

Triggering of eruptions by earthquakes

Documented for a long time

- Pliny's 1st century AD encyclopedia

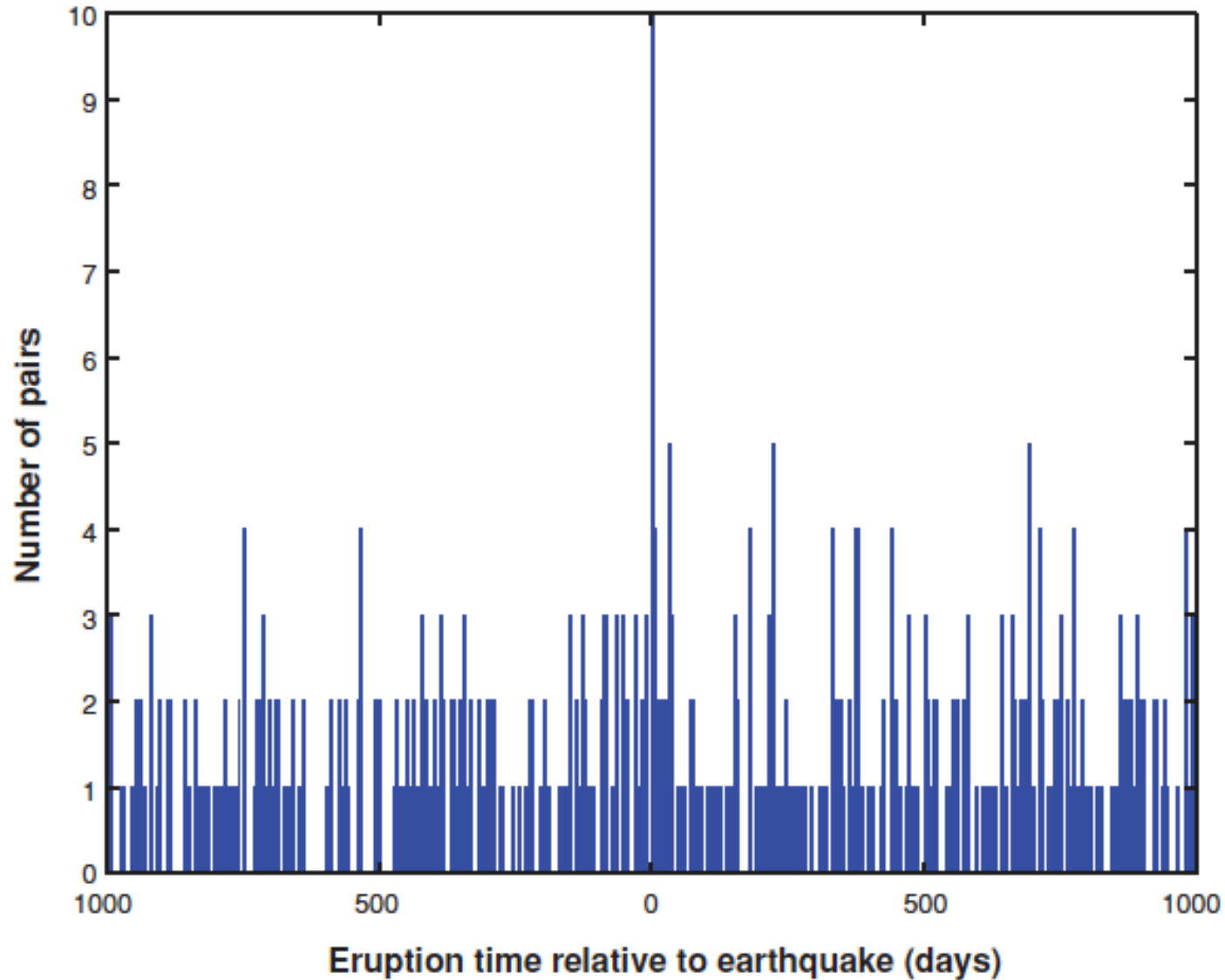
Why?

- Probe some of the processes that initiate eruptions?
- Determine critical thresholds

How to establish?

- Look for space-time correlations between earthquakes and eruptions
- Short-time triggering is easiest to document and establish

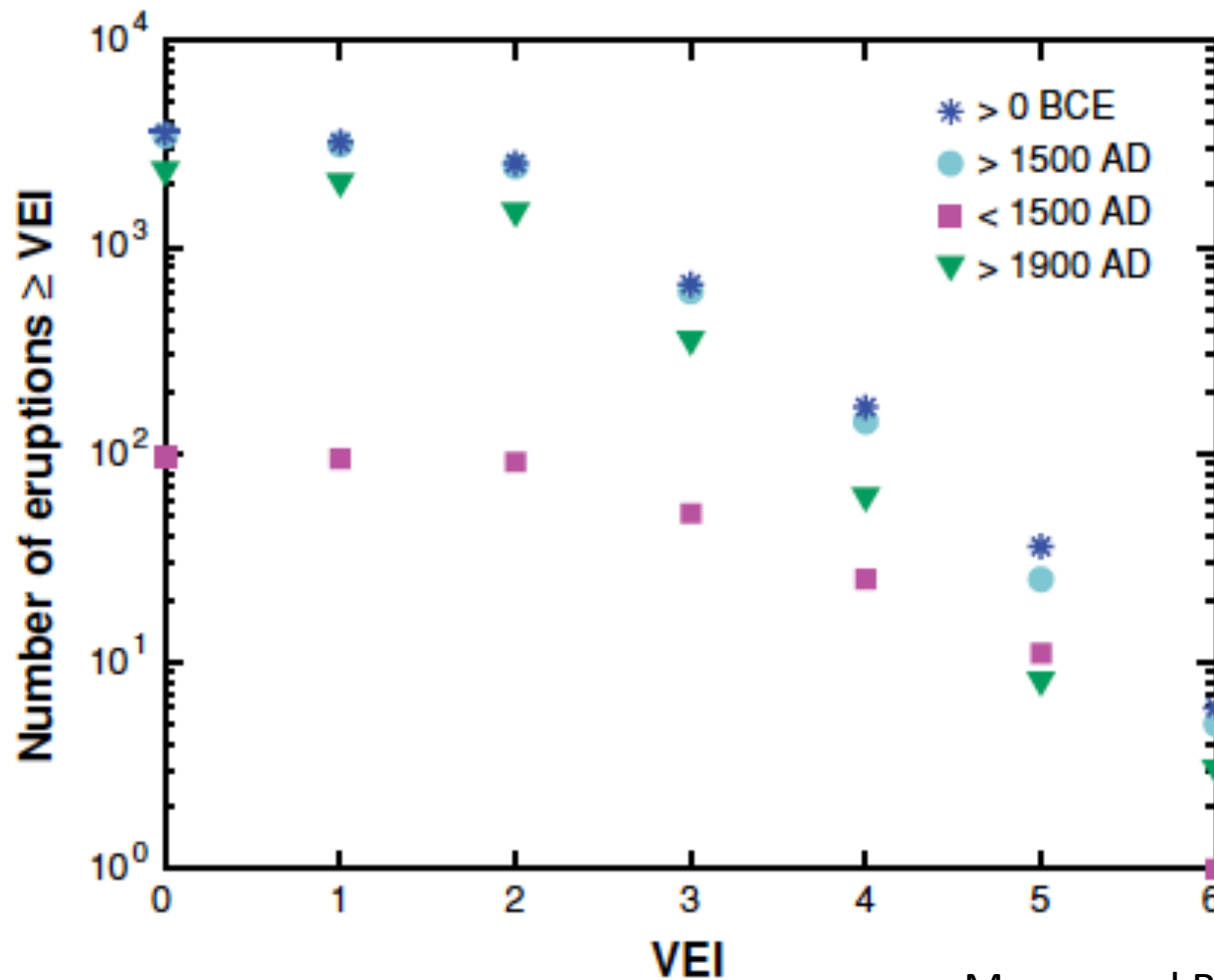
Time between eruptions and earthquakes



Manga and Brodsky, AREPS (2006); see also Linde and Sacks, Nature (1998)

Issues to think about . . .

Completeness of the catalog (earthquakes AND eruptions)



Manga and Brodsky, AREPS (2006)

How many do we expect?

Assuming uniform rate of pressurization, probability of triggering

$$\pi_v = \Delta P_{EQ} / \Delta P_c,$$

Probability of a sufficiently large earthquake

$$\pi_{EQ} = 1 / T_{EQ},$$

Fraction of triggered eruptions

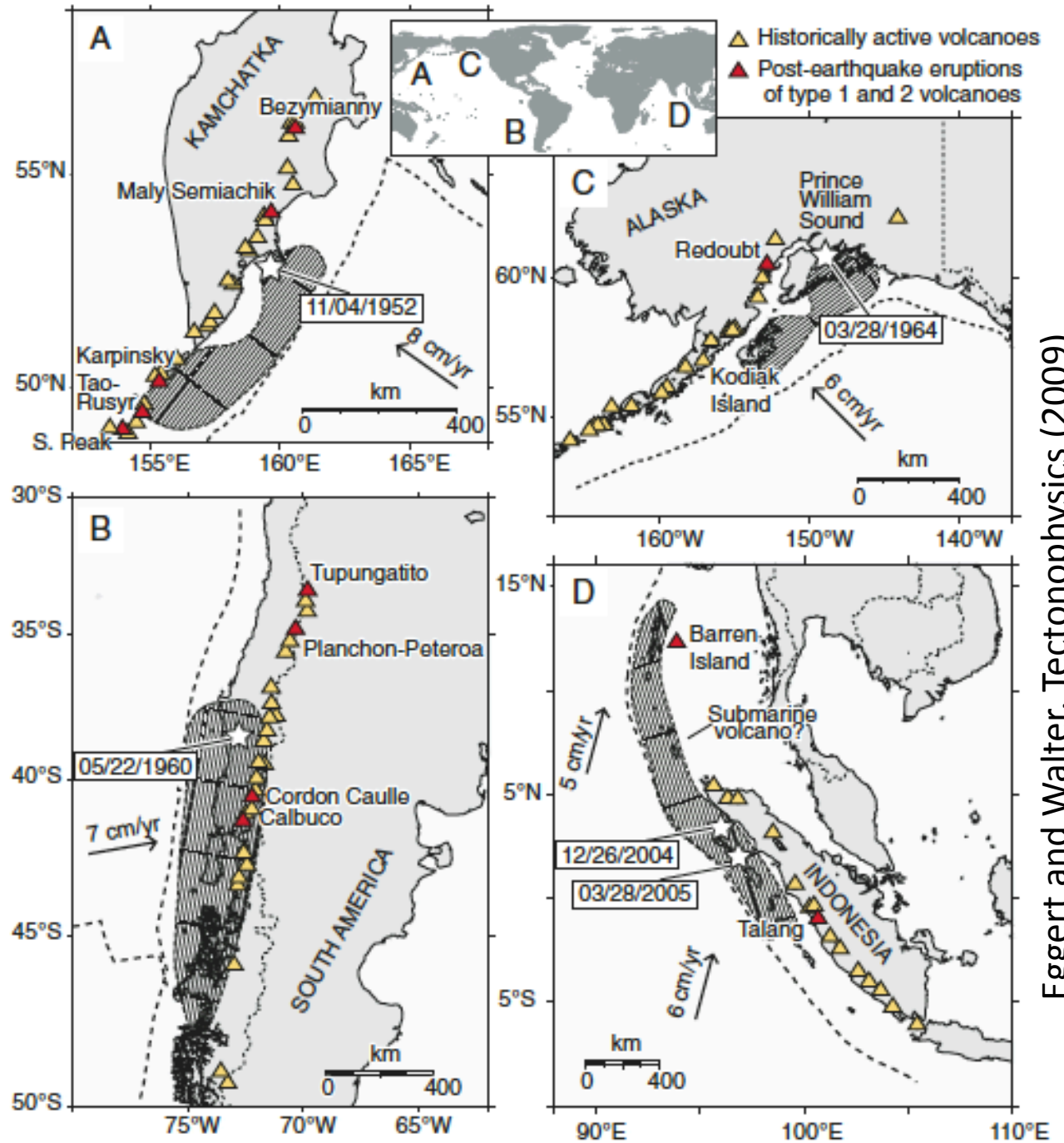
$$X_t = \Delta P_{EQ} T_v / \Delta P_c T_{EQ}.$$

