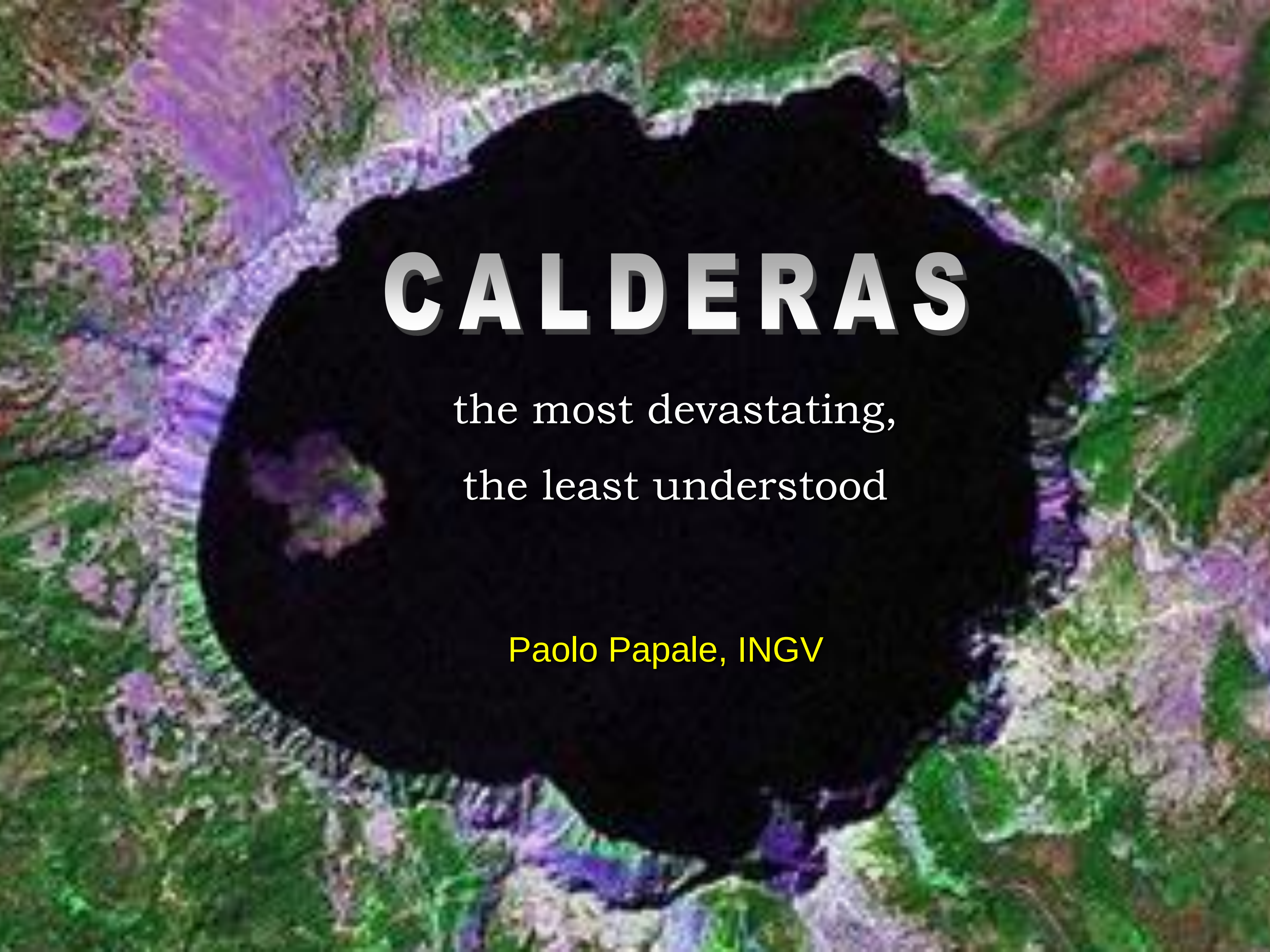


CALDERAS

the most devastating,

the least understood

Paolo Papale, INGV

STRATOVOLCANOES

Kanaga, Alaska

Fujii, Japan

Colima, Mexico

Cotopaxi, Ecuador


Aso, Japan

Crater Lake, Oregon

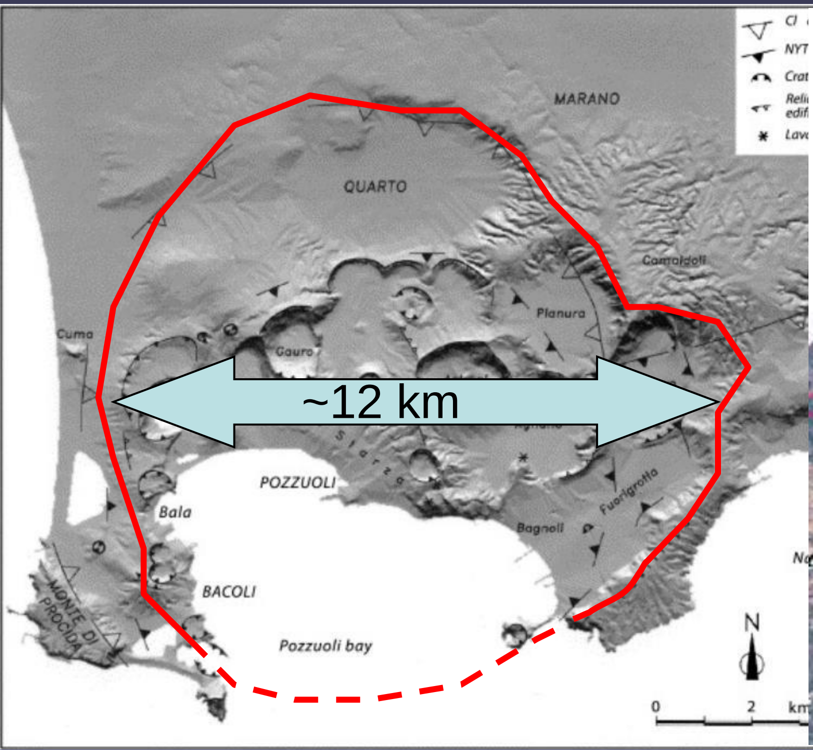
C A L D E R A S

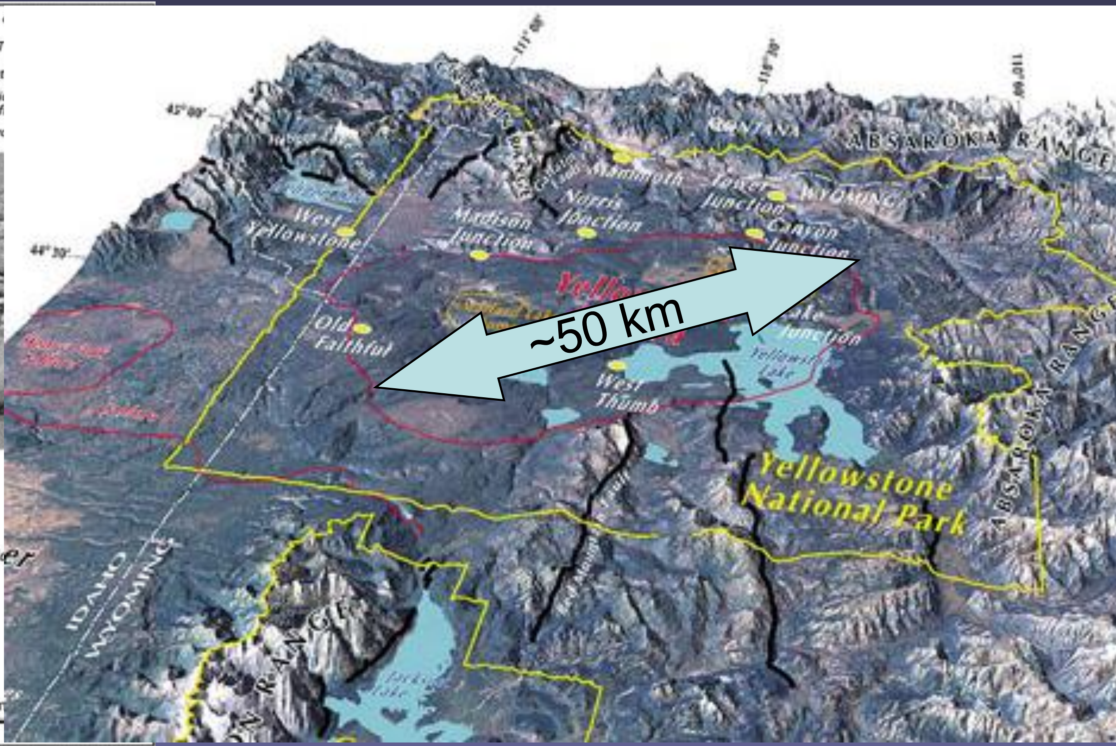

Kaguyak, Alaska

Santorini, Greece

Campi Flegrei, Italy

Yellowstone, Wyoming





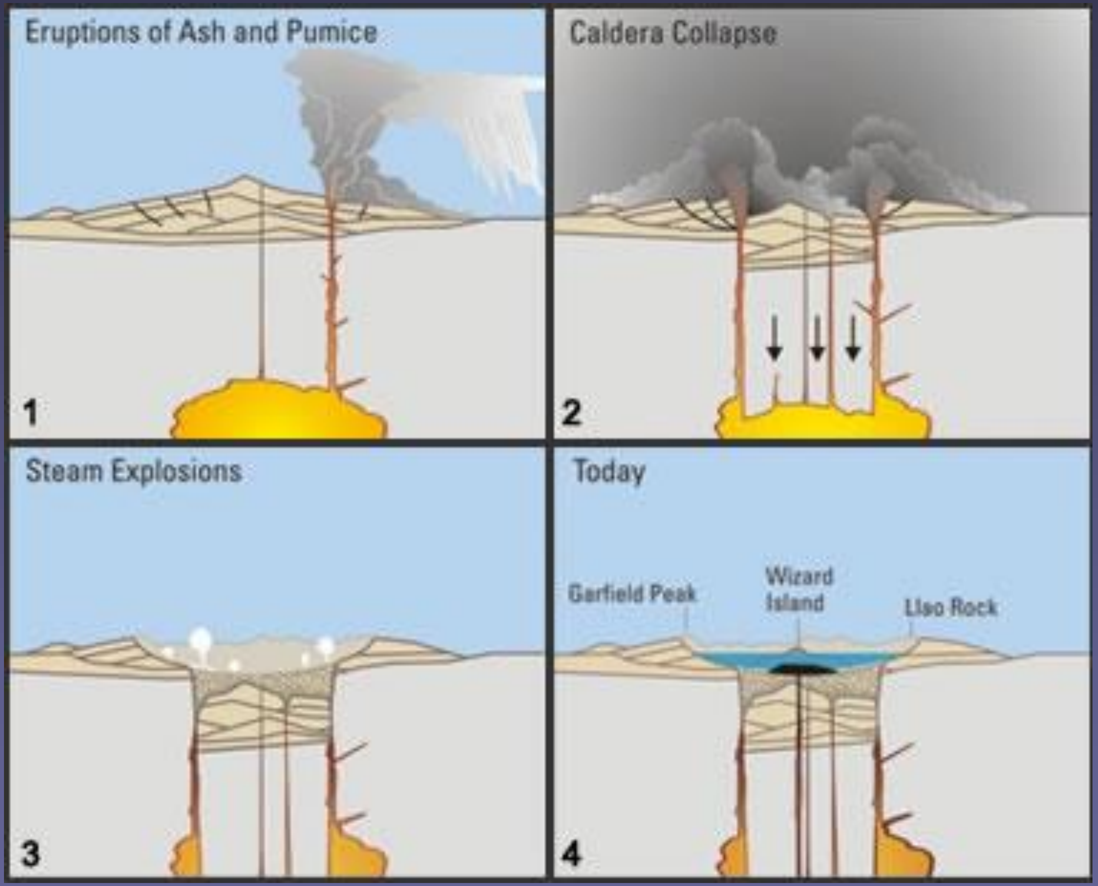

Campi Flegrei, Italy


La Solfatara, Campi Flegrei


Yellowstone, WY (US)


