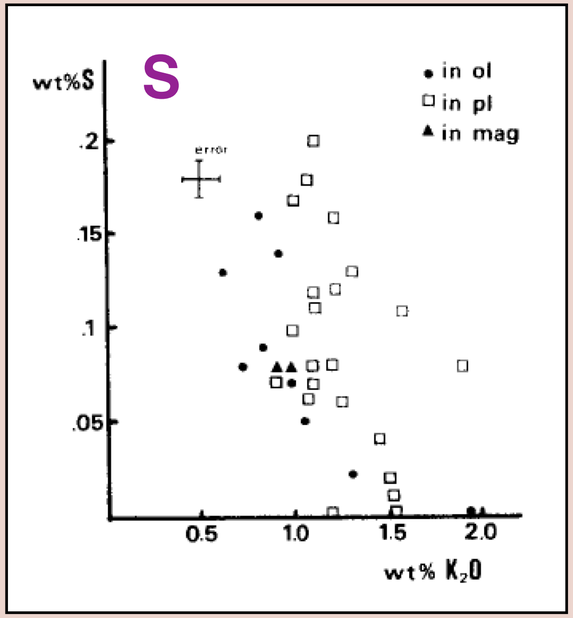
[1] *Michigan Technological University, Houghton, Mich. 49931 (U.S.A.)*
[2] *University of Chicago, Chicago, Ill. 60637 (U.S.A.)*
[3] *Instituto Geográfico Nacional, Guatemala City (Guatemala)*

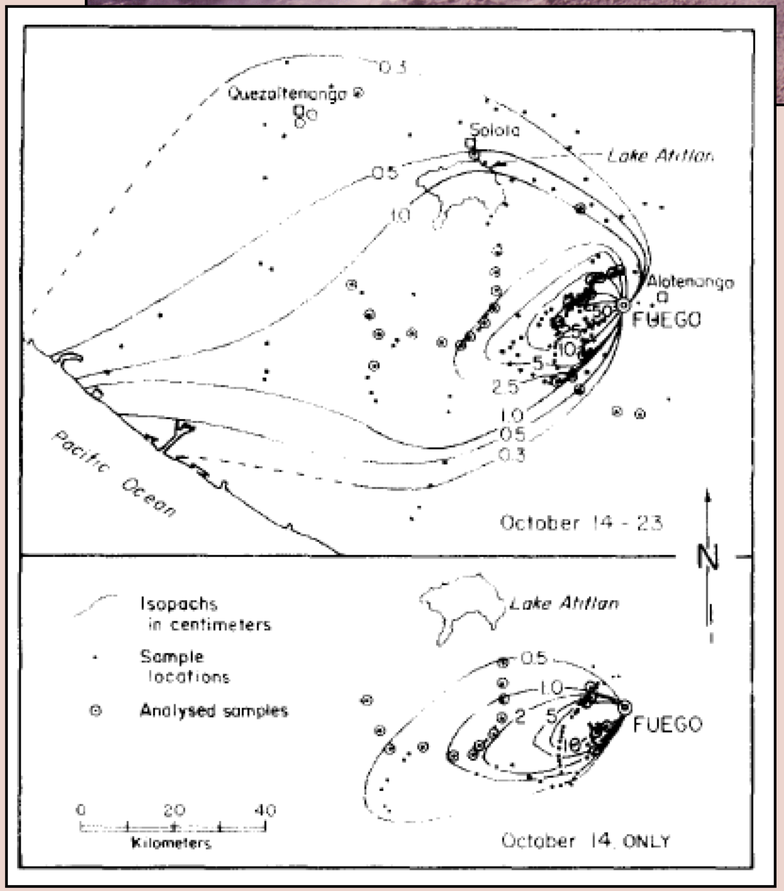
(Revised and accepted February 23, 1978)

Multi-disciplinary study of a volcanic eruption *including* measurements of volatiles in melts



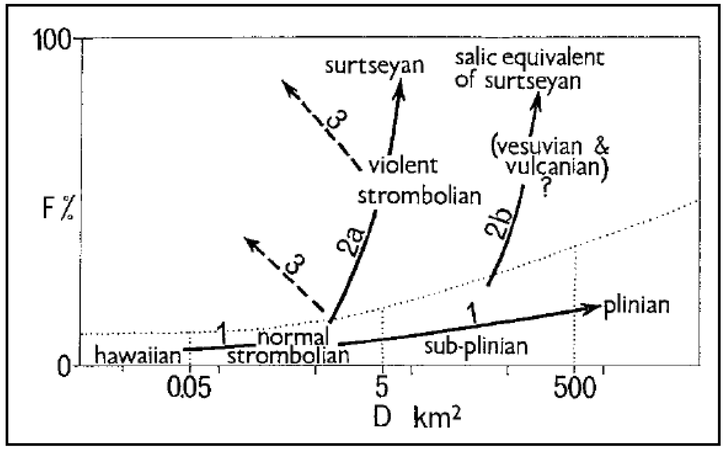






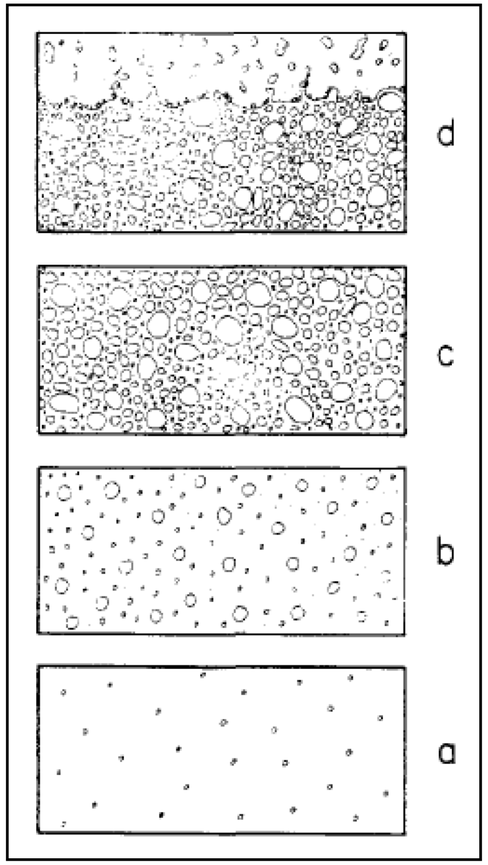
Conceptual advances of the 1970s:
Quantifying approaches to physical volcanology

PYROCLASTIC DEPOSITS



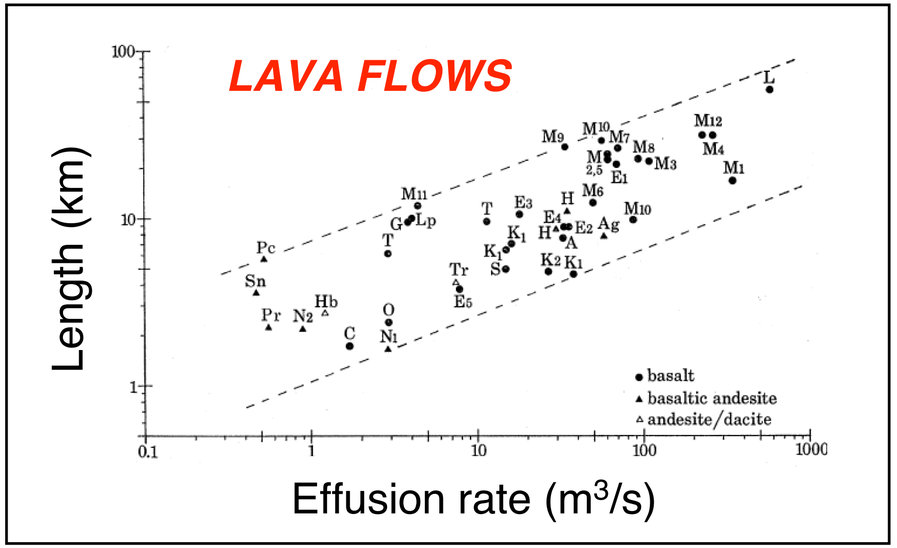
Walker (1973)

FRAGMENTATION



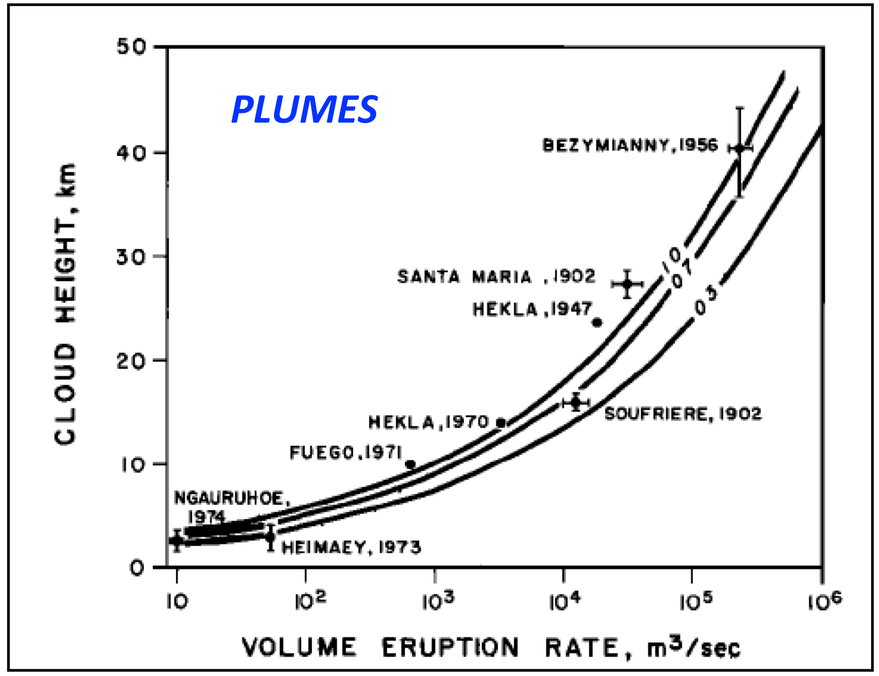
Sparks (1978)

LAVA FLOWS



Walker et al. (1973)

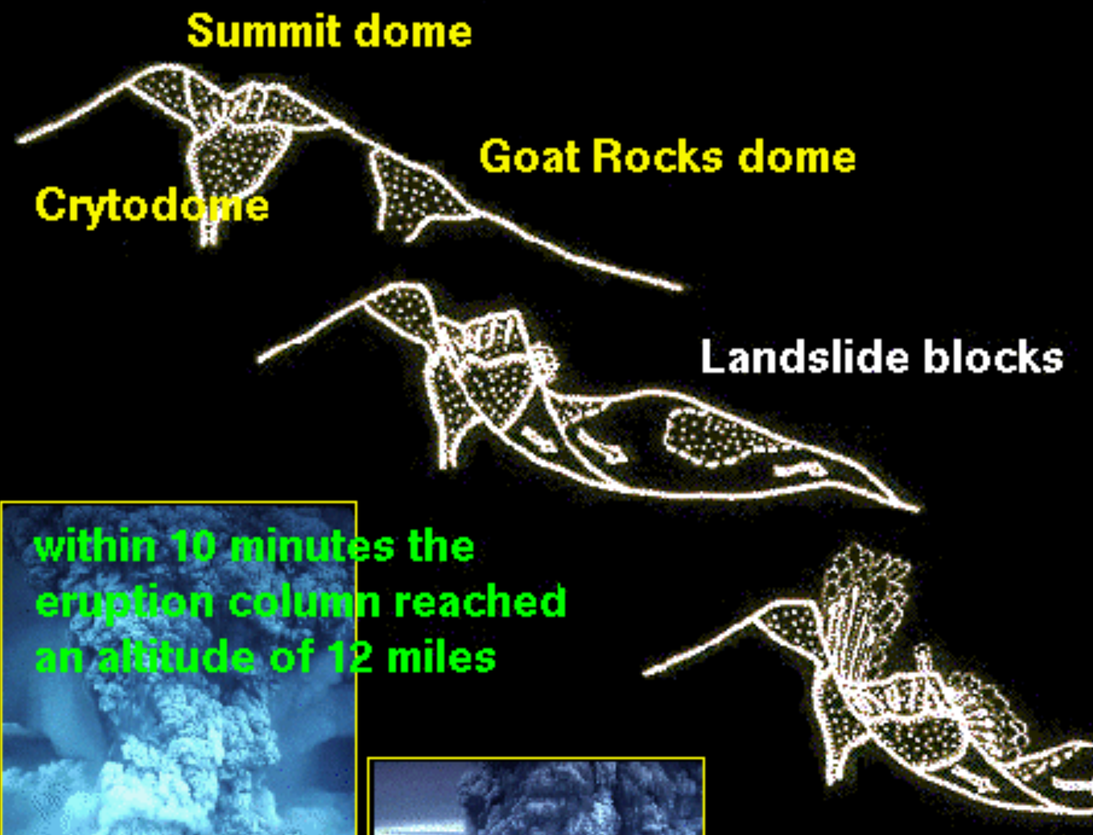
PLUMES



Wilson et al. (1978)

Mount St. Helens May 18, 1980 Eruption Sequence

At 8:32 a.m., May 18, 1980, a 5.1 earthquake shook loose the north flank of Mount St. Helens, resulting in the largest known landslide in historic time. Removal of more than half a cubic mile of material released pressure and triggered a devastating lateral blast and ash-laden eruptive column.



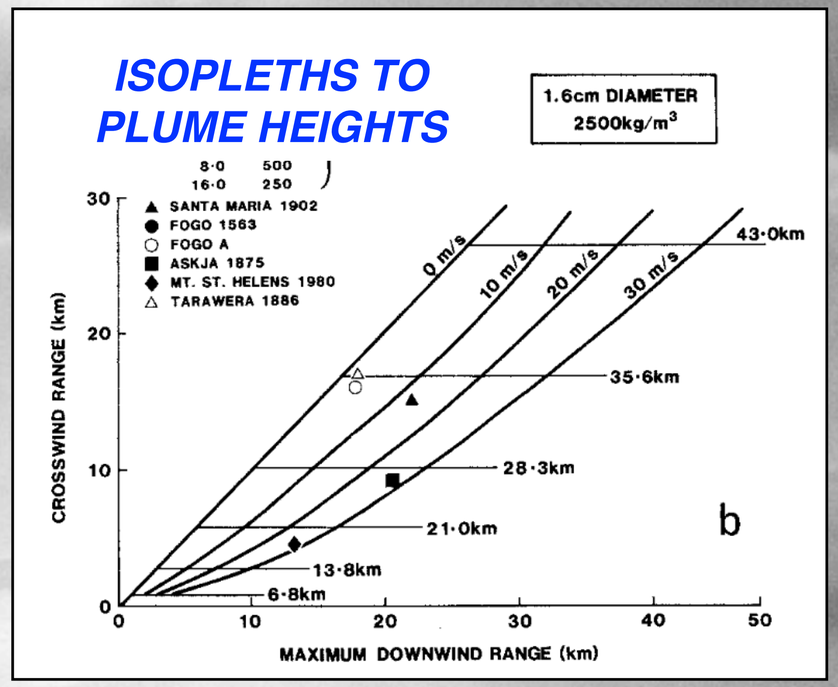
within 10 minutes the eruption column reached an altitude of 12 miles

USGS Photos by A.Post (left) and D.Swanson (right)