Stress change ~ 0.01 - 0.1 Mpa (critical is ~ 10 Mpa)

Reccurence time $T_v \sim 1$ - 100 years, $T_{EQ} \sim 100$ - 1000 years

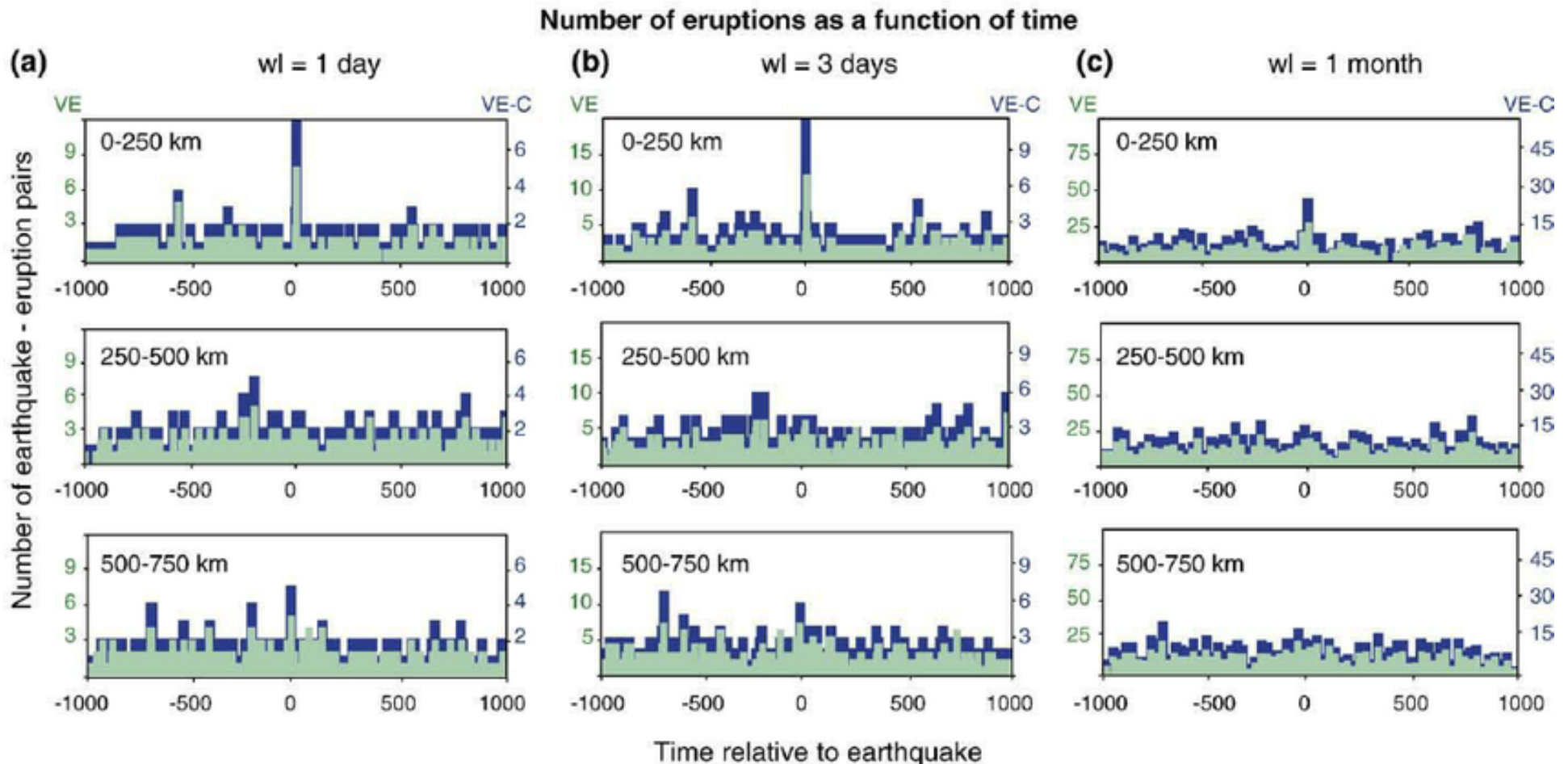
$X_t \sim 0.01$ - 0.1% (catalog suggests 0.1%)

Within 3
years . . .

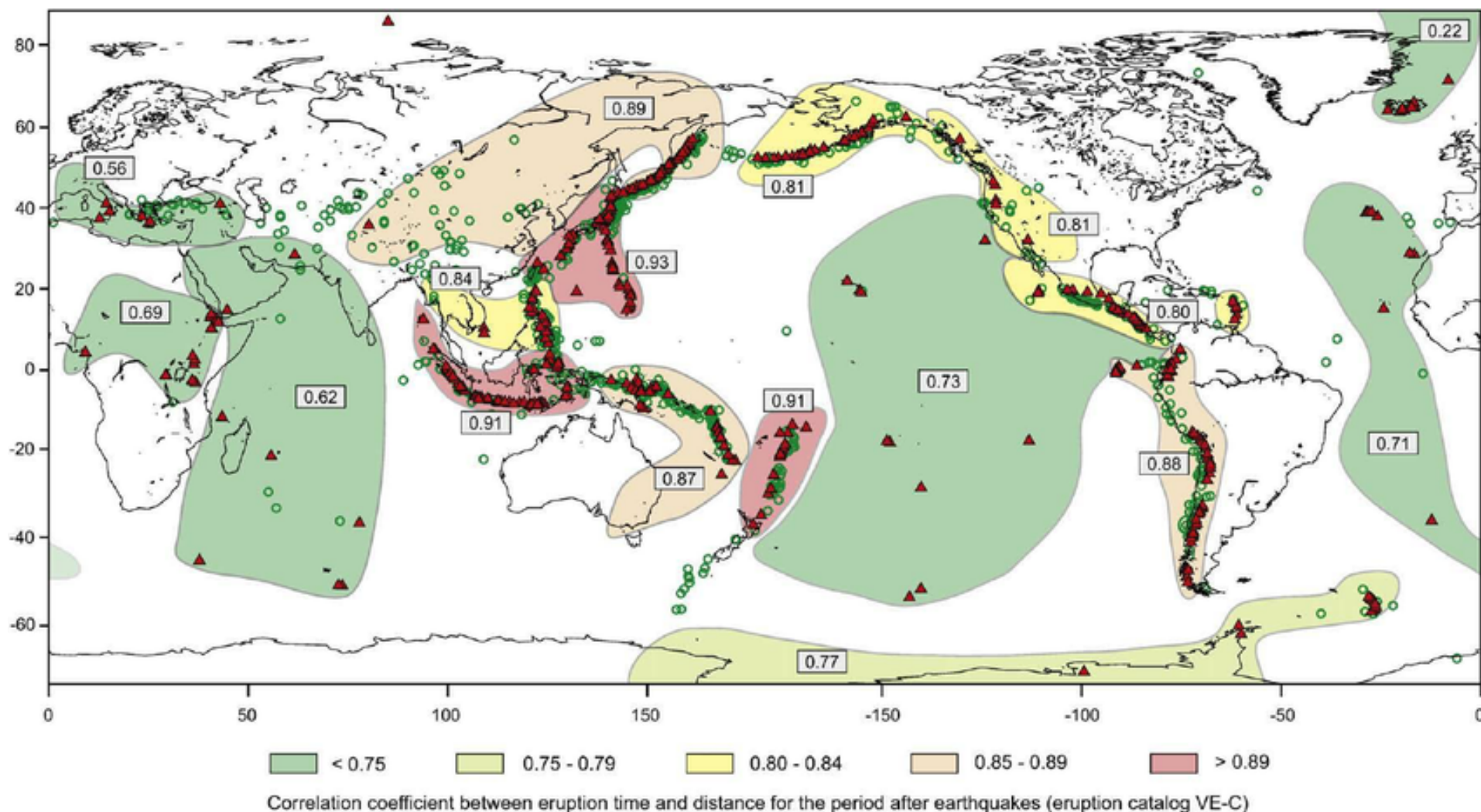


Eggert and Walter, Tectonophysics (2009)

