Volcanic tremor

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Volcanic tremor

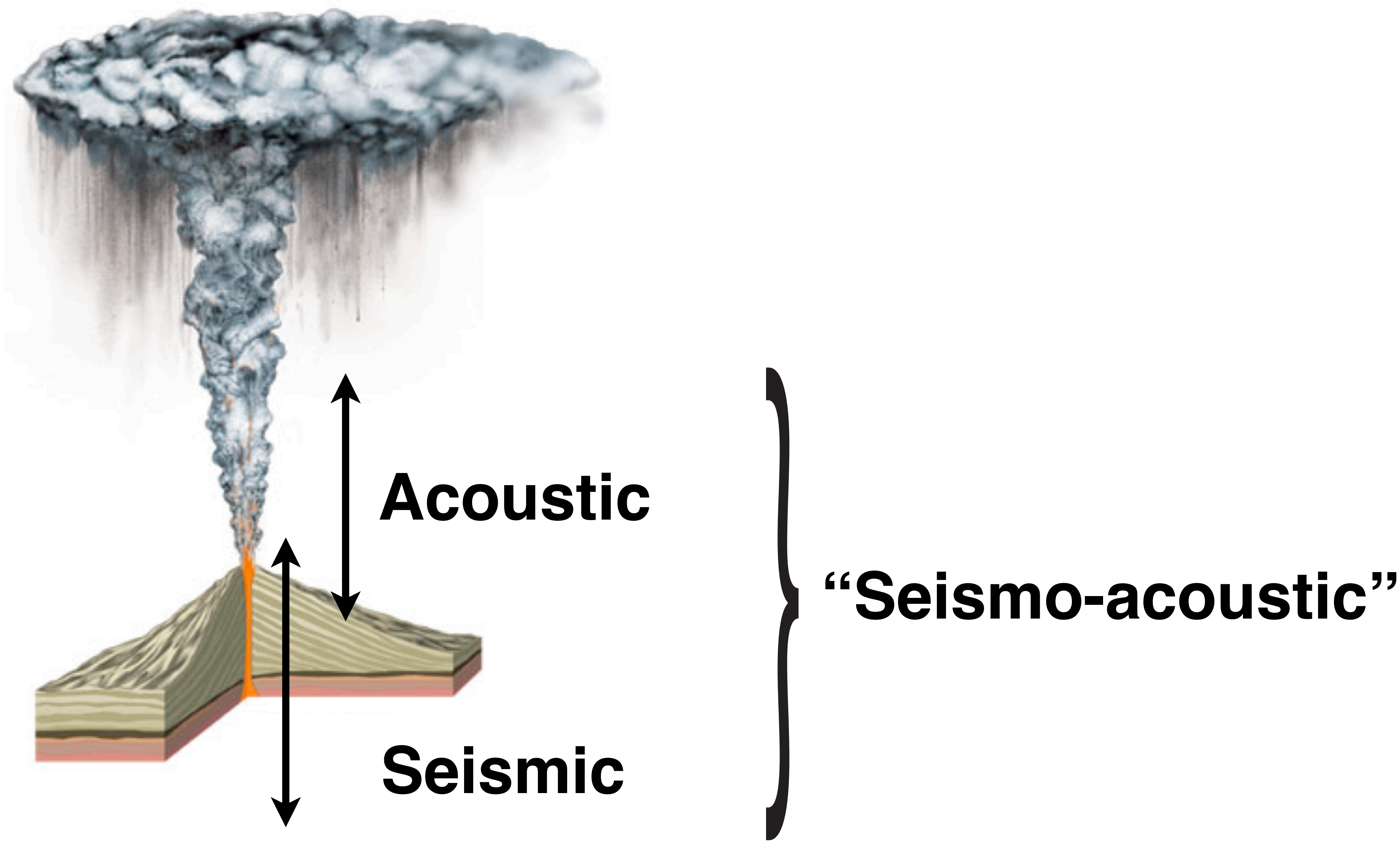
e.g., Luigi Palmieri 1856
“continuous tremor” at Vesuvius

Volcanic tremor

e.g., Sakai et al. [1996]
infrasonic harmonic tremor at Sakurajima

e.g., Luigi Palmieri 1856
“continuous tremor” at Vesuvius

Volcanic tremor



Volcanic tremor:

a catch-all term for *sustained* seismic and acoustic signals associated with a wide range of volcanic activity

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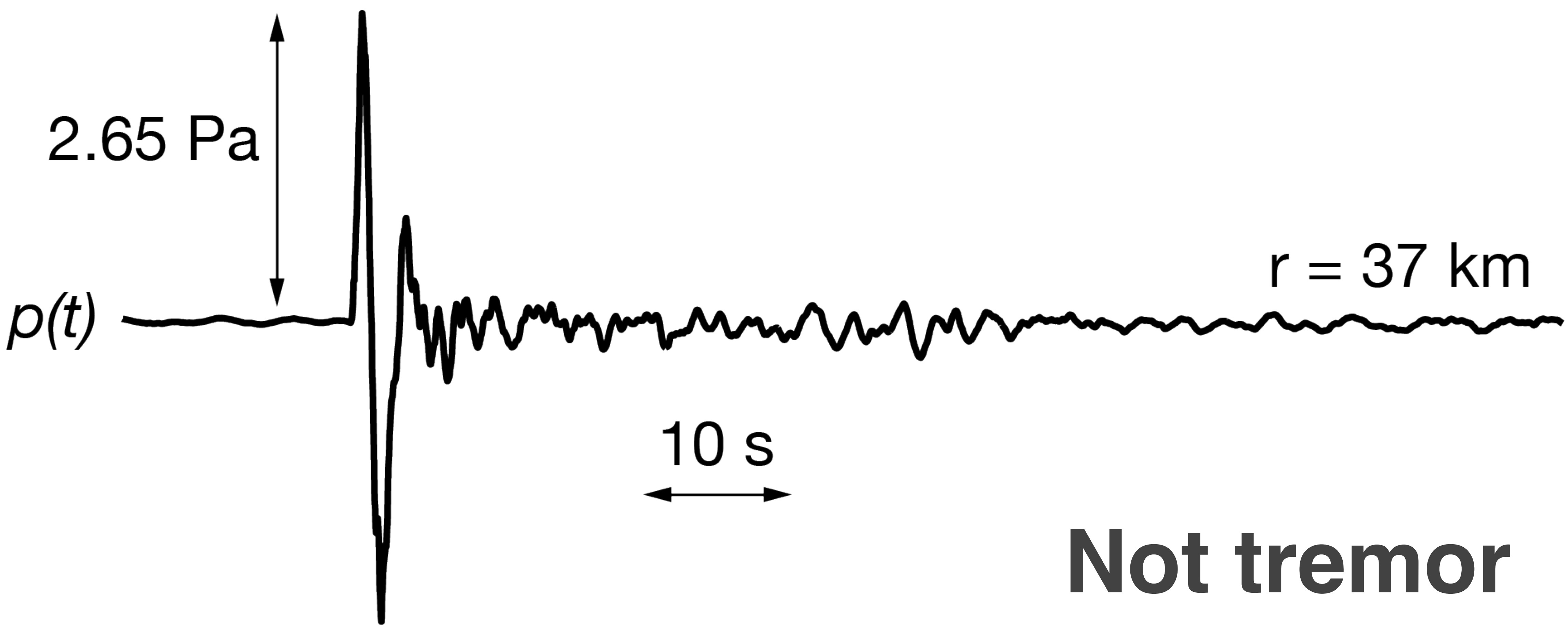

Not tremor

Volcanic tremor:

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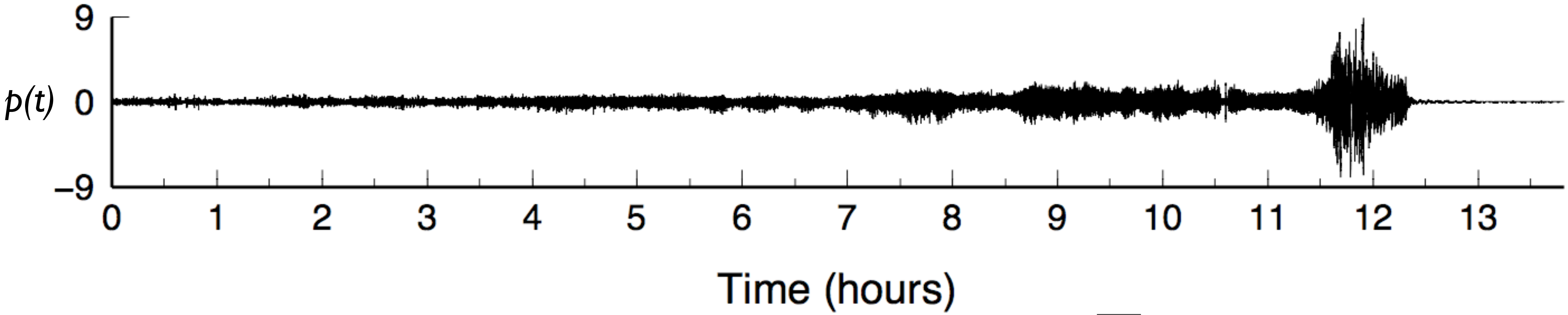

Tremor

Volcanic tremor:

a catch-all term for *sustained* seismic and acoustic signals associated with a wide range of volcanic activity

- **Harmonic**
- **Monotonic/monochromatic**
- **Spasmodic**
- **Eruption**
- **Banded**
- **Tremor storm**

etc.? ...

e.g., Mcnutt [1992], Konstantinou and Schlindwein [2002]

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etc.? ...

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Outline

- Eruption tremor
- Harmonic & monotonic tremor

Eruption tremor

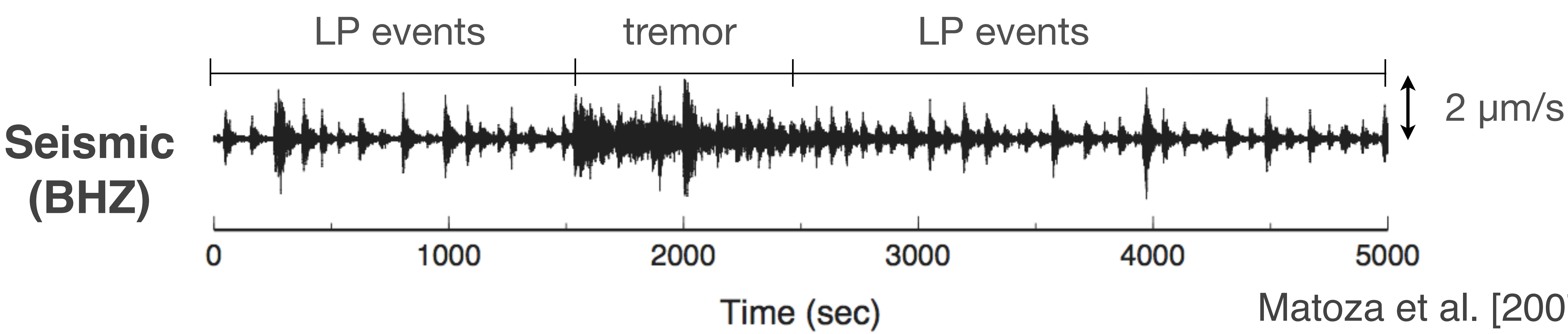
Volcanic tremor that occurs during eruptions

Seismic: broadband signal with temporal variations linked to the mass eruption rate [McNutt, 2000; McNutt and Nishimura, 2008]

Acoustic: broadband signal which resembles jet noise [Matoza et al. 2009, Fee et al. 2010]

Eruption tremor

8 March 2005 phreatic "explosion", Mount St. Helens



Matoza et al. [2007]

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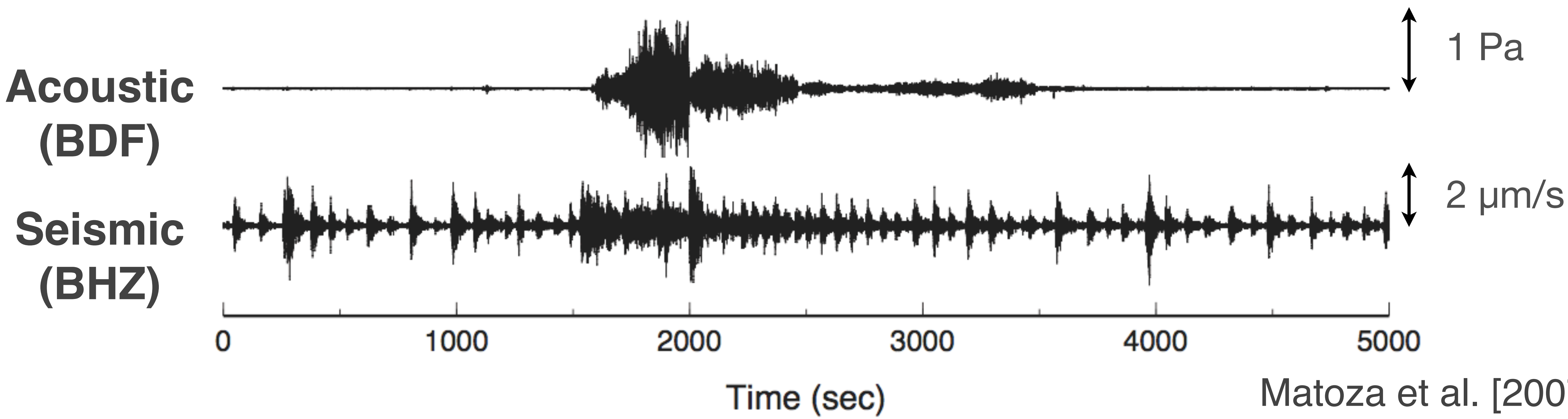
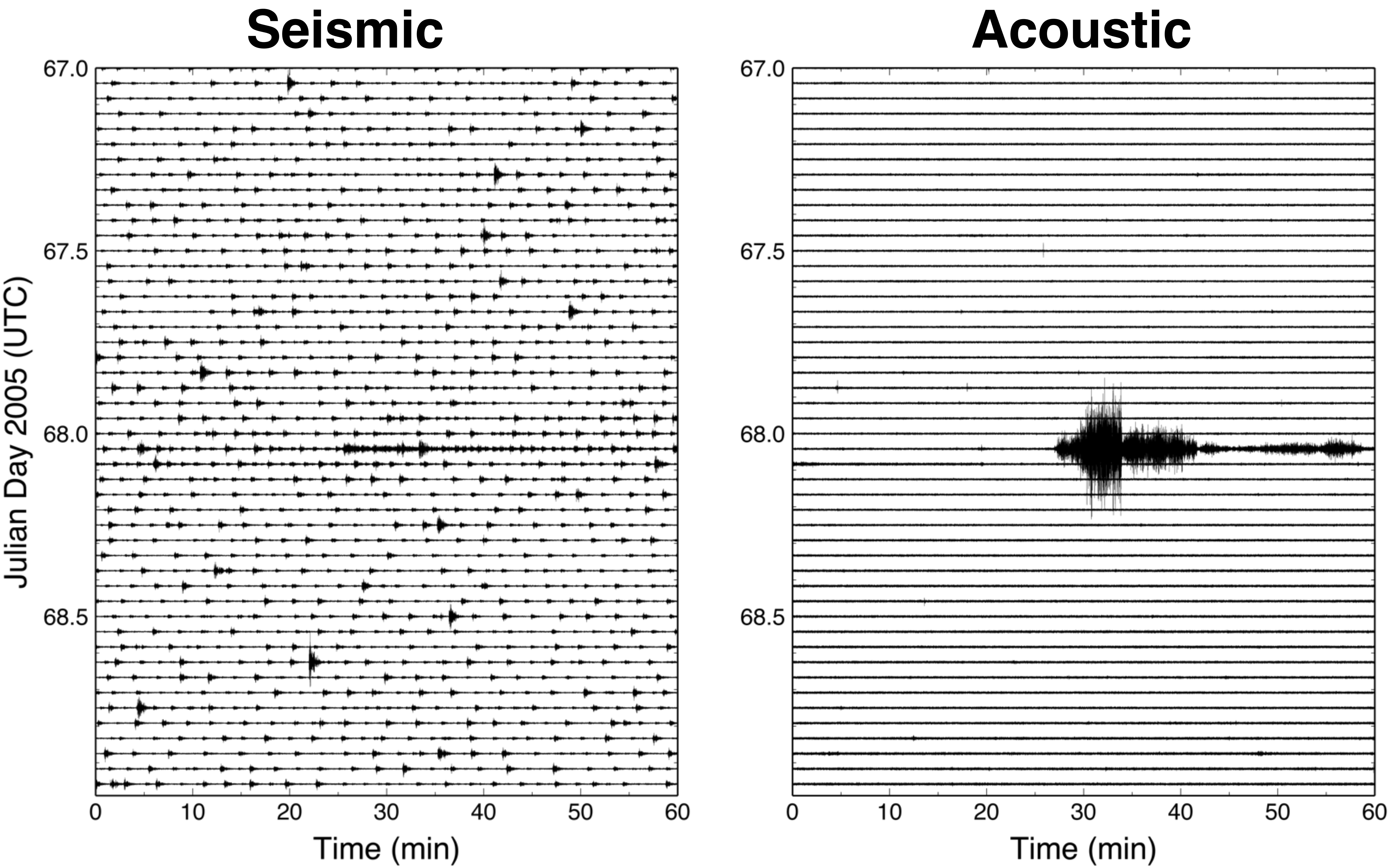


