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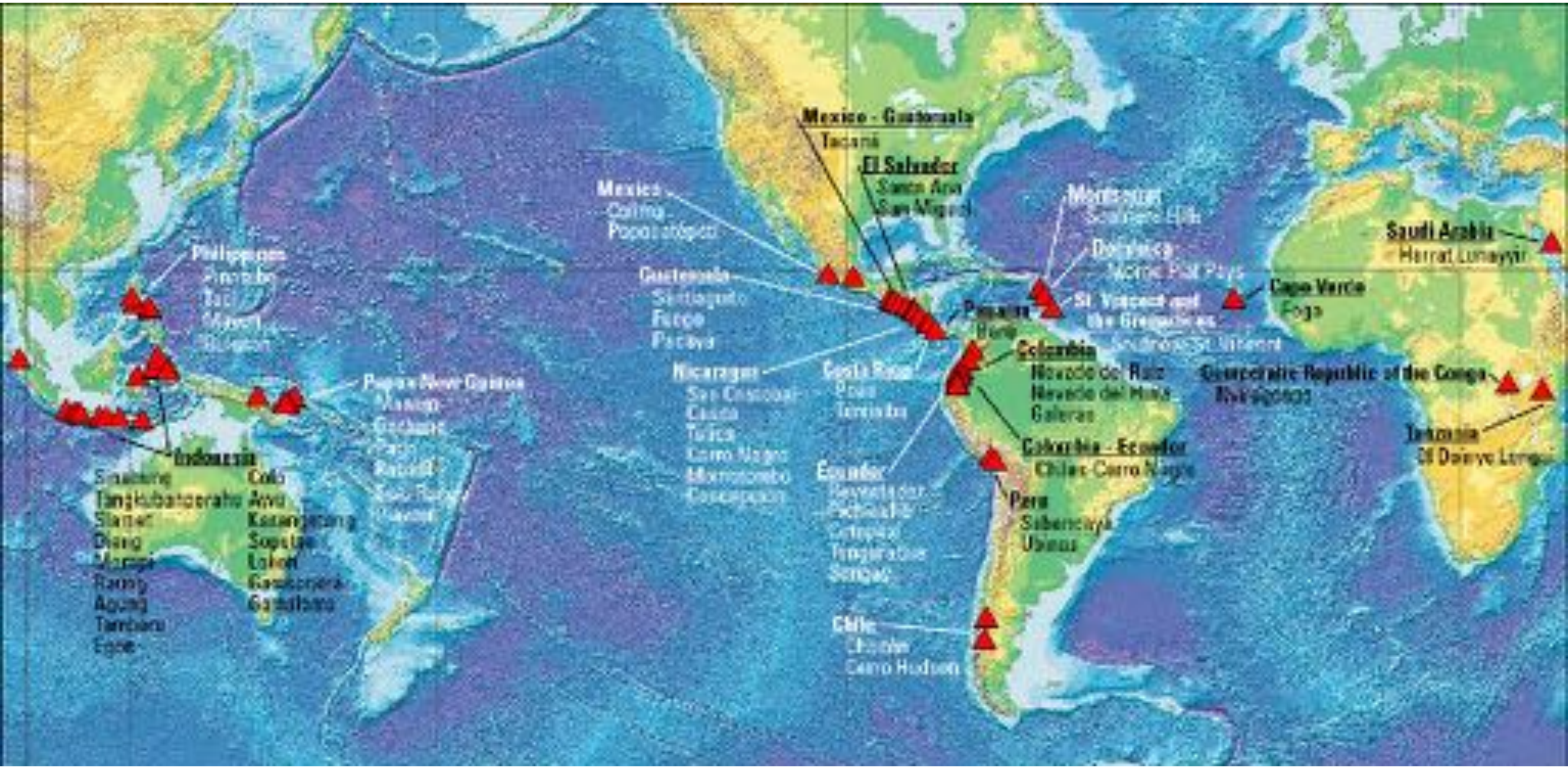
Volcanoes, Calderas and Eruptions: What we know and what we don't know.

Jake Lowenstern
USGS
Vancouver, WA

Cotopaxi 2015, by Henri Leduc, used with permission

Volcano Disaster Assistance Program



~80 Volcano responses by VDAP since 1986 in 20 countries

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THIS TALK

- **Eruptions**
  - How good are we at forecasting them?
  - What hinders our progress?
  - How well do we understand magmatic systems?
  - What's a typical run-up to an eruption?

- **Efforts to save lives**
  - What is important in keeping people safe?
  - What's the role of science?
  - How specific should we be with a forecast?

Four sections

I. How do we typically forecast eruptions?

II. How successful are we at forecasting eruptions and their effects?

III. Our understanding of the subsurface leads to great uncertainty in our forecasts.

IV. The challenge of volcanic-risk mitigation

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About Volcanic Hazards

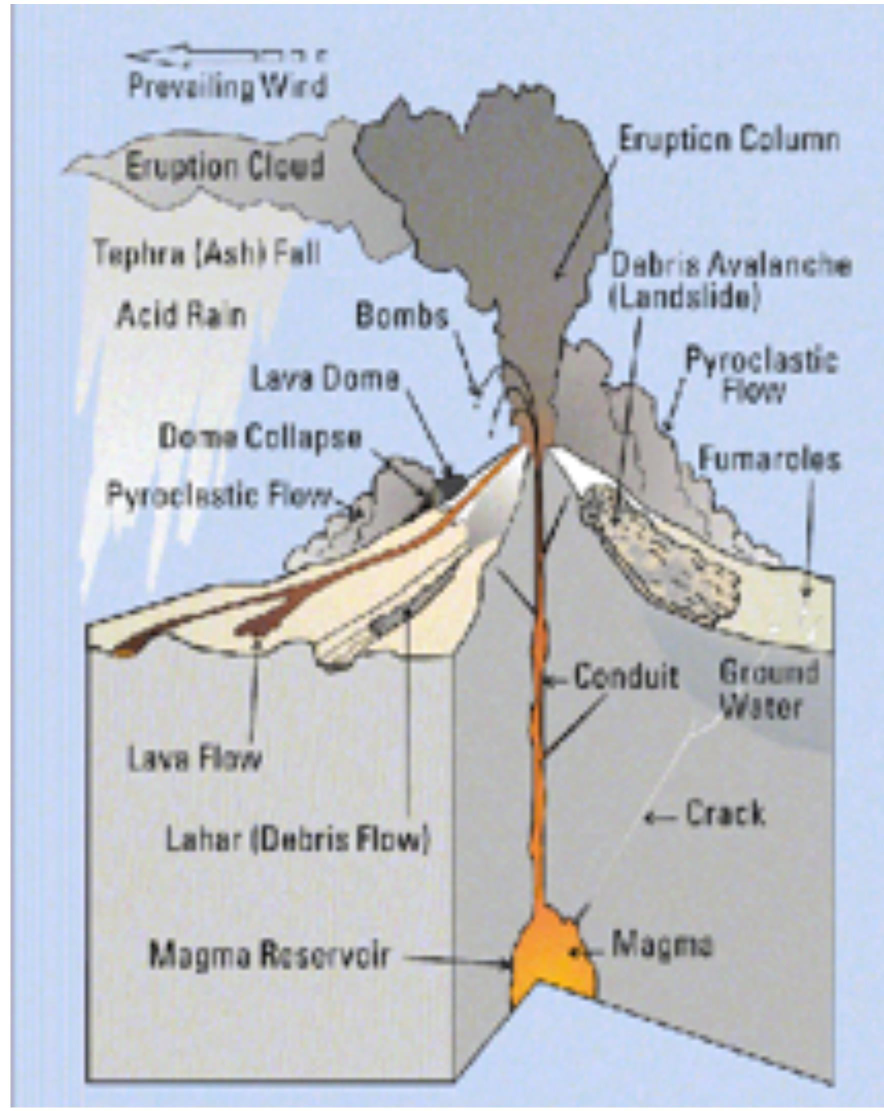
Principal Volcanic Hazards

- Ashfall *(roof collapse, agricultural and aviation hazards)*
- Pyroclastic flows & surges *(nothing in path survives)*
- Lahars *(mudflows; major killer, long-term impacts)*
- Lava *(locally serious)*

Volcanic Explosivity Index

- Eruptions range from tiny to immense.

What are we predicting?



USGS Illustration

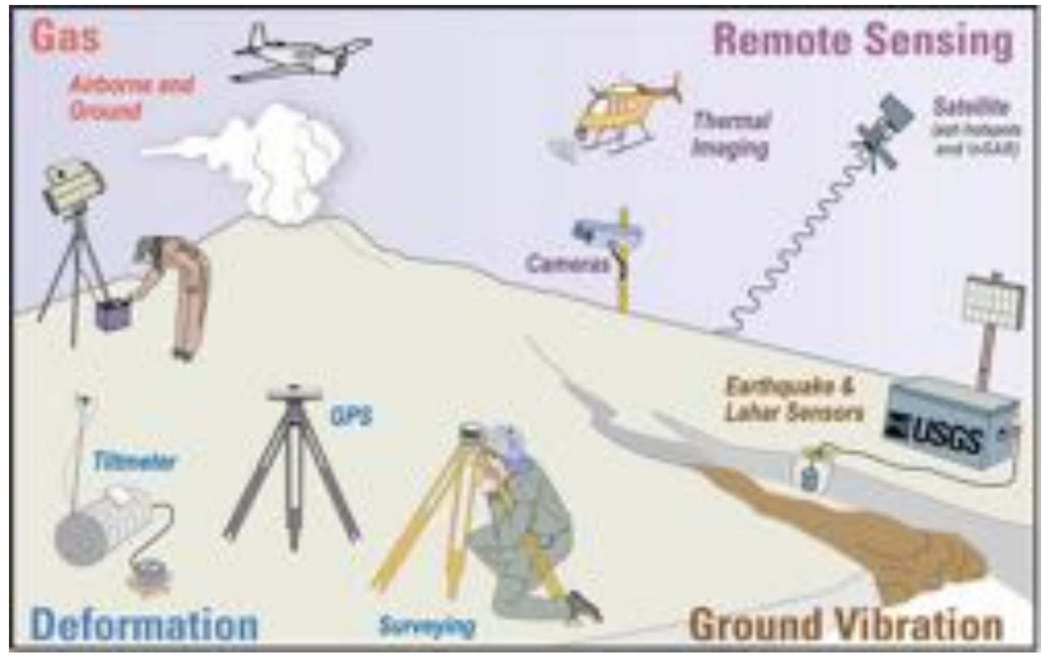
Monitoring Volcanoes

Principal Techniques

- Seismic
- Geodetic
- Gas
- Satellite
- Visual (cameras)

Other Techniques

- Thermal
- Gravity
- Magnetics



USGS Illustration

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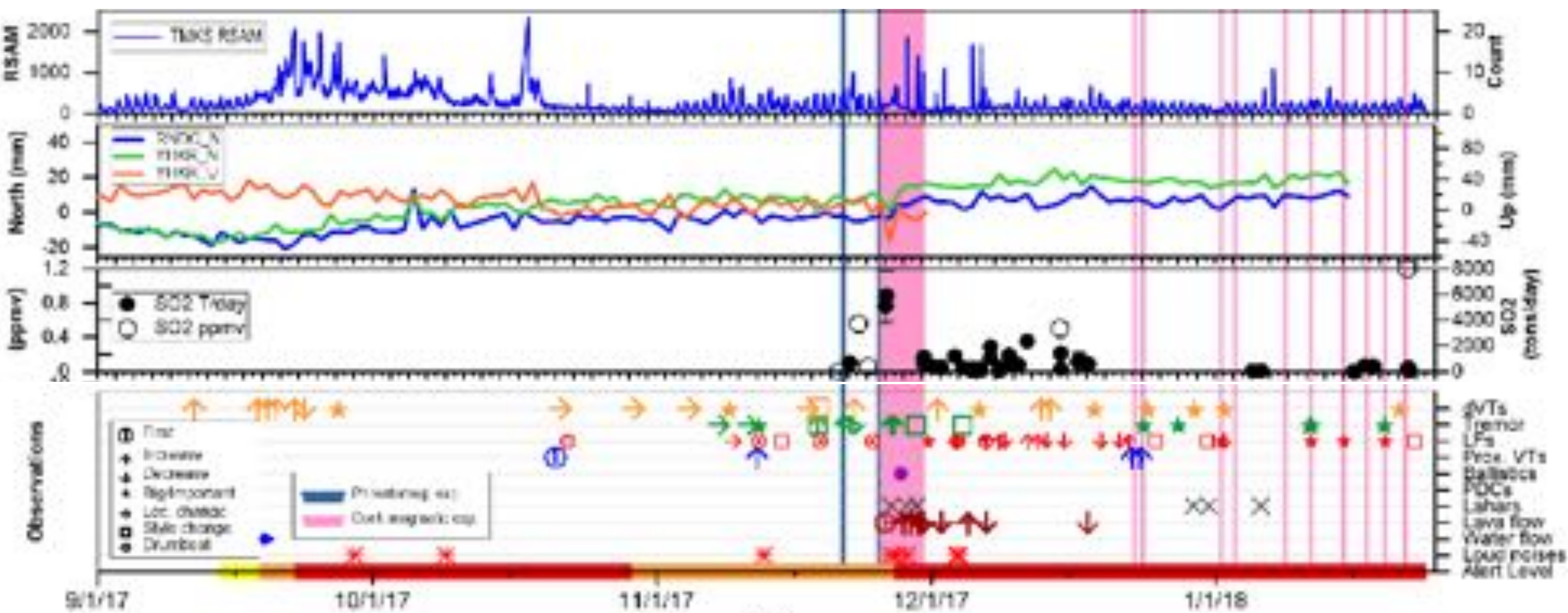
I. How do we typically forecast eruptions?