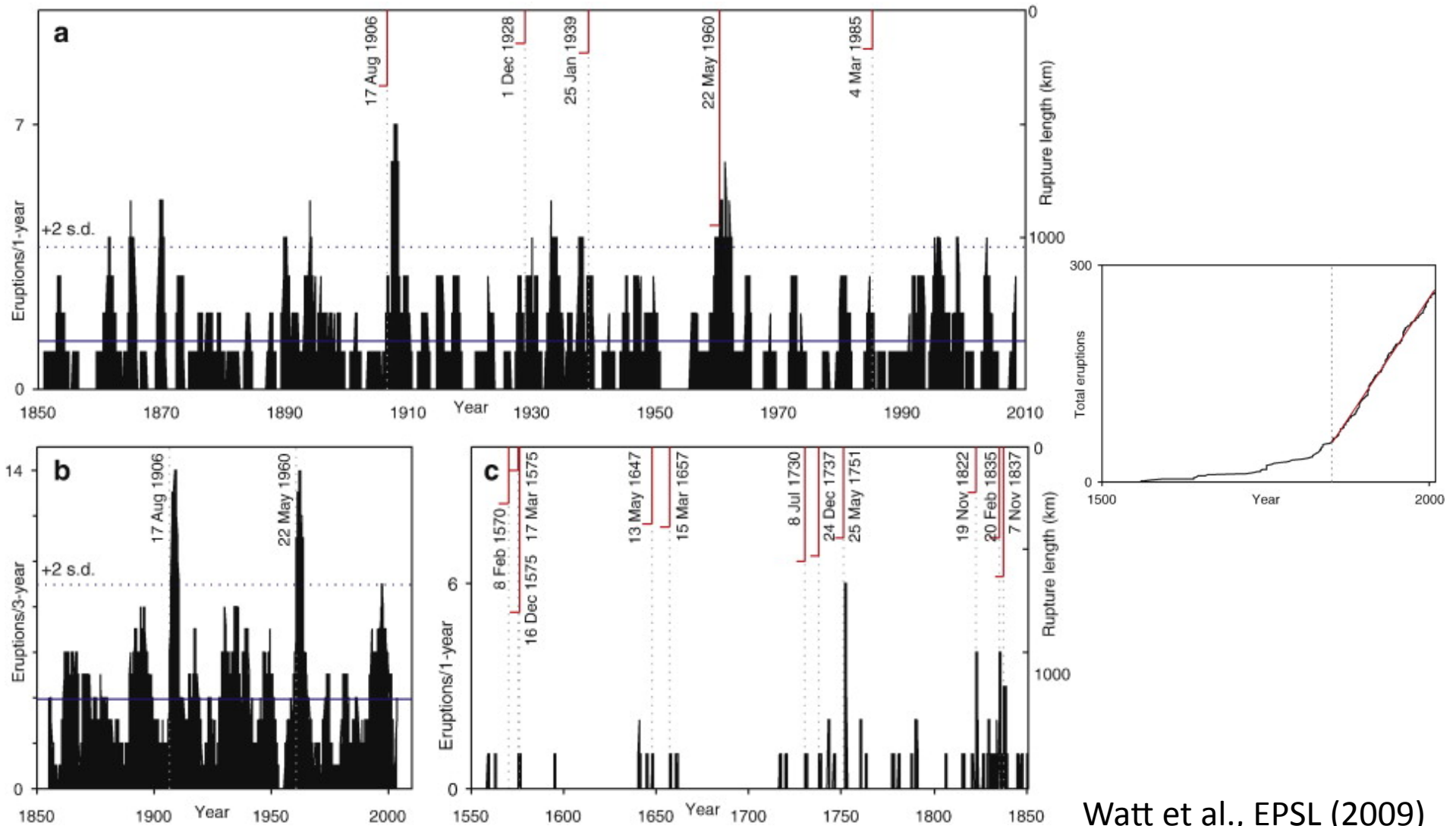
Time between eruptions and earthquakes



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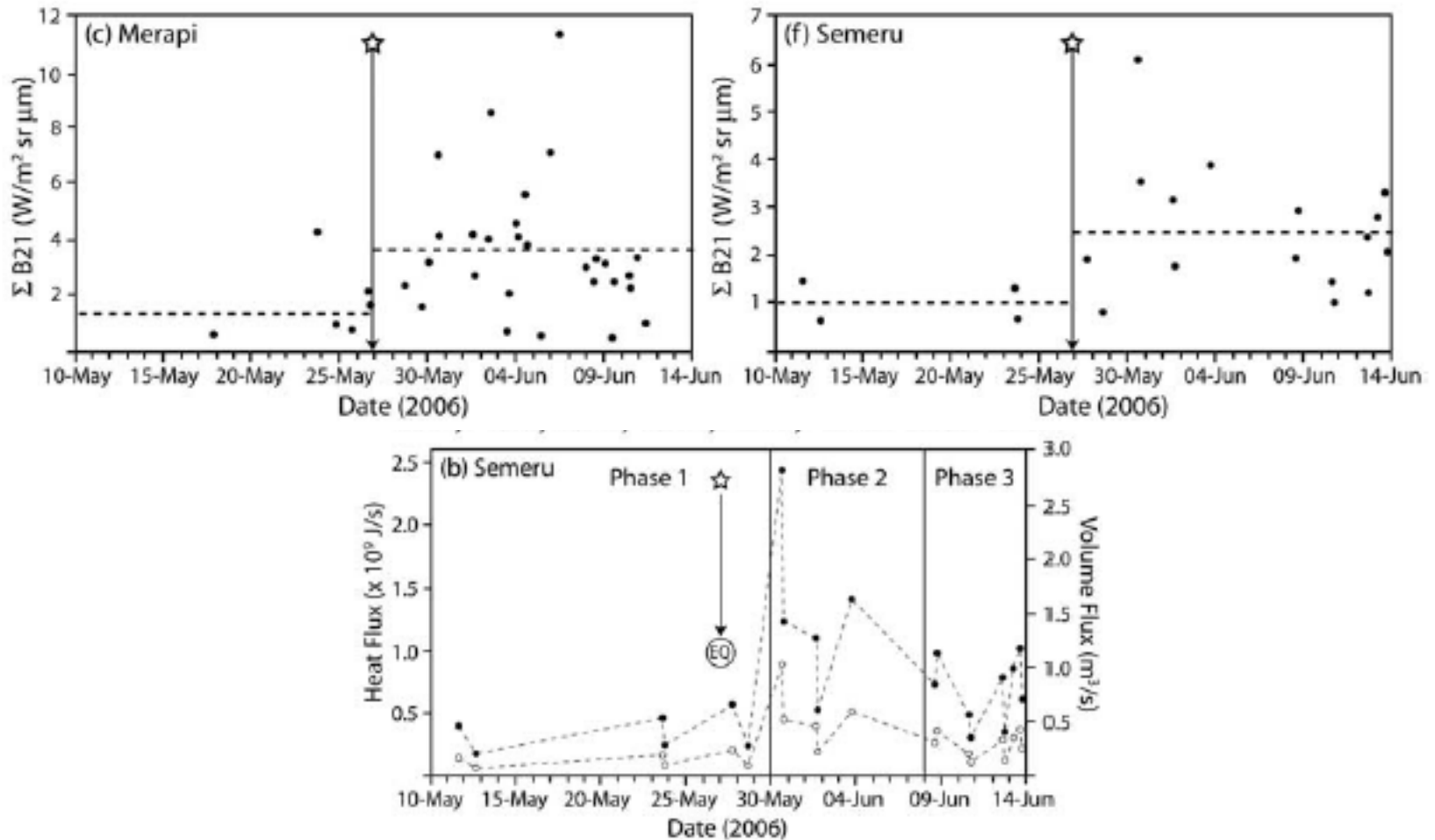


Time between eruptions and earthquakes

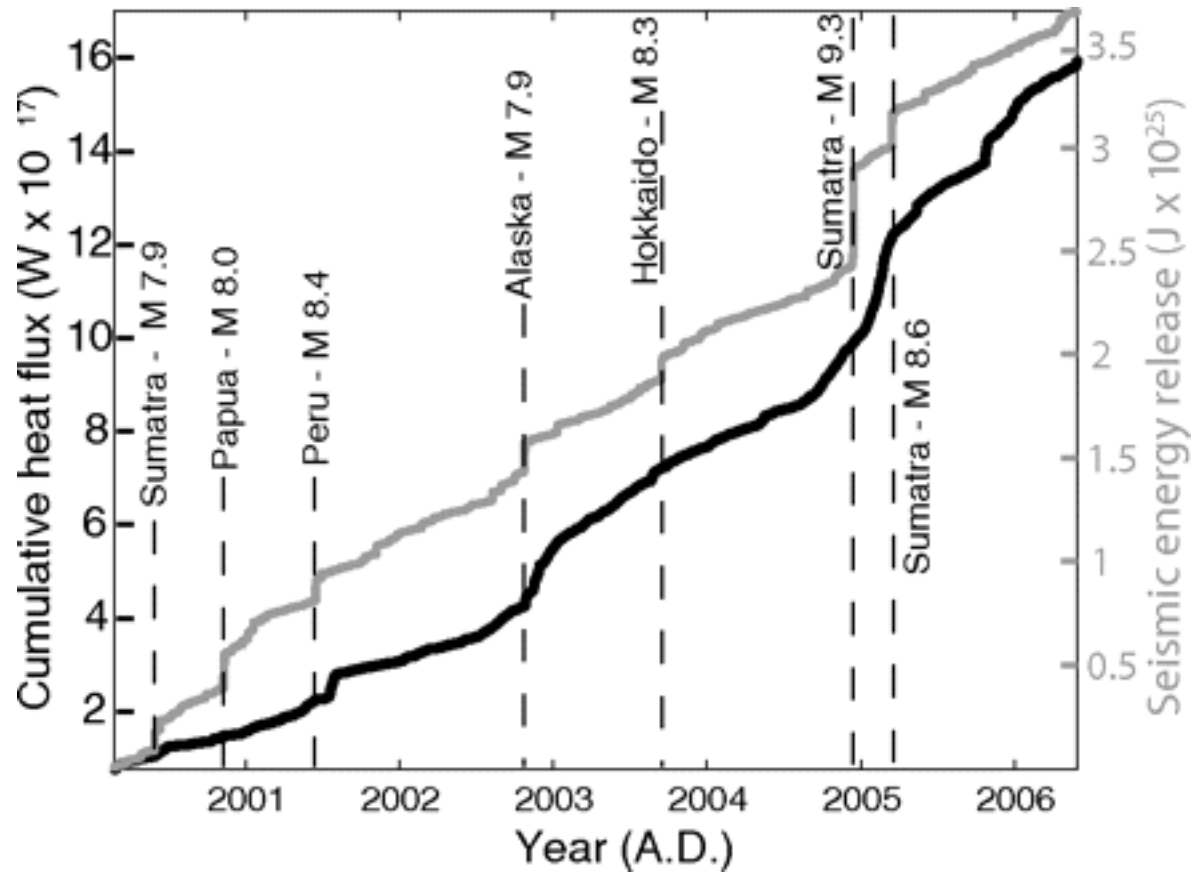


Watt et al., EPSL (2009)

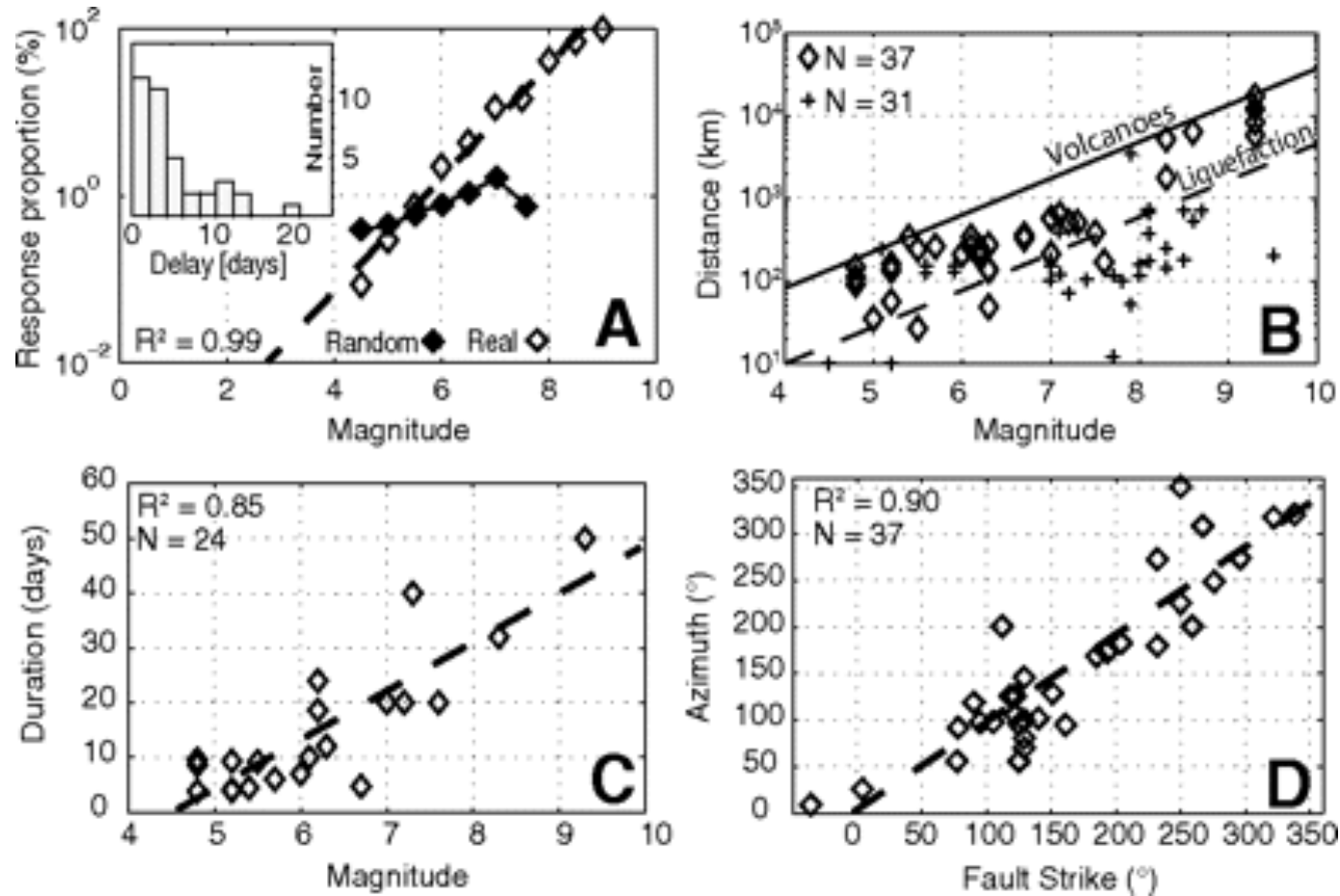
Already erupting volcanoes seem to be more sensitive?