Old Faithful Geyser, Yellowstone

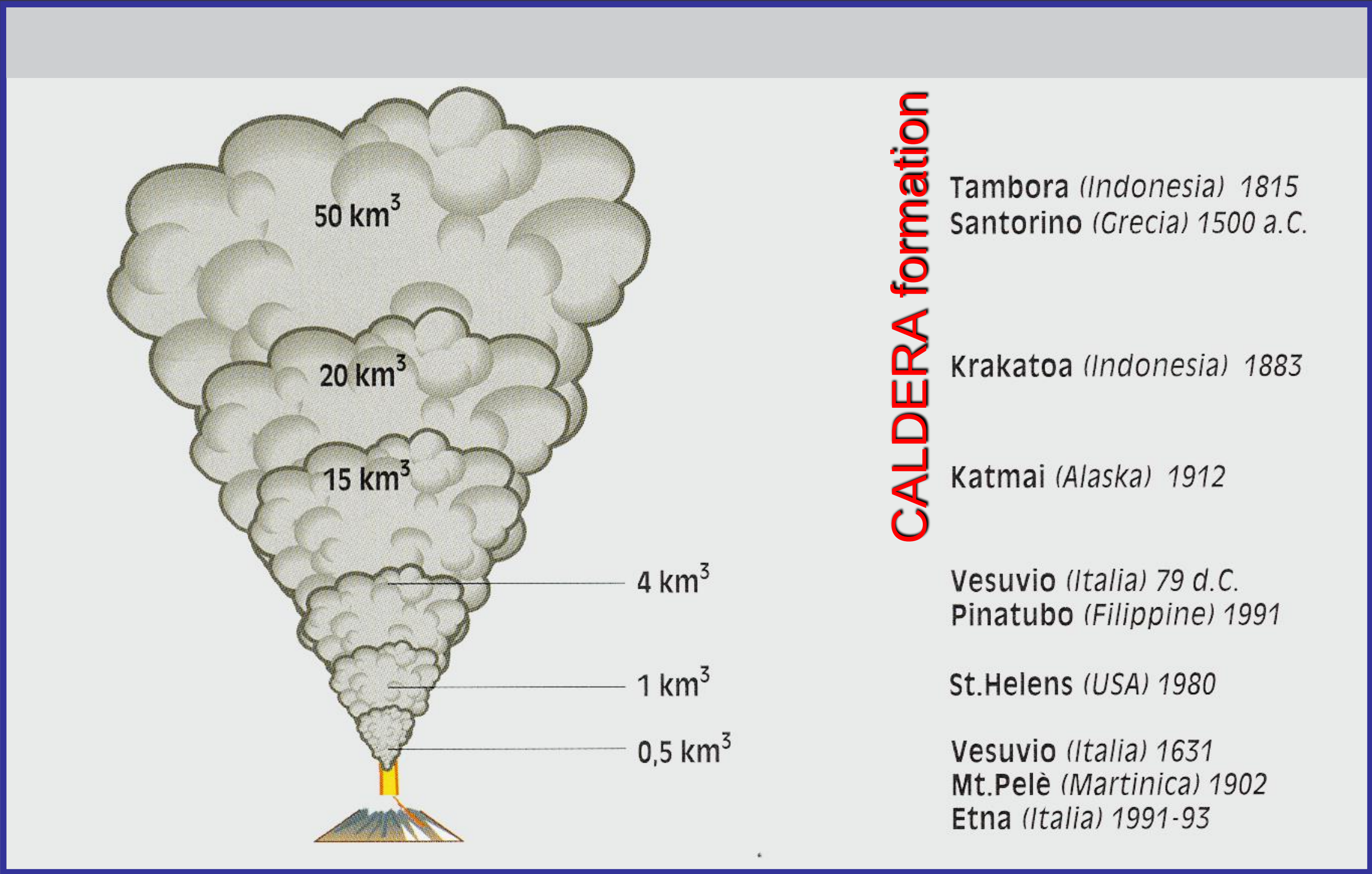
Caldera formation mechanisms

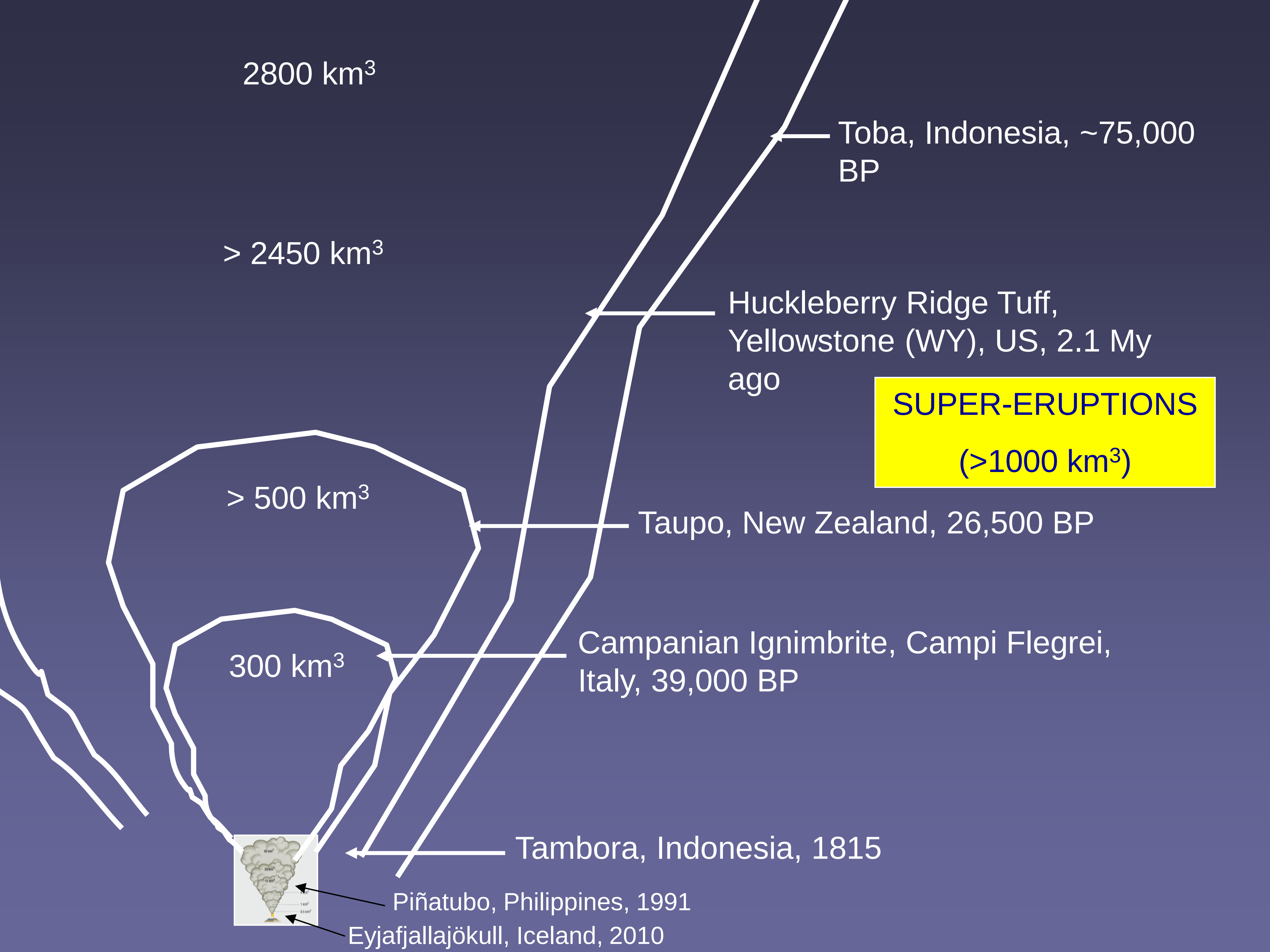


Example from Crater Lake caldera, OR, US

source: USGS

Erupted magma volumes in historical eruptions



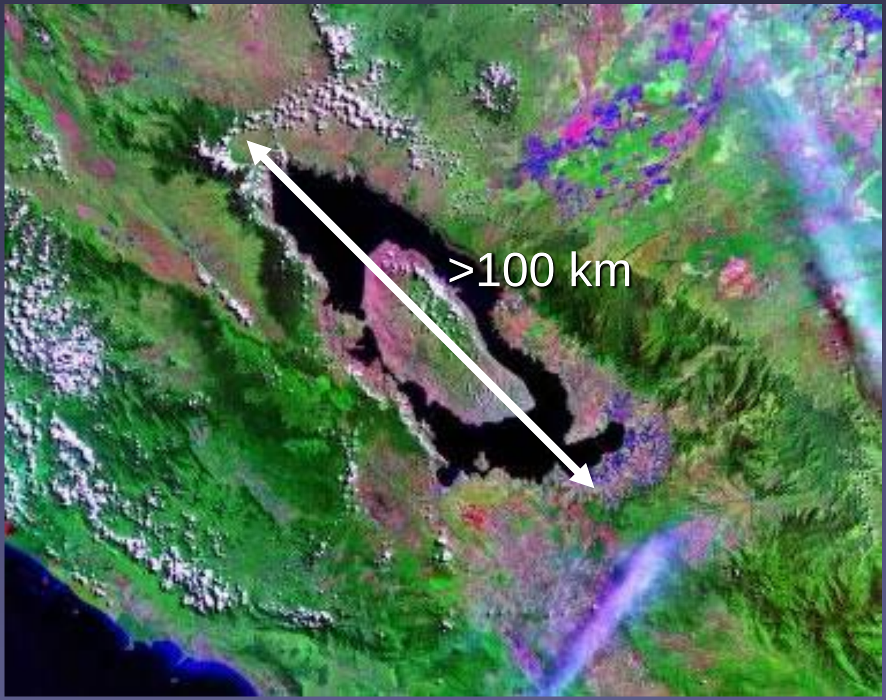

2800 km^3
Toba, Indonesia, ~75,000 BP
> 2450 km^3
Huckleberry Ridge Tuff, Yellowstone (WY), US, 2.1 My ago
SUPER-ERUPTIONS
(>1000 km^3)
> 500 km^3
Taupo, New Zealand, 26,500 BP
300 km^3
Campanian Ignimbrite, Campi Flegrei, Italy, 39,000 BP
Tambora, Indonesia, 1815
Piñatubo, Philippines, 1991
Eyjafjallajökull, Iceland, 2010

Landsat image of Toba caldera, Sumatra island, Indonesia

2800 km^3 of magma

Mount St. Helens 1980: 2.8 km^3

Piñatubo 1991: ~12 km^3



The energy release can be estimated as 1,000 Hiroshima atomic bombs exploding every second (!!!)

The Toba eruption is associated to the Toba catastrophe theory: the eruption caused a 6 – 10 years global winter and possibly triggered a ~1000 years cooling period, nearly leading to extinction of several species; studies on human mitochondrium suggest that about 75,000 years ago humans were decreased to a few thousands units, providing an explanation to the poor genetic variability of our species

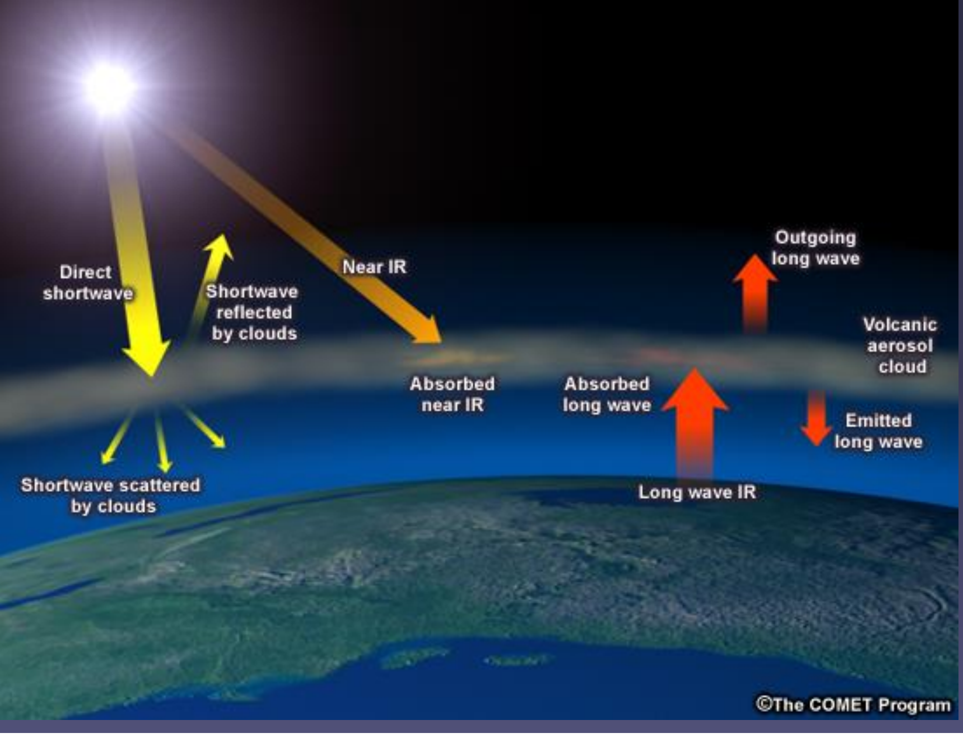
“Super-eruptions are different from other hazards such as earthquakes, tsunamis, storms or floods in that – like the impact of a large asteroid or comet – their environmental effects threaten global civilisation.”

“Our present civilisation depends on global trade and food production, with much reliance on air travel and space-born communications, all of which could be at considerable risk if a super-eruption occurred.”

“An area the size of North America or Europe could be devastated, and pronounced deterioration of global climate would be expected for a few years following the eruption. Such events could result in the ruin of world agriculture, severe disruption of food supplies, and mass starvation. The effects could be sufficiently severe to threaten the fabric of civilisation.”