Monitoring Data



Mt. Agung data, in Syahbana et al., 2019

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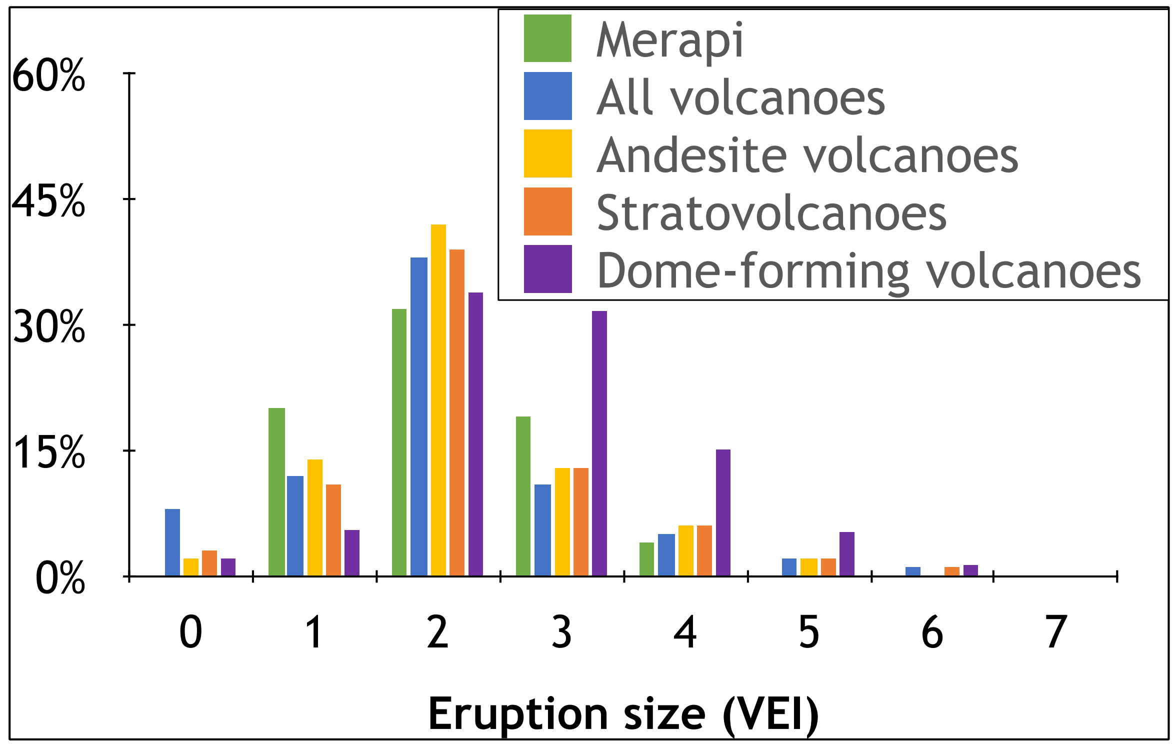
Analogues to inform expectations

Global Data



Slide courtesy of Sarah Ogburn, USGS

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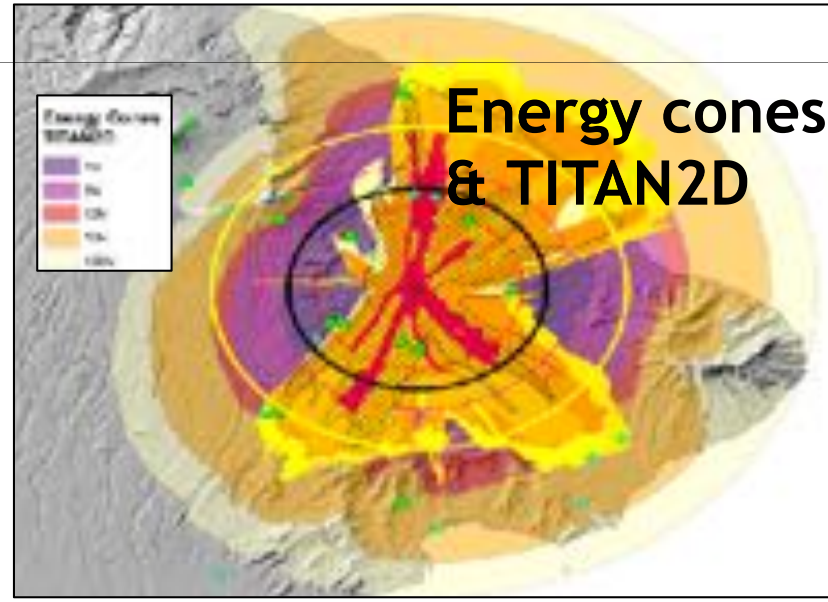
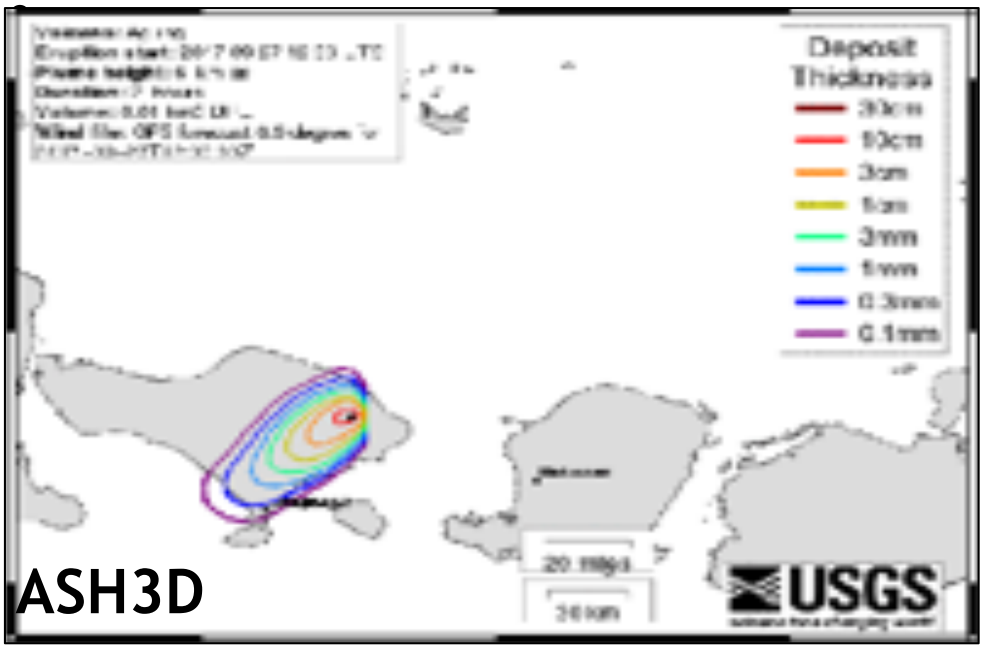
Models to estimate impacts

- Statistical model (energy cone) for pyroclastic flows
- LAHARZ for lahars
- Geophysical model (TITAN2D) for pyroclastic flows
- ASH3D for ash dispersal



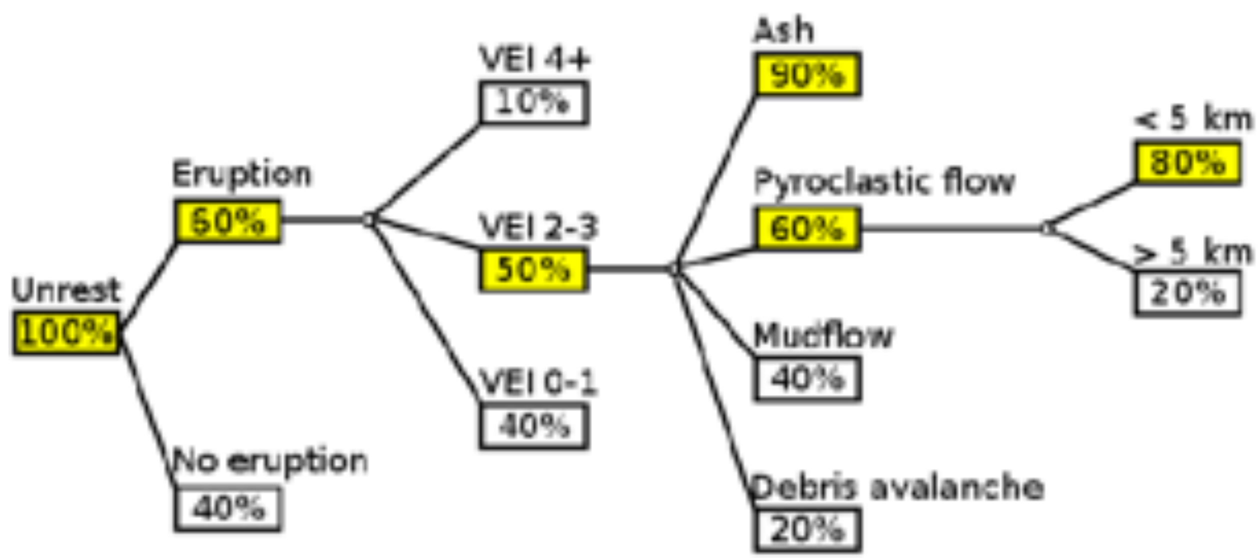


Slide courtesy of Sarah Ogburn, USGS

Event Trees: Putting it all together

- How big are eruptions at this volcano in the past or at volcanoes like this one from around the world?
  - How many other volcanoes had seismicity like this before erupting? What rate of seismicity is anomalous?
    - How far do pyroclastic flows travel at this volcano according to the geologic map or a computer model?
      - How long do eruptions at similar volcanoes last?

Event Tree



Slide courtesy of Sarah Ogburn, USGS

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I. How do we typically forecast eruptions?

Summary Statement:

Forecasting requires good monitoring, good models, complete databases, methodology to determine probabilities (expert solicitations or pre-defined thresholds). It's a huge continuing challenge.

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II. How successful are we at forecasting eruptions and their effects?

To be useful, a forecast should:

- Provide a timeframe.
- Provide a magnitude for the event.
- Provide geographic boundaries for the area that will be affected.
- Be understood so it can be acted upon.

This is difficult.

Volcano forecasts by Alaska Volcano Observatory

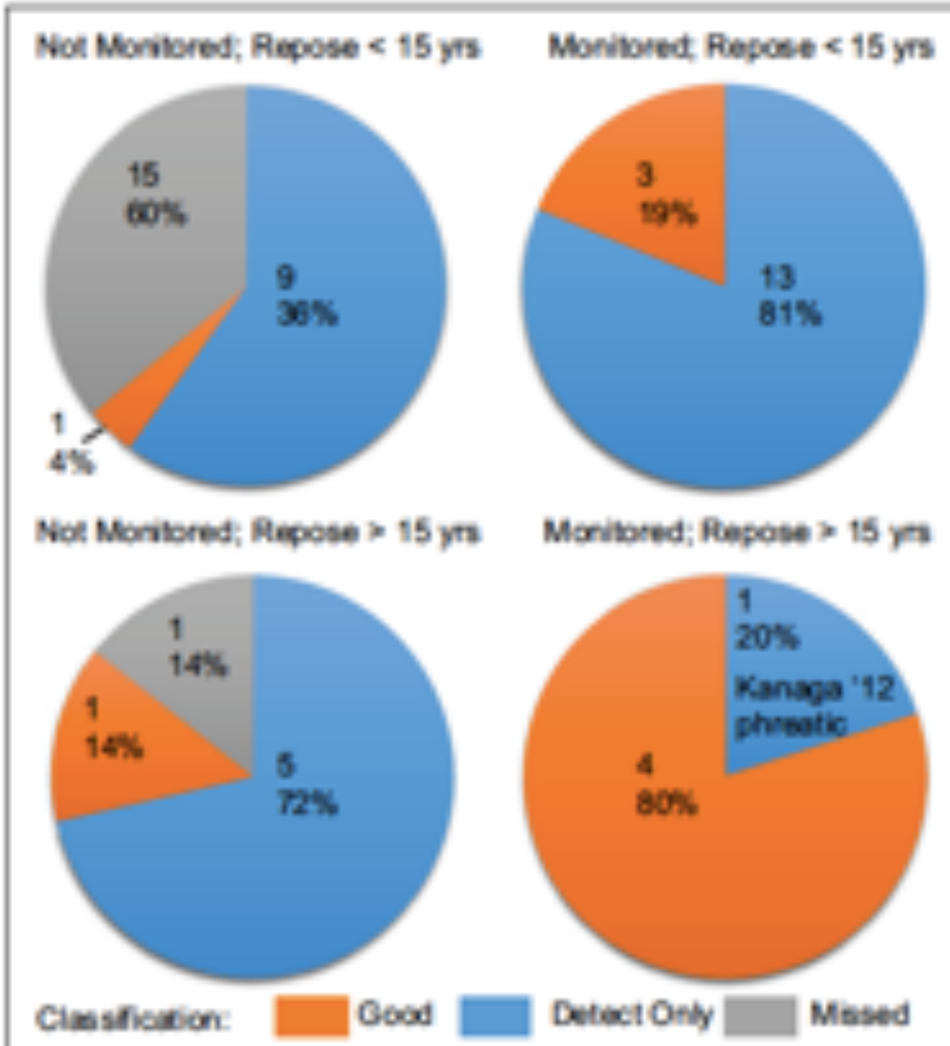

FIGURE 9 | Four pie charts, showing event-notification classes for eruptions, based on seismically monitored/unmonitored status and repose less than or greater than 15 years. Number of eruptions and percentage of the pie are shown in each slice. For the lower right pie chart, showing those eruptions with both seismic monitoring and repose times longer than 15 years, Kanaga 2012 (the single not-forecast event) is the only phreatic eruption of this group.

Cameron et al. 2018

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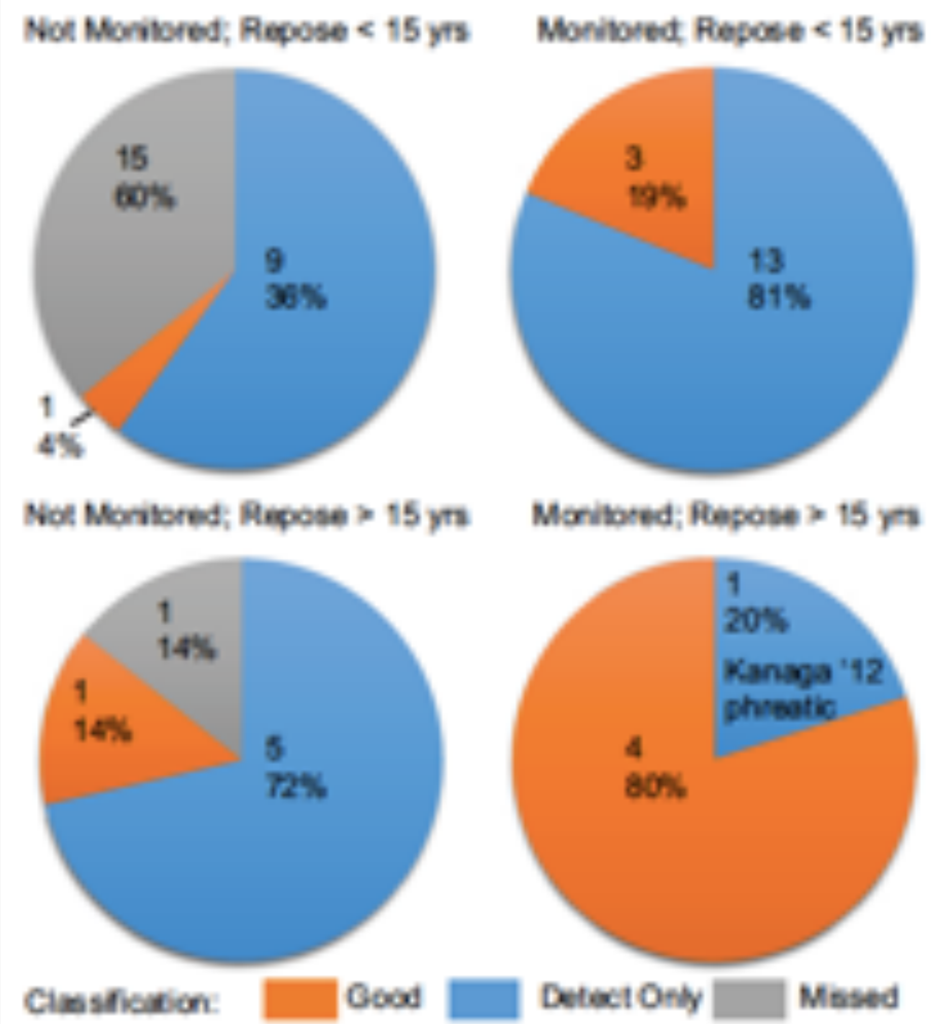
Volcano forecasts by Alaska Volcano Observatory

- We do better on monitored volcanoes.
- Frequently active volcanoes are harder to predict than ones that erupt out of long-term quiescence.