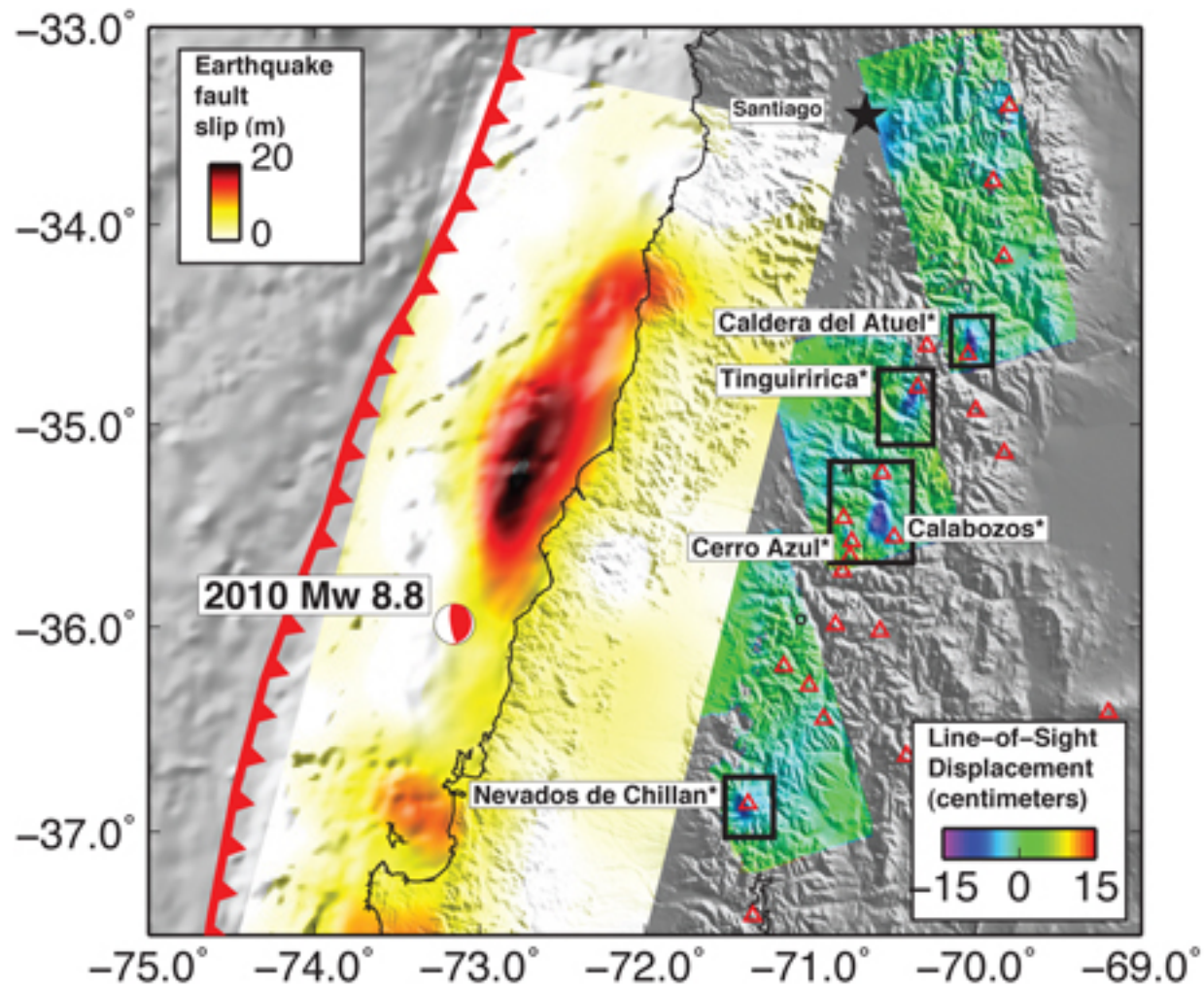
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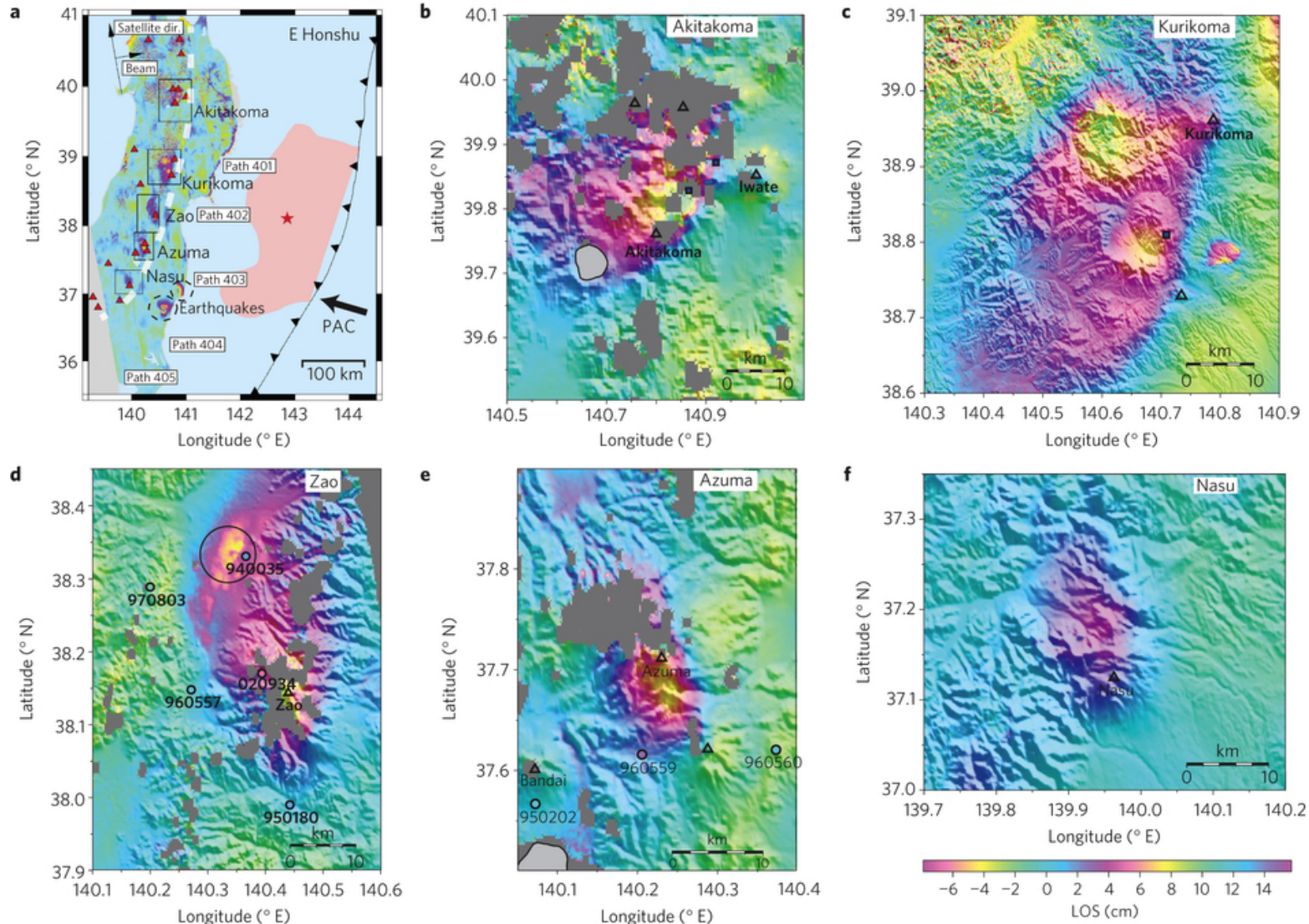
Already erupting volcanoes seem to be more sensitive?



Earthquakes may suppress eruption?



