Eliza S. Calder
Center for Geohazards
State University New York at Buffalo

Workshop on ground-based and remote sensing of volcanic unrest (IUGG 2011)

Why A Monitoring Course ?

- Volcanology science taught from process based perspective.
- Volcanologists however come from diverse backgrounds (geologists, geochemists, remote sensors, geophysicists).
- Multi-disciplinary approaches most useful for understanding physical processes.
- To integrate data, need to understand each others data.

=> Methods-based course.

What we don’t intend to do:

Cover every type of monitoring method used to monitor volcanoes.

Or teach you every step of how collect, process and interpret monitoring data from different instruments.

Or, tell people who work in volcano observatories how to do their jobs !

Instead, our intention is to:

Show some detailed examples of how we use the data collected to understand volcanic systems, interpret aspects of their plumbing or improve our understanding of the physical processes involved.

Stress : utility of multi-parameter approaches to understand volcanic processes.

Workshop Schedule

9:00 - 9:45 am - Eliza Calder (overview multi-disciplinary monitoring)
9:45 - 10:30 am - Diana Roman (volcano seismology)
10:30 - 11:00 am - Morning coffee break
11:00 - 11:45 am - David Fee (volcano infrasound)
11:45 - 12:30 am - Jo Gottsman (volcano geodesy)

12:30 - 1:30 pm – Lunch

1:30 - 2:15 pm - Mike Ramsey (ground-based thermal monitoring)
2:15 - 3:00 pm - Rob Wright (remote thermal monitoring)
3:00 - 3:30 pm - Afternoon coffee break
3:30 - 4:15 pm - Simon Carn (ground-based and remote sensing of gas)
4:15 - 4:30 pm - Eliza Calder (wrap-up and optional discussion)

Multi-parameter monitoring

A very general overview

What is multi-parameter monitoring ?

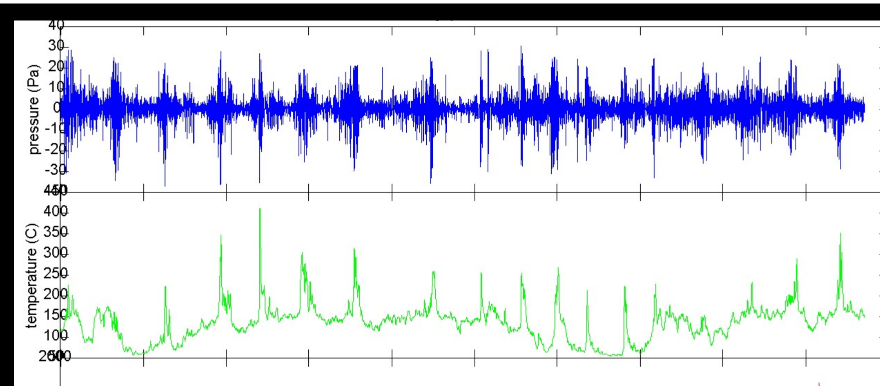
What are we trying to measure ?

What are the problems with it ?

Where are we going with it ?

Q1: What is multi-parameter monitoring ?

Why are we interested in it ?



Simple thought experiment

Process : Tourist getting on a London bus.

Methods : IUGG Workshop Monitoring Team

Remote sensing

- **Rob Wright** (satellite-based thermal remote sensing) : Little hot spot coalesces with big hot spot, then track movement across town.
- **Mike Ramsey** (ground-based thermal sensing) : Large object has hot front, and hot gas plume comes out the back of it and that these signatures increase when the object moves.
- **Simon Carn** (gas spectroscopy) : Variations of gas species and concentrations over time, source of emissions migrates with time.

=> Spectral imaging of surface characteristics associated with, or emissions resulting from, the activity.

Geophysicists

- **Jo Gottsman** (Ground deformation) : Object undergoes lateral displacement, and reassure us object doesn’t inflate or subside.
- **David Fee** (Infrasound) : Detect engine ‘noise’ (explosions) and perhaps noise associated occupants.
- **Diana Roman** (Seismicity) : Detect ground tremor generated by the moving bus, when it stops and starts, environmental noise generated by the occupants. Detect the response of the road (brittle failure?) caused by the load of the bus.

=> Detecting motion generated by (mostly) internal physical processes.

But…

- No single method can tell us it's a bus picking up a passenger.

  ->Need to combine approaches, to reduce degrees of freedom.

- No single method knows where the bus came from or what happens to it in the future (so if it were an isolated event we would struggle to have any idea).

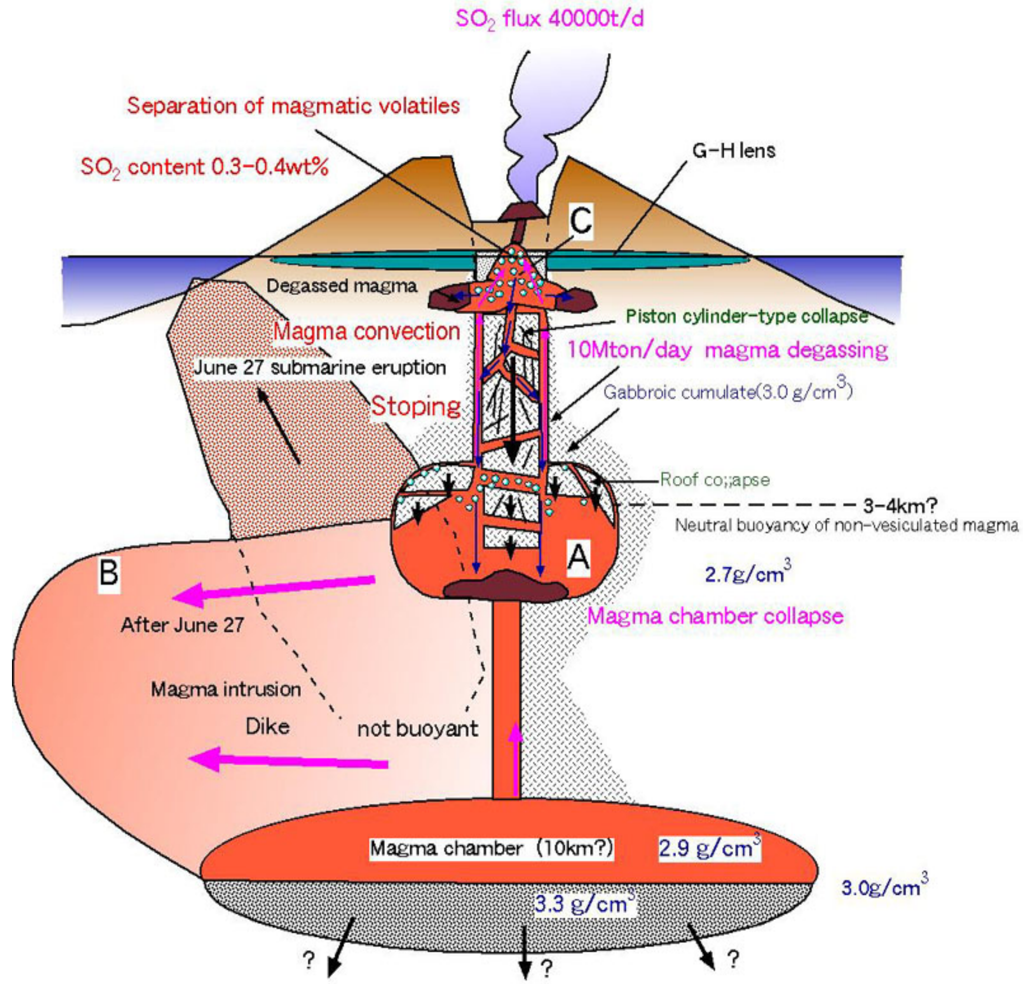
  ->But if many buses came, we could all measure repeatedly, different places and times, we might have a chance. So, repeated observations, improve our chances of a better understanding.

Volcanic systems are complicated natural systems

Objective of multi-parameter monitoring is to build an understanding of the internal workings of active volcanic systems with their complex plumbing systems and where material properties change with time.

Based on collecting disparate data sets and making sense of the common story that they tell.

e.g. Miyakejima, Japan



http://staff.aist.go.jp/kazahaya-k/miyakegas/COSPEC.html

Geological Survey of Japan

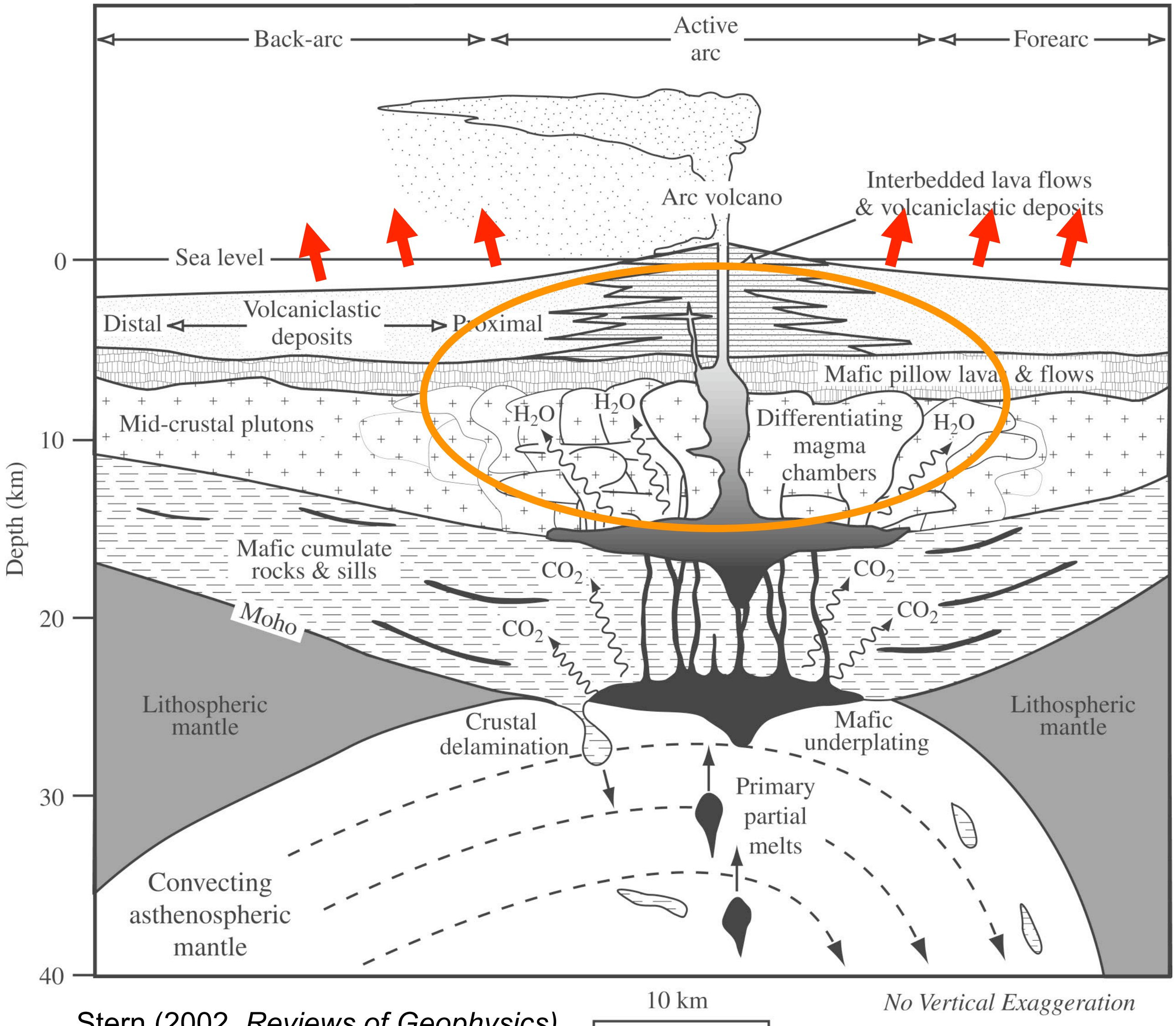
Q2: What are we trying to measure ?