Matoza et al. [2007]

Eruption tremor



Matoza et al. [2007]

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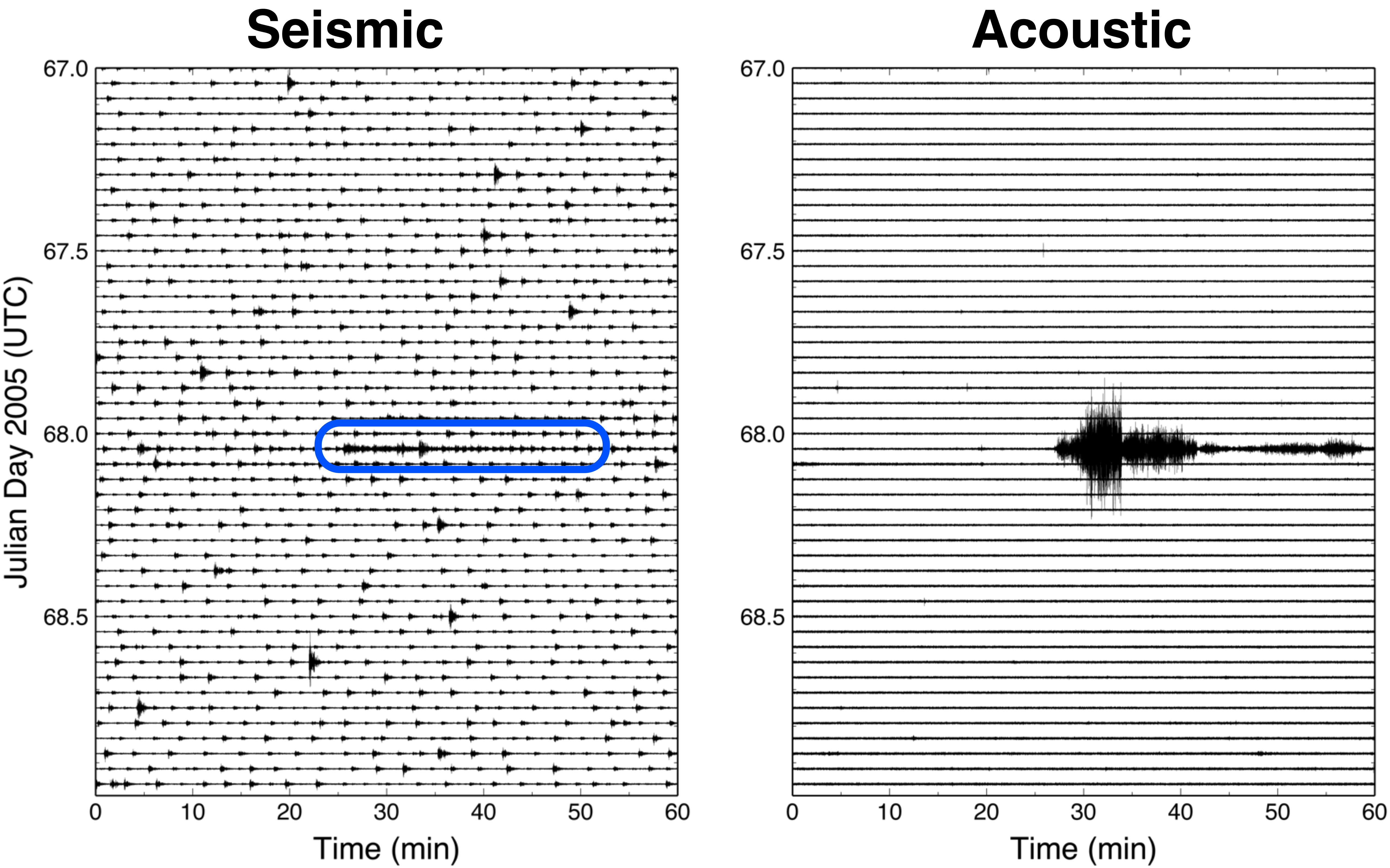

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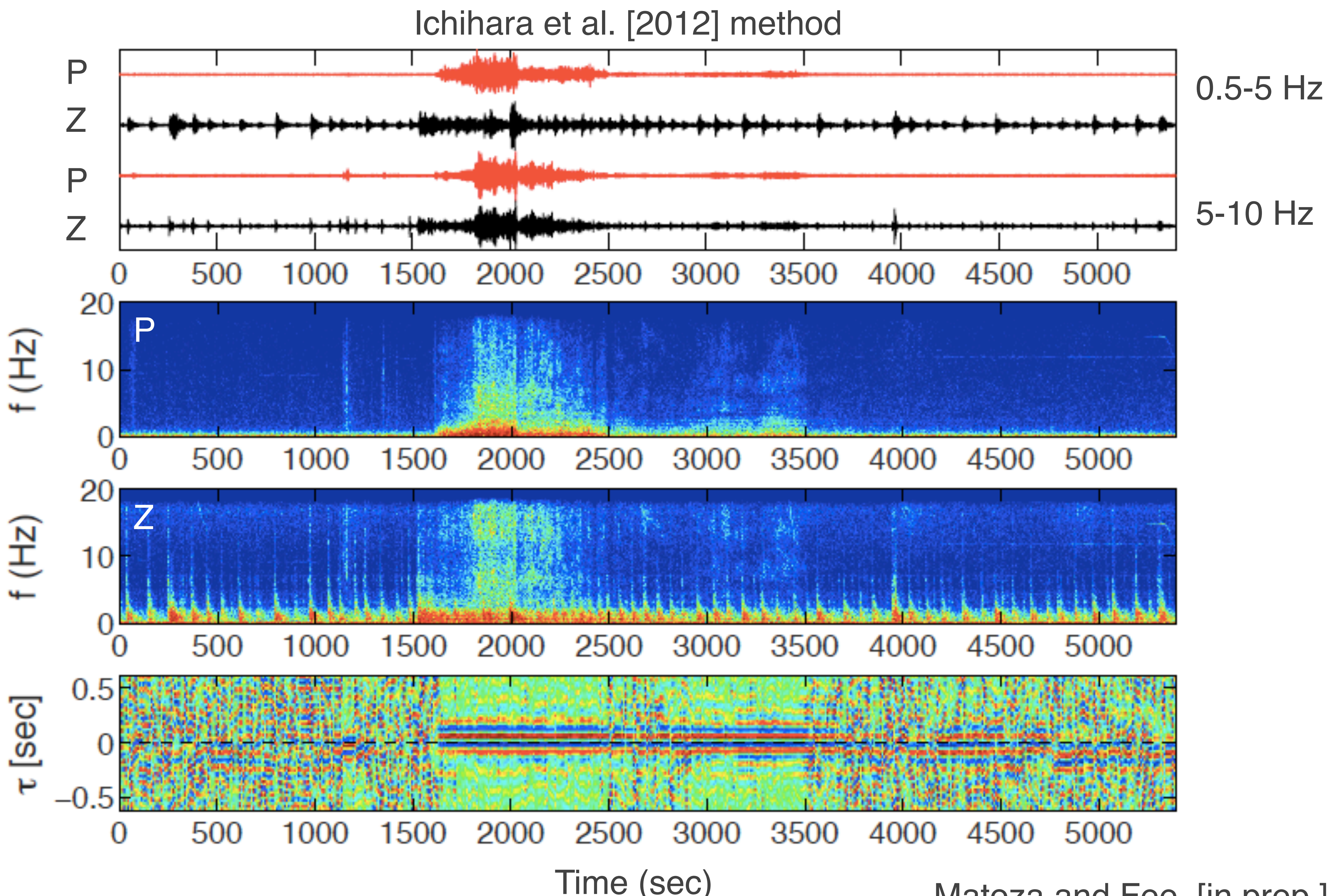
Eruption tremor



Matoza and Fee, [in prep.]

Harmonic & monotonic tremor

Jagger/Omori: early 20th Century

Spasmodic tremor:
irregular vibrations

Harmonic tremor:
more rhythmic vibrations

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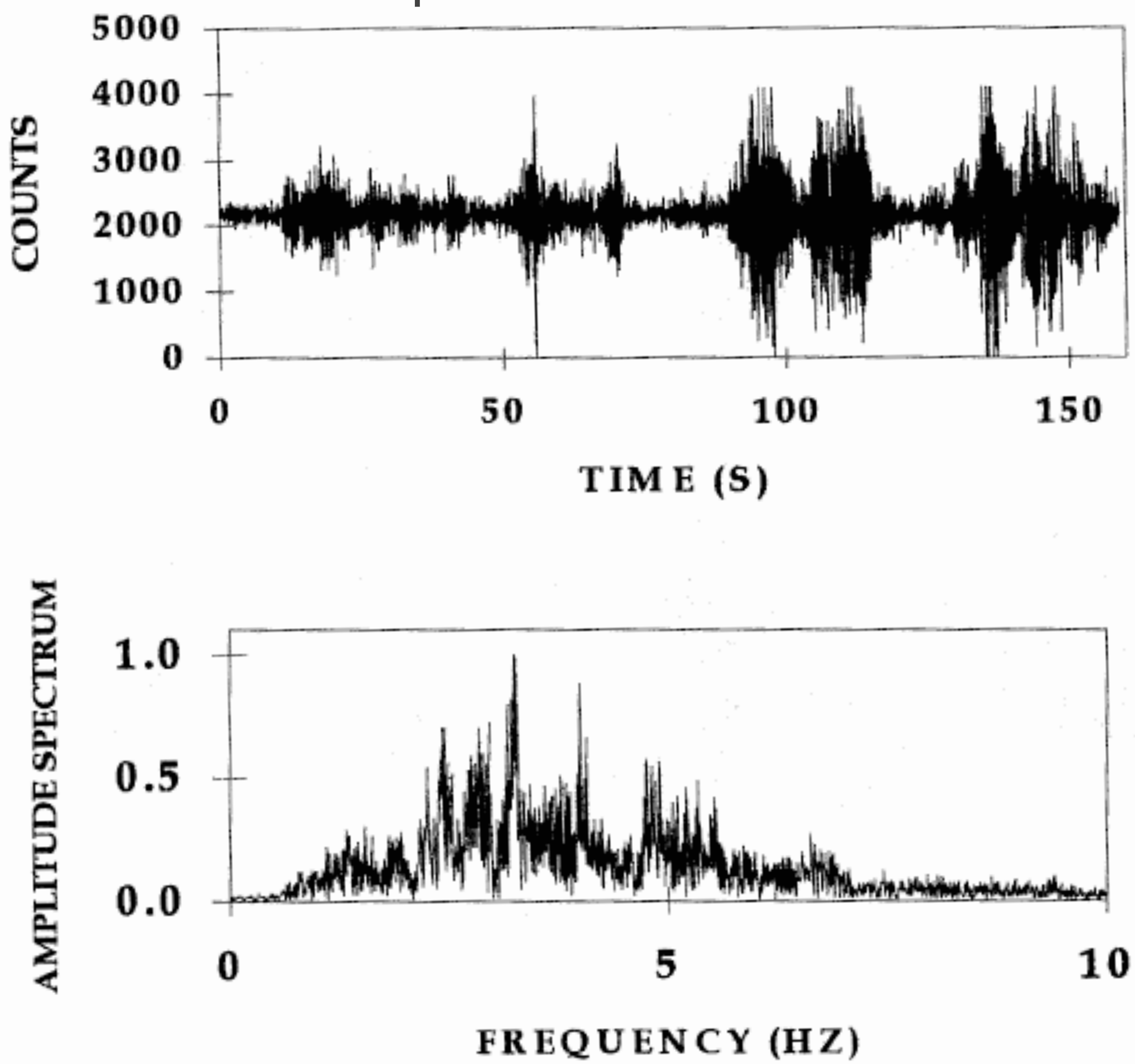
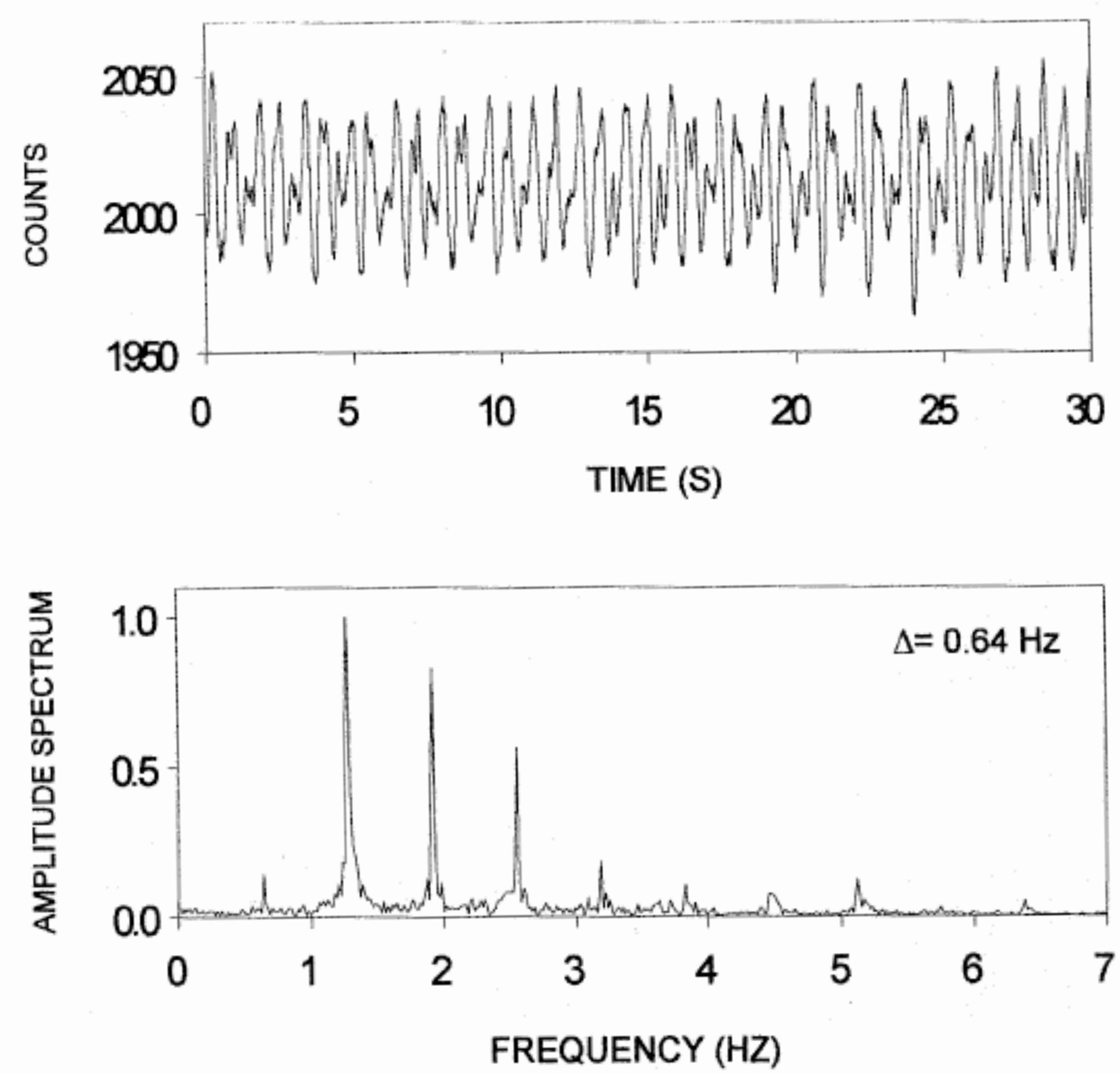
Seismograms from Galeras, Colombia, Gil Cruz [1999]