“Sooner or later a super-eruption will happen on Earth and this is an issue that also demands serious attention. While it may in the future be possible to deflect asteroids or somehow avoid their impact, we know of no strategies for reducing the power of major volcanic eruptions.”

Report of a Geological Society of London Working Group:
S. Sparks, S. Self, et al.



Volcanic ash

Fine volcanic ash can remain suspended in the atmosphere for months to years and be dispersed worldwide. Ash shades sunlight and cause **cooling** over large areas of the Earth.

Greenhouse gases

Volcanoes release large amounts of greenhouse gases such as water vapor and carbon dioxide. The amounts put into the atmosphere from a large eruption don't change the global amounts of these gases very much. However, there have been times during Earth history when intense volcanism has significantly increased the amount of carbon dioxide in the atmosphere and caused **global warming**.

Sulphur

Sulfur dioxide discharged into the atmosphere is much more effective than ash particles at cooling the climate. Sulfur dioxide combines with water to form sulfuric acid aerosols. The sulfuric acid makes a haze of tiny droplets in the stratosphere that reflects incoming solar radiation, causing **cooling** of the Earth's surface. The aerosols can stay in the stratosphere for up to three years, moved around by winds and causing significant cooling worldwide.

Piñatubo, Philippines, 1991

Height: 40 km

SO_2 injection: 17 Mtons

• Largest perturbation to the stratospheric aerosol since Krakatau 1883

• The aerosol rounded the globe in 3 weeks, and attained global coverage in 1 year, causing a dramatic decrease in the amount of net radiation reaching the Earth surface

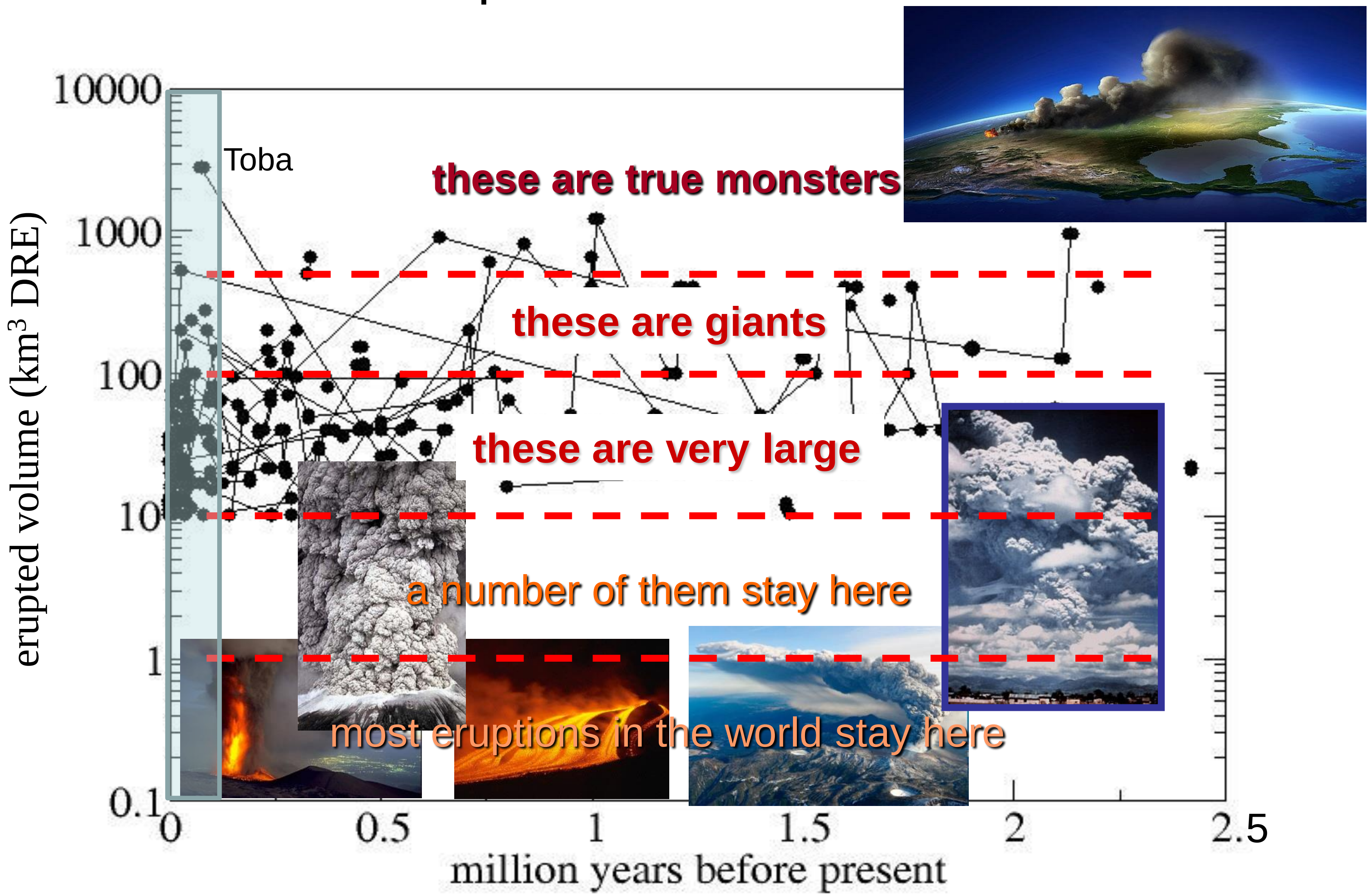
• Cooling of Northern Hemisphere of up to 0.5 – 0.6 °C

The Piñatubo climate forcing was stronger than the opposite, warming effects of either the El Niño event or anthropogenic greenhouse gases in the period 1991-93.

