The National Academies of
SCIENCES • ENGINEERING • MEDICINE

Report briefing to Subcommittee on Disaster Reduction

Michael Manga (chair)
University of California, Berkeley

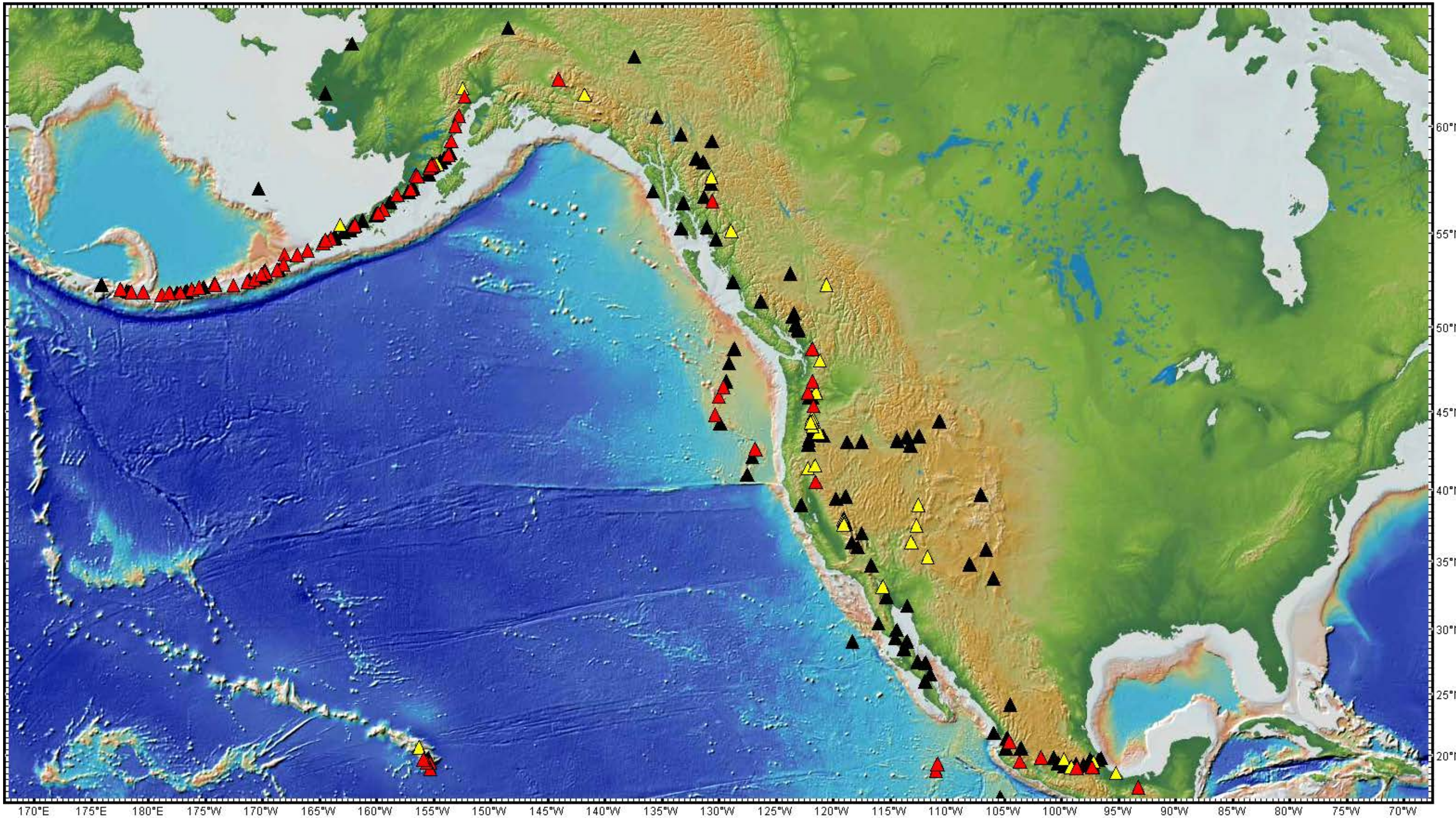
May 4, 2017

1. Introduction
Why do volcanoes matter?

- Eruptions are common – 50 in the USA in the past 31 years; globally more than a dozen at any time and close to 100 in any year
- Large eruptions have global effects and can cause global catastrophes
- Key part of the Earth system, modifying landscapes, changing climate, and creating geothermal systems and ore deposits

Volcanoes in the USA

Figure 1.4



169 potentially active volcanoes, red showing those that erupted since 1800

Fewer than ½ have a seismometer, only 3 have continuous gas measurements (as of Nov 2016)

Volcanic eruptions are different from other natural hazards

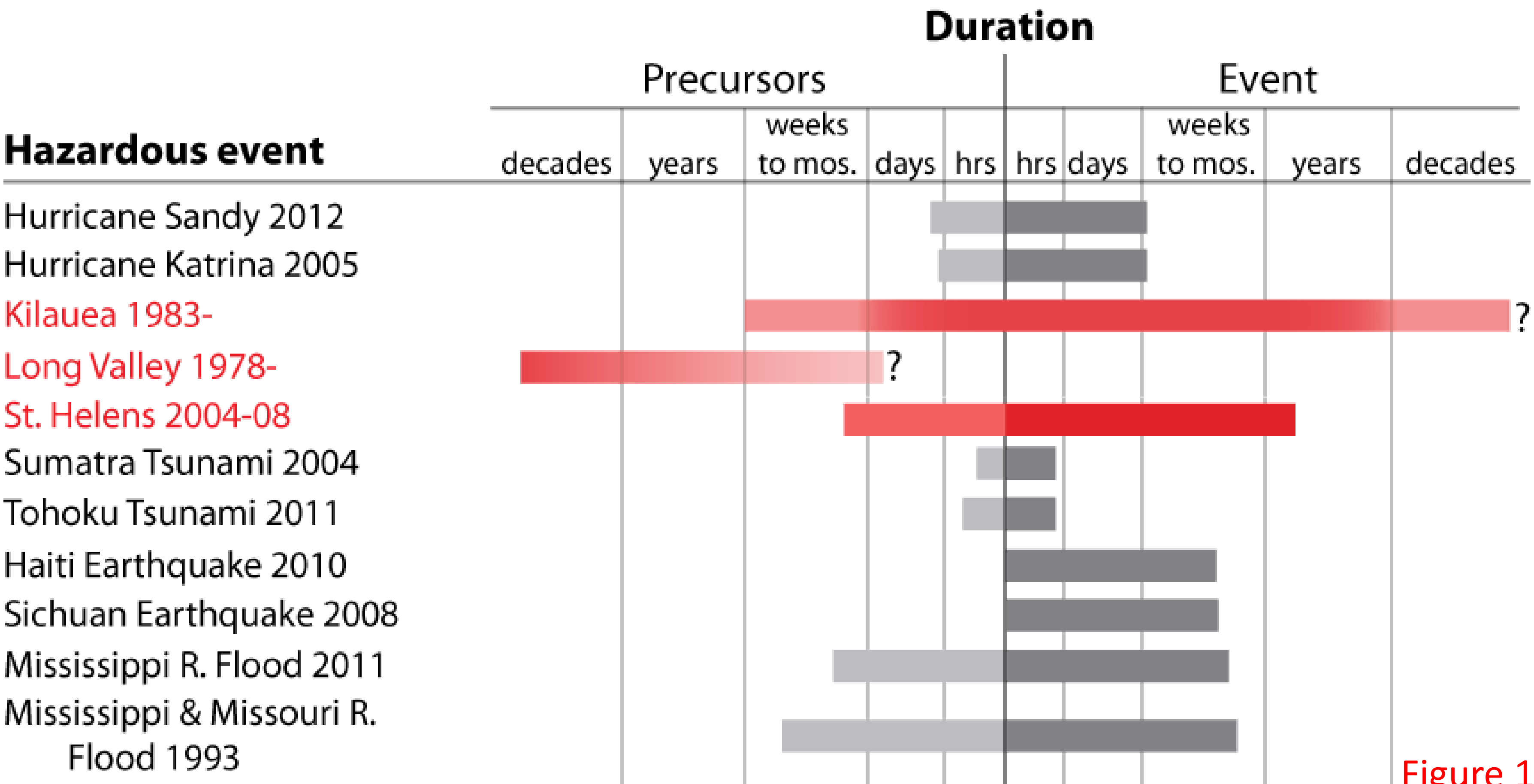


Figure 1.3

What types of unrest are precursors to eruptions?