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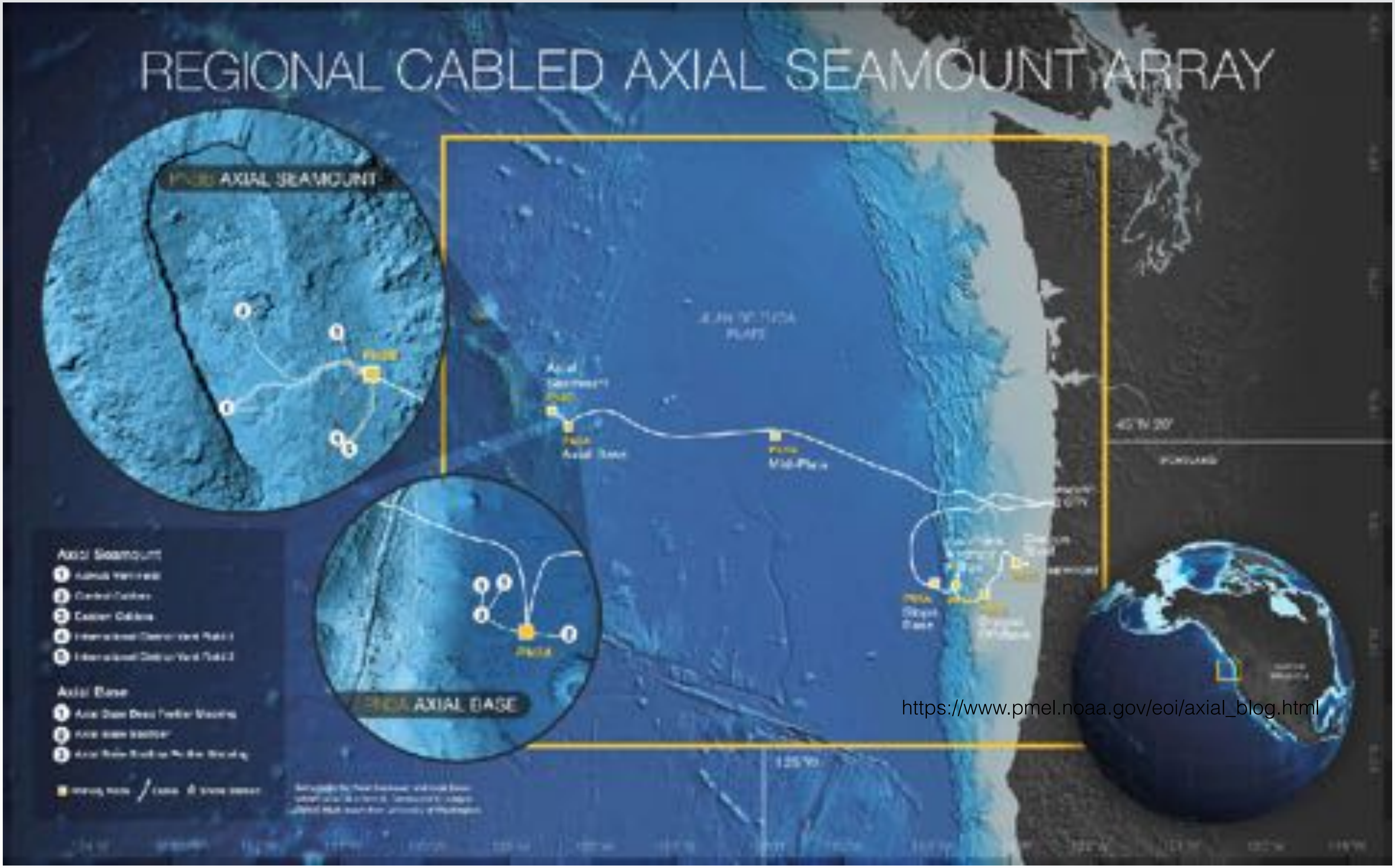
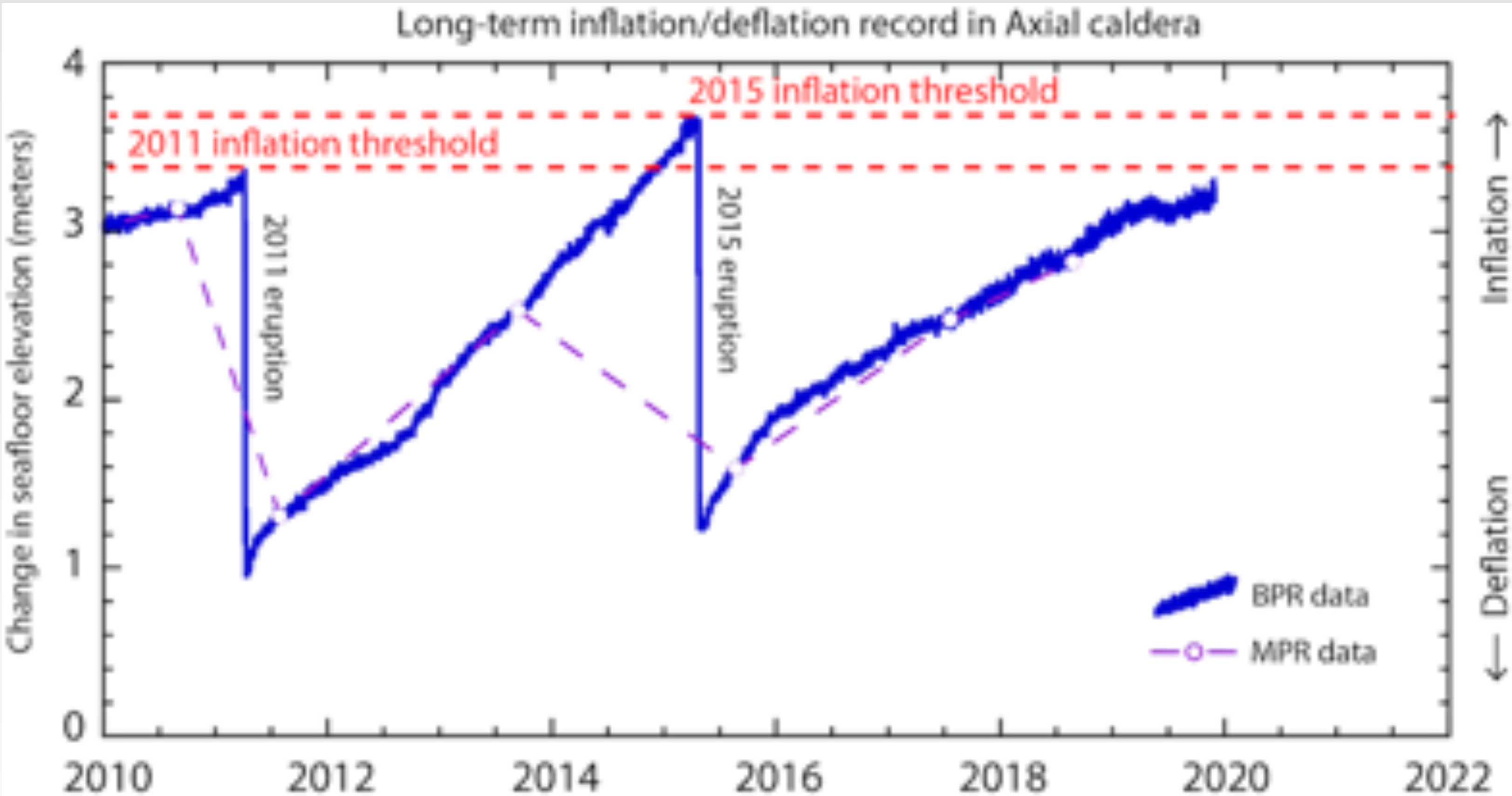
Cameron et al. 2018

Ideal "steady state" behavior



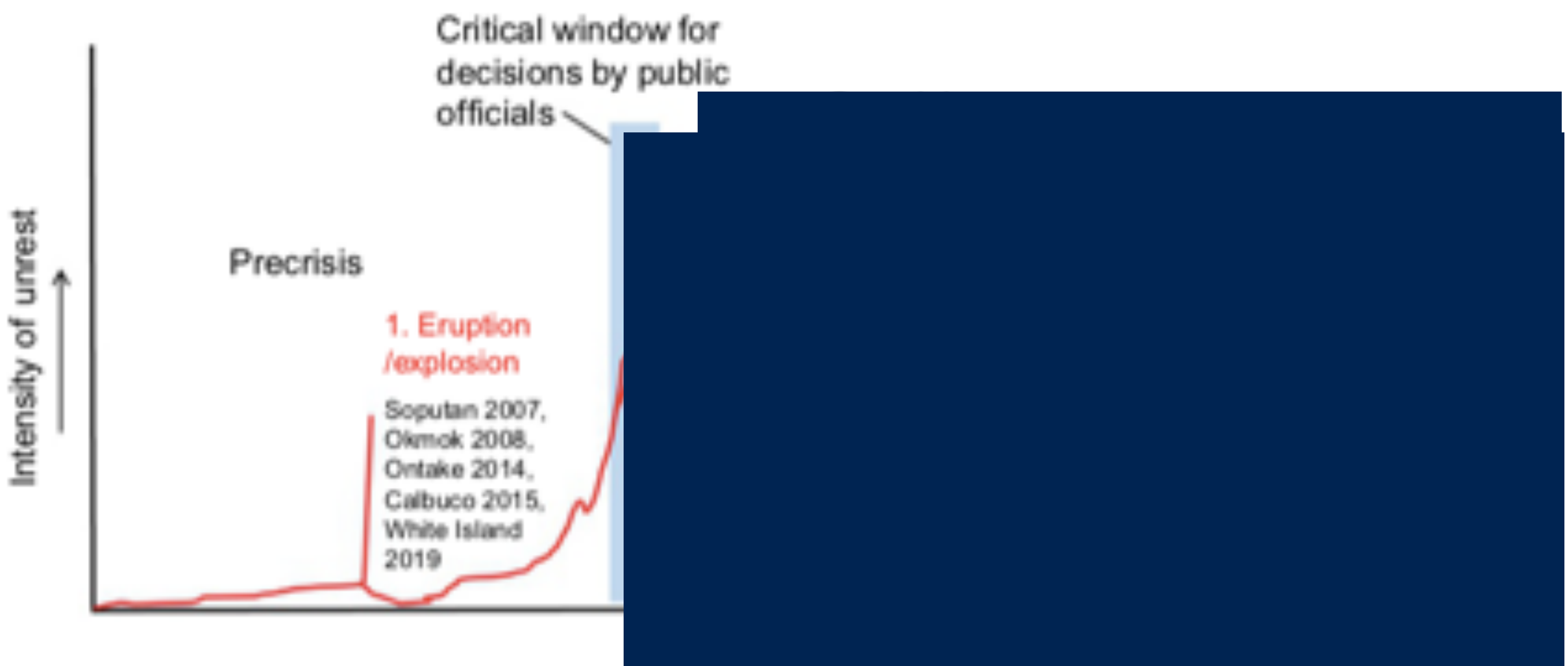
Center for Environmental Visualization, University of Washington

Ideal "steady state" behavior



https://www.pmel.noaa.gov/eoi/axial_blog.html

Timing of Unrest



Dan Miller, USGS diagram
Updated in Newhall et al., 2020

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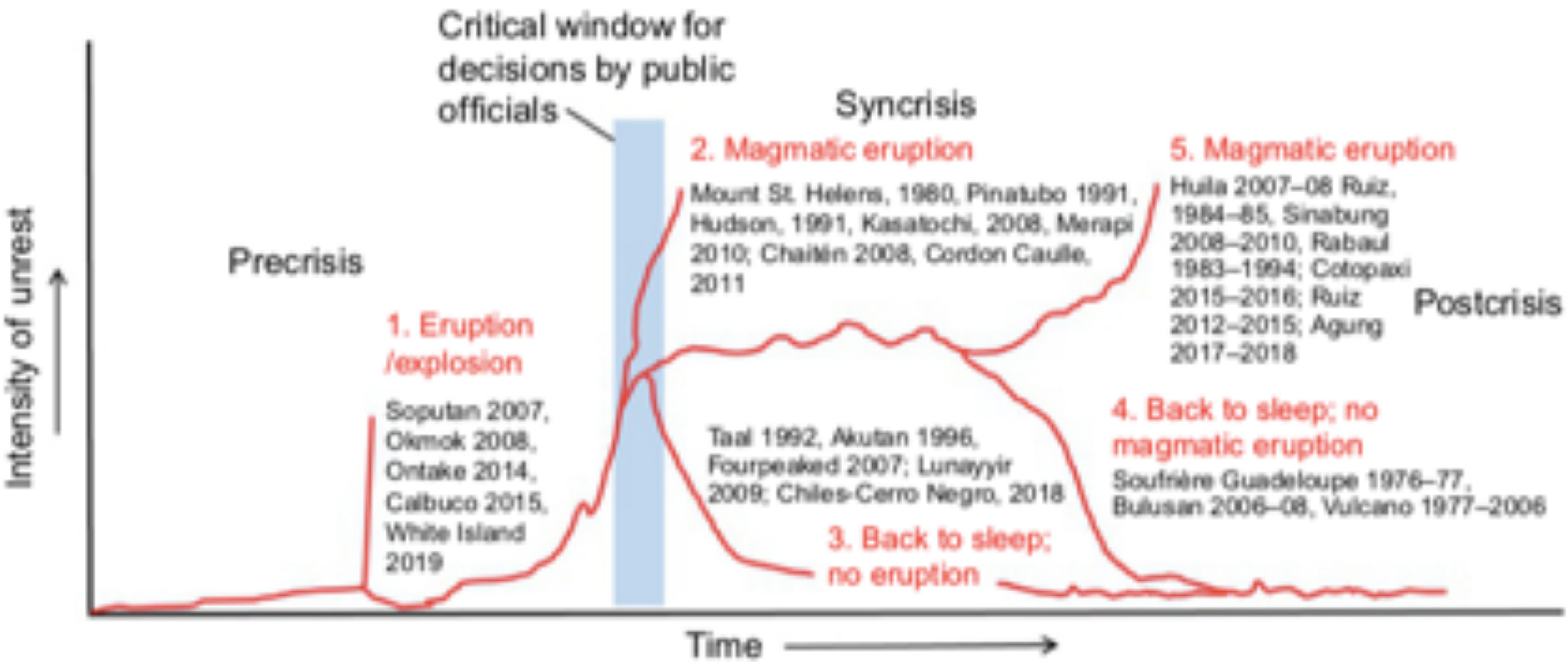
Timing of Unrest



Dan Miller, USGS diagram
Updated in Newhall et al., 2020

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Note: We have had many successes

Pinatubo 1991
Rabaul 1994
Usu 2000
Merapi 2010

USGS Photo of Pinatubo Crater, 1991: Tom Casadevall

And we're continually improving.

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Case Study From Bali: Agung

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1963 VEI 5 Eruption


PART I

By WINDSOR P. BOOTH

Disaster in Paradise

Two National Geographic reporters describe the eruption of Bali's sacred Mount Agung and its tragic aftermath

Illustrations by National Geographic photographer ROBERT F. SISSON

LAST MARCH 16 I realized a lifelong dream of visiting the fabulously beautiful island of Bali. The day after I arrived, Bali's most sacred volcano, Gunung Agung, which islanders call the "navel of the world," exploded in my face.

Before Mount Agung simmered down, it had destroyed much of northeastern Bali, made a wilderness of a paradise, and killed more than 1,500 of some of the world's handsomest and most talented people. Countless homes and farms were demolished or grievously damaged.