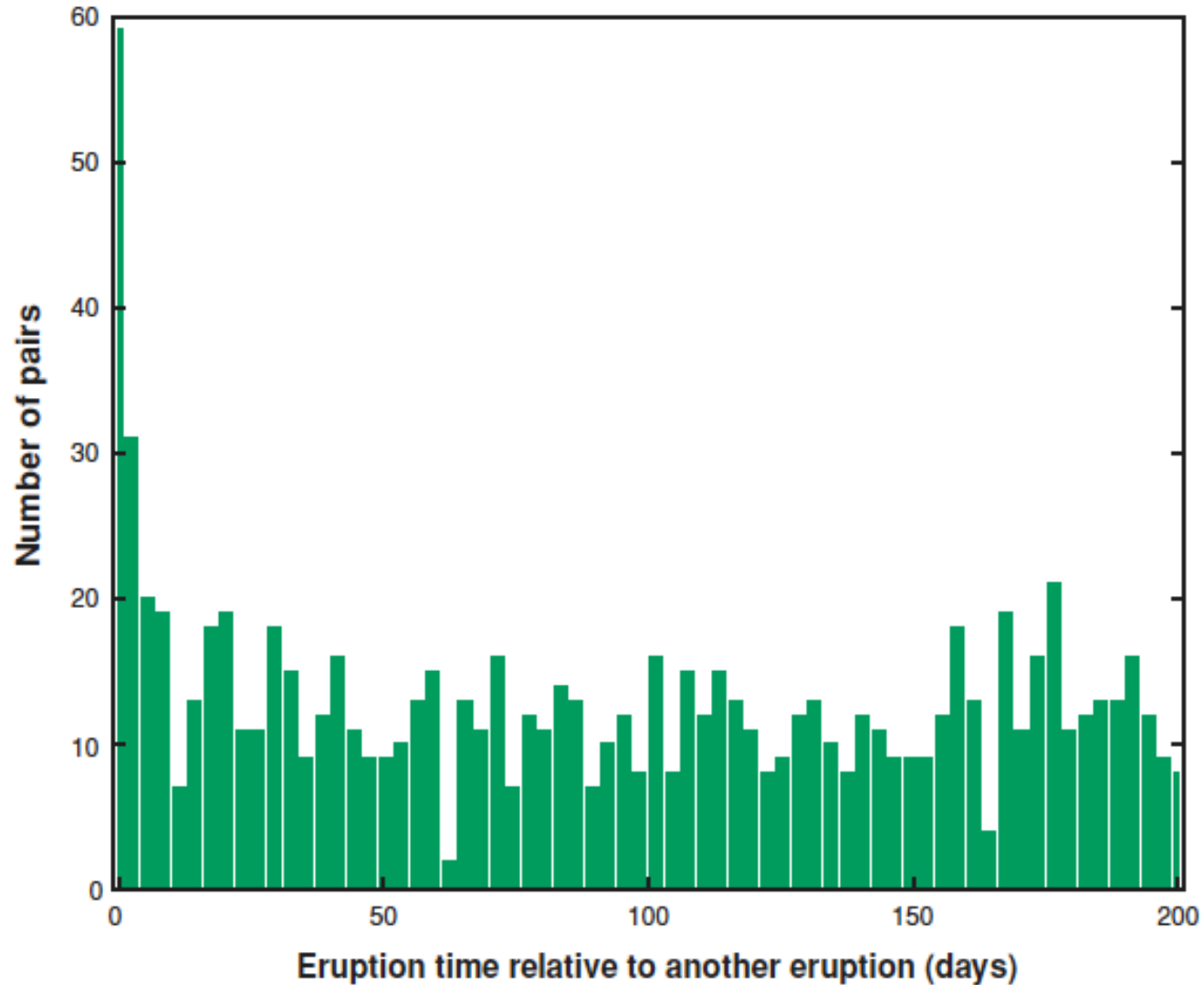
Earthquakes may suppress eruption?



2011 M9 Tohoku EQ, no triggered eruptions

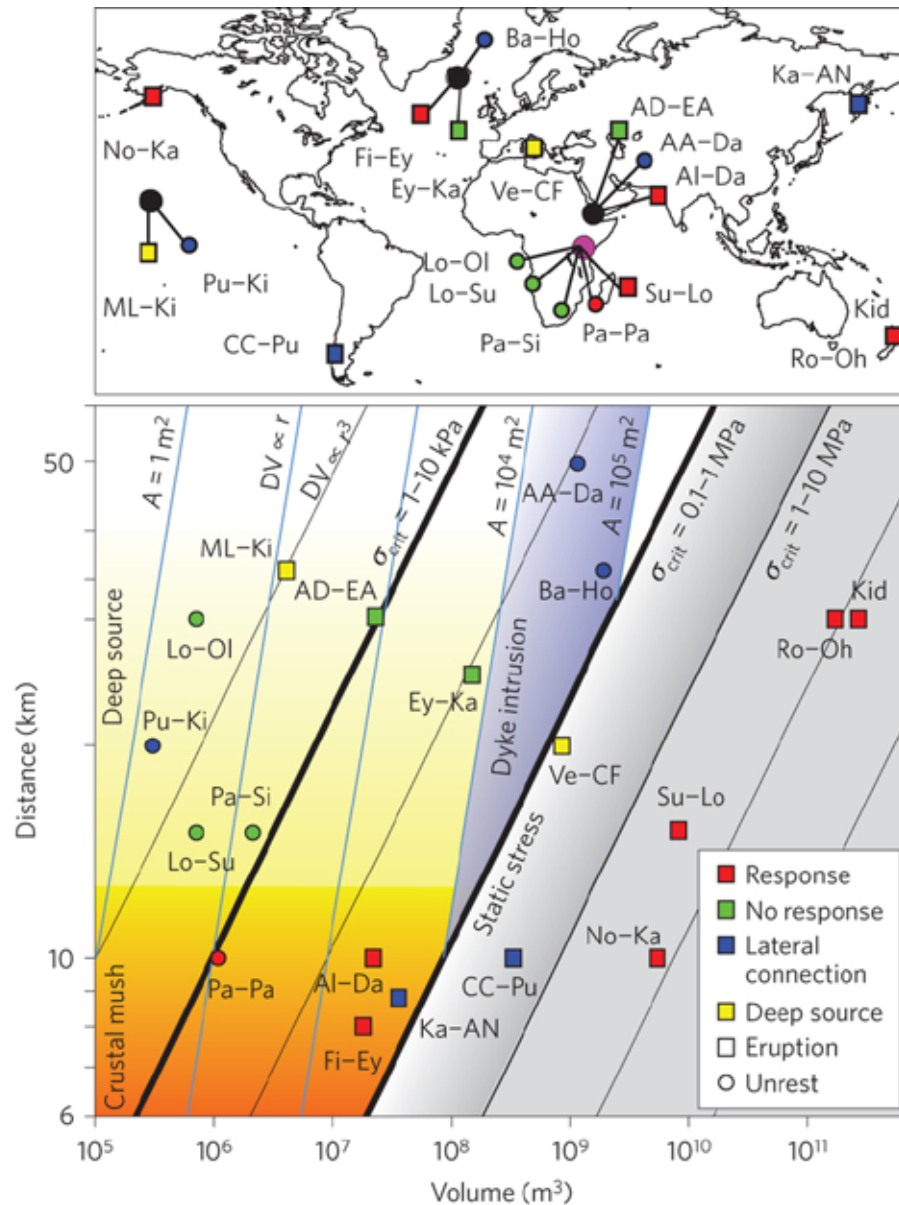
Takada and Fukushima, Nature (2013)

Time between eruptions and eruptions



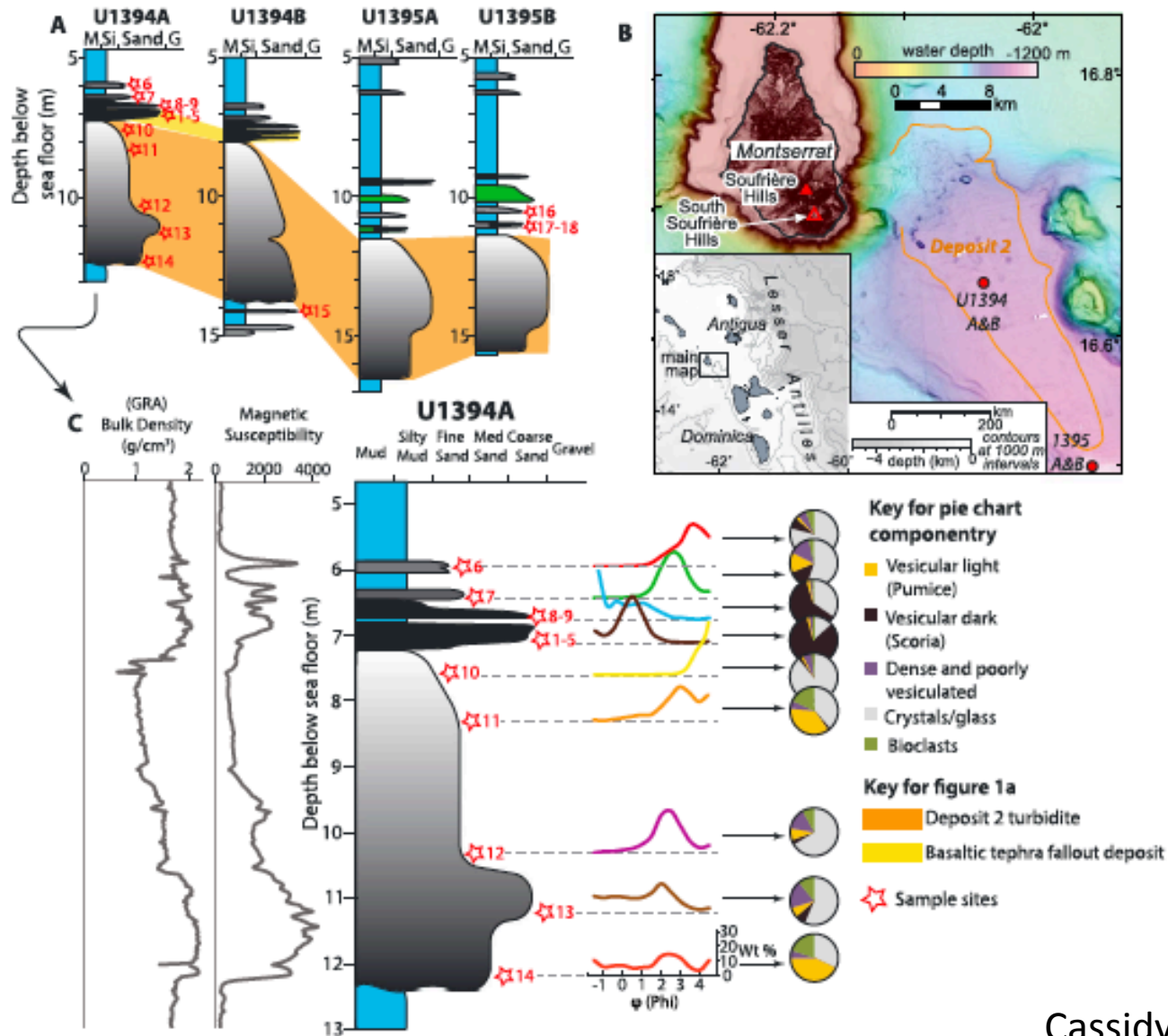
Manga and Brodsky, AREPS (2006); see also Linde and Sacks, Nature (1998)

