The Abdus Salam International Centre for Theoretical Physics

2053-11

Advanced Workshop on Evaluating, Monitoring and Communicating Volcanic and Seismic Hazards in East Africa

17 - 28 August 2009

Seismic monitoring on volcanoes in a multi-disciplinary context

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Seismology at different time scales in the context of volcanic processes

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&

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Institute of Geophysics & Tectonics
School of Earth & Environment
The University of Leeds

Part I

(i) Case study Montserrat
(ii) Volcano tectonic earthquakes (VTs)
(iii) Very-long-period earthquakes (VLPs)
(iv) Long-period earthquakes (LPs)

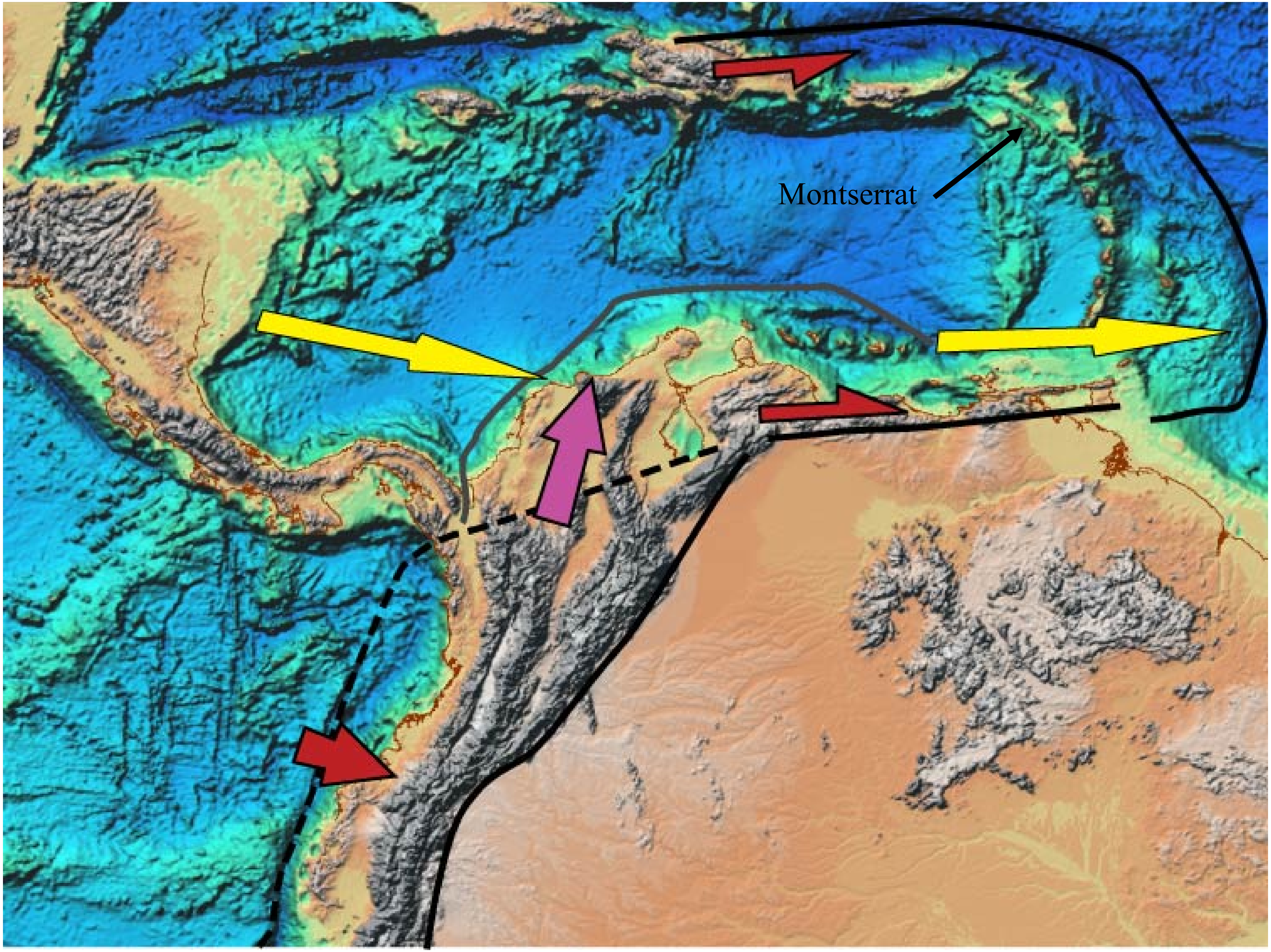
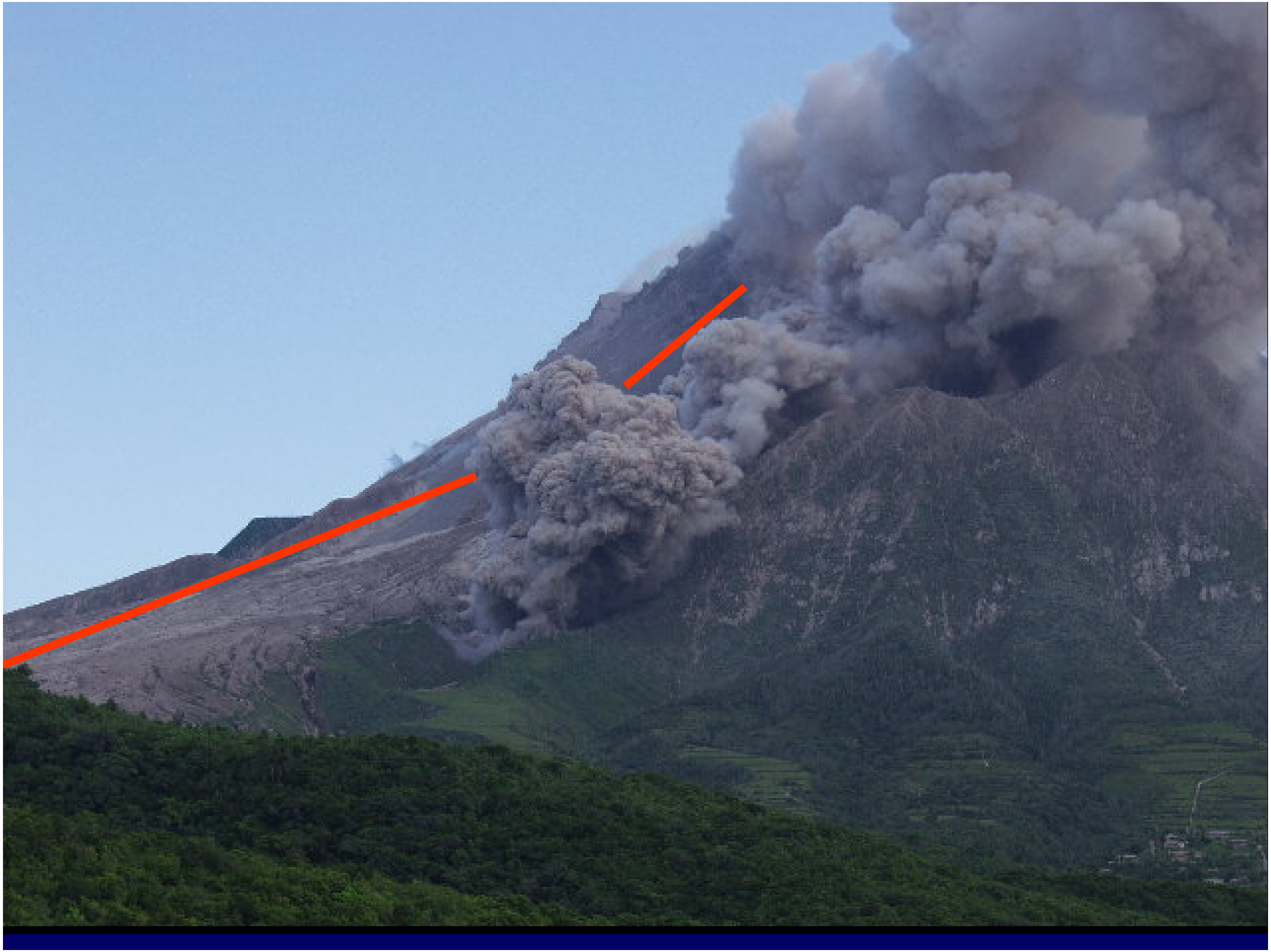
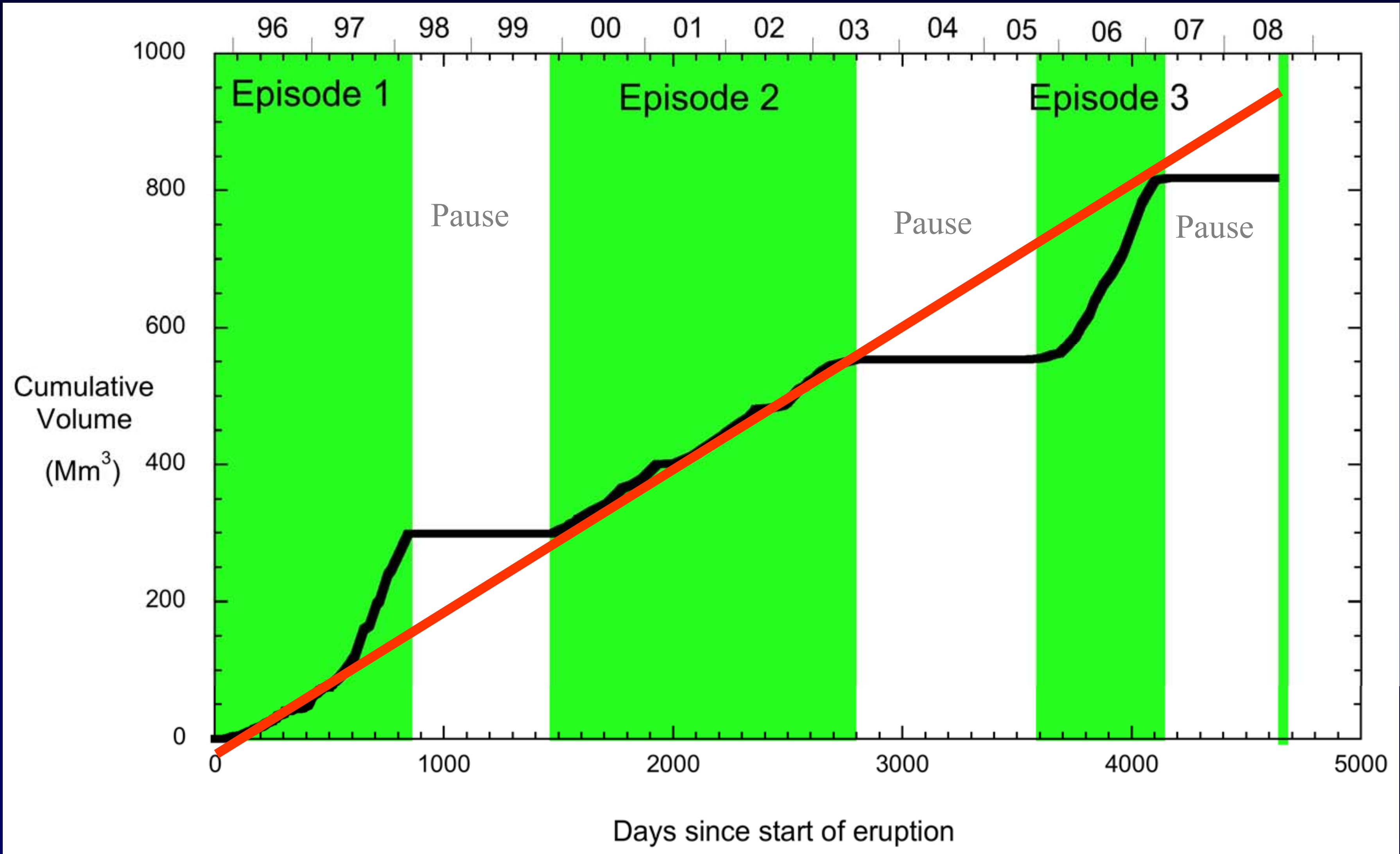

Montserrat

Photo : R Herd, MVO



Estimation of dome volume



VTs

Volcano-tectonic earthquakes:
usual earthquakes in a volcanic setting

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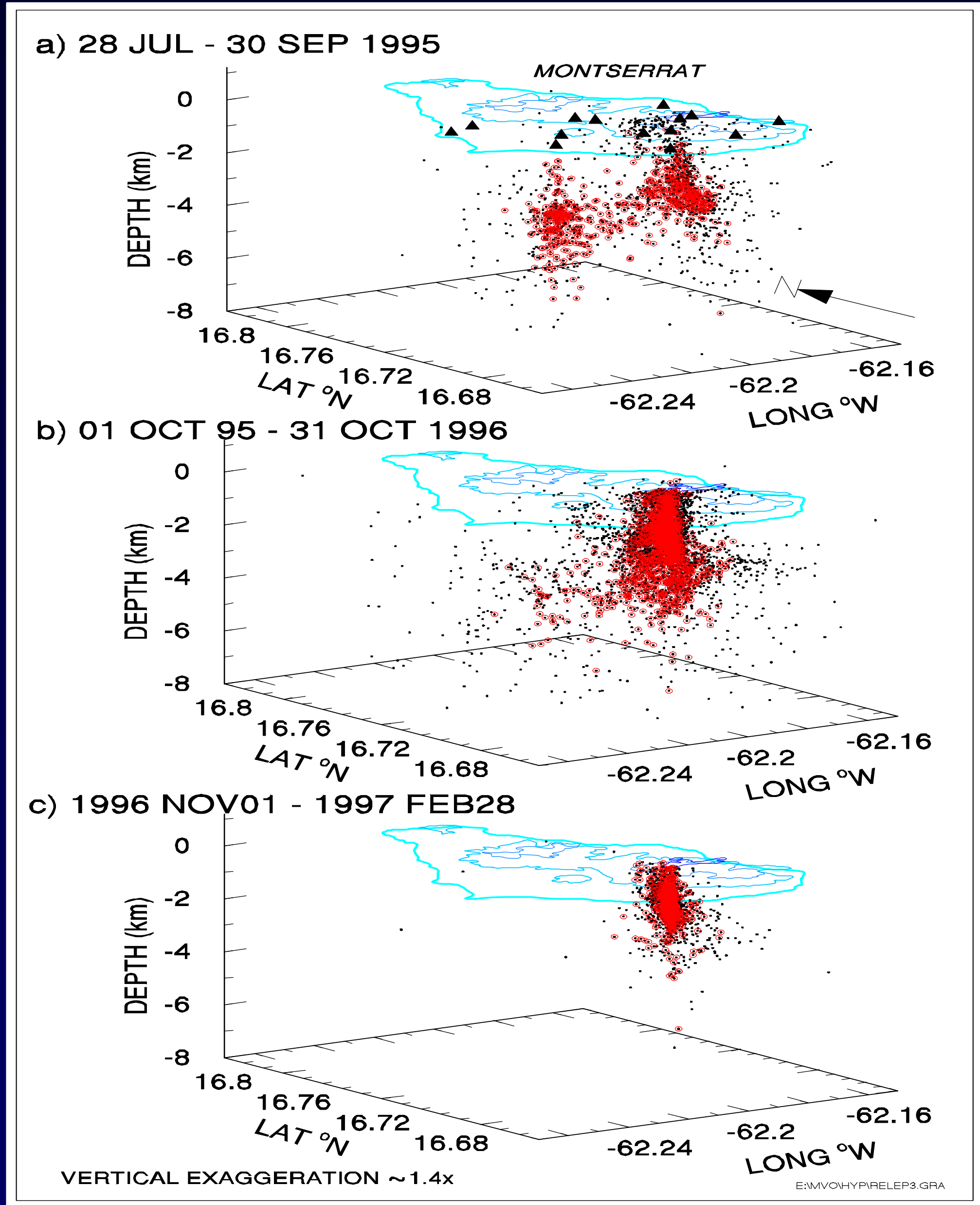
Volcano tectonic events: Indicator of magma ascent

…not mapping
of magma reservoir

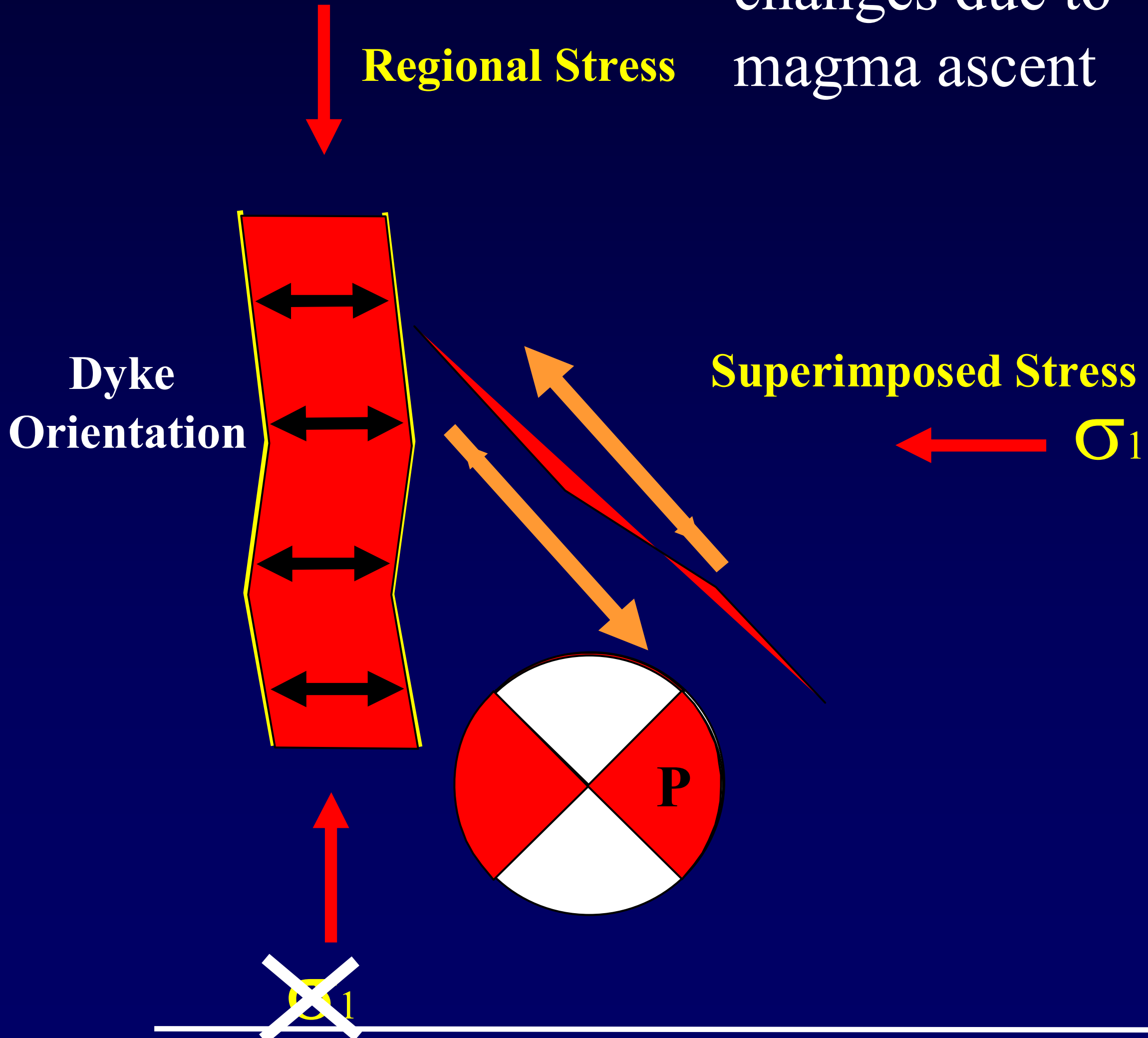
Changes in stress field:
- temperature
- ascending magma