Which precursors forecast the onset, style, duration of eruptions?

Study tasks

- Summarize current understanding of how magma is stored, ascends, and erupts
- Discuss new disciplinary and interdisciplinary research on volcanic processes and precursors that could lead to forecasts of the type, size, and timing of volcanic eruptions
- Describe new observations or instrument deployment strategies that could improve quantification of volcanic eruption processes and precursors
- Identify priority research and observations needed to improve understanding of volcanic eruptions and to inform monitoring and early warning efforts

Sponsors: NSF, NASA, USGS, National Academies

All four tasks are related

- Understanding guides forecasting
- Space- and ground-based monitoring provides data to develop understanding

We know a lot about volcanoes

In general terms and conceptually, we understand

- How plate tectonics explains where and why volcanoes exist
- How melt is generated in the mantle and rises towards the surface
- How magma is stored and evolves in the crust
- The variety of ways to initiate eruptions
- Why some eruptions are explosive and some volcanoes erupt more often than others
- The detailed and quantitative picture of eruptions once they begin

But many key questions remain, detailed in chapters 2-4

2. How do volcanoes work?

2.1 How are magmas stored and transported in the crust?

2.2 How do eruptions begin, evolve and end?

2.3 What happens when volcanoes erupt?

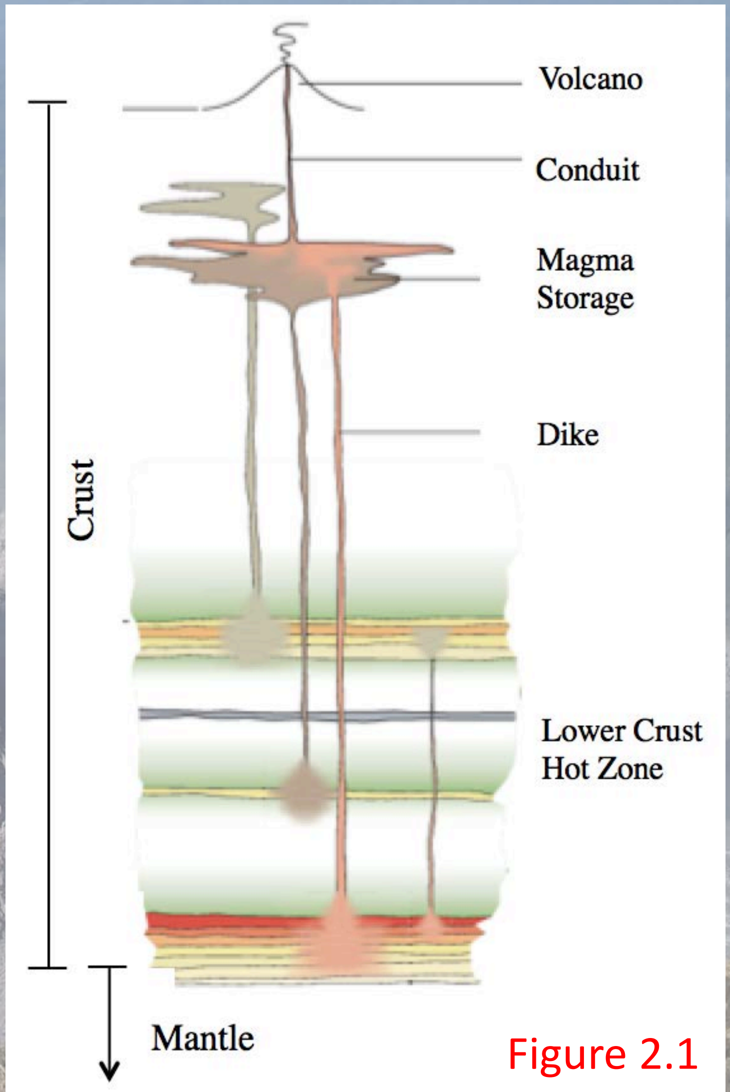


Figure 2.1

2.1 How are magmas stored and transported in the crust?

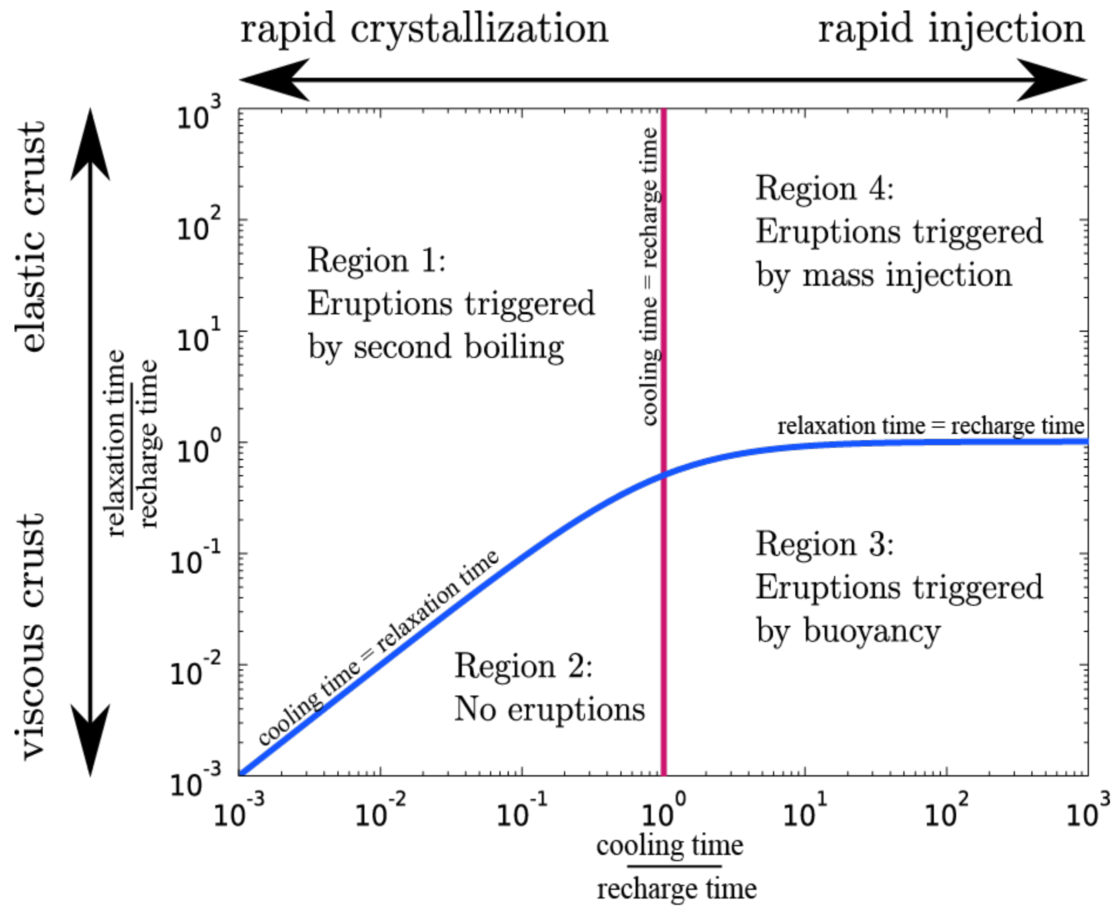


Figure 2.5

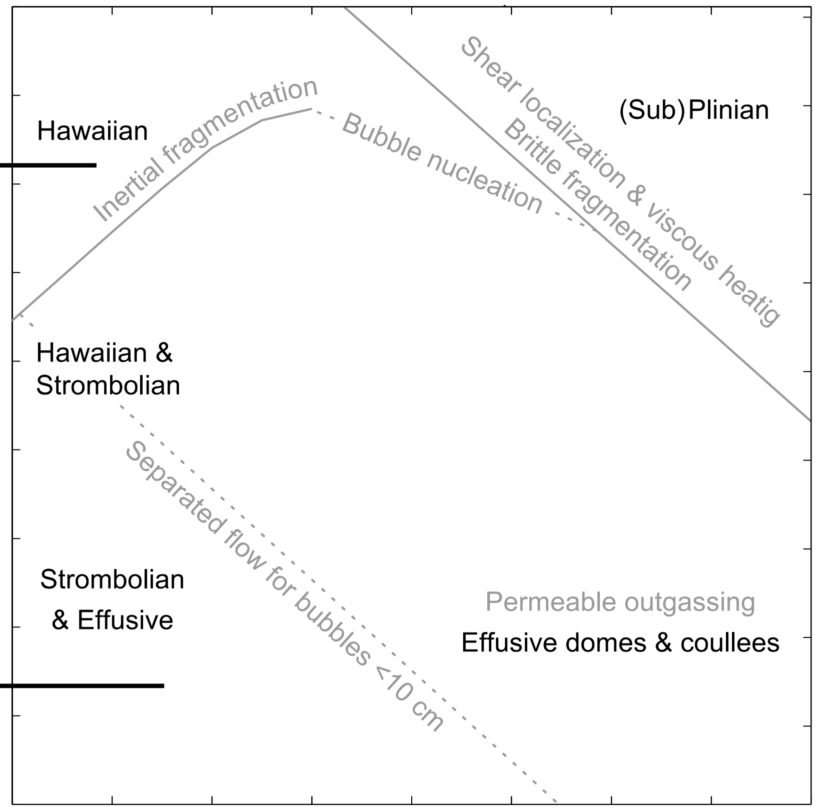
Geometry? Timescale to assemble magma bodies? How quickly do they mobilize? (what are the quantities on the axes)

Connect physical and thermal processes, imaging, monitoring, and crystal records

2.2 How do eruptions begin, evolve and end?

Kilauea Iki 1959

Hawaii



St Helens

Kilauea 1983-present

Figure 2.8

Transition in eruption style? Evolution of eruptions?

Connect ascent processes, their geophysical signatures, and record in crystals and textures

2.3 What happens when volcanoes erupt?

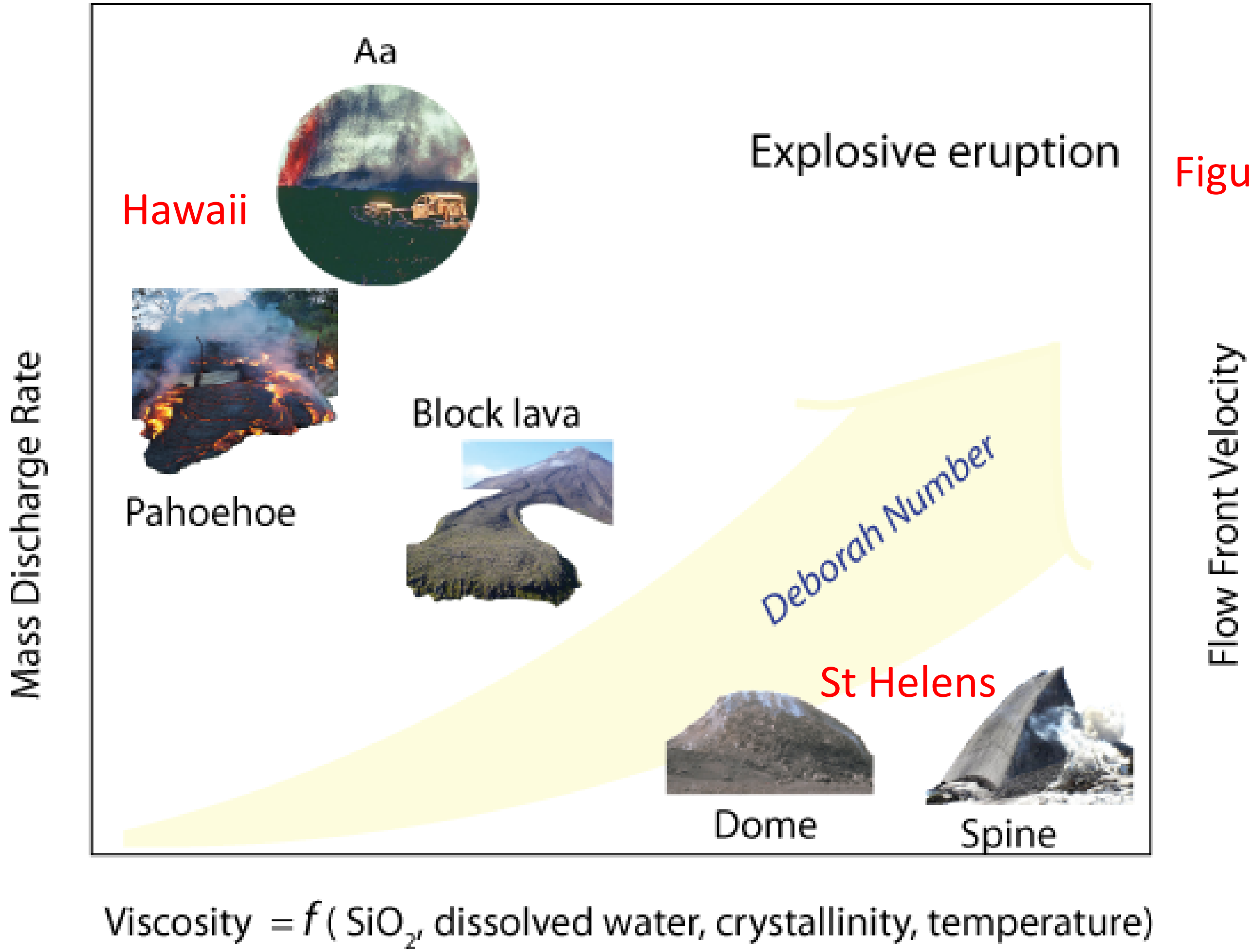


Figure 2.13

What are thresholds? Role of external environment?
Very small and large eruptions, and submarine eruptions, are poorly documented