Note: Focus on application not methods

However, Methodology or (technology involved) defines limits of what can practically be measured. Easy to let the methodology guide research

1. Deep plumbing systems
2. Shallow plumbing (explosive, effusive, dome building)
3. Surface Processes (explosive, effusive, dome building)

1. Deep Plumbing (Macroscopic)



Stern (2002, *Reviews of Geophysics)*

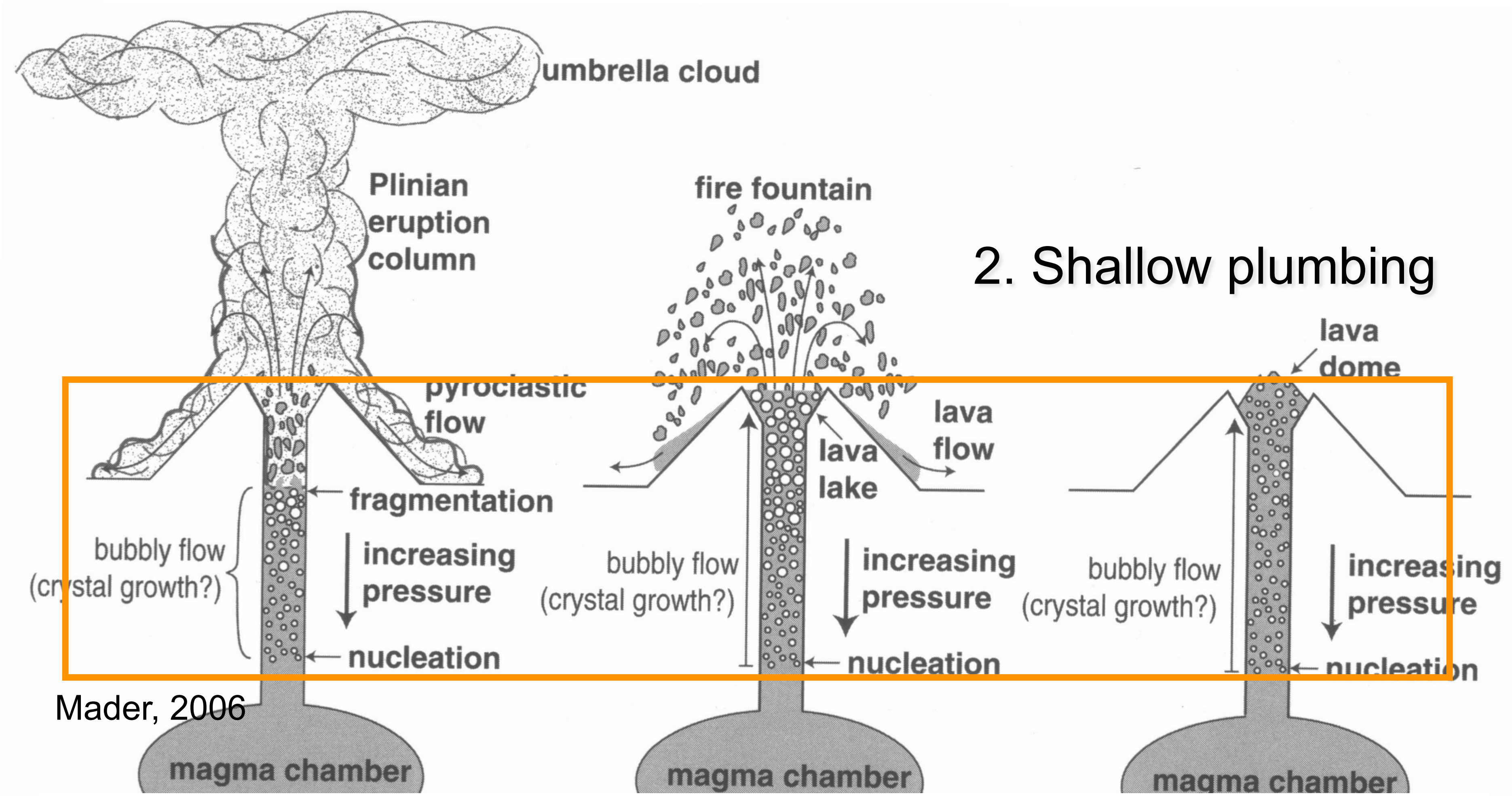
Schematic diagram of *deep* plumbing of a stratovolcano in an oceanic arc setting

<u>Processes</u>
Rising & ponding of new magmas
Dike injection
Interaction with hydrothermal systems

<u>Tools</u>
Ground Deformation
Gravity
Seismics
Petrology

Important for long-term forecasting of eruptive episodes

2. Shallow plumbing



Mader, 2006

Explosive eruptions | Effusive eruptions | Lava-dome eruptions

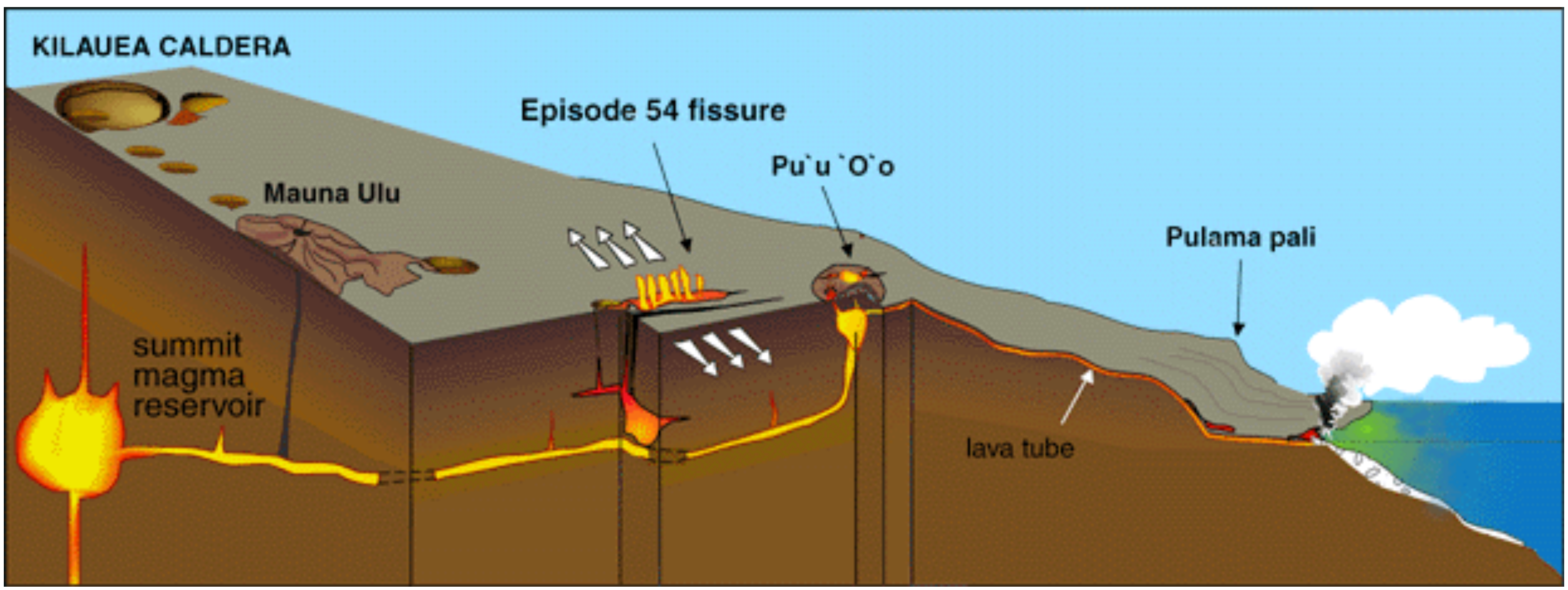
Bubble nucleation, rise, coalescence
Fragmentation
Crystal growth/solidification
Conduit flow
Conduit convection

Seismicity
Infrasound
Gas spectroscopy
Thermal remote sensing

e.g. Shallow plumbing in effusive systems, Kilauea, Hawaii

Complicated plumbing system
Spatial dimension important
Utility of some methods over others