Spasmodic tremor



Harmonic tremor



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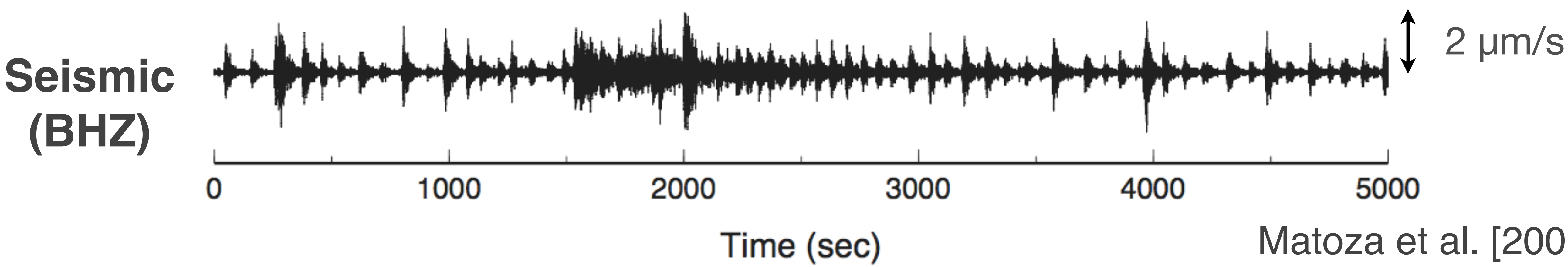

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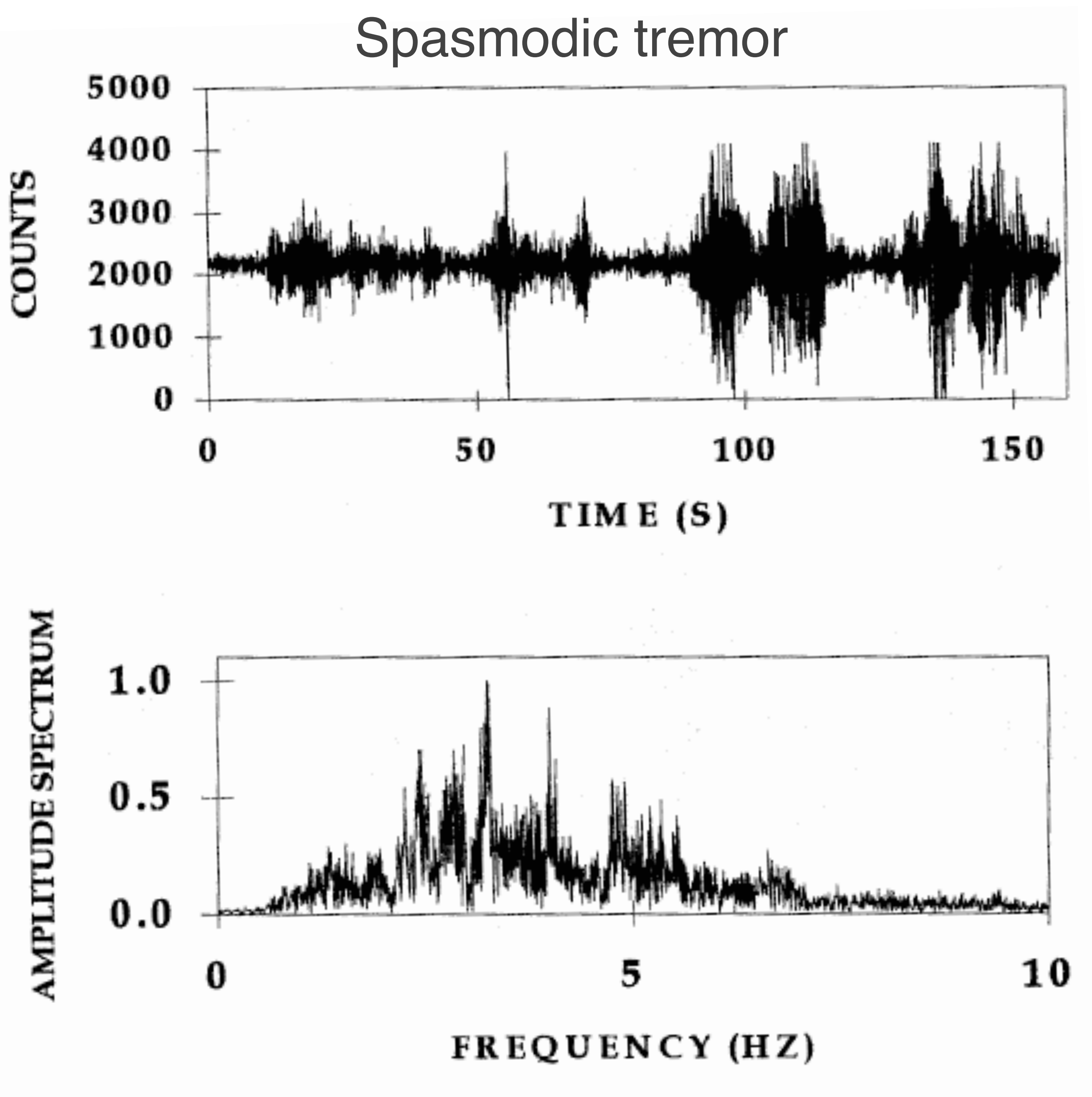
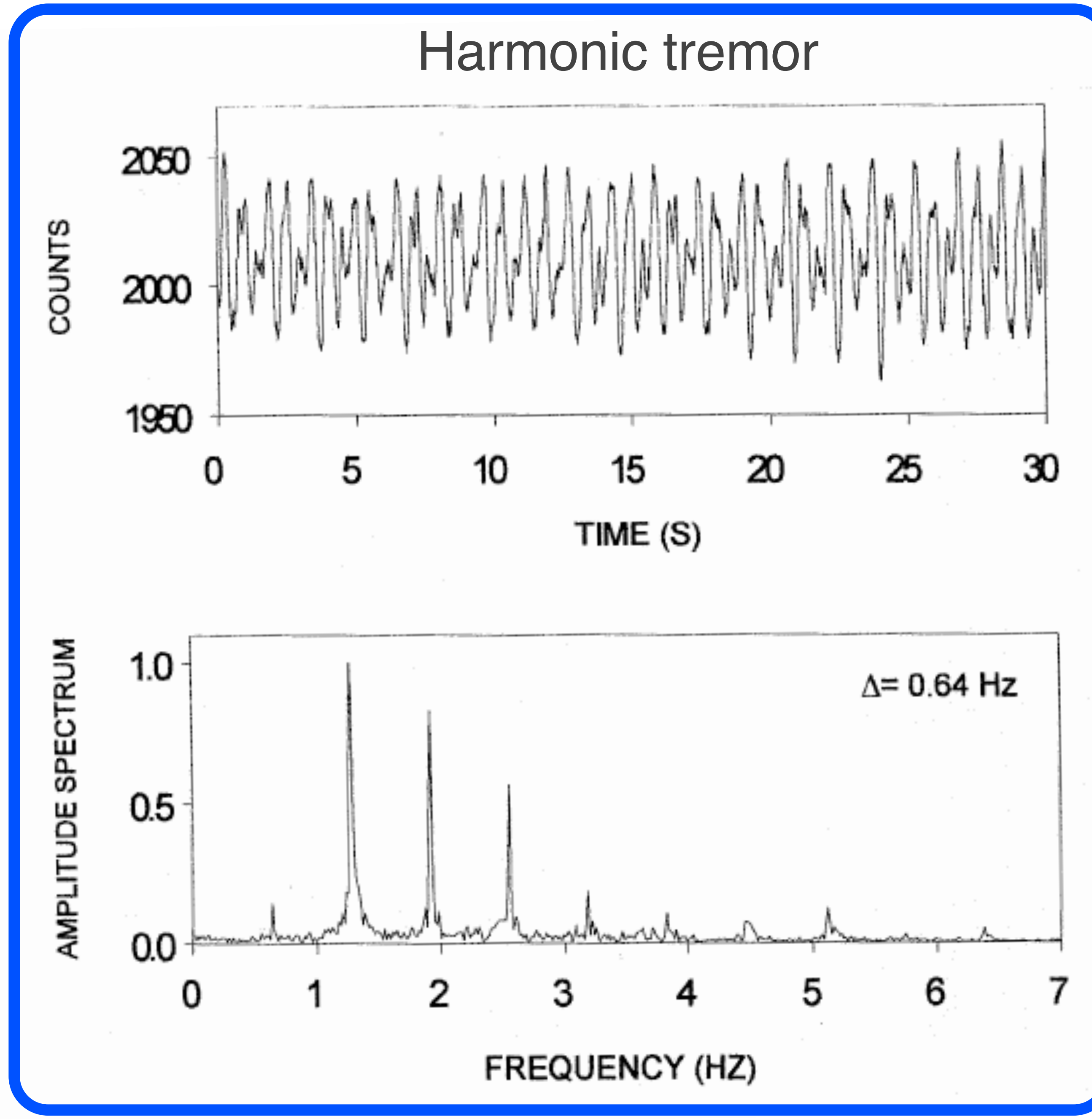




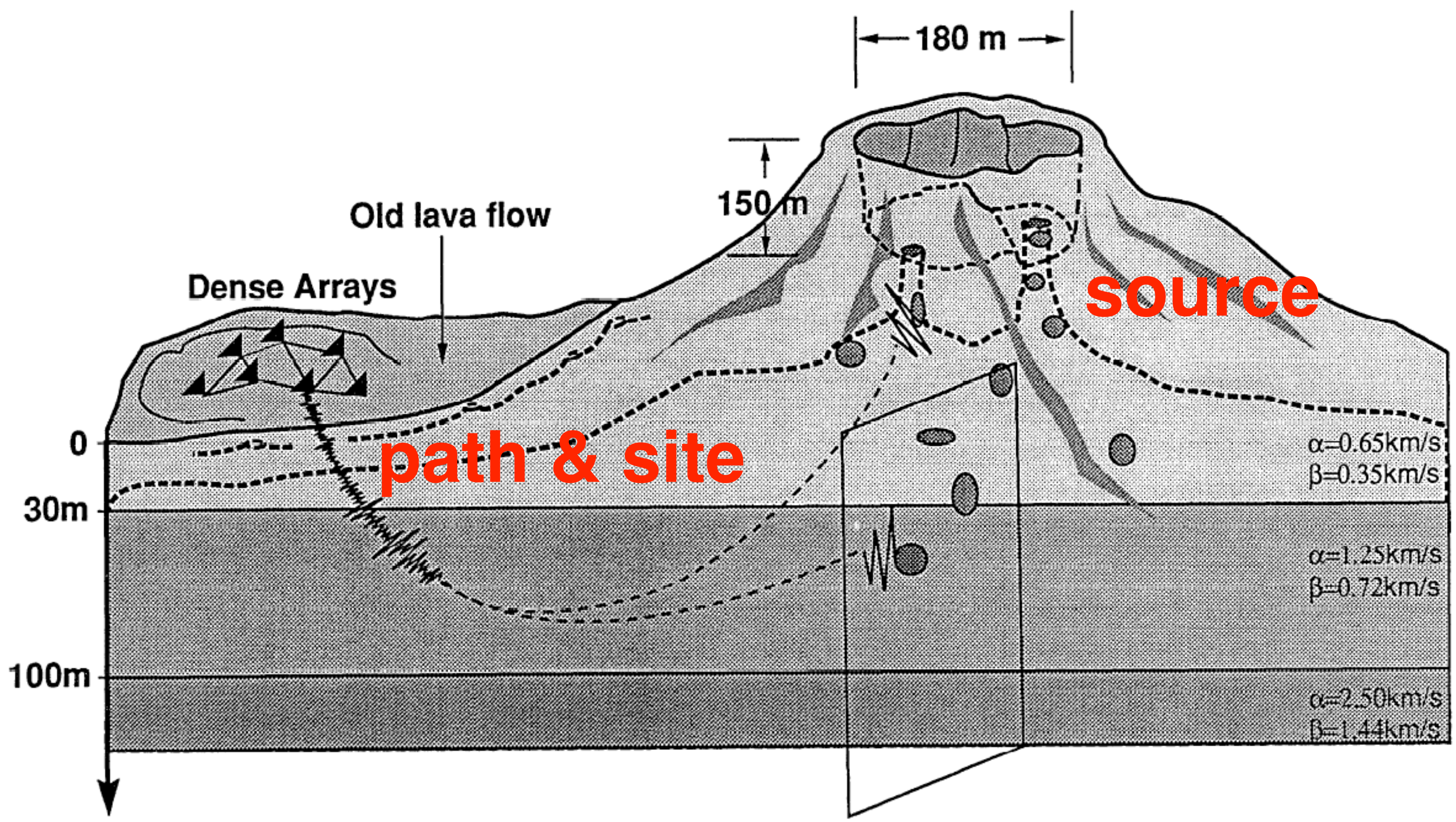
Seismic harmonic tremor: source vs. path effects

seismogram: $w(t) = s(t) * l(t) * g(t)$

excitation/trigger

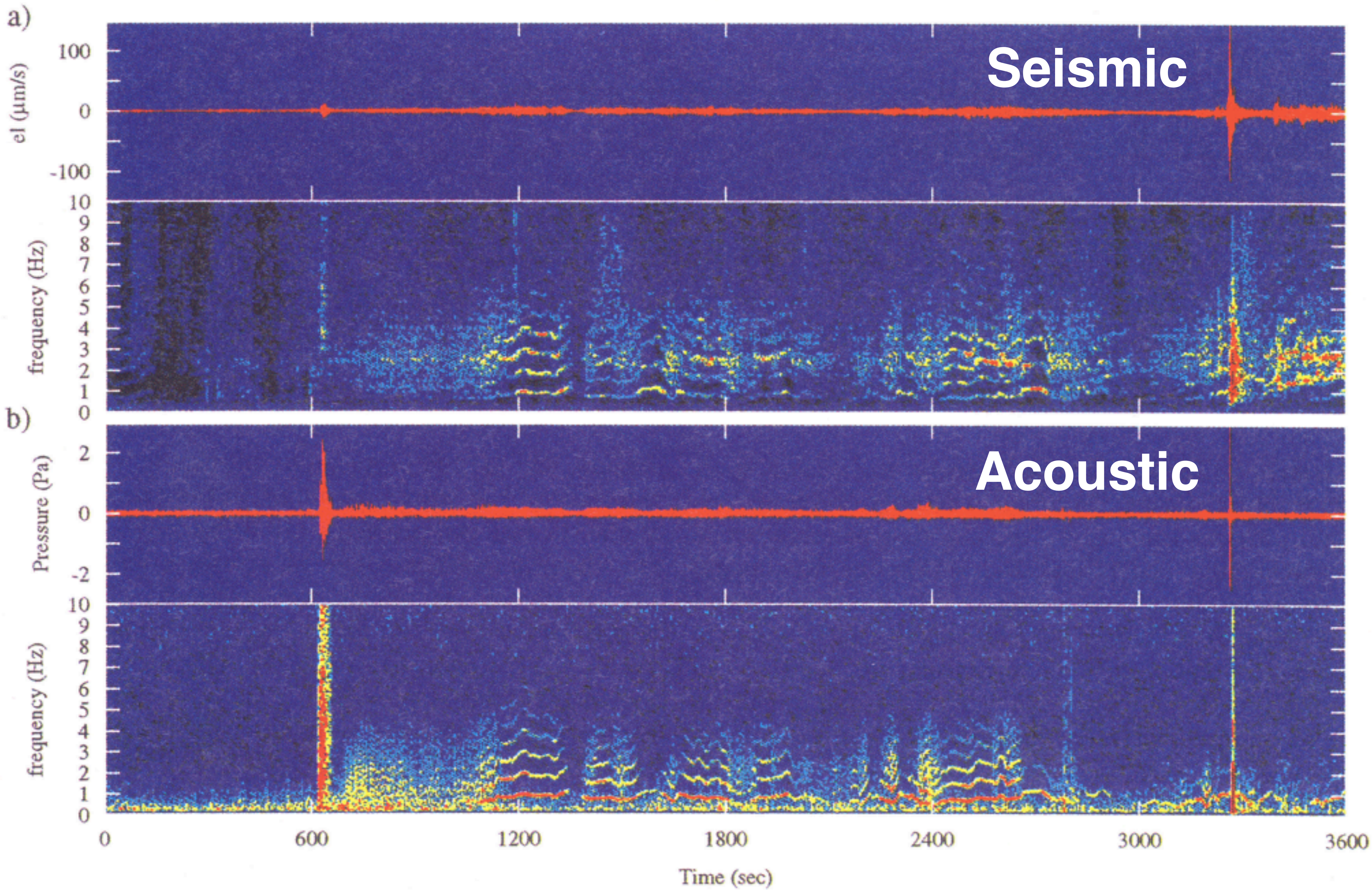
crack/conduit resonance

path & site effects



Goldstein and Chouet [1994]