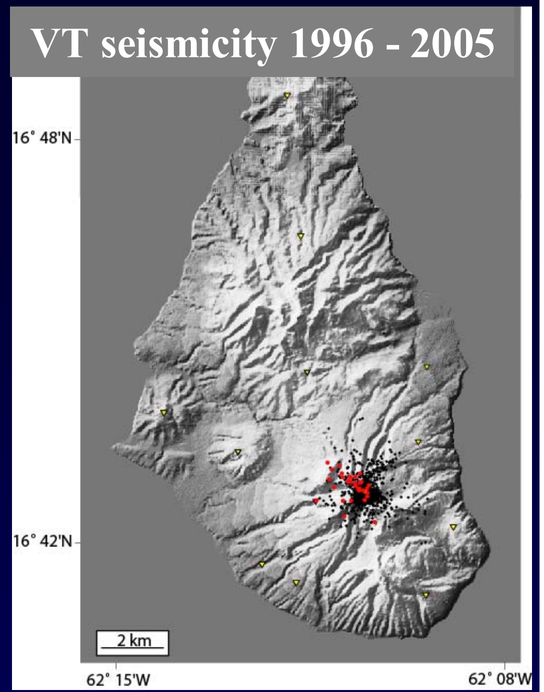


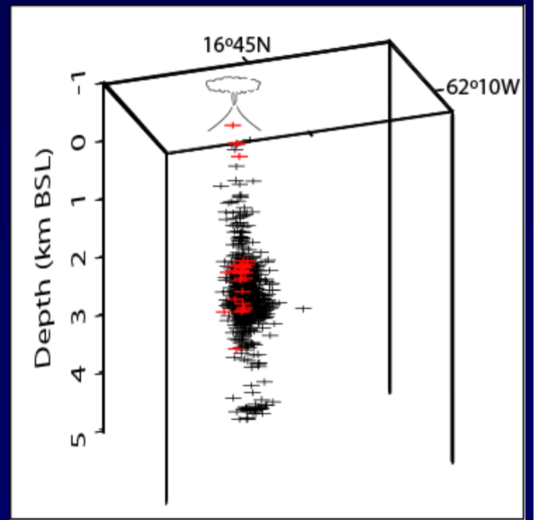
(Aspinall et al, 1998)

Indicators of magma ascent:

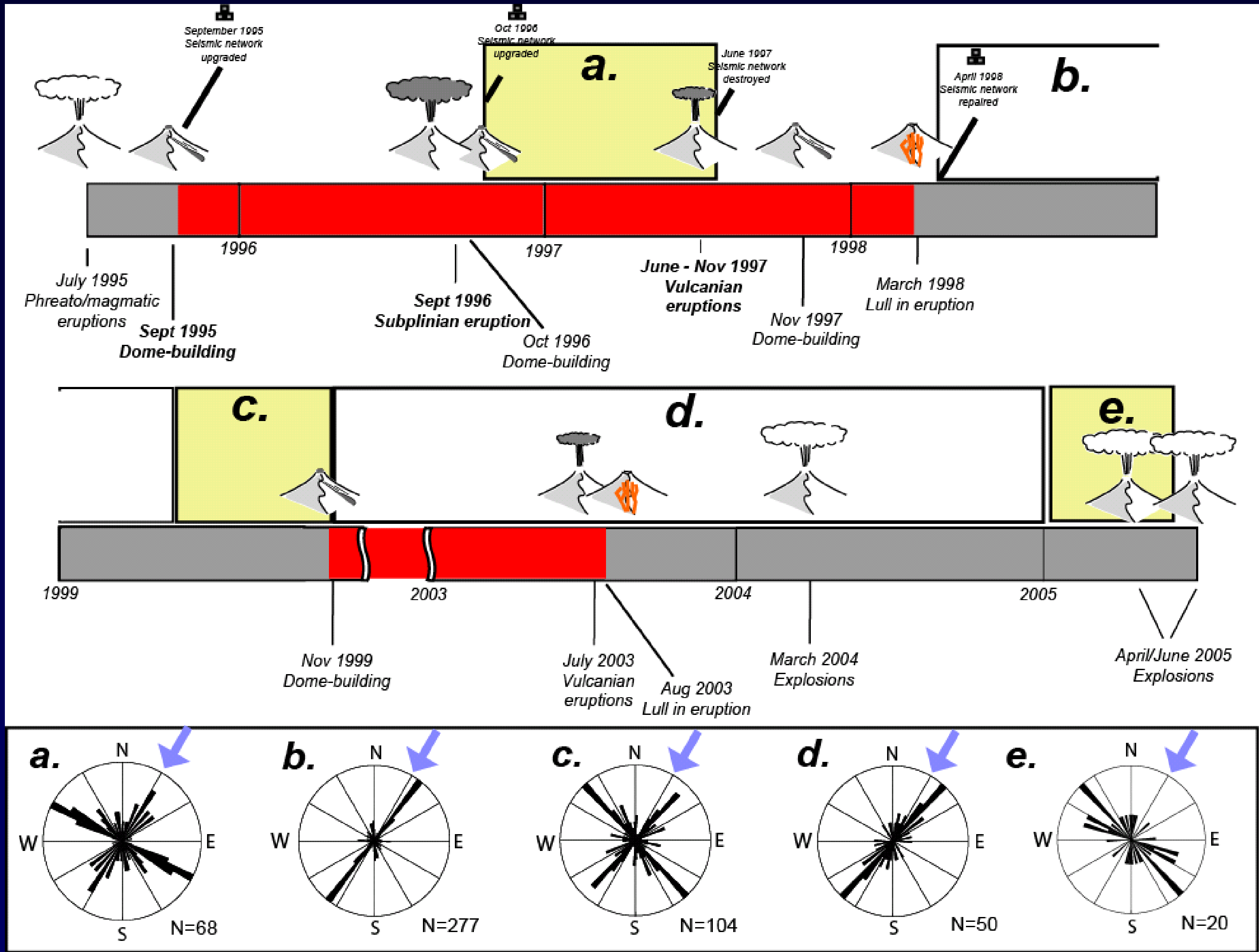
Volcano tectonic events → indicate stress changes due to magma ascent







Local stress field rotation at Montserrat



(Roman, Neuberg and Luckett, 2006)

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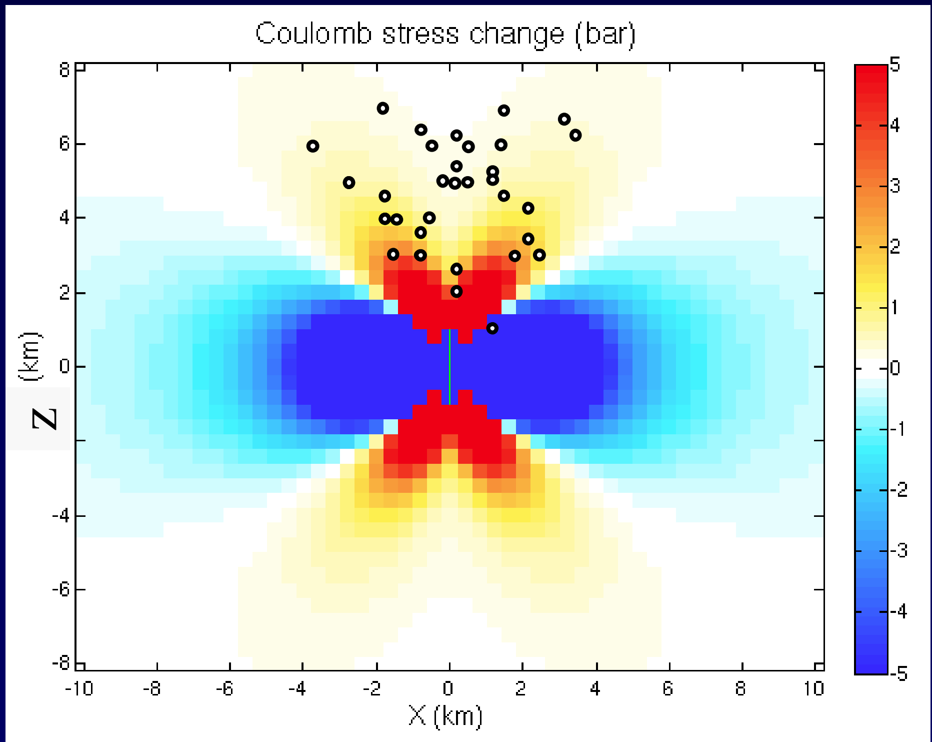
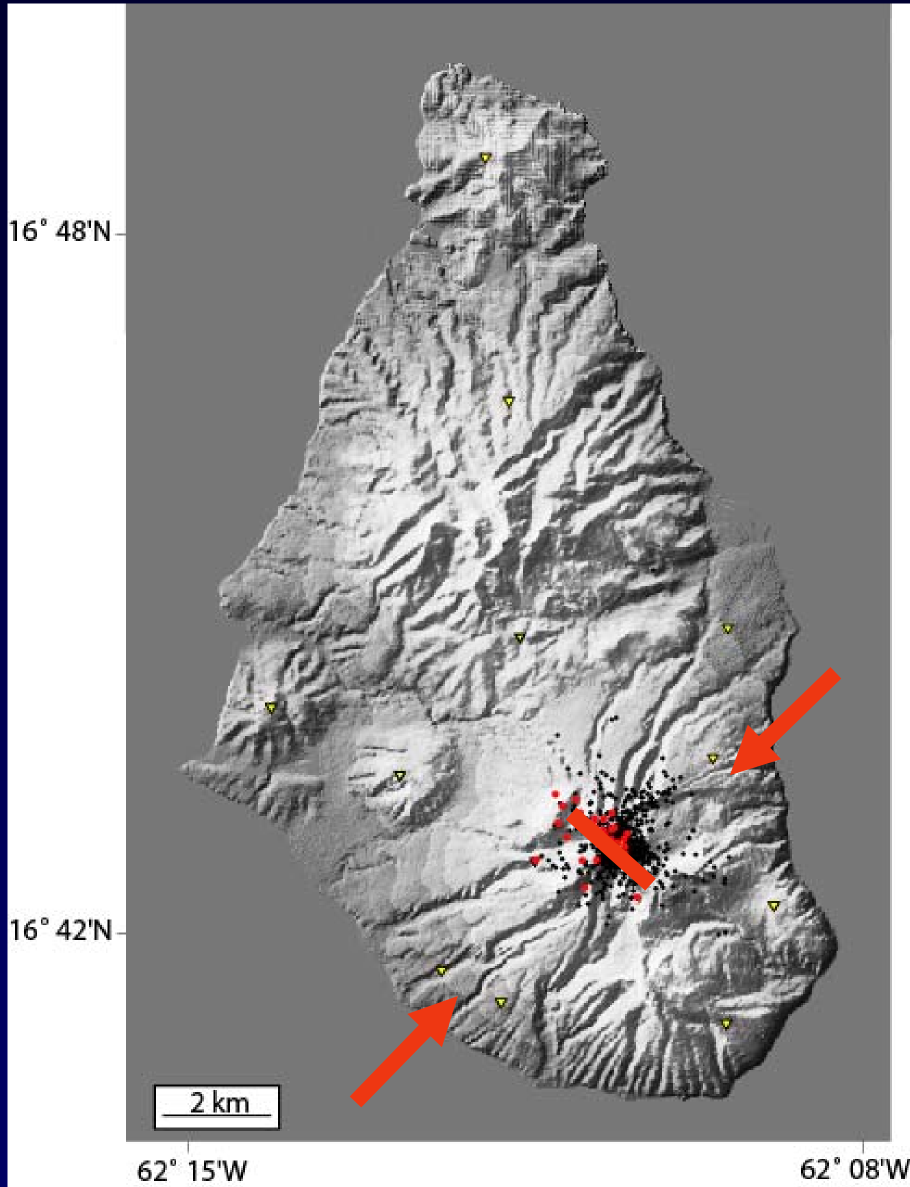
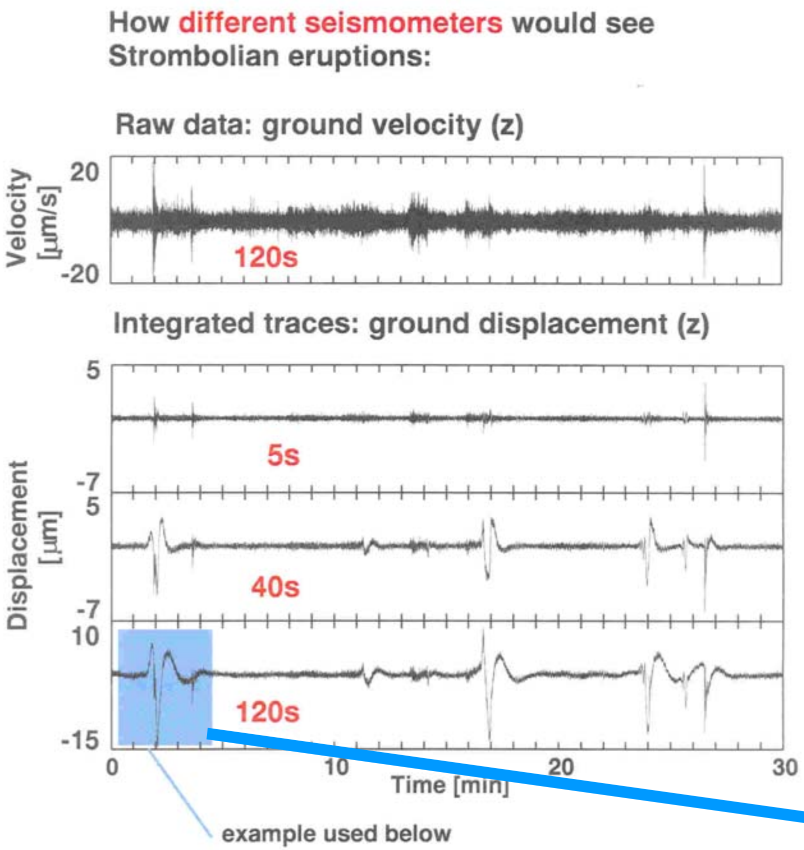
Dyke perpendicular to regional stress, below epicentres, can explain seismic data

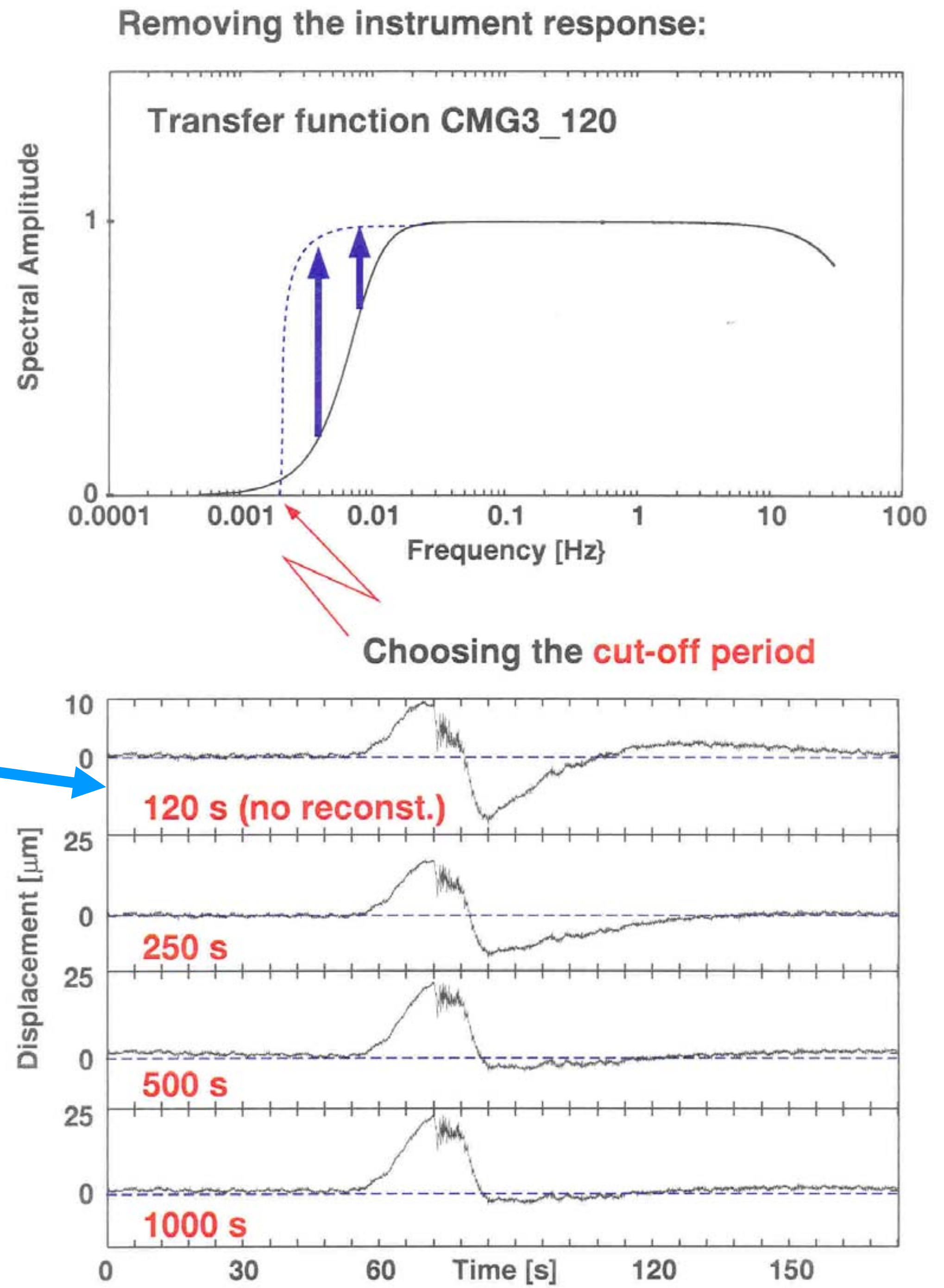




VLPs

Very long period earthquakes:
Transients implying mass movement

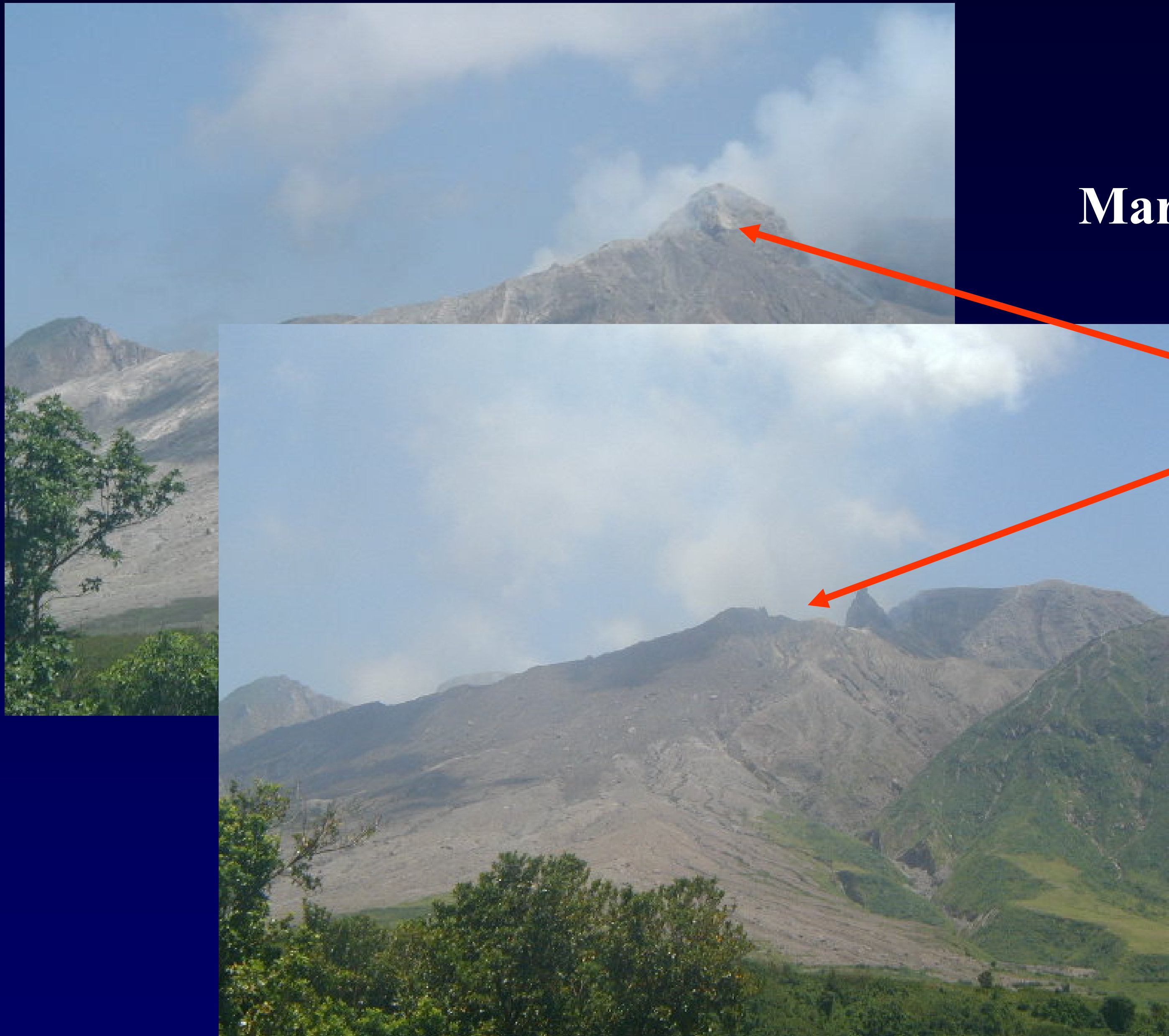




Each instrument is a filter

Seismometer:
- differentiation
- bandpass limitation

March 3rd event:



NW Buttress

(Photos courtesy MVO)

March 3rd 2004

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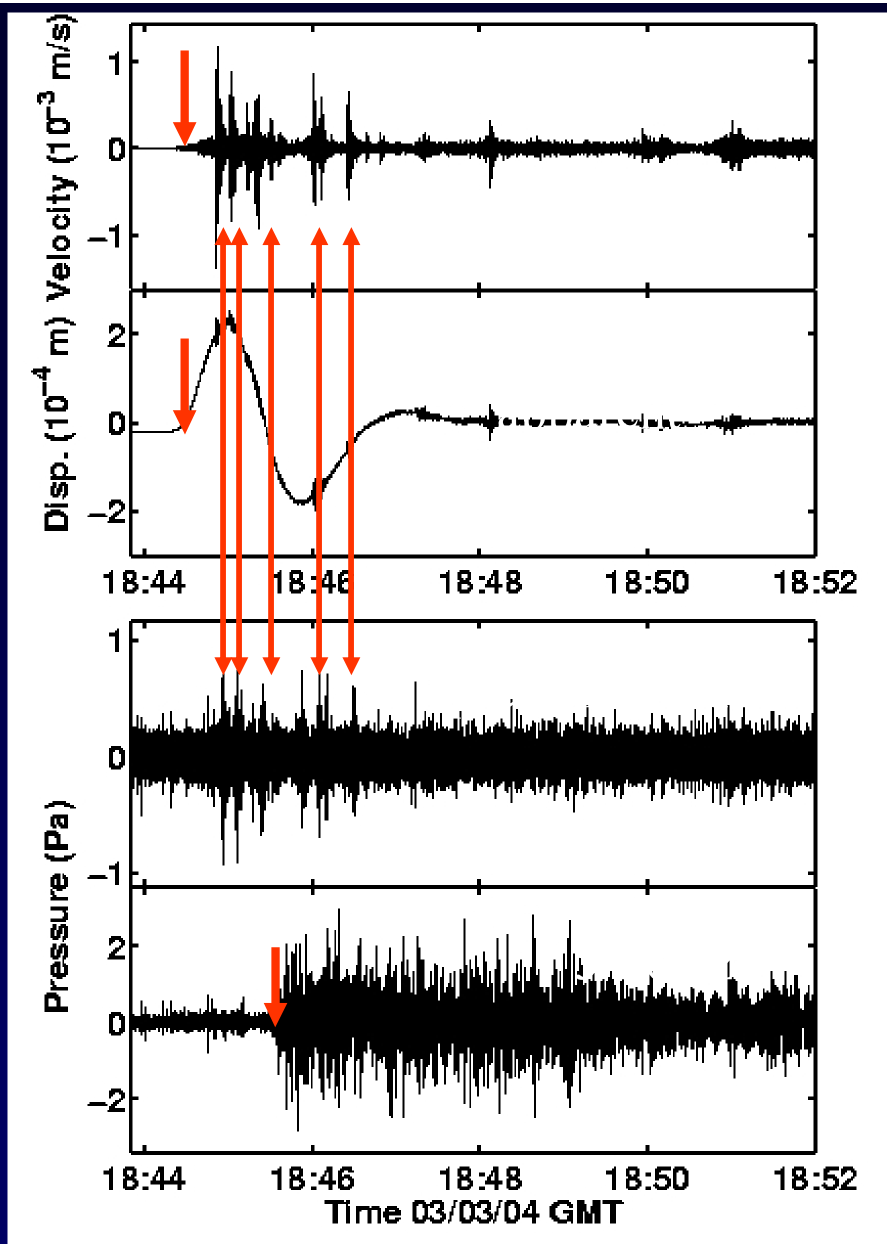
Multi-parameter data set:

- Onset of seismic trace

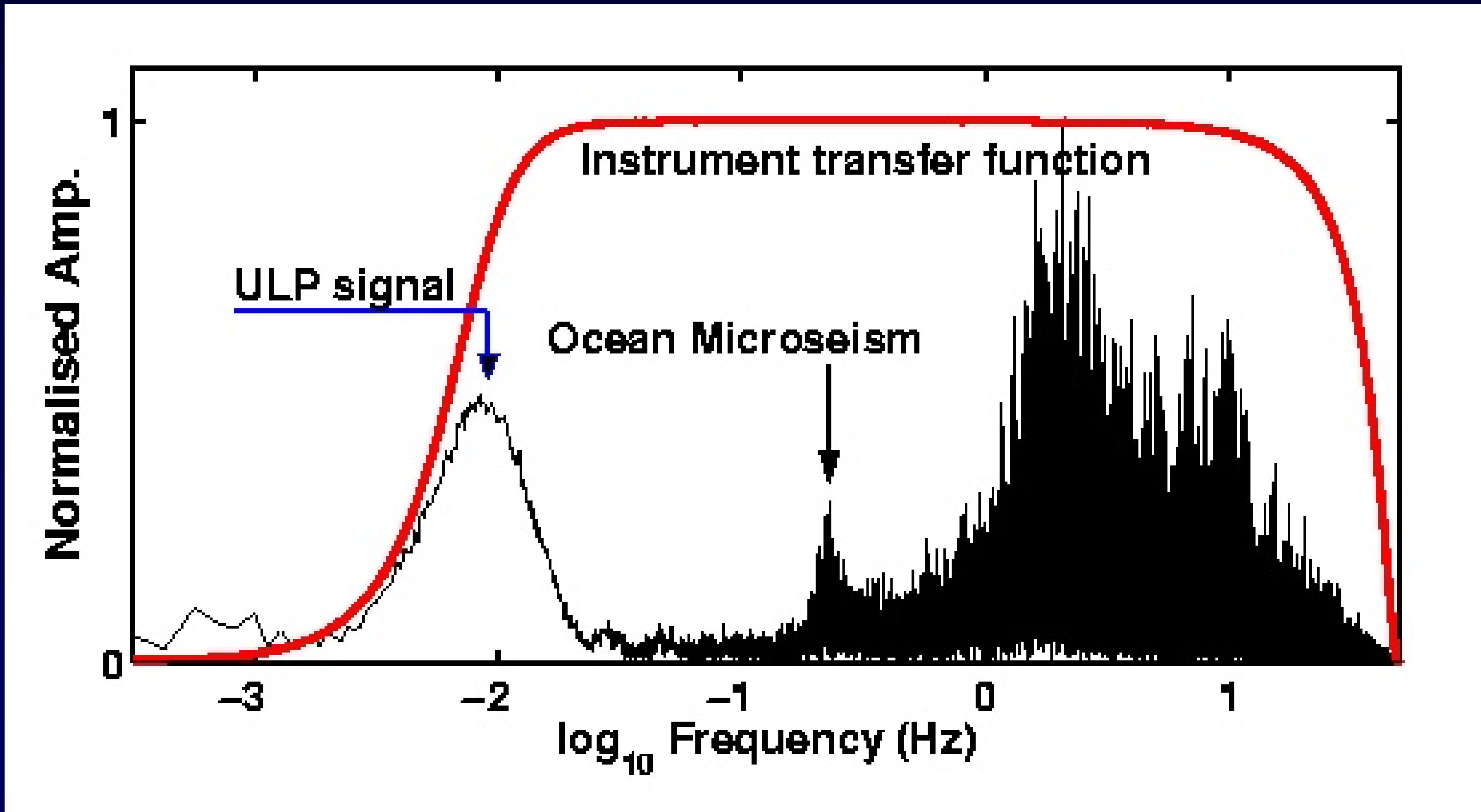
- Explosion signal on seismics & infrasound

- Onset of plume forming ash venting



Seismic frequency spectrum

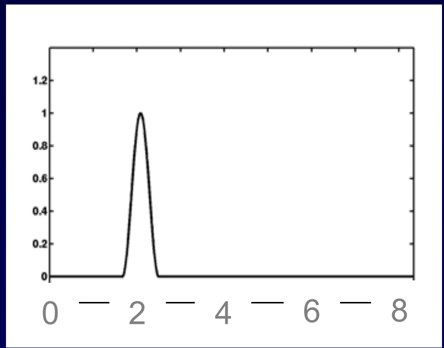
Transfer function cuts through long period signal

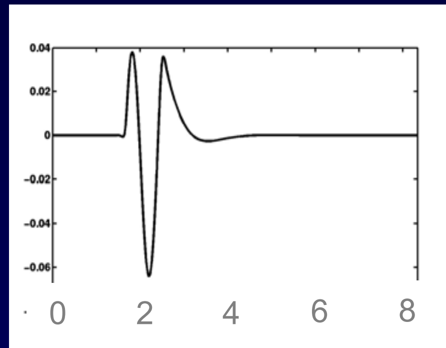


Broadband Seismometer

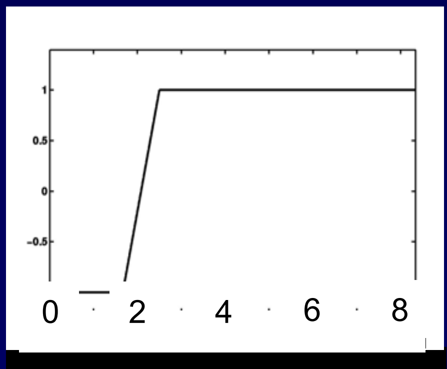
Ground Displacement → Differentiator / Bandpass Filter → Velocity Seismogram

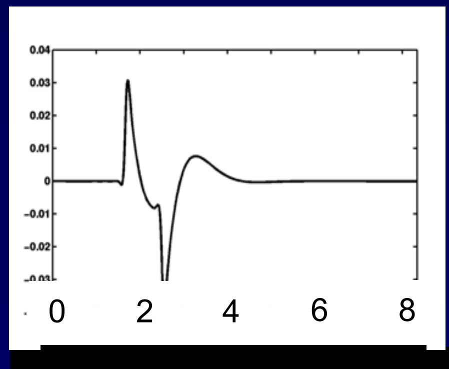
Spike





Ramp

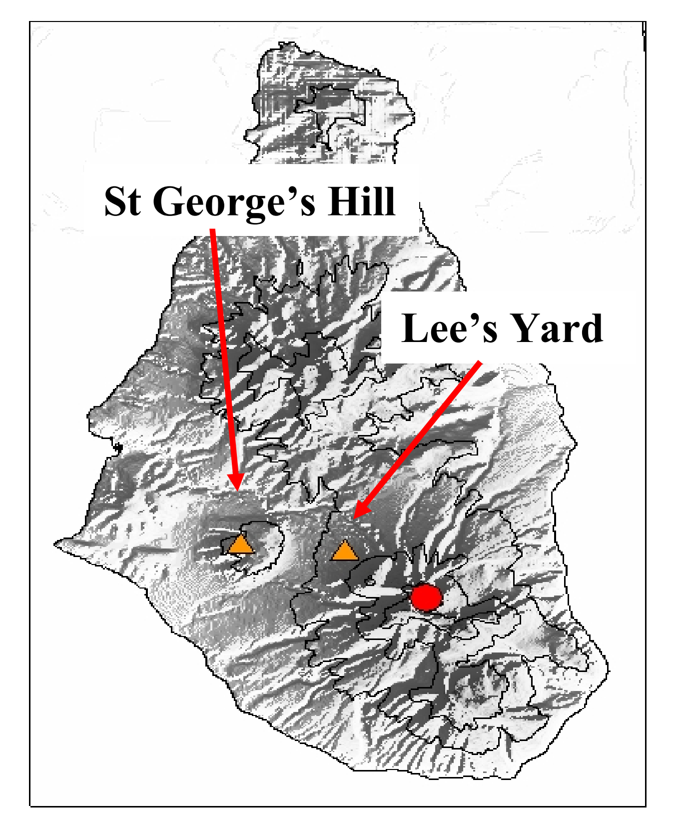


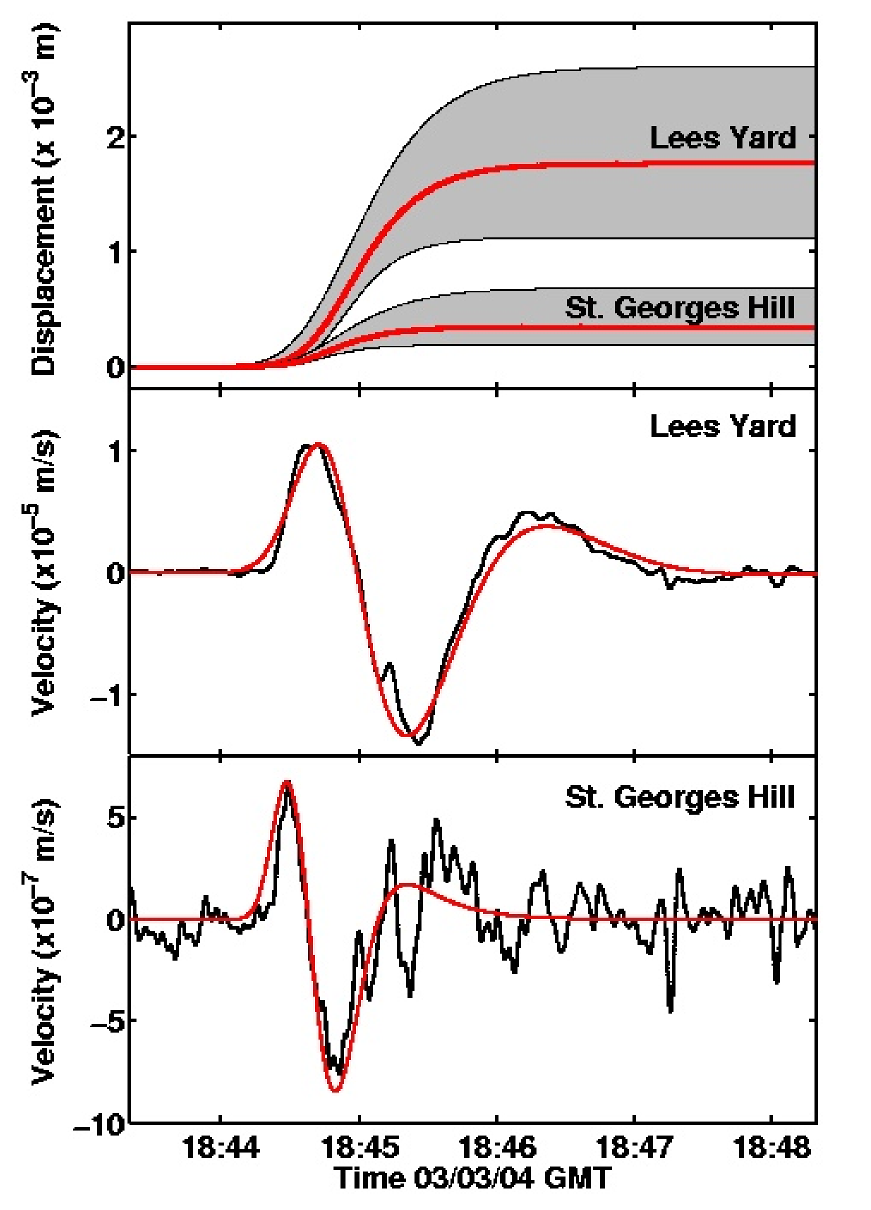


Time [s]

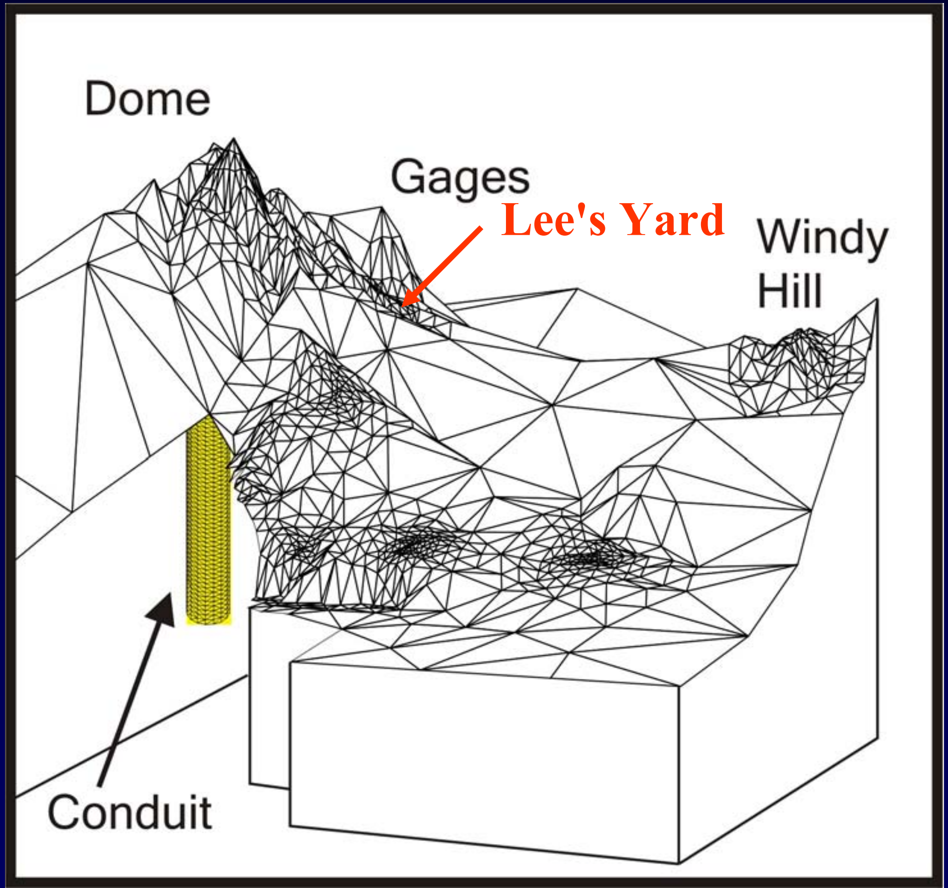
Time [s]

Fit two stations, use ratio of displacement for ground deformation modelling





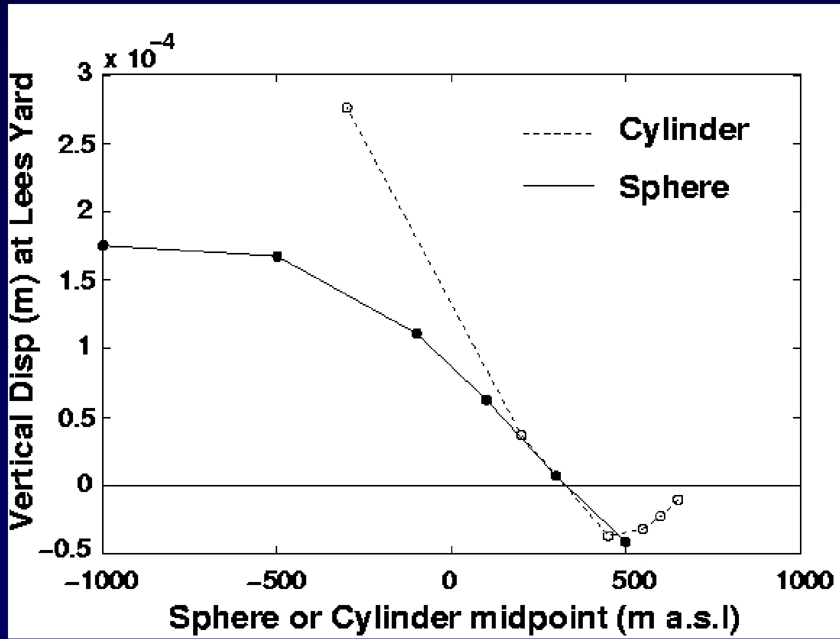
Models for seismicity & deformation



3D detail - cut out to see tilt source
(vertically exaggerated x 3)