Gas
Deformation
Gravity
Seismics
Thermal Remote sensing

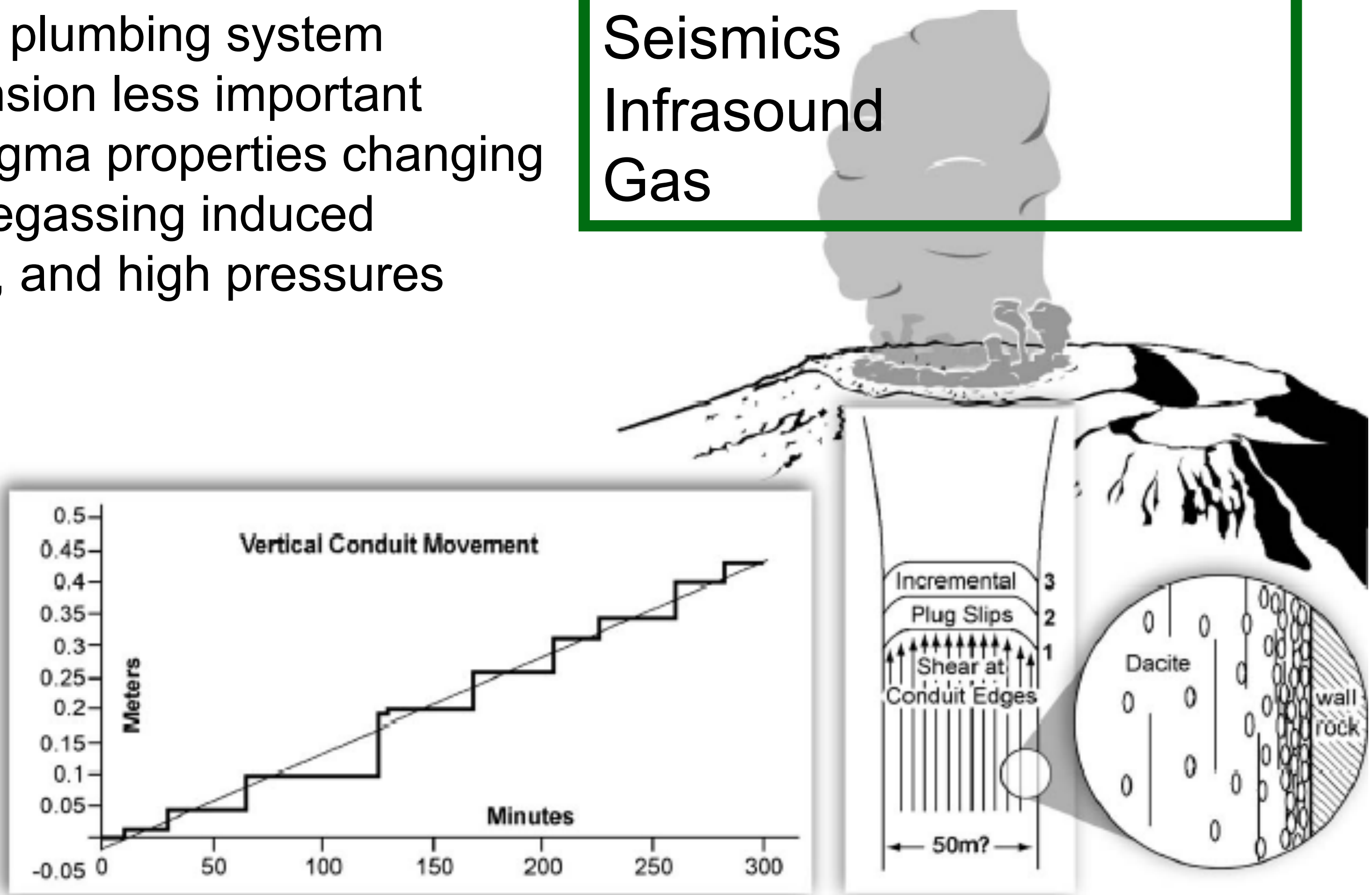


http://www.albion.edu/geology/geo210_hawaii/Kilauea/Kilauea%20homepage.htm

e.g. Shallow plumbing in lava dome system, Santiaguito, Guatemala

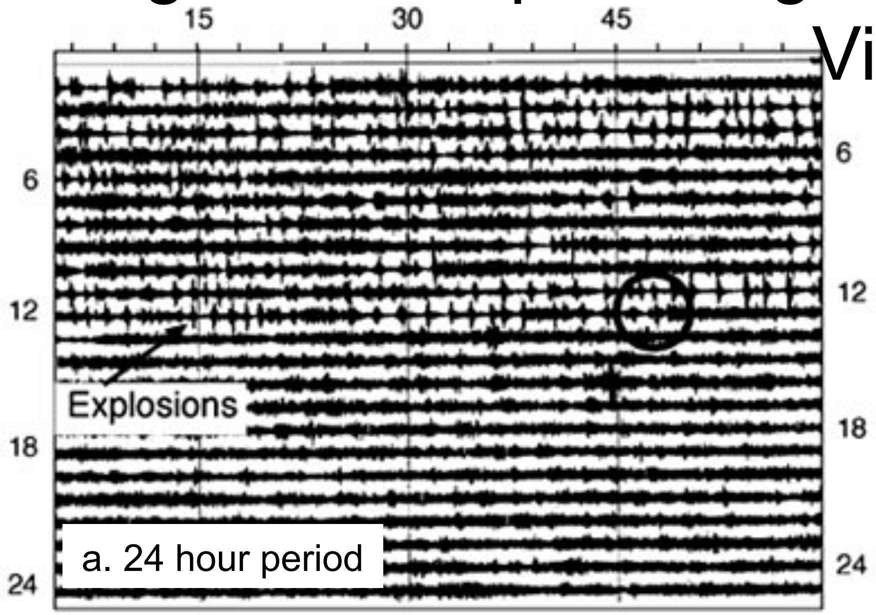
More 'simple' plumbing system
Spatial dimension less important
However, magma properties changing with depth, degassing induced crystalization, and high pressures building up.

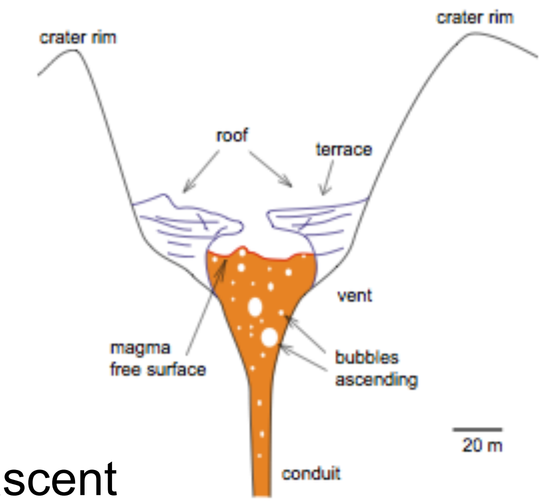
Thermal Remote sensing
Seismics
Infrasound
Gas



Santiaguito, Guatemala, from Bluth & Rose, 2004

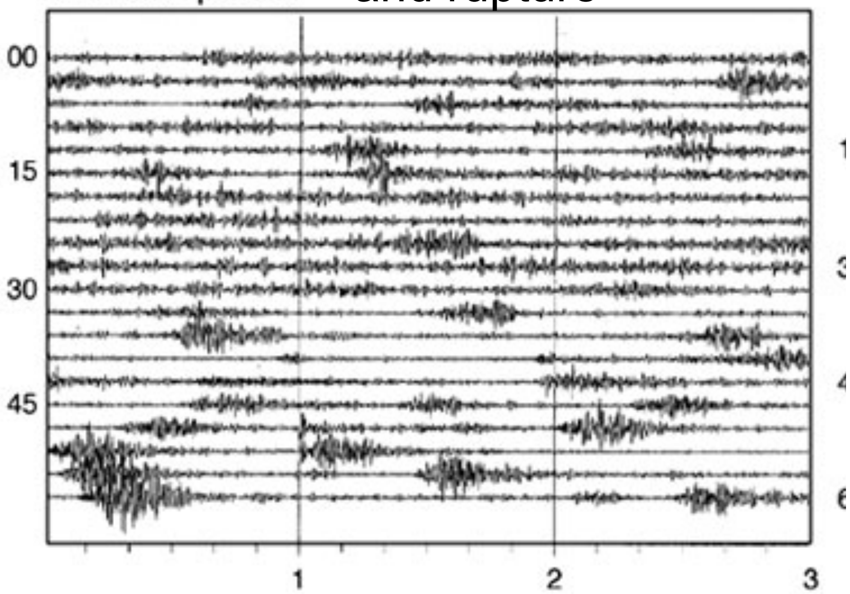
e.g. Shallow plumbing in effusive systems, Villarrica, Chile

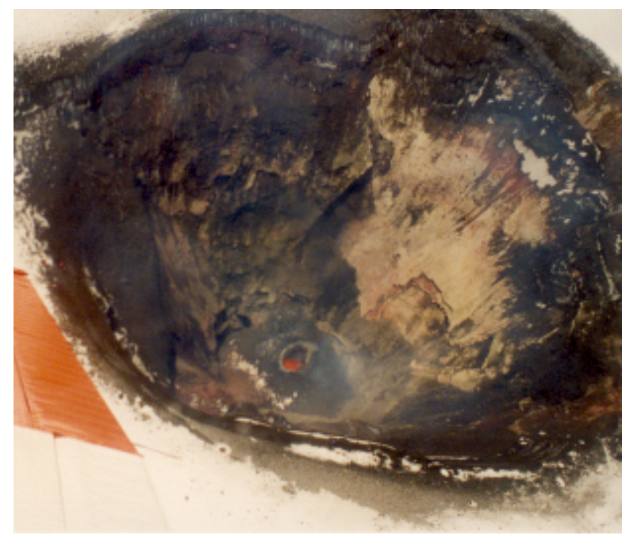




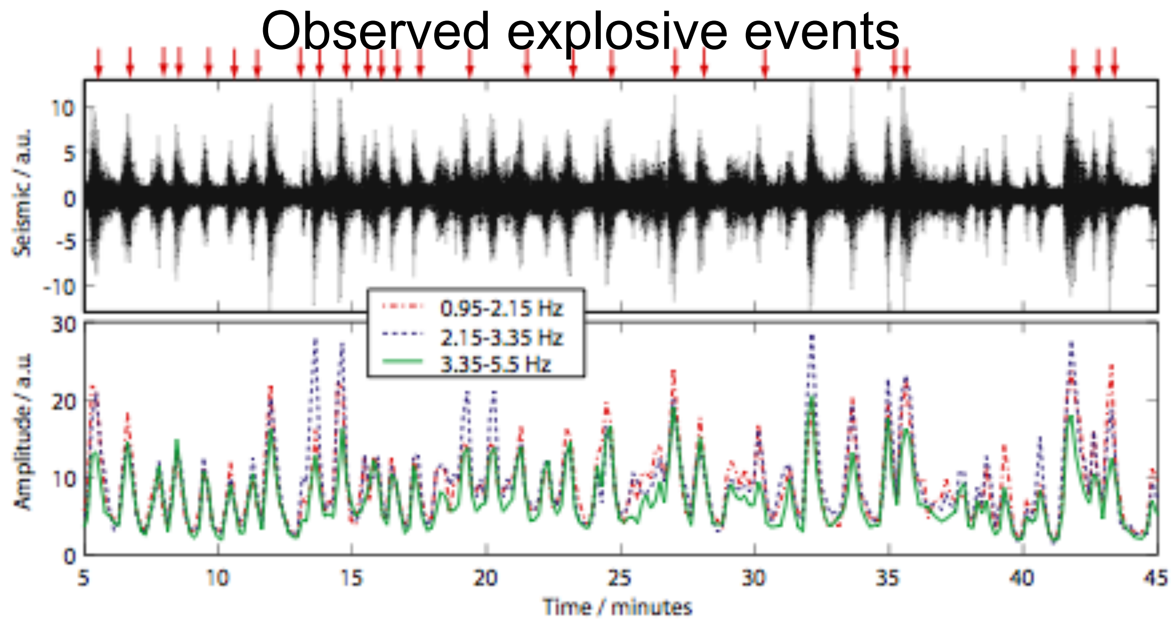
Semi-continuous gas slug ascent and rupture