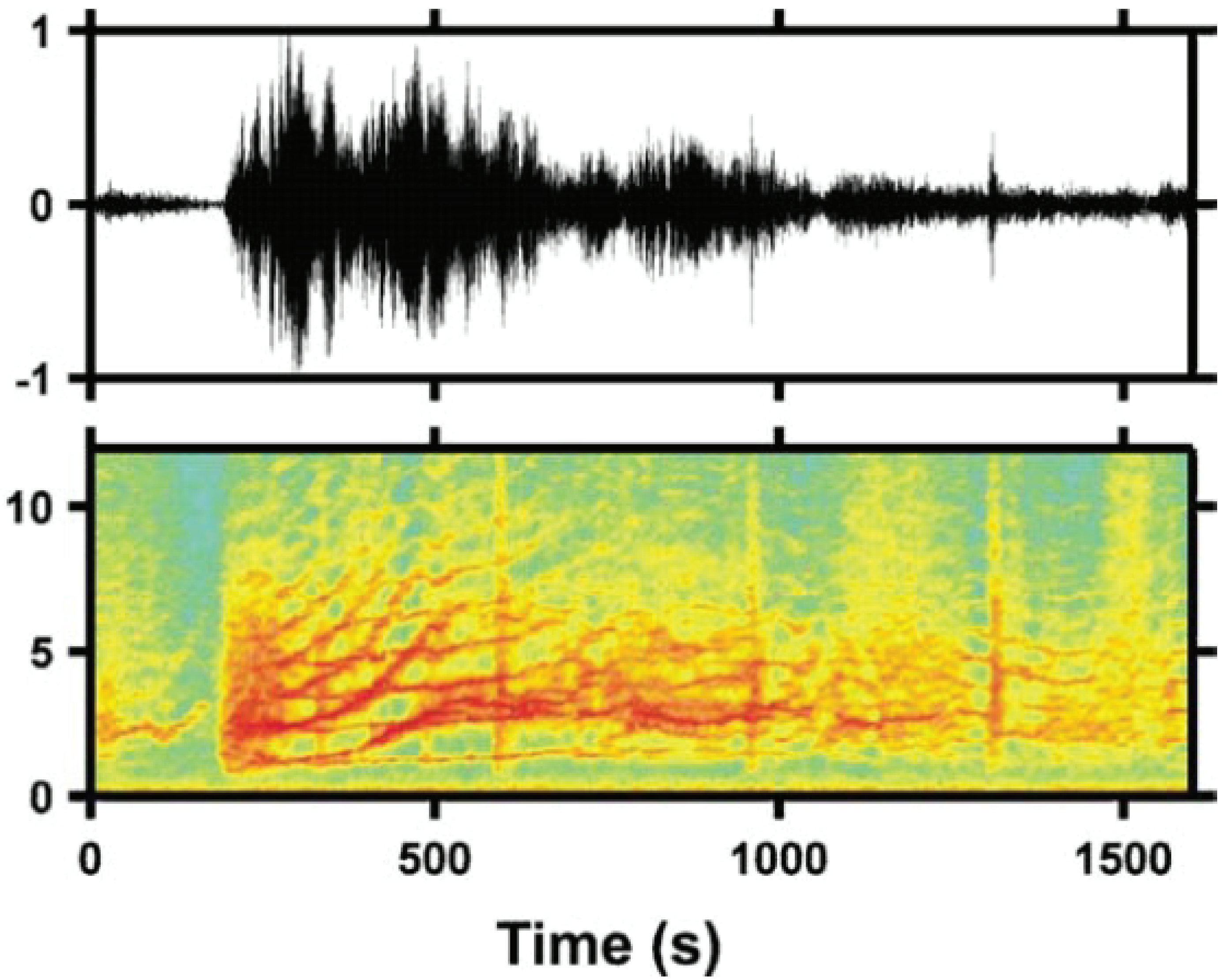
Harmonic & monotonic tremor



Arenal, Costa Rica, Garces et al. [1998]

Harmonic & monotonic tremor

Seismic



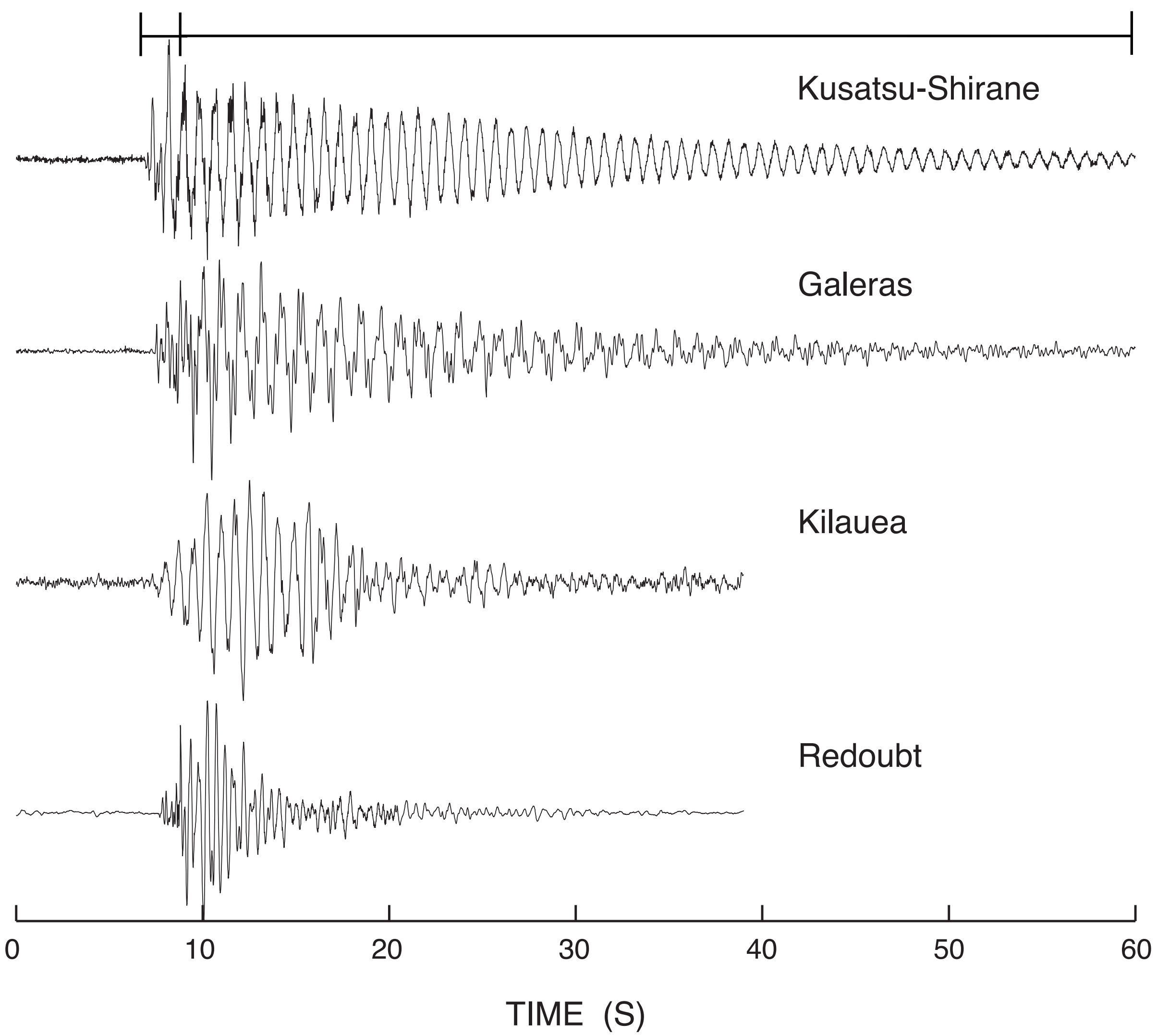
Arenal, Costa Rica, Lesage et al. [2006]

Resonance

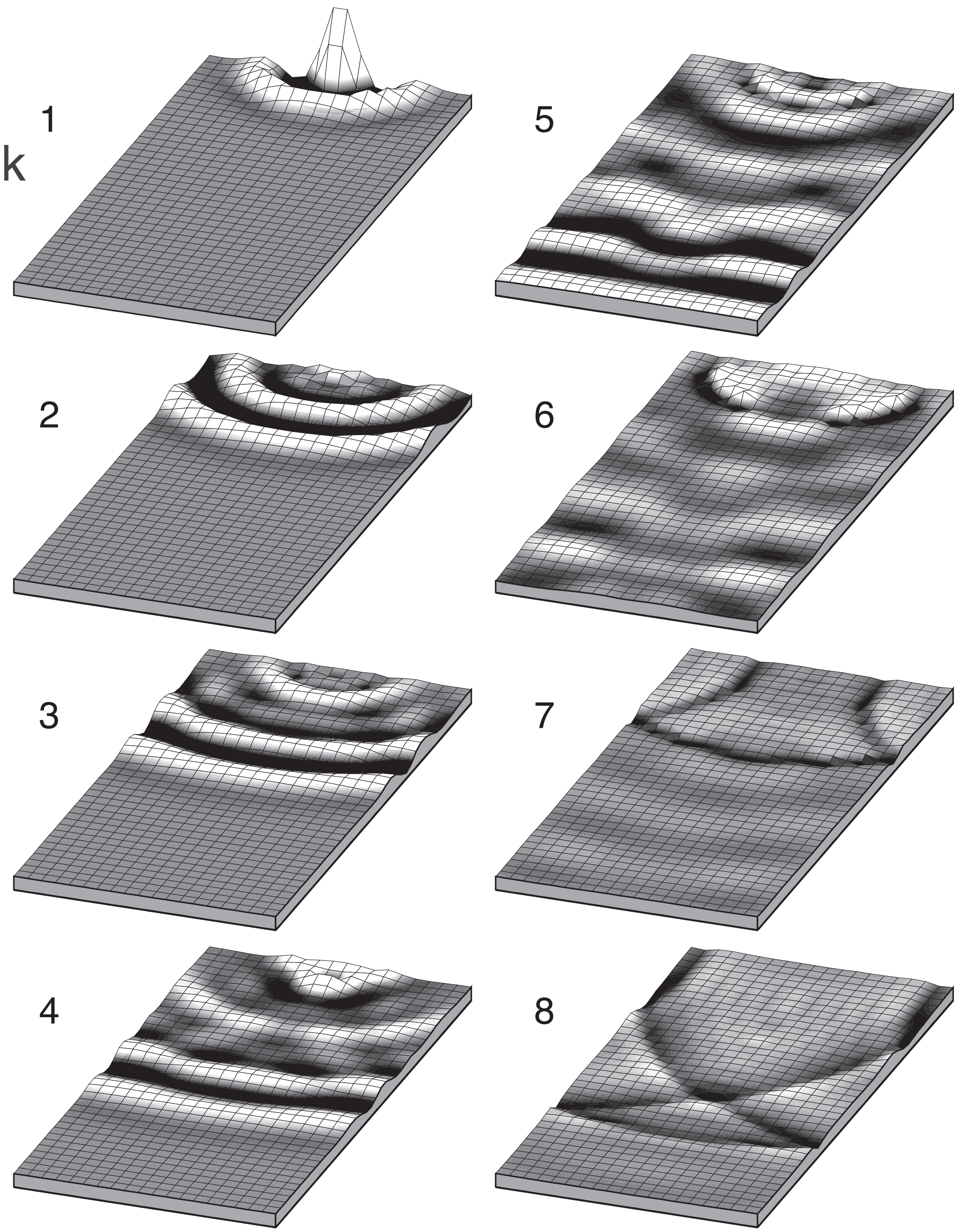
1. Crack waves

Solid-fluid interface waves in fluid-filled crack in an elastic solid

$$s(t) * l(t)$$



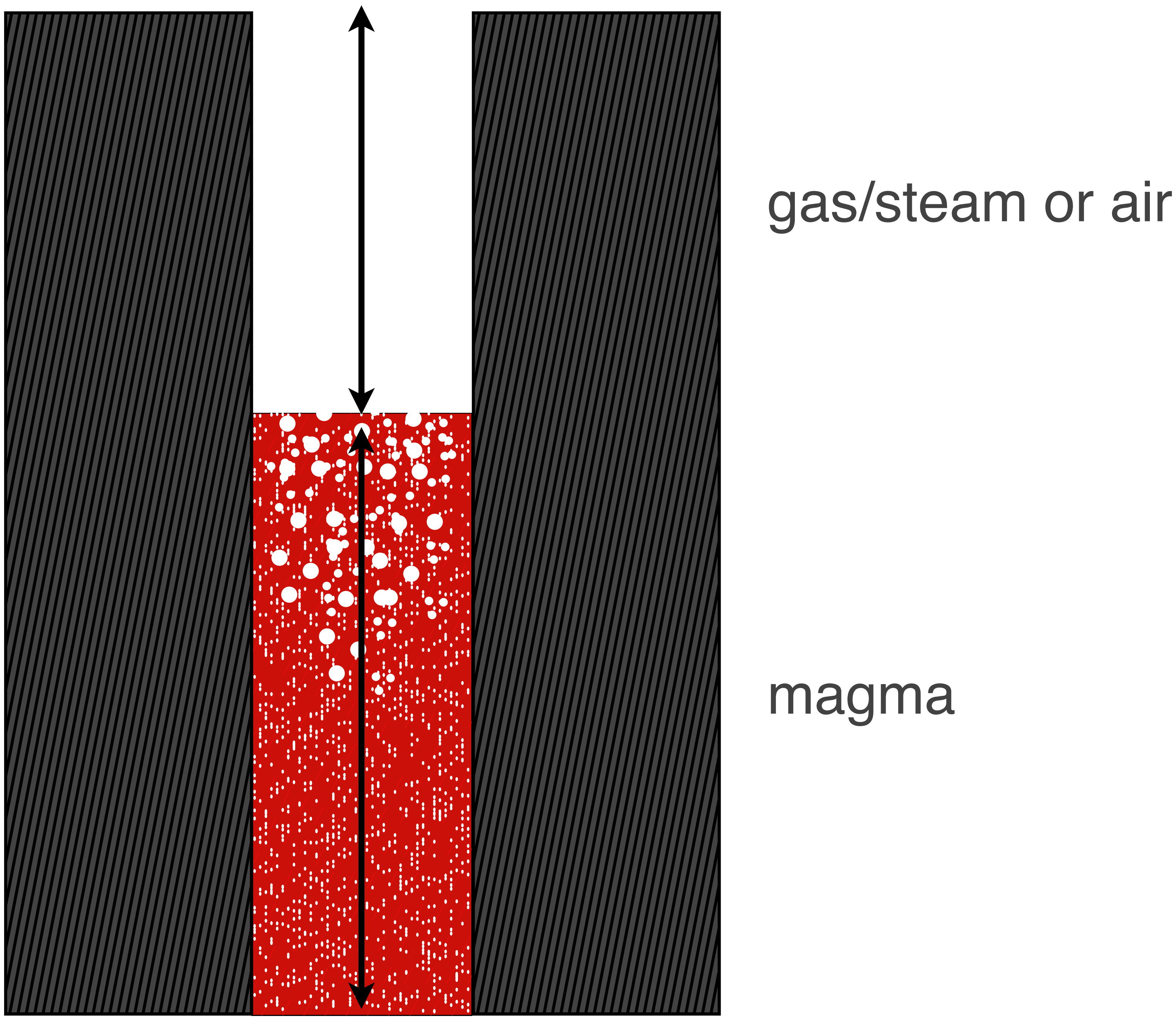
Long-period (LP) seismic events



Chouet and Matoza [2013]