As a result of the presence of the aerosol particles, midlatitude ozone concentrations reached their lowest levels on record during 1992-93, the Southern Hemisphere "ozone hole" increased in 1992 to an unprecedented size, and ozone depletion rates were observed to be faster than ever before recorded.

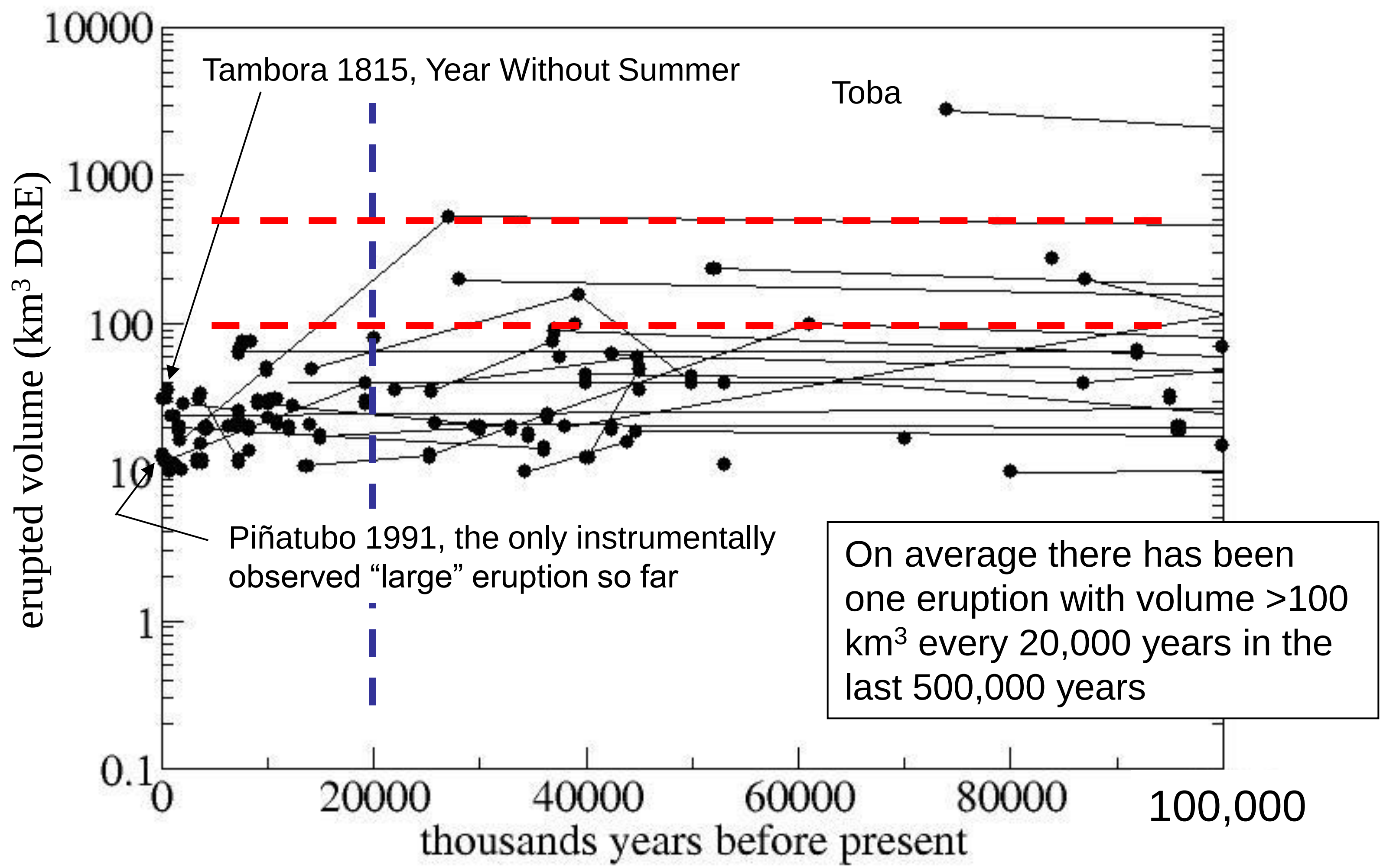
Source: Self et al., 2004

known eruptions with volume > 10 km^3



source of data: LaMEVE (Large Magnitude Explosive Volcanic Eruptions) database: http://www.bgs.ac.uk/vogripa

known eruptions with volume > 10 km^3



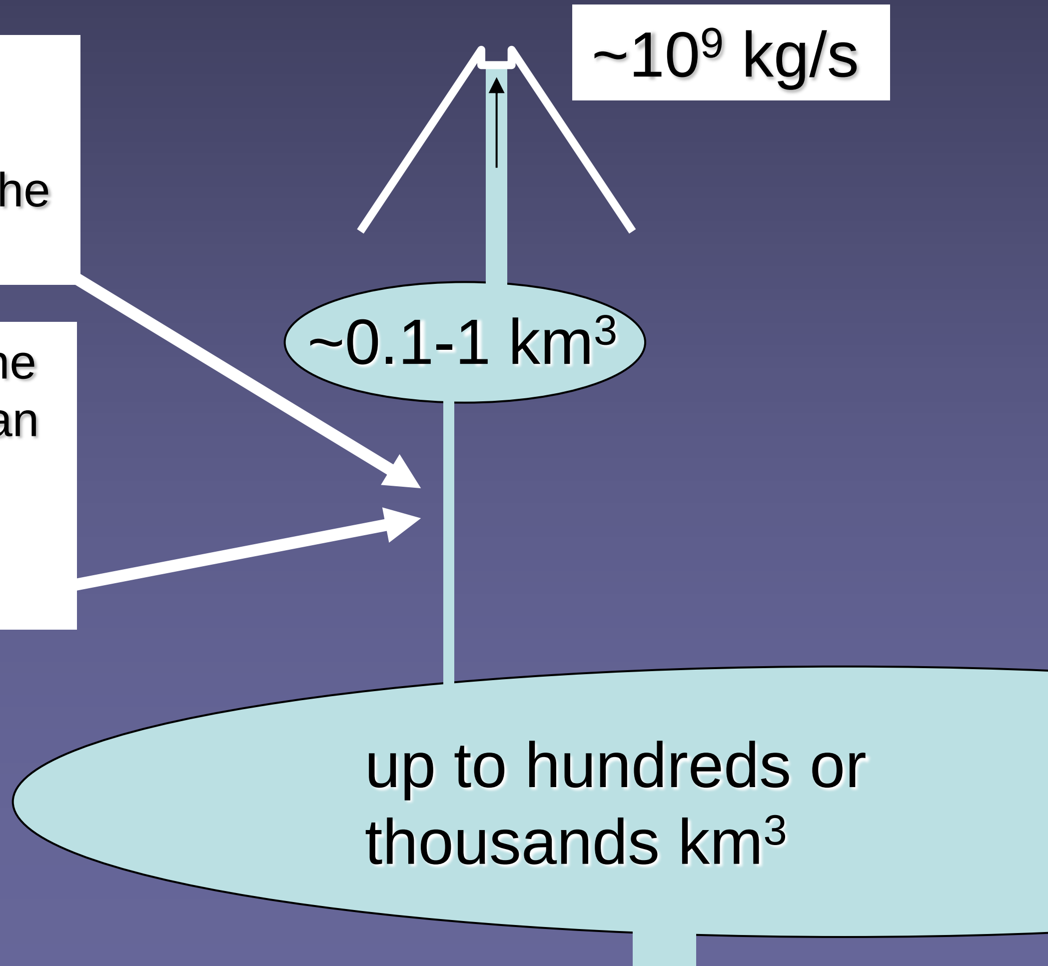
source of data: LaMEVE (Large Magnitude Explosive Volcanic Eruptions) database: http://www.bgs.ac.uk/vogripa

One of the most critical problems in volcanology:

There is not yet a confident method to estimate the scale of a likely or imminent eruption from the pre-eruptive observations

If the flux is not sustained here, the pressure in the shallow system is destined to rapidly decrease closing the eruption

If instead the flux is sustained here, the magma in the deep, large reservoir can be discharged abundantly before pressure decrease leads to caldera formation



The efficiency of deep interconnections is critical in determining the size and impact of an eruption

A second critical problem in volcanology

Anticipating the occurrence of an eruption at calderas is far more difficult than for typical stratovolcanoes

Campi Flegrei caldera, in Italy, and the city of Naples, 3 million people

CALDERAS: why are they different?

- The structure of calderas is profoundly different from that of stratovolcanoes

  - “negative” as opposed to “positive” edifice
  - boarder faults
  - chaotic rock assemblage
  - development of large geothermal circulation
  - resurgency
  - compressional/extensional portions
  - several distinct post-collapse vents
  - …

CALDERAS: why are they different?