b. 1 hour period



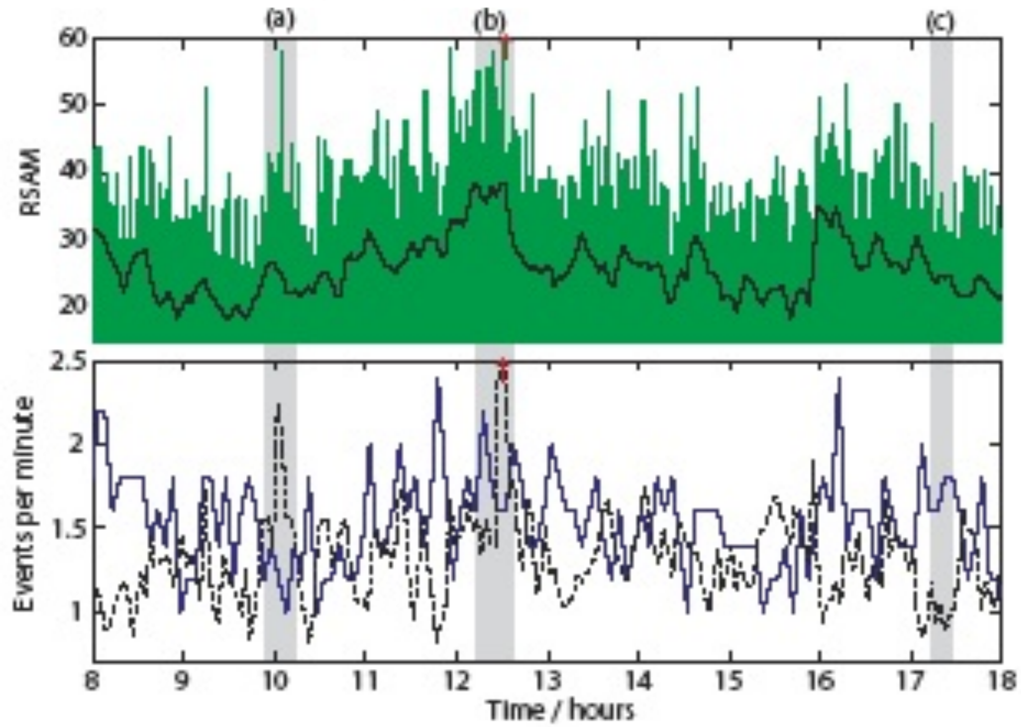


Palma et al, 2010

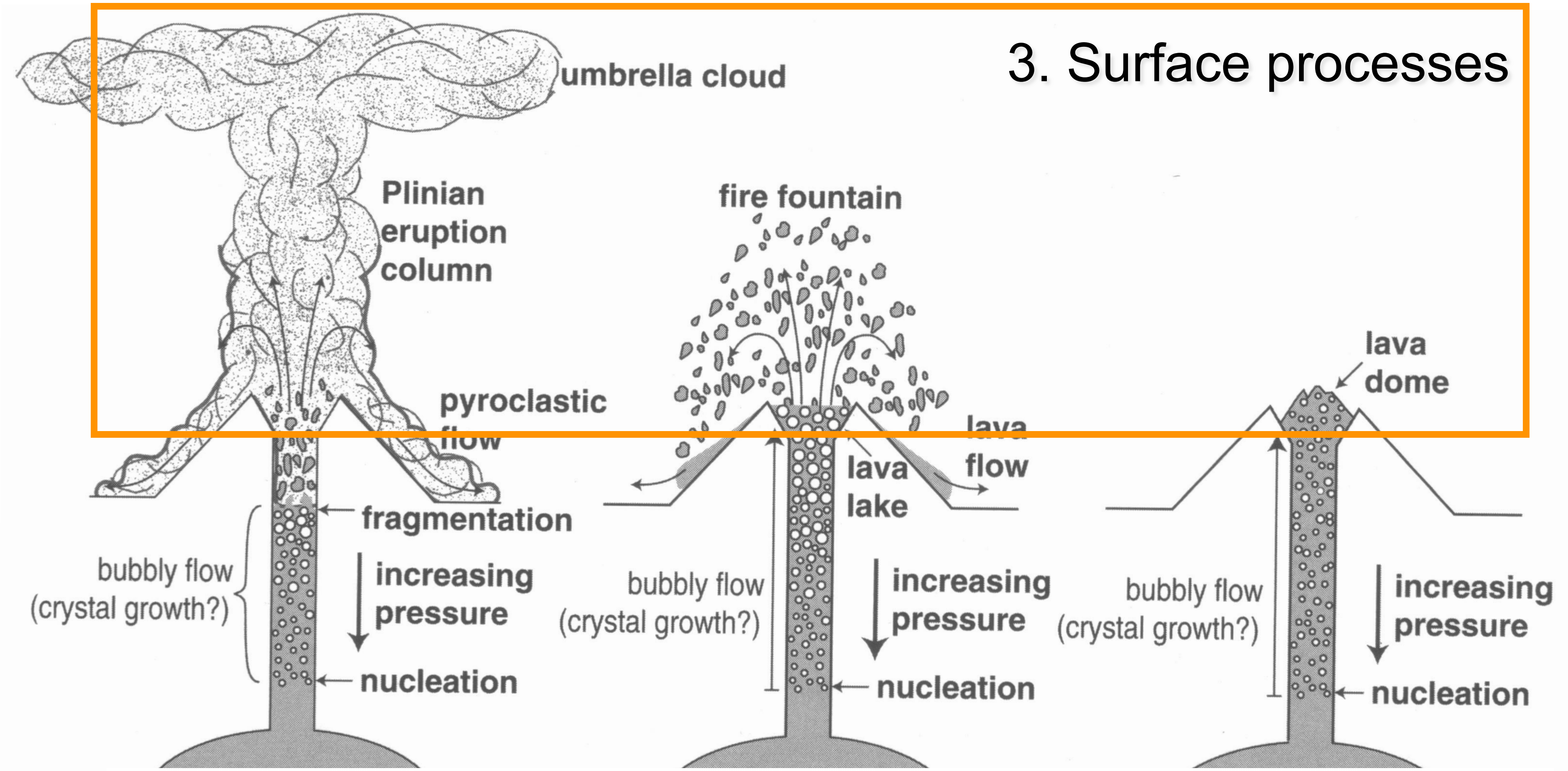


Observational data is ‘data’ - most usefully captured on timed digital video !

Utility of seismic data limited (short period, single component) but combined with observational data - source of transients clearly linked to surface explosions.



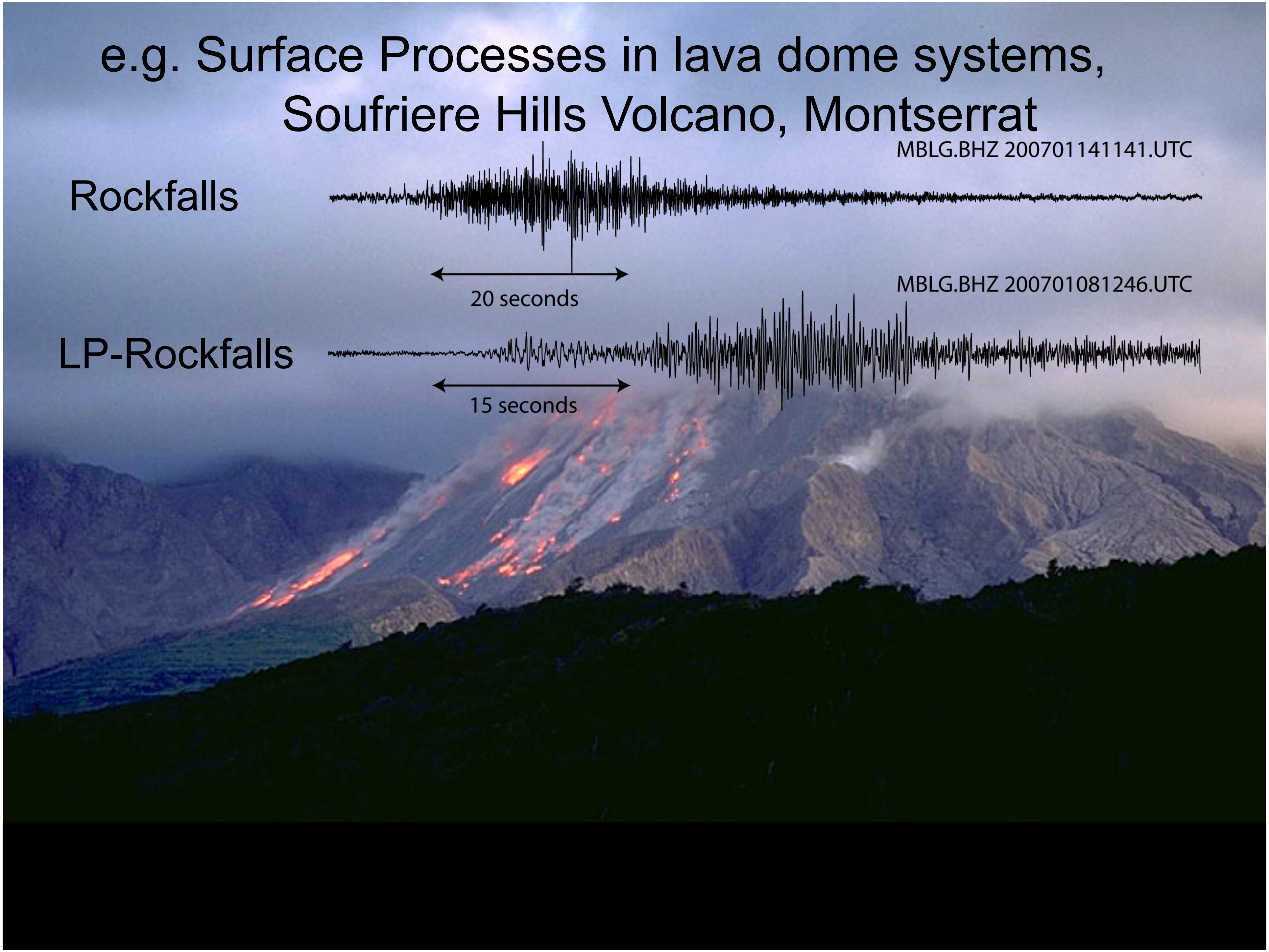
3. Surface processes



Plume characteristics (proximal/distal)
Fragmentation
Degassing
Lava extrusion characteristics
Flow processes

Visual Observations/video
Thermal imaging
Gas spectroscopy/imaging
Seismics
Radar
Remote sensing

e.g. Surface Processes in lava dome systems, Soufriere Hills Volcano, Montserrat

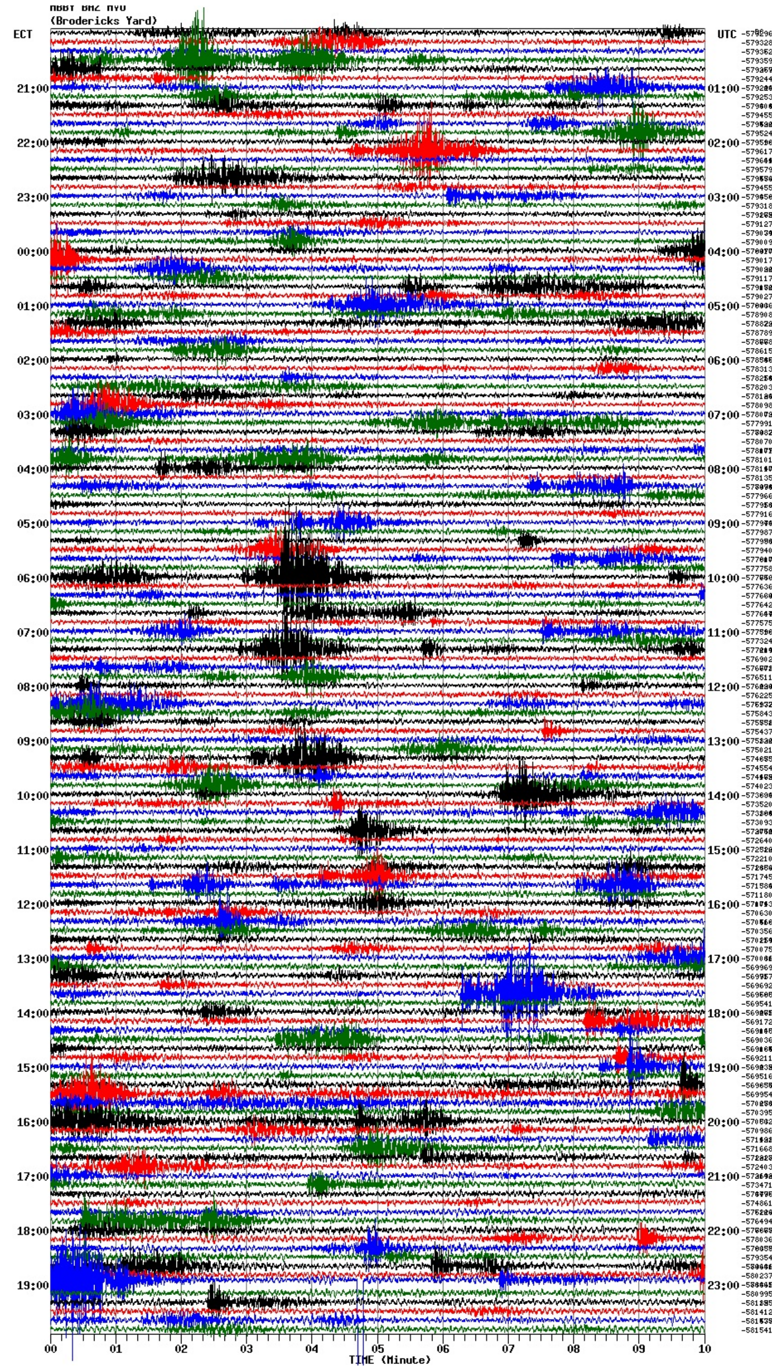


- Seismic record of surface processes (rockfall/pyroclastic flows) provides information on timing, repose, duration, energy, frequency content and data is collected systematically.