Resonance

2. Conduit resonance

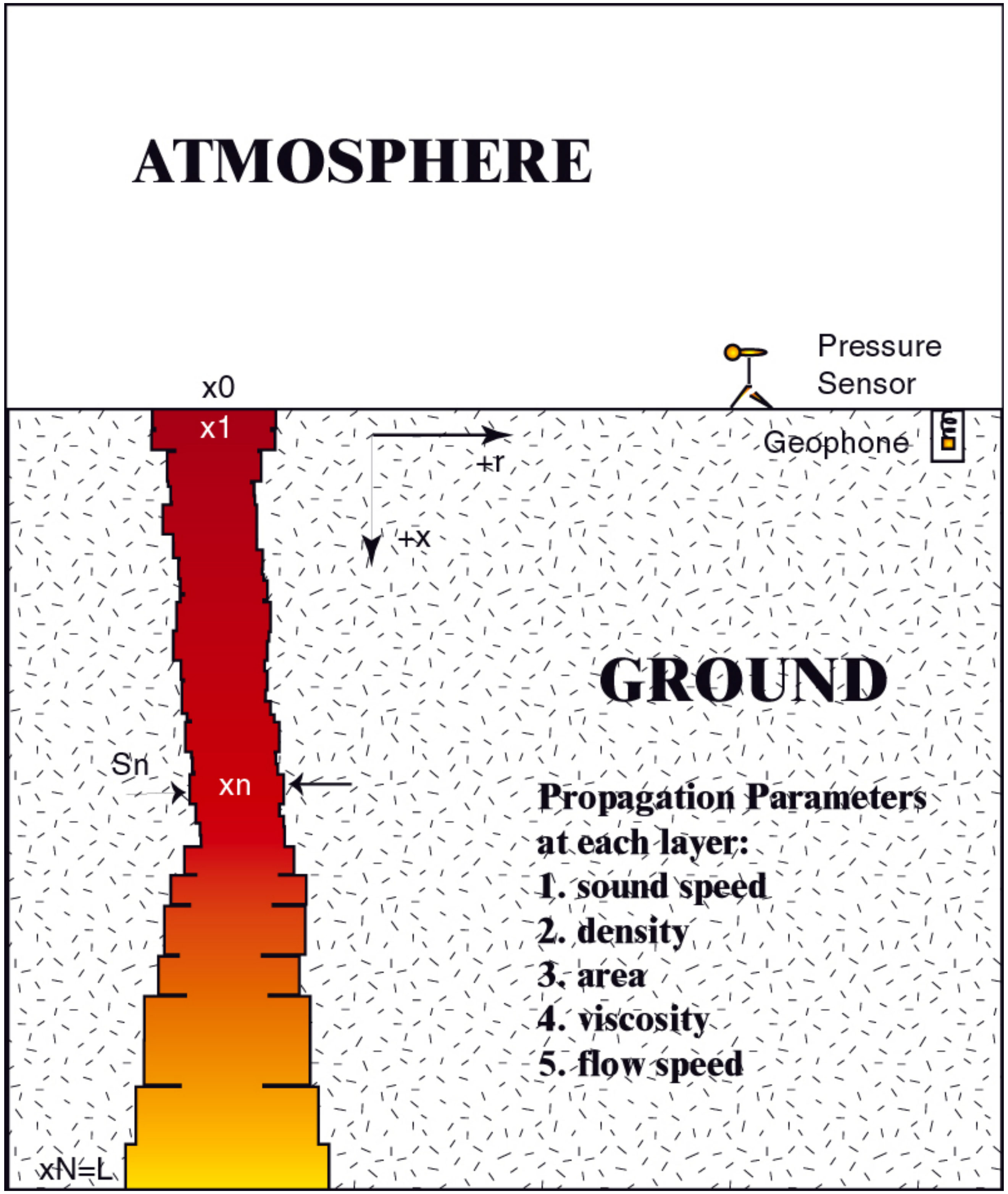


Resonance

2. Conduit resonance

Analytic solution for airborne sound from a resonant magma conduit

From: Buckingham and Garces [1996] to: Garces [2000]



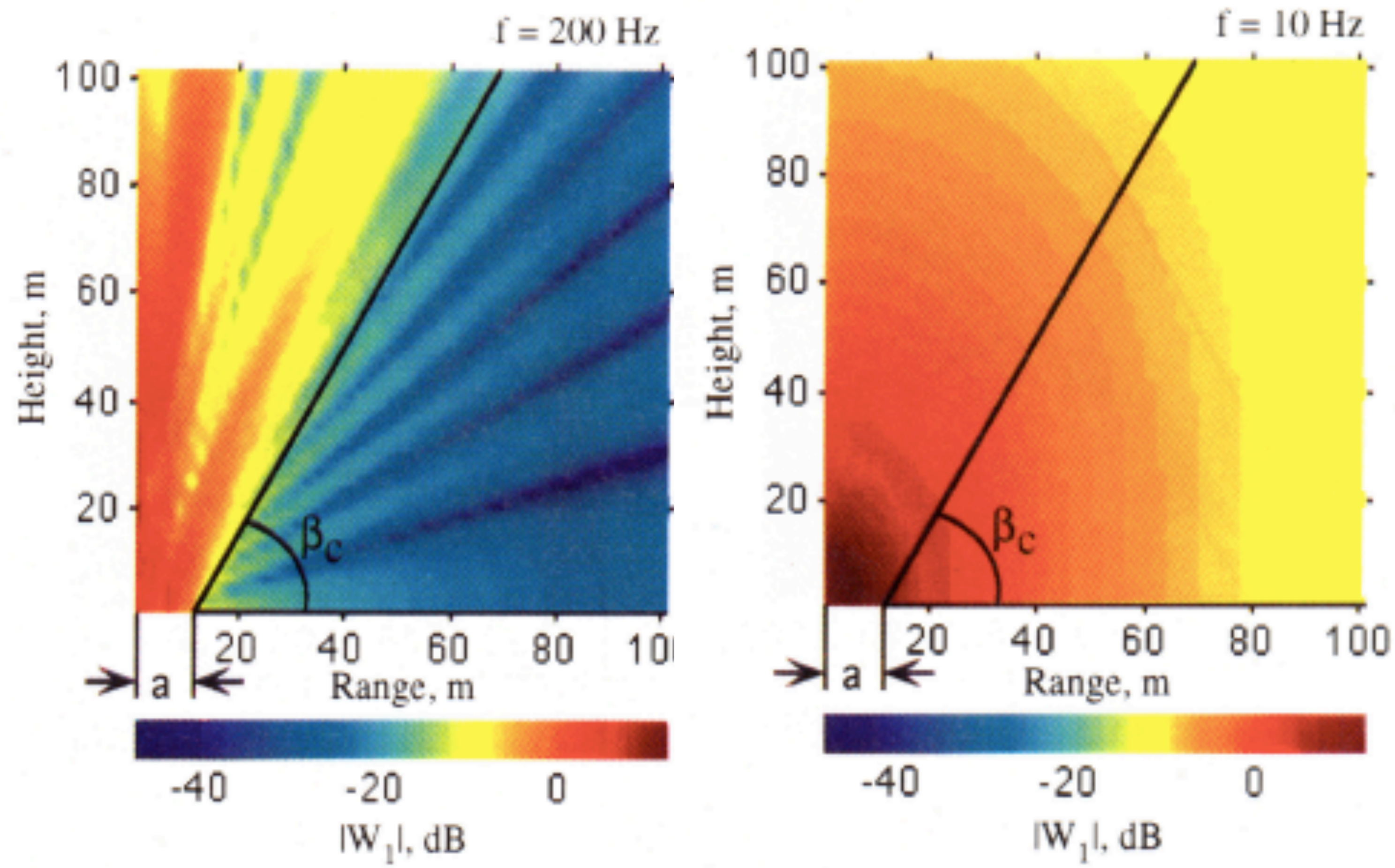
Garces [2000]

Resonance

2. Conduit resonance

Key question #1: how does sound couple from the magma conduit into the air?

1. Diaphragm-like motion of the magma surface [Buckingham and Garces [1995]



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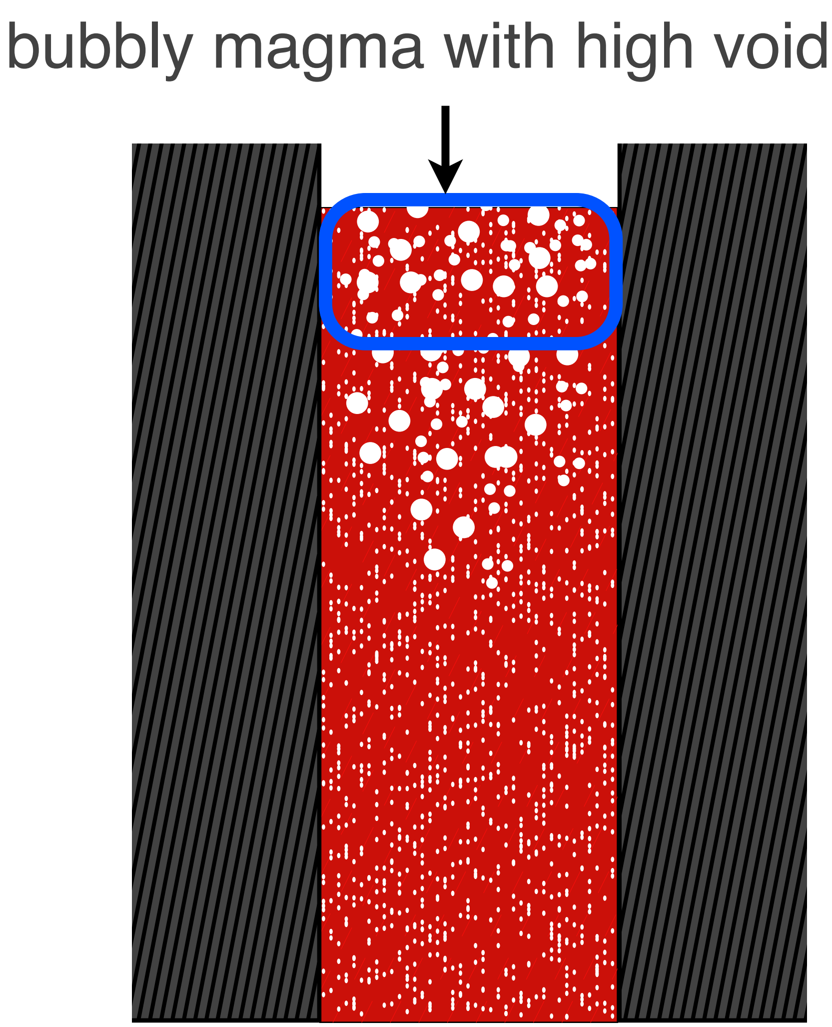

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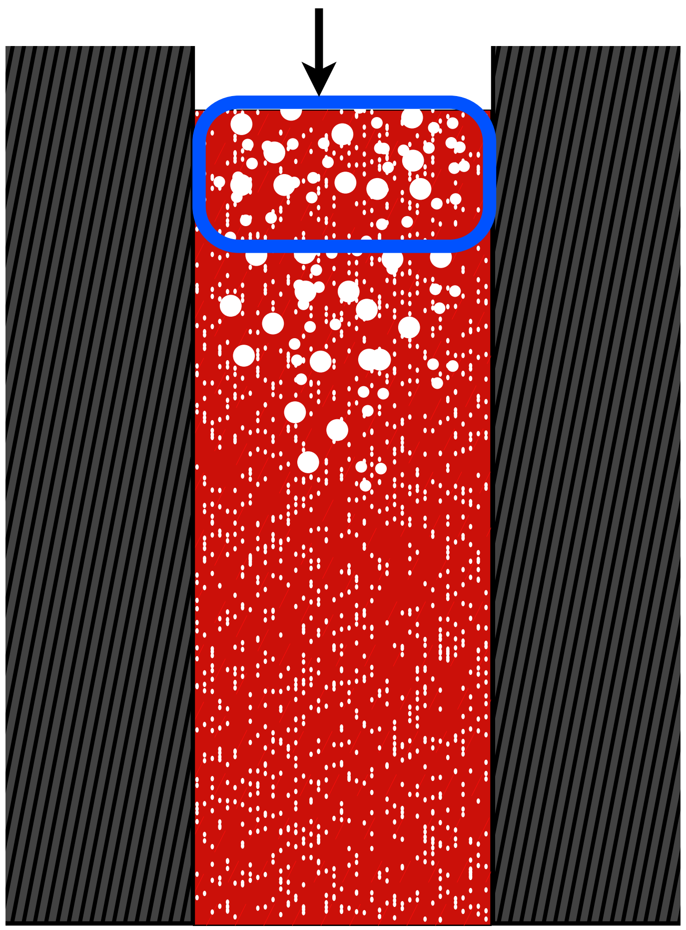

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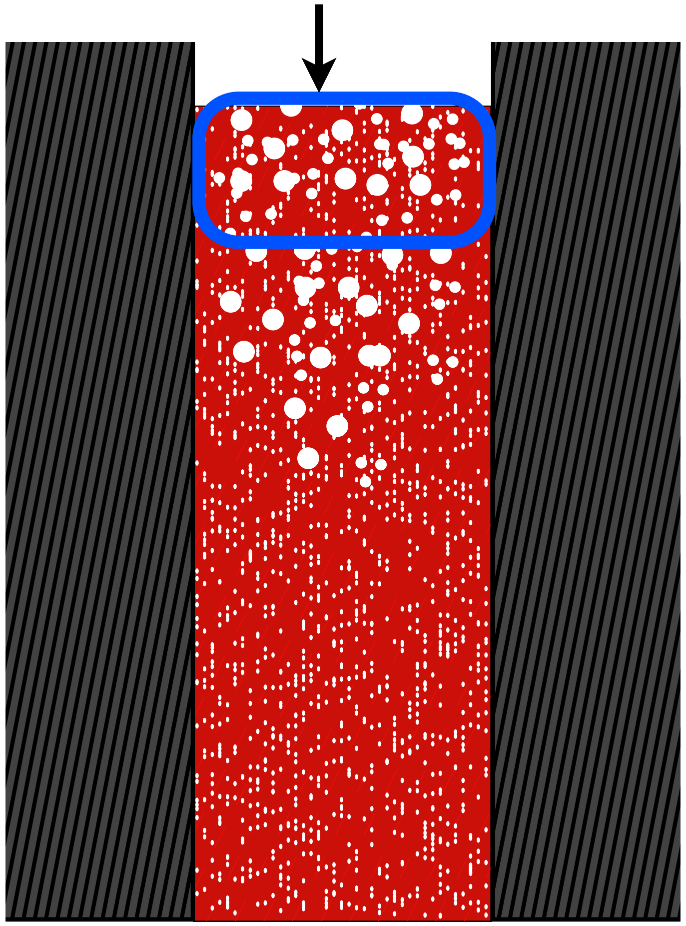
4. “Anomalous transparency” of the magma-air interface at infrasonic frequencies [Matoza et al., 2010, Godin 2006, 2007]

bubbly magma with high void fraction



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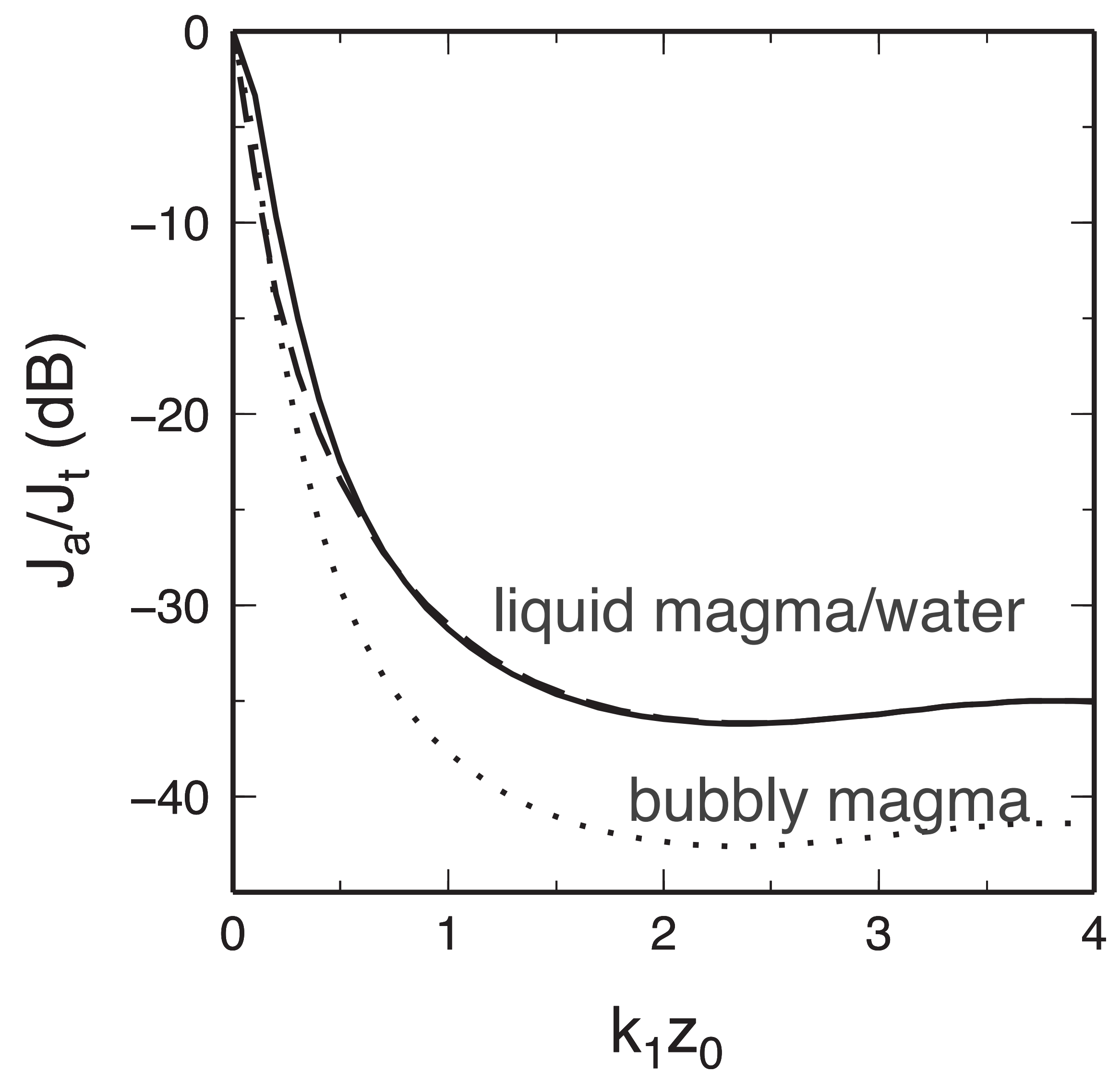