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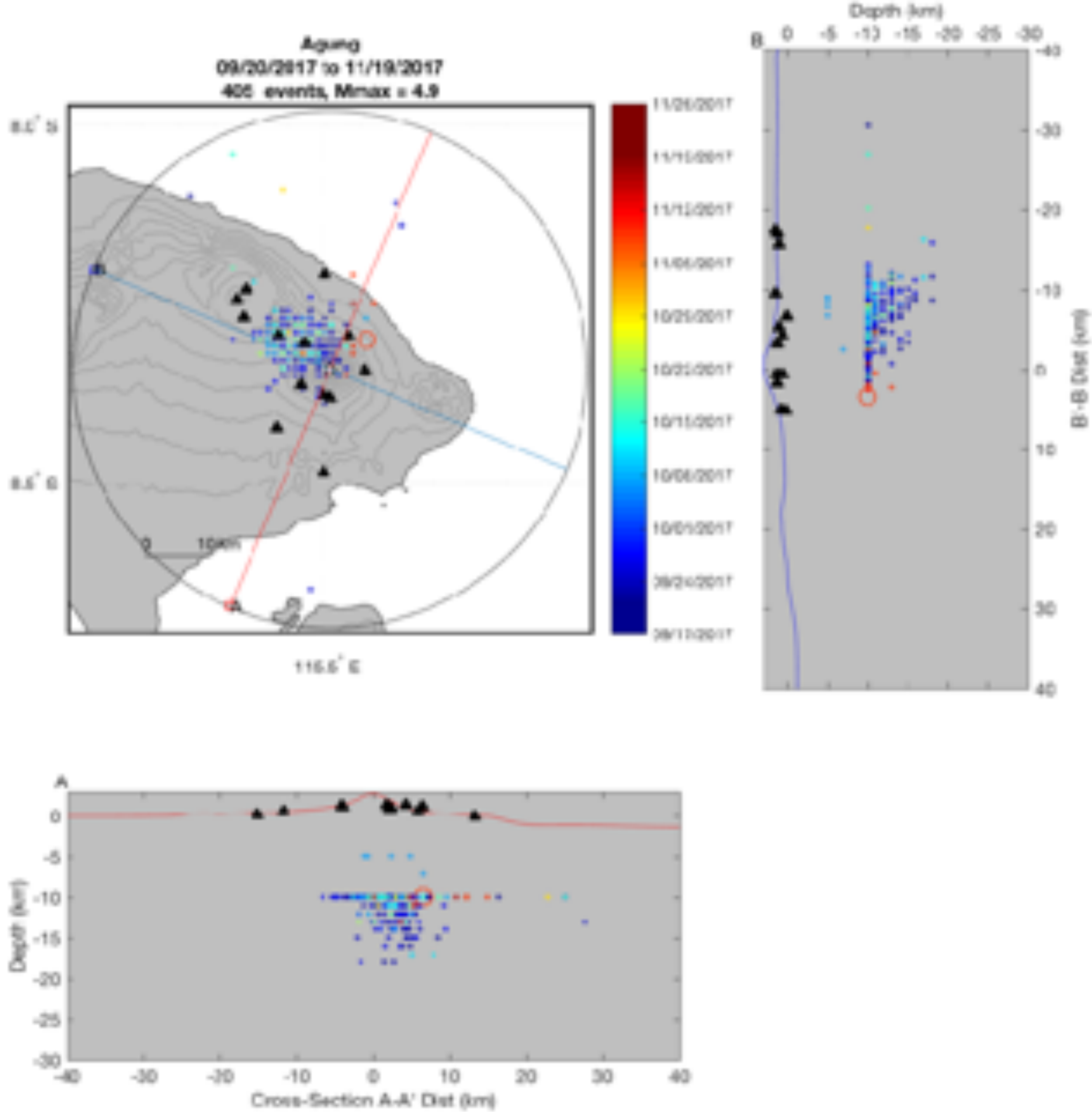

Data and plots supporting Syahbana et al. 2019

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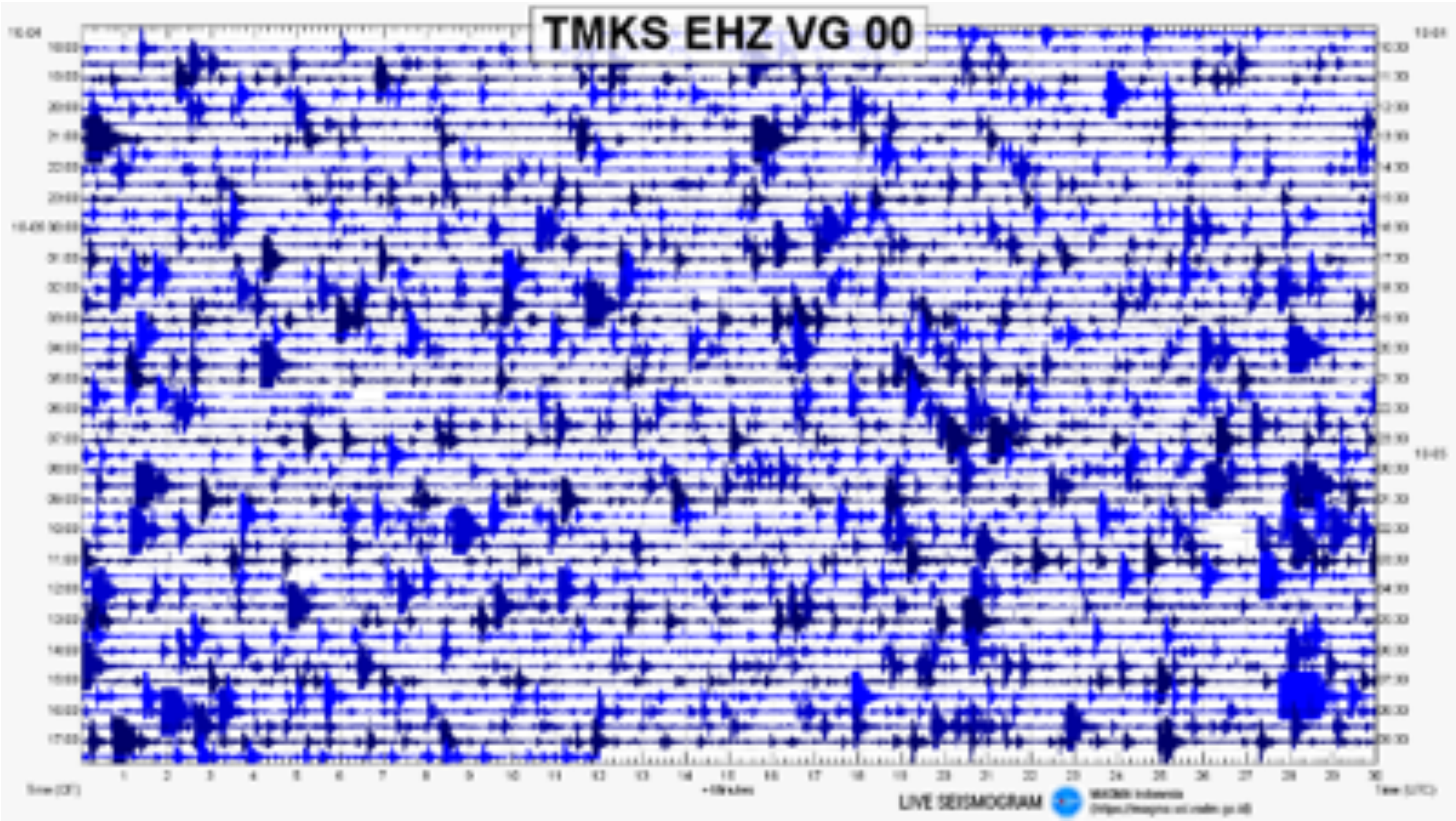
Oct 4, 2017



From Magma Indonesia website

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Crater of Mt. Agung, photographer unknown, courtesy of CVGHM

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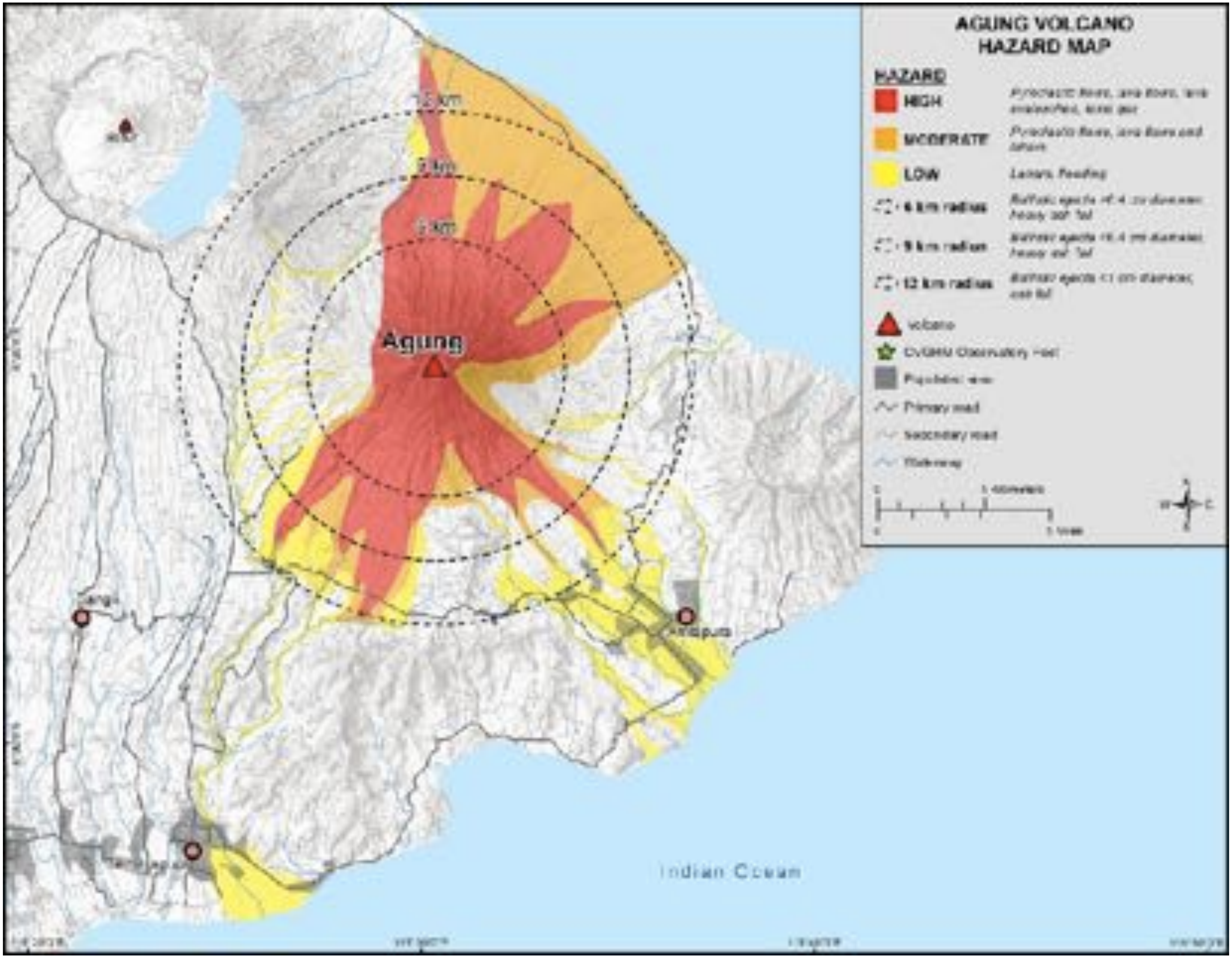

Simplified unpublished Hazard map used by VDAP and based on official map.

USGS photo

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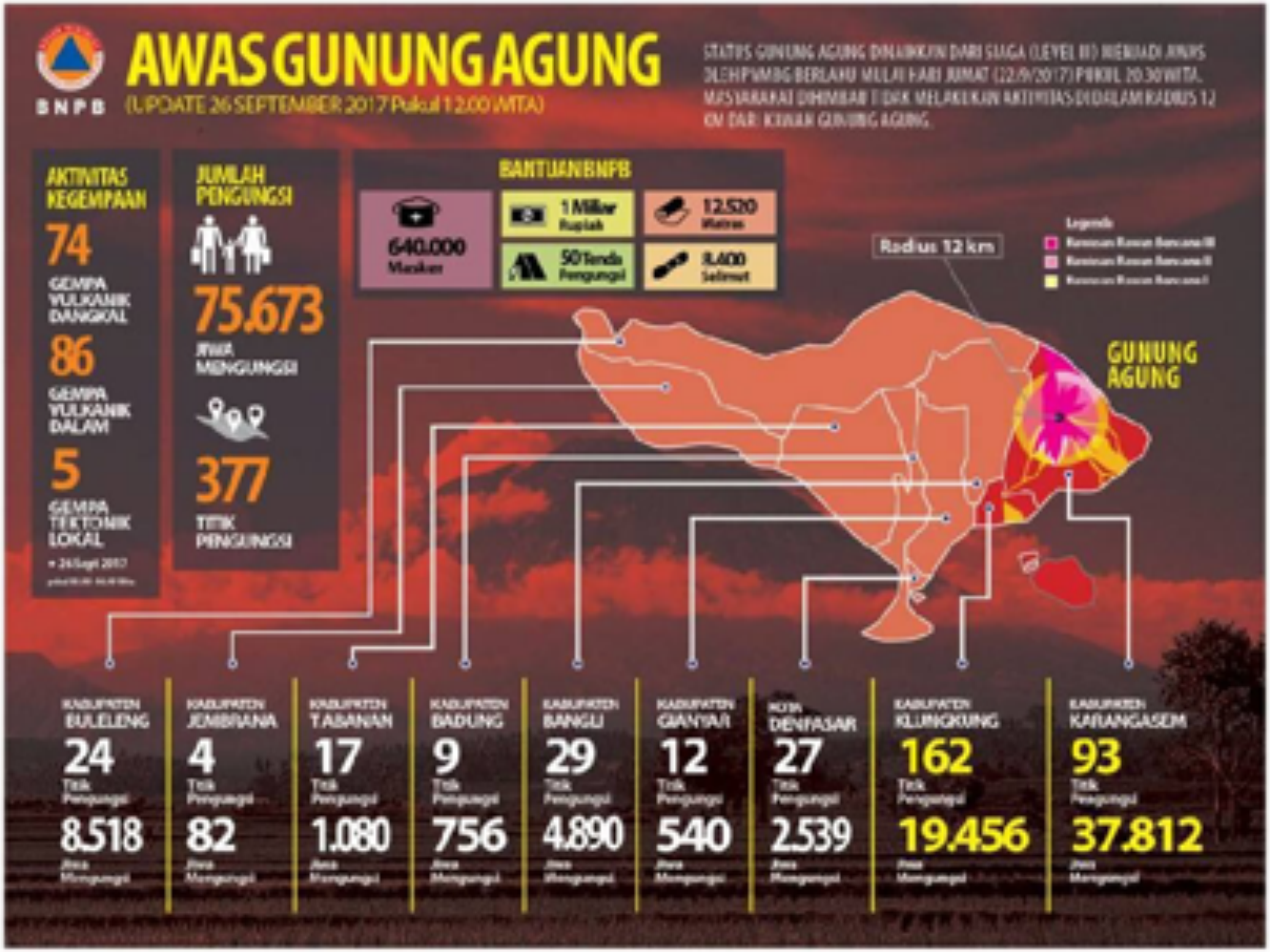
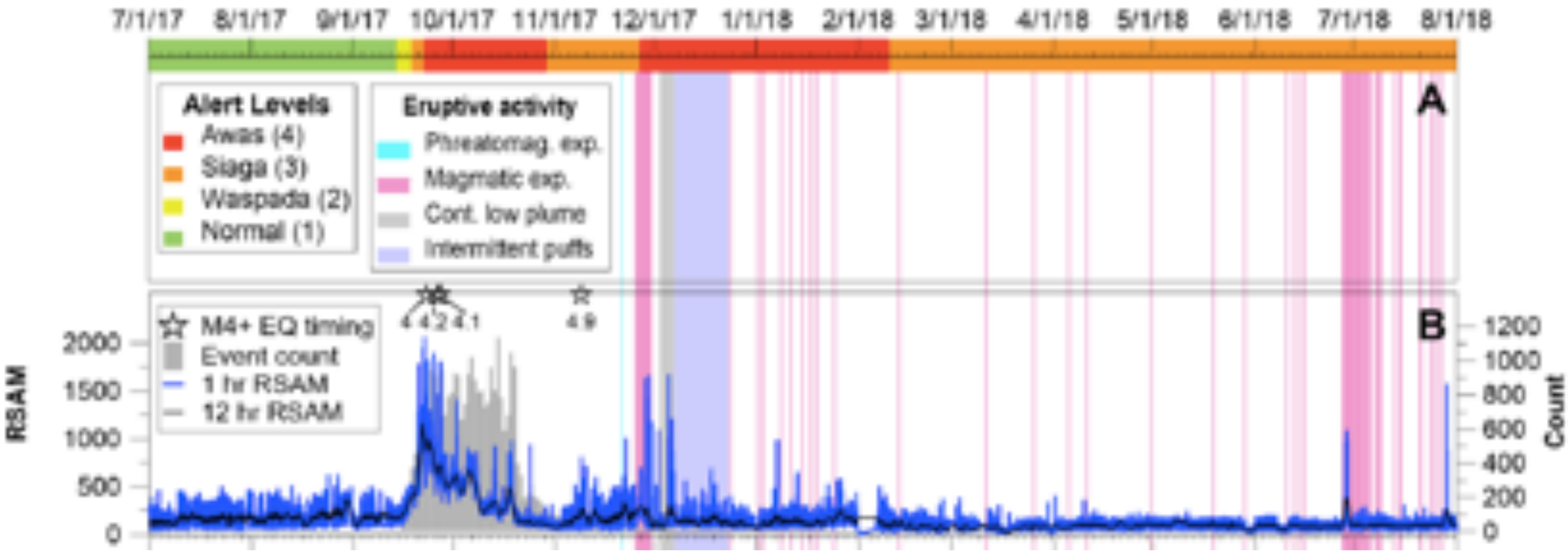