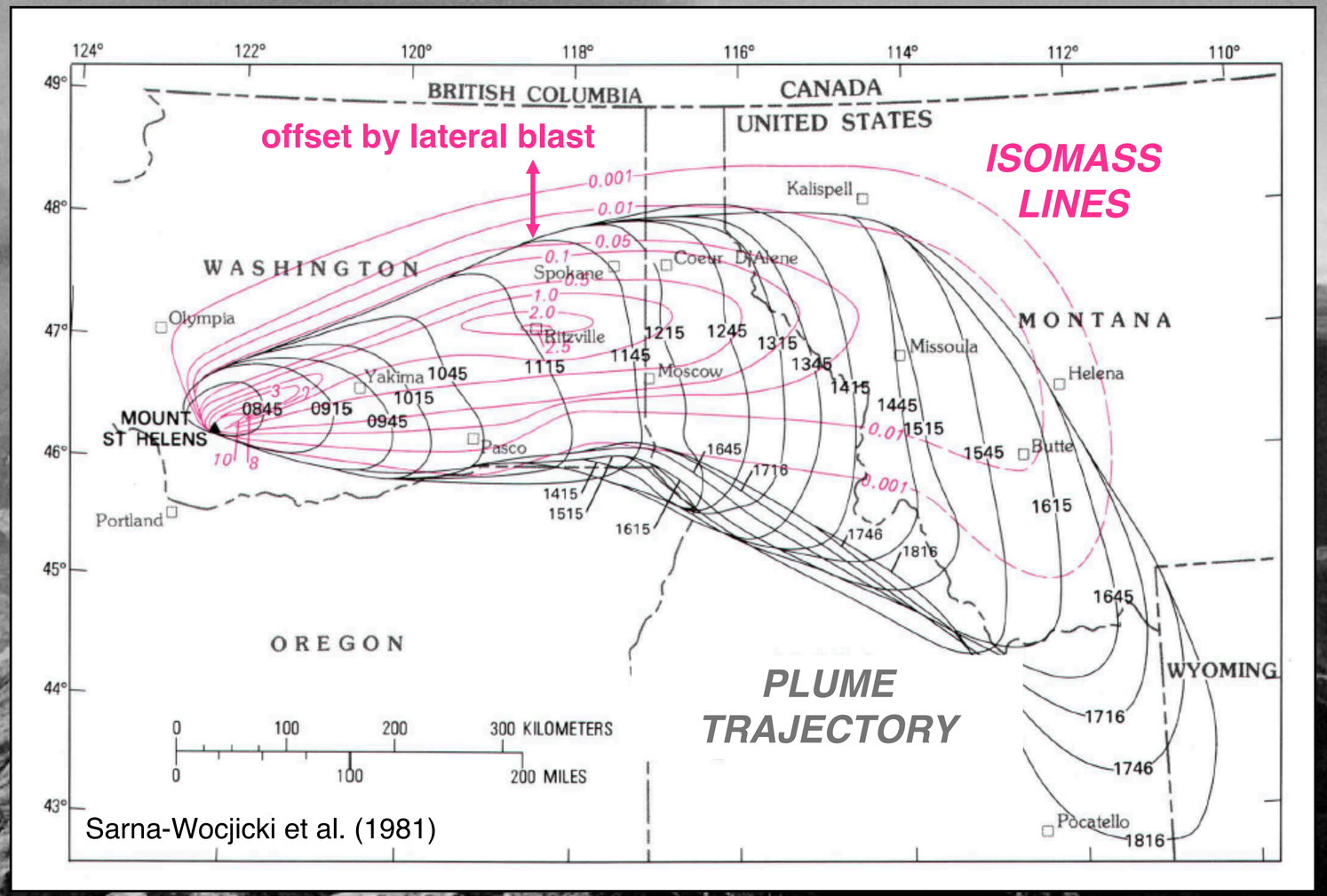
USGS

Topinka, USGS/CVO, 1998, Modified from: Brantley and Topinka, 1984, Earthquake Information Bulletin v.16, no.2

Satellite observations combined with rapid mapping allowed testing of new plume models

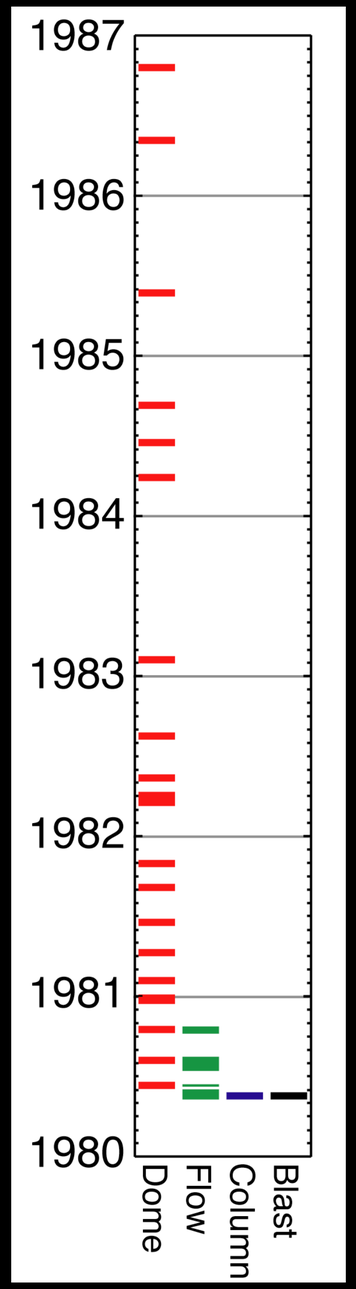


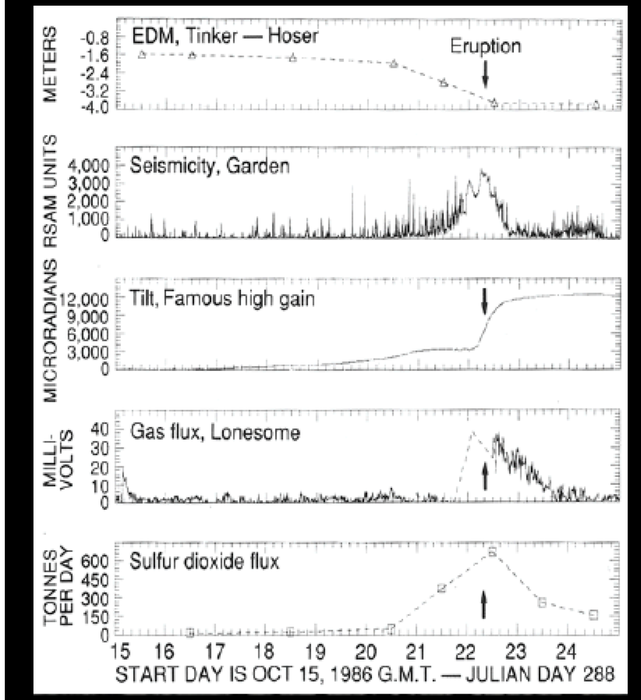
Carey and Sparks (1986)



Sarna-Wocjicki et al. (1981)

Monitoring activity 1980-1986

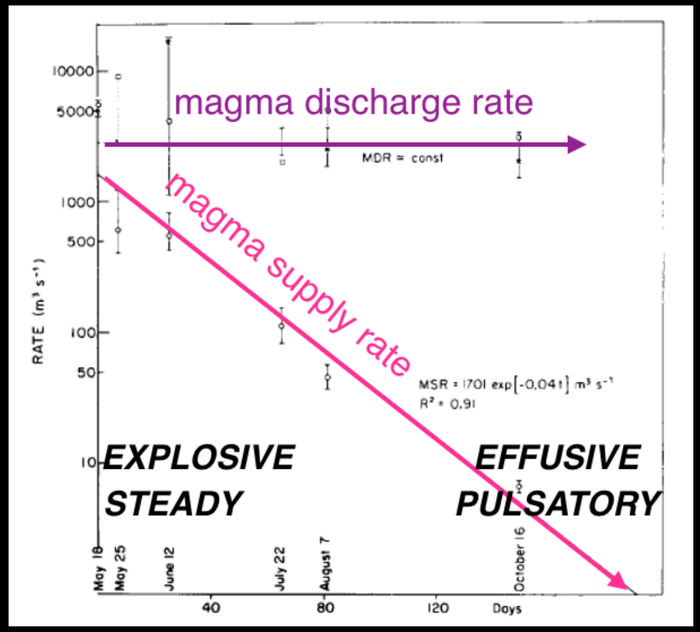




Swanson et al. (1985)

Accurate predictions of dome-building events

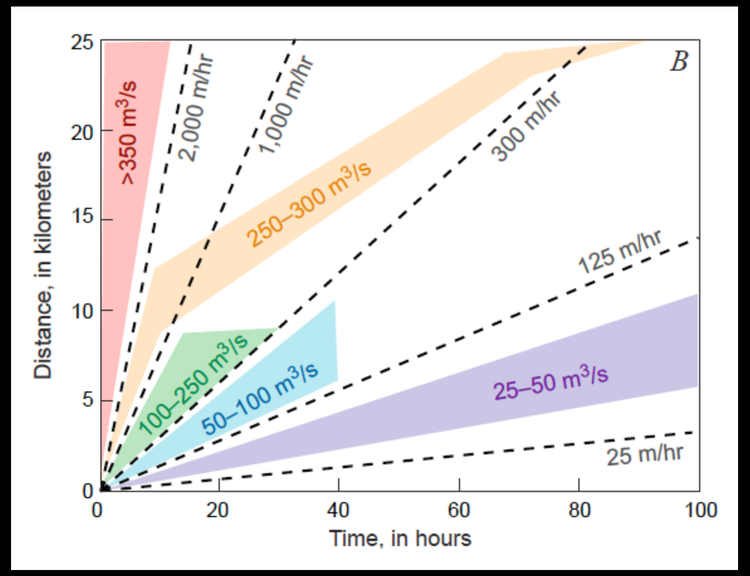
New insights into eruption transitions

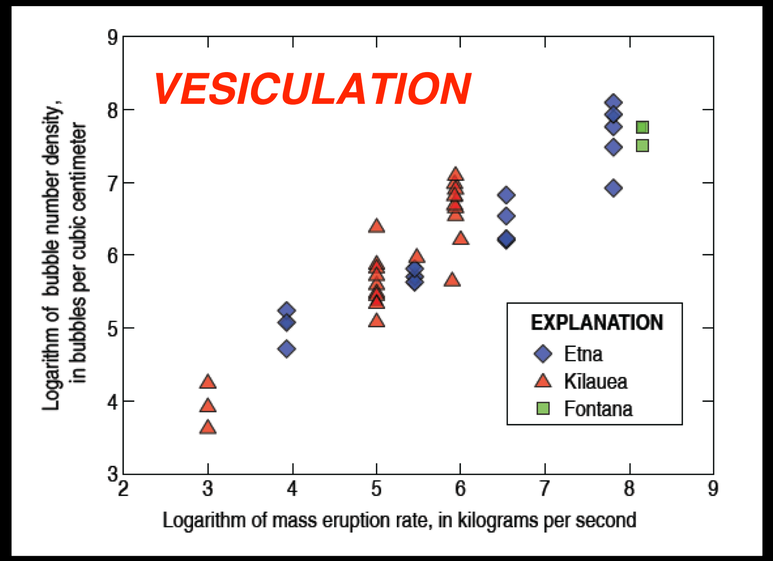


Scandone and Malone (1985)

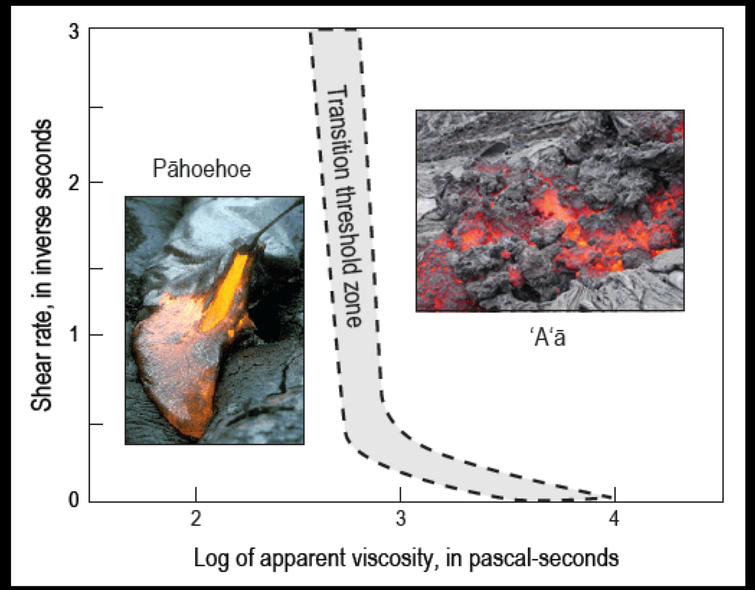
Kilauea and Mauna Loa

LAVA FLOW ADVANCE





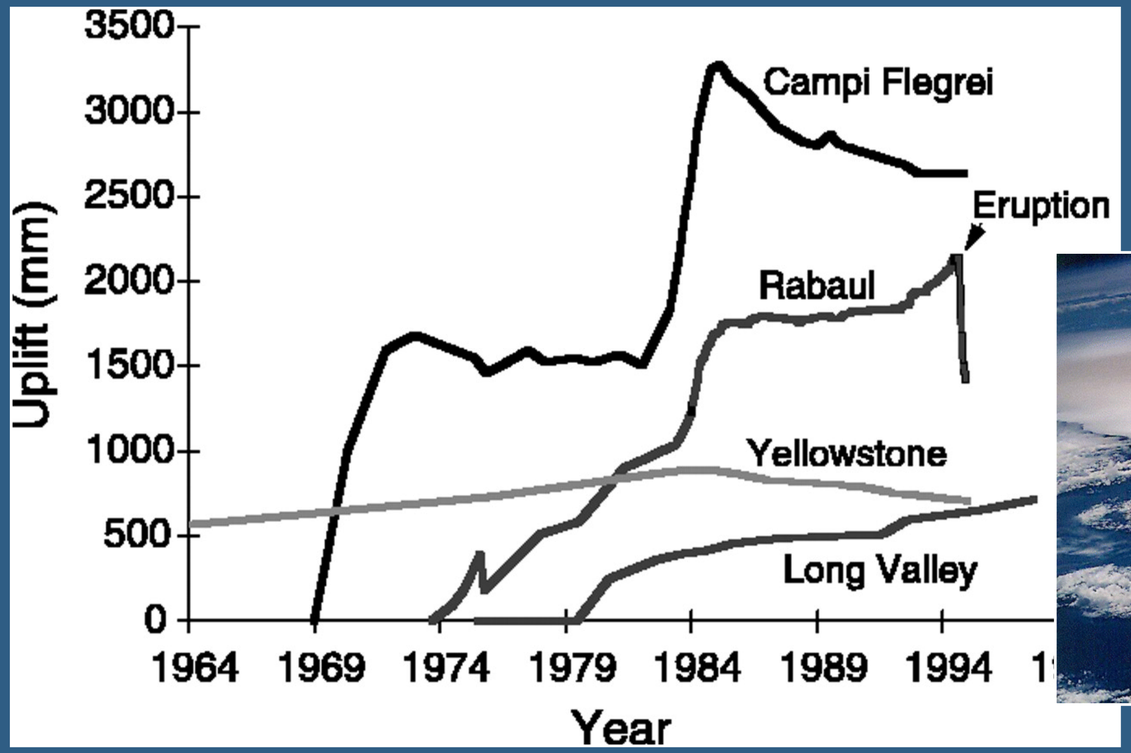
PAHOEHOE-AA TRANSITION



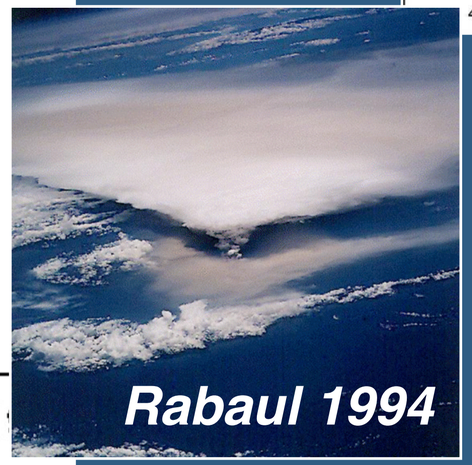
Cashman & Mangan (2014); Mangan et al. (2014)

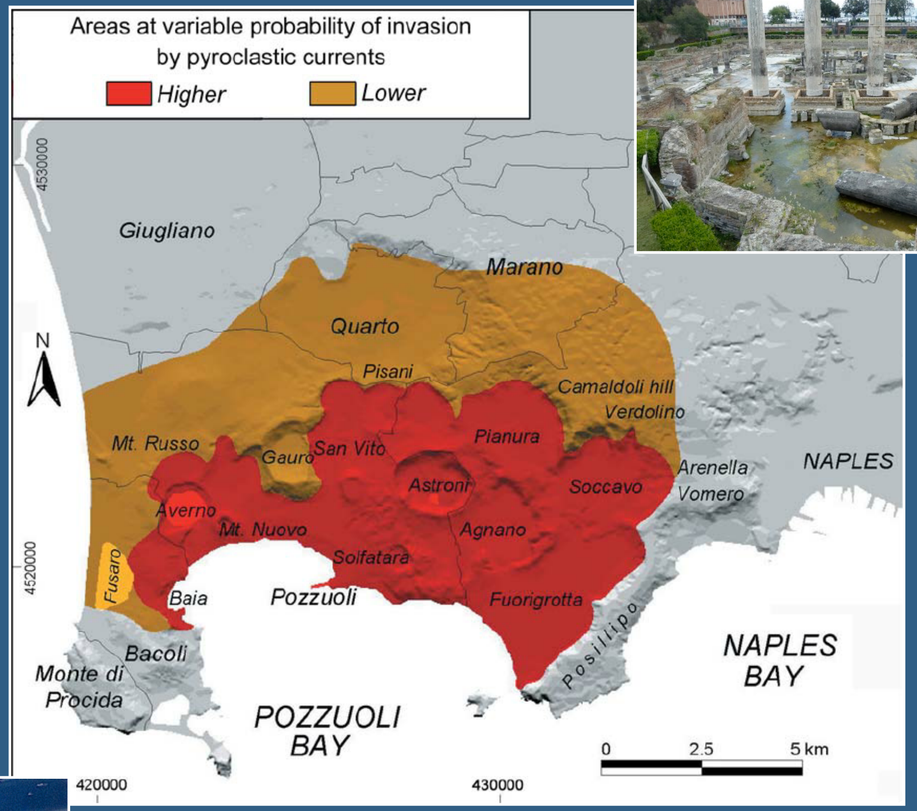
Restless calderas

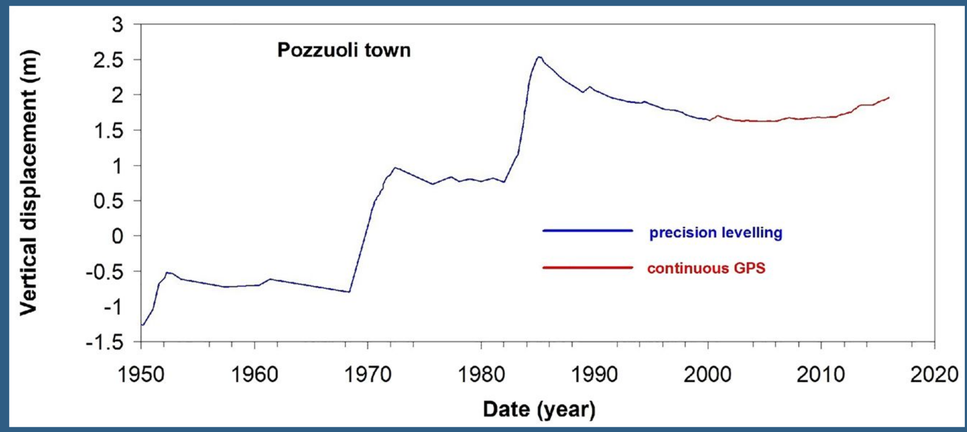
The 1980s identified restlessness (seismicity, deformation) at several calderas around the world…
only one erupted