Upper few tens of meters couple well into atmosphere

Matoza et al. [2010]

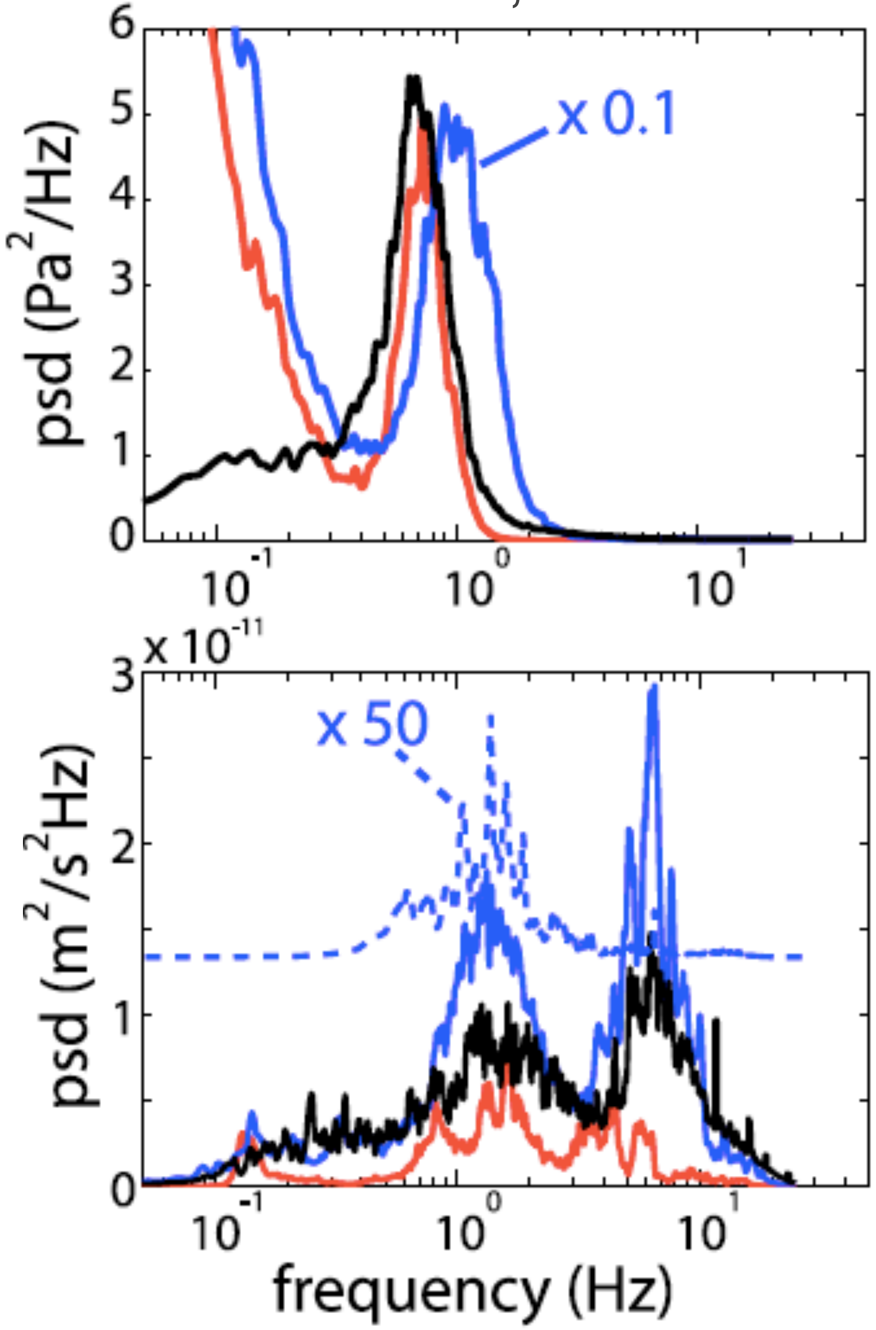
Resonance

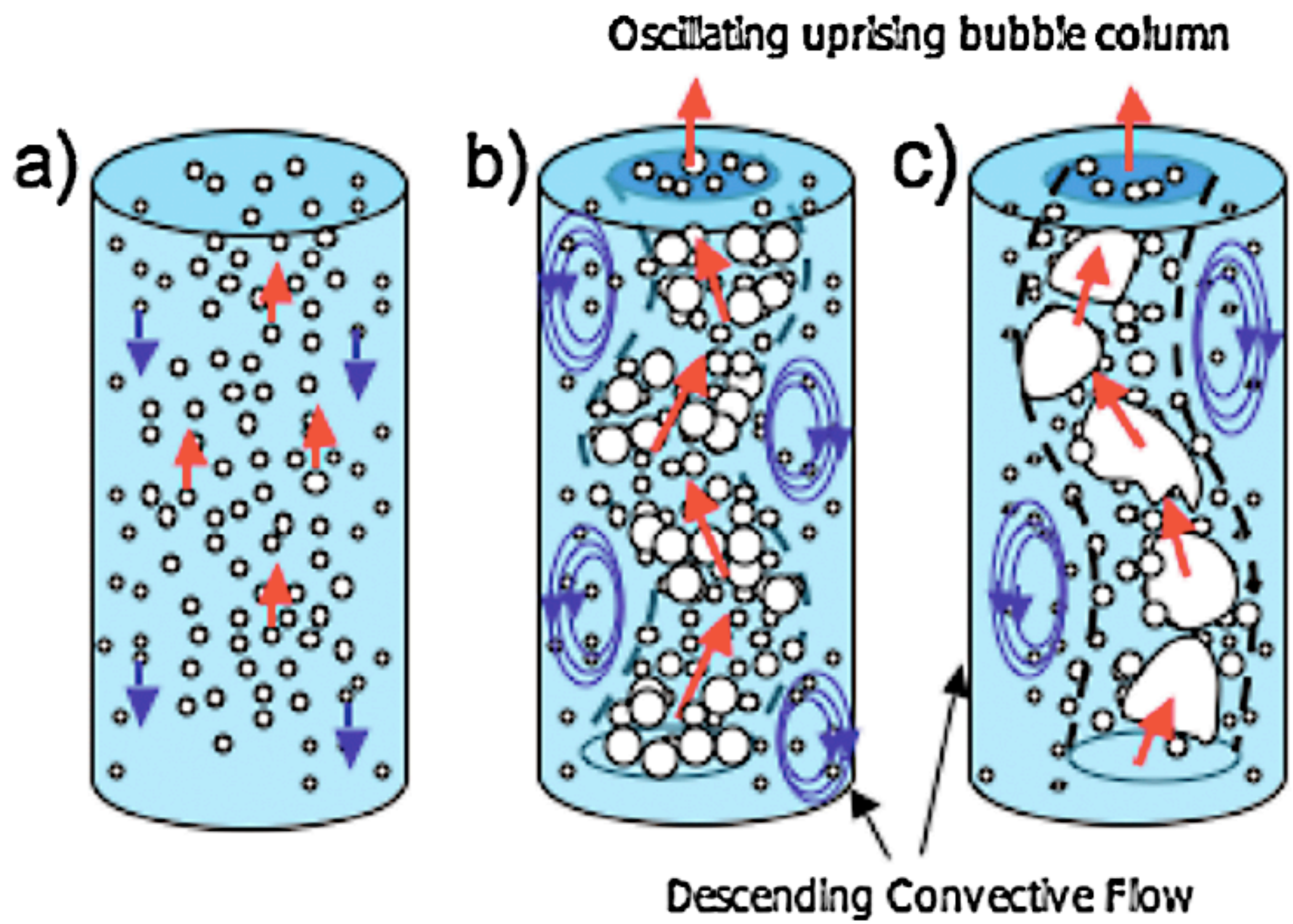
2. Conduit resonance

Key question #2: what drives the oscillation?

1. Bubble cloud oscillation [Chouet, 1996; Matoza et al. 2010]
2. Density-driven oscillations of the bubble column [Ripepe et al. 2010]

Villarrica, Chile

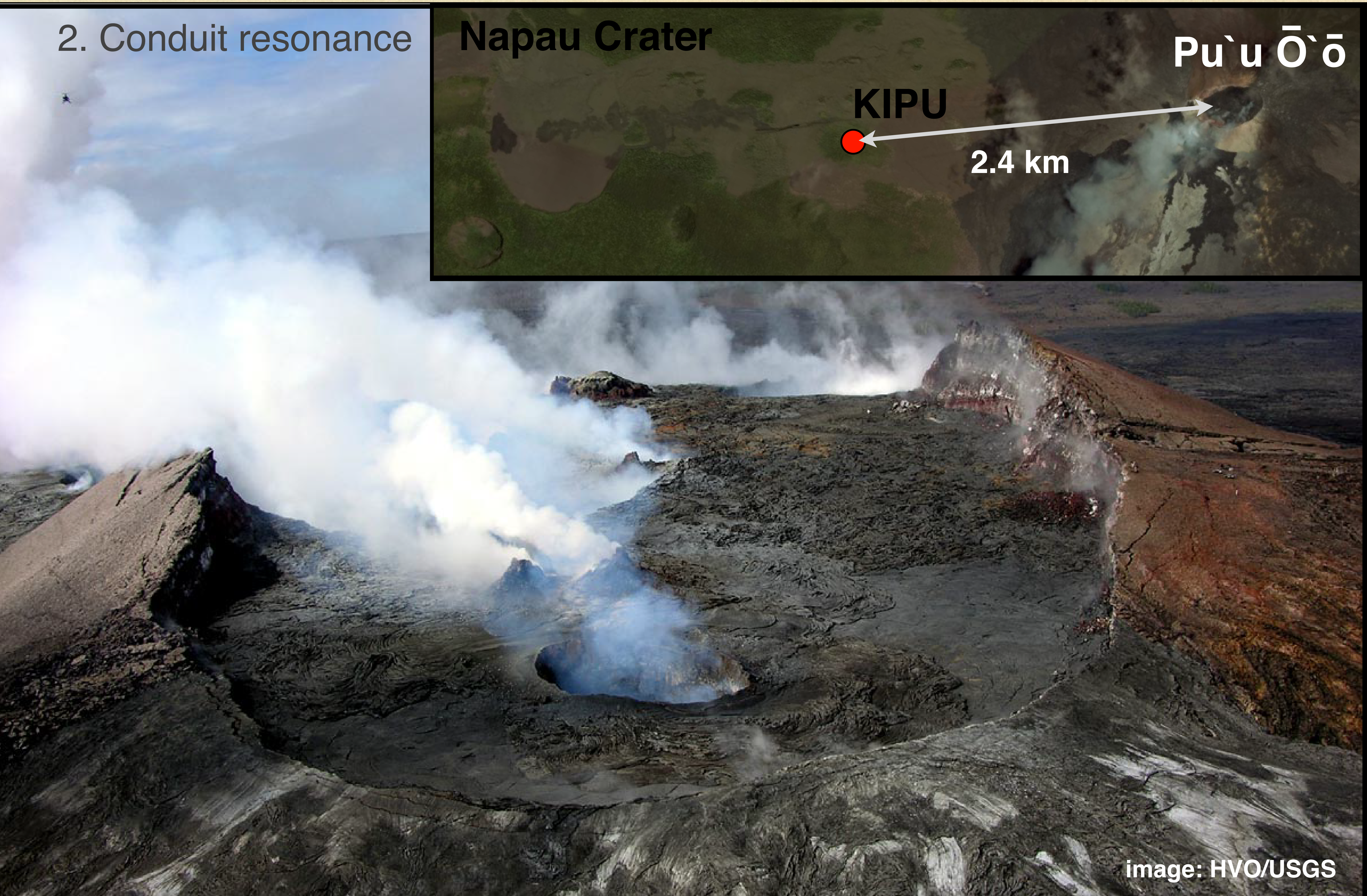




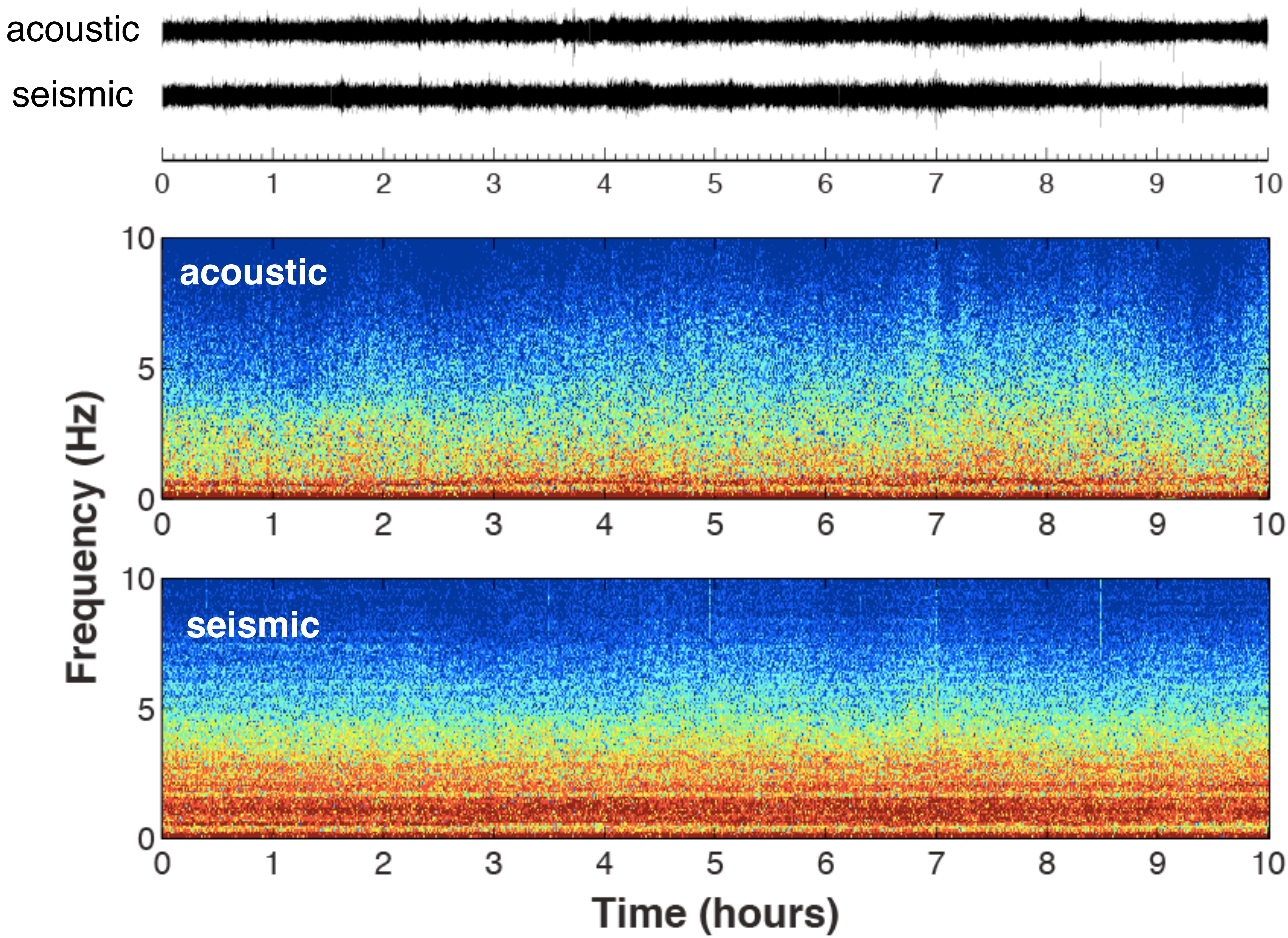
Ripepe et al. [2010] after Mudde [2005]