Official information released by BNPB

Timing of Unrest and Eruption



Syahbana et al., 2019

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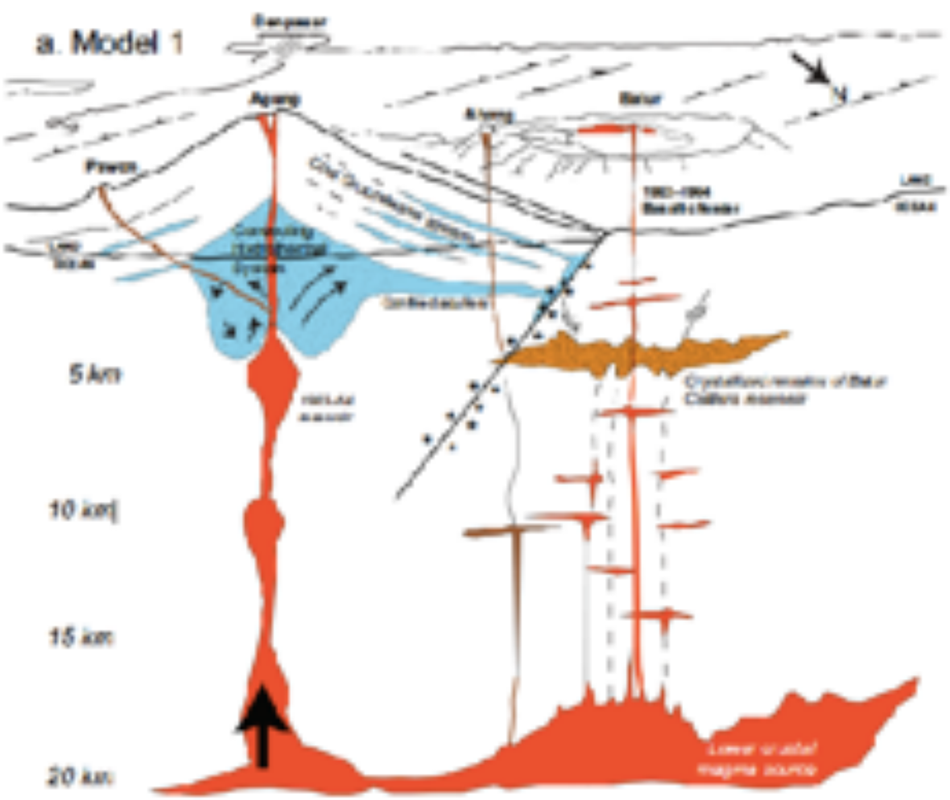
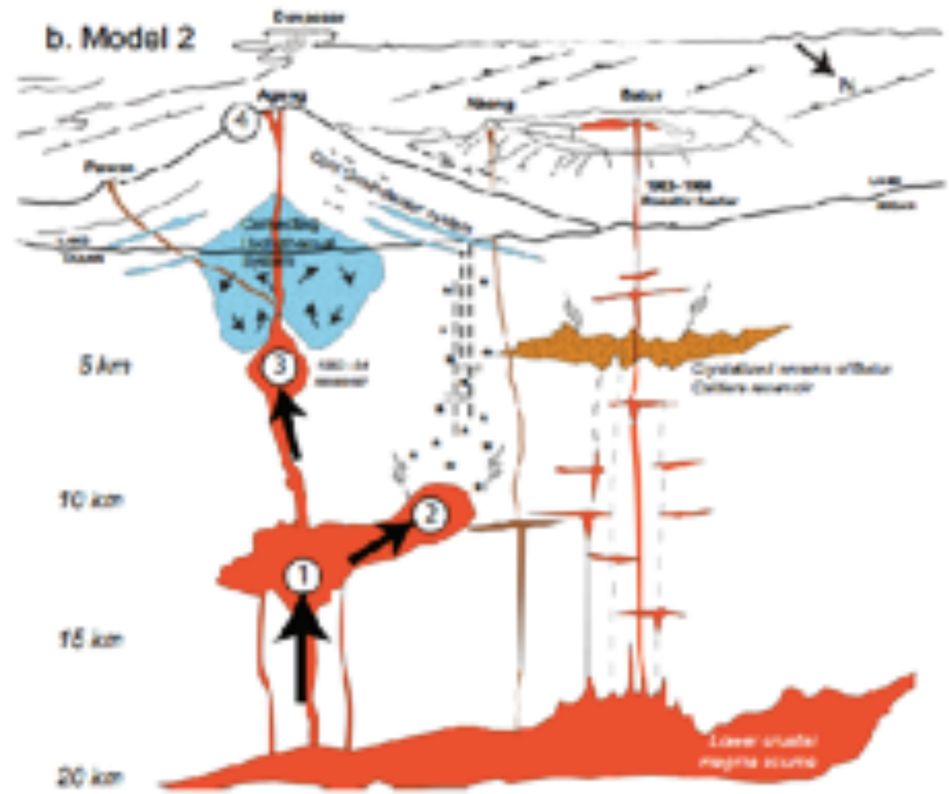
What happened?





Syahbana et al., 2019

Part II. How successful are we at forecasting eruptions and their effects?

Summary Statement

Forecasts are USEFUL, but are uncertain in timing, magnitude, and effects. Rarely do we have enough information to provide certainty for decision-makers.

Part III. Our understanding of the subsurface is inadequate.

Physics-based models require knowledge of:

Compressibility

Permeability

Seismic Velocity

Conductivity

Stress Regime

Temperature

Porosity

Pore Pressure

Mineralogy

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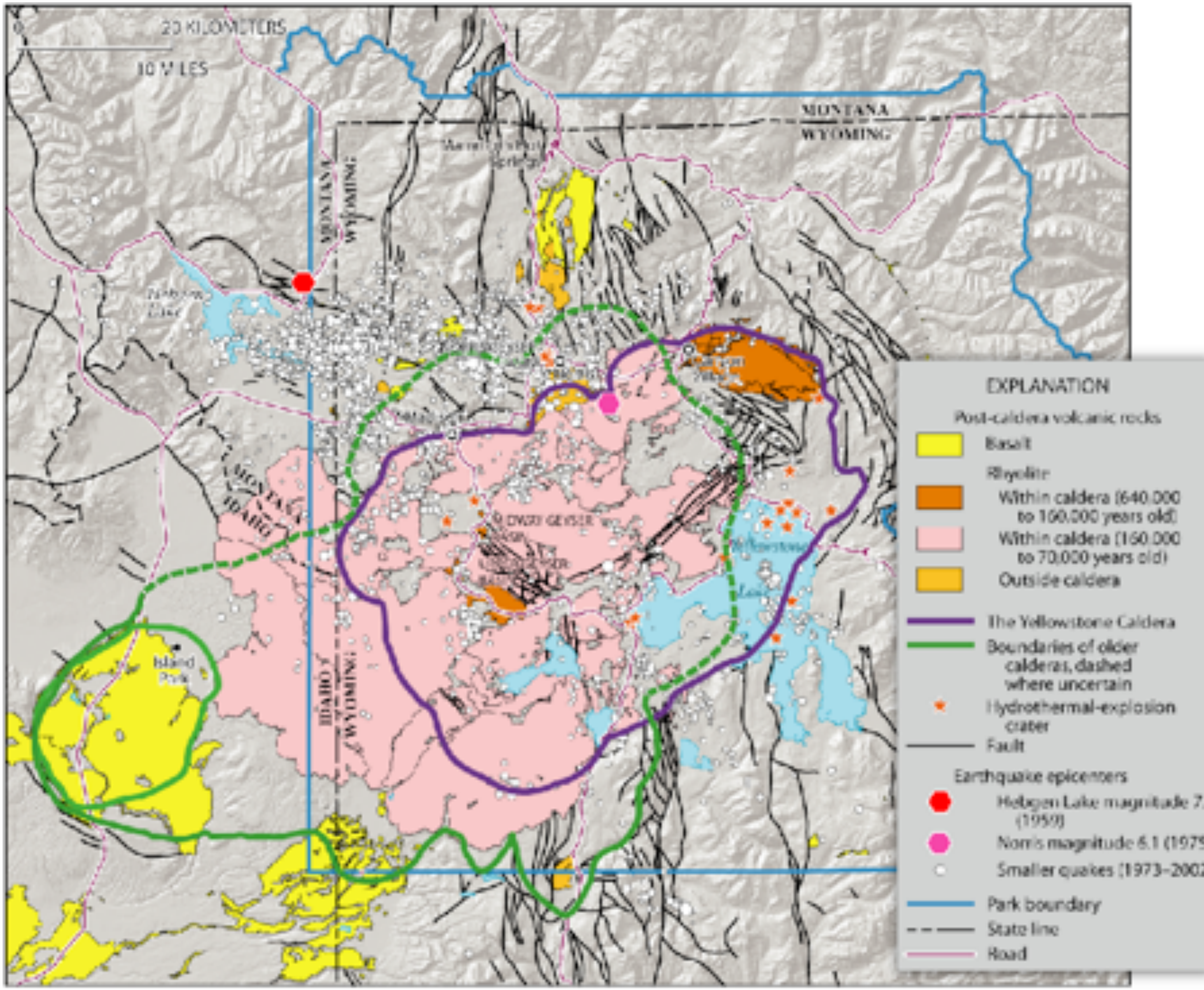
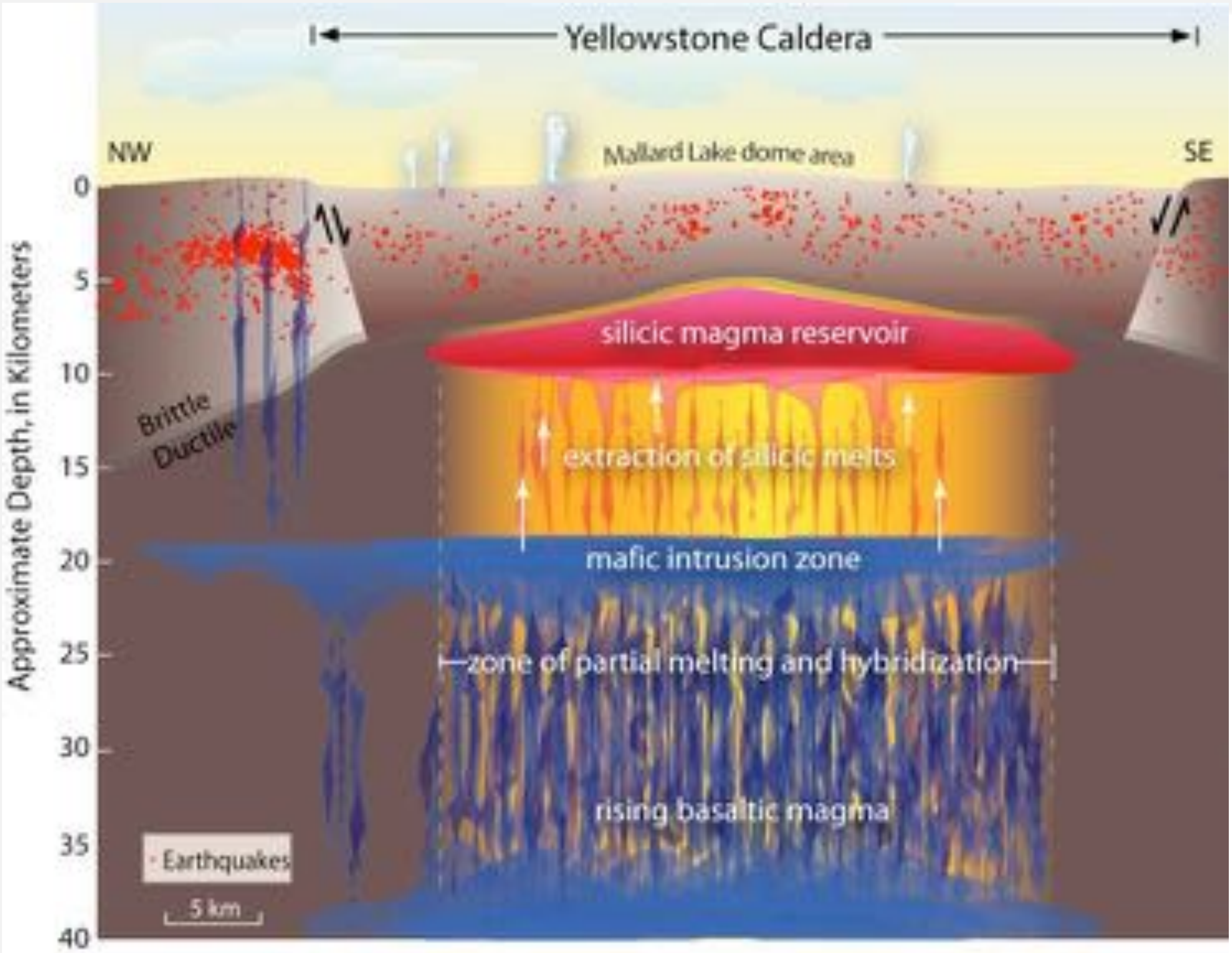
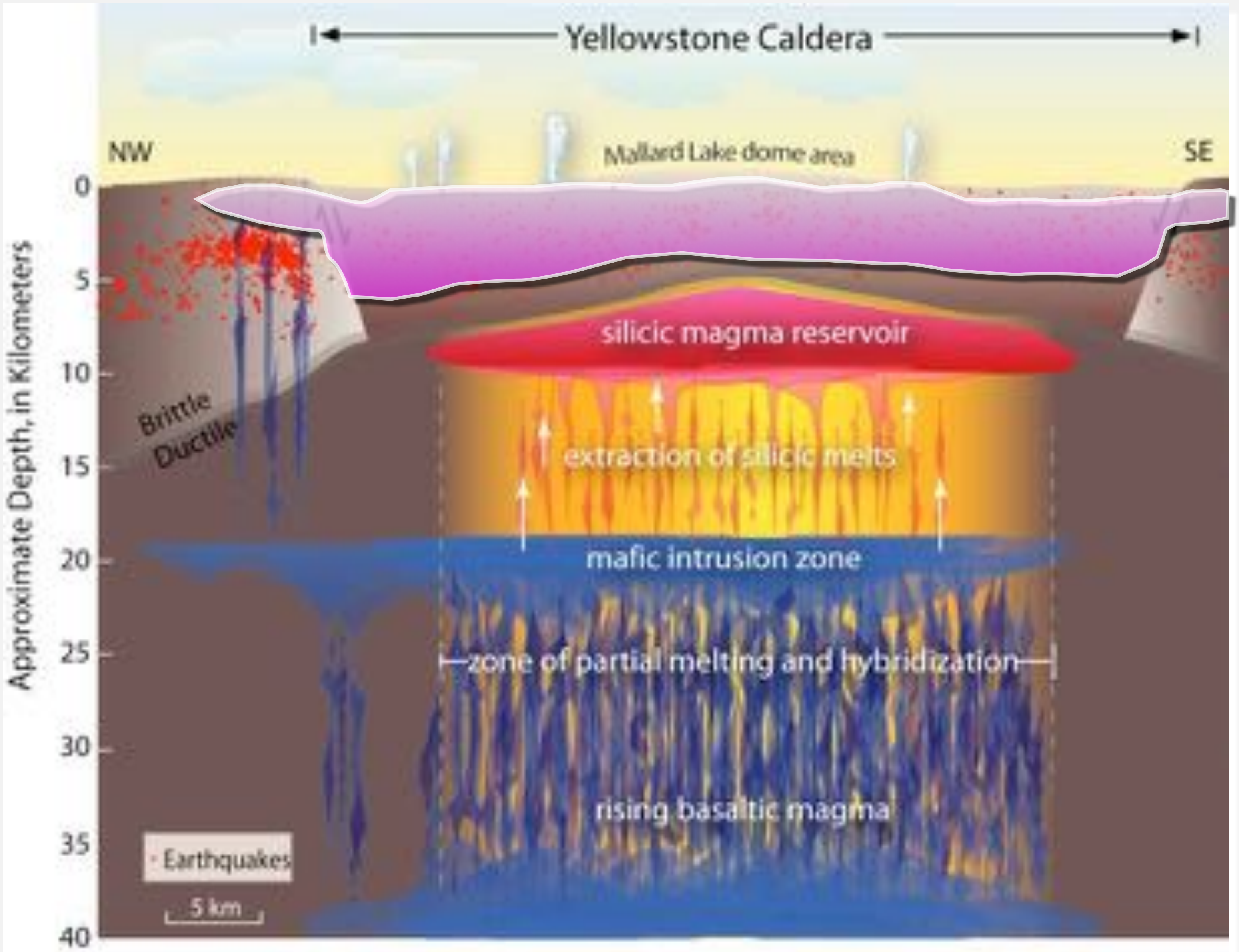