Modelling parameters:

cylinder and sphere at different depths & topography



Best fitting model:
collapsing gas pocket at 500m below dome

(Green & Neuberg, 2006)

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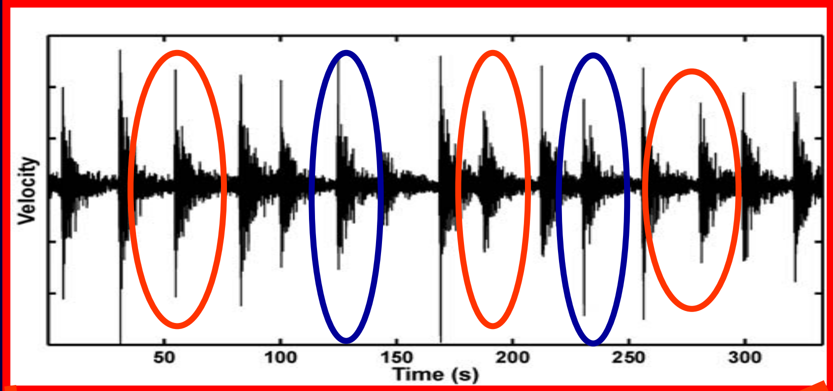
LPs

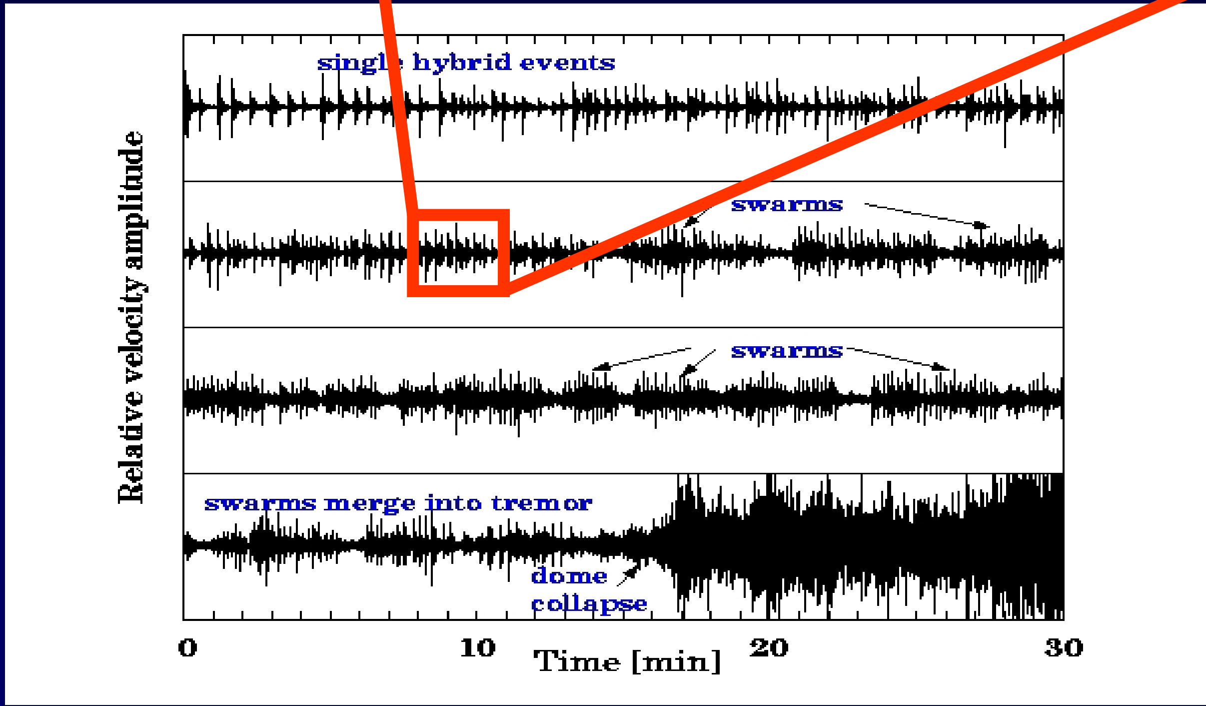
Low frequency/long period earthquakes: involvement of a fluid phase

Low-frequency events

Characteristics:

- Occur in swarms of similar waveforms
- Precede volcanic events
- Correlated with ground deformation & tilt
- P onset & low frequency coda





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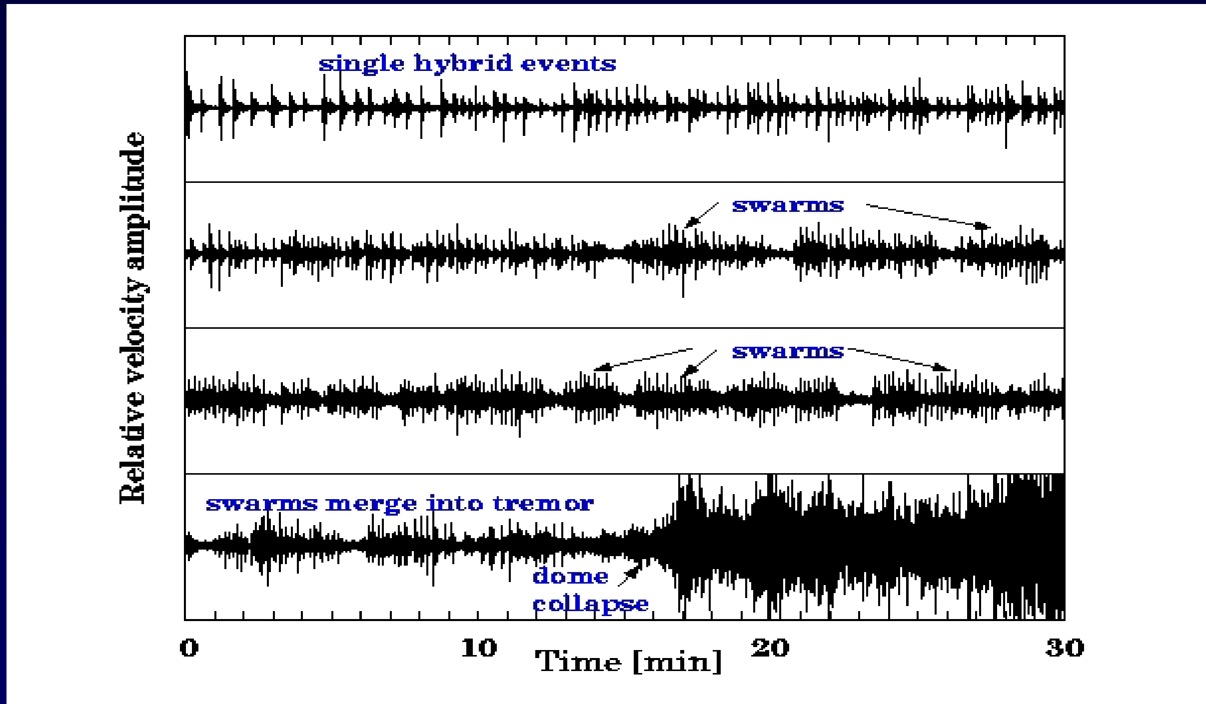


Low-frequency events

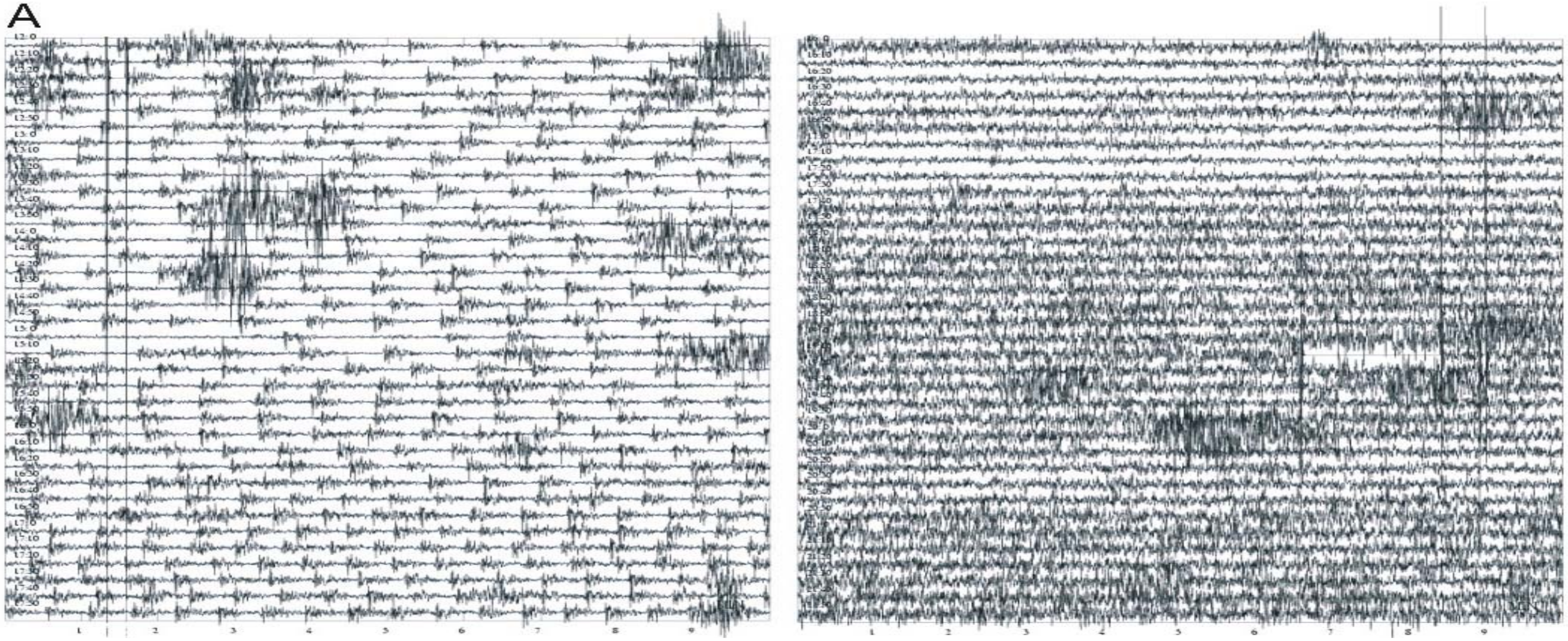
Low-frequency events

Dome collapse
July 12, 2003

Example dome collapse

13 July, 2003

Dome collapse July 2003



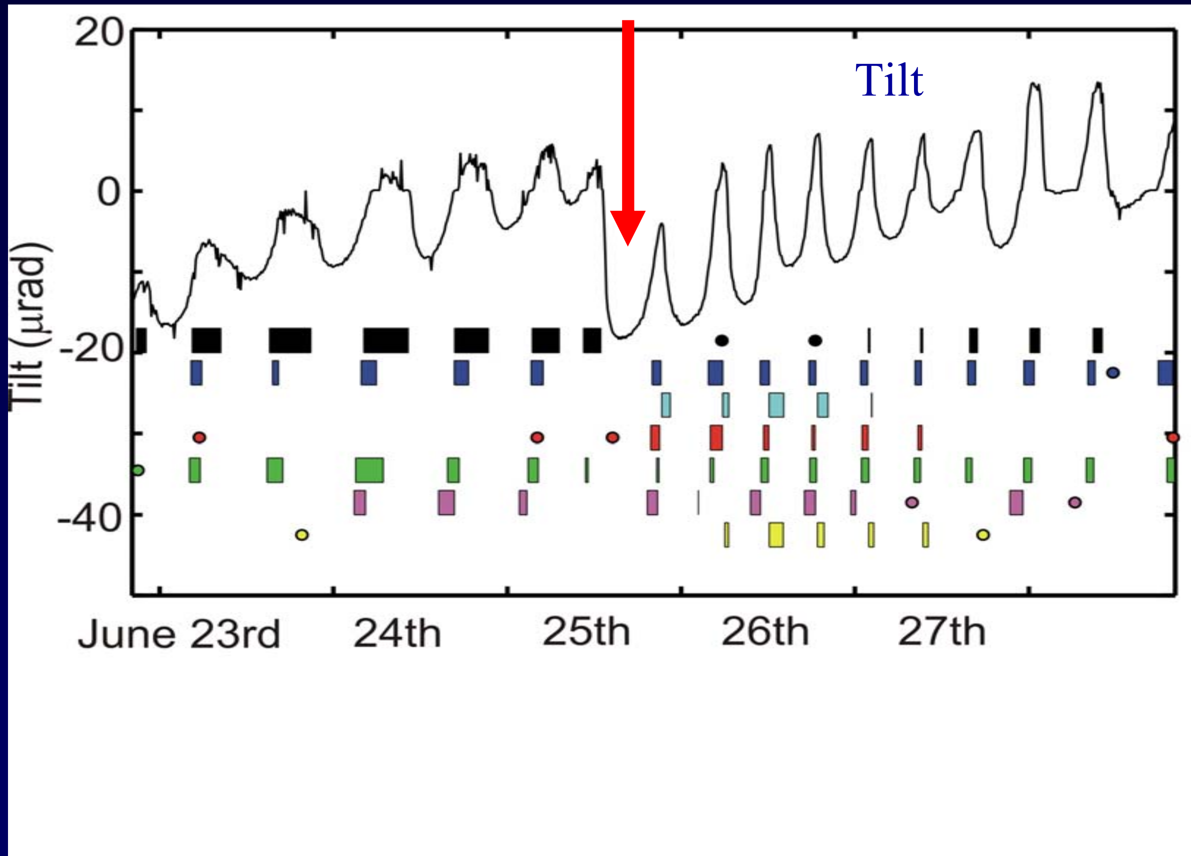
Data acquisition

Low-frequency events

Characteristics:

- Occur in swarms of similar waveforms
- Precede volcanic events
- Correlated with ground deformation & tilt
- P onset & low frequency coda

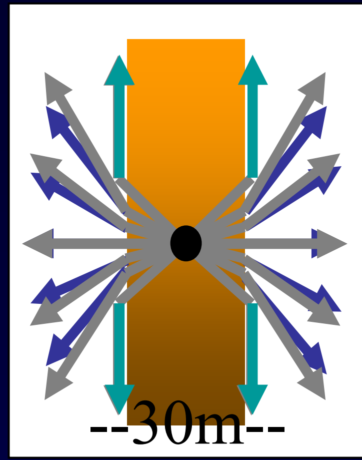
Dome collapse

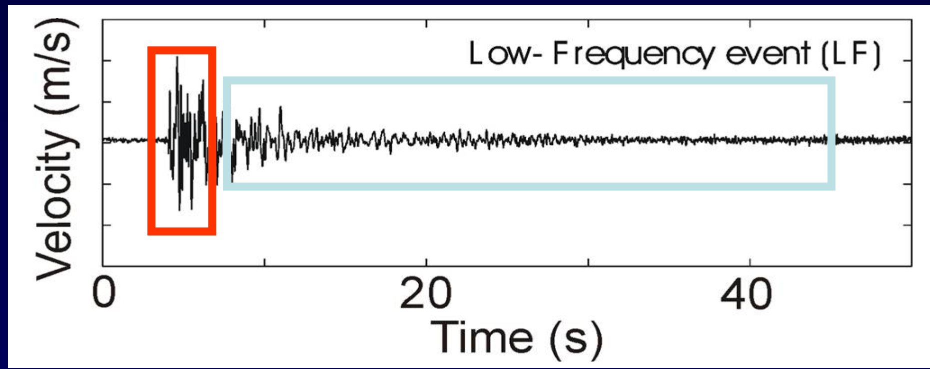


Low-frequency events

Characteristics:

- Occur in swarms of similar waveforms
- Precede volcanic events
- Correlated with ground deformation & tilt
- **P onset & low frequency coda**





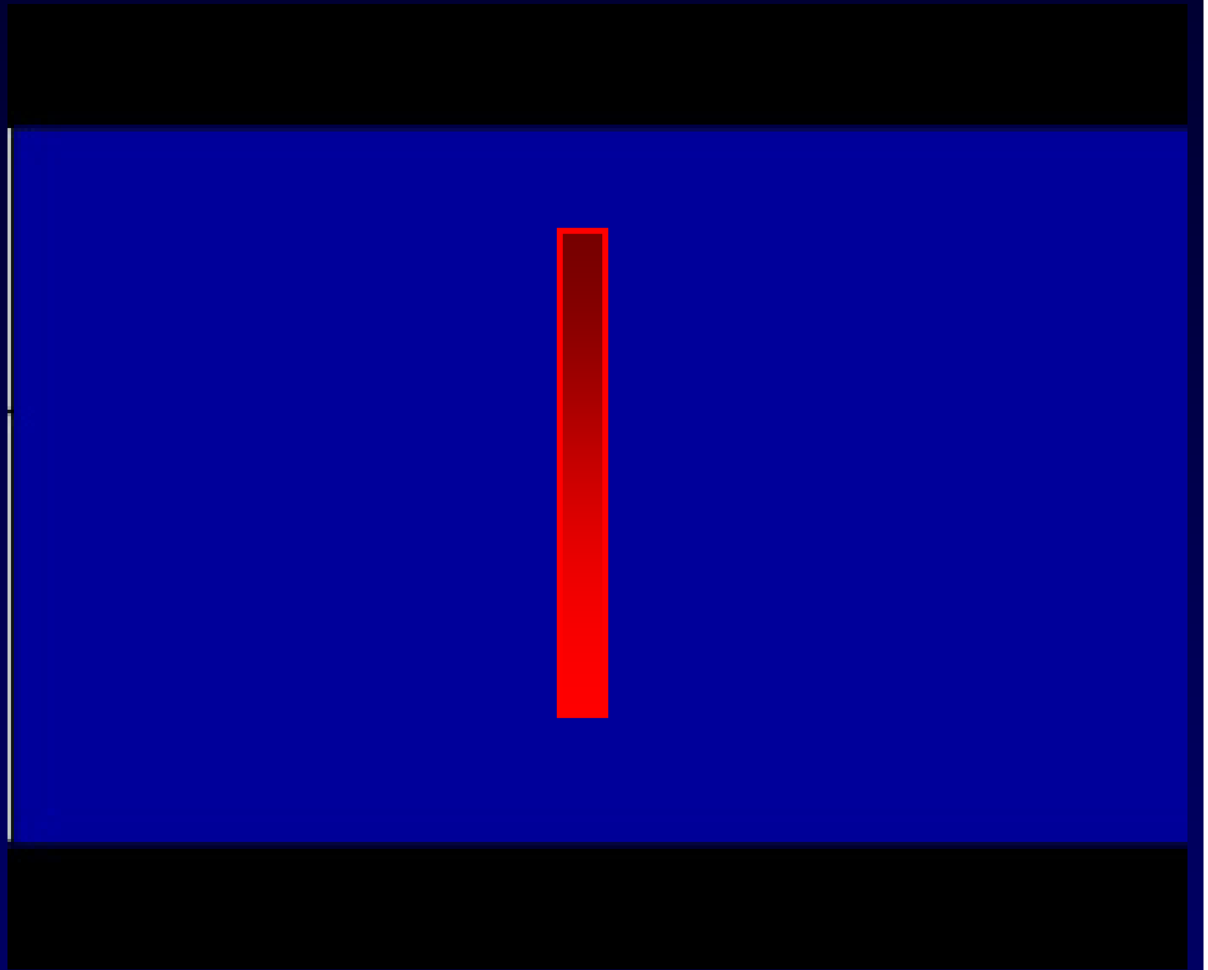
$$u_x = (-\phi l_c e^{-l_P|x|} - i k_z \psi e^{-l_S|x|}) e^{i k_z z} e^{-i\omega t}$$
$$u_z = (i \phi k_z e^{-l_P|x|} - \psi l_s e^{-l_S|x|}) e^{i k_z z} e^{-i\omega t}$$

u_x and u_z: displacement components
k_z: wave number;
l_P: f(k_z, ω, V_P); l_S: f(k_z, ω, V_S)
ϕ and ψ: potentials of the P- and S-waves