2.3 What happens when volcanoes erupt?

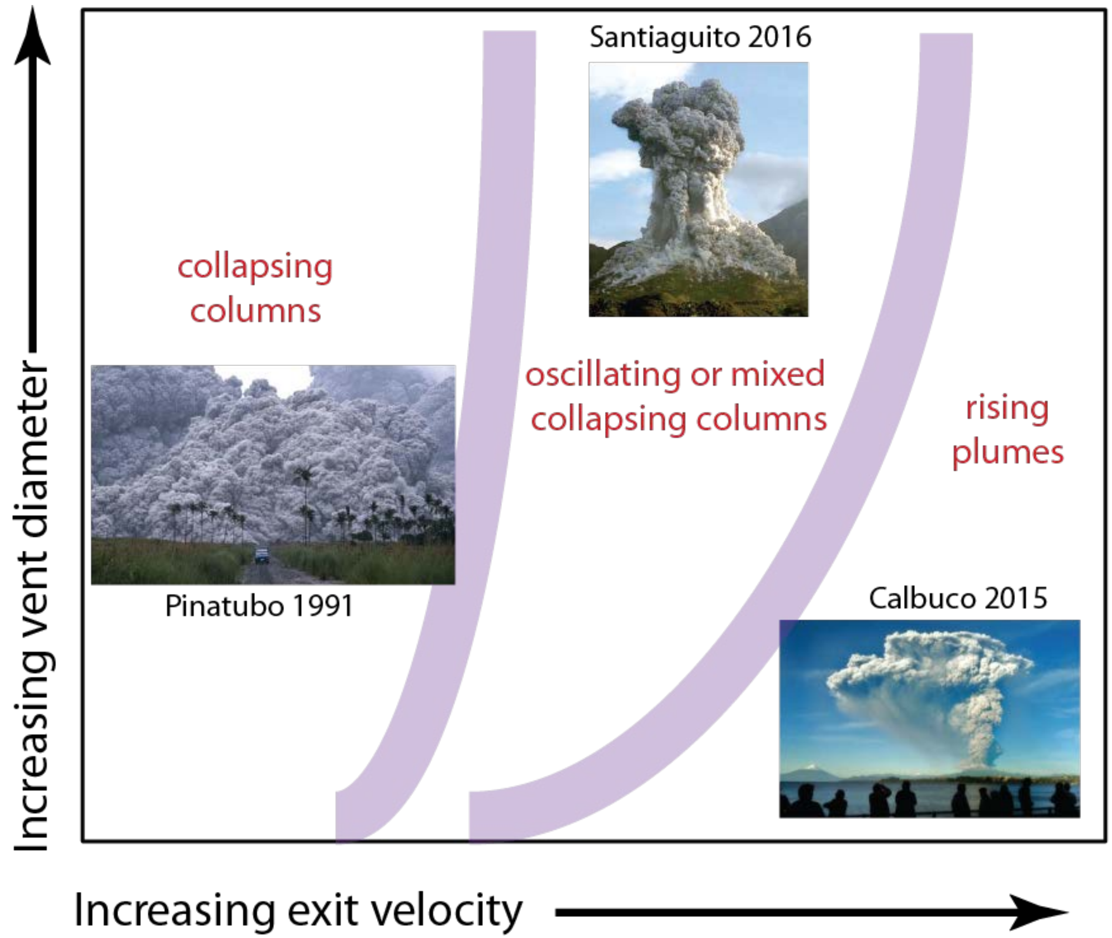


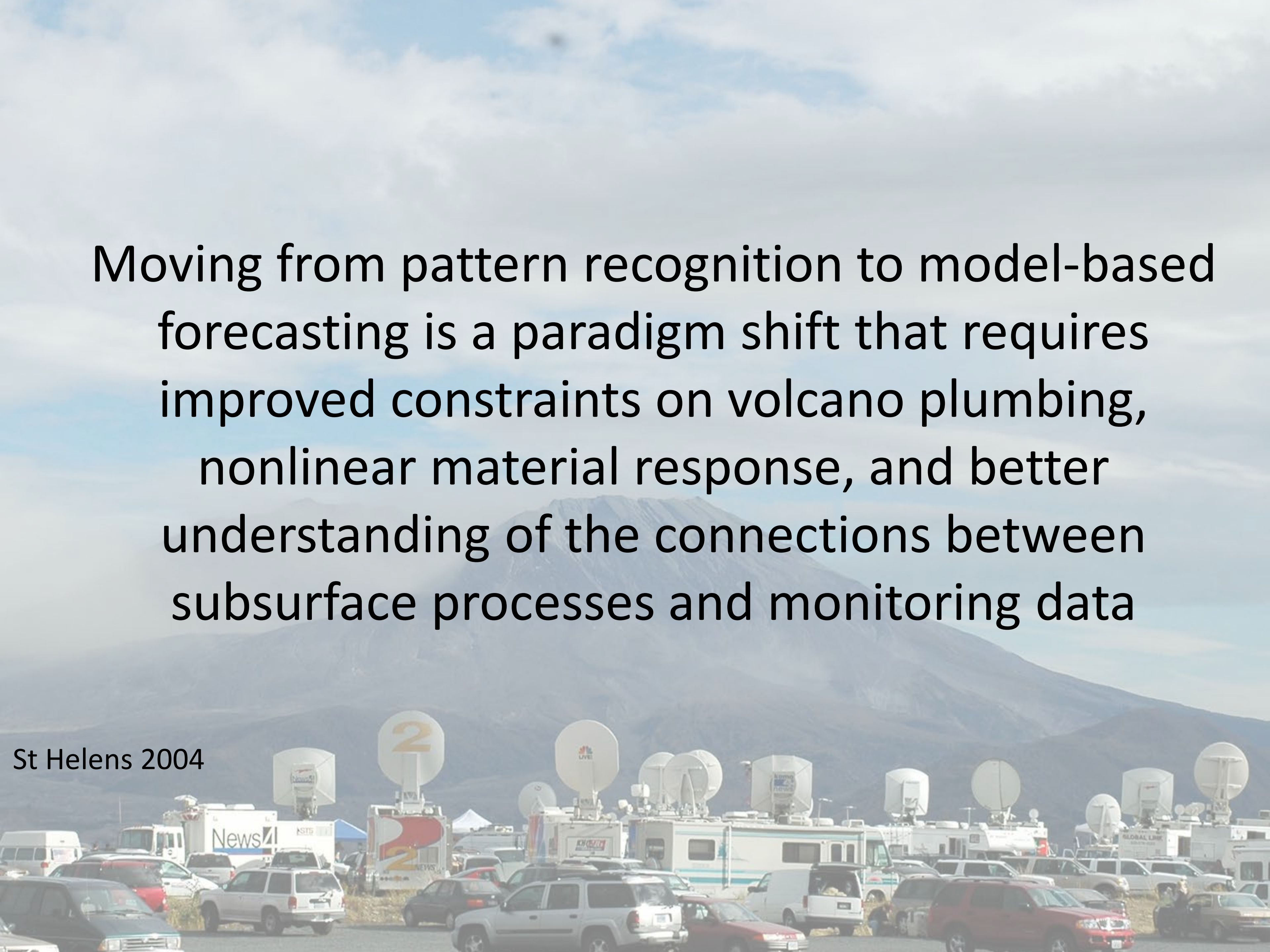
Figure 2.11

Controls on grain-size distribution and evolution? Role of environment (water, substrate, atmosphere) on dynamics?

Model particle scale processes and high resolution imaging

3. Forecasting eruptions

- An eruption forecast is a probabilistic assessment of the likelihood and time of volcanic activity
- May include style, duration and consequences
- Historically based on the geological record and monitoring data through pattern recognition
- Some notable successes, but few eruptions have been forecast
- By analogy to weather forecasting, models combined with space- and ground-based data could improve forecasting



Moving from pattern recognition to model-based forecasting is a paradigm shift that requires improved constraints on volcano plumbing, nonlinear material response, and better understanding of the connections between subsurface processes and monitoring data

St Helens 2004

How our biased understanding of the lifecycle of volcanoes affects understanding and forecasting