Battaglia et al. (1999)



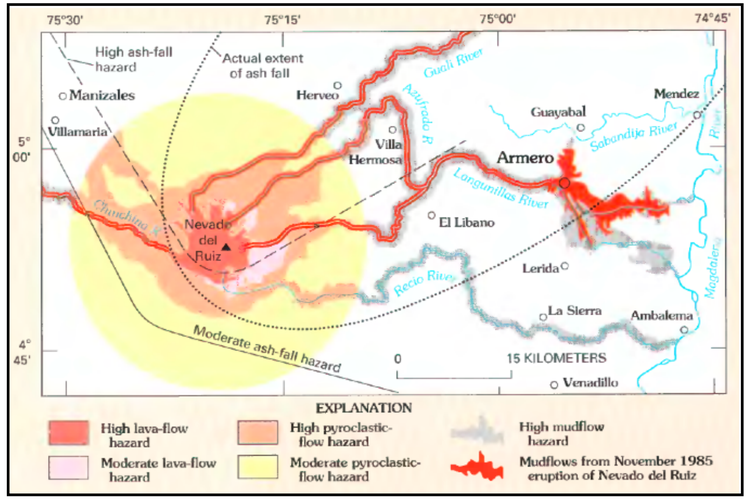




Moretti et al. (2018)

A focus on hazards: lahars and civil aviation

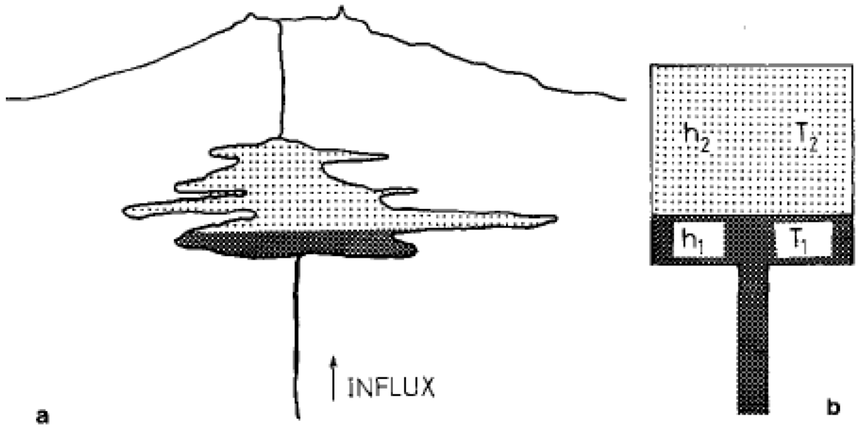
As with the 1902 eruption of Mont Pelee, the loss of life during this event shocked the global volcanology community and prompted, among other things, the USGS VDAP program

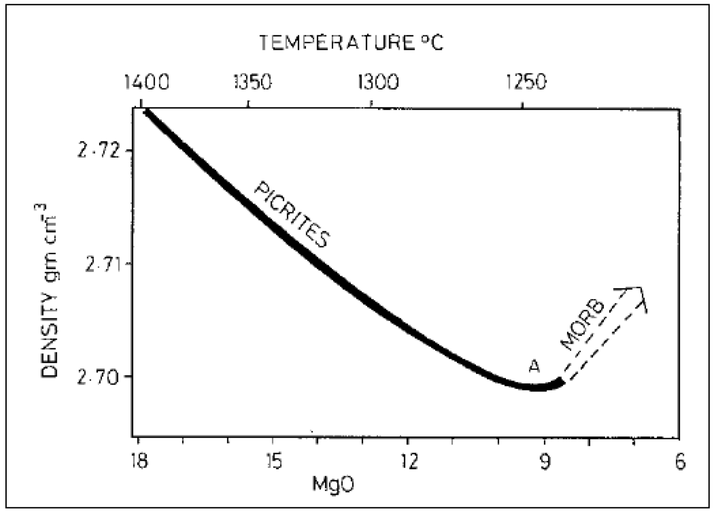


The 1980s also saw an increase in ash-aircraft encounters (Galunggung 1982; Redoubt 1989)

Conceptual models of the 1980s:
Applications of geophysical fluid dynamics to volcanoes

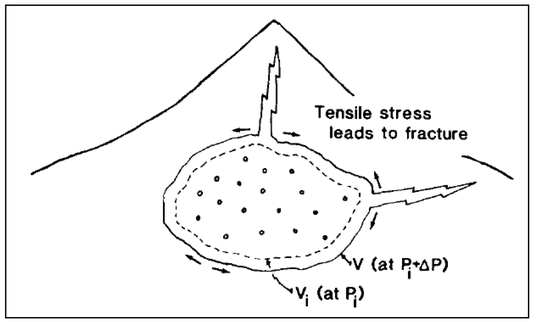
MAGMA CHAMBER PROCESSES



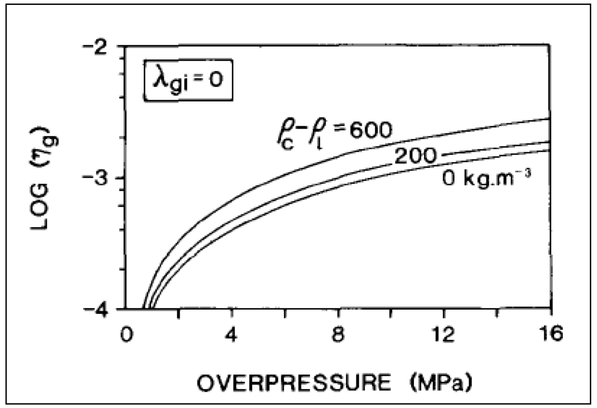


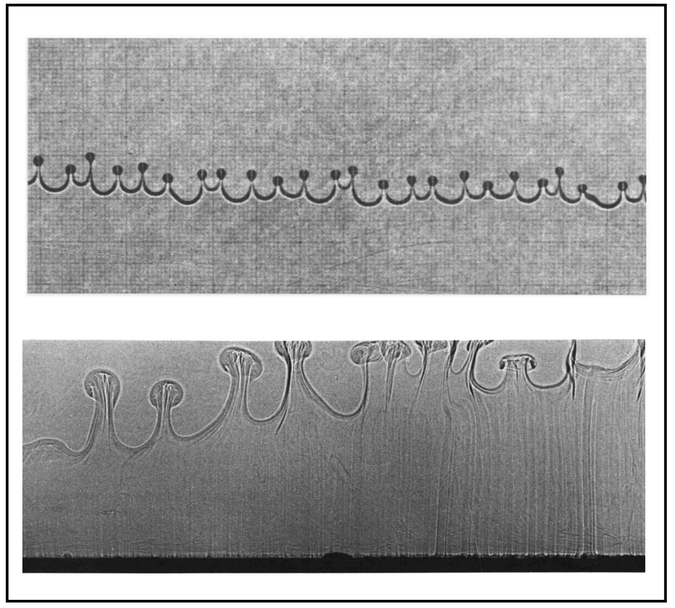
Huppert and Sparks (1981)

ERUPTION TRIGGERS



Tait et al. (1989)

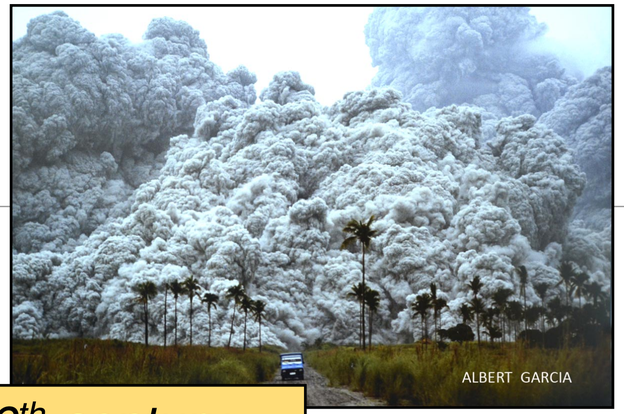




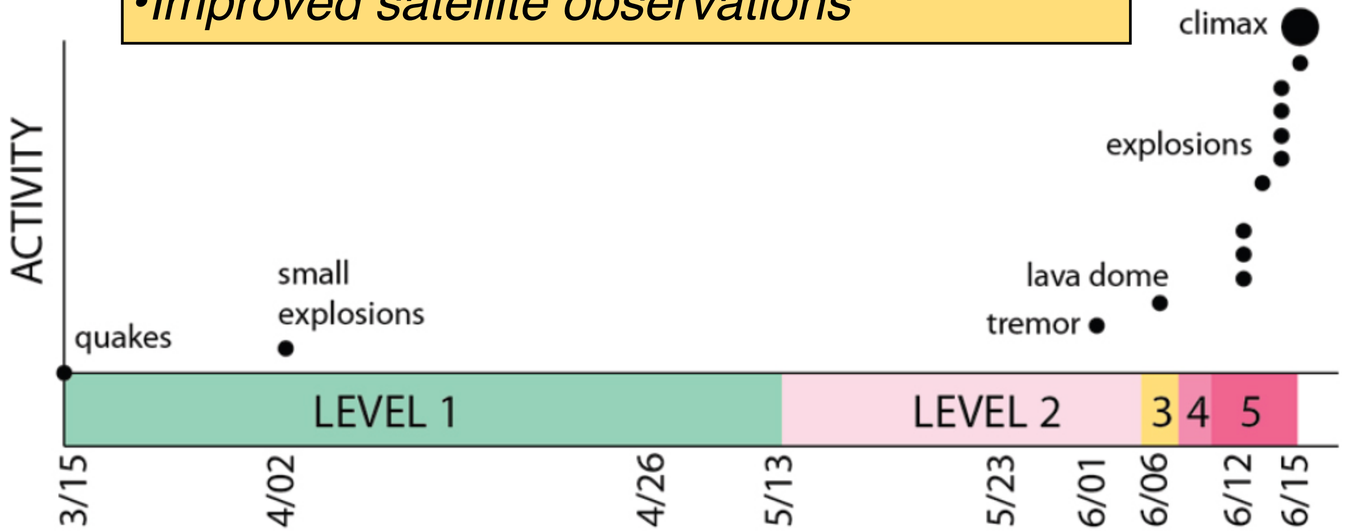
Kerr and Lister (1988)

PLUMES AS R-T INSTABILITIES

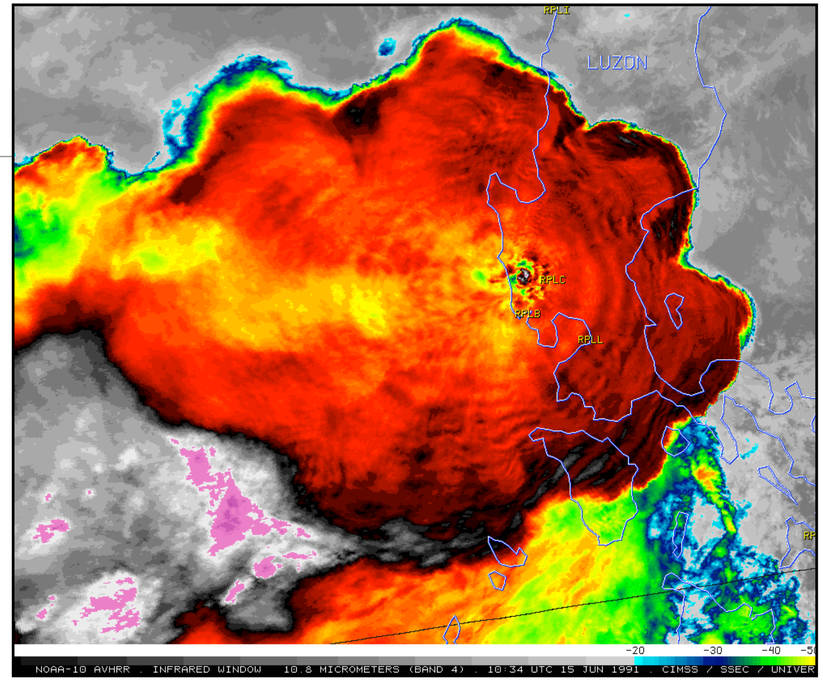
Pinatubo 1991

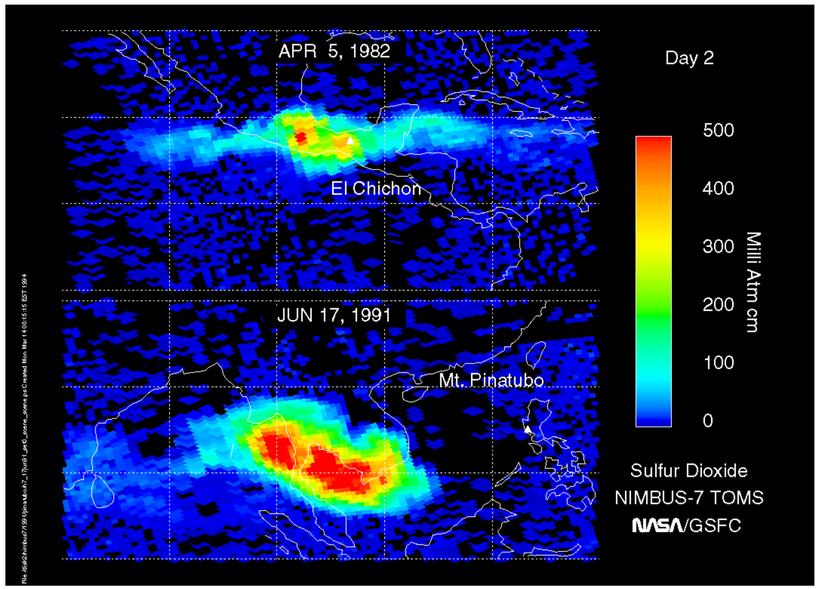


- *Third largest eruption of the 20th century*
- *Successful prediction and evacuation*
- *Improved satellite observations*

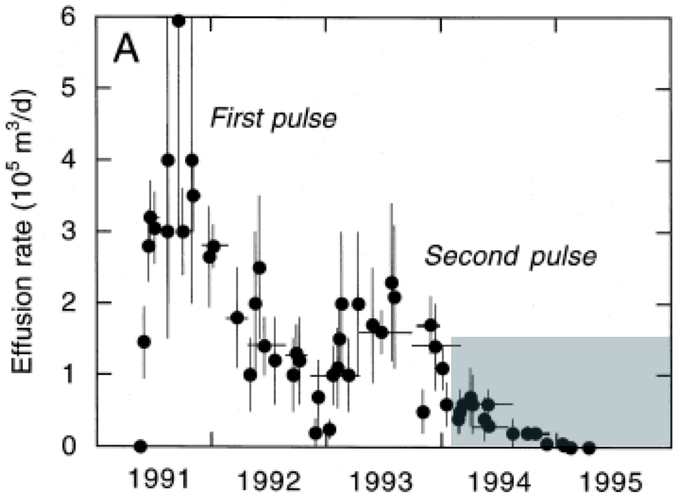


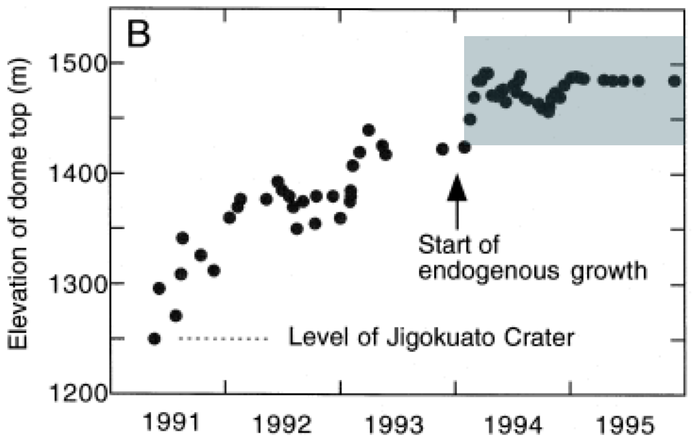
6/05 – 10,000 evacuated
6/09 – 20 km zone, 25,000 evacuated
6/10 – 40,000 evacuated
6/12 – 30 km evacuation zone
6/14 – 40 km zone, 65,000 evacuated
6/15 – eruption climax