Low-frequency events

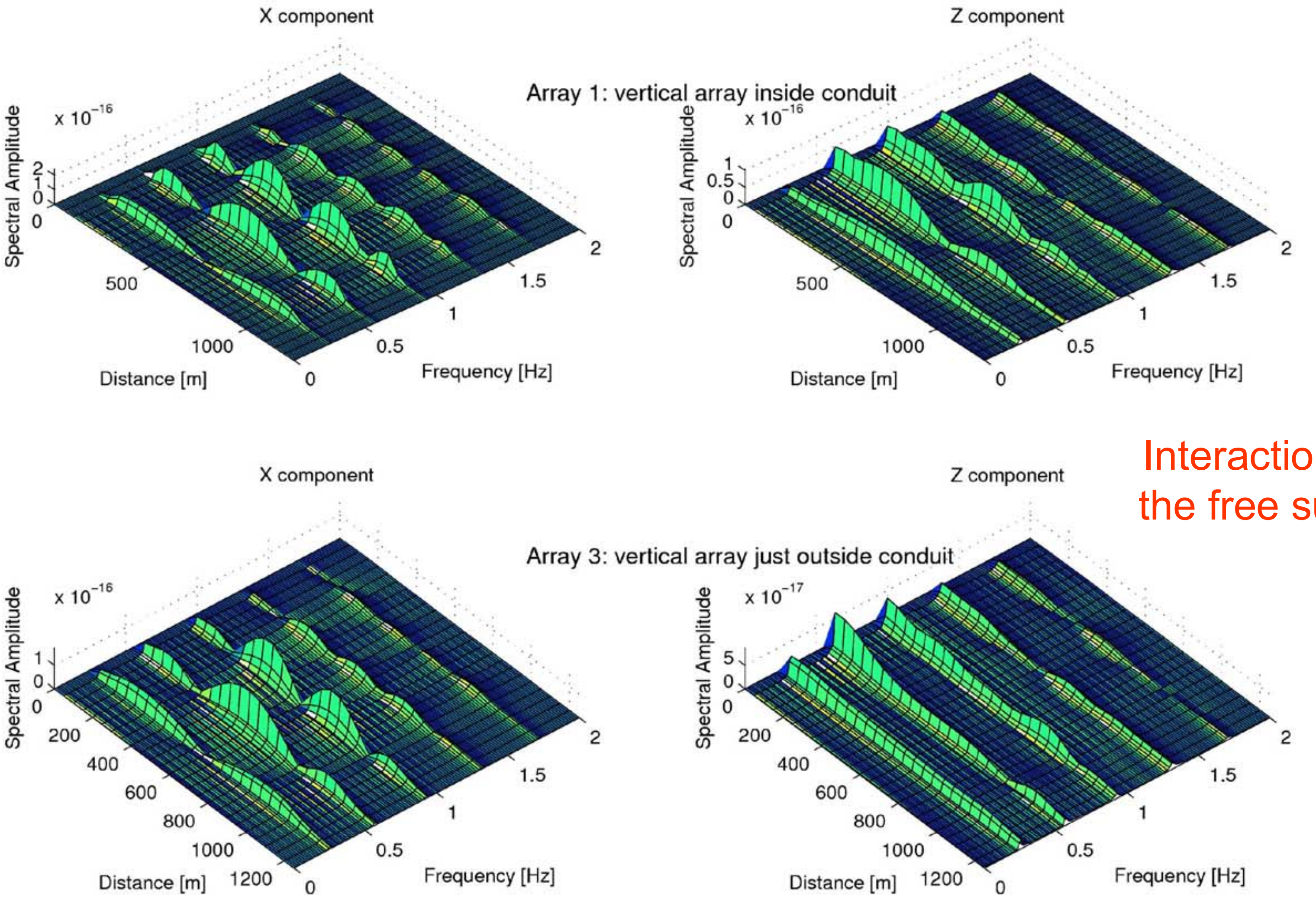
Characteristics:

- Occur in swarms of similar waveforms
- Precede volcanic events
- Correlated with ground deformation & tilt
- P onset & low frequency coda



Clear resonance modes or harmonic overtones

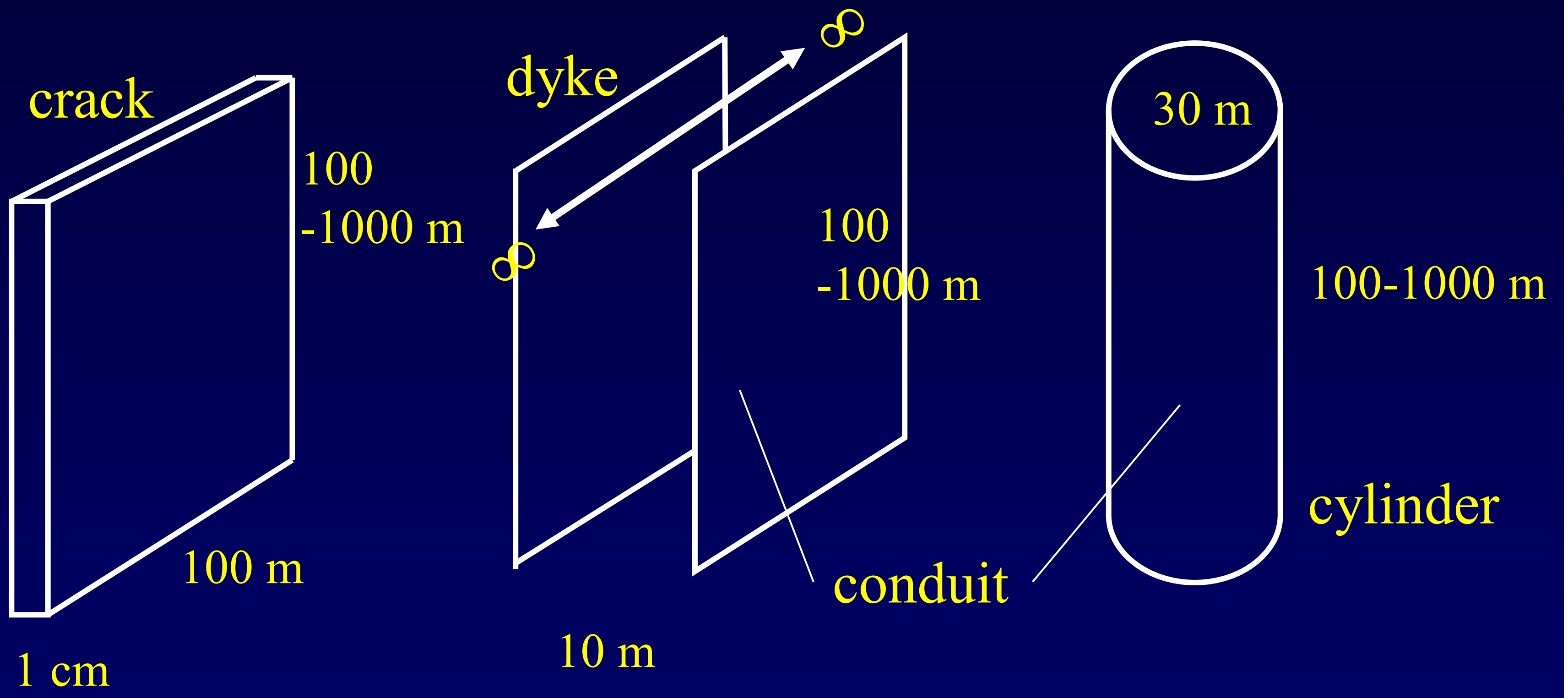
2Hz Kupper wavelet



Interaction with the free surface

Principle model:

"Fluid-filled container embedded in solid medium"



Ferrazzini & Aki, 1987

Chouet 1986, 1996, Chouet et al 1994,
Kumagai et al 2002, Molina et al 2004

Neuberg et al 2000
Jousset et al 2004

Principle model:

"Fluid-filled container embedded in solid medium"

→ Pressure perturbation in the fluid

→ Excitation of crack waves, tube waves, interface waves

→ Resonance in container

→ Stiffness factor (Aki 1977) $C = \dfrac{L\,B}{D\,\mu}$

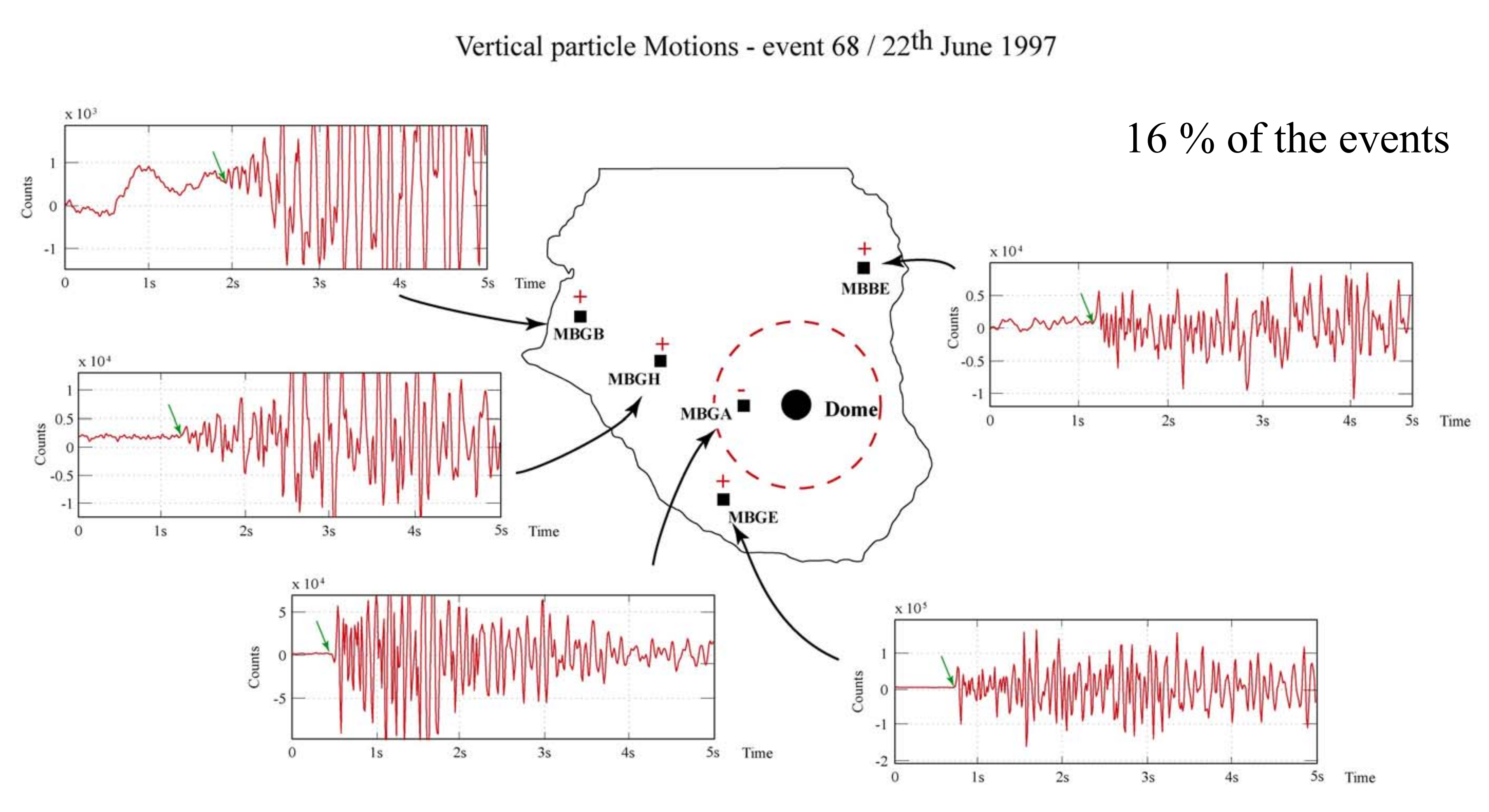
B Bulk modulus
L Length of container, wavelength
D Thickness, diameter
μ shear modulus of solid

→ Dispersive waves : $V_{phase} < V_{acoustic}$

Part II

(i) Moment tensor analysis
(ii) Magma modelling
(iii) Trigger mechanism
(iv) Degassing
(v) Dynamic behaviour

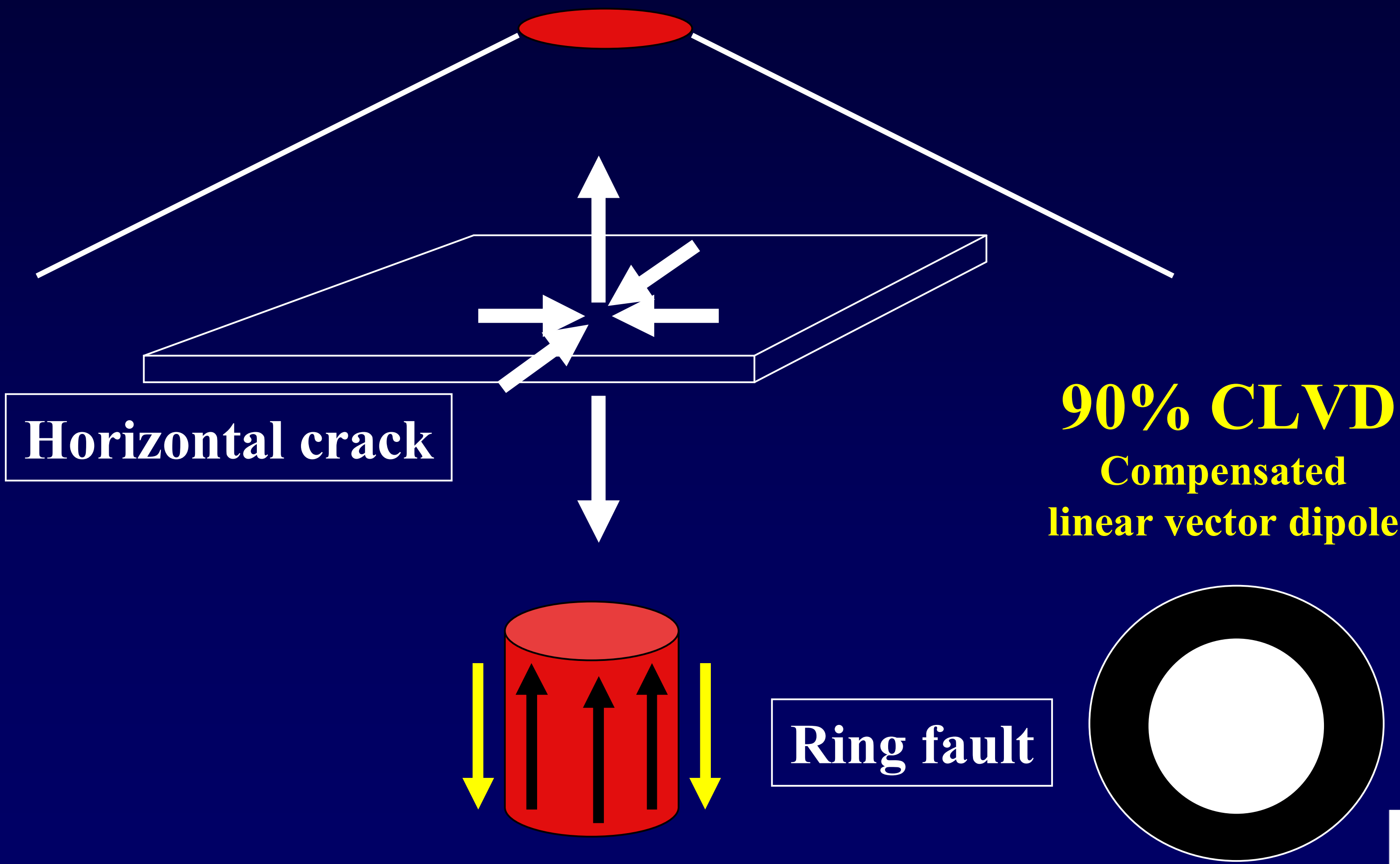
Moment tensor analysis of volcano seismic events



Particle motions compatible with shallow descending magma

Moment tensor analysis of volcano seismic events

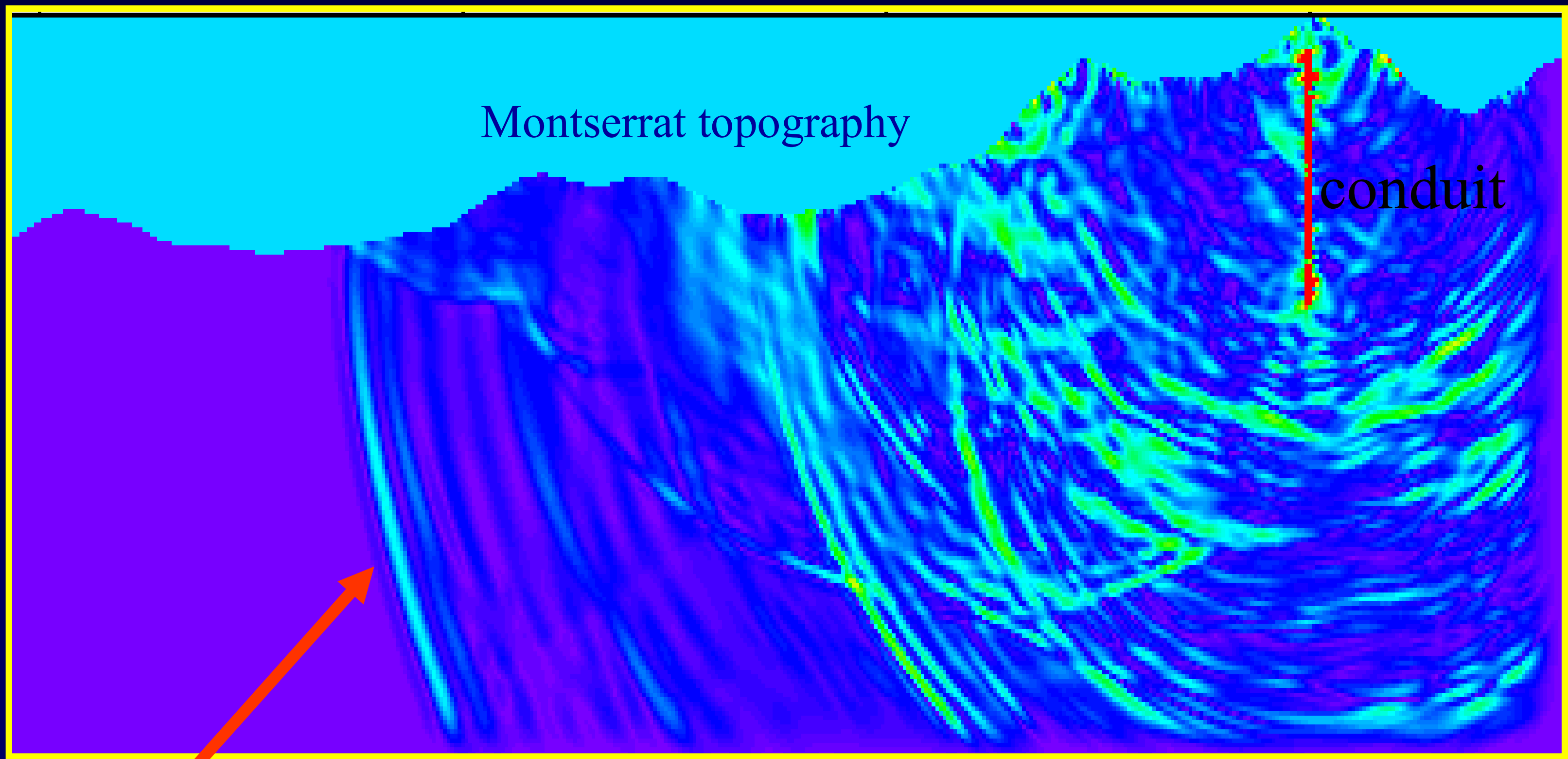
(MTINVERS, courtesy T. Dahm & D. Roessler)