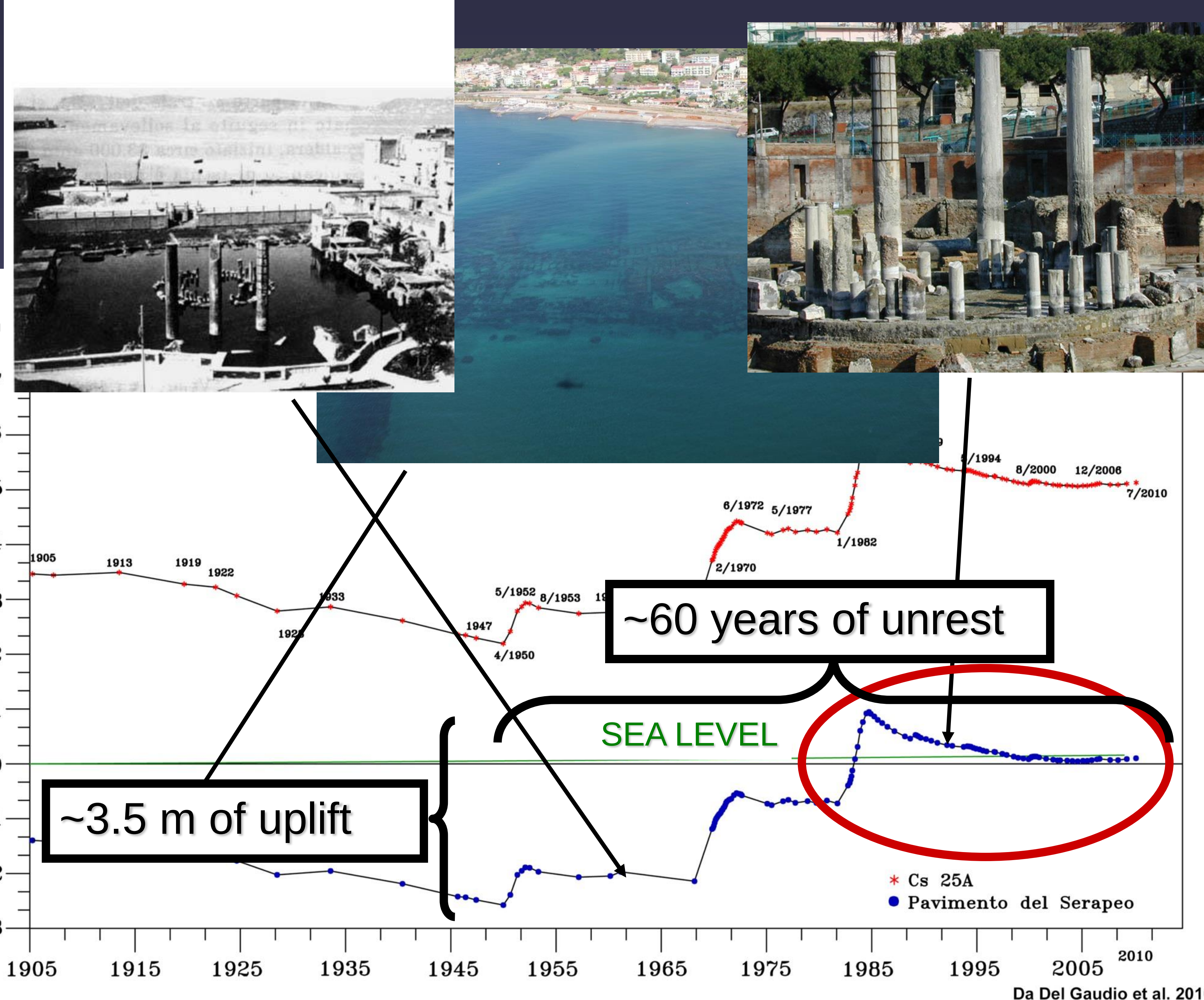
They often display unrest dynamics that if observed at central volcanoes, they would almost certainly culminate into an eruption

Observations that are often reported as "critical" for near-term eruption forecast:

- acceleration in seismicity
- acceleration in deformation
- increase of gas fluxes, especially CO_2 flux (and concentration)

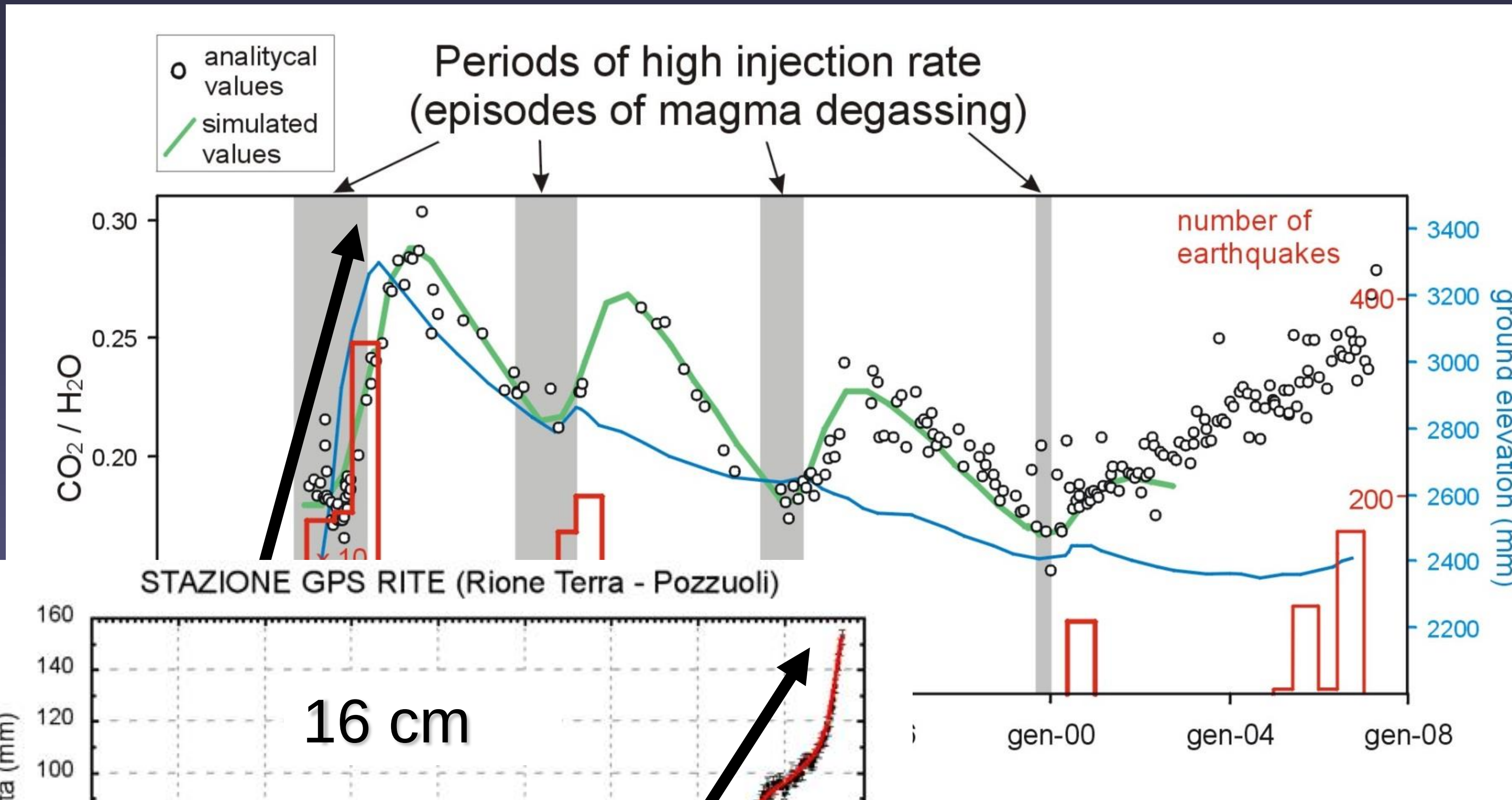
Are they equally diagnostic / critical at calderas?

G



~60 years of unrest
~3.5 m of uplift
SEA LEVEL
Quota in metri (slm 1905)
1905
1913
1919
1922
1933
1947
4/1950
5/1952
8/1953
2/1970
6/1972
5/1977
1/1982
8/2000
12/2006
7/2010
Cs 25A
Pavimento del Serapeo
Da Del Gaudio et al. 2010