USGS Fact Sheet 2005-3024



modified from Lowenstern and Hurwitz, 2008



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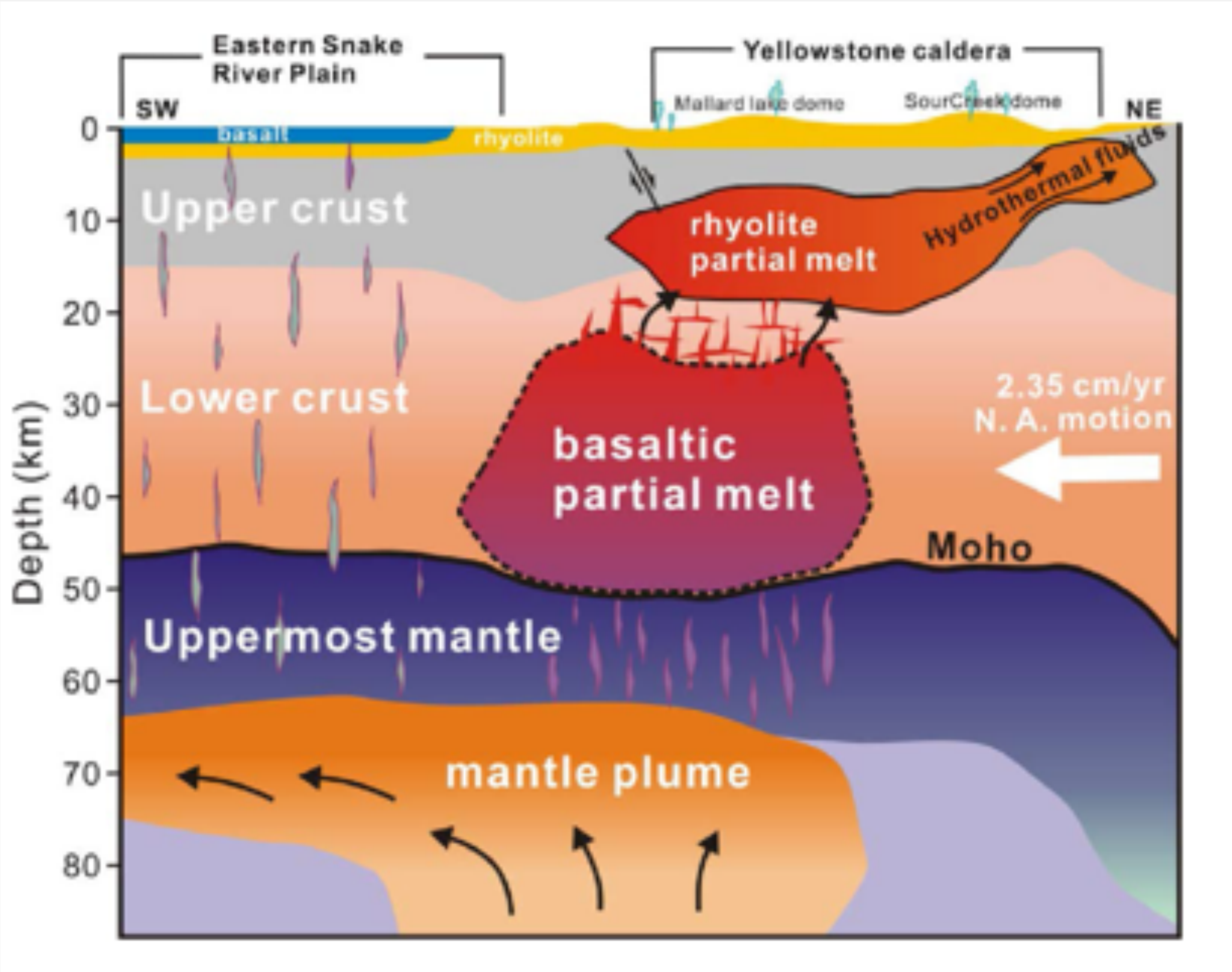
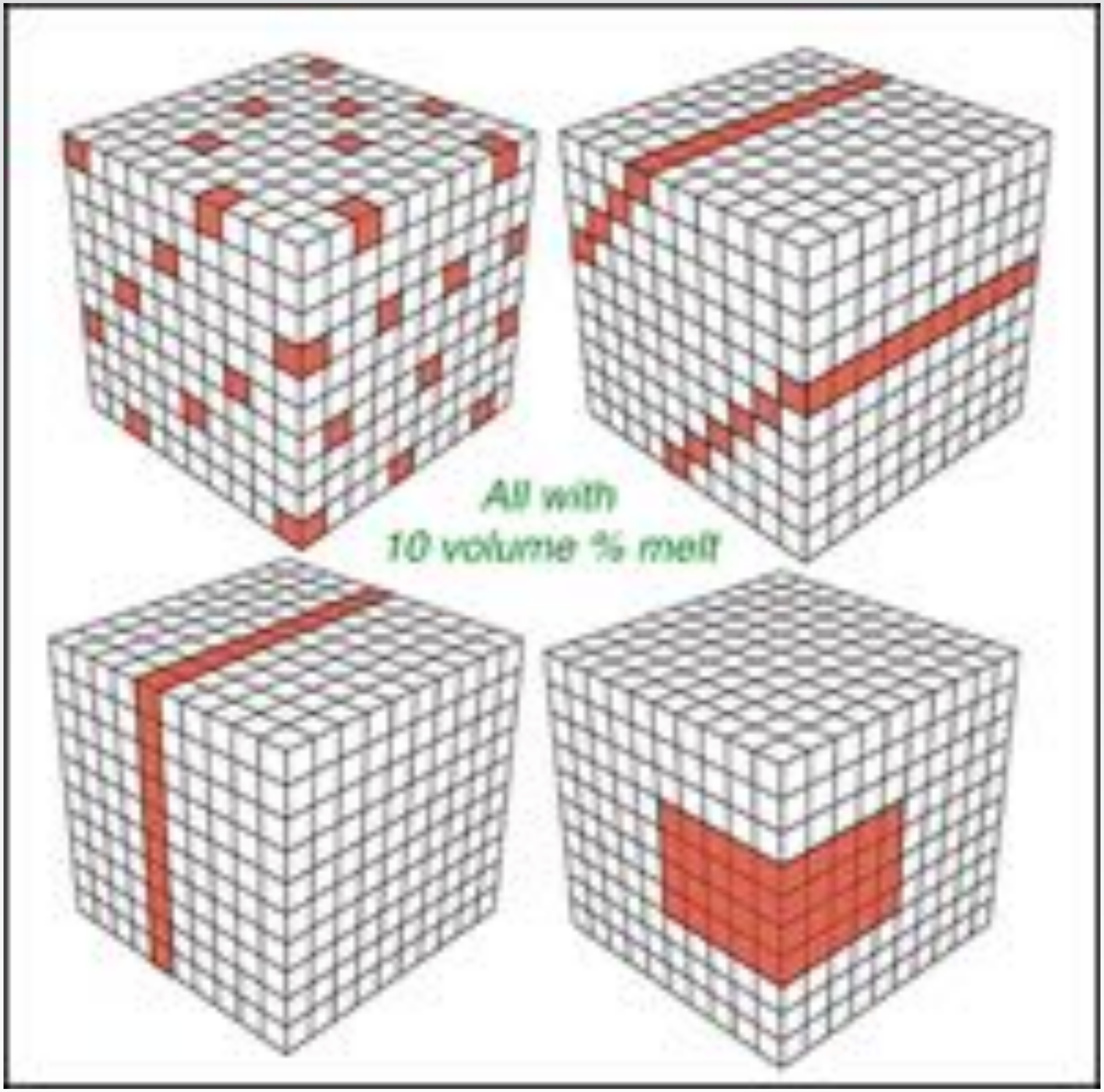
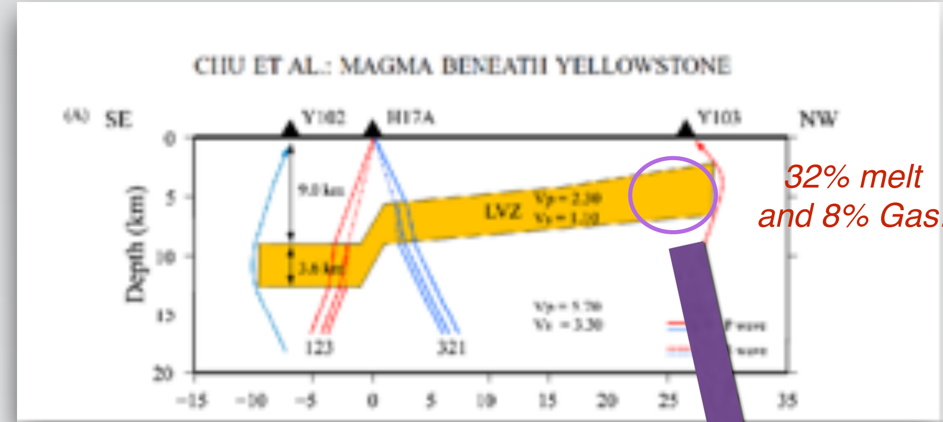


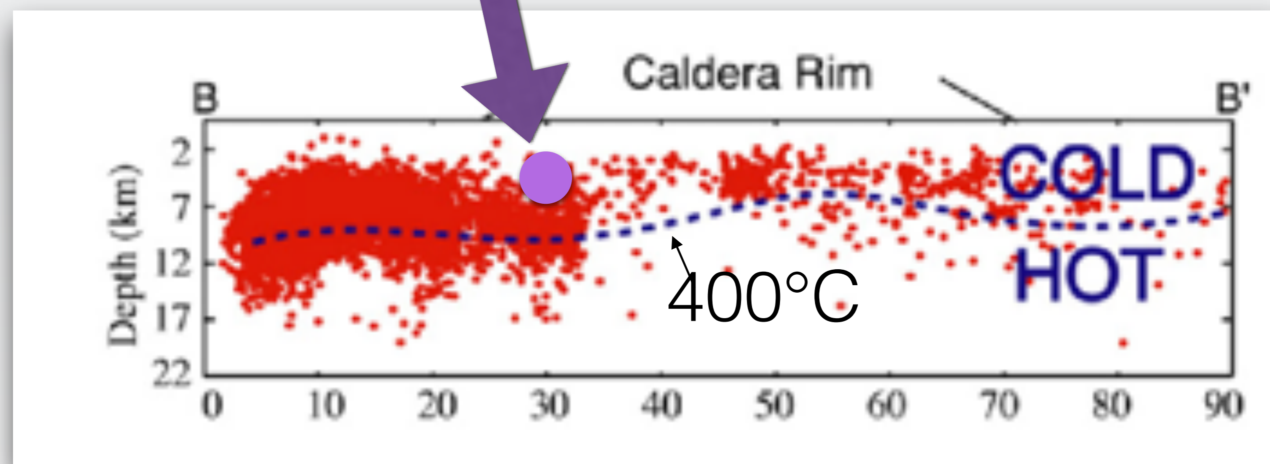
Huang et al., 2015



Lowenstern et al. Eos, 2018



An ultra low velocity zone (LVZ) is embedded in the upper crust beneath the Caldera with a thickness of 3.8 km.
Chu et al., 2010, GRL



Well-located hypo centers and inferred brittle-ductile transition.
Smith et al., 2009, GRL