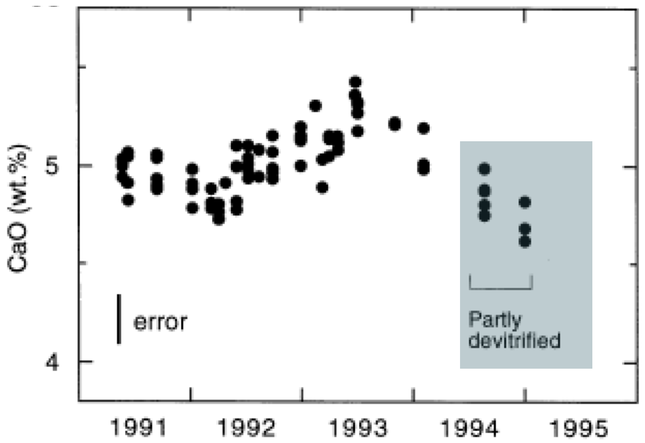




Dome-building eruptions: Unzen and Soufriere Hills, Montserrat



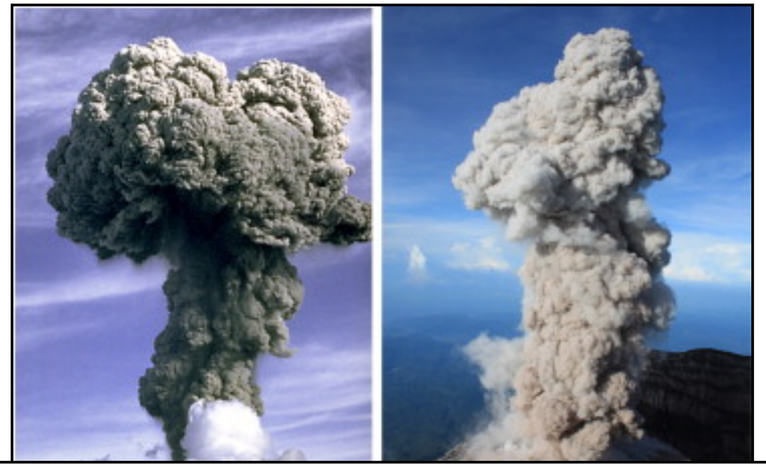




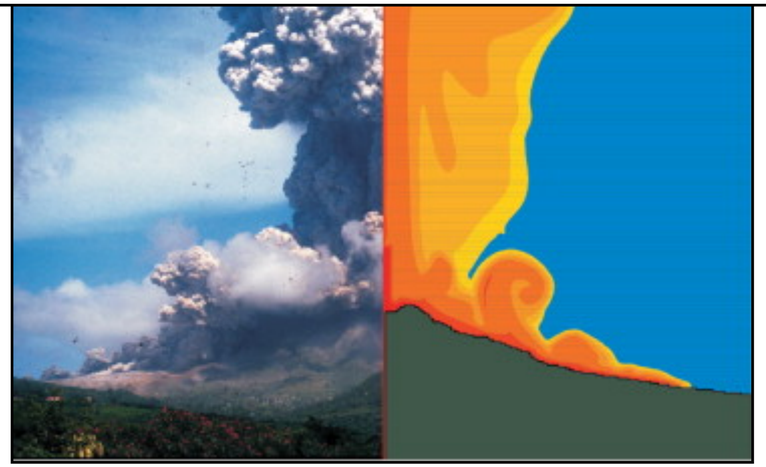
Nakada and Motumura (1995)

UNZEN

Detailed observations of the physical and chemical properties of the dome as a function of time

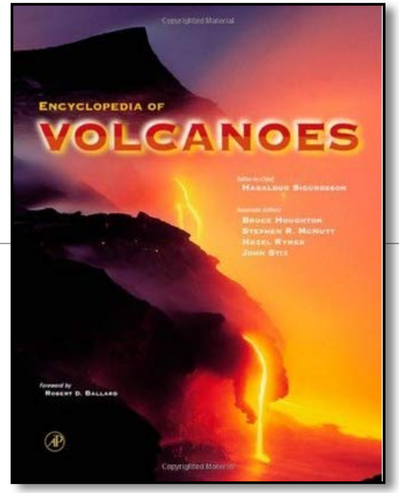


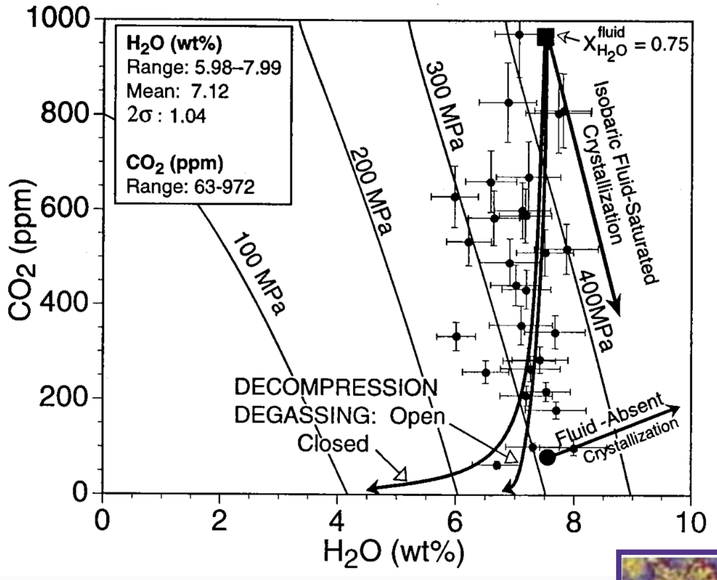
New insight into Vulcanian eruption cycles



Clarke et al. (2015)

New insights from new measurements

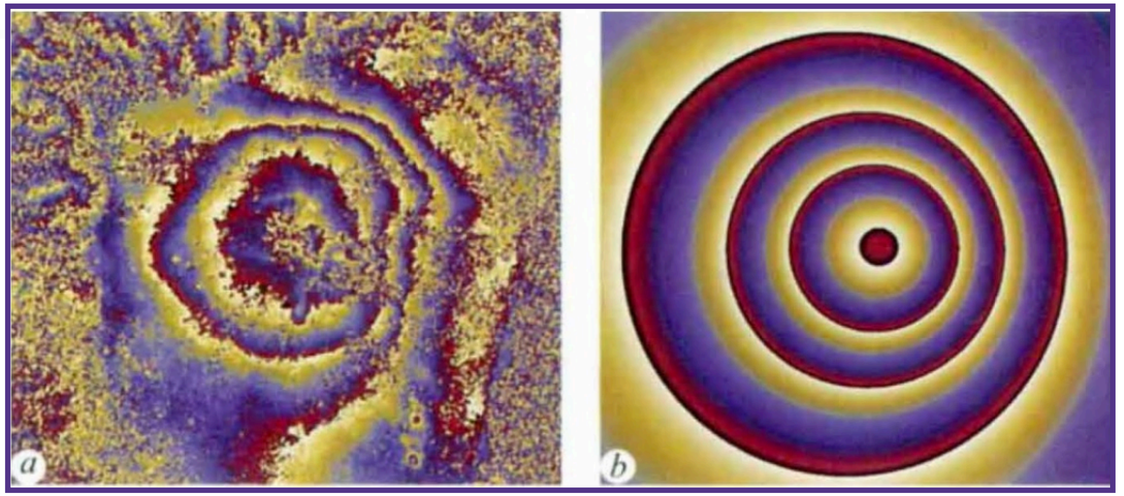




Lowenstern (1994)

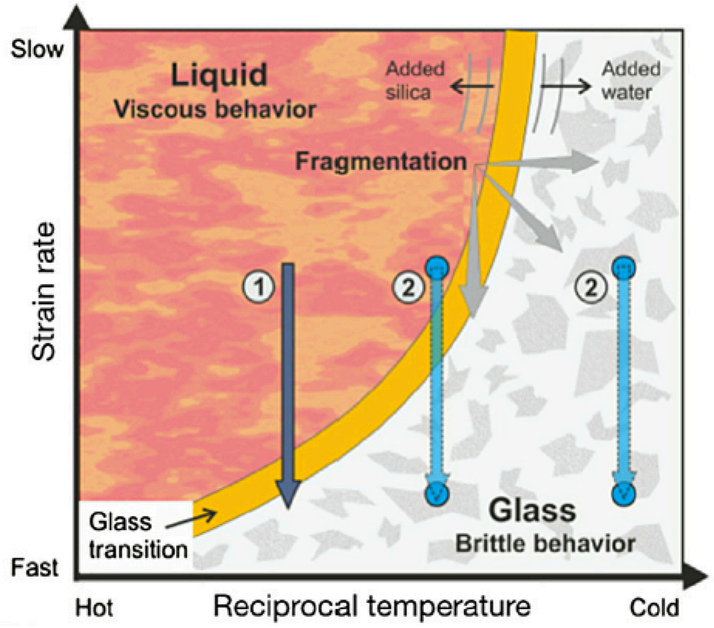
Volatile analyses of melt inclusions track decompression paths

InSAR provides a new way to measure volcano deformation



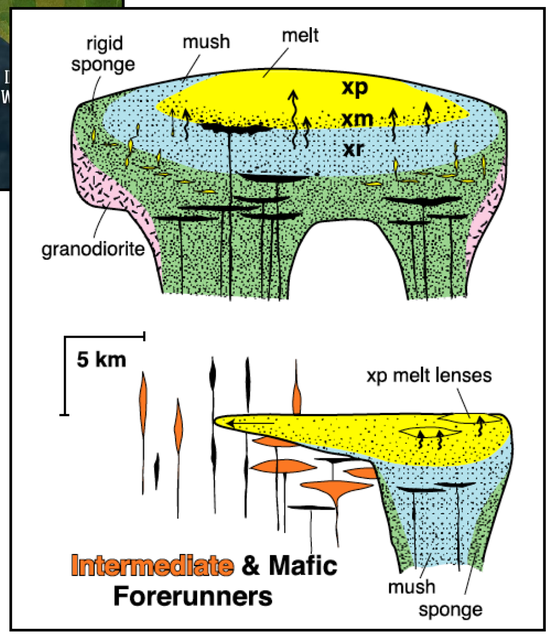
Massonet et al. (1995)

Experimental volcanology constrains melt properties



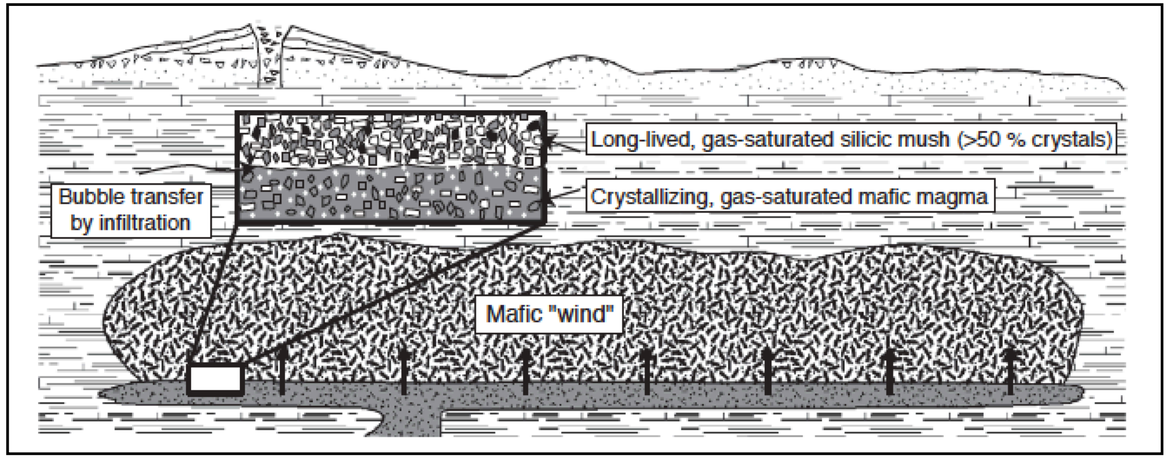
modified from Dingwell (1996)

Supervolcano eruptions



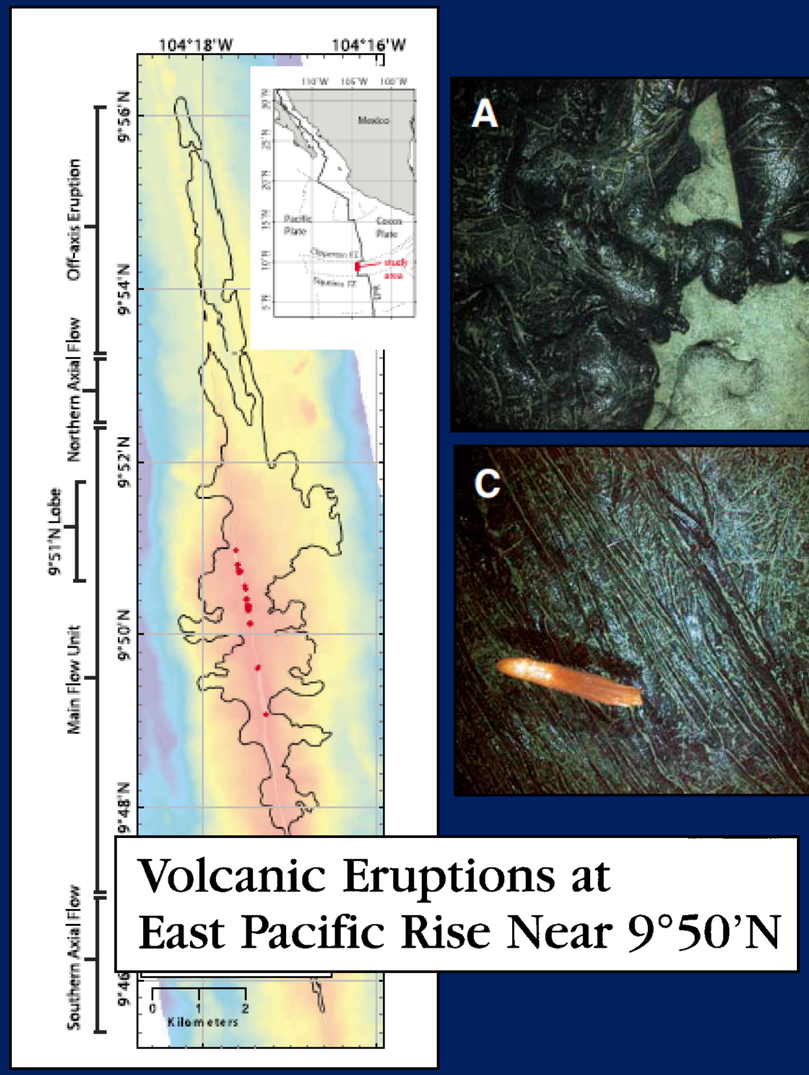
Hildreth (2004)

The early 21st century saw the onset of super volcano hysteria, but also advances in conceptual models for generating large volumes of both crystal-poor and crystal-rich magma



Bachmann & Bergantz (2006)

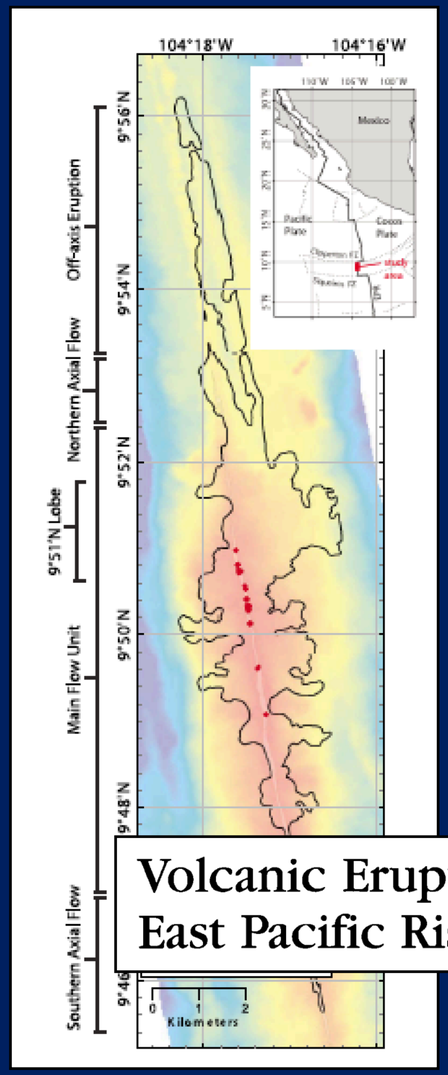
Volcanoes in the ocean



Volcanic Eruptions at
East Pacific Rise Near 9°50'N

Soule et al. (2007)