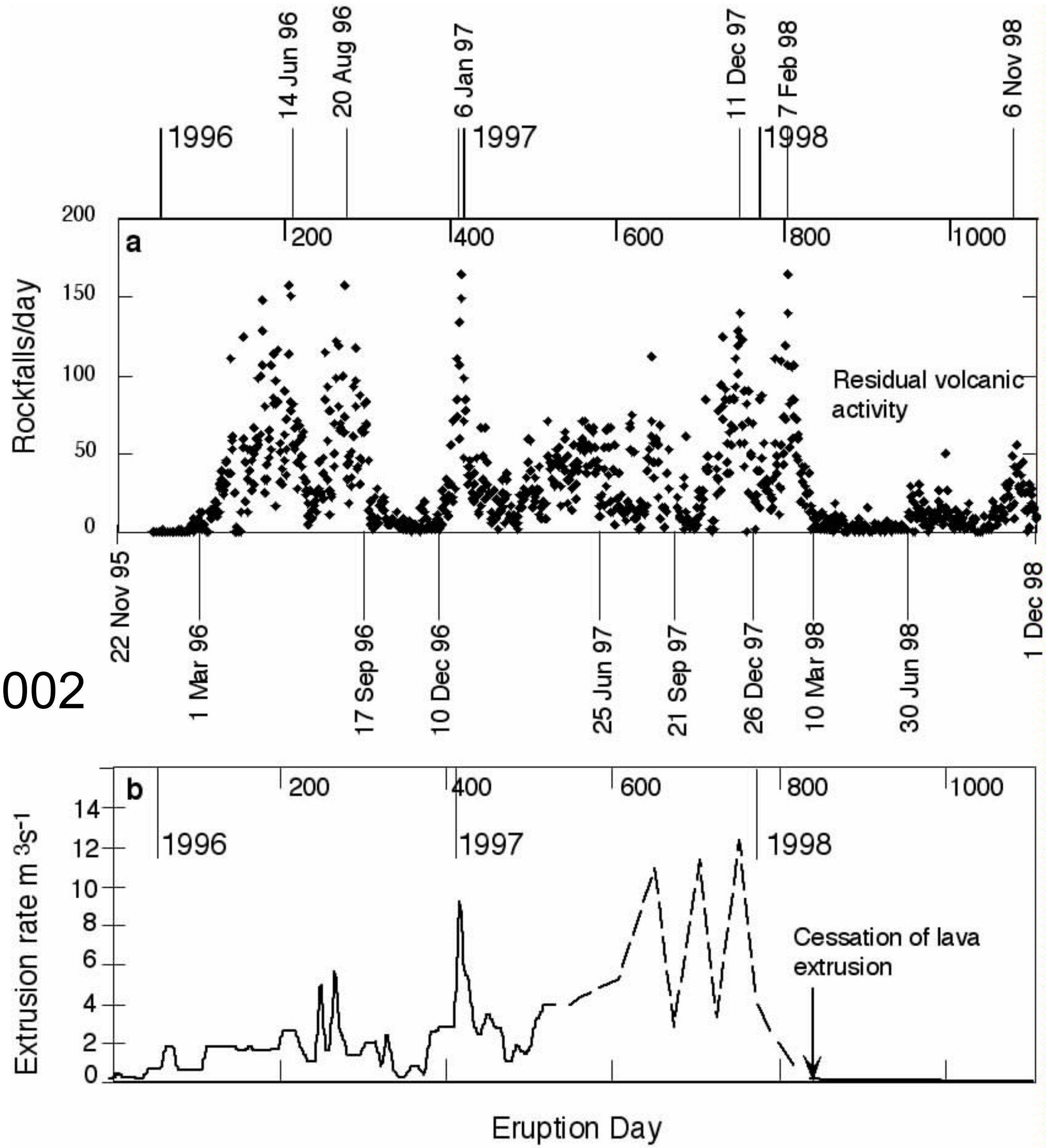
- 500,000 rockfalls over 15 yrs

- Observational: 47 Dome collapses > 1 M m^3

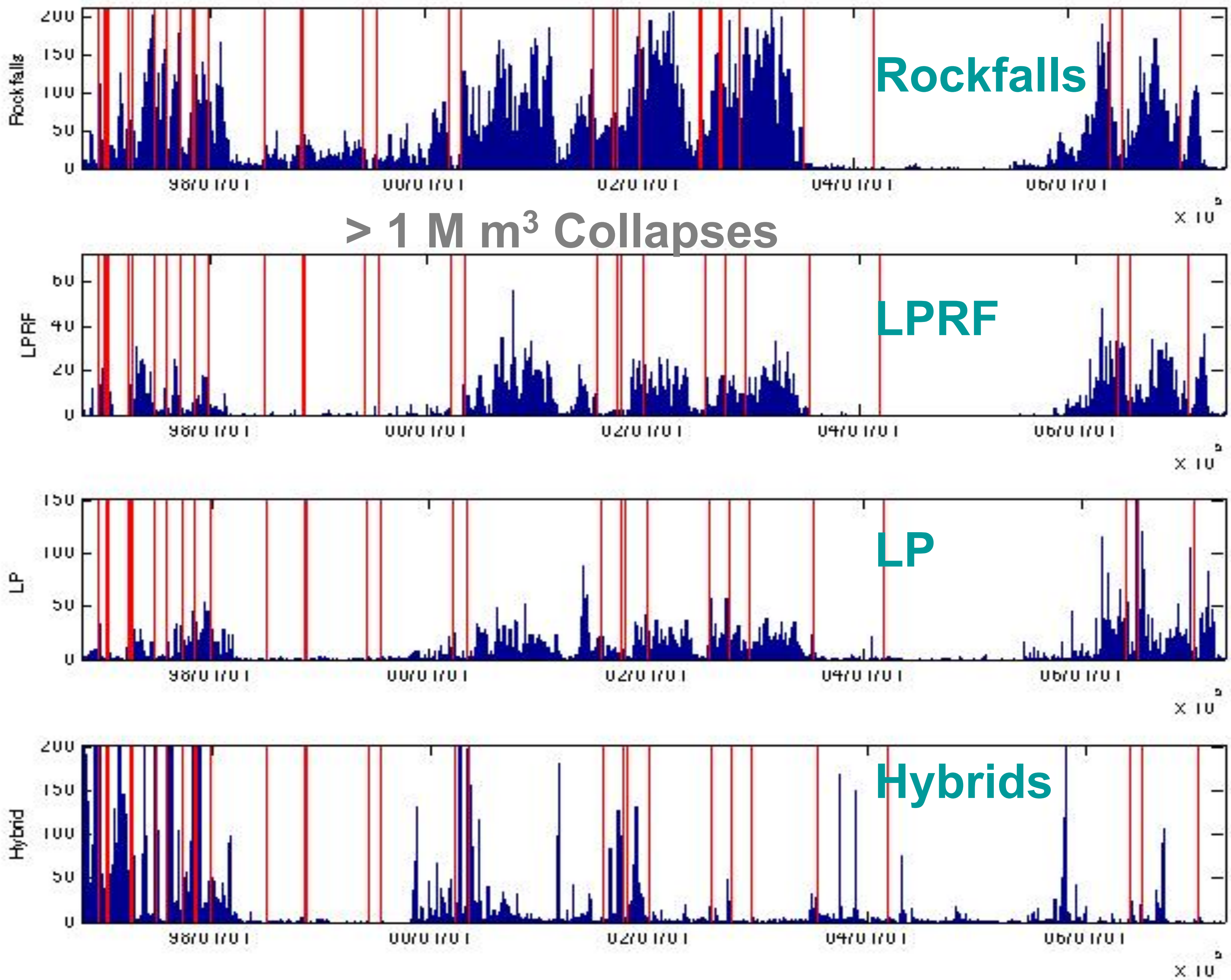
- Used for understanding evolution of dome stability



Rockfalls and extrusion rate Calder et al., 2002



Other seismic signals as indicator of internal processes



Surface process is telling us about dynamics lava extrusion

Q3: What are the problems ?

Required Set of Initial Conditions

- People - involves willingness to collaborate between experts
- Instrument pools
- Active, accessible volcanoes

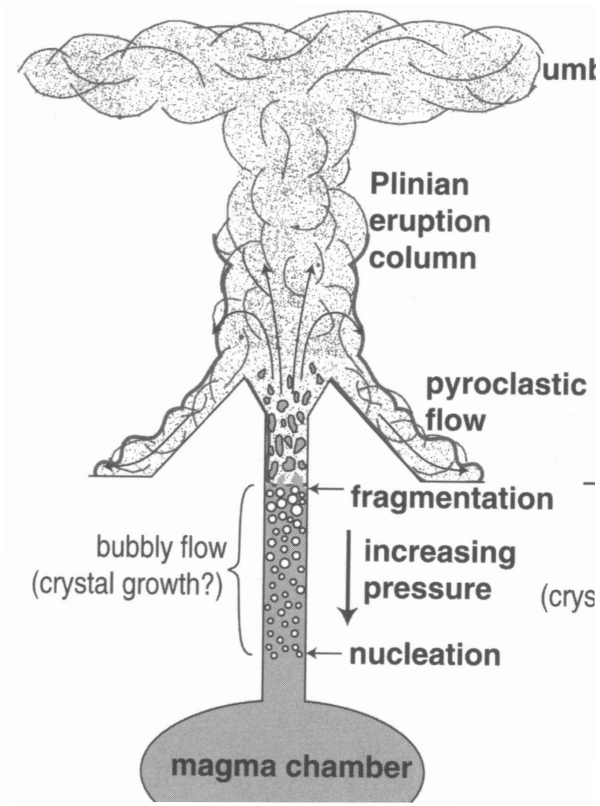
  Such as Persistently active systems
  - Stromboli
  - Kilauea
  - Erebus

  Or Longstanding eruptions
  - Soufriere Hills, Montserrat
  - Santiaguito, Guatemala
  - Mount St Helens
  - Merapi

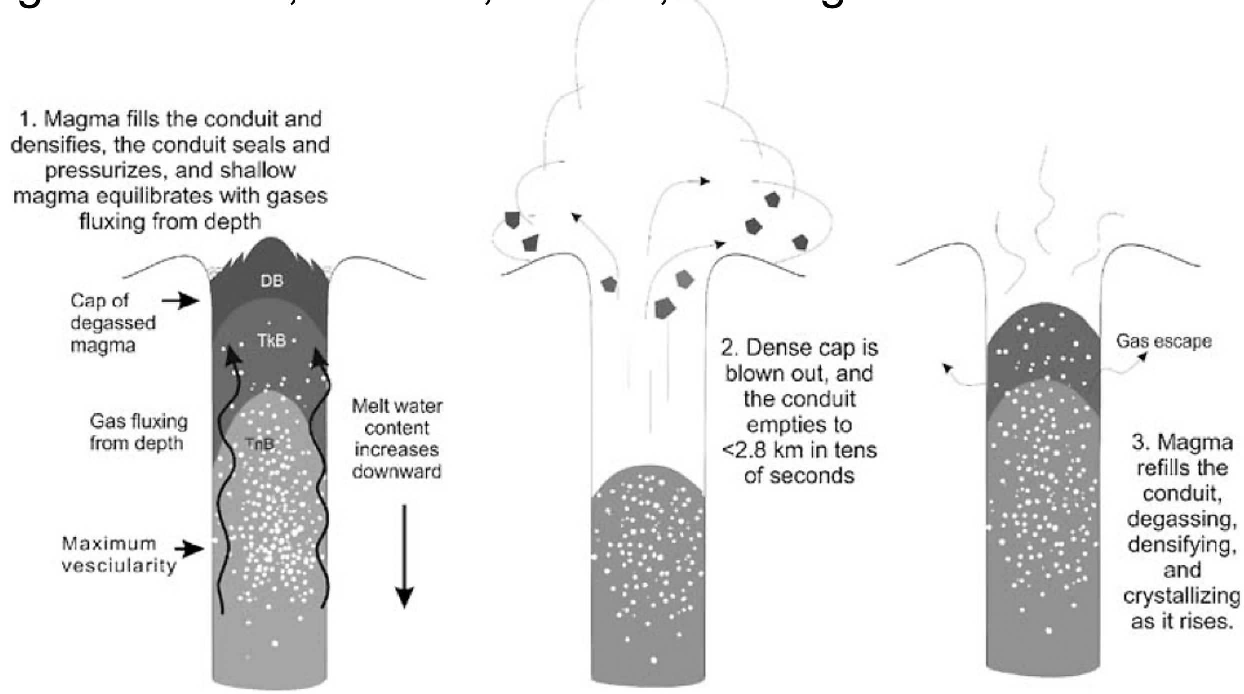
  Do we/can we cover Major Explosive eruptions adequately ?