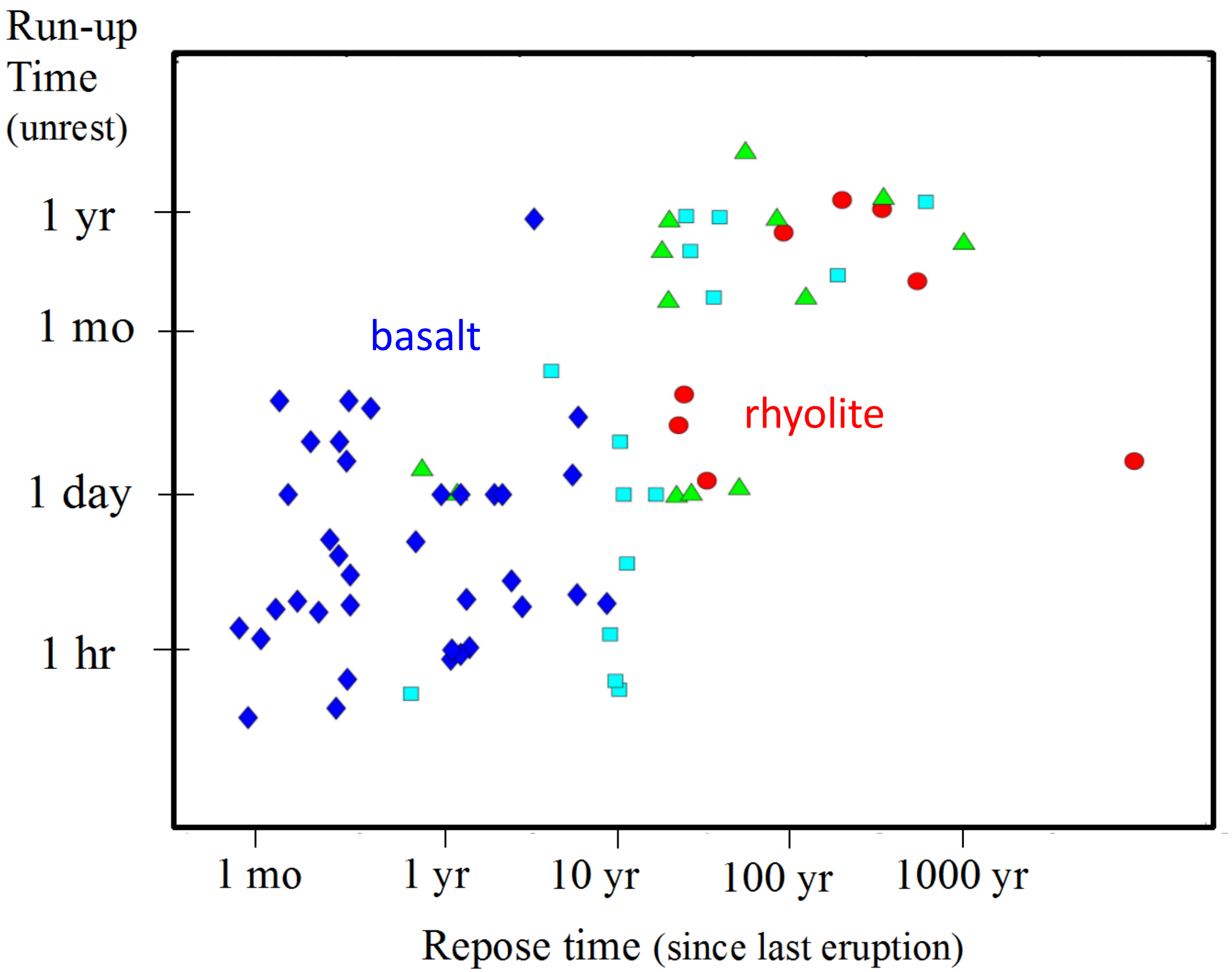


Figure 2.5

Eruption
Repose
Unrest
Precursors
Timing

heterogeneous monitoring (Unrest); incomplete chronology (Repose)

How our biased understanding of the lifecycle of volcanoes affects understanding and forecasting

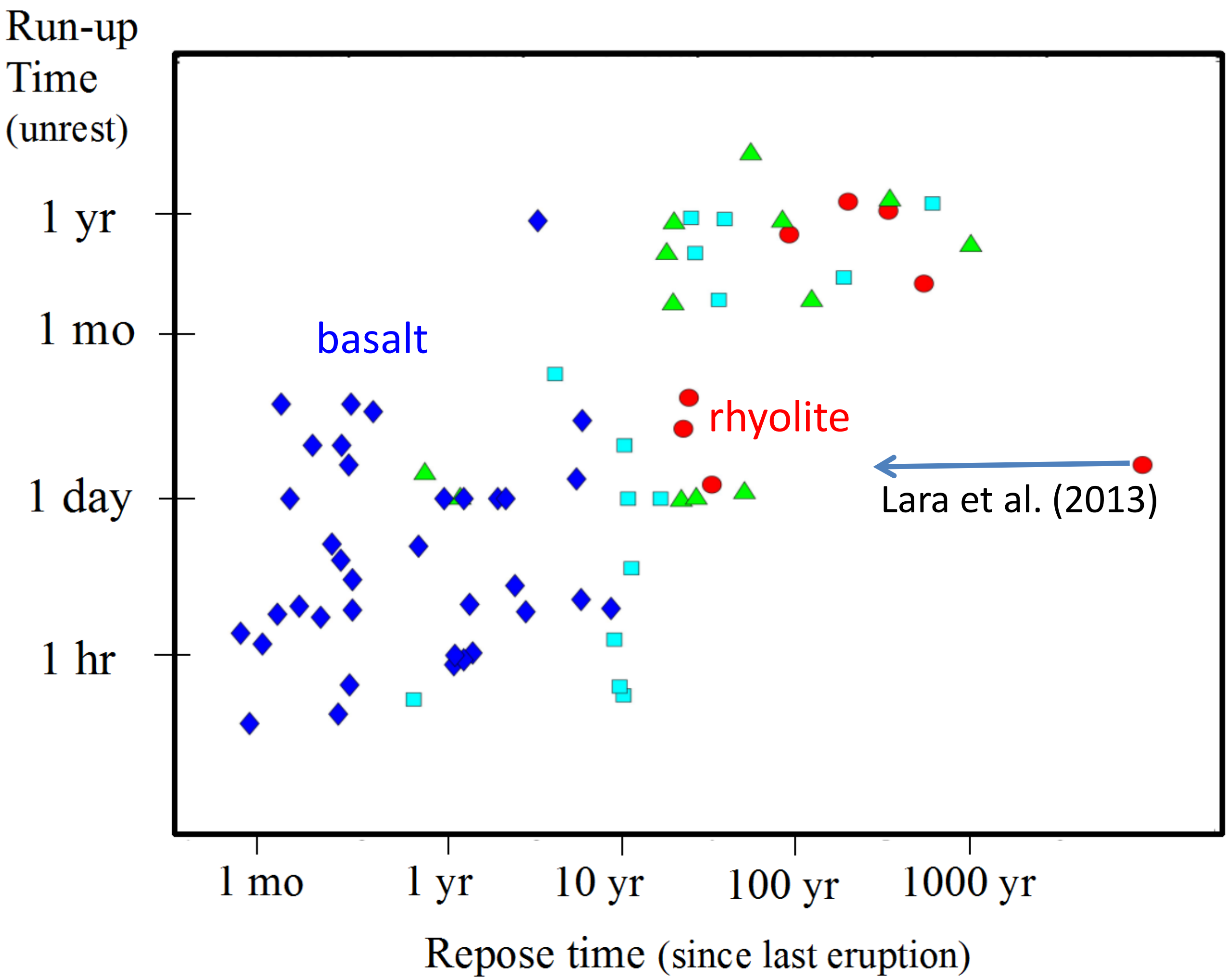


Figure 2.5

heterogeneous monitoring (Unrest); incomplete chronology (Repose)

How our biased understanding of the lifecycle of volcanoes affects understanding and forecasting