Low-frequency events

Characteristics:

Conduit filled with melt, gas & crystals



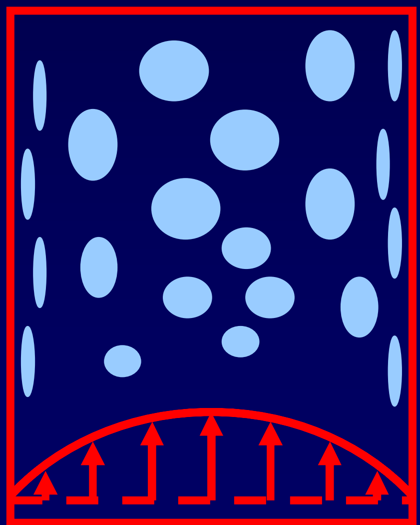
(Jousset et al., 2006)

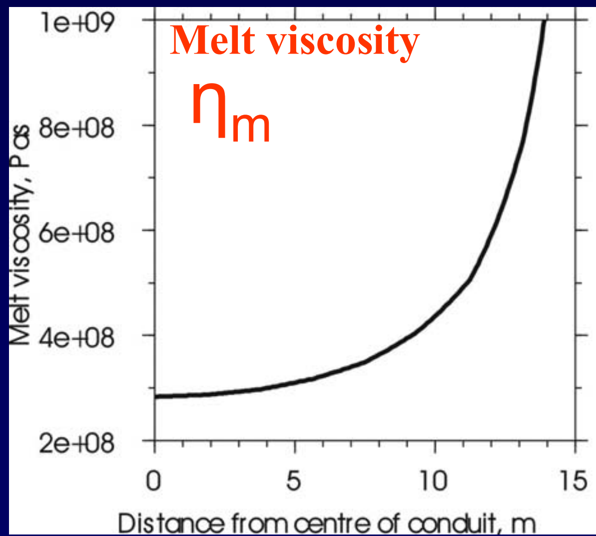
Onset contains information on trigger mechanism

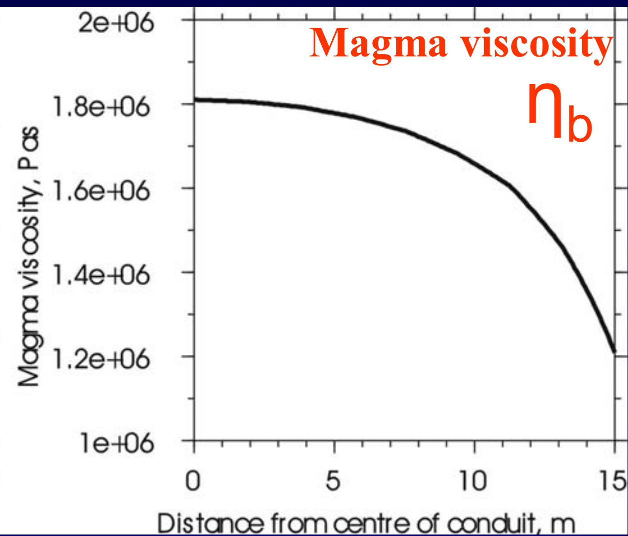
The Model: Magma flow modelling:

Magma = Melt + Crystals + Gas

- Magma: ρ_b η_b
  - $\rho_b = \rho_m(1 - \chi_g - \chi_c) + \rho_g \chi_g + \rho_c \chi_c$
- Melt: ρ_m η_m
  - ρ_m: const (~ 2300 kg m^{-3})
  - η_m: f(Cm, P) (Hess & Dingwell, 1996)
- Crystals: ρ_c χ_c
  - const (ρ_c=2680 kg m^{-3}, χ_c= 30 %)
- Gas: ρ_g η_g
  - ρ_g: mP/RT
  - η_g: const (~1,5 10^{-5} Pa s)







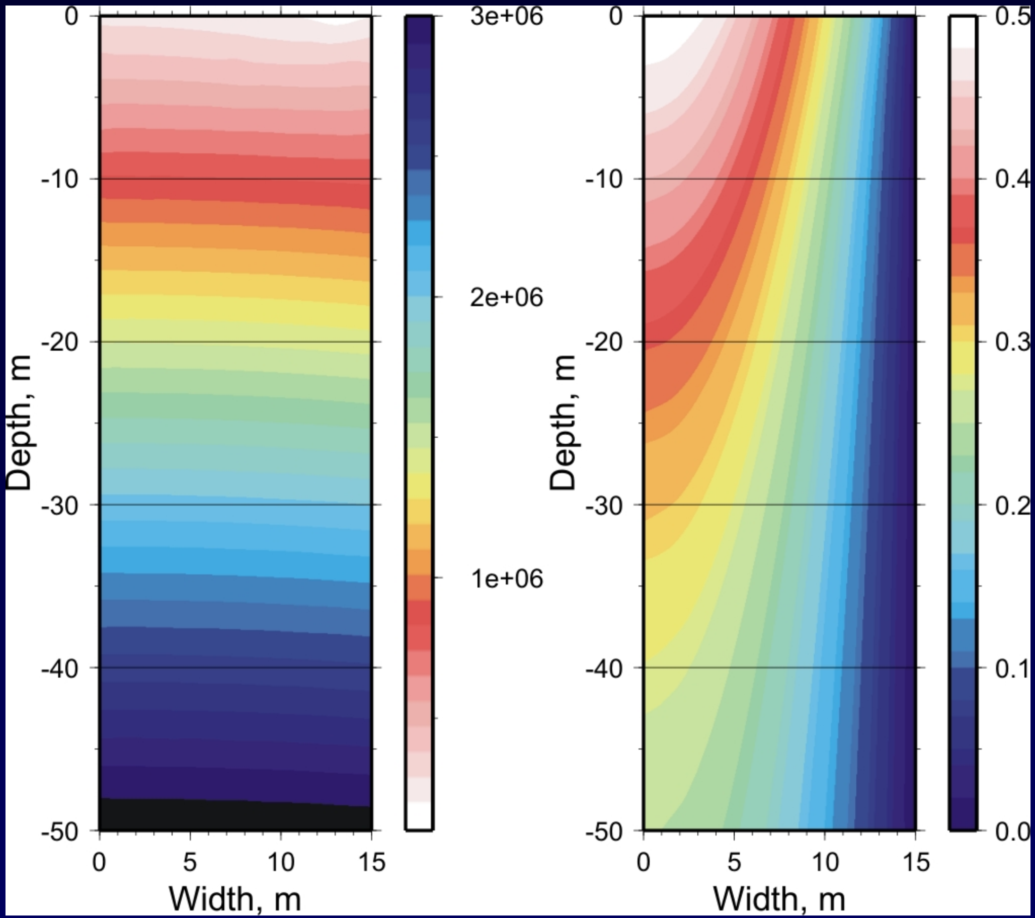
Finite Element modelling of magma flow:

Employ:

Navier Stokes equation
for compressible flow,
gas loss – permeability,
temperature loss & friction,
water solubility, viscosity

Determine:

pressure, density, temperature,
viscosity, gas volume %,
magma velocity,
velocity gradient (= strain rate)

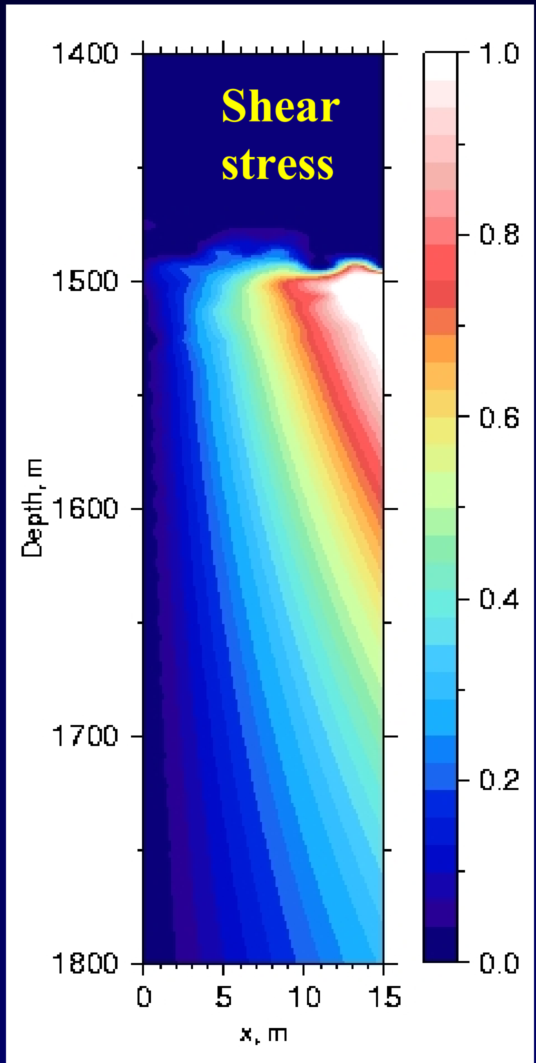


Pressure   Magma velocity

(Collier & Neuberg, 2006)

Low-frequency events

Trigger mechanism:

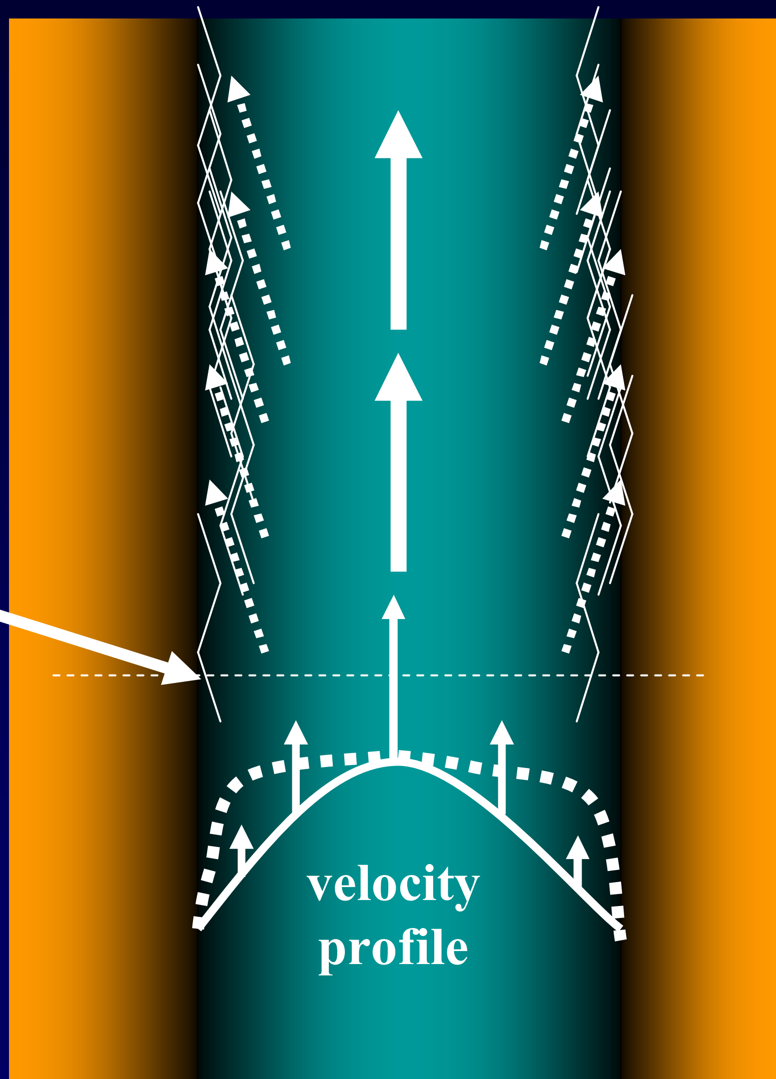


Magma ruptures if

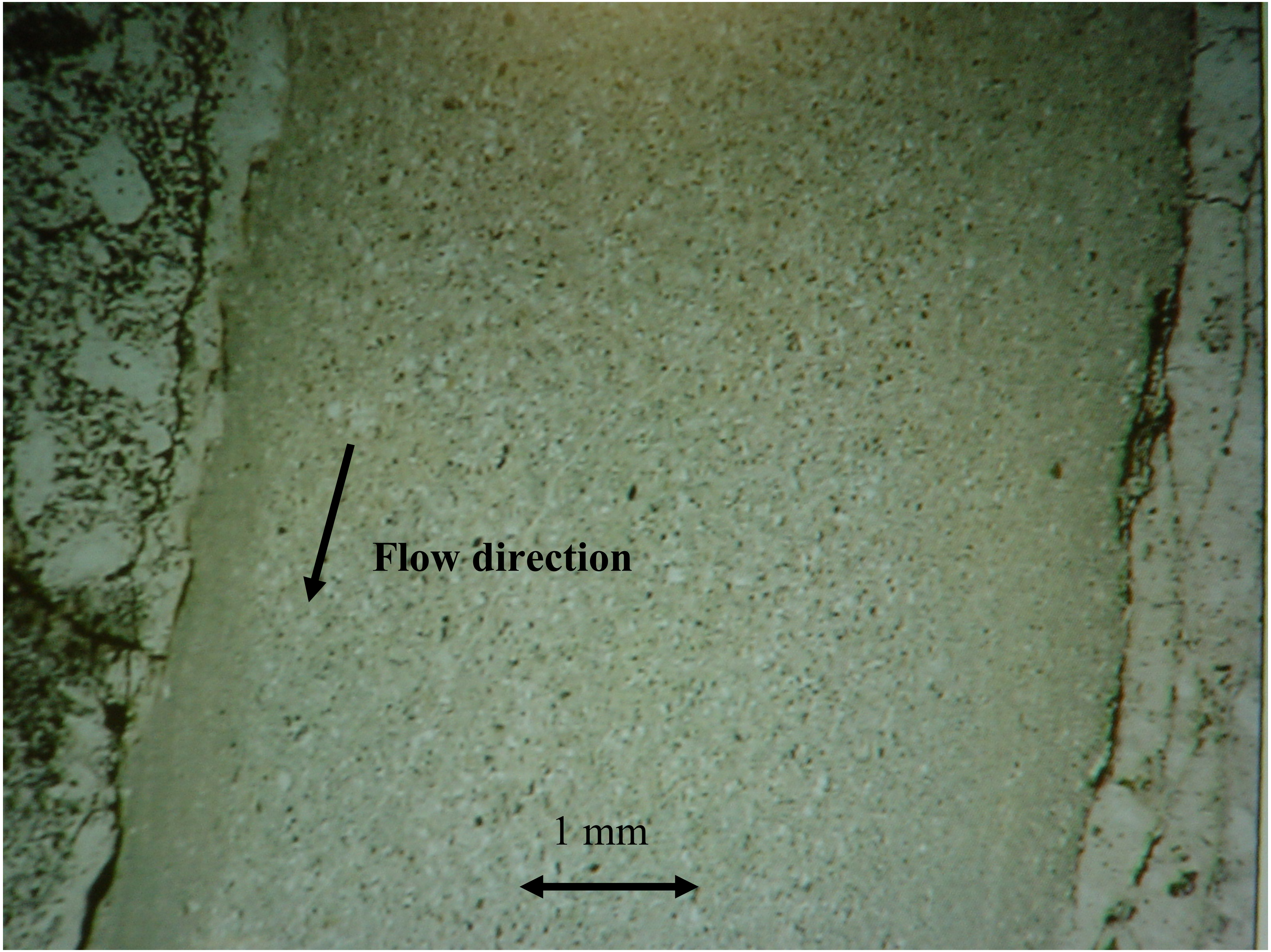
$$\dot{\varepsilon}\,\mu > 10^{7}\ \mathrm{Pa}$$

at constant depth

Conduit resonance where viscosity is low



(Neuberg et al., 2006)


Flow direction
1 mm

Montserrat:
Ash venting in August 2006

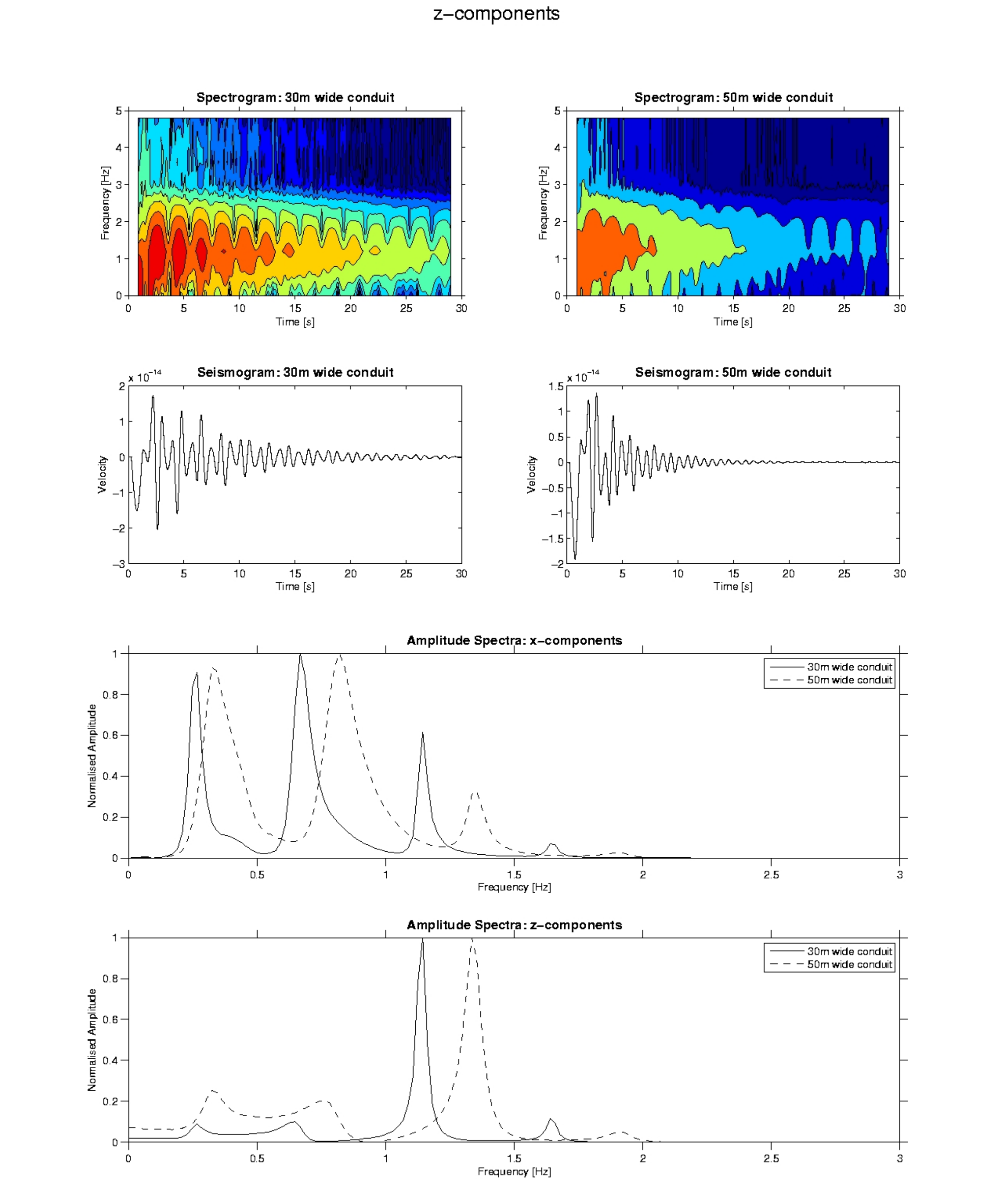
Photo: J. Neuberg

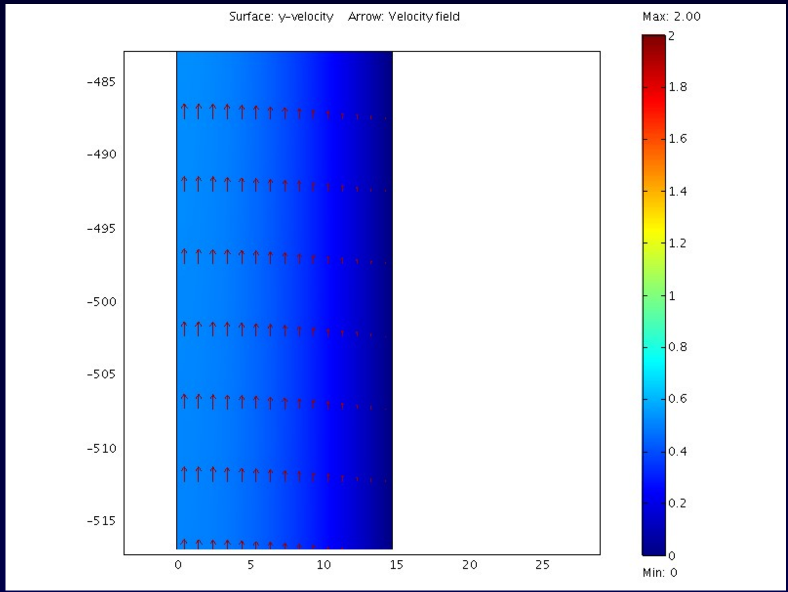
Degassing of a conduit:

Santiaguito, Guatemala; courtesy Bill Rose

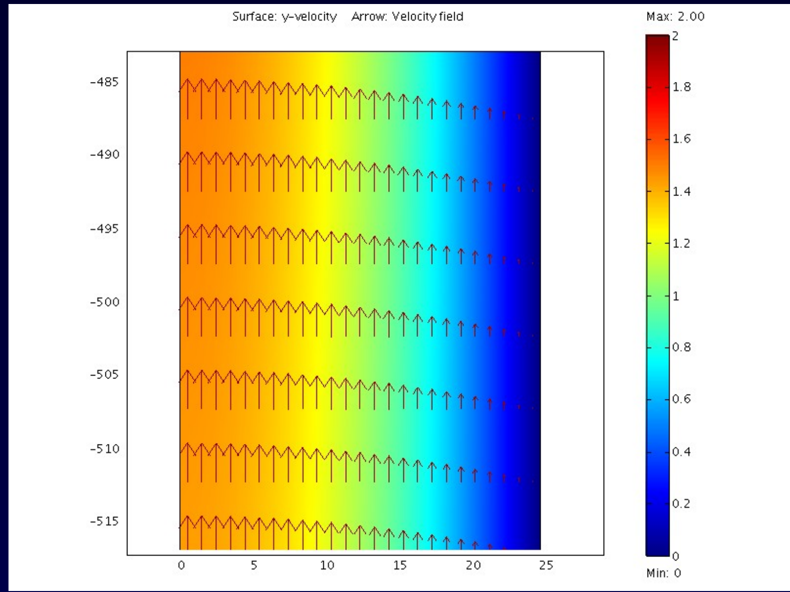
Conduit widening from 30m to 50m

Corresponding frequency shift

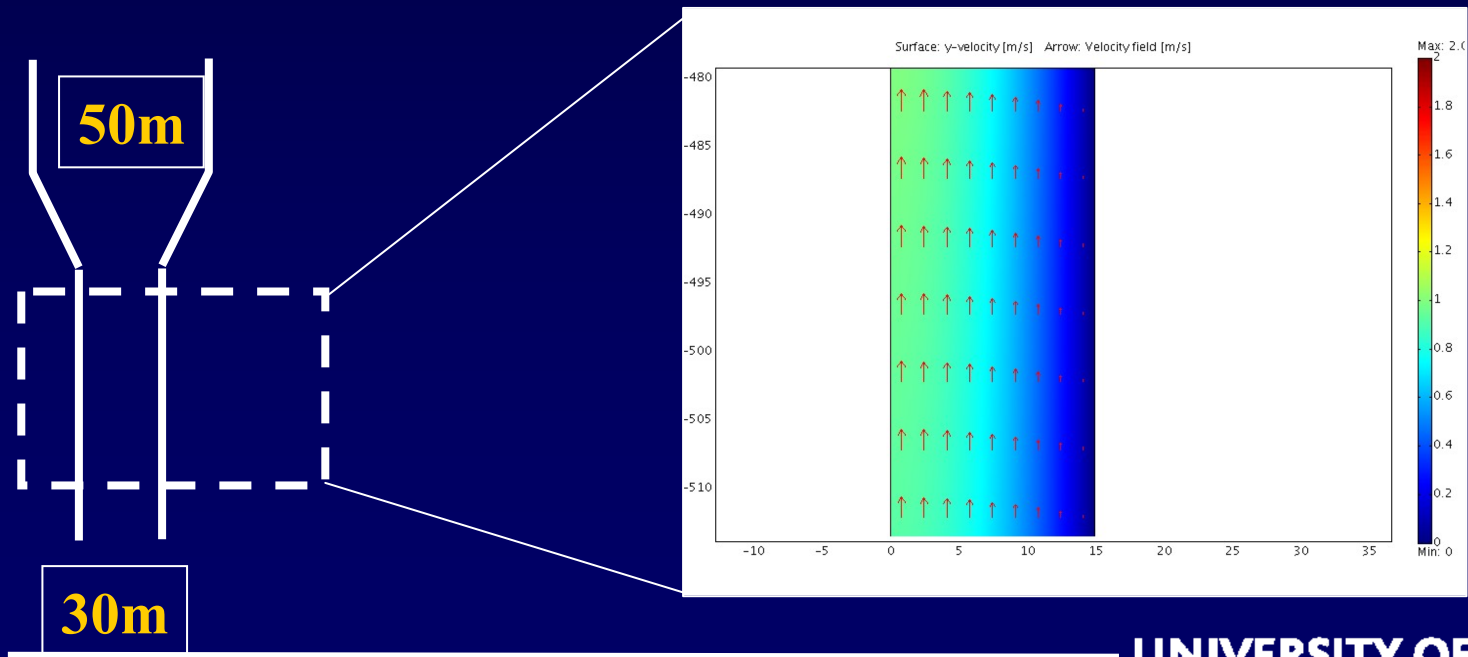




30m conduit



50m conduit



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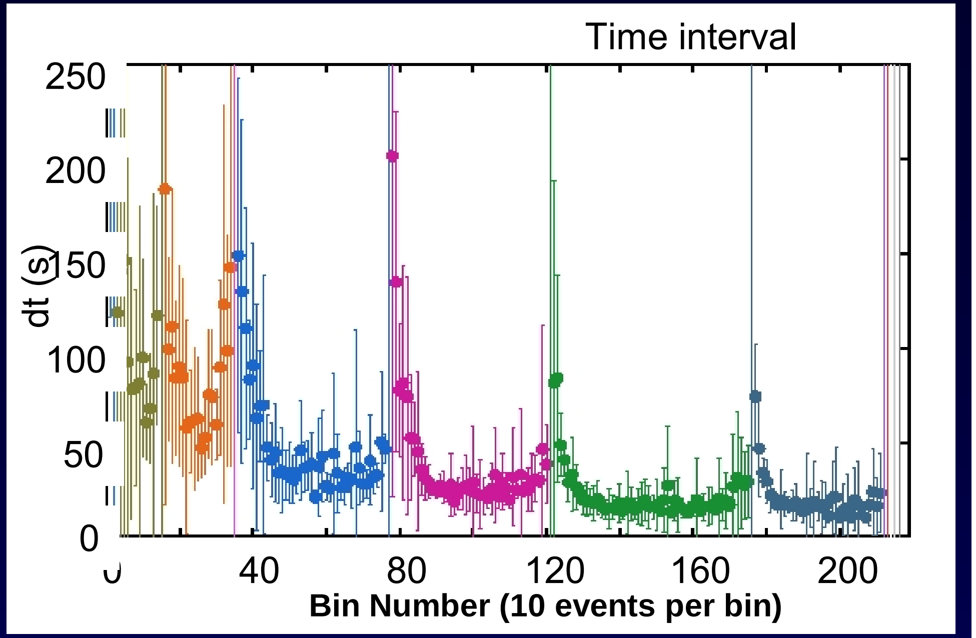
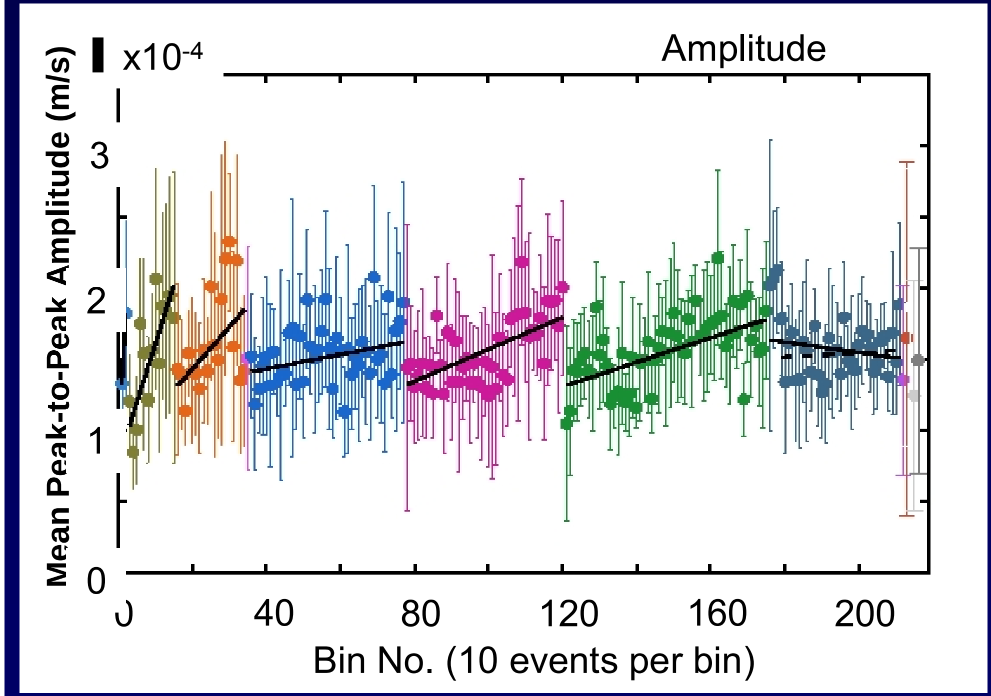
Evolution of single family over several swarms



Event rate



Amplitude

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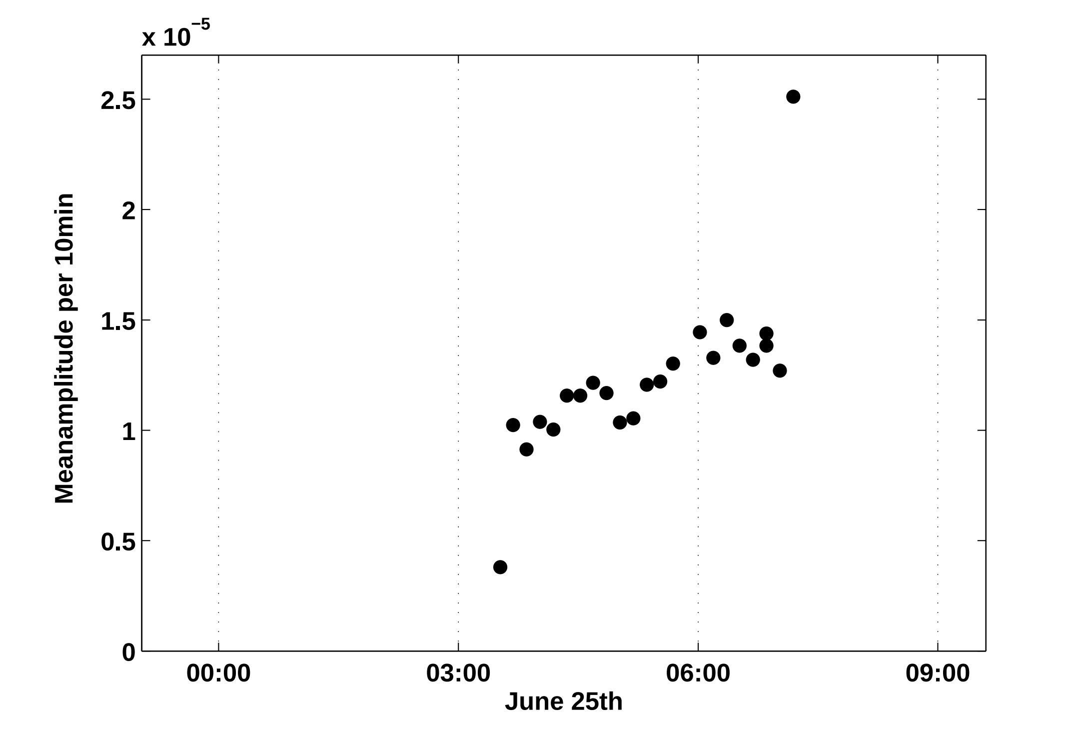
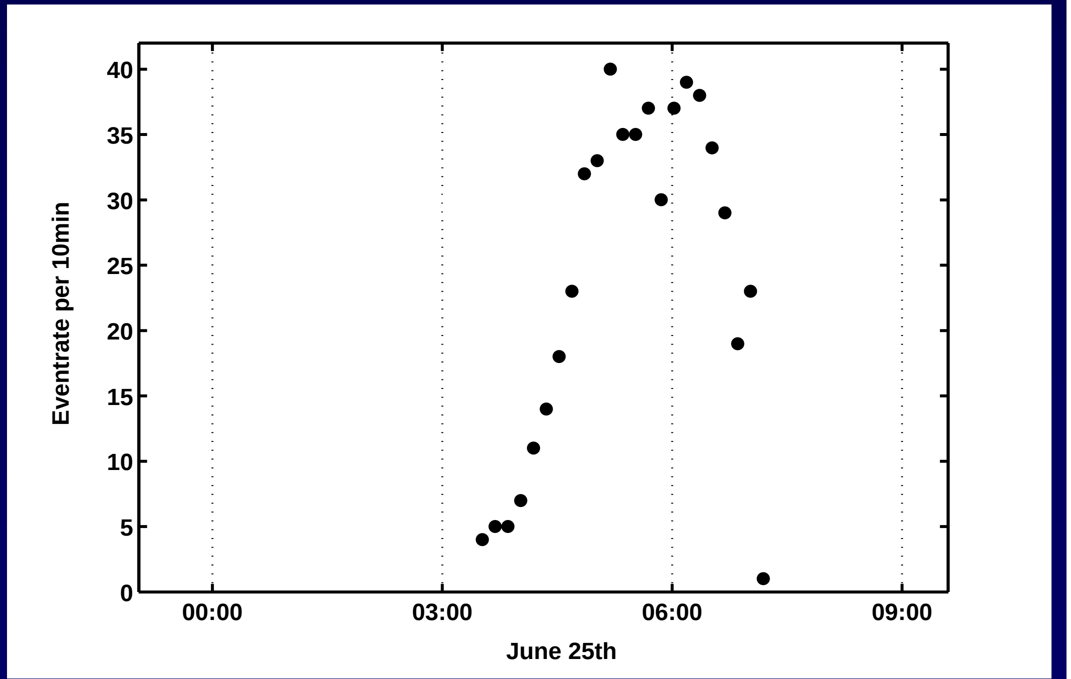
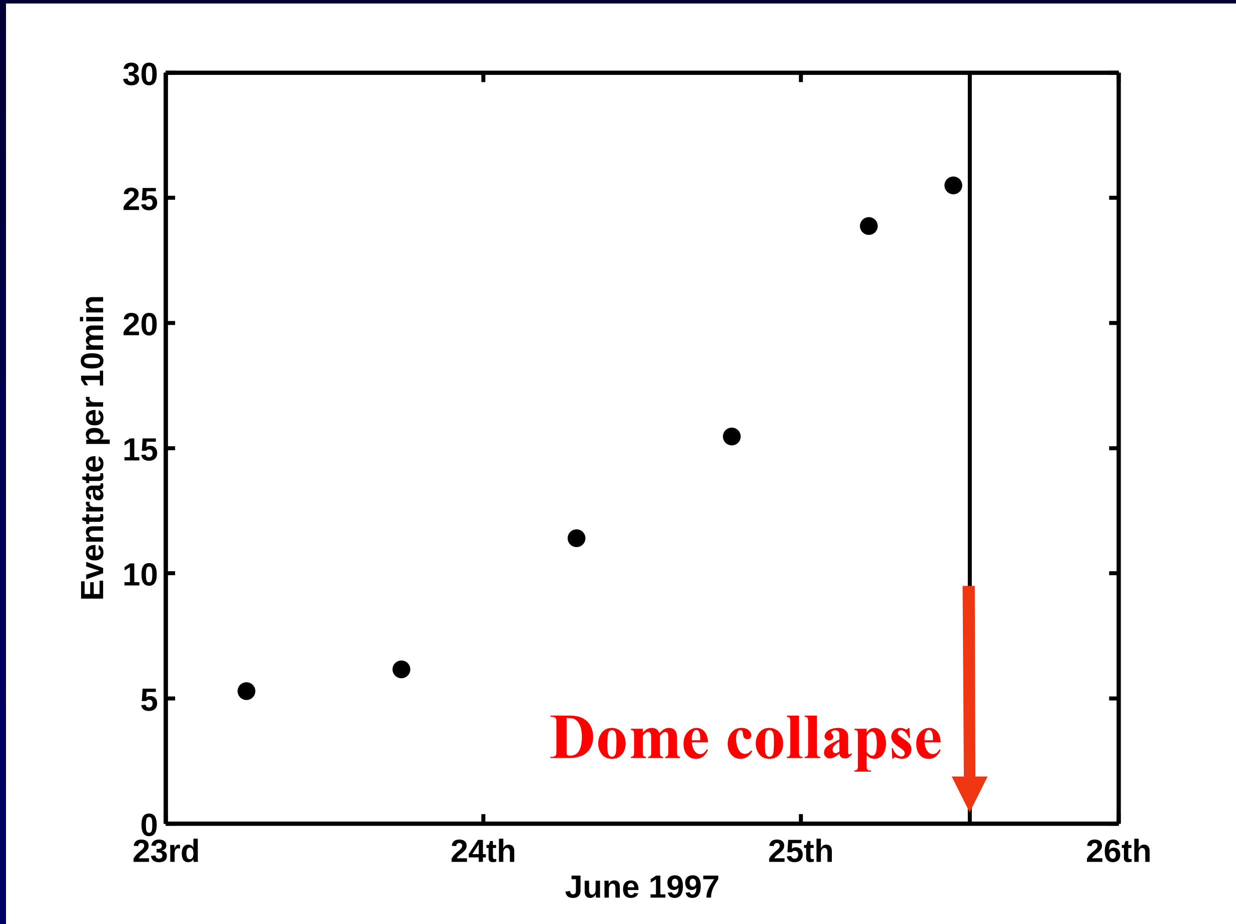