Resonance

2. Conduit resonance

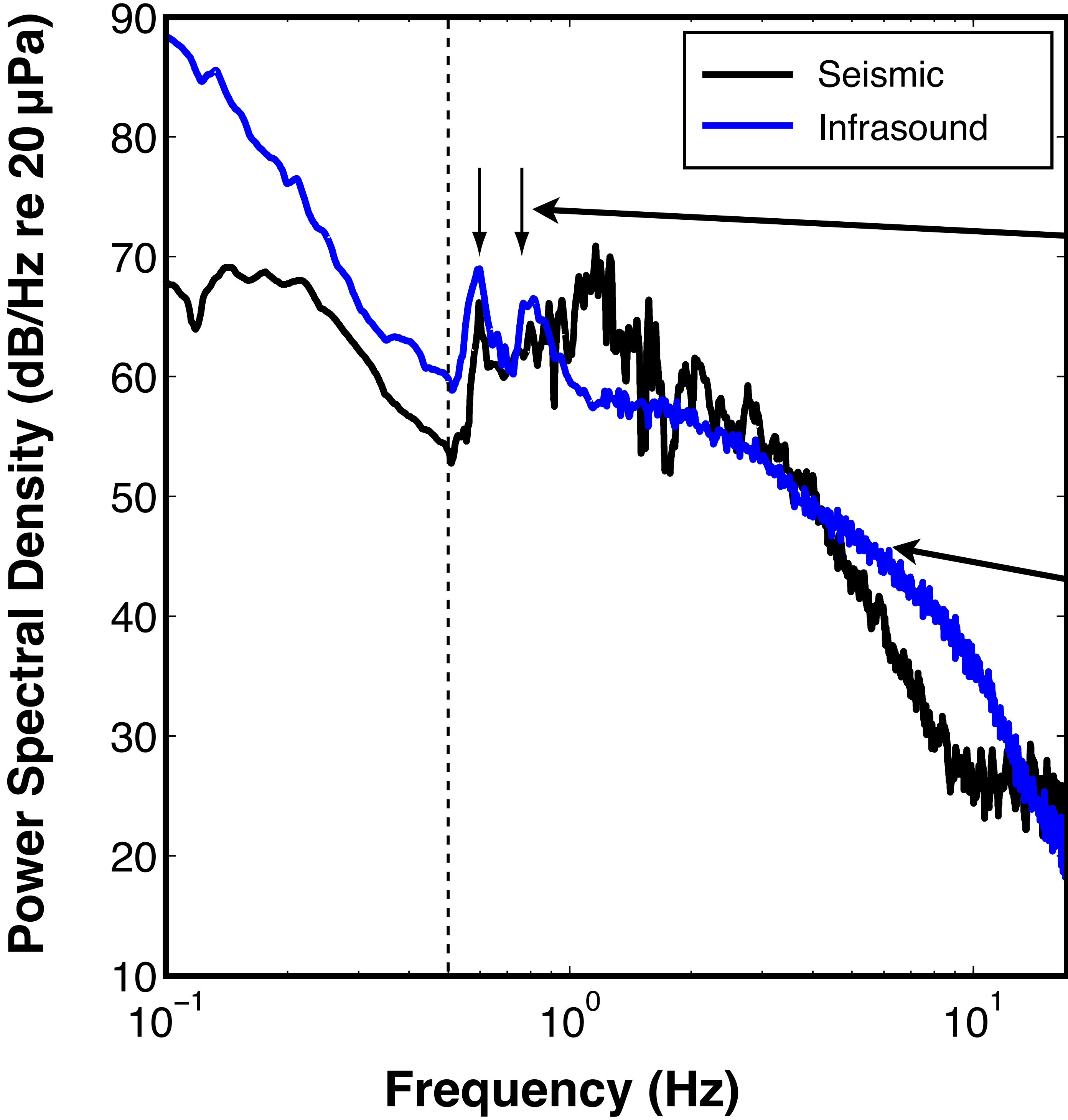


Resonance



acoustic
seismic
0 1 2 3 4 5 6 7 8 9 10
acoustic
seismic
Frequency (Hz)
Time (hours)

Resonance



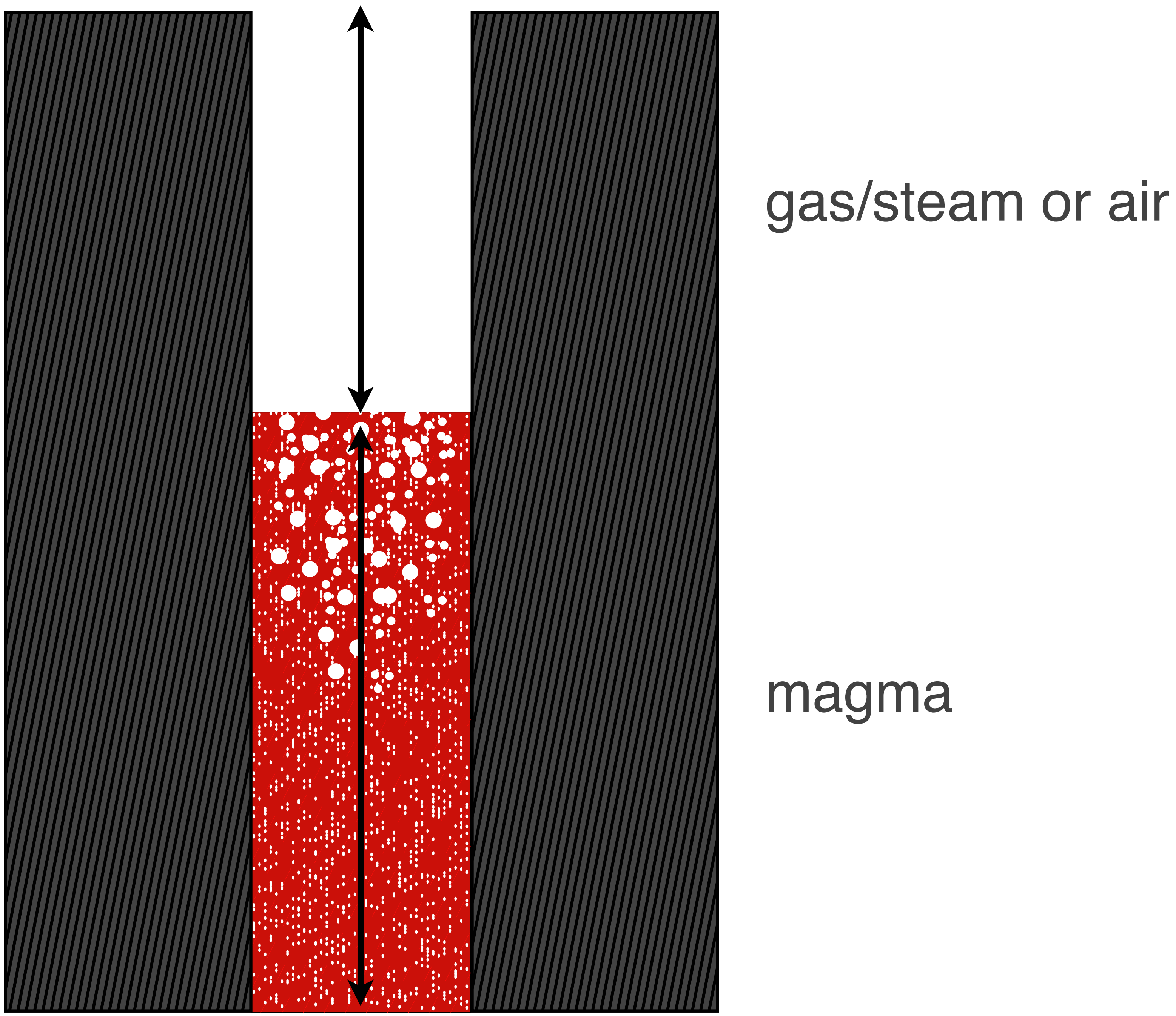
Monotonic/bifurcating signal:
Conduit resonance? Gas flow?

Broadband signal:
Bubble cloud
oscillation?

Matoza et al. [2010]

Resonance

2. Conduit resonance



Resonance

3. Helmholtz resonance of a conduit/cavity

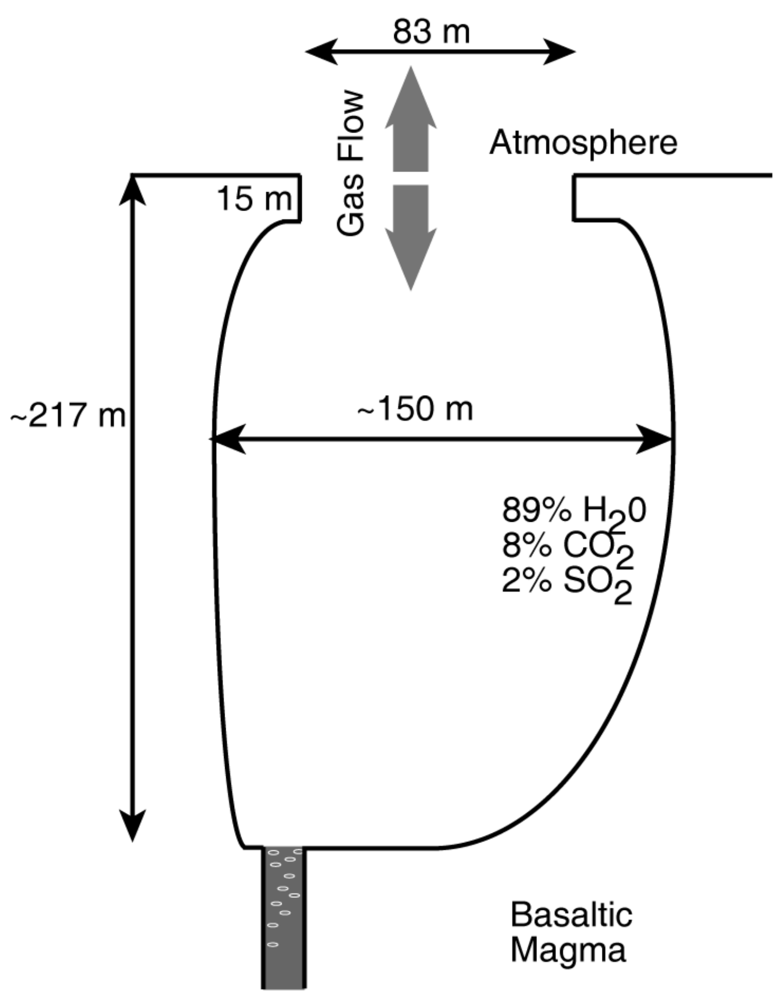
For wavelengths larger than the dimensions of the volume:

$$f_H = \frac{c}{2\pi}\sqrt{\frac{S_a}{L_H V}}$$

S_a ← cross-sectional area of neck

L_H: effective neck length

V: cavity volume

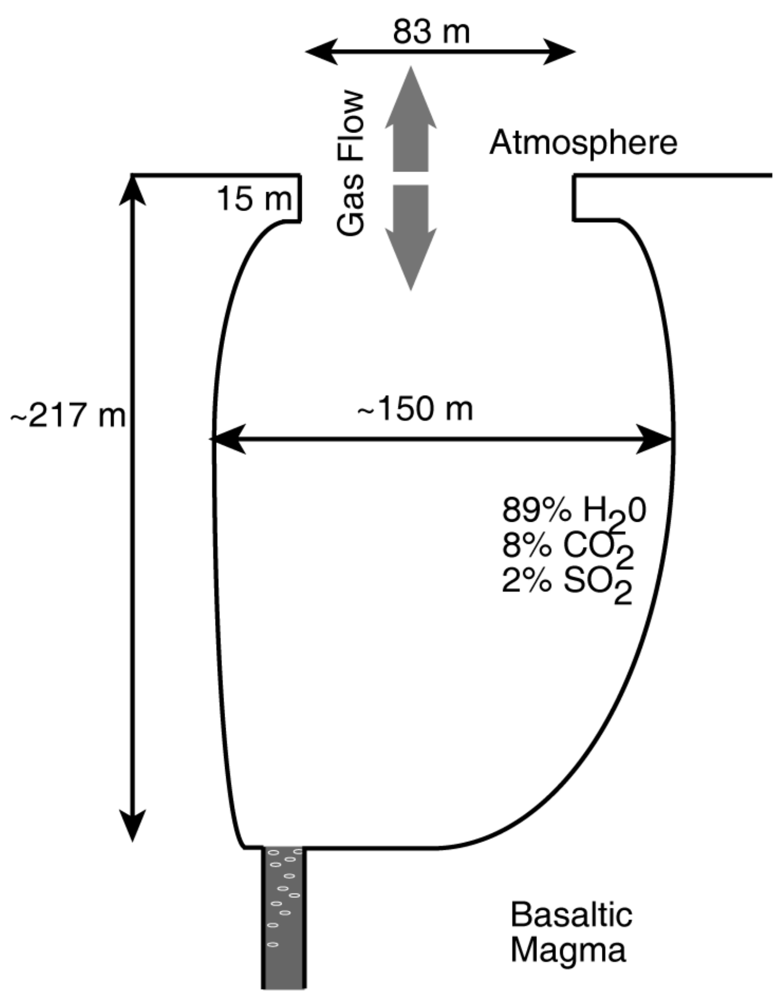


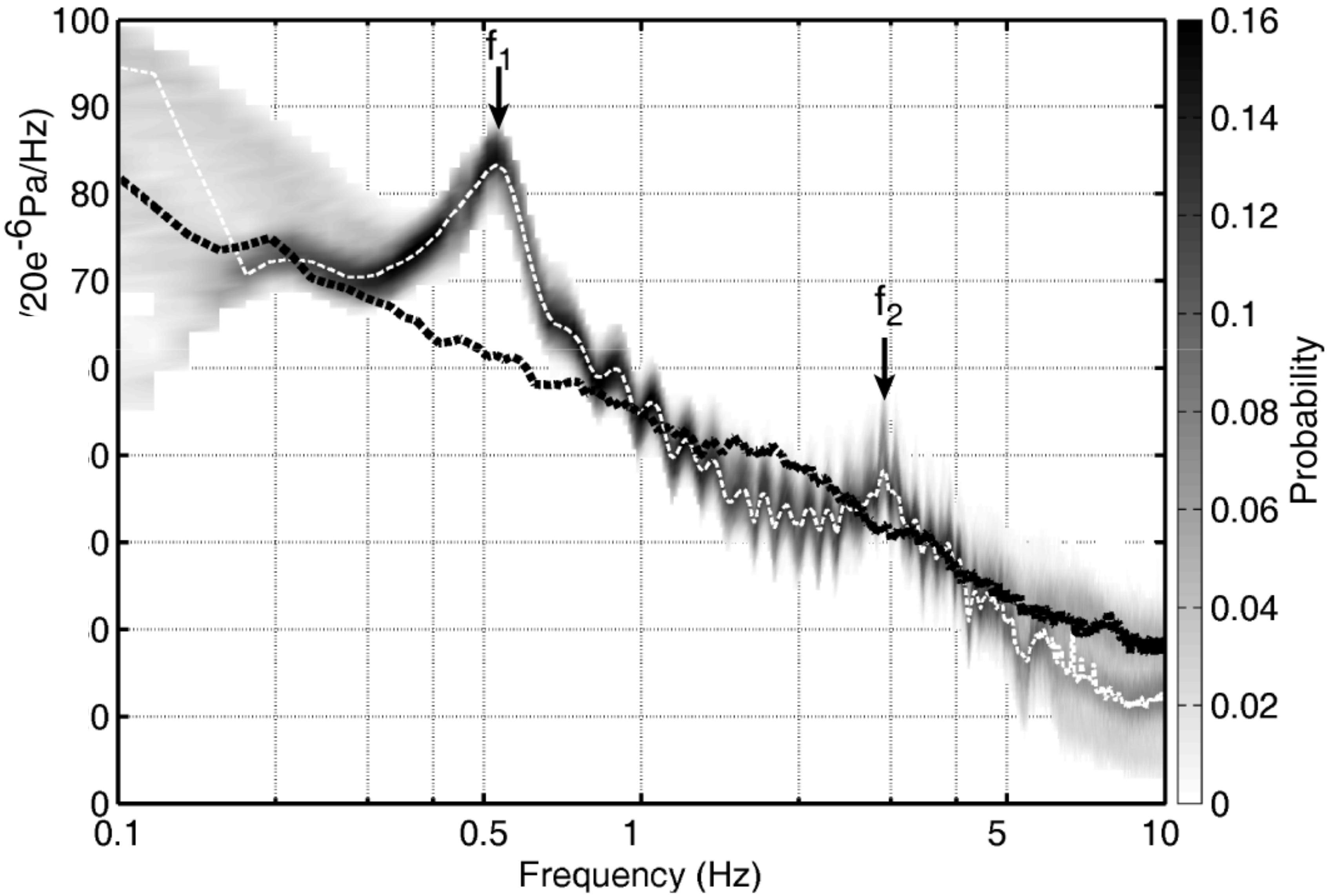
Fee et al. [2010]

Resonance

3. Helmholtz resonance of a conduit/cavity

Driving mechanism required!