Shallow plumbing in Vulcanian systems

Relatively small, often <u>repetitive</u>



e.g. Monserrat, Galeras, Colima, Santiaguito



Cashman et al., 2006

Chaiten 2008, Chile

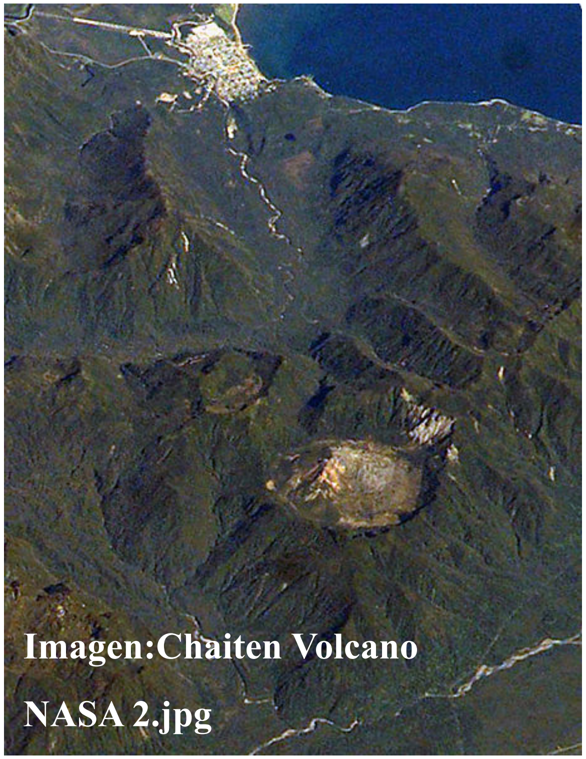


Imagen:Chaiten Volcano NASA 2.jpg

Foto Eric Manríquez T

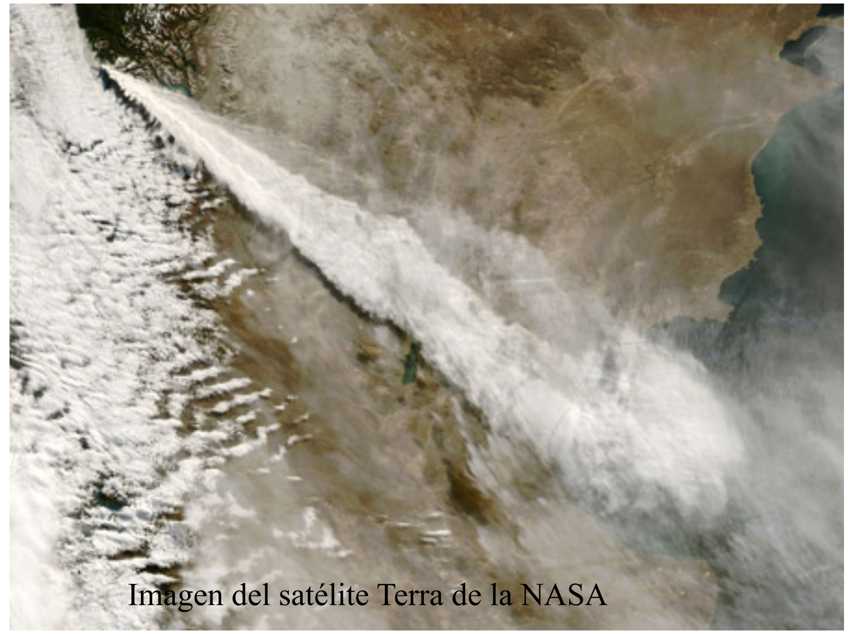


Imagen del satélite Terra de la NASA

agaudi.files.wordpress.com/2008/05/volcan-chaitén

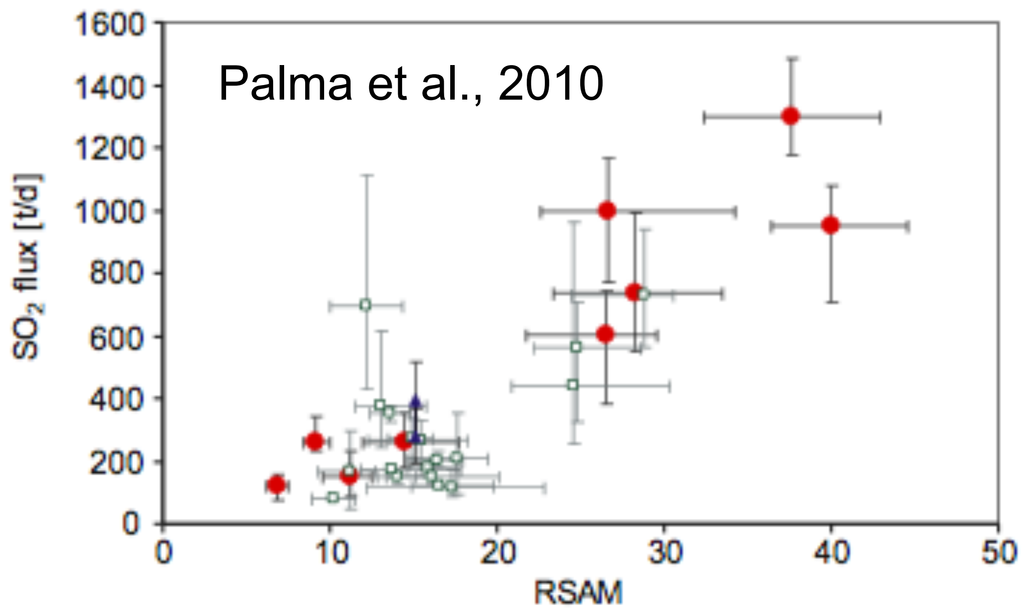
sobrefotos.com/wp-content/uploads/2008/05

Q3: What are the problems ? ..continued

Measuring

Instrument-determined limitations on temporal resolution of data :

e.g. COSPEC surveys few times/ day (now much improved DOAS)
e.g. Continuous seismic/ infrasound etc



Measuring over timescales over which volcanic processes of interest operate:

- Timescale of a sequence of bubbles rising and rupturing in a strombolian system (seconds-minutes)
- Timescale of conduit convection (weeks-months)
- Timescales of injection of new basaltic magma into an andesite magma chamber (months-years)

(will come back to this)

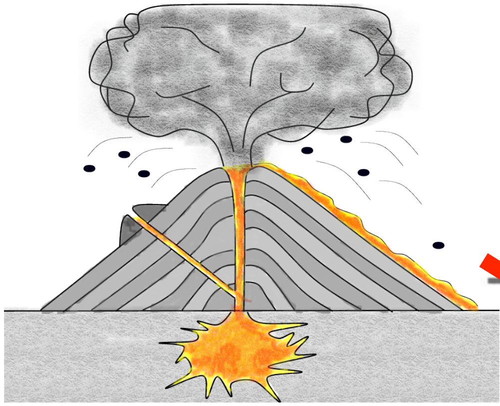
Q3 : What are the problems ? ..continued

A <u>small</u> list of few <u>big</u> problems

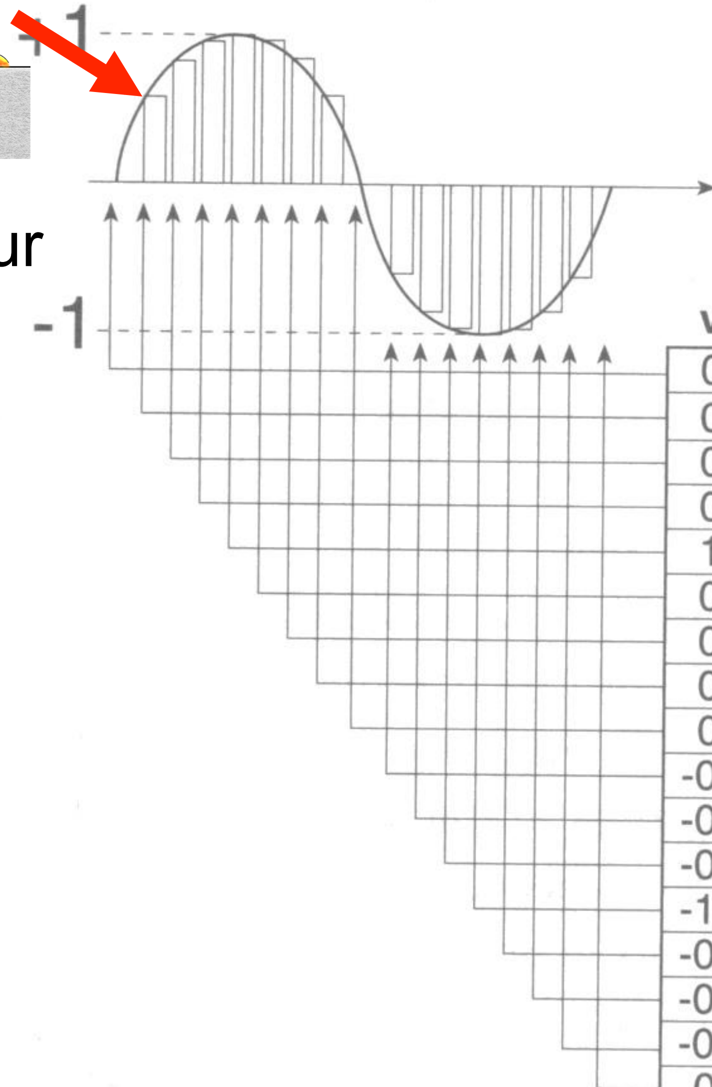
- The logistics of using a common time
- Instruments are filters
- Data don't always seem to tell the same story
- Often have to measure important things indirectly

- Analysis of large data streams - relatively new problem for geologists (need to become proficient in time series analysis and other statistical tools etc).