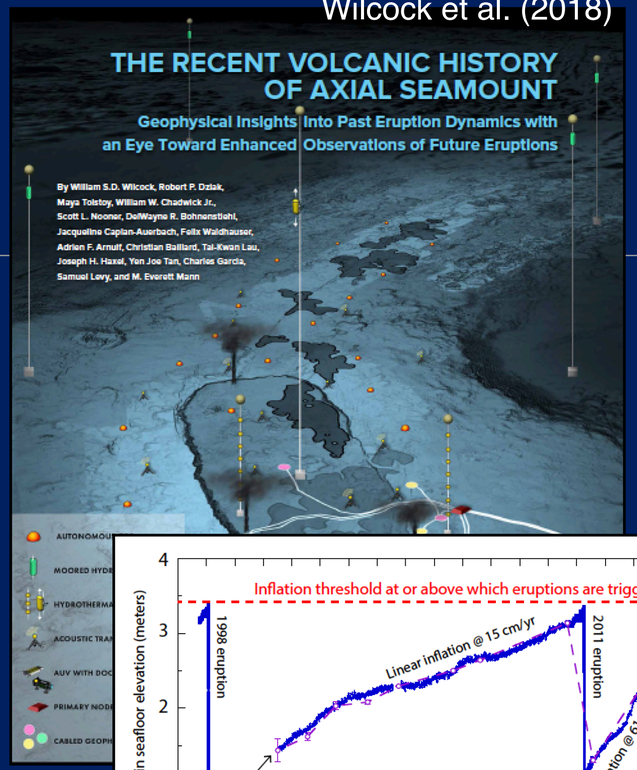
Volcanoes in the ocean



Soule et al. (2007)

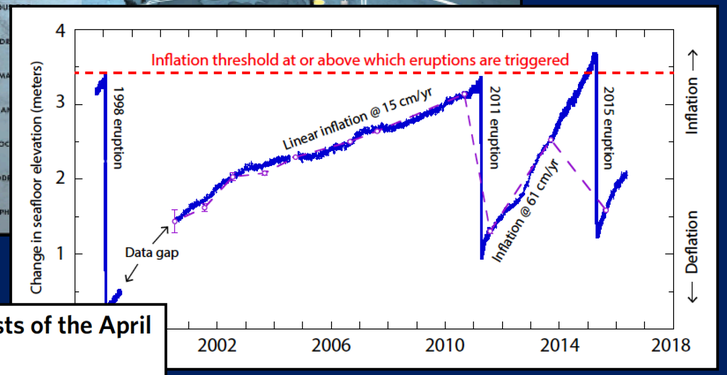
Volcanic Eruptions at East Pacific Rise Near 9°50'N

Wilcock et al. (2018)

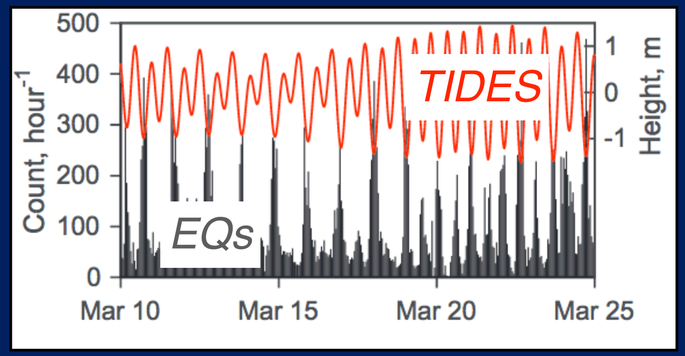


Seafloor deformation and forecasts of the April 2011 eruption at Axial Seamount

William W. Chadwick Jr[1]*, Scott L. Nooner[2], David A. Butterfield[3] and Marvin D. Lilley[4]

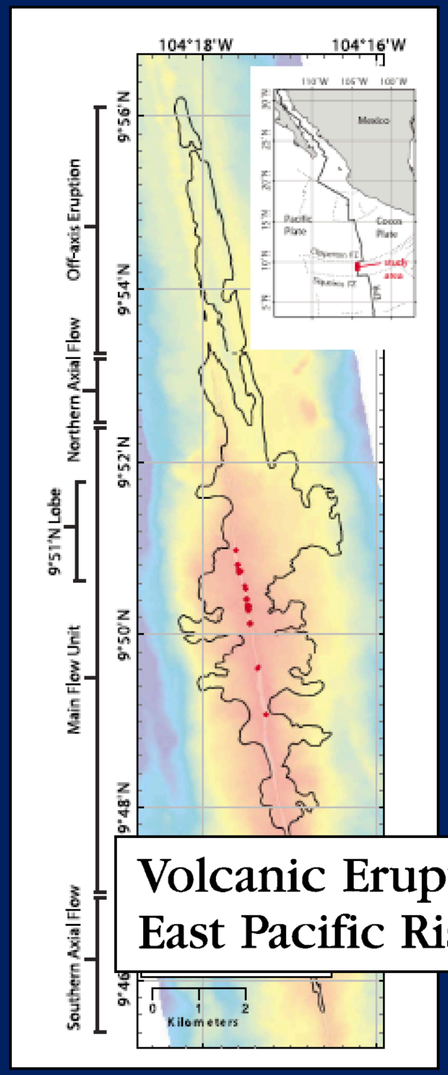


Nooner and Chadwick (2016)



Wilcock et al. (2016)

Volcanoes in the ocean



Soule et al. (2007)

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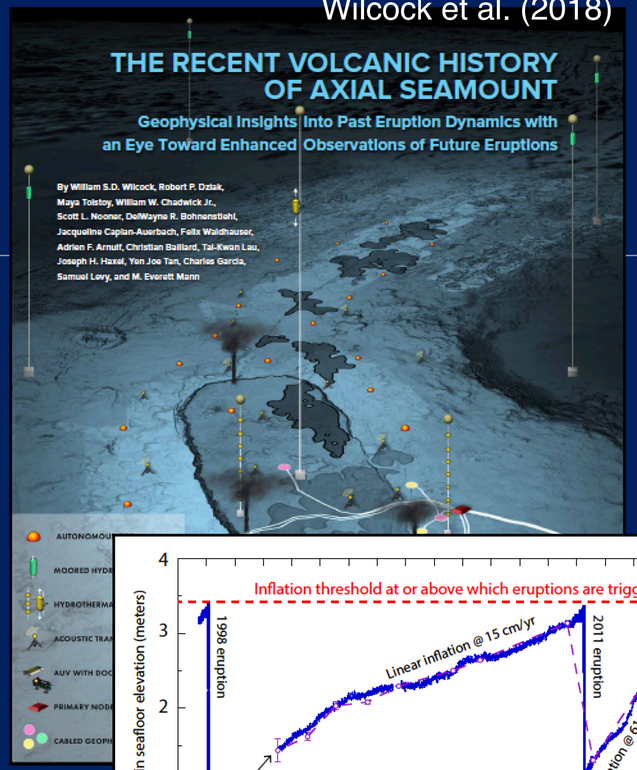

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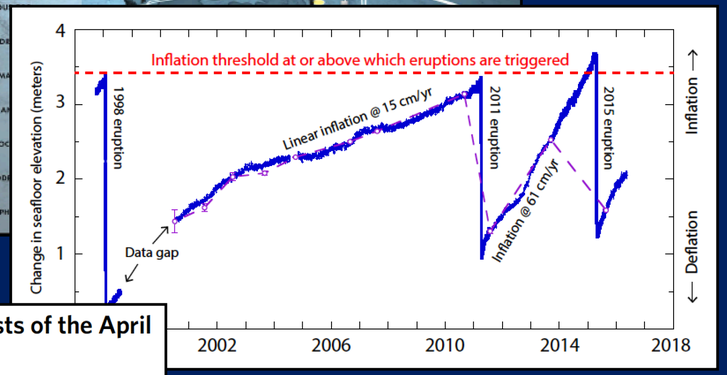
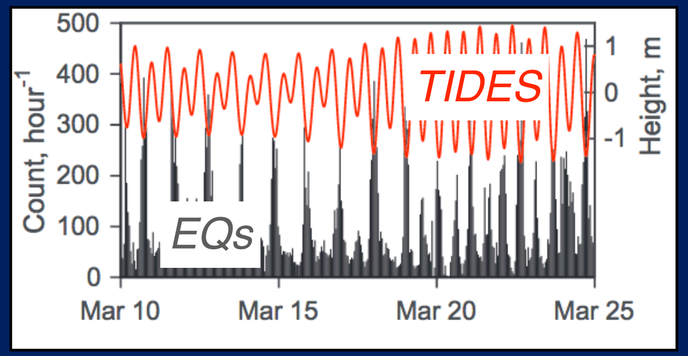
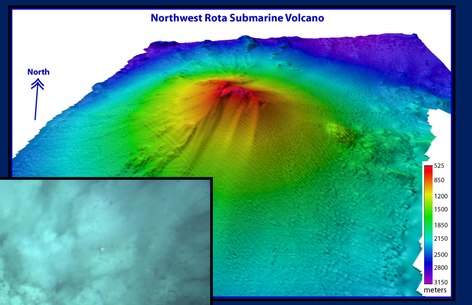


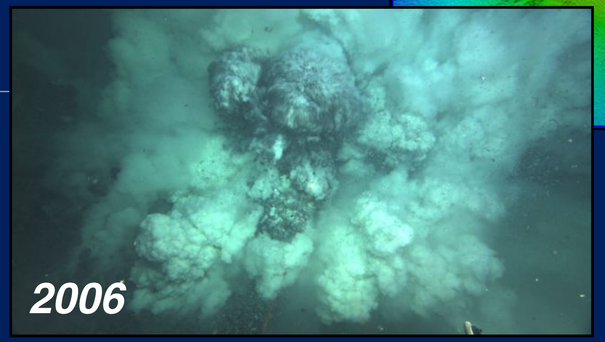
Nooner and Chadwick (2016)

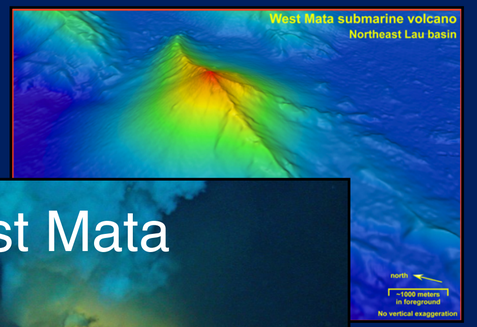


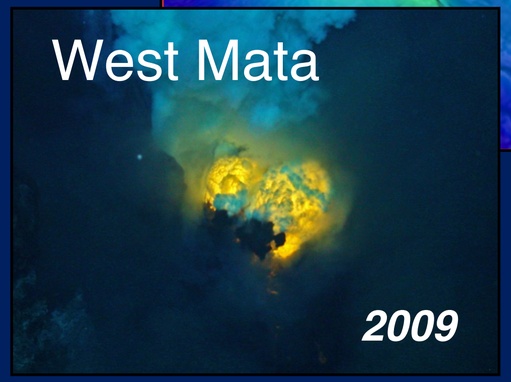
Wilcock et al. (2016)

NW Rota-1





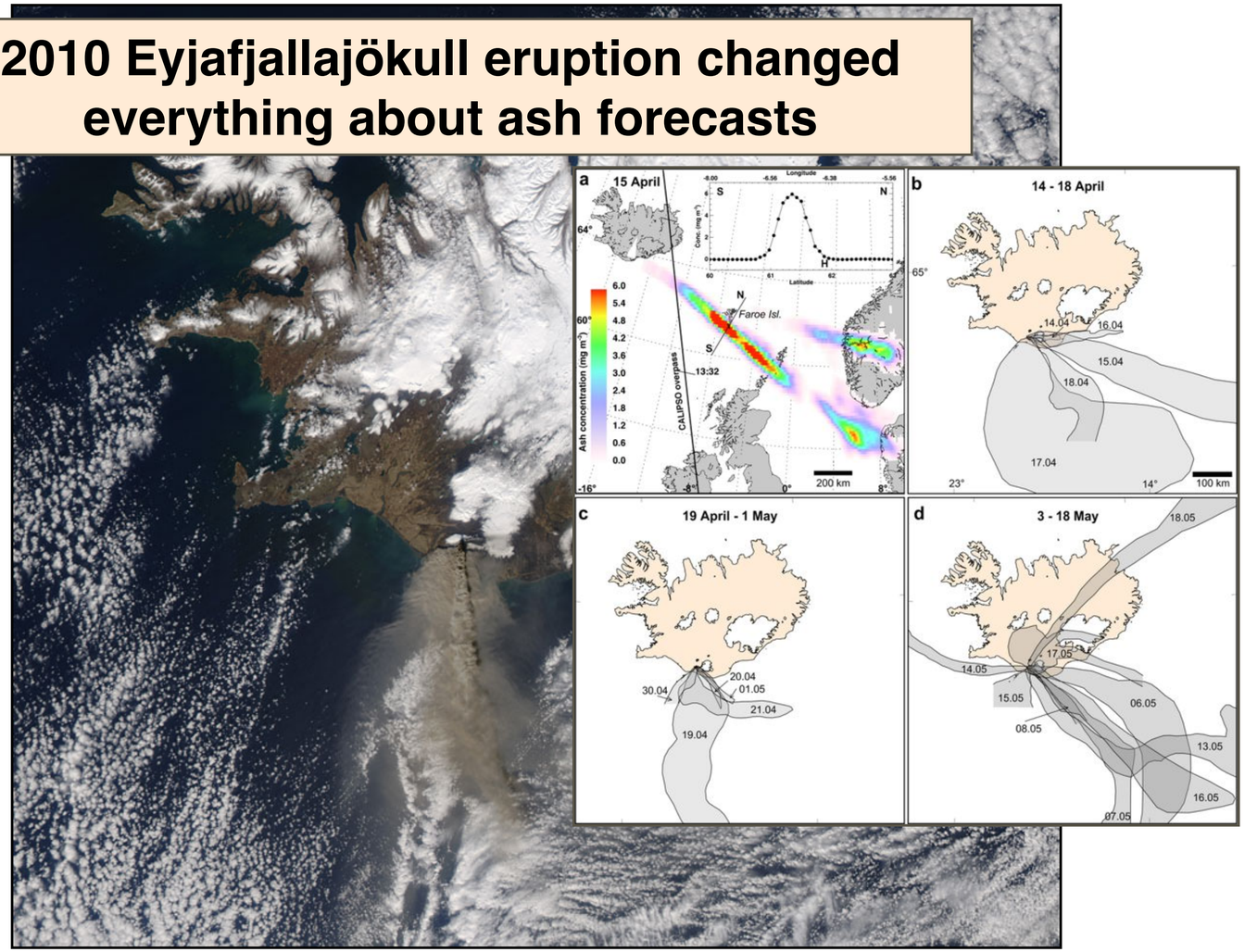


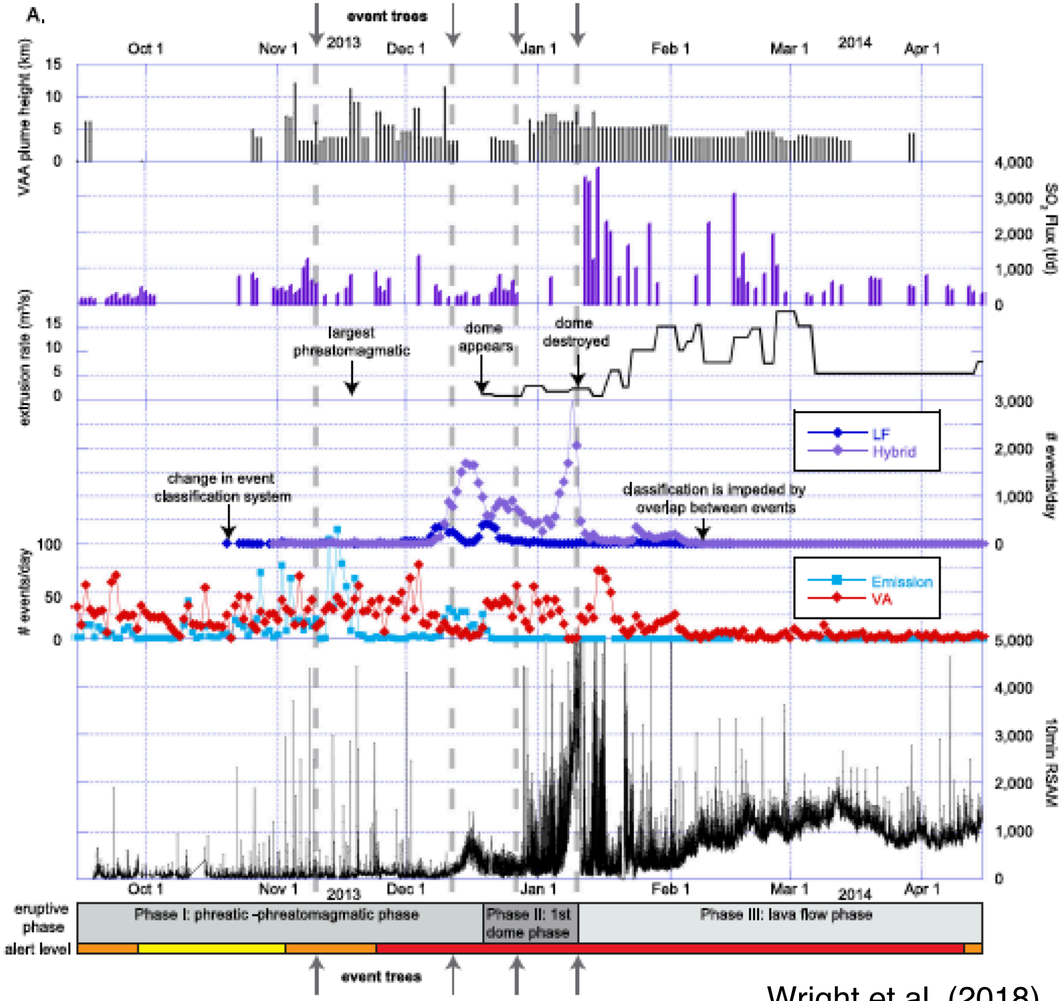


Studies of submarine eruptions in the western Pacific are extending our understanding of global volcanism