Fee et al. [2010]

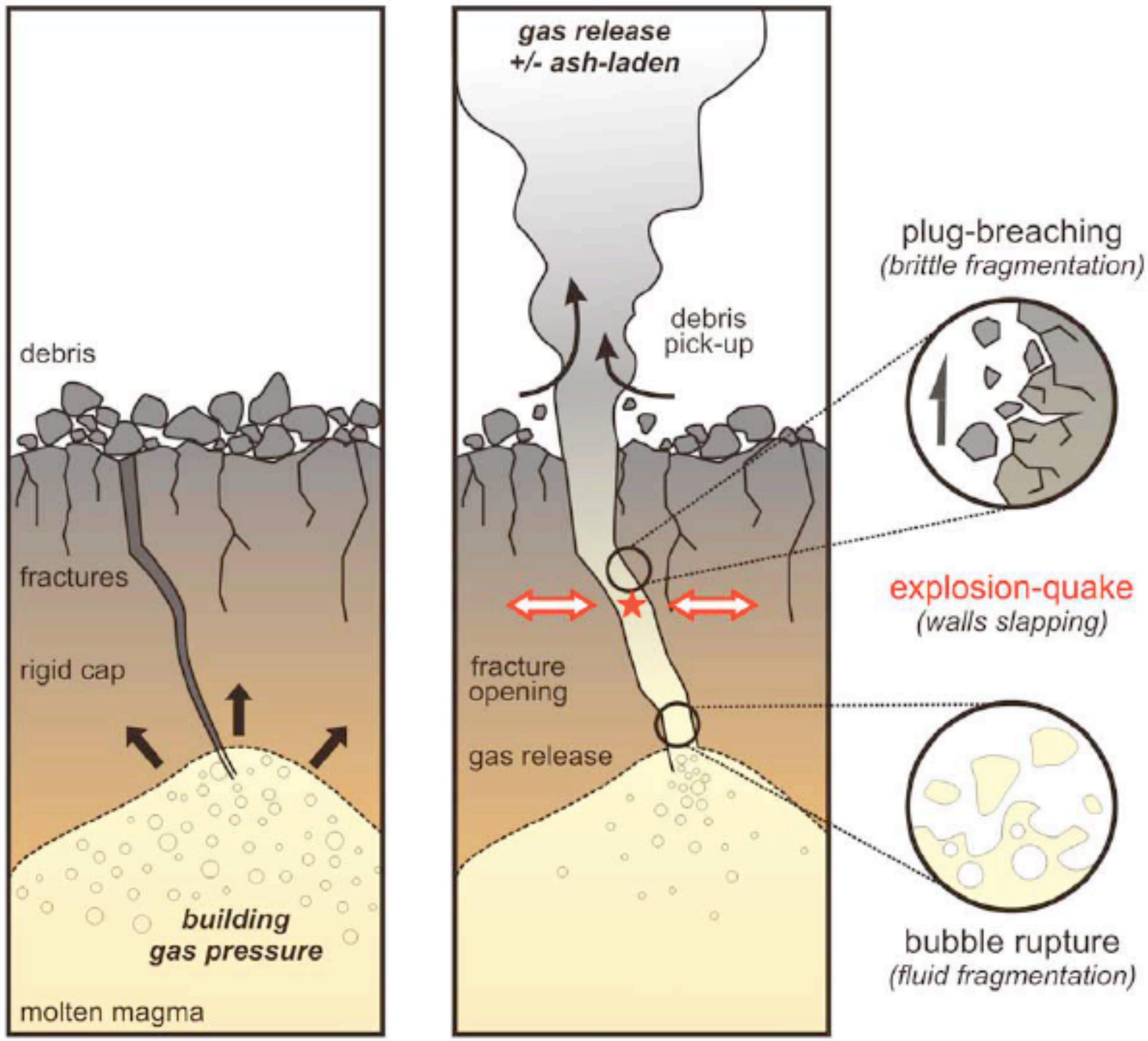
Resonance

4. Degassing through sealed caps

e.g.,
Gil Cruz and Chouet [1997]
Hellweg [2000]
Johnson and Lees [2000]
Lesage et al. [2006]
Valade et al. [2012]

...can be coupled with and controlled by upper conduit/cavity resonance

Hagerty et al. [2000]
Lesage et al. [2006]
Matoza et al. [2010]



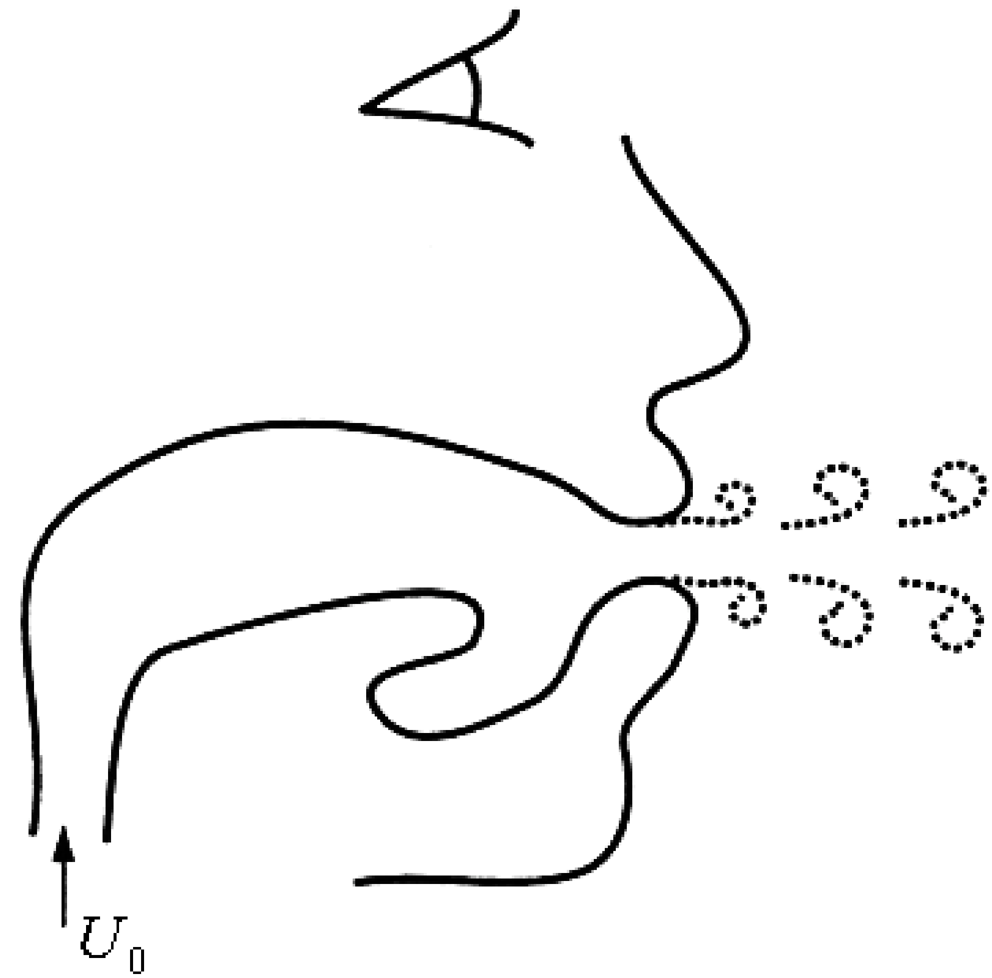
Valade et al. [2012]

Resonance

5. Degassing through sealed caps and/or vent

1. Discrete acoustic tones from interaction of a shear layer with a solid boundary

2. Family of processes: edge tone, hole tone, air-flow over cavities, whistler nozzle



Matoza et al. [2010]

Resonance

5. Degassing through sealed caps and/or vent

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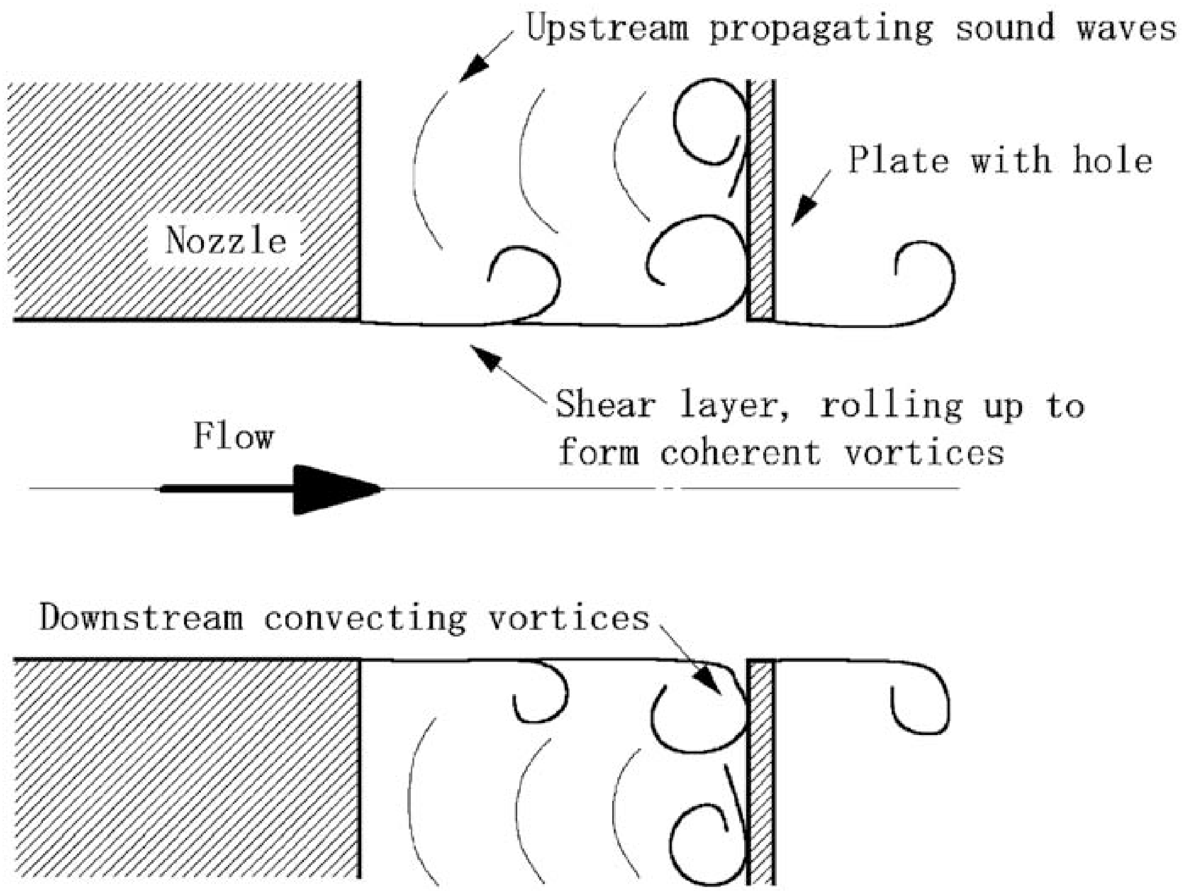
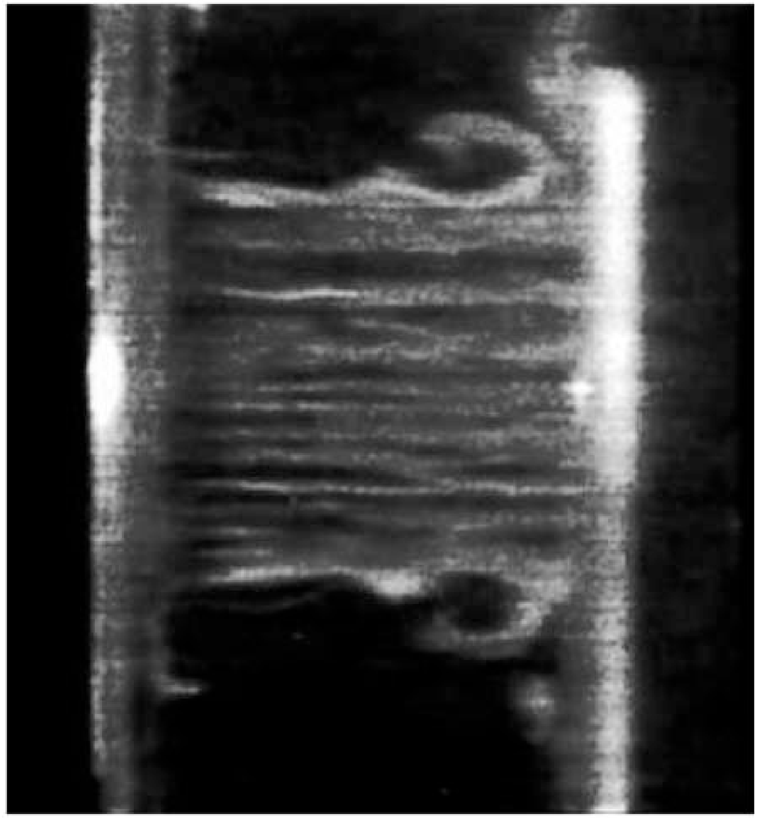
Rossiter modes:

$$f_m = \frac{U}{L} \frac{(m - \gamma)}{(\frac{1}{K} + M)}$$

U mean jet velocity
L length-scale
M mach number

$U_c = KU$
U_c vortex convection velocity





Langthjem and Nakano [2005]

Resonance

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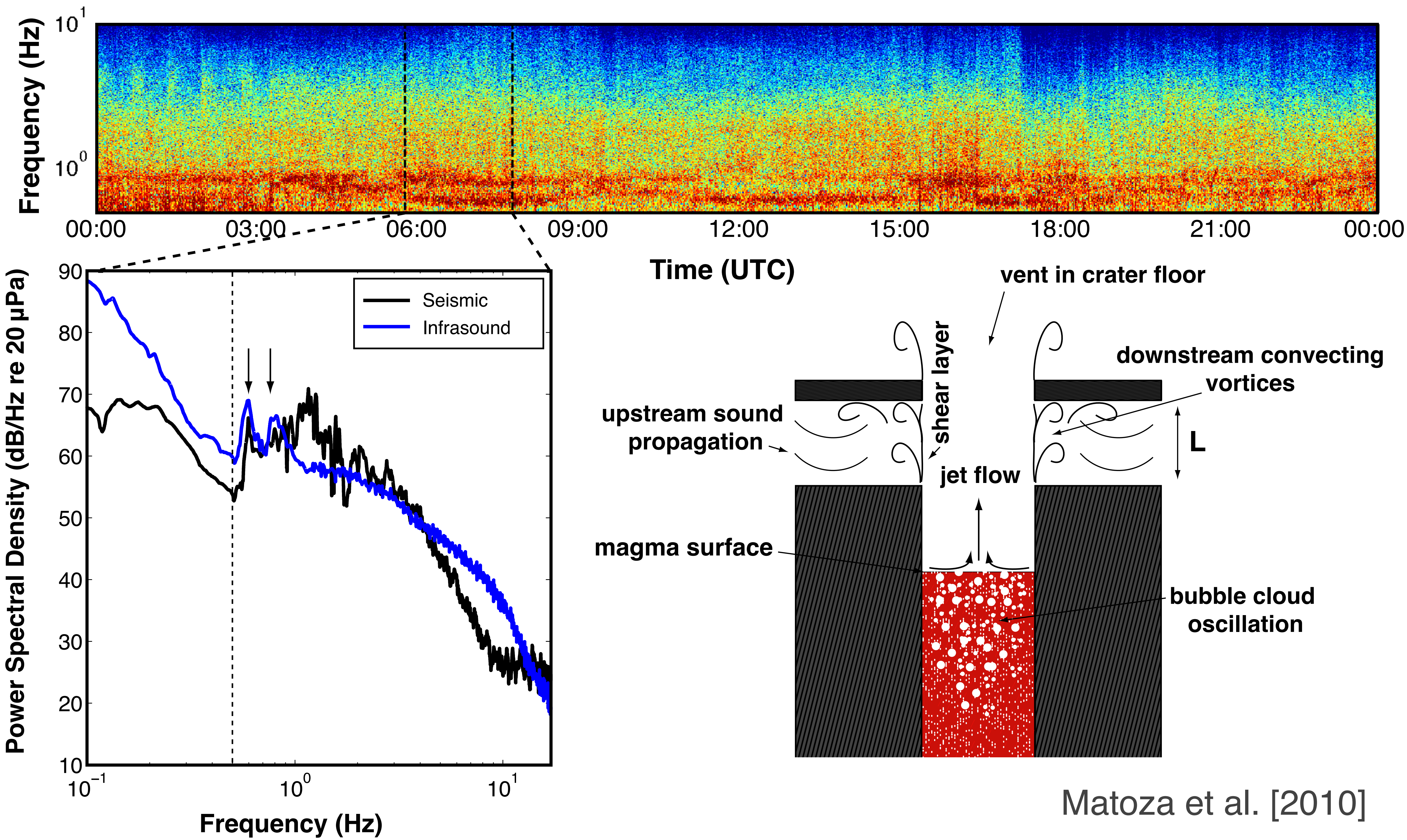

Matoza et al. [2010]

Conclusions

- Tremor is multifarious
- It is a seismo-acoustic process:
    - purely seismic $\longleftrightarrow$ purely acoustic
- Resonance is inevitable in volcanic fluid systems
- But what is resonating?
- What is driving the resonance?
- Coupled interactions between gas flow and resonance