Eruptions and eruption interactions



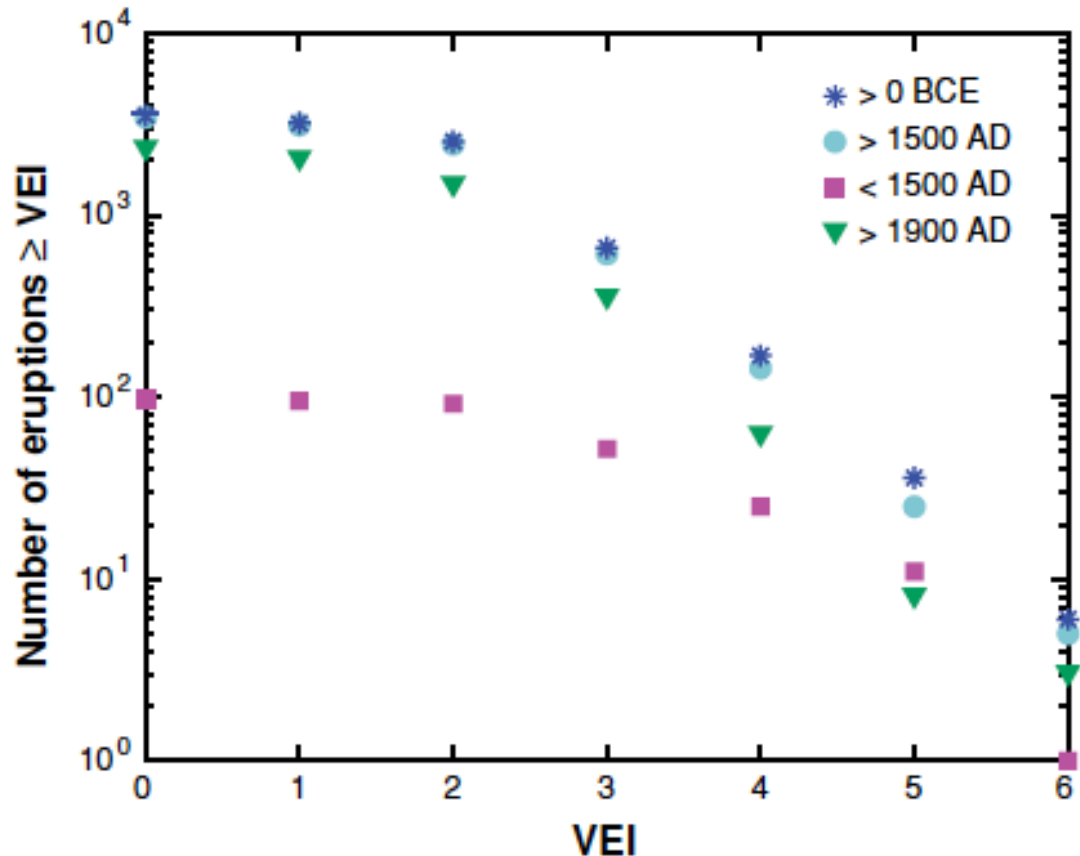
Biggs et al., Nat. Geo. (2016)

Earthquakes initiate flank collapse and then eruption?



Issues to think about . . .

- Completeness of the catalog (earthquakes AND eruptions)
- Biases in reporting?



Why?

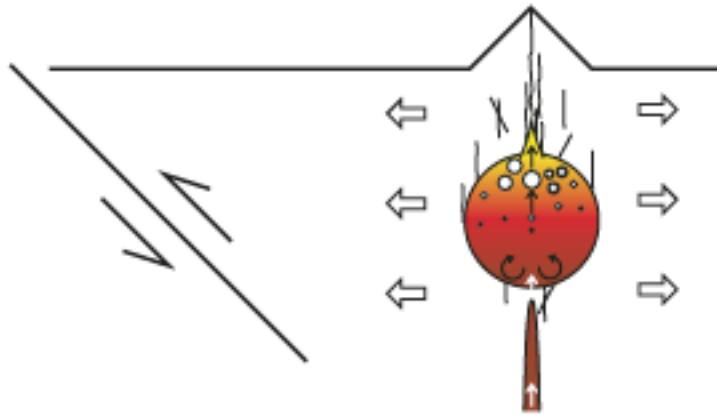
		Stress (MPa)		Period
Solid Earth tides		10^{-3}		12 h
Ocean tides		10^{-2}		12 h
Hydrological loading		10^{-3} – 10^{-1}		days–years
Glacier loading		10^1 – 10^2		10^3 years
	10^2 km	10^3 km	10^4 km	
Static stress changes, M8	10^{-1}	10^{-4}	10^{-7}	NA
Dynamic stress changes, M8	3	0.06	0.001	20 s

deglaciation appears to be accompanied by eruptions

static stress changes \ll dynamic stresses

Static vs dynamic strains?

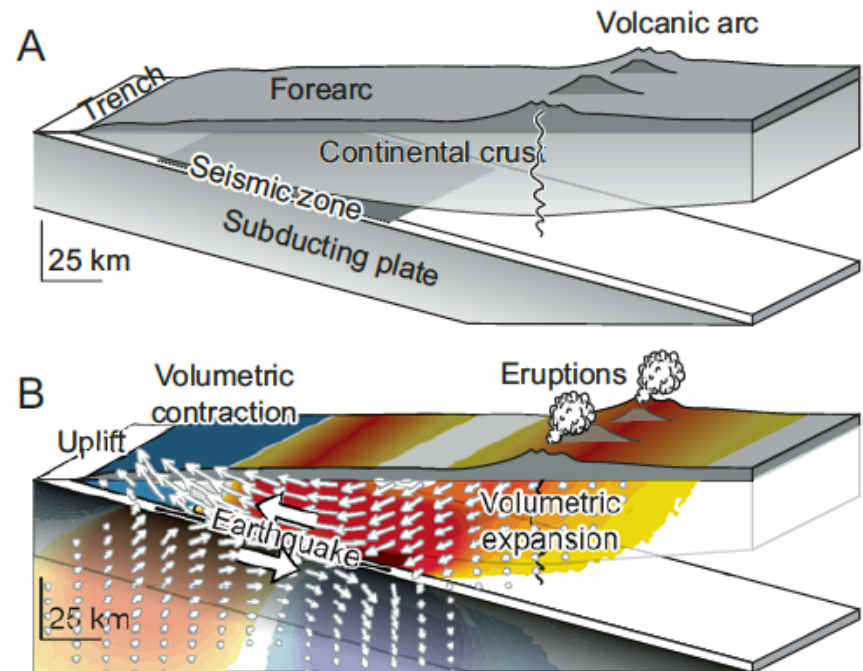
How earthquakes may trigger eruptions



- Unclamping
- Dike formation and propagation
- Volatile exsolution
- Density and viscosity decrease
- Bubble growth
- Mingling of different magmas
- Magma ascent and depressurization

Amelung and Walter,
Geology (2007)

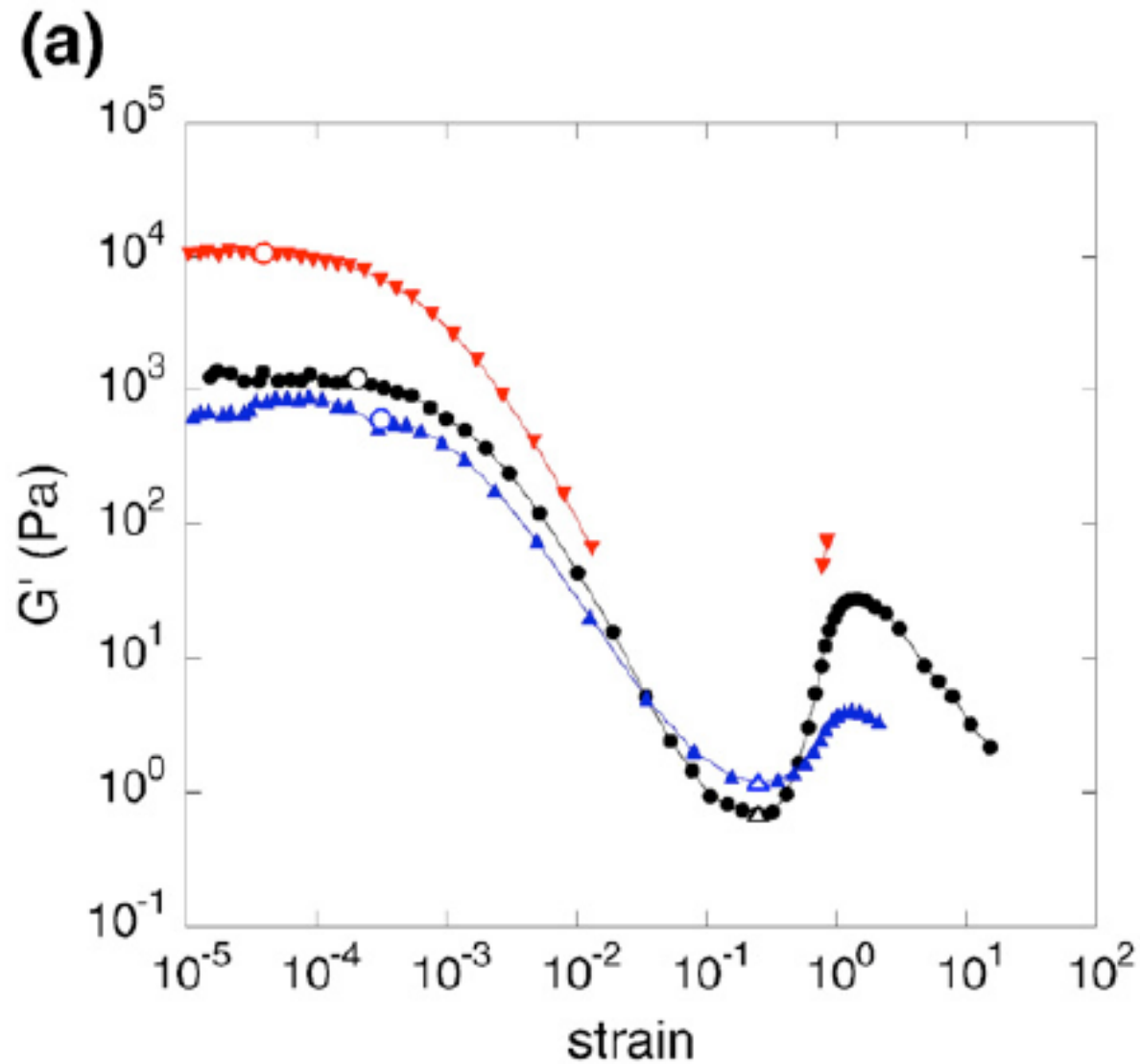
Various studies invoke contraction or expansion of crust around chambers (recent review Bonini et al., Tectonophysics, 2016)