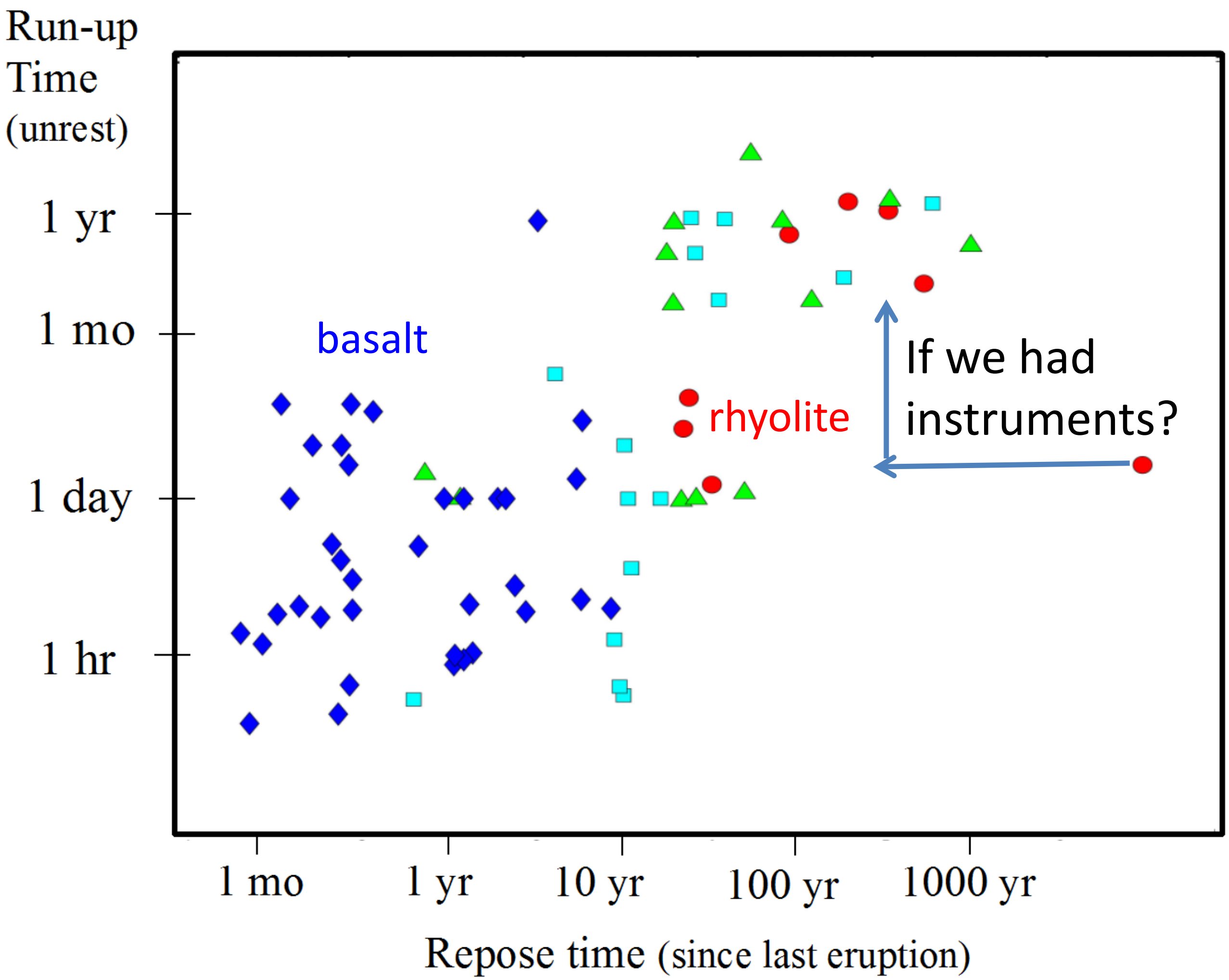


Figure 2.5

heterogeneous monitoring (Unrest); incomplete chronology (Repose)

3. Forecasting eruptions

Key questions

- What physical parameters and processes can be identified and used to improve forecasts of whether an episode of volcanic unrest will culminate in an eruption?
- What is the best way to estimate the depth and volume of eruptible magma and use it to anticipate the magnitude of an impending eruption?
- How can precursory phenomena be used to forecast eruptive intensity and style?
- How can we forecast the duration of an eruption once it begins?
- What are the physical parameters of volcanic systems that are most helpful in indicating which of those systems are most likely to erupt in coming decades ?

3. Forecasting eruptions

Research priorities

- Implement multidisciplinary monitoring and four-dimensional imaging of the full range of phenomena during repose, unrest and eruption at many more volcanoes
- Develop flexible, open-access databases of diverse observations for immediate use, and maintain them over the long term
- Aim for seismic monitoring of each potentially active volcano and routine daily monitoring of volcanic unrest from satellites
- Develop and test physics-based forecasting models that assimilate monitoring data and syn-eruptive observations

Common theme: need for models

- Developed for all processes, including melt transport in the mantle evolution of magma in the crust, ascent to the surface, eruption
- Used for improving understanding, interpreting measurements from prehistoric and active eruptions, and closing observational gaps
- Make quantitative and testable predictions, supporting forecasting and hazard assessment (including undocumented types of eruptions)

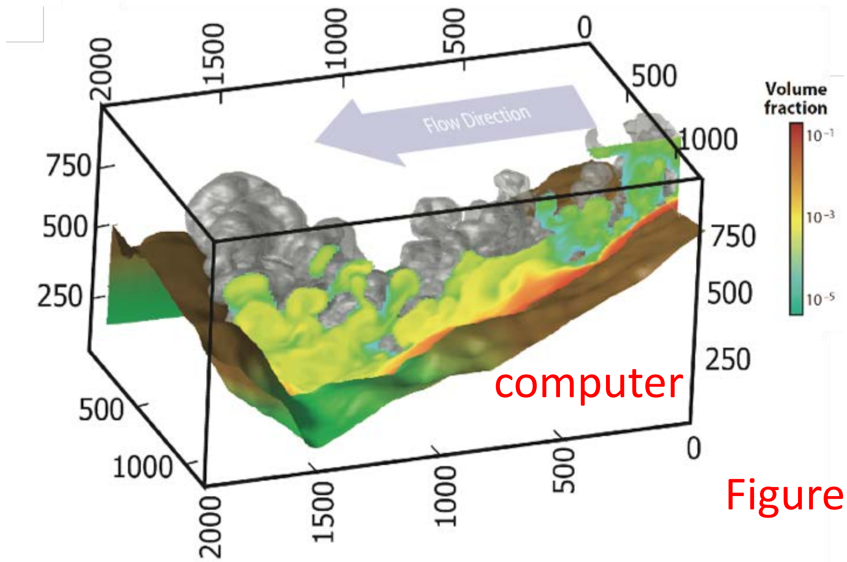


Figure 1.10

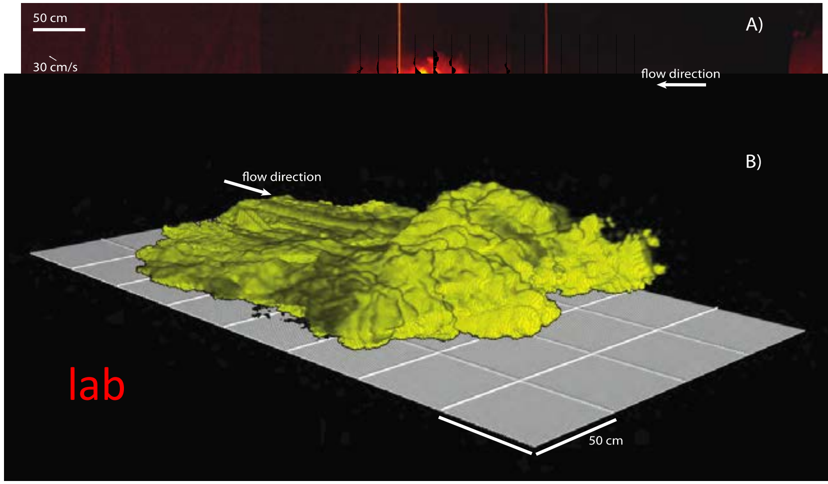


Figure 1.11

4. How do Earth Systems interact with eruptions

Volcanoes affect a host of Earth systems, and vice versa

4.1 How do landscapes, the hydrosphere and atmosphere respond to volcanic eruptions?

4.2 How do volcanoes respond to tectonics and changes in climate?

Important test of models for volcanoes and eruption thresholds, and hence improves hazard mitigation