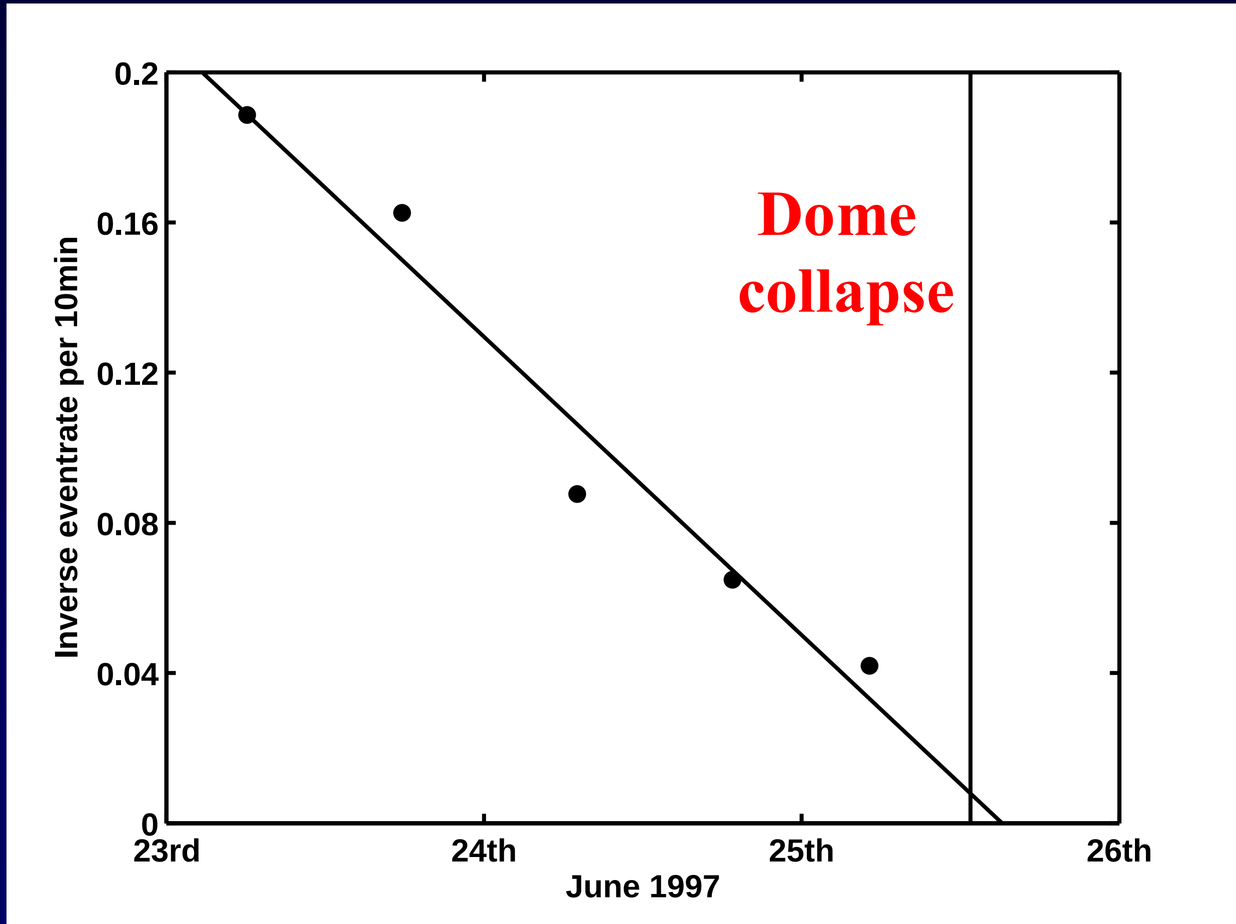
Single Swarm



Average event rates for several swarms

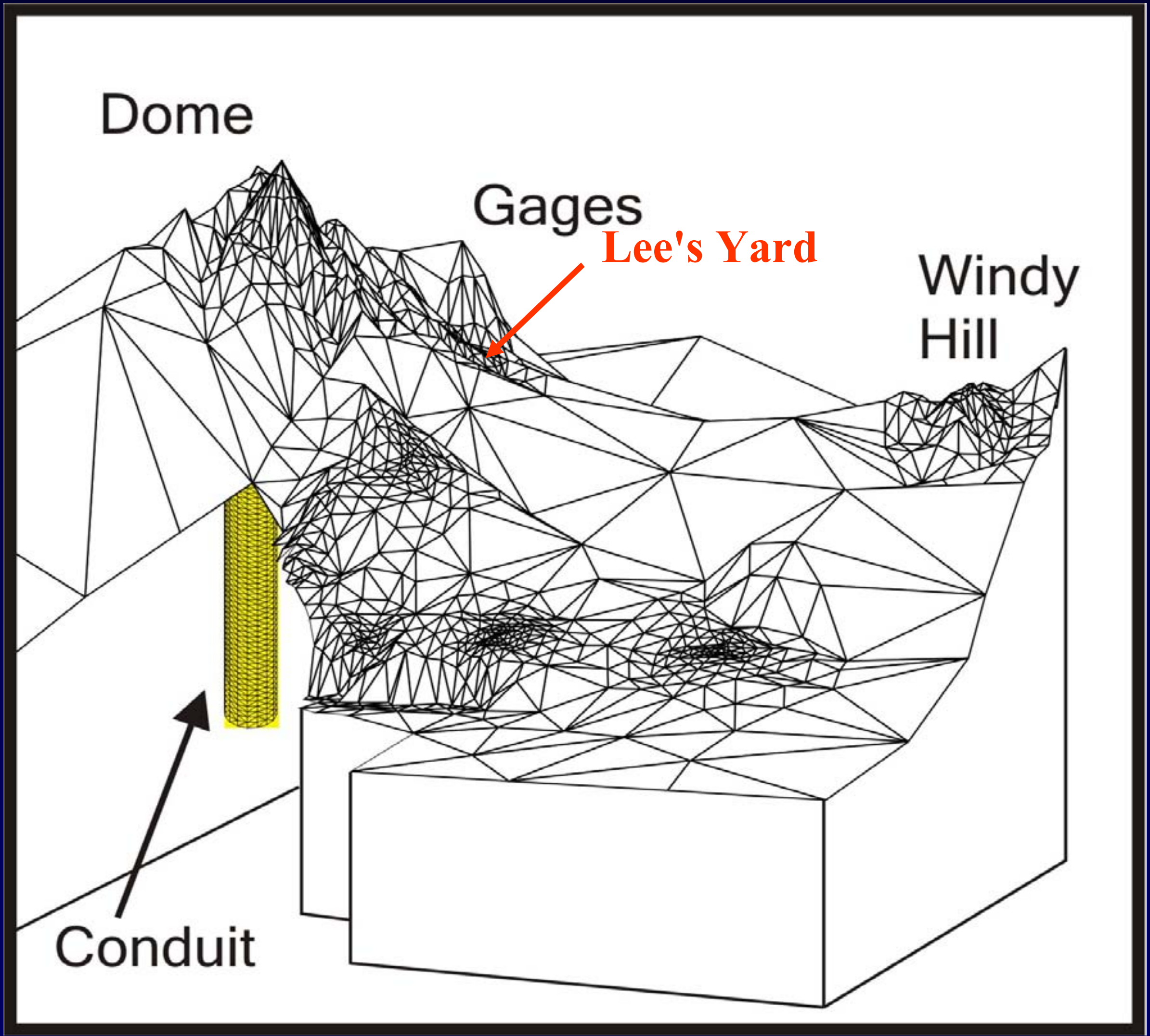


Inverse event rate for several consecutive swarms behaves according to material failure law → Note: magma rupture – not dome collapse



(Hammer & Neuberg, 2009)

Models for seismicity & tilt:



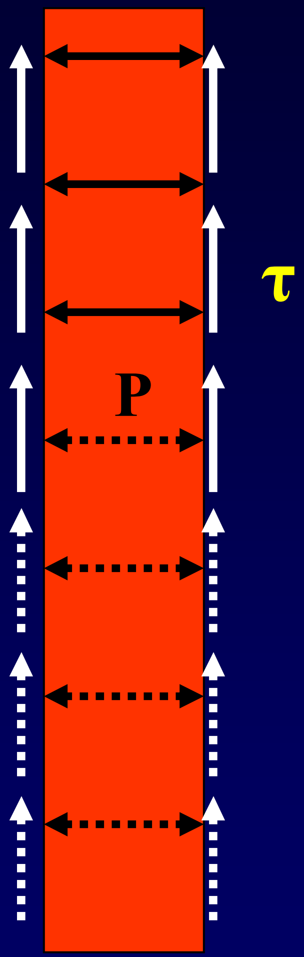
(Green, Neuberg & Cayol, 2006)

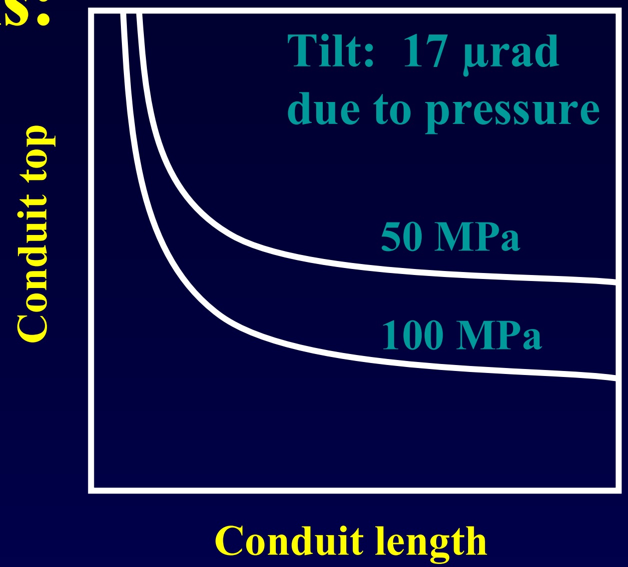
Modelling parameters:

conduit top & pressure

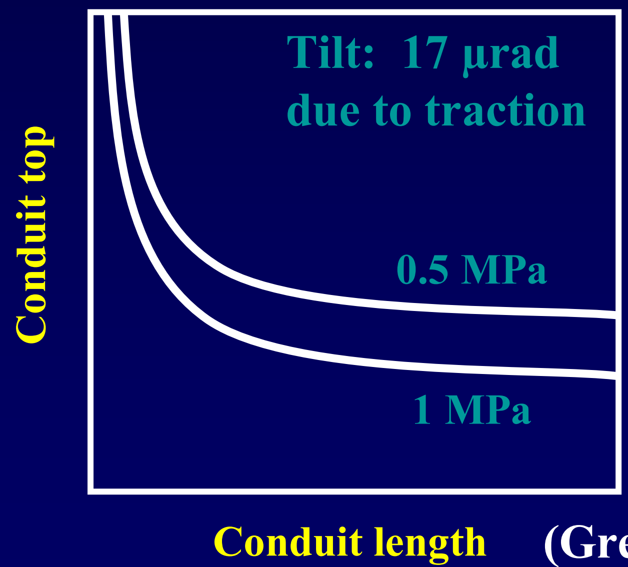
3D detail - cut out
to see tilt source
(vertically exaggerated x 3)

Deformation models:





Tilt ←→ Pressure



Tilt ←→ Traction
→ Strain rate
→ Magma velocity

(Green, Neuberg & Cayol, 2006)

Consider traction – not only pressure !!!!!

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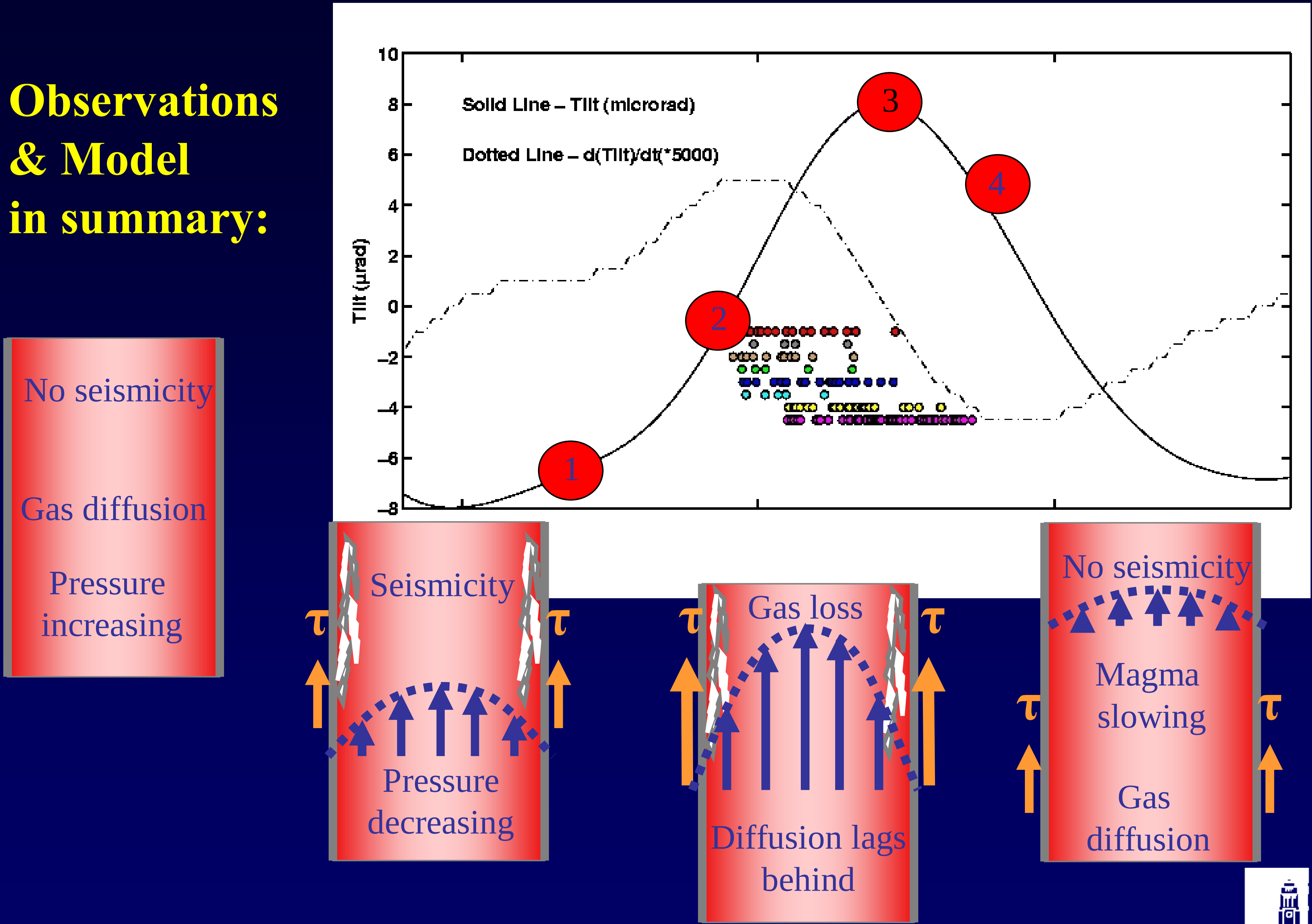
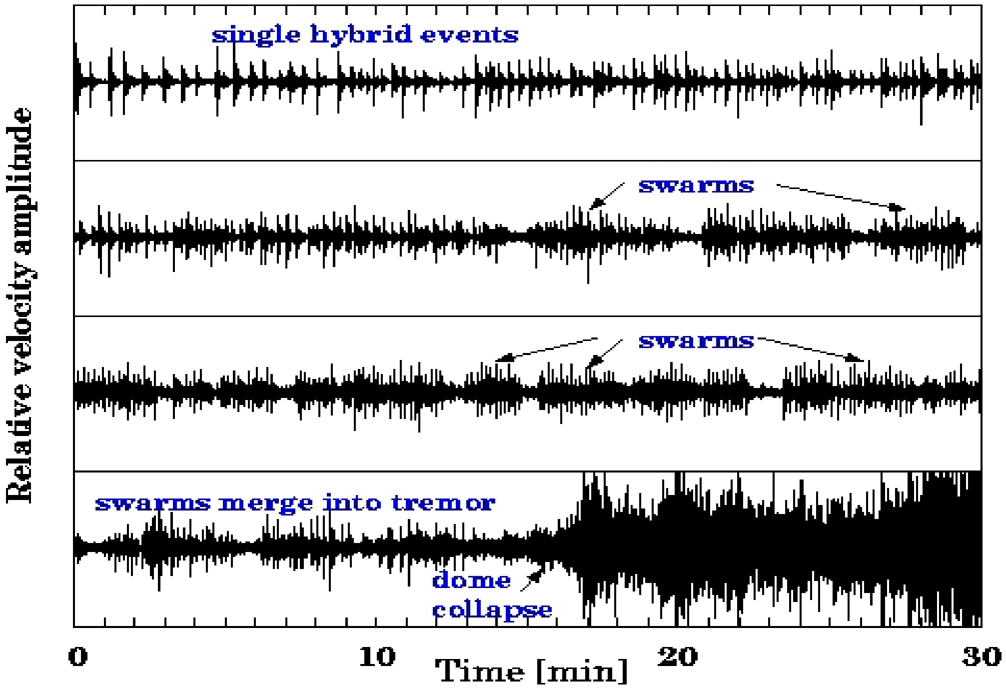
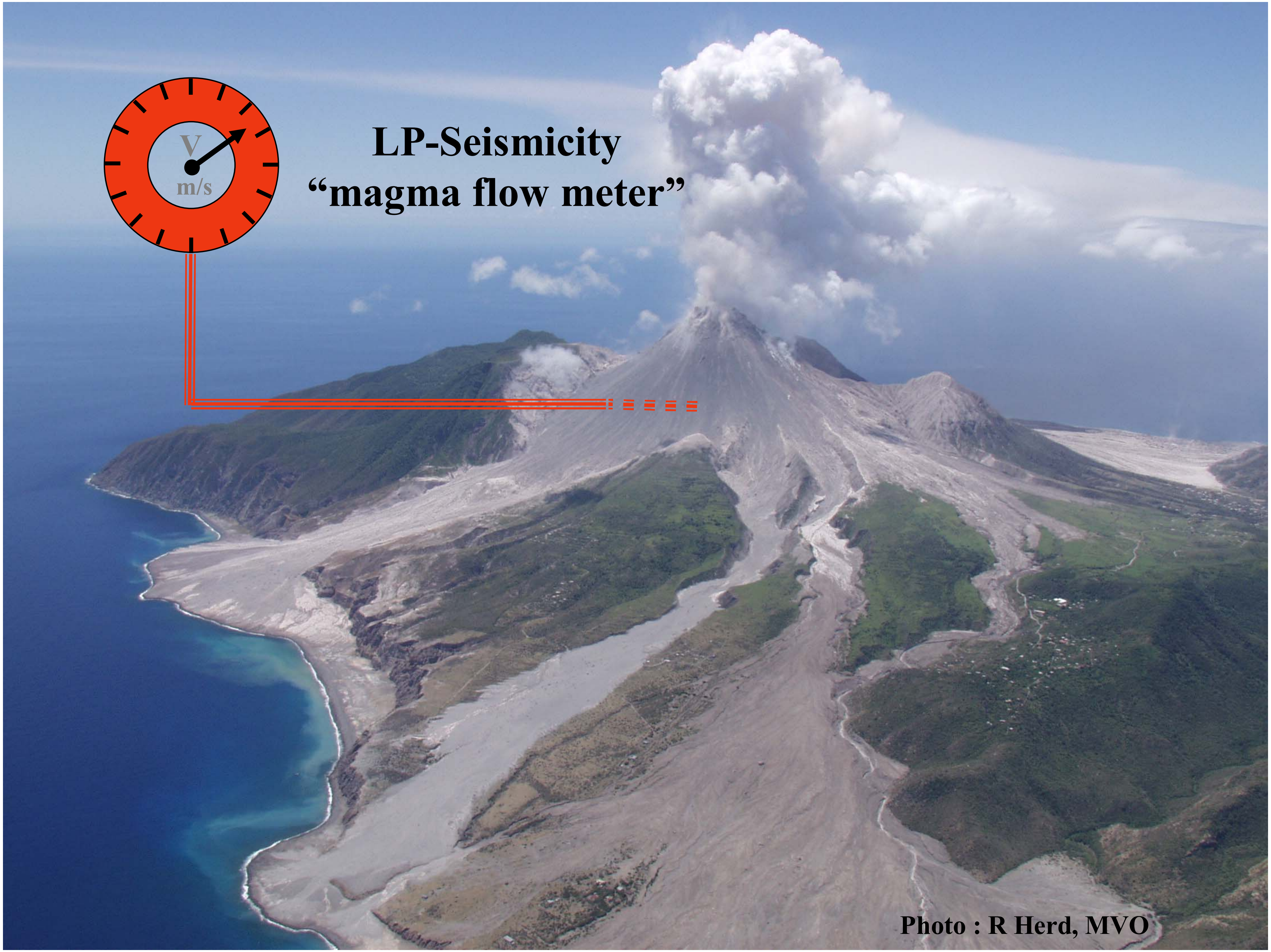
Observations & Model in summary:



Combining :
Magma flow models
&
Seismic models
&
Deformation models

Link seismicity
with
magma movement
at depth




V
m/s
LP-Seismicity
“magma flow meter”
Photo : R Herd, MVO