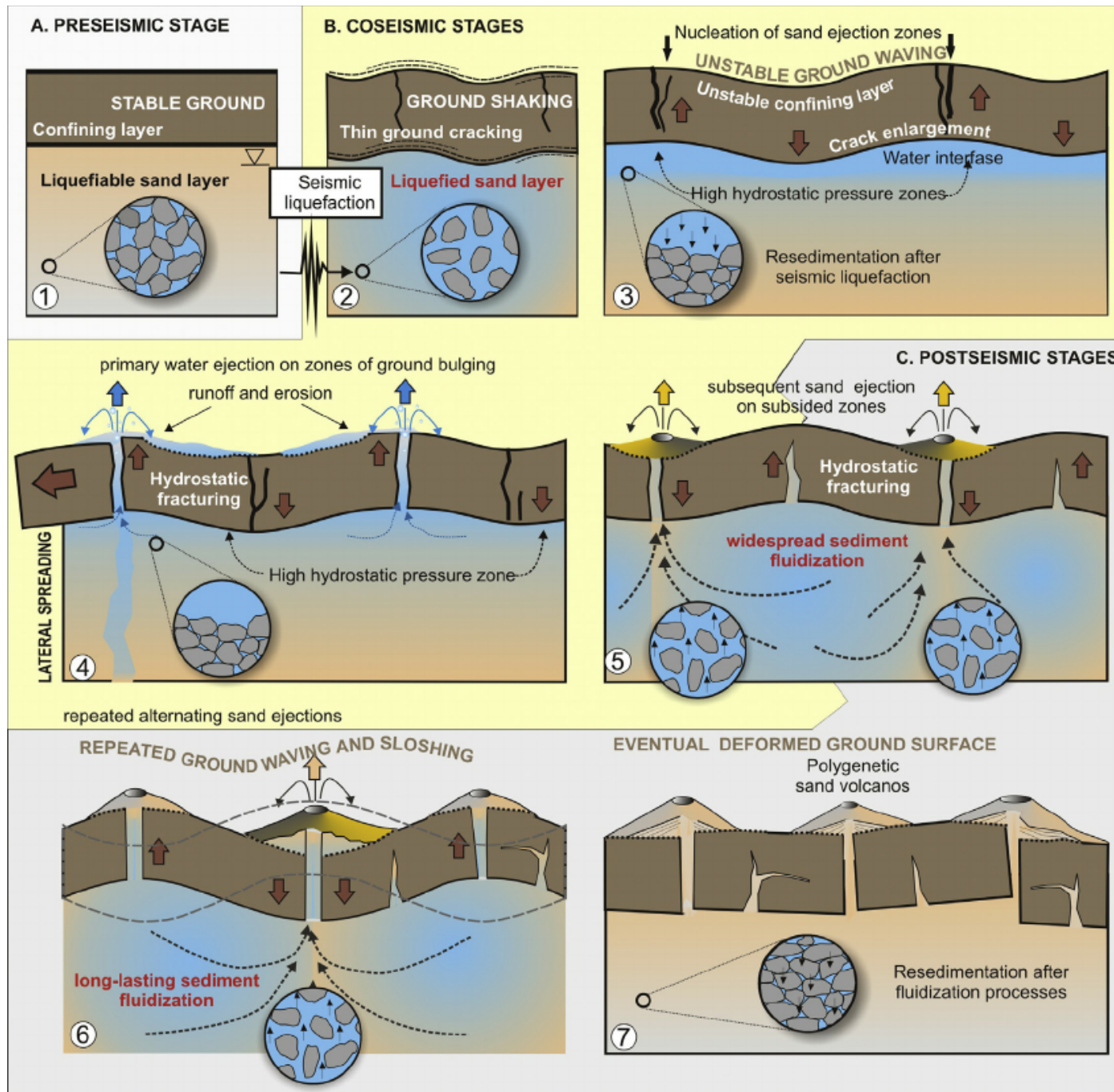


Mechanisms that invoke dynamics strains

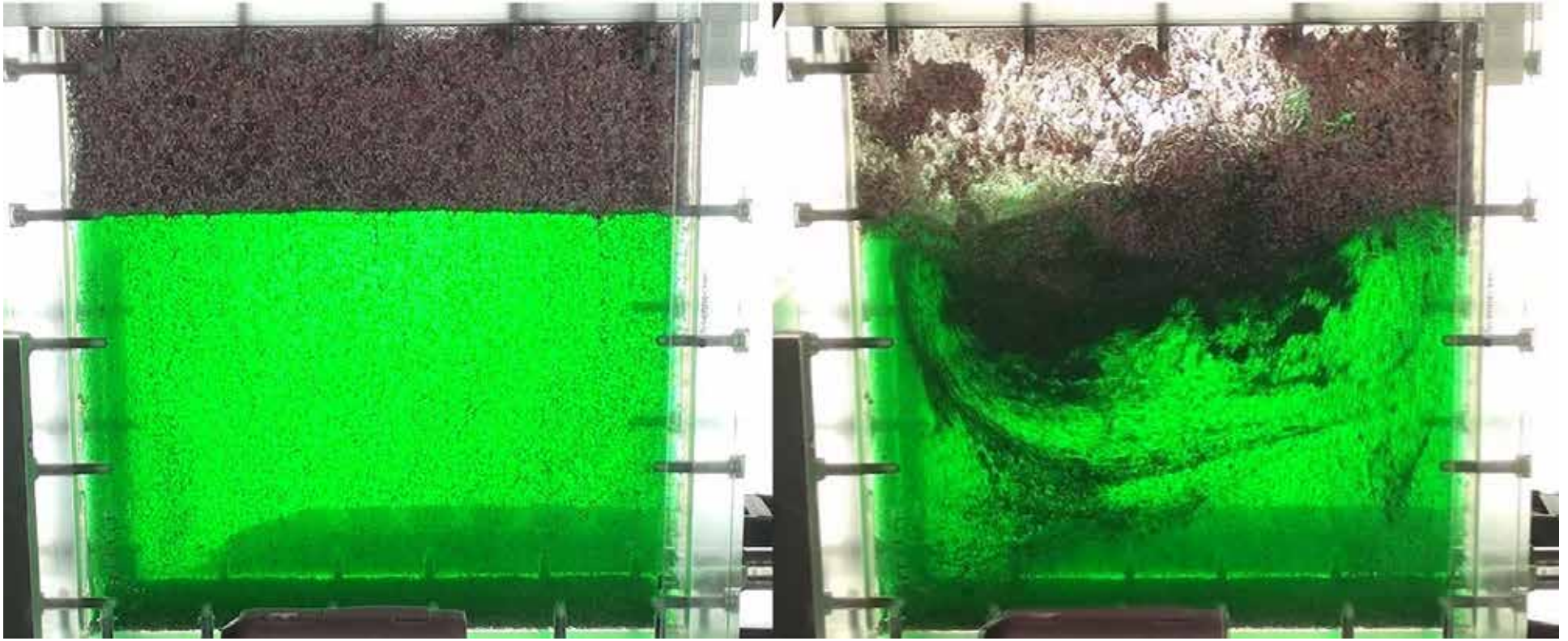
- Bubbles 1: Rectified diffusion
(e.g., Brodsky et al., JGR 1998; but see Ichihara and Brodsky, GRL 2006)
- Bubbles 2: Advective overpressure
(e.g., Steinberg et al., 1989; Sahagian and Proussevitch, Nature 1992; but see Bagdassarov, 1994; Pyle and Pyle, 1995)
- Bubbles 3: Nucleation
(e.g., Manga and Brodsky, 2006)
- Initiate convection
(e.g., Hill et al., Physics Today, 2002; Sumita and Manga, EPSL 2008)
- Sloshing
(Namiki et al., JVGR 2016)

Strain-weakening and liquefaction



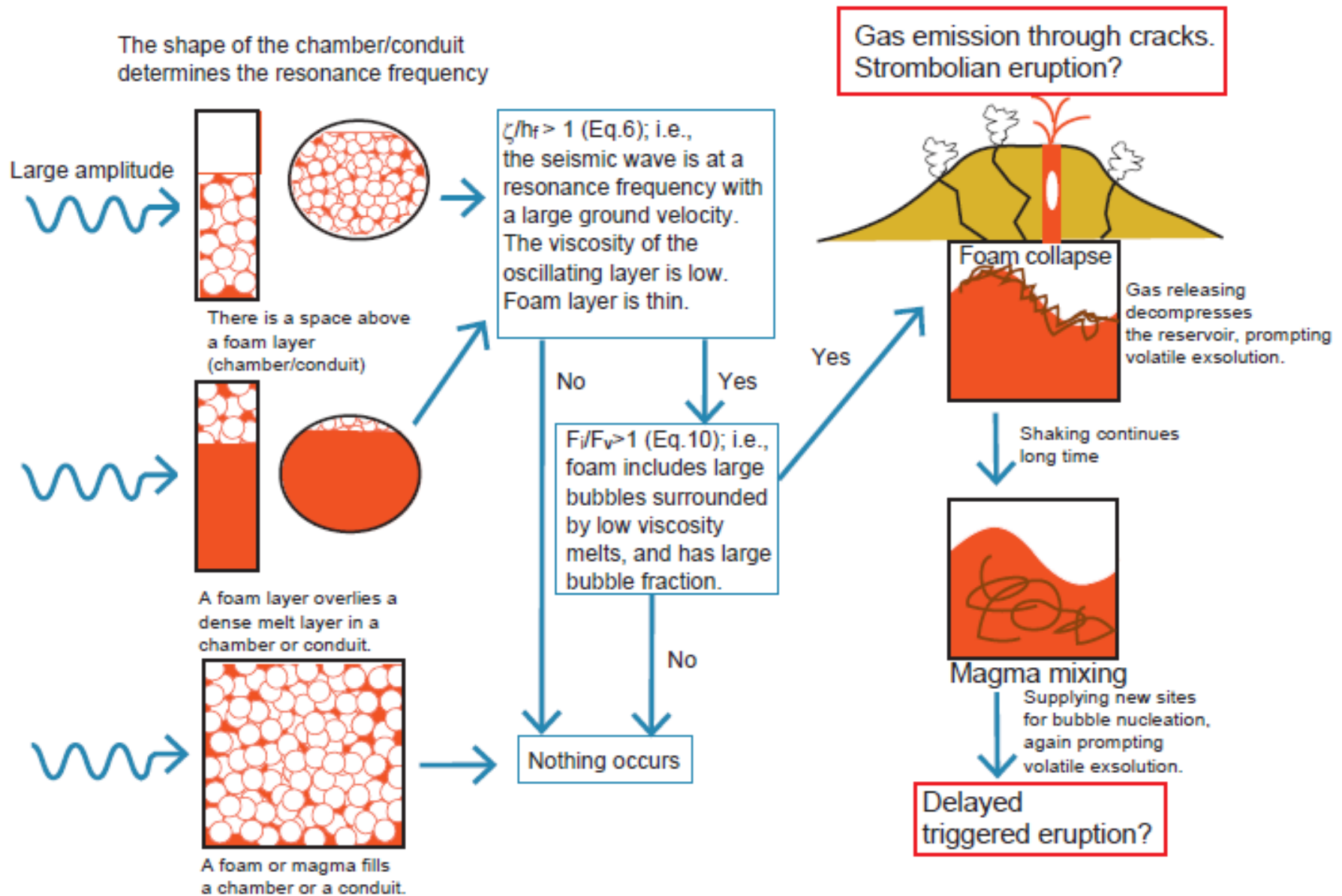


Sloshing (dynamics strains)