Instruments as filters



Volcanic behaviour
(analog signal)

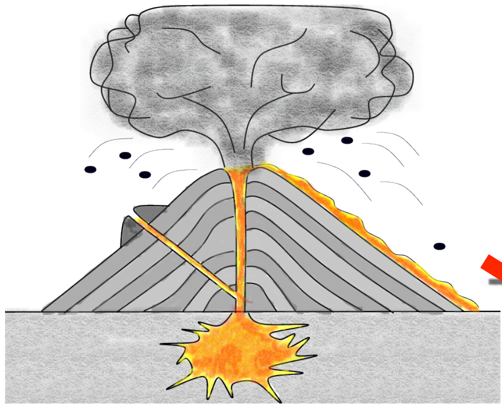


Instrument #1
Digitizes signal

value	address
0	00
0.3827	01
0.7071	02
0.9239	03
1	04
0.9239	05
0.7071	06
0.3827	07
0	08
-0.3827	09
-0.7071	10
-0.9239	11
-1	12
-0.9239	13
-0.7071	14
-0.3827	15
0	16

Signal is
filtered

Instruments as filters



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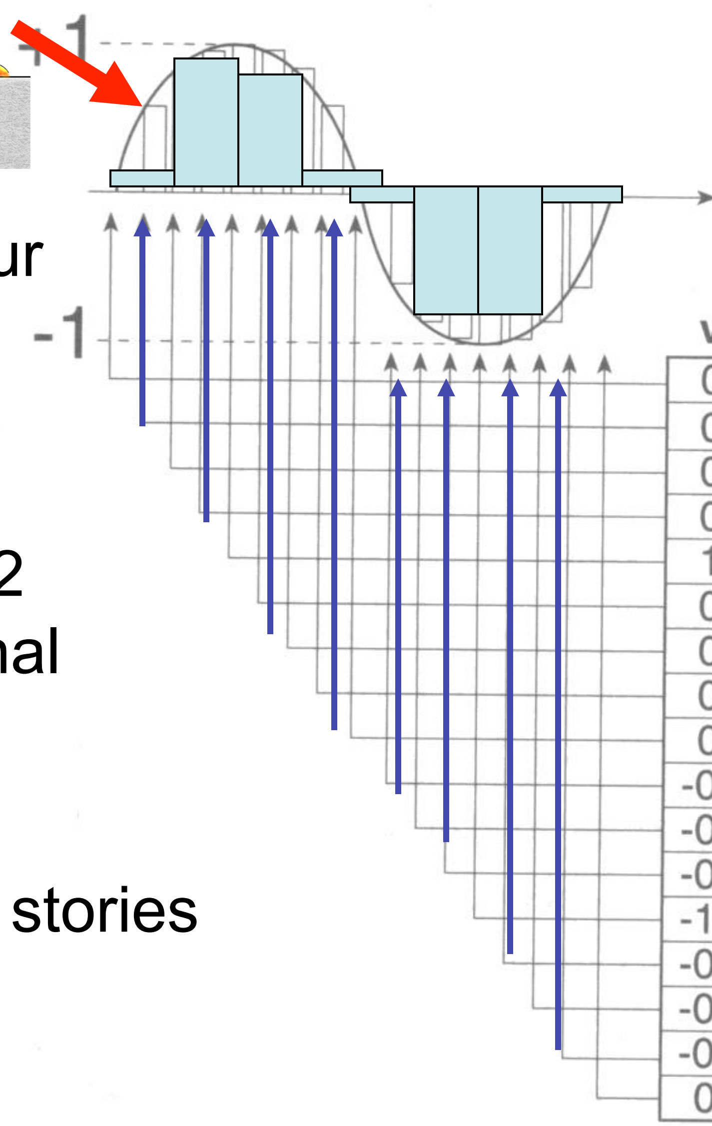

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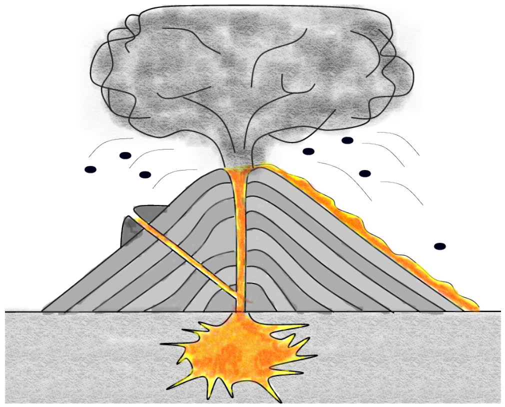
-0.7071	10
-0.9239	11
-1	12
-0.9239	13
-0.7071	14
-0.3827	15
0	16

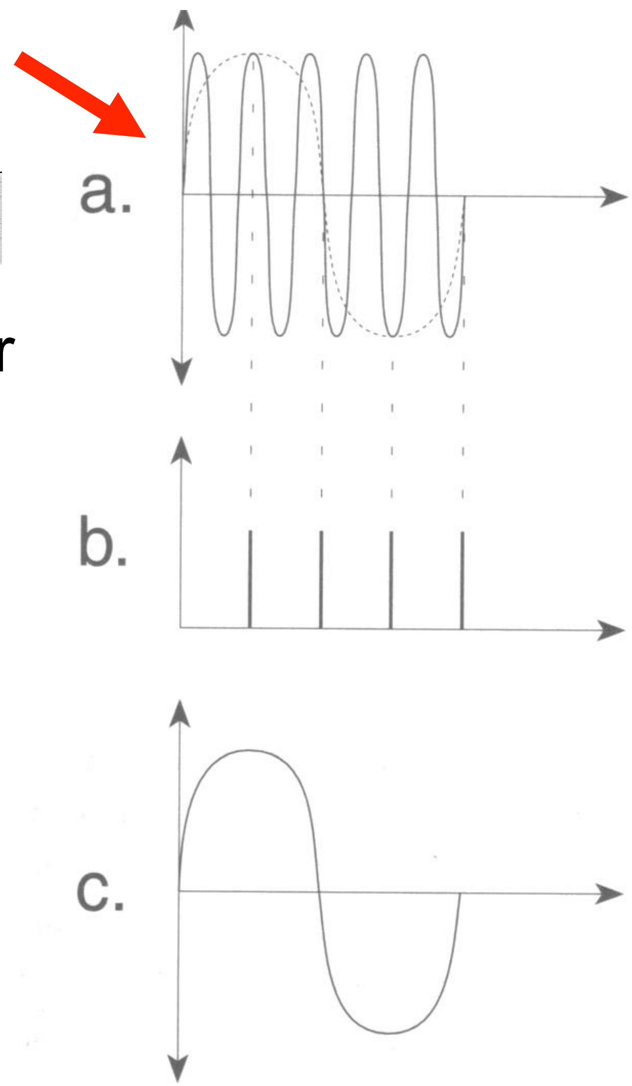
Instrument #2
Digitizes signal

-> 2 Filters, 2 stories



Volcanic behaviour
(analog signal)

Undersampling processes of interest



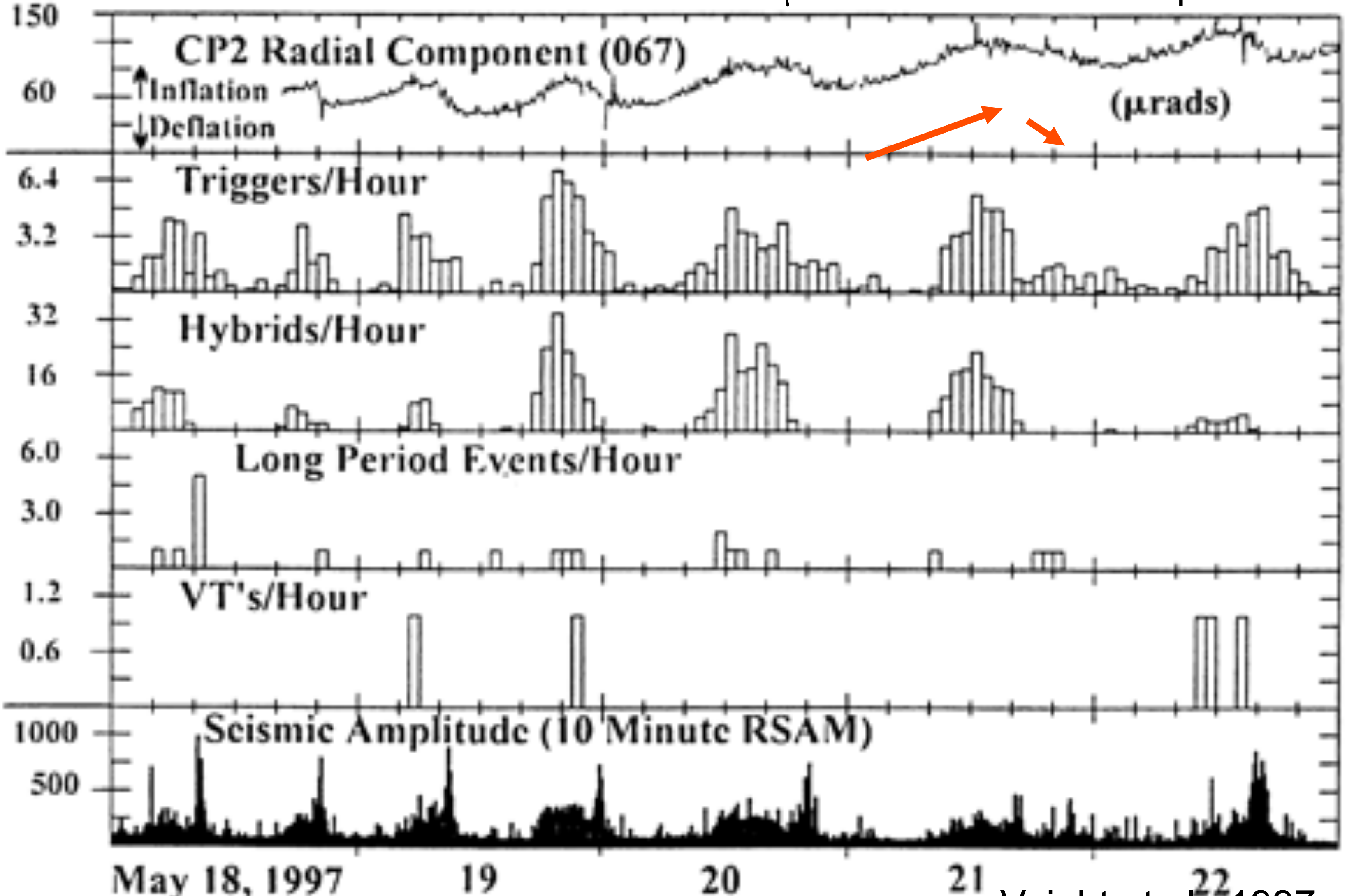
5 Hz sine (5 cycles/s)

Nyquist rate - Sampling rate has to be twice the highest waveform frequency.

Aliasing : 5 Hz sine is under-sampled, leads to incorrect reproduction of a 1 Hz sine.

Lucky windows and well-placed instruments

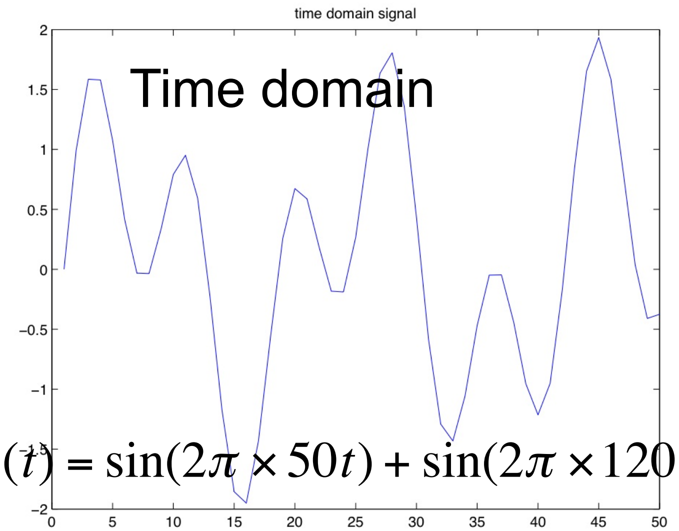
15-20 μrads with 12-18 hour periods



Voight et al., 1997

…Sometimes good data provides a clear picture with minimal analysis

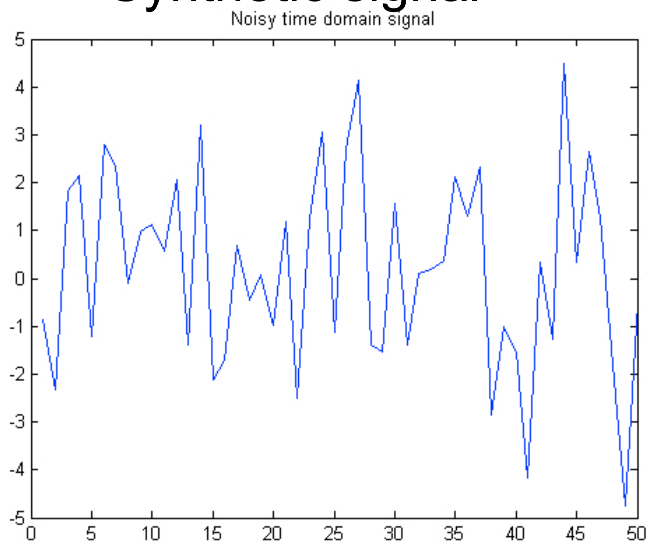
Understanding patterns by converting data to Frequency Domain