4.1 How do landscapes, the hydrosphere and atmosphere respond to volcanic eruptions?

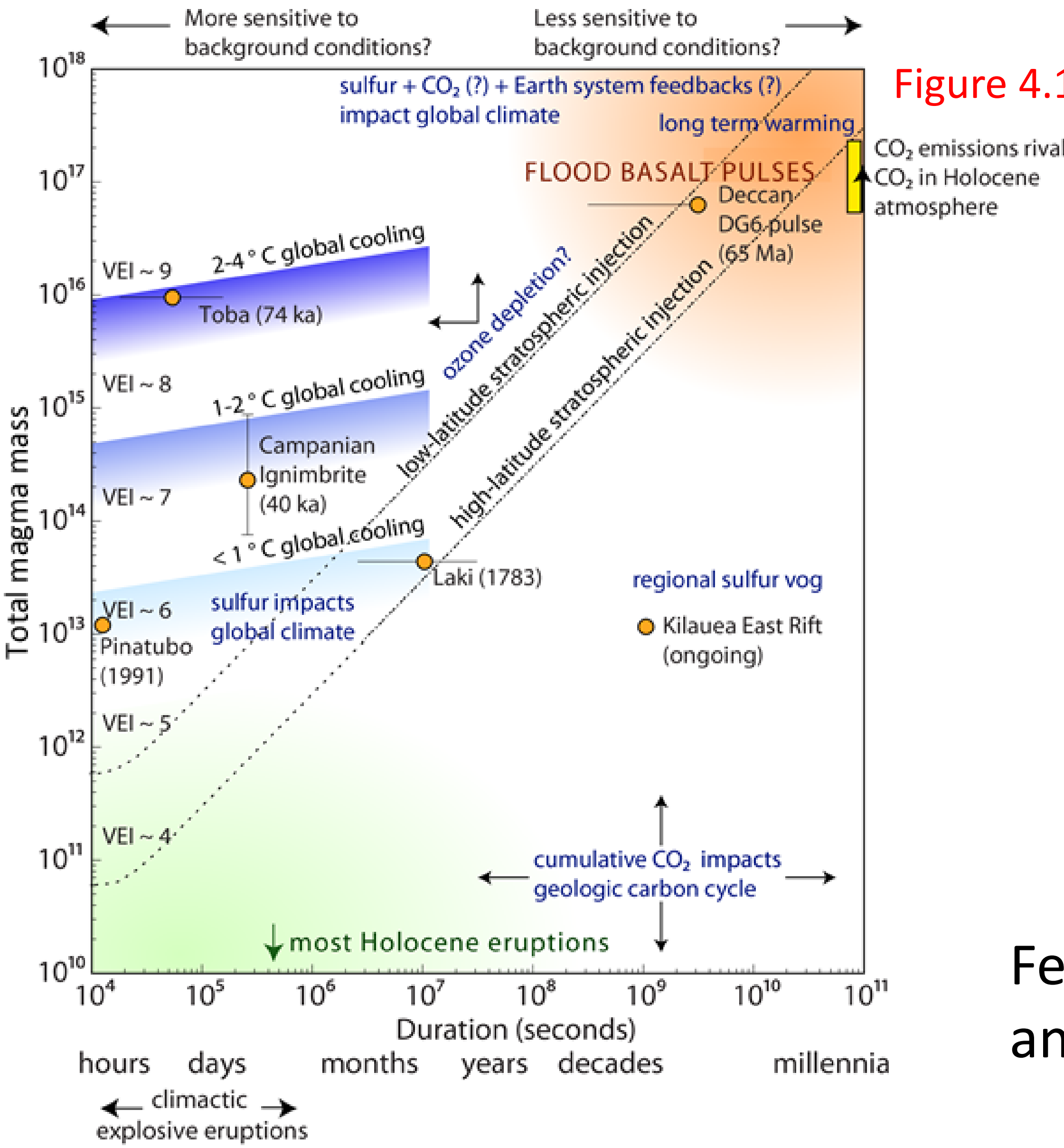
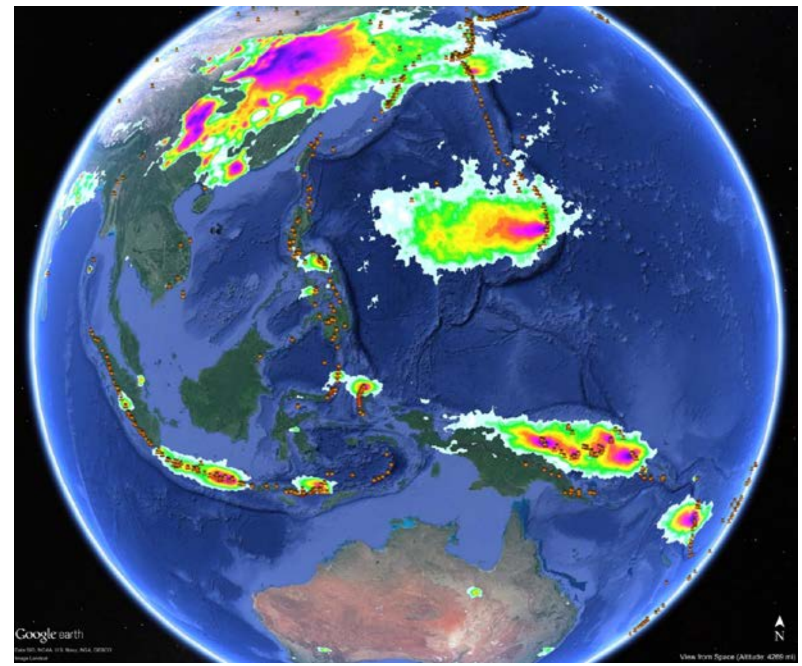


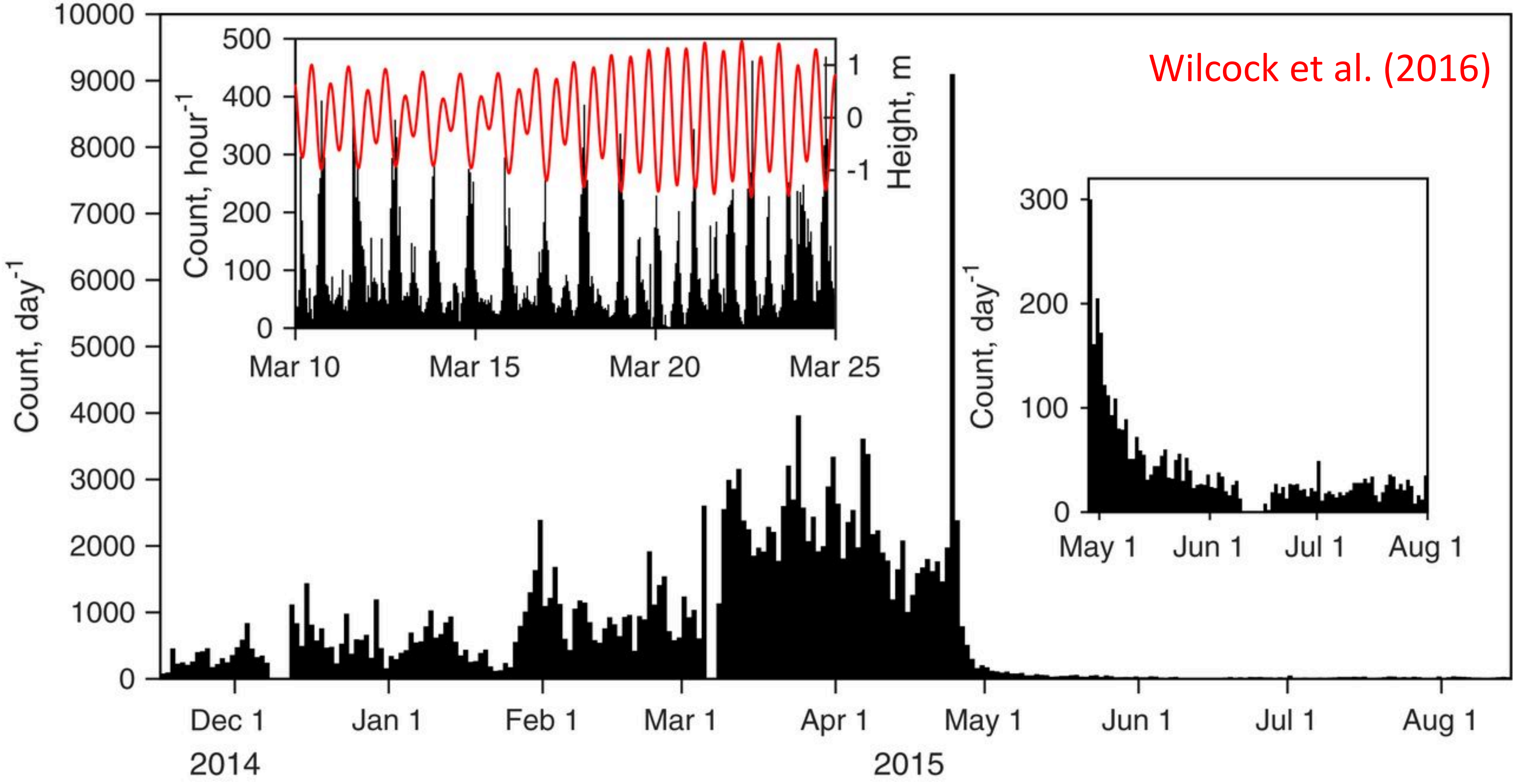
Figure 4.1

Figure 4.2



Feedbacks between eruptions and other Earth systems

4.2 How do volcanoes respond to tectonics and changes in climate?



Response to ocean tides at the submarine Axial volcano, monitored by a cabled observatory, reveals that volcano is critically stressed

5. Strengthening volcano science

Requirements for an effective volcano science community

- Support for interdisciplinary collaboration and training, which is essential to making discoveries and integrating models and measurements
- Shared community infrastructure, which is necessary for state-of-the-art modeling, analytical facilities, monitoring and field experiments
- Databases that preserve and facilitate open exchange of information and hence enable exploration of the life cycle of volcanoes and improve forecasting
- New technology and instruments that permit new detection, measurements and sampling, including previously inaccessible parts of ongoing eruptions
- A coordinated response by the research community to eruptions globally to overcome observational bias
- Observatory-academic partnerships, which will accelerate the translation of basic science to applications and monitoring