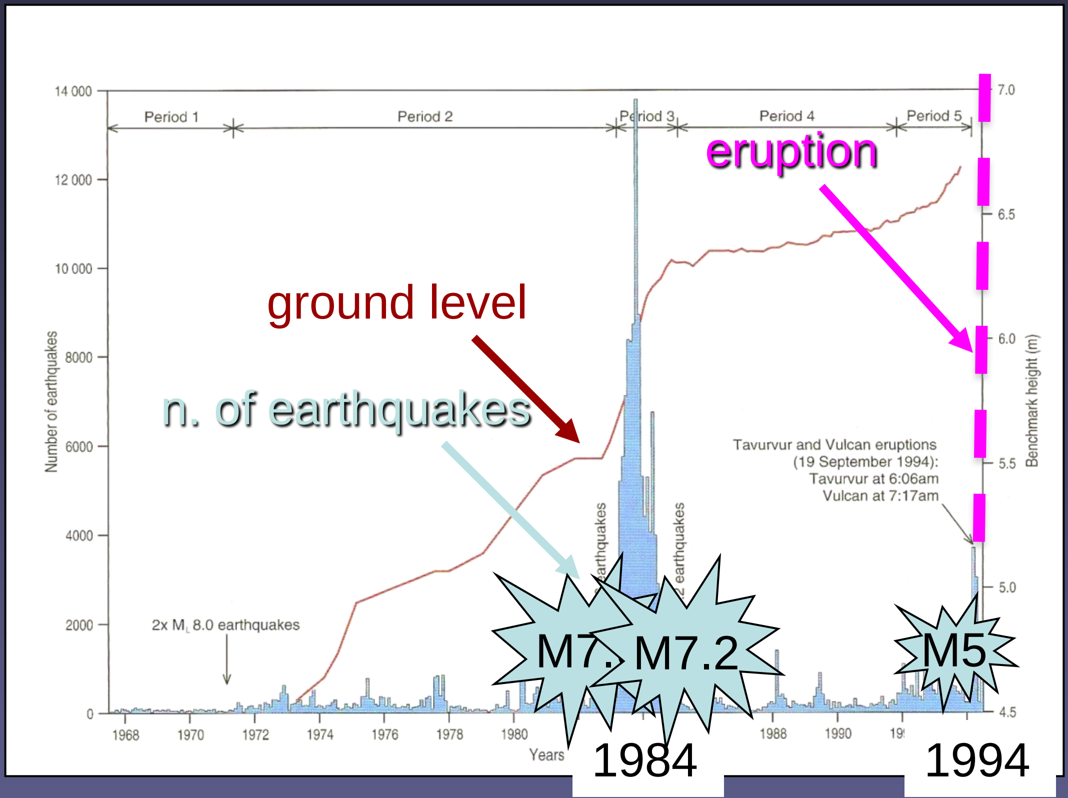
Campi Flegrei caldera, Italy



From *Chiodini et al., 2008.*

Data from INGV – Osservatorio Vesuviano

RABAUL caldera, Papua New Guinea



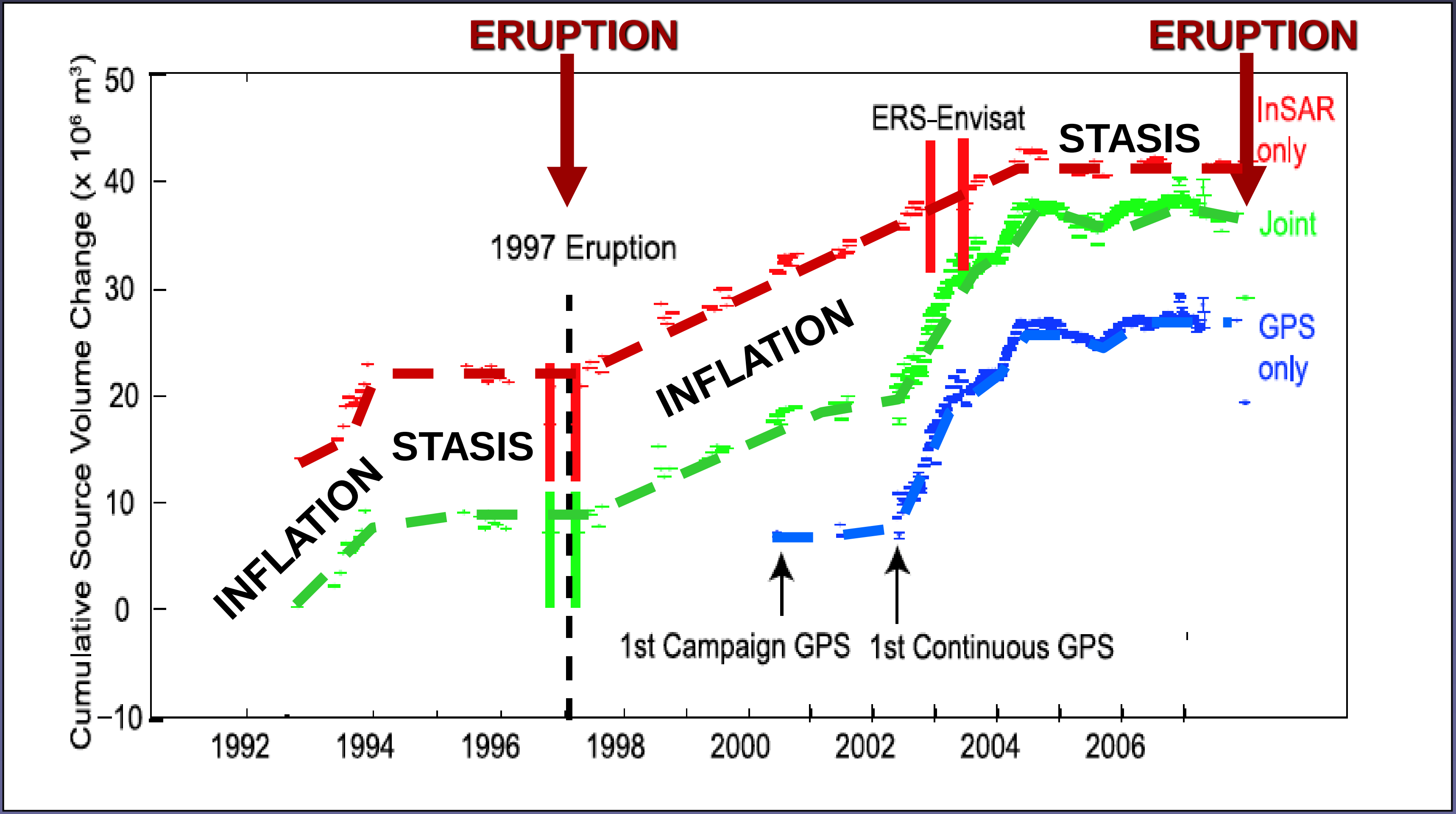
"The eruption began on September 18, **after less than a day of intense seismicity**…"

"The people who lived there were reminded of the inevitability of an eruption by intense earthquake activity and uplift of the ground within the caldera in the mid-1980's."

"However, despite warnings and a declared stage-2 emergency in 1983 and 1984, Rabaul did not erupt and, in fact, **activity waned and remained at low levels until hours before the latest eruption broke out**…"

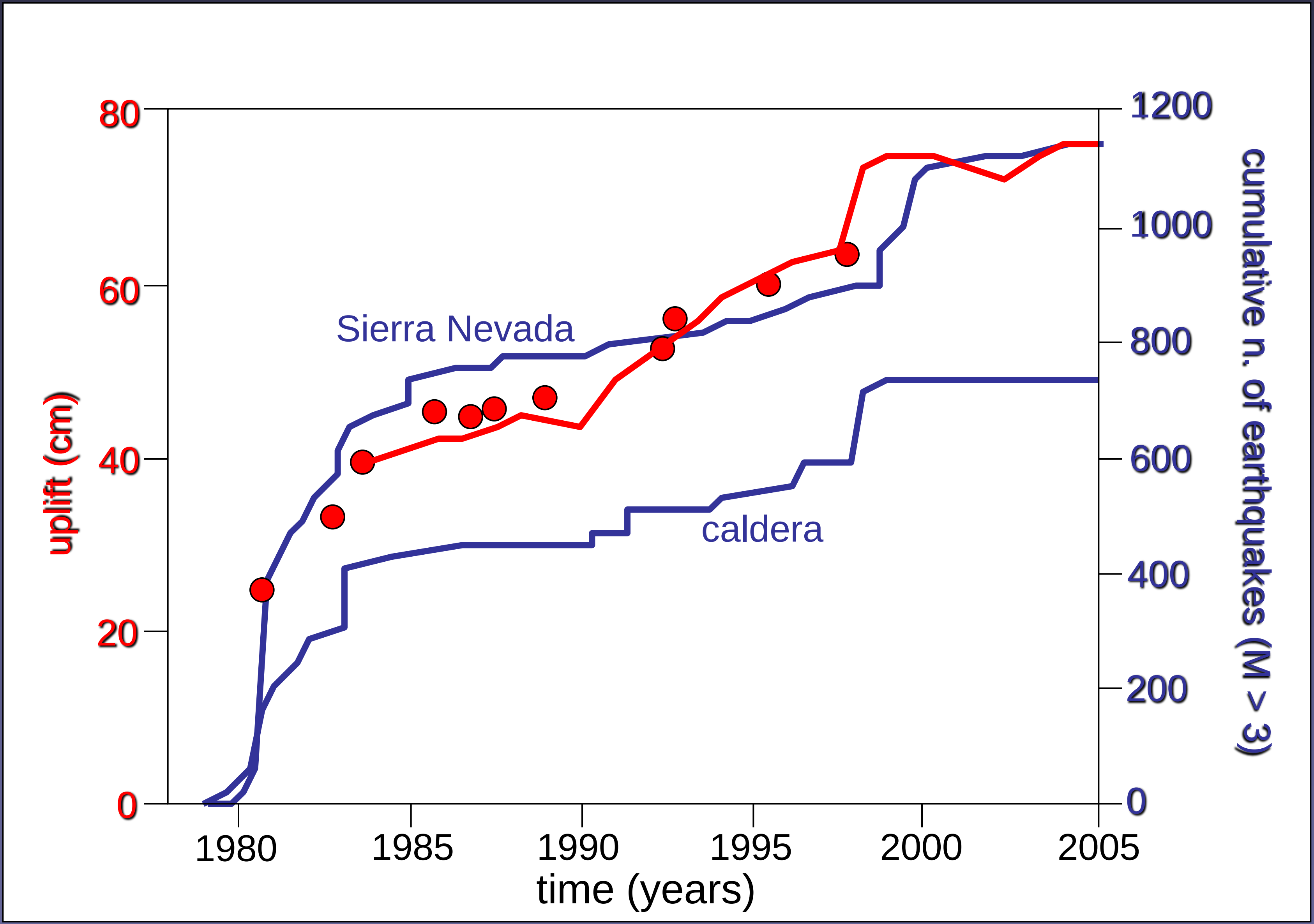
Source: http://hvo.wr.usgs.gov/volcanowatch/1994/94_09_23.html