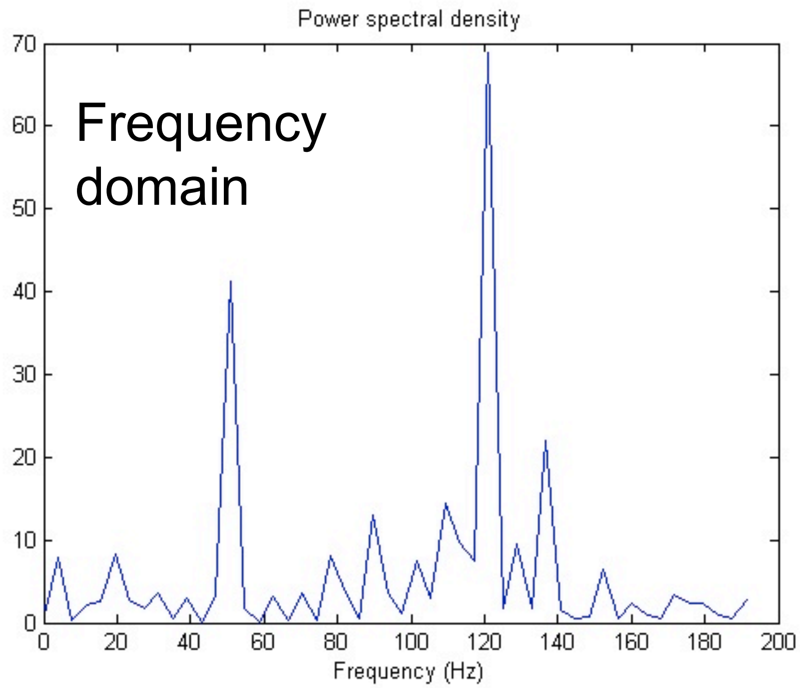
Time domain

$$x(t) = \sin(2\pi \times 50t) + \sin(2\pi \times 120t)$$

Synthetic signal

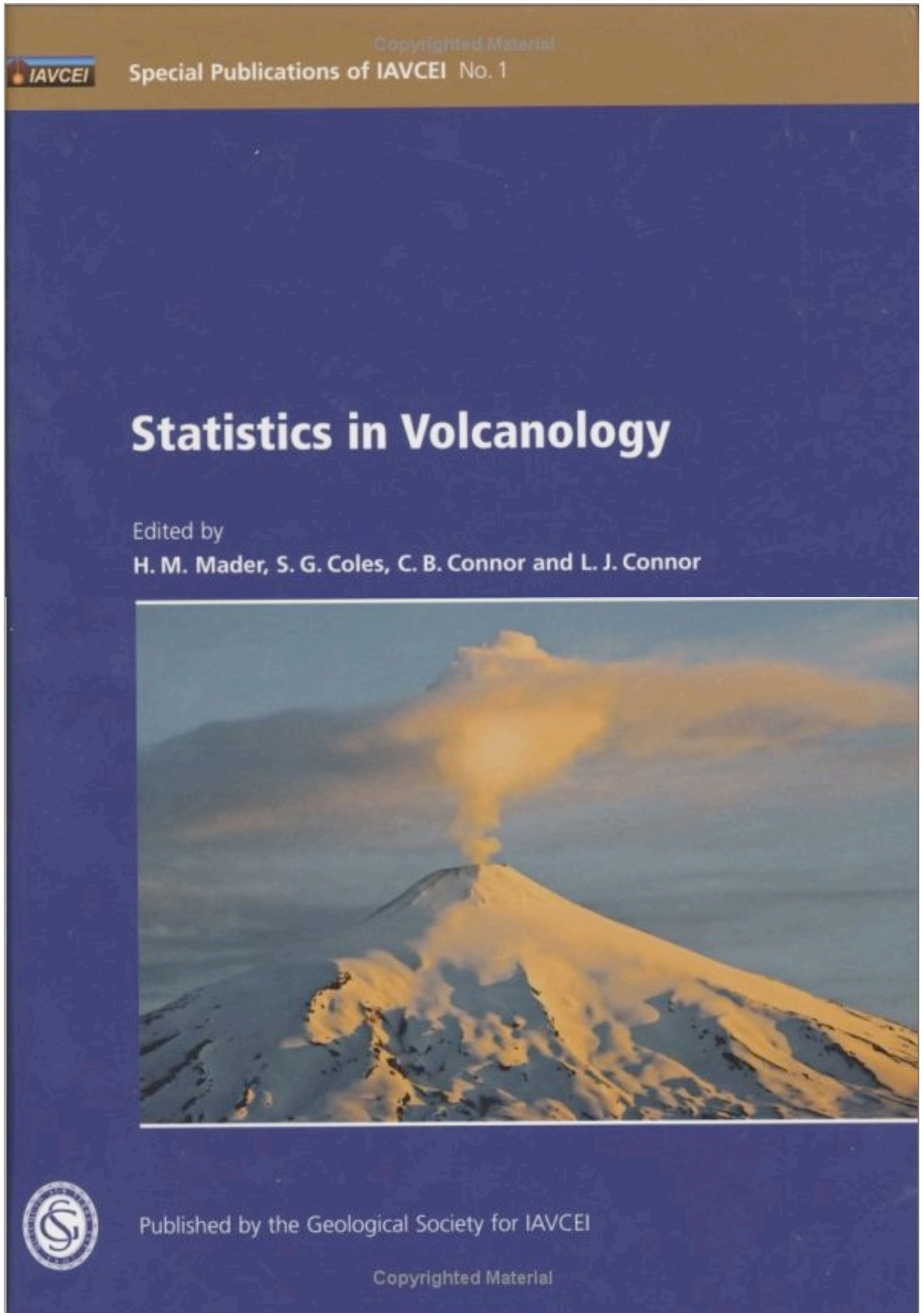


Same signal with added noise
(also indicates the importance of filtering)



Frequency domain

FFT analysis (finite Fast Fourier Transform) converts to frequency domain



The IAVCEI Commission on Statistics in Volcanology (COSIV)

"to foster statistical analysis of volcanological data. In the last decade or so, researchers have begun to exploit a wide range of analytical and statistical methods for dealing with stochastic and distributed datasets. This represents a major step forward within physical volcanological modeling as we move to a new generation of probabilistic or statistical models. The primary aim of all this new activity is to develop rigorous methods for quantifying the likelihood of outcomes given the set of current and past observations"

-> Link statistical characteristics of data to processes

Q4 : Where are we going ?

1. Models of plumbing system and processes

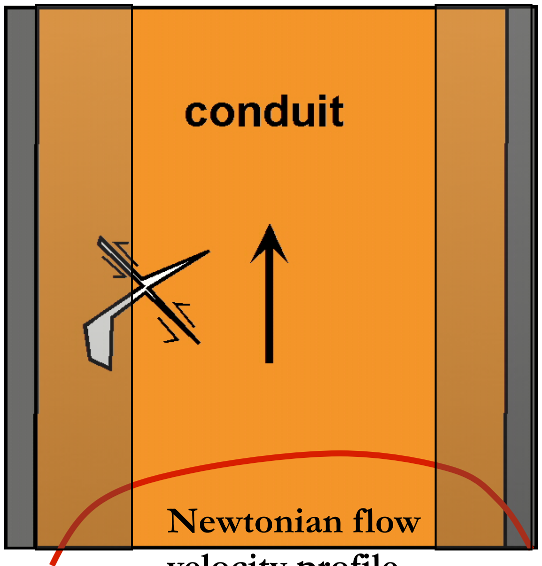
- Physical models can never represent the full complexity of a natural phenomenon
- Monitoring data/collection community need to communicate with modeling community. (e.g. Plume /flow modeling community)
- Are field data providing information useful for modeling, or are there other important parameters we are lacking information about.

2. Back to Basics

- Back to geology and dissected old volcanoes
- Several cases emerging where advances in our understanding of these systems dictates that we re-examine old deposits.

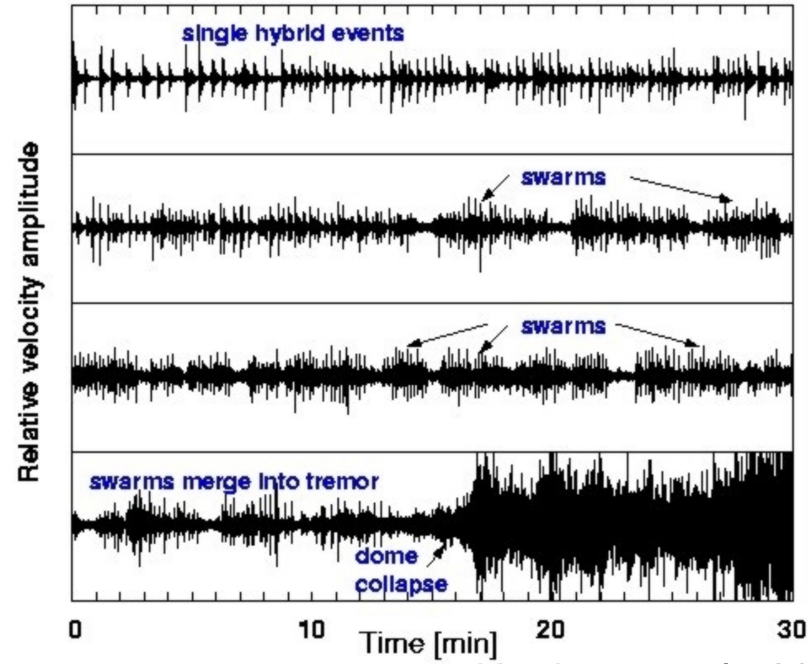
- An example

Shallow plumbing at lava domes:
Shear fractures in conduit walls



Zone of high shear rates

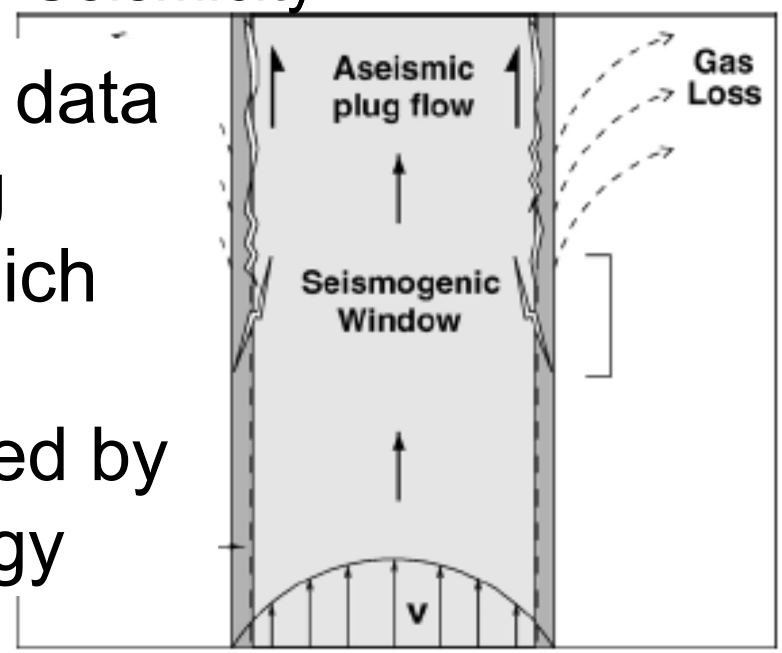
->fracture of the magma



Seismicity

Neuberg et al., 2006

Monitoring data suggesting models which can be corroborated by field geology



Tuffen et al 2003 *Geology,*

Tuffen & Dingwell 2005 *Bull. Volcanol.*


Take home message:
Making detailed measurements in the field is becoming easier (*and more fun*) : as a community we need to adapt and learn how to deal with this data.