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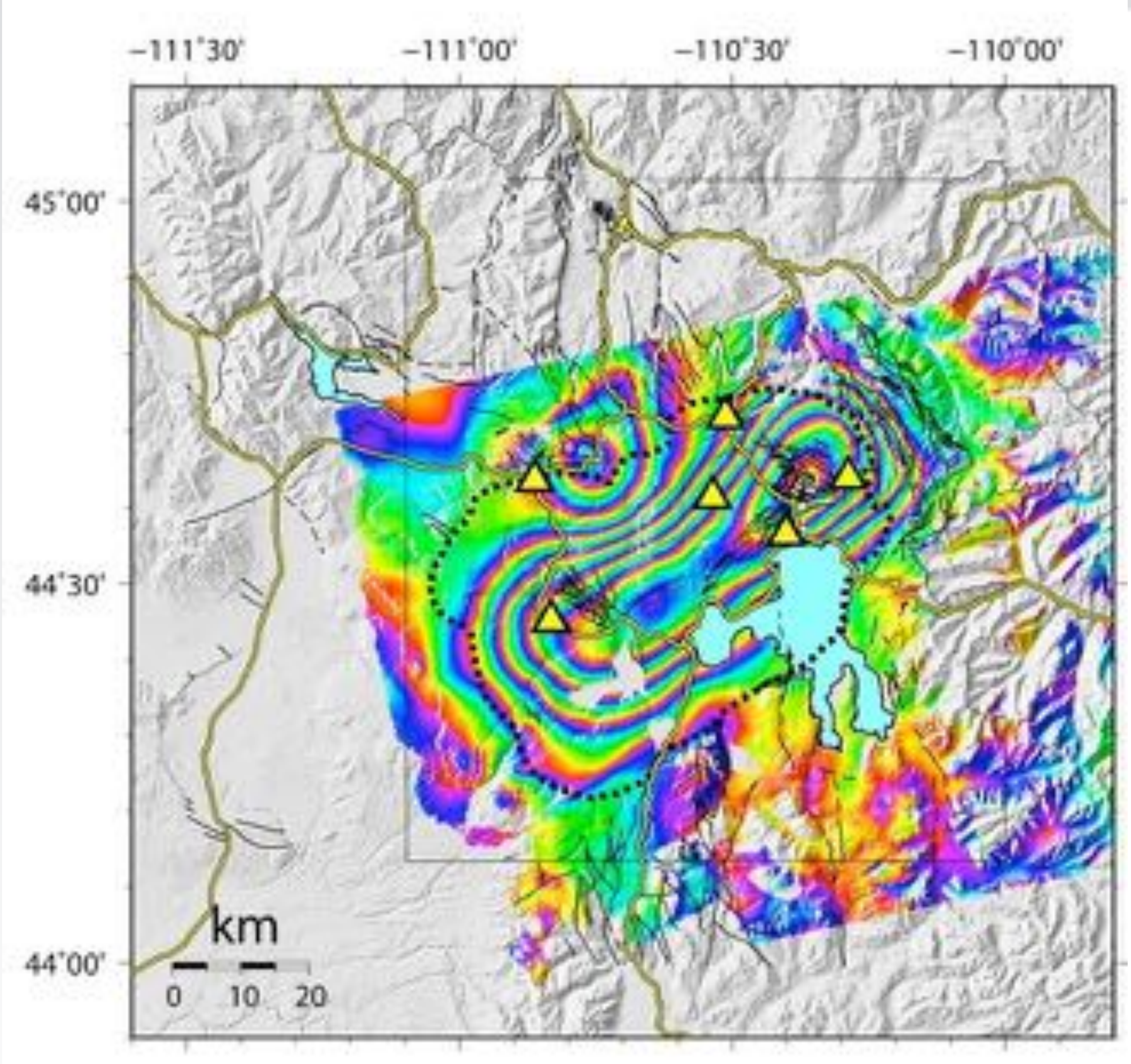

2005-2007

InSAR image from Chuck Wicks: USGS

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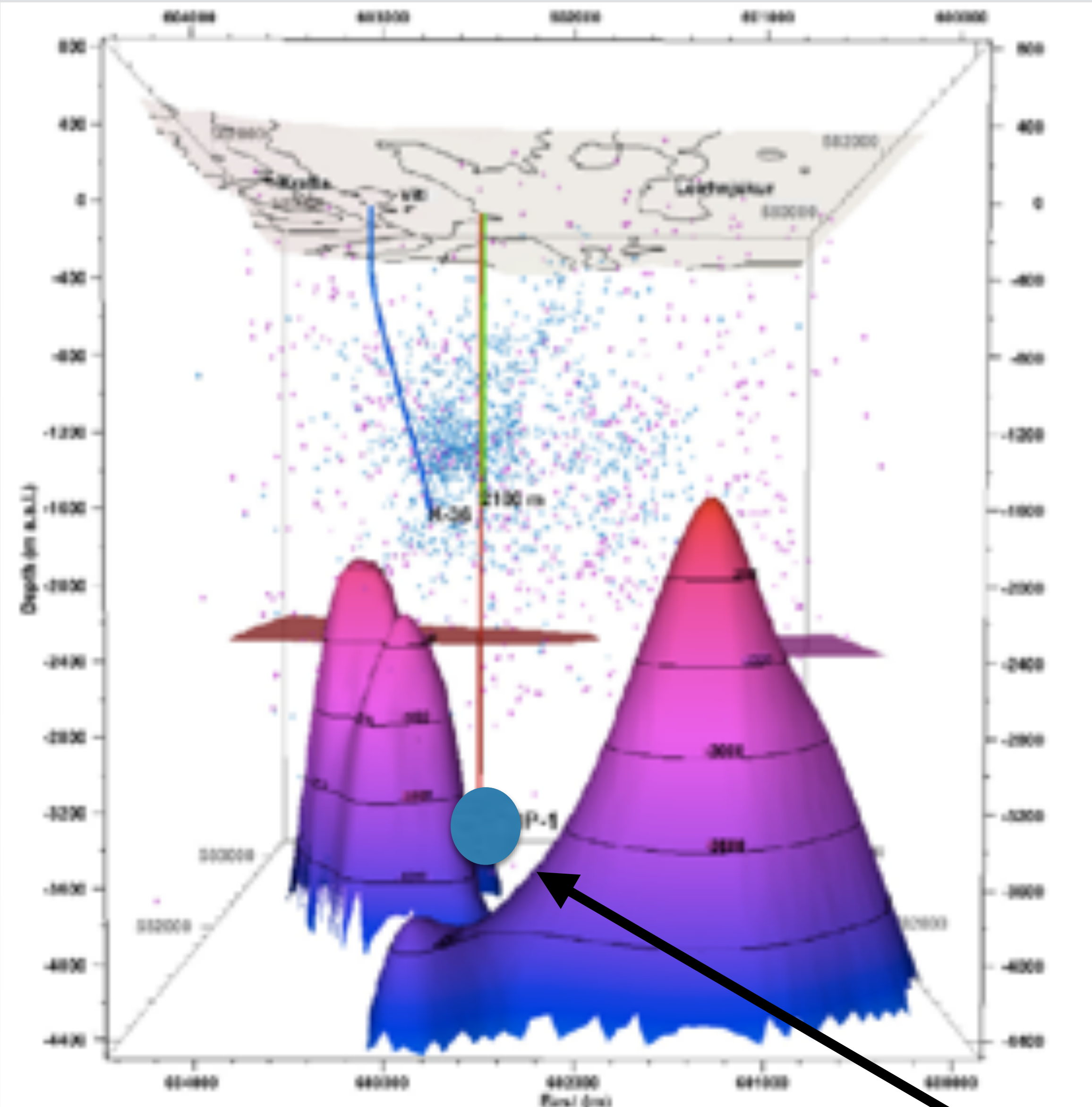
Krafla 2009



Zierenberg et al. 2012

Drill to here!

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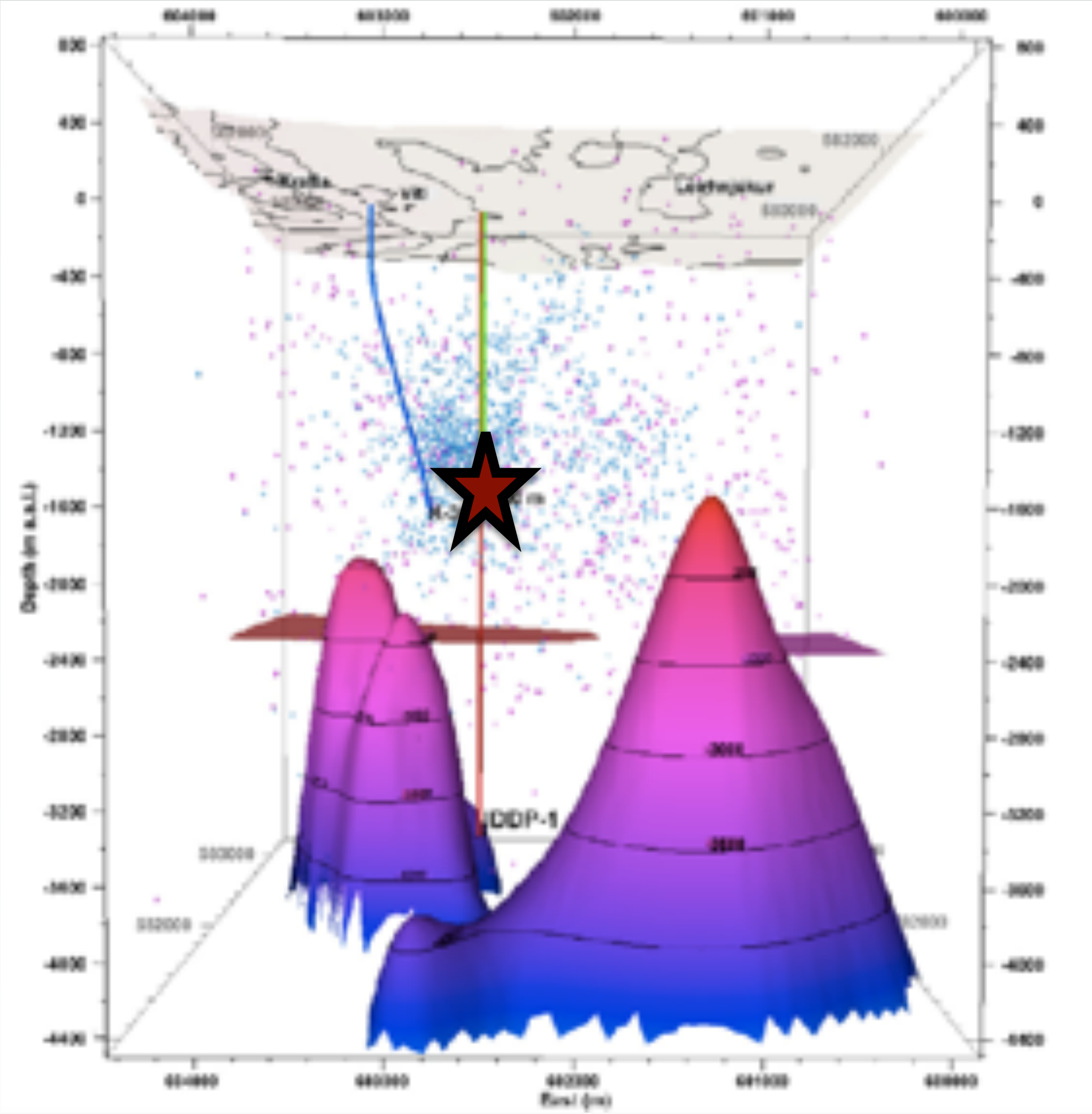
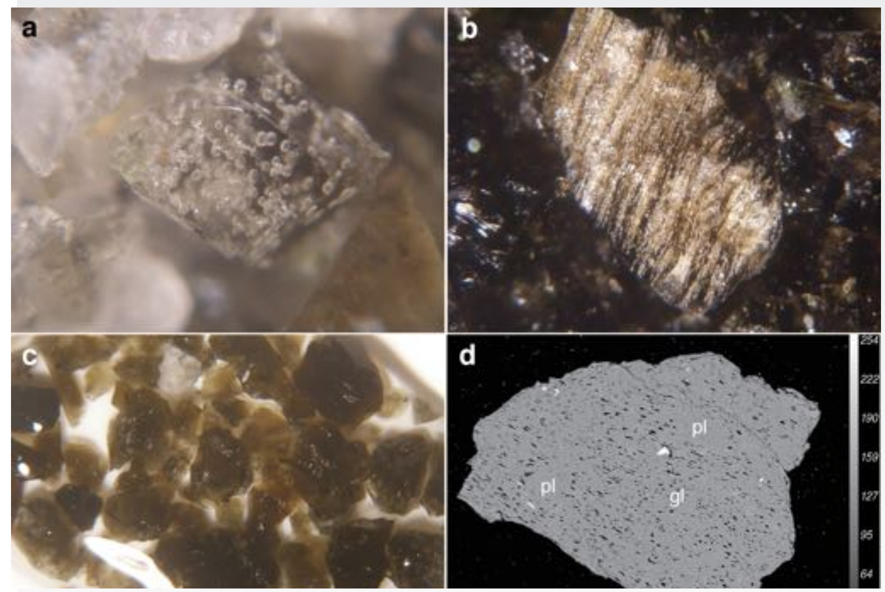
Krafla 2009



Zierenberg et al. 2012



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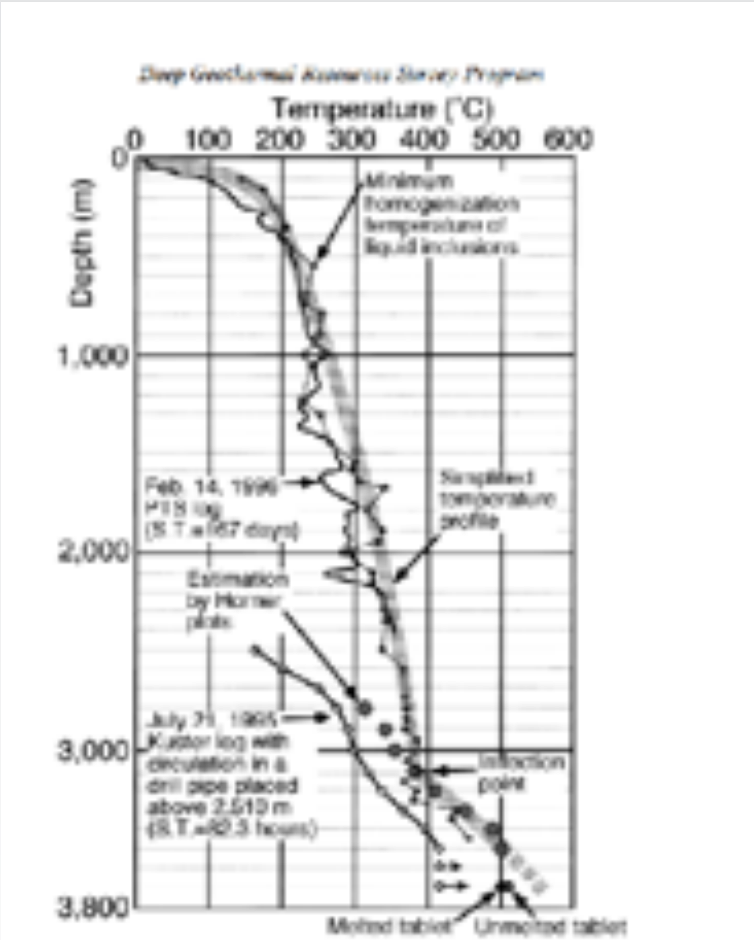
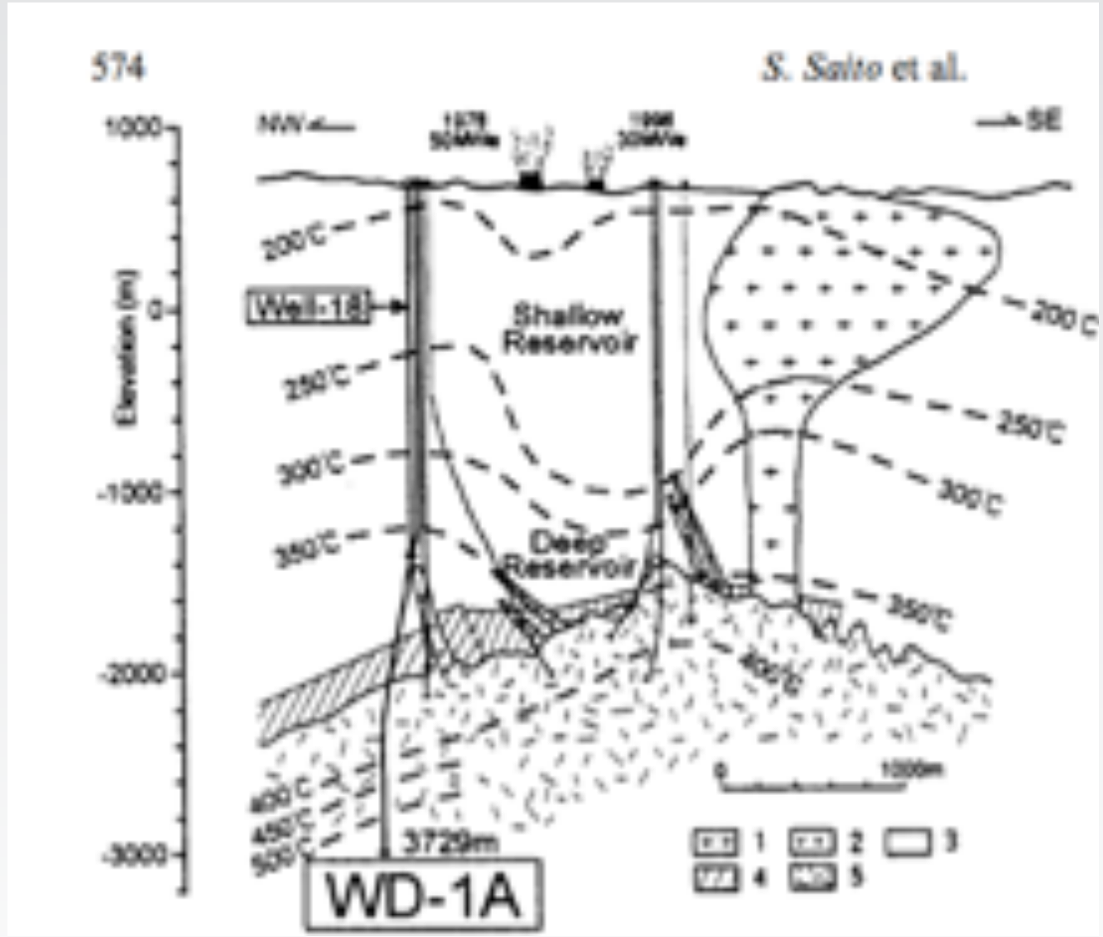
Kakkonda