2010-2019: renewed focus on forecasting and hazards

2010 Eyjafjallajökull eruption changed everything about ash forecasts



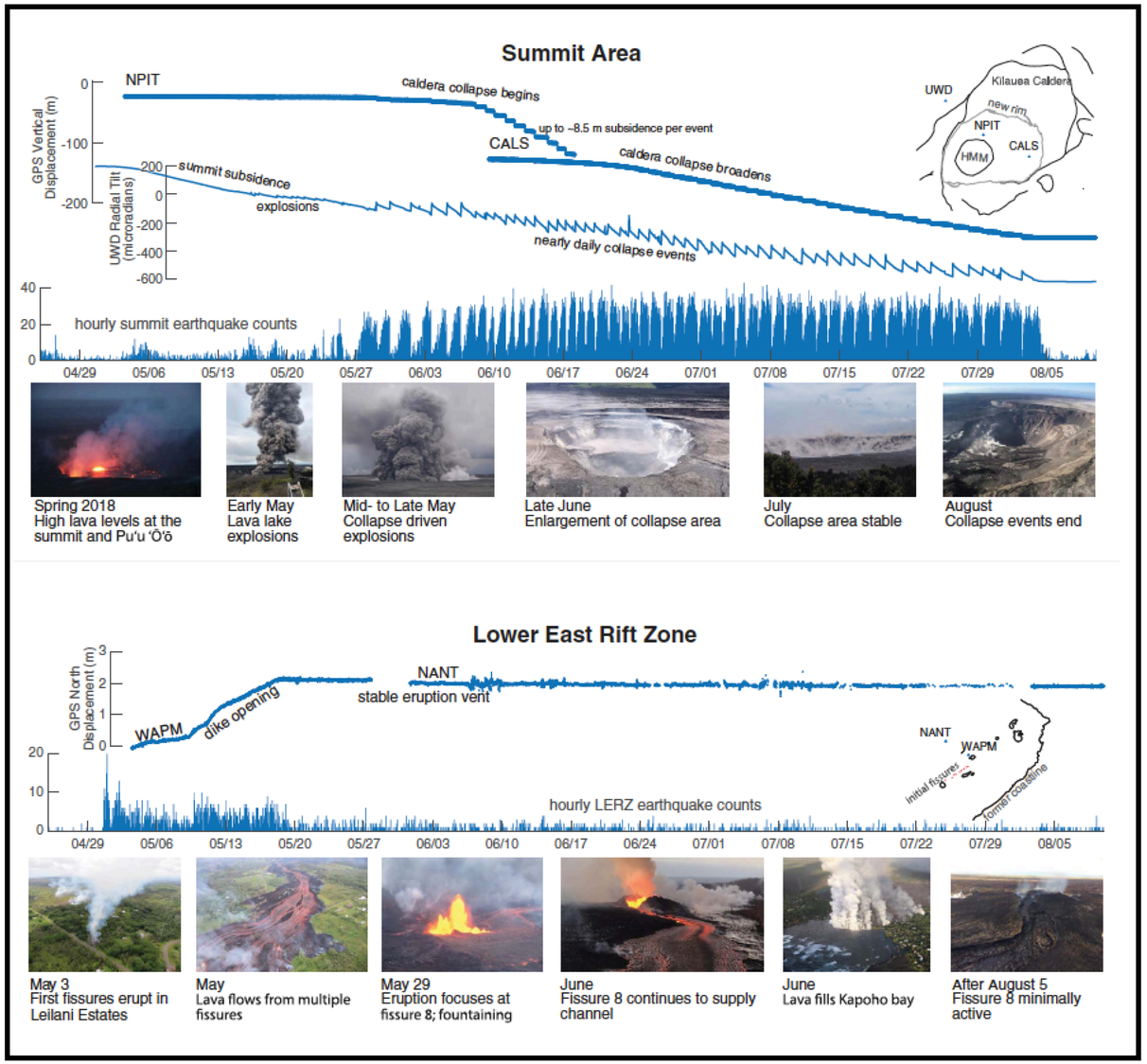


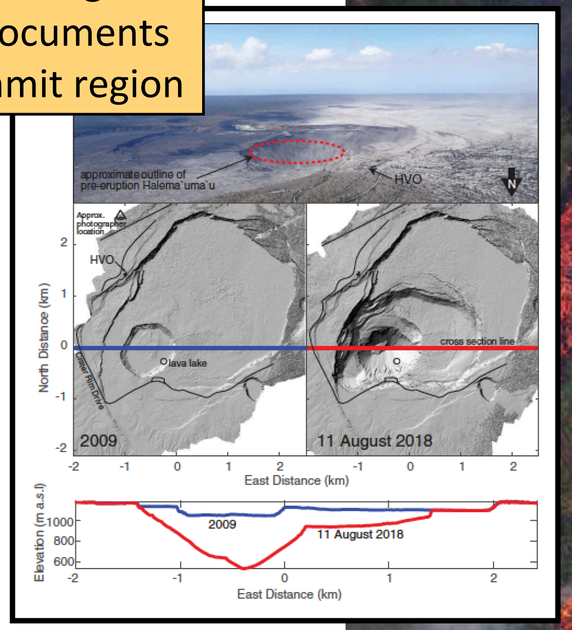
Wright et al. (2018)

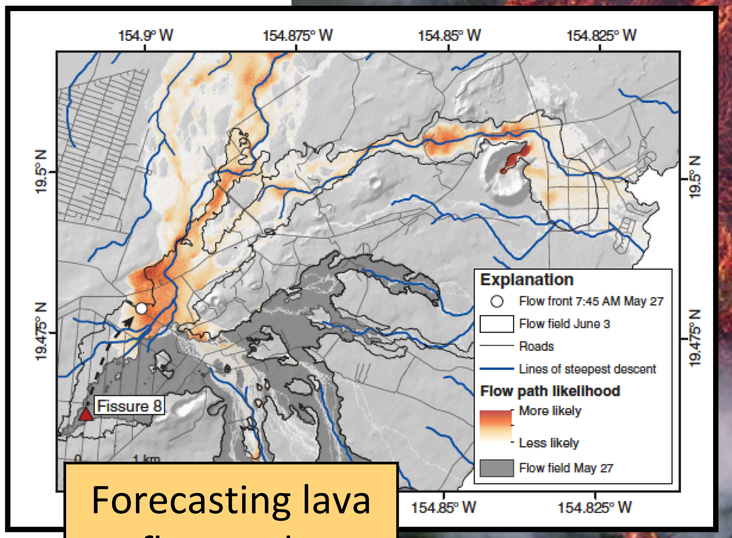
2013- Sinabung eruption
Forecasting by frequent updating of event trees aided by (near-) continuous monitoring data

Kilauea 2018

High resolution digital topography documents collapsing summit region





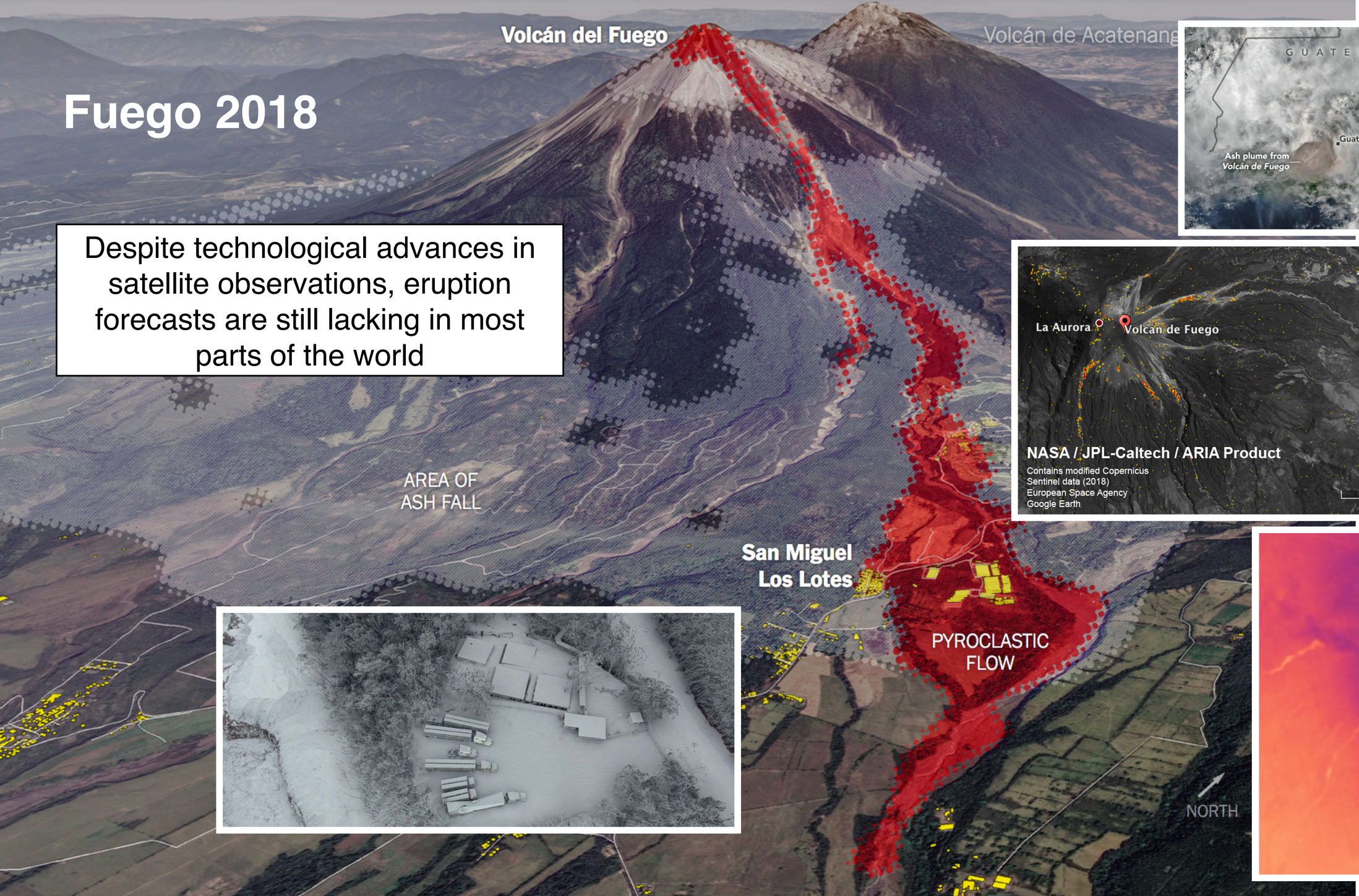


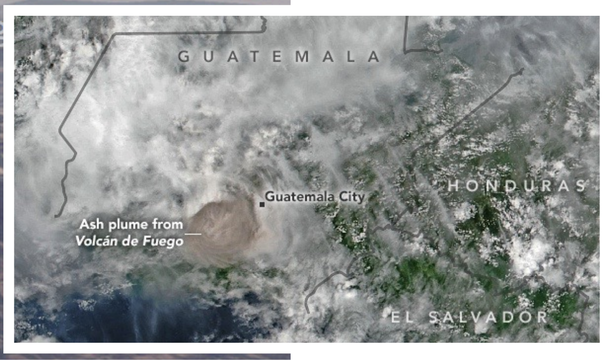
Forecasting lava flow paths

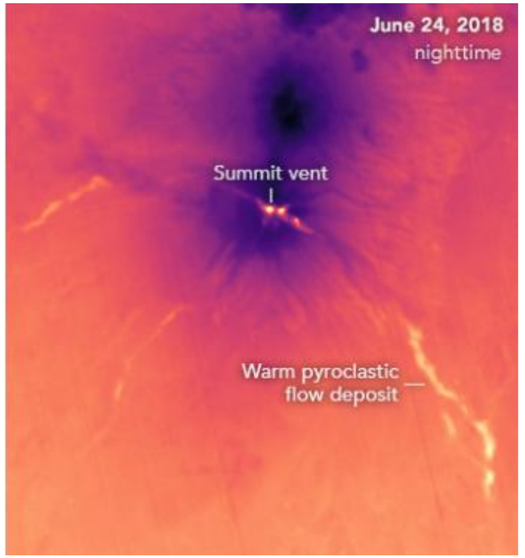
Neal et al. (2019)

Fuego 2018

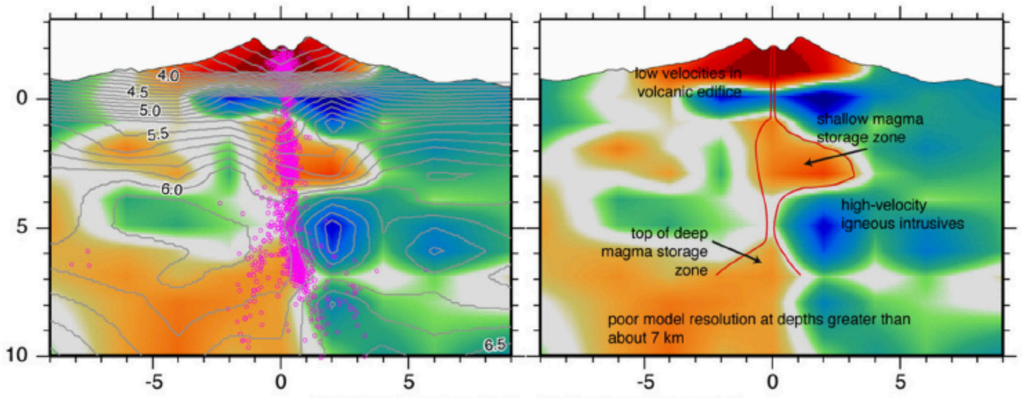
Despite technological advances in satellite observations, eruption forecasts are still lacking in most parts of the world







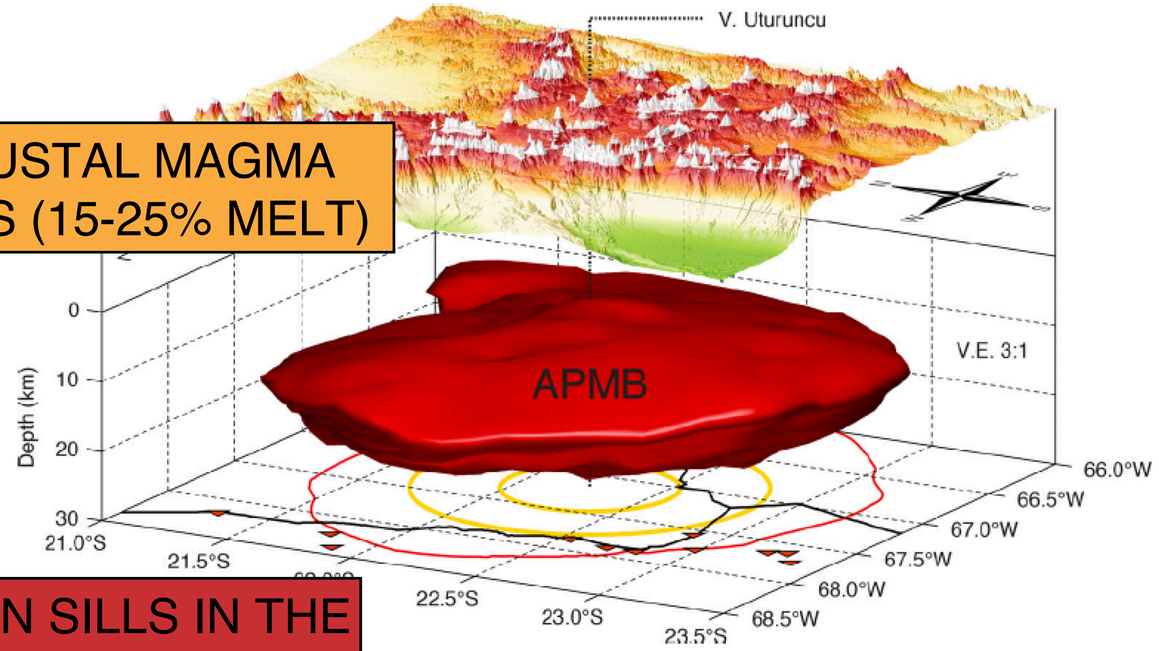
21st century insights: Geophysical imaging of magmatic systems



Dzurisin (2018)