Okmok caldera, Aleutian Arc, US



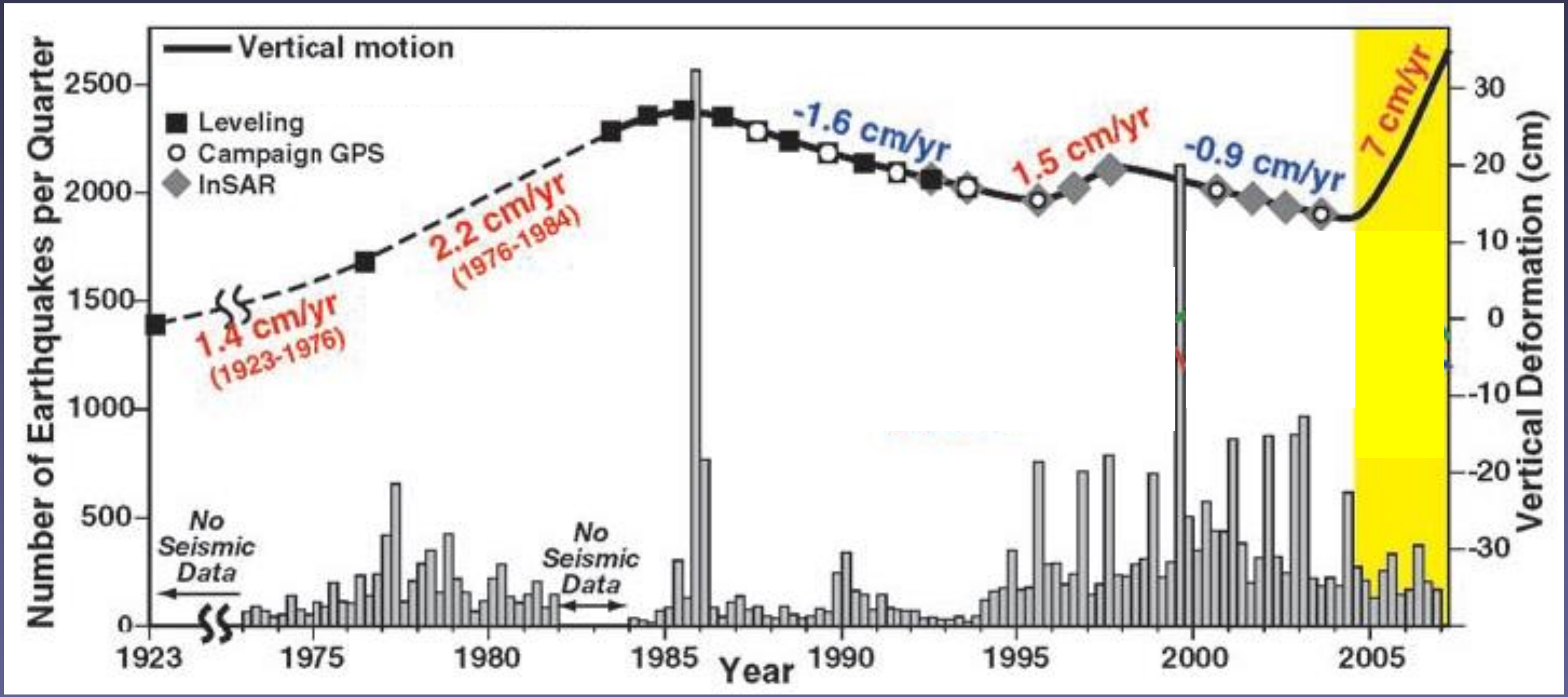
Biggs et al., 2010

Long Valley caldera, California, US



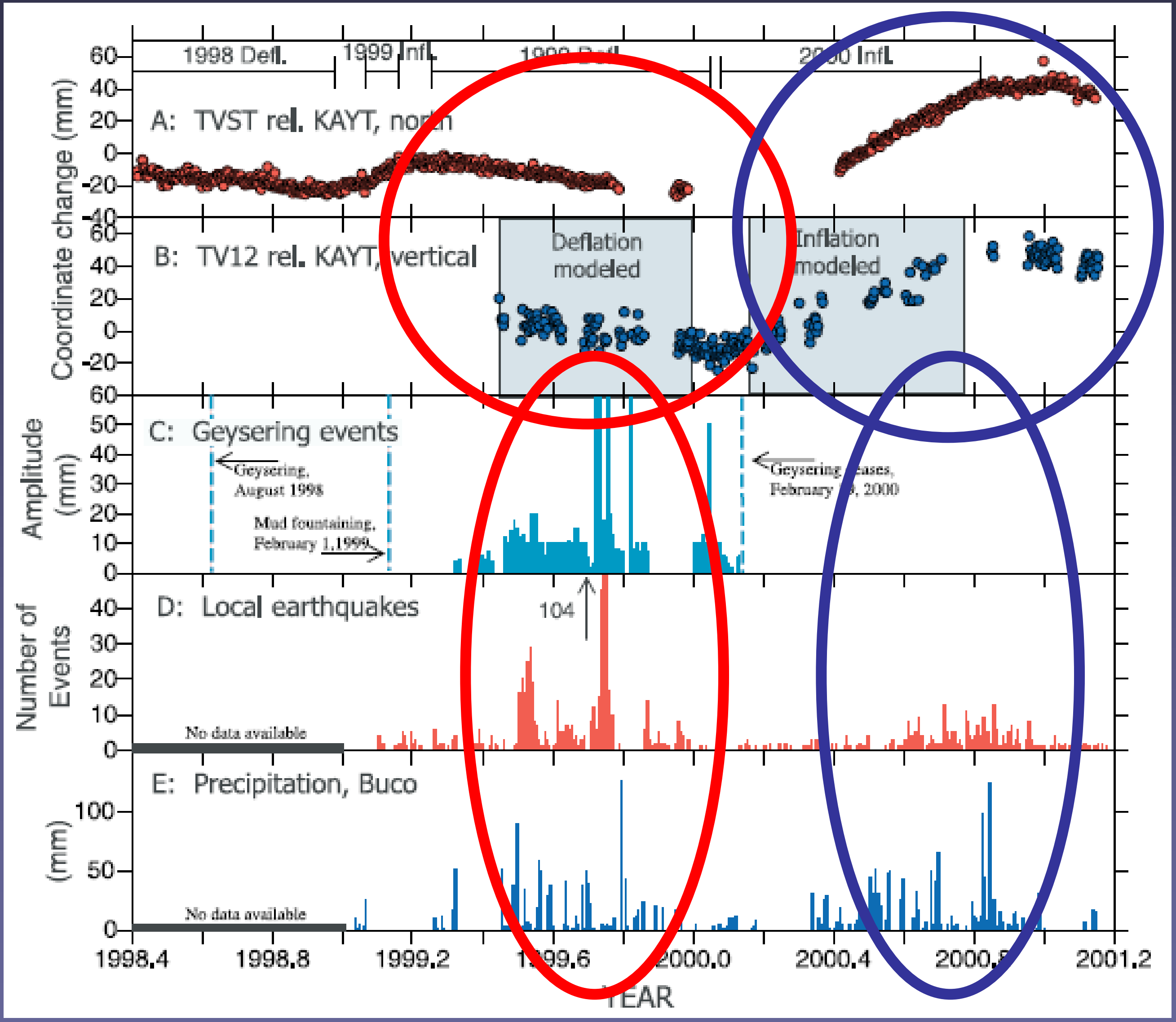
Hill et al., 2006 (re-drawn)

Yellowstone caldera, Wyoming, US



Wu-Lung Chang et al., 2007

Taal caldera, Philippines



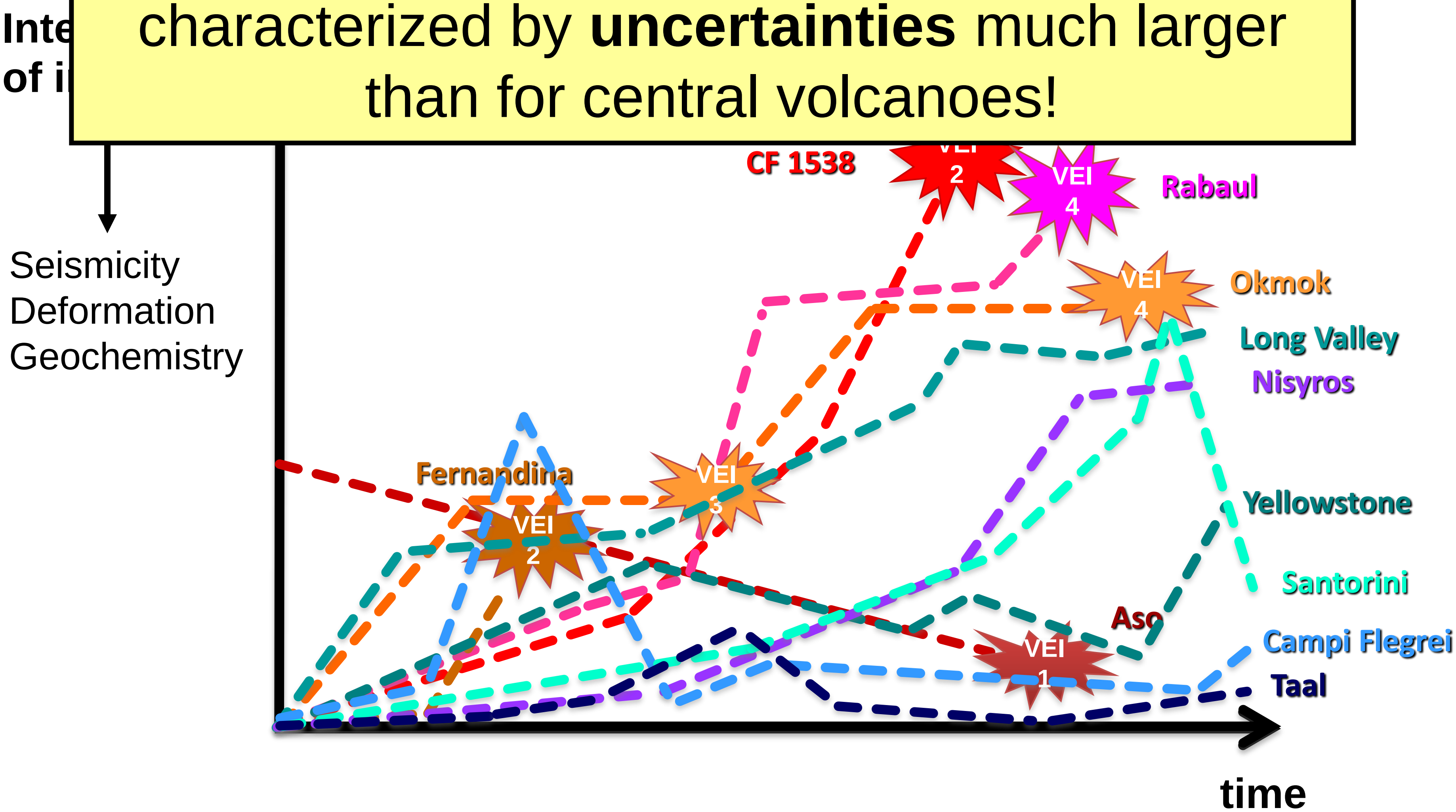
CALDERAS: the “hot” questions

• what’s the relative roles of magma and hydrothermal circulation in determining unrest dynamics at calderas?