6. Grand challenges in volcano science

1. Forecast the size, duration and hazard of eruptions by integrating observations with quantitative models of magma dynamics

Developing conceptual models, and models that inform forecasting, require integrating data and methodologies from multiple disciplines

6. Grand challenges in volcano science

2. Quantify the life cycles of volcanoes globally and overcome our biased understanding

Key for interpreting precursors and unrest, revealing processes that govern the initiation, magnitude and duration of eruptions, and evolution during quiescence

Expanded monitoring from the ground, space and at sea will fill observational gaps

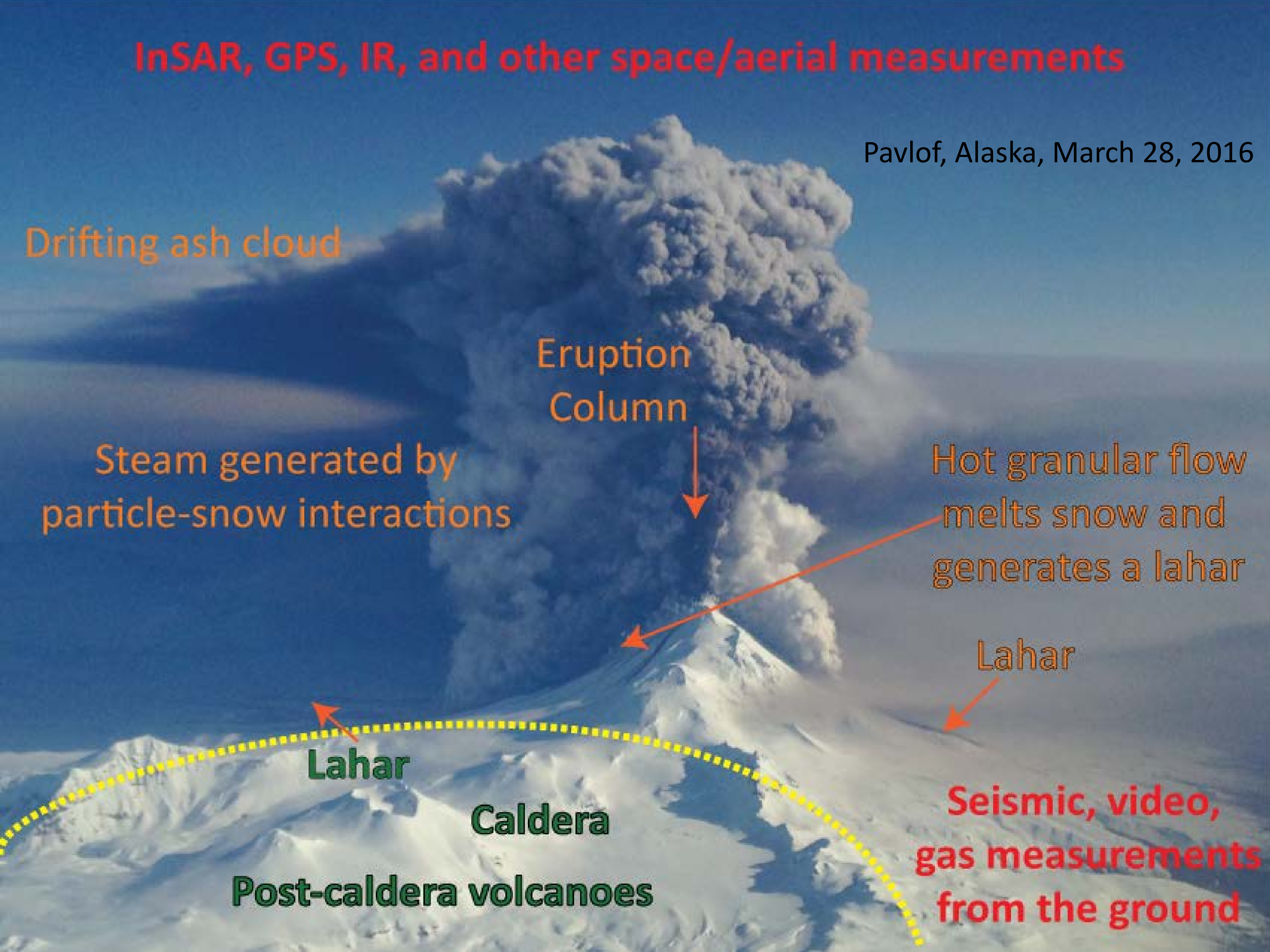
Emerging monitoring and lab technologies provide previously unimagined opportunities

6. Grand challenges in volcano science

3. Develop a coordinated volcano science community to maximize scientific returns from *any* volcanic event

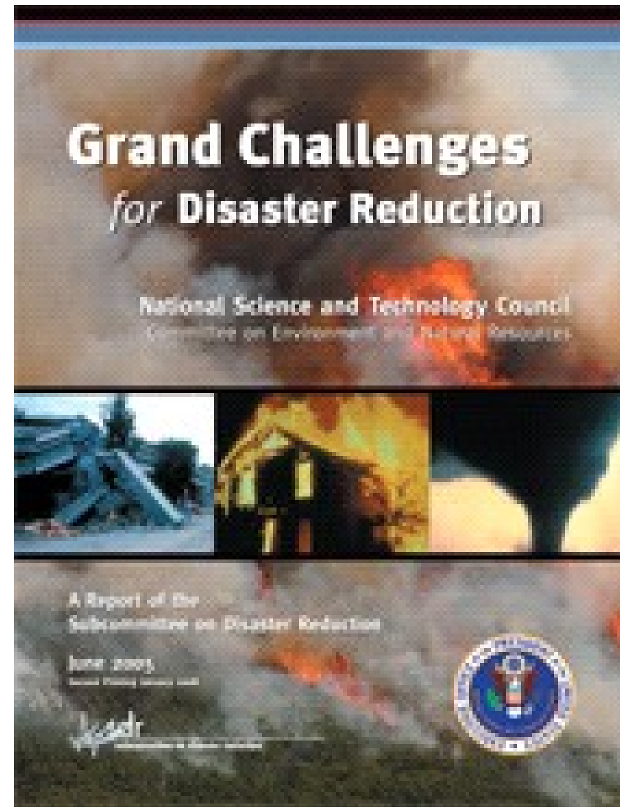
The research community needs to be prepared to monitor and respond to eruptions globally

Requires multidisciplinary research, USGS-academic partnerships, training networks


InSAR, GPS, IR, and other space/aerial measurements
Pavlof, Alaska, March 28, 2016
Drifting ash cloud
Eruption
Column
Steam generated by
particle-snow interactions
Hot granular flow
melts snow and
generates a lahar
Lahar
Lahar
Caldera
Post-caldera volcanoes
Seismic, video,
gas measurements
from the ground

Overlap of key questions with Grand Challenges for Disaster Reduction (volcano implementation plan)

- Grand challenge 1: Provide hazard disaster information where and when it is needed
- Grand challenge 2: Understand the natural processes that produce hazards
- Part of grand challenge 4: Reduce vulnerability of infrastructure
- Part of grand challenge 5: Assess disaster resilience



We understand the basics of how volcanic systems work, yet we have accurately forecast few volcanic eruptions.

Major improvements in understanding and forecasting are possible through

- enhanced monitoring (observing all potentially active volcanoes)
- advances in experimental and mathematical models of volcanic processes, and
- integration of research and monitoring to maximize scientific returns from any volcanic event

Committee

Michael Manga (Chair), University of California, Berkeley

Simon Carn, Michigan Technological University, Houghton

Katharine Cashman, University of Bristol, United Kingdom

Amanda Clarke, Arizona State University, Tempe

Charles Connor, University of South Florida, Tampa

Kari Cooper, University of California, Davis

Tobias Fischer, University of New Mexico, Albuquerque

Bruce Houghton, University of Hawaii at Manoa

Jeffrey Johnson, Boise State University, Idaho

Terry Plank, Columbia University, New York

Diana Roman, Carnegie Institution for Science, Washington, DC

Paul Segall, Stanford University, California

Stephen McNutt, COSG liaison

Anne Linn, National Academies staff