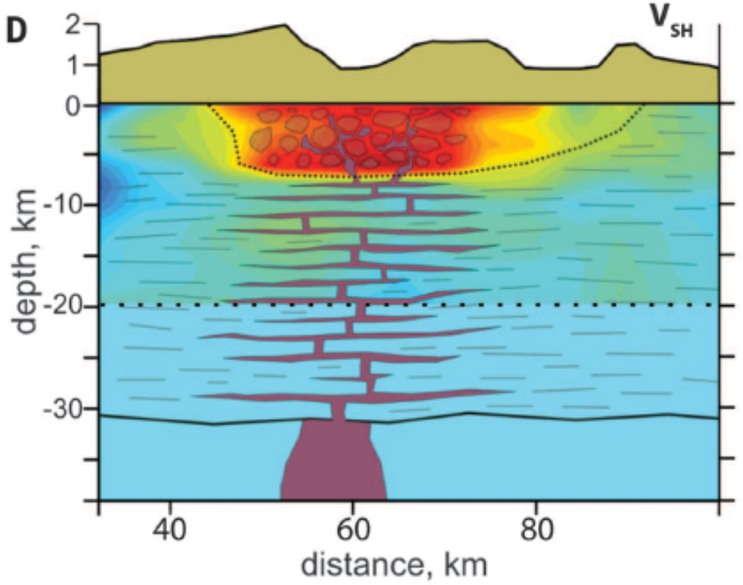
SMALL & TEMPORARY UPPER CRUSTAL STORAGE REGIONS (>50% MELT)

LARGE MID-CRUSTAL MAGMA ACCUMULATIONS (15-25% MELT)



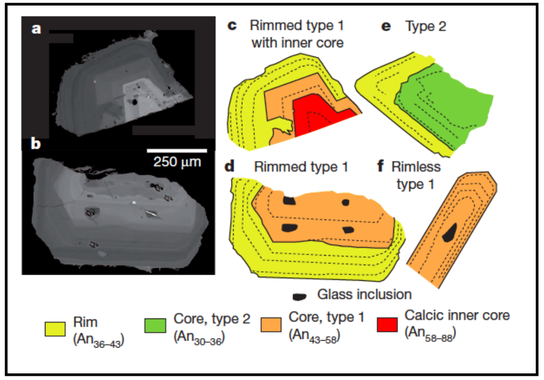
Ward et al. (2014)

MAGMA STORAGE IN SILLS IN THE LOWER CRUST (<10% MELT)

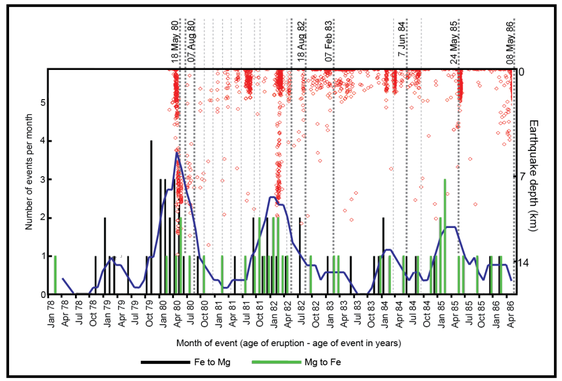


Jaxybutalov et al. (2014)

21st century insights:
Petrologic imaging of magmatic systems

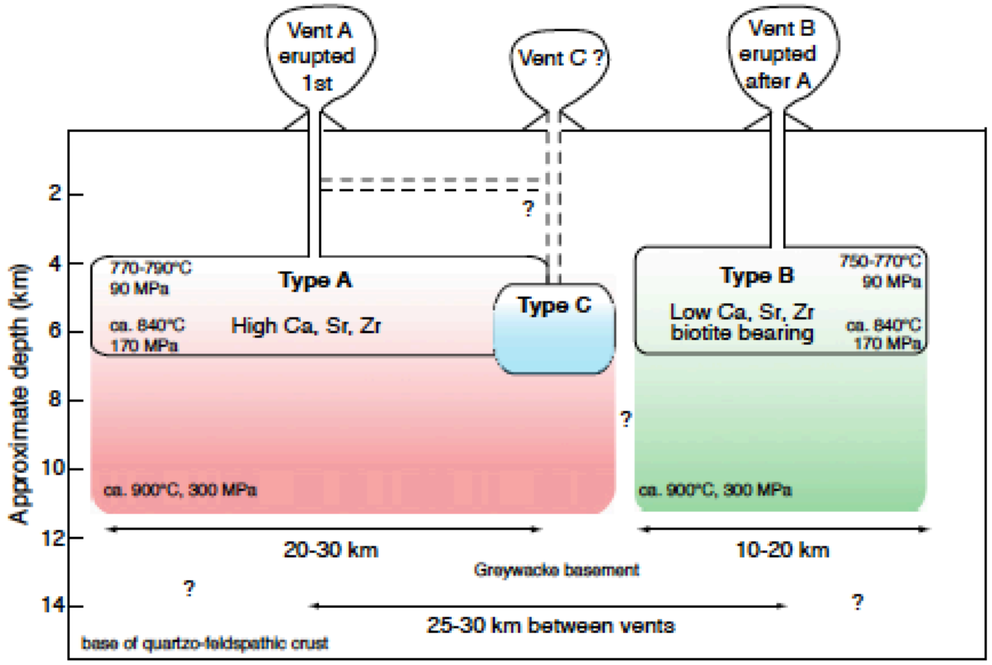


Druitt et al. (2012)



Saunders et al. (2012)

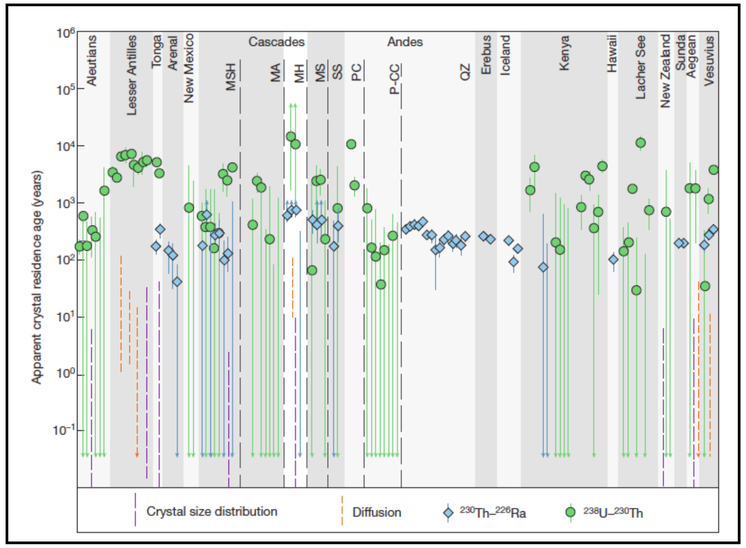
DIFFUSION TIMESCALES RECORD MAGMA ACCUMULATION IN UPPER CRUST



Cooper et al. (2012)

COMPOSITIONAL EVIDENCE FOR MULTIPLE MAGMA RESERVOIRS

Log Crystal Age (yrs)

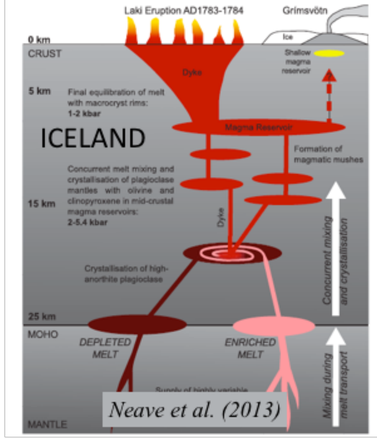


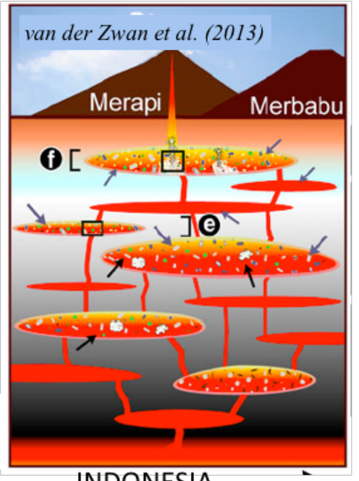
Cooper and Kent (2014)

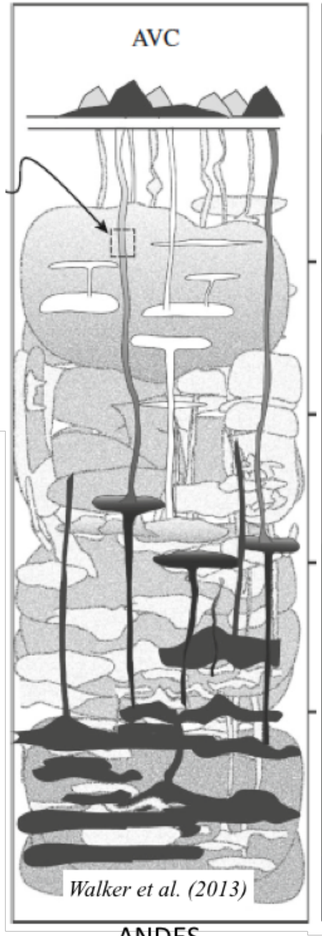
OLD CRYSTAL CORES ATTEST TO THE LONGEVITY OF MAGMATIC SYSTEMS

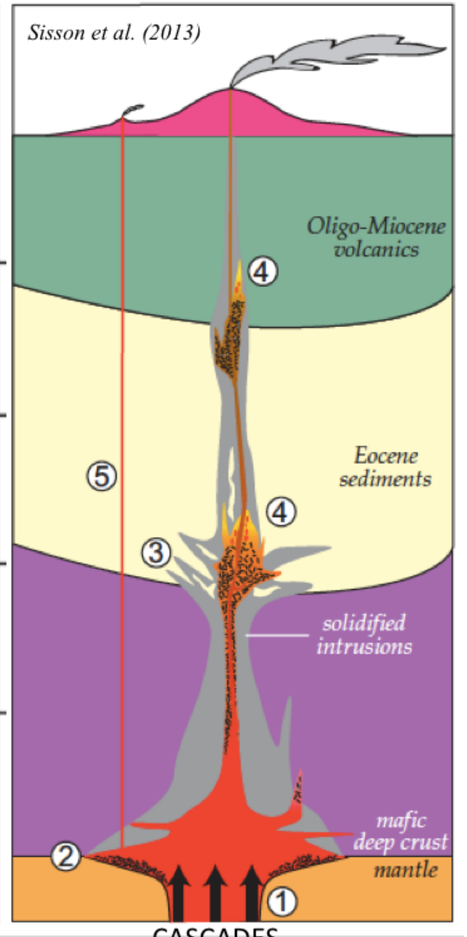
Paradigm shift

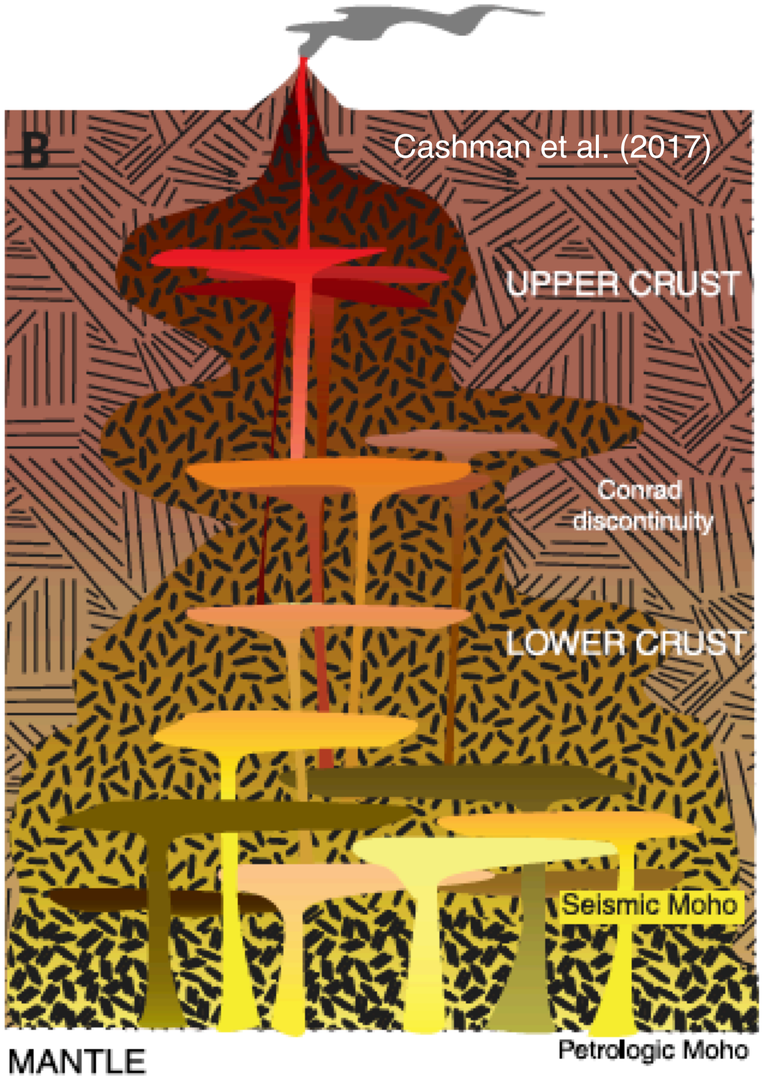
Trans-crustal magmatic systems

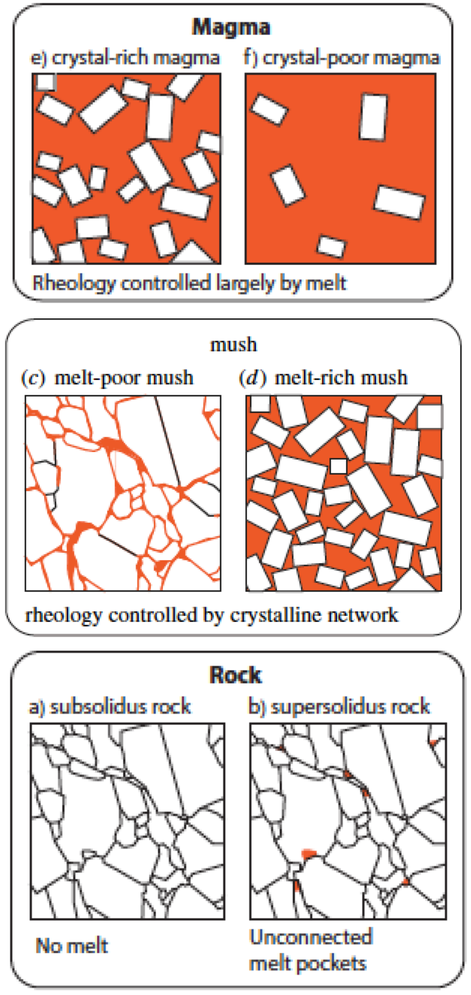






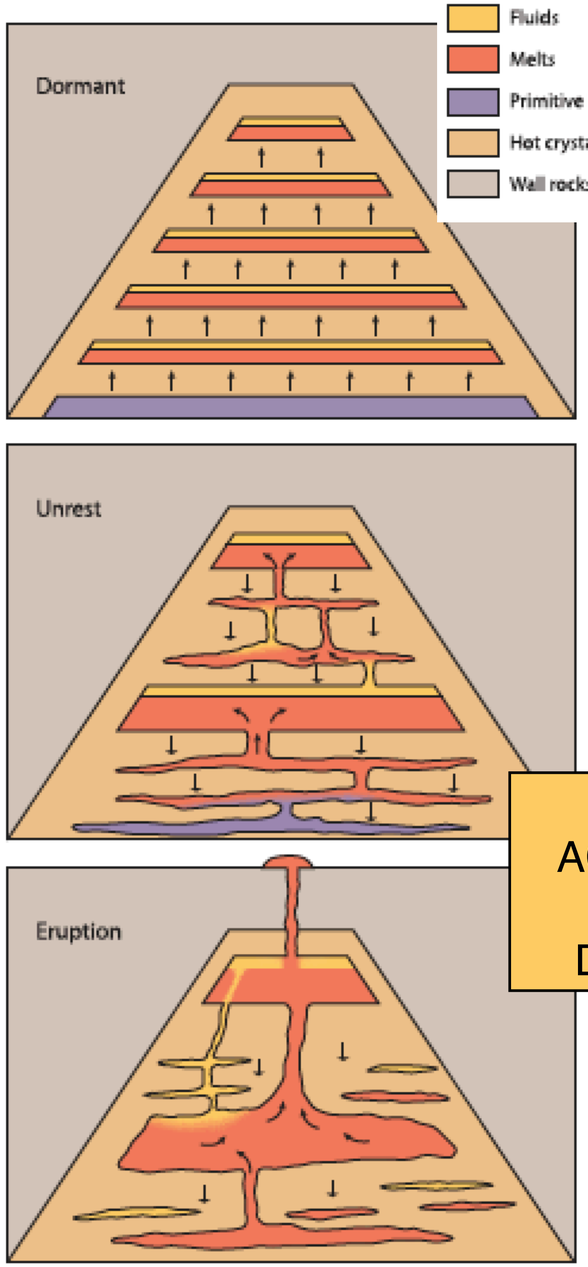






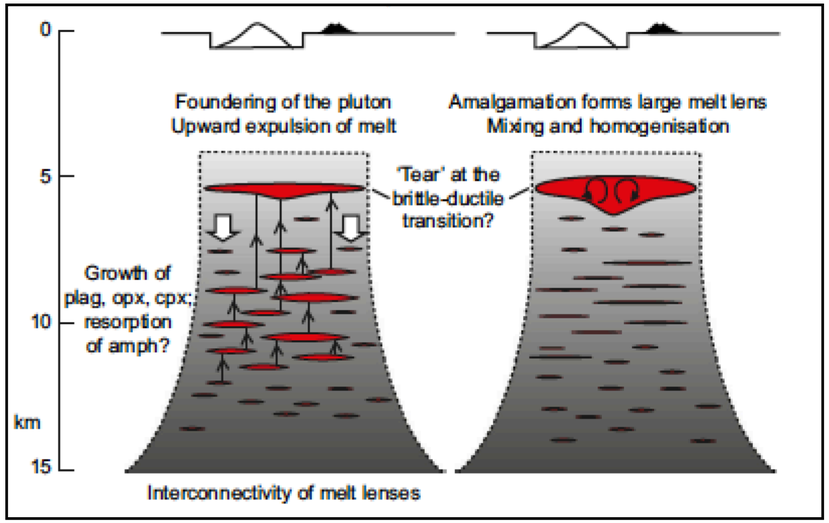
Sparks et al. (2019)