• why so often large unrest dynamics do not culminate in an eruption, whereas instead variations much smaller in duration and amplitude may do?

• how to anticipate the occurrence of eruptions at calderas?

Forecasts at calderas are generally characterized by **uncertainties** much larger than for central volcanoes!



Di Lorenzo, Acocella, Scandone, 2013 (redrawn)

(project INGV-DPC 2012-13 – report)

THE FACTS

Large to monster-size caldera-forming eruptions happen!

We do not have (or only have very limited) direct experience of them

Their impacts are global, and can be devastating. There's no large-scale, regional or global resilience plan in place, anywhere

Our capability to anticipate them is limited (no previous instrumental observations; on a lower scale, no confident methods to anticipate the scale of the eruption; large uncertainties in eruption forecasts at calderas)

WE ARE NOT PREPARED!

WHAT TO DO?

Report of a Geological Society of London Working Group: S. Sparks, S. Self, et al.

"Although at present there is no technical fix for averting super-eruptions, improved monitoring, awareness-raising and research-based planning would reduce the suffering of many millions of people."

"**Preparedness** is the key to mitigation of the disastrous effects of a super-eruption."

Investment in research to improve our understanding of regional and global impacts of major volcanic eruptions" [and] "to determine more accurately the composition and amount of volcanic gases and dust released in super-eruptions;"

"An expanded programme to produce comprehensive **inventory of large magnitude explosive eruptions** in recent geological times"

"Initiatives to improve **public understanding** of the nature of volcanic hazards."

"Establishment of a **multidisciplinary Task Force** to consider the environmental, economic, social, and political consequences of large magnitude volcanic eruptions."

My addition:

Promotion of regional-scale and global-scale **resilience plans**, to be managed by regional governments (e.g., the U.S. Federal Government; the European Community; etc.) and international organizations (e.g. the United Nations)

MUCHAS GRACIAS POR SU ATENCIÒN

Forecasts at calderas are generally characterized by **uncertainties** much larger than for central volcanoes!

Campi Flegrei – Pre-eruptive Event Tree

ELICITATION V		BACKGROUND	Gray area	UNREST	Gray area	MAGM. UNREST	Gray area	ERUPTION
VT (M > 0.8)	[ev/day]	5		15				
LP/VLP/ULP	[ev/month]	2		10				
Rate uplift	[cm/month]	0.7		1.3				
Uplift	[cm]	2		6				
Uplift (unrest → magm. unrest)	[cm]			6		15		
T Pisciarelli		100		110				
VLP/ULP				1		5		
Deep VT (M > 0.8)	[ev/day]			2		20		
Deep LP (> 2 Km)	[ev/day]			3		20		
Disp. Hypocenters	[km]					1		3
Tremor								YES
Deep Tremor (>3.5 Km)						YES		
Acc. seismic events								YES
Acc. RSAM								YES
New fractures								YES
Macr. (dm) variation in def.								YES
Migr. max uplift								YES
Ext degassing				YES				
Magm. comp. gases						YES		
HF - HCl - SO2						YES		YES
Phreatic activity								YES

DELPHI METHOD

Red parameters: Seismicity

Green parameters: Deformation

Blue parameters: Geochemistry

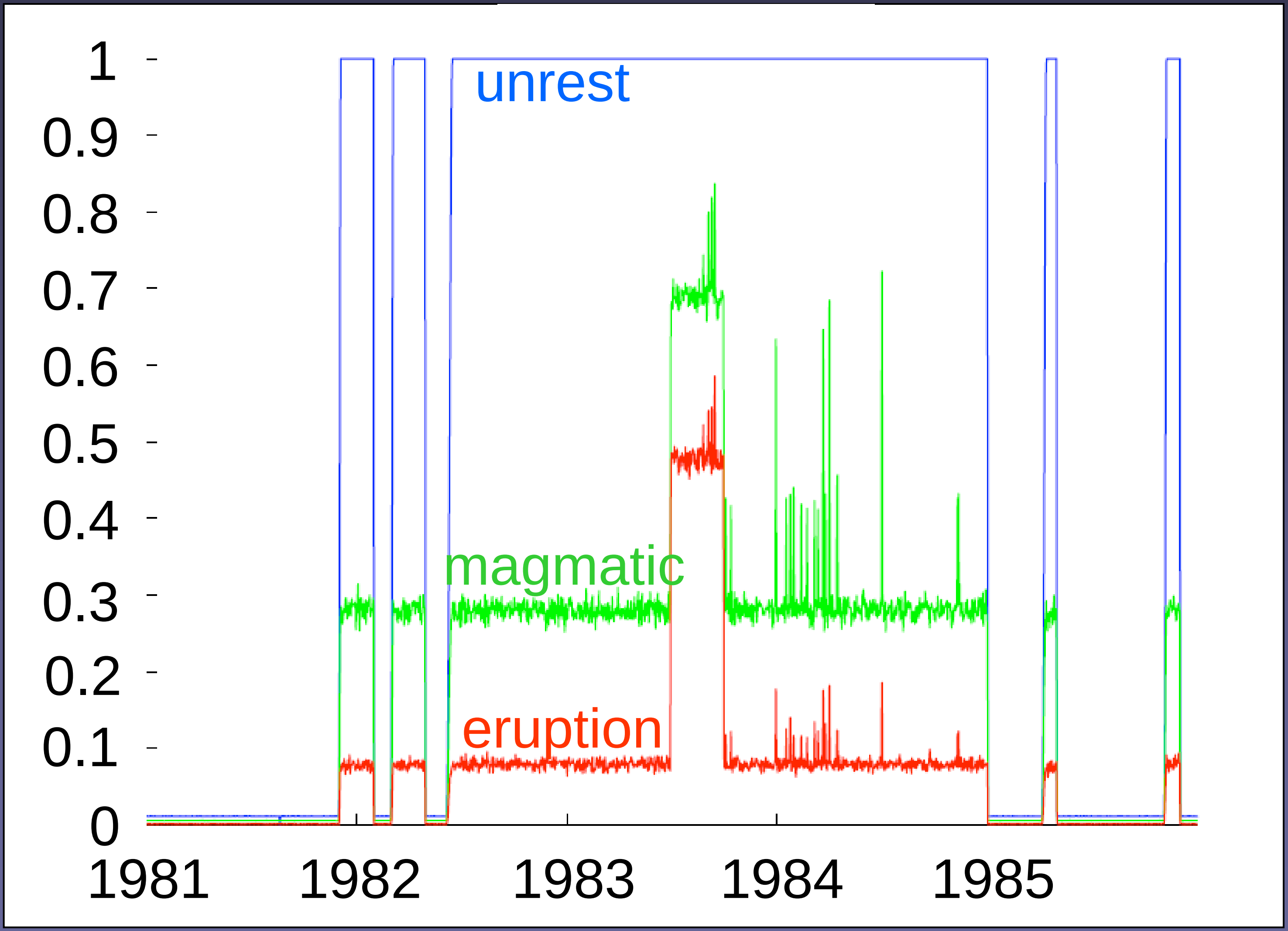
Boolean parameters are represented by "YES"

"Gray areas" correspond to variable probability of being in the adjacent states, depending on the measured values

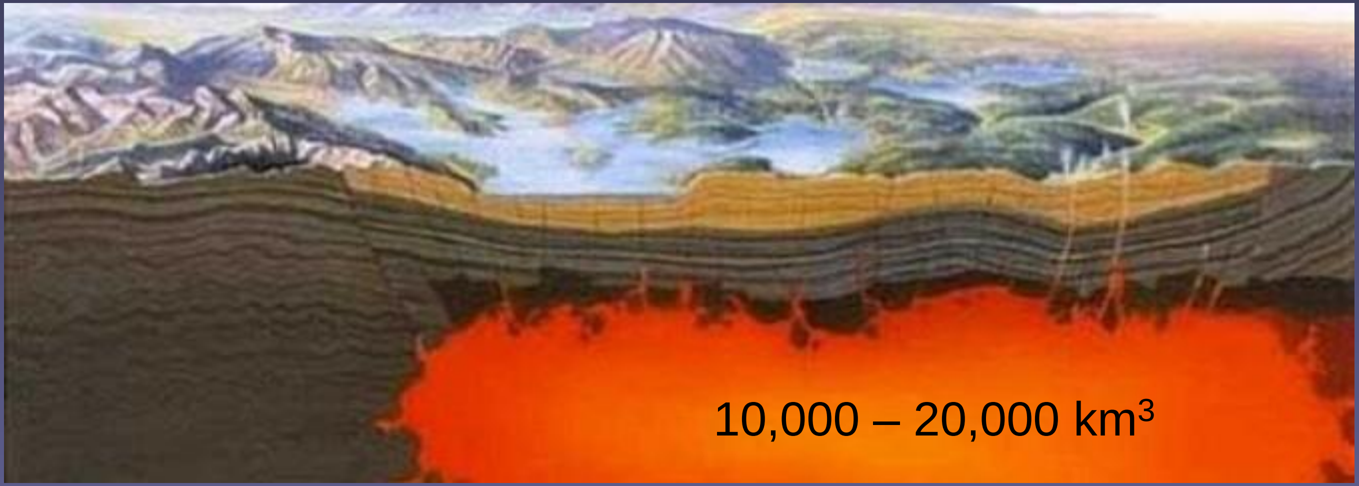
after Selva et al., 2011

Probabilistic approach to eruption forecast

Application to Campi Flegrei crisis 1982-1984



after Selva et al., 2010



Yellowstone National Park

Image: Sean Callinan Source: News Limited

Iceland at noon, during the Eyjafjallajokull eruption, Iceland, in 2010

Ash-covered, devastated landscape after the 1991 Piñatubo eruption, Philippines

Plinian eruptions

Eyjafjallajökull, Iceland, 2010


Grimsvotn, Iceland, 2011


Puyehue, Chile, 2011


Puyehue, Chile, 2011


Kurili Islands, 2009