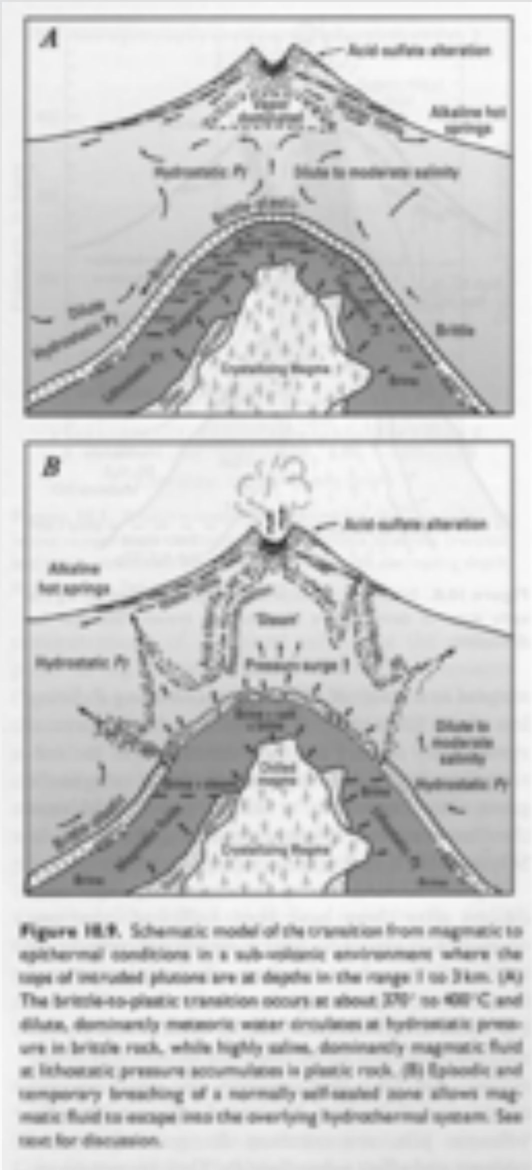


Muraoka et al. Geothermics, 1998

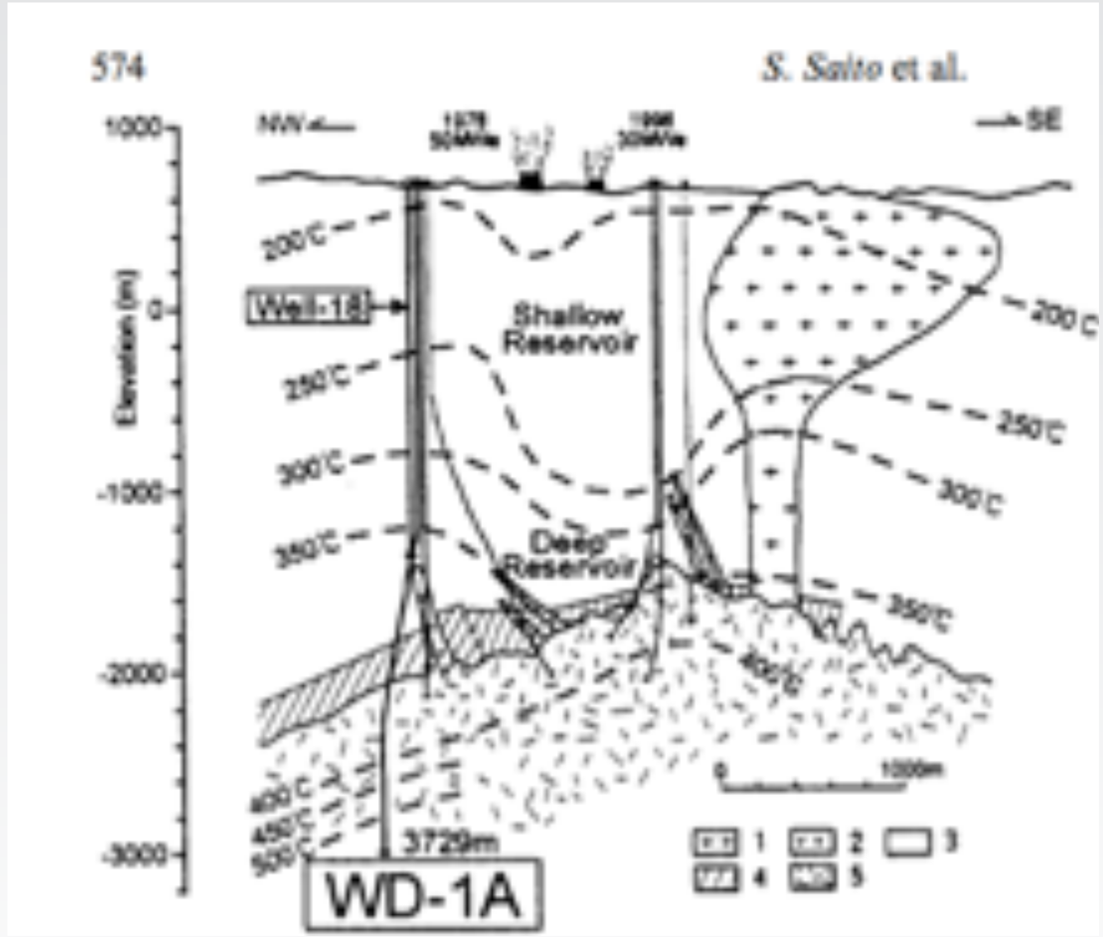


Saito et al. Geothermics, 1998

Kakkonda



Fournier, 2007 version of 1980s model



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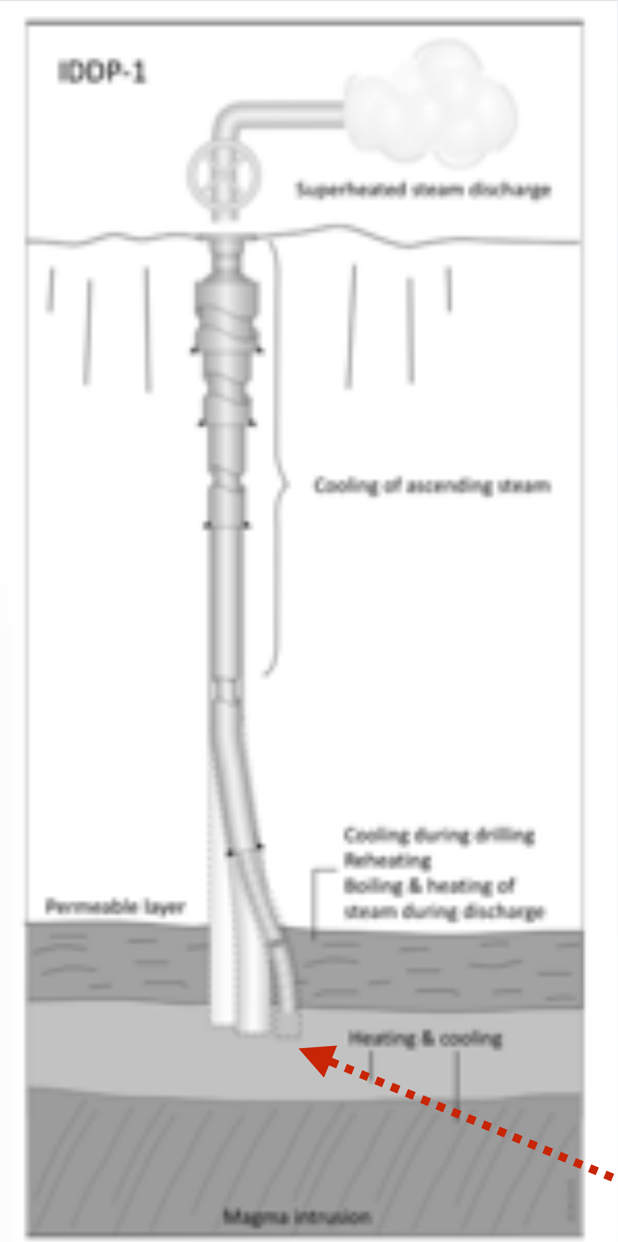
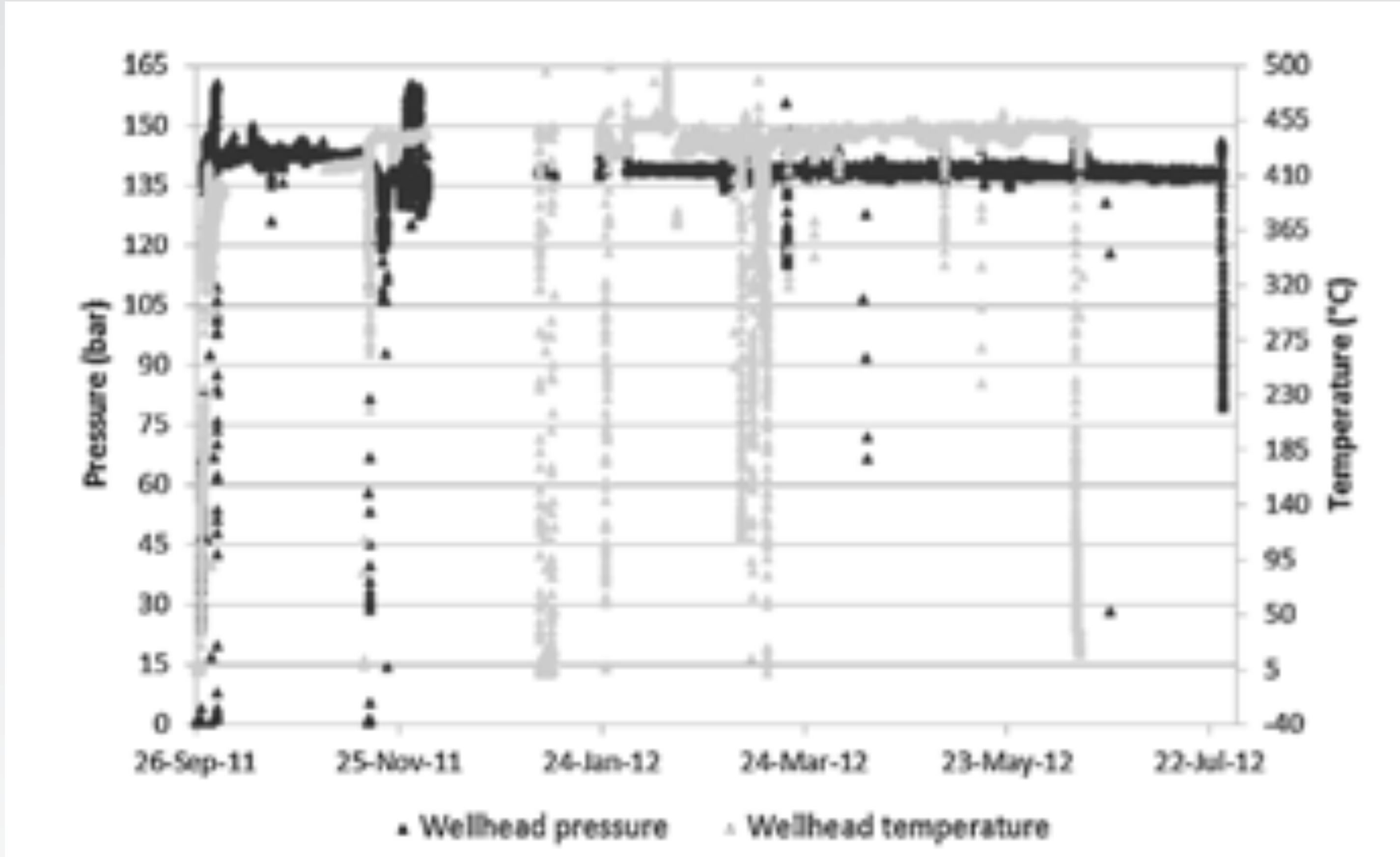
Krafla



Axelsson et al., 2014



Ingason et al., 2014

Permeable and over 450°C

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Part III Summary Statement

- There remains considerable uncertainty about the structure and diversity of magma-hydrothermal systems.

- Such conceptual barriers and uncertain parameters make it difficult to create deterministic/physics-based models for eruption forecasts.

- There is no one-size-fits-all model that can be universally applied to magmas, volcanoes and eruptions.

Part IV. The challenge of risk mitigation during eruptions

Agung, Bali
Photo by
Andri Tambunan
Getty Images
Used with permission

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What needs to go right?

- Good monitoring.
- Correct interpretation.

Nevado del Ruiz, November 1985

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What needs to go right?

- Good monitoring.
- Correct interpretation.
- Actionable forecast.

Nevado del Ruiz, November 1985

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What needs to go right?

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Dante’s Peak: Pierce Brosnan, Universal Pictures

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What needs to go right?

- Good monitoring.
- Correct interpretation.
- Actionable forecast.
- Functioning partnership with civil defense.

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What needs to go right?

- Good monitoring.
- Correct interpretation.
- Actionable forecast.
- Functioning partnership with civil defense.
- Cooperation of affected population.

Calbuco: AFP Photo: Martin Bernetti

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Goals for Capacity Building

Oldoinyo Lengai, USGS

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Goals for Capacity Building

- Try and make it permanent.

Oldoinyo Lengai, USGS

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Goals for Capacity Building

- Try and make it permanent.
- Enable the people who make a difference.

Oldoinyo Lengai, USGS

Goals for Capacity Building

- Try and make it permanent.
- Enable the people who make a difference.
- Offer a true collaboration.

Oldoinyo Lengai, USGS

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Goals for Capacity Building

- Try and make it permanent.
- Enable the people who make a difference.
- Offer a true collaboration.
- Make it sustainable.

Oldoinyo Lengai, USGS

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Goals for Capacity Building

- Try and make it permanent.
- Enable the people who make a difference.
- Offer a true collaboration.
- Make it sustainable.
- Institution-building, not just assistance to people.

Oldoinyo Lengai, USGS

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Take Home Messages

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- Volcanic eruptions are hard to forecast, and even under optimal circumstances, remain highly uncertain.

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- Science is only a part of keeping people safe. Education, planning, communications and trust are paramount.

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- Volcanic eruptions are hard to forecast, and even under optimal circumstances, remain highly uncertain.
- The above statement is partly because our understanding of the subsurface remains insufficient, and will largely remain so for a while.
- Science is only a part of keeping people safe. Education, planning, communications and trust are paramount.
- Capacity building requires institution-building and a long-term view.

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