Implications for volcanic eruptions



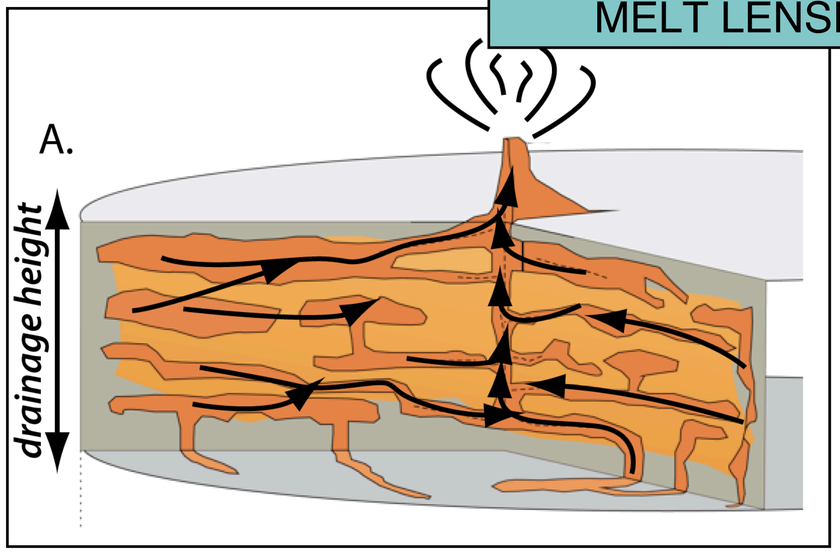
Christopher et al. (2015)

MAGMA ACCUMULATION BY MELT LENS DESTABILIZATION

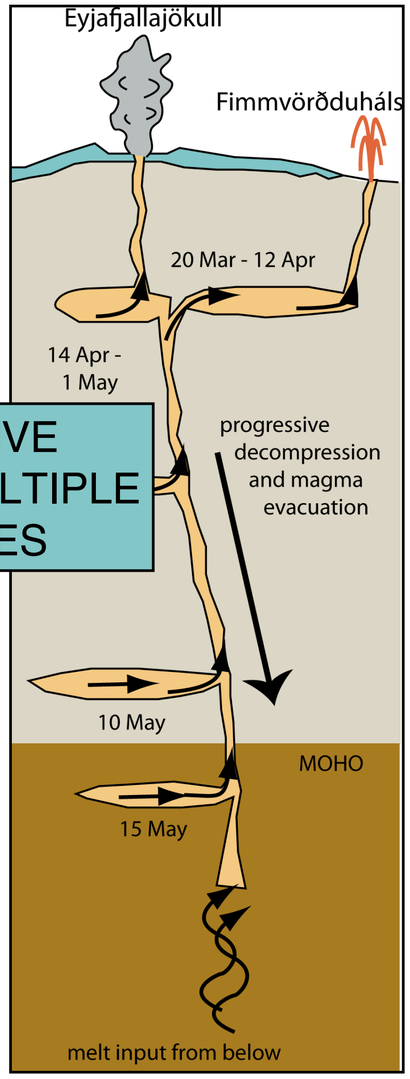


Flaherty et al. (2018)

SYN-ERUPTIVE TAPPING OF MULTIPLE MELT LENSES



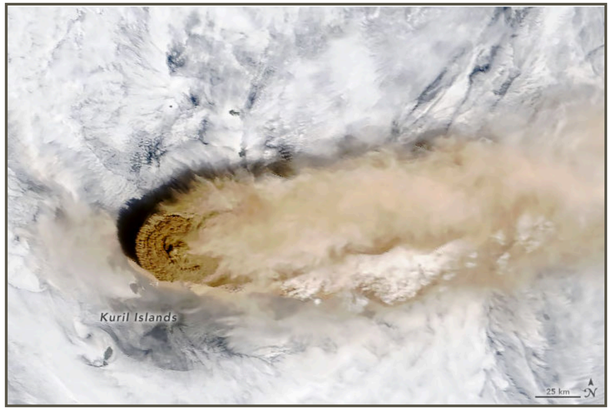
Cashman and Giordano (2014)

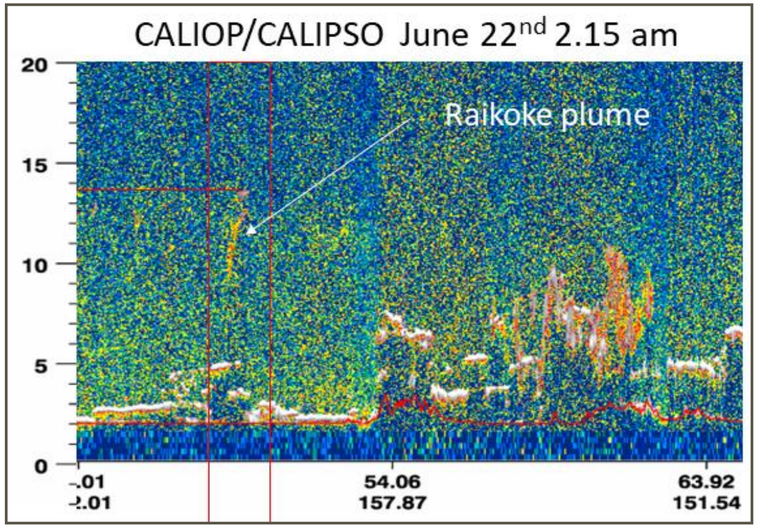


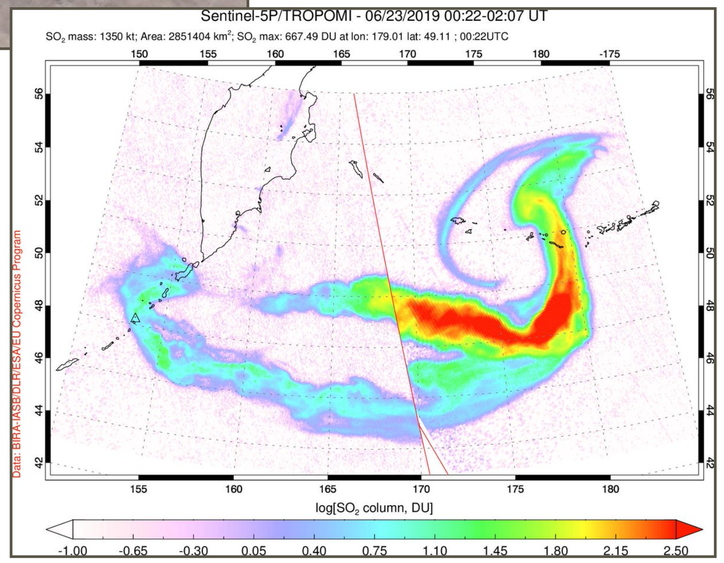
redrafted from Tarasewicz et al. (2012)

Raikoke June 22, 2019

Rapid information flow in response to an unexpected eruption

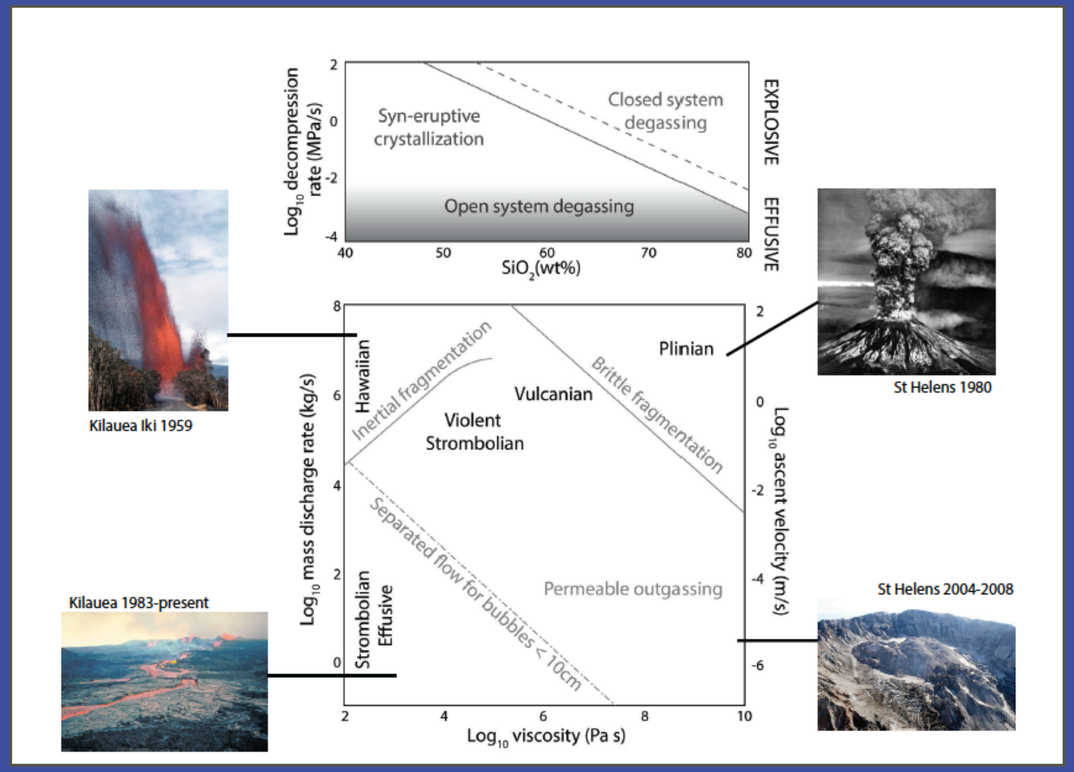






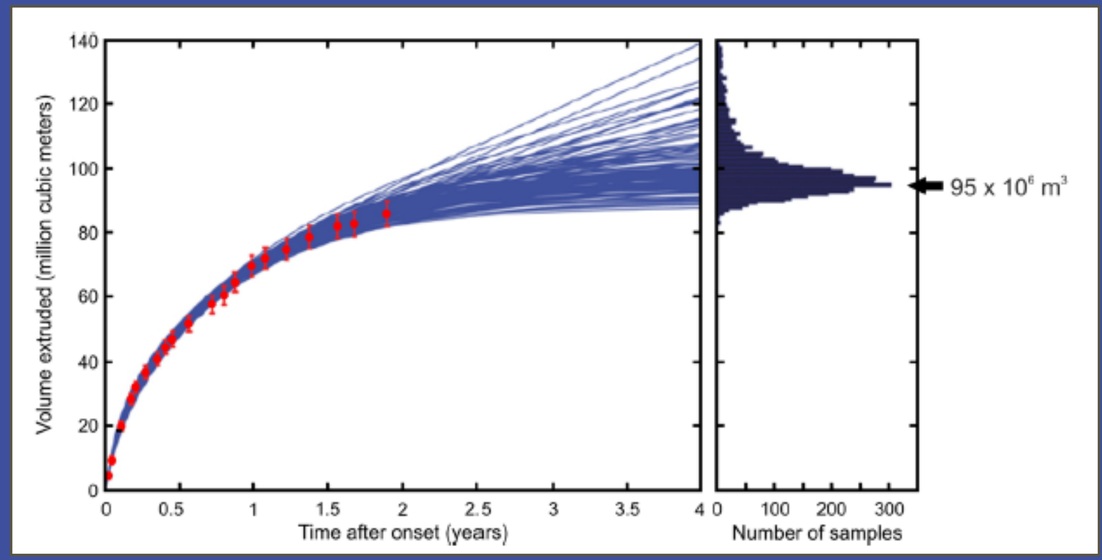
What's next?

A physics-based framework for forecasts, models and basic understanding of volcanic systems



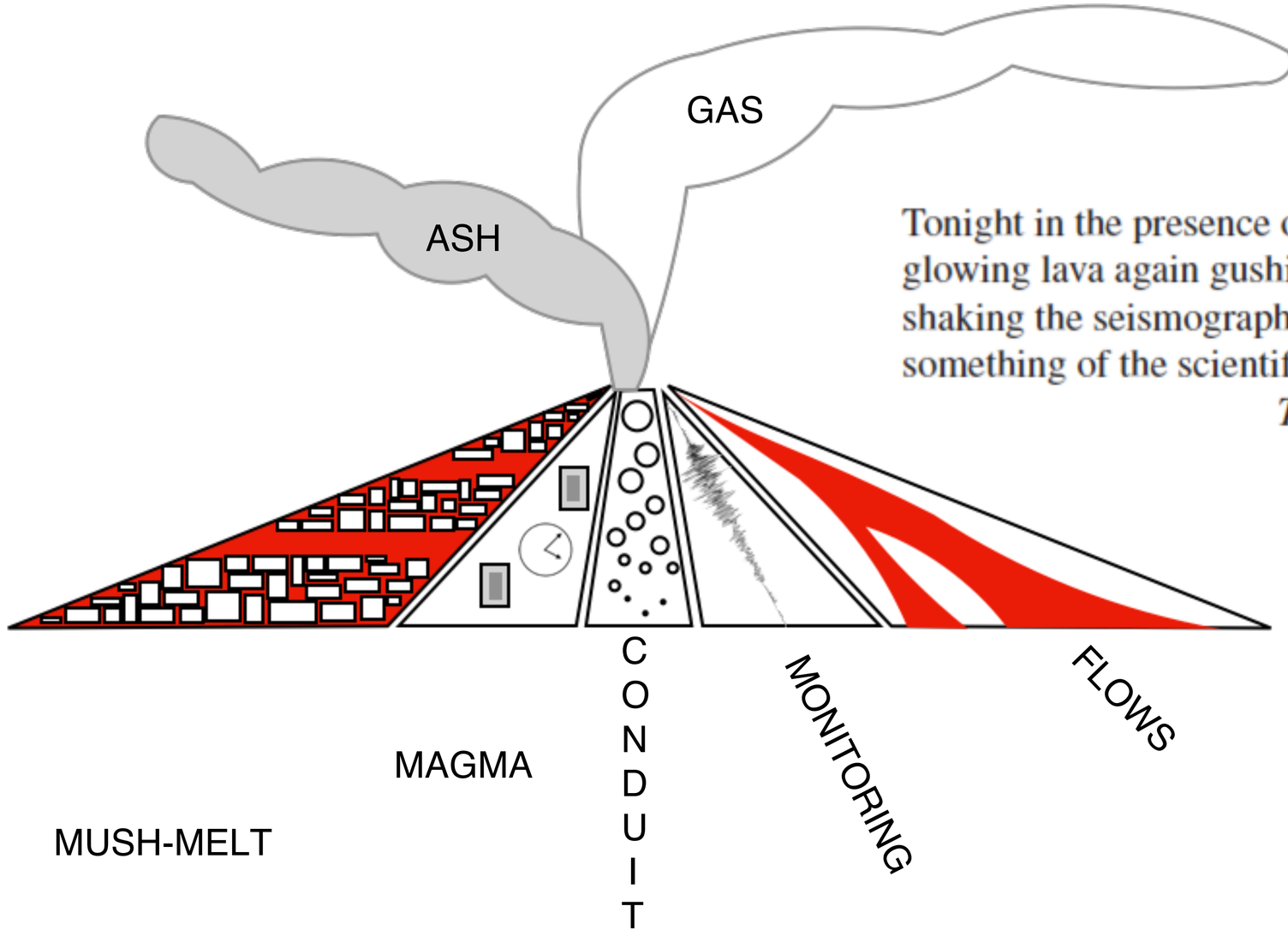
NAS report 2017

Data assimilation from (near) real-time monitoring data



Dzurisin et al. (2015) after Segall (2013)

Thanks to a century of volcanologists…
and apologies for everything I left out!



Tonight in the presence of the fire pit, with the glowing lava again gushing and pounding and shaking the seismographs, I am asked to tell you something of the scientific meaning of it.

Thomas A. Jaggar (1945)