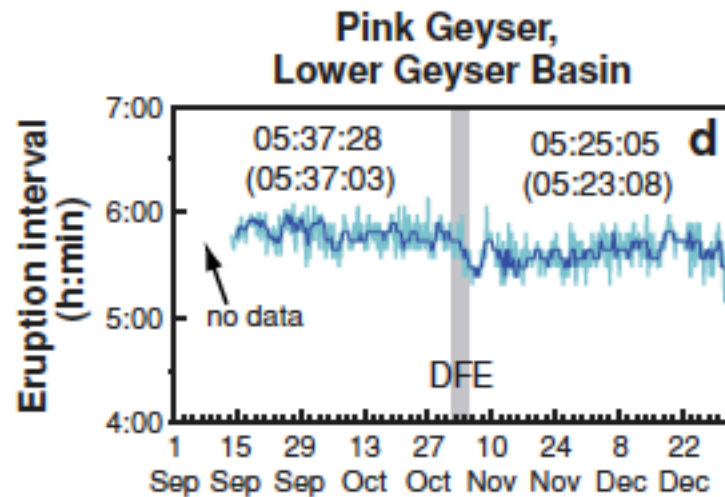
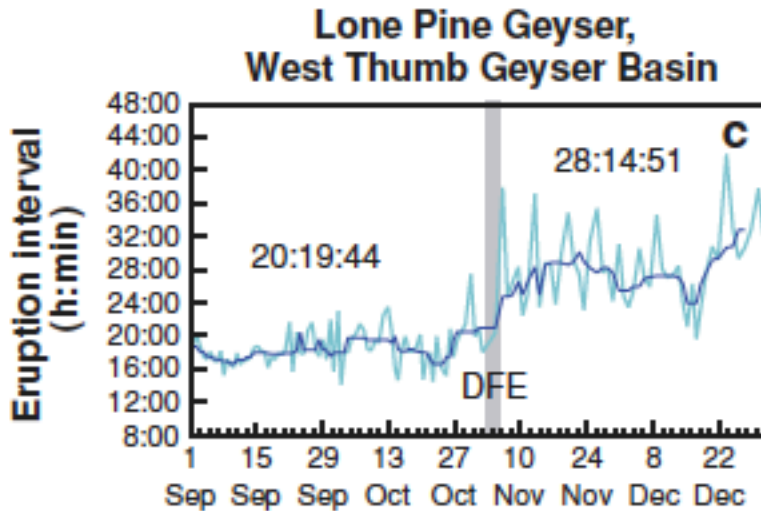
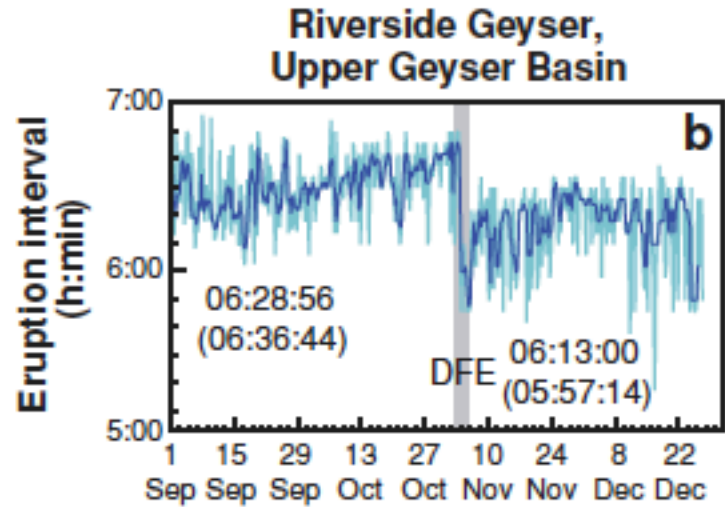
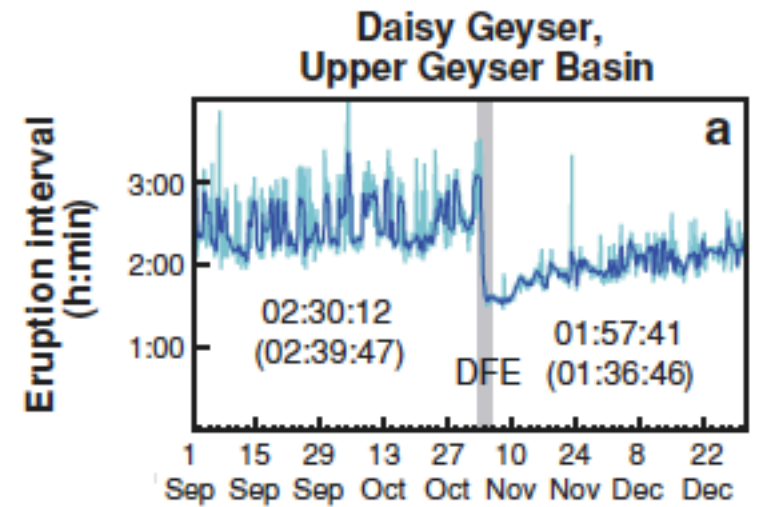


Namiki, Rivalta et al., JVGR (2016)

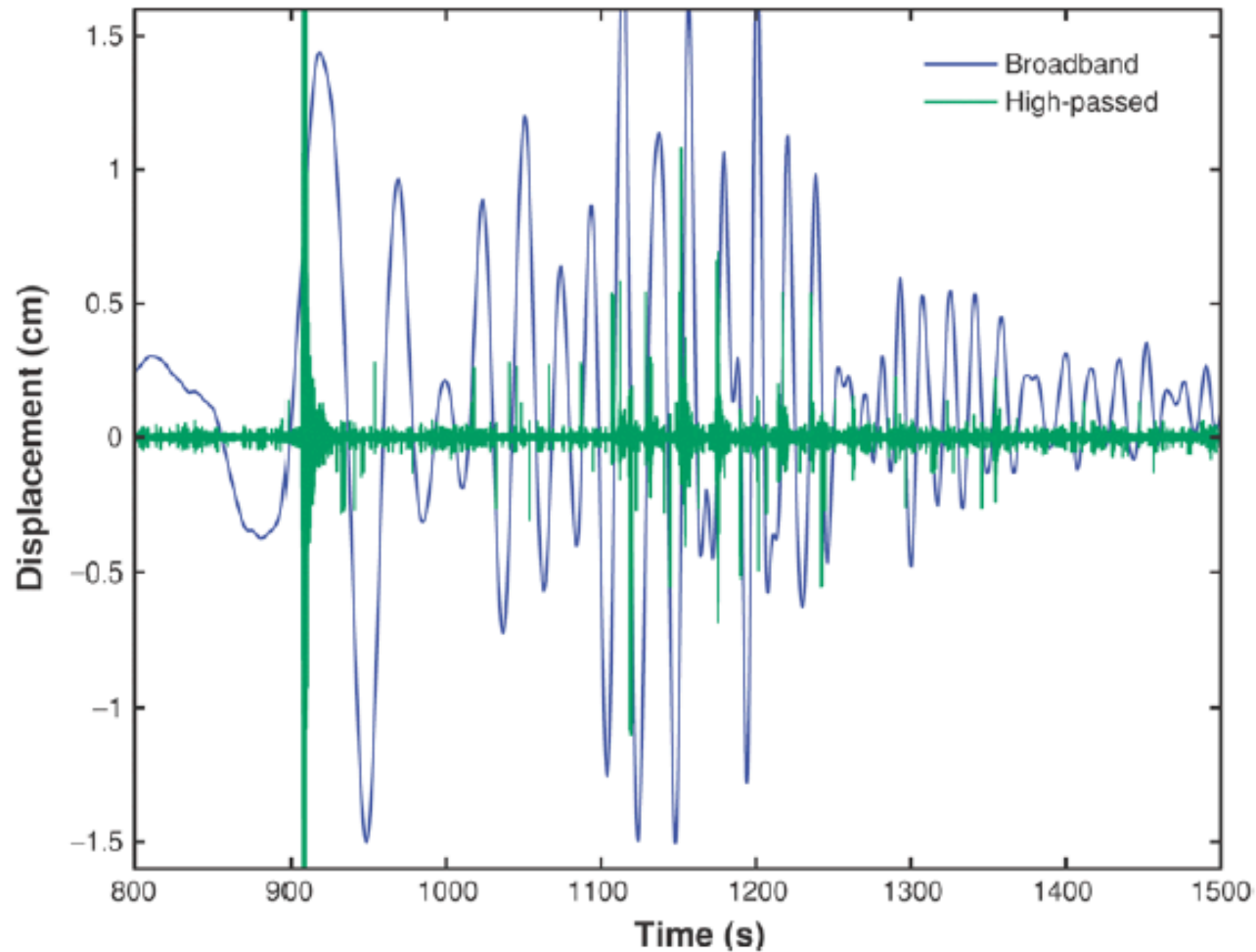
Sloshing (dynamics strains)



Other triggered fluid phenomena: geysers

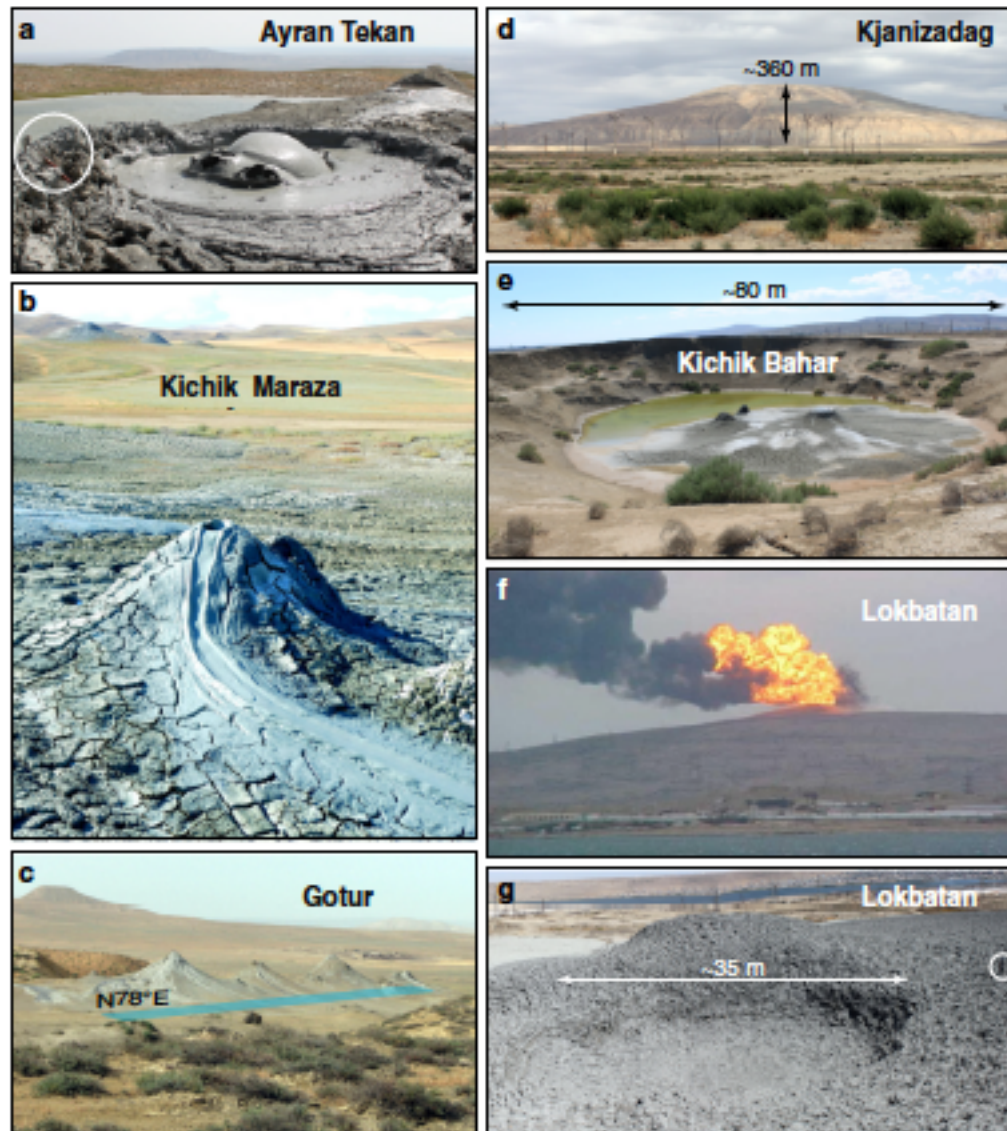


Other triggered fluid phenomena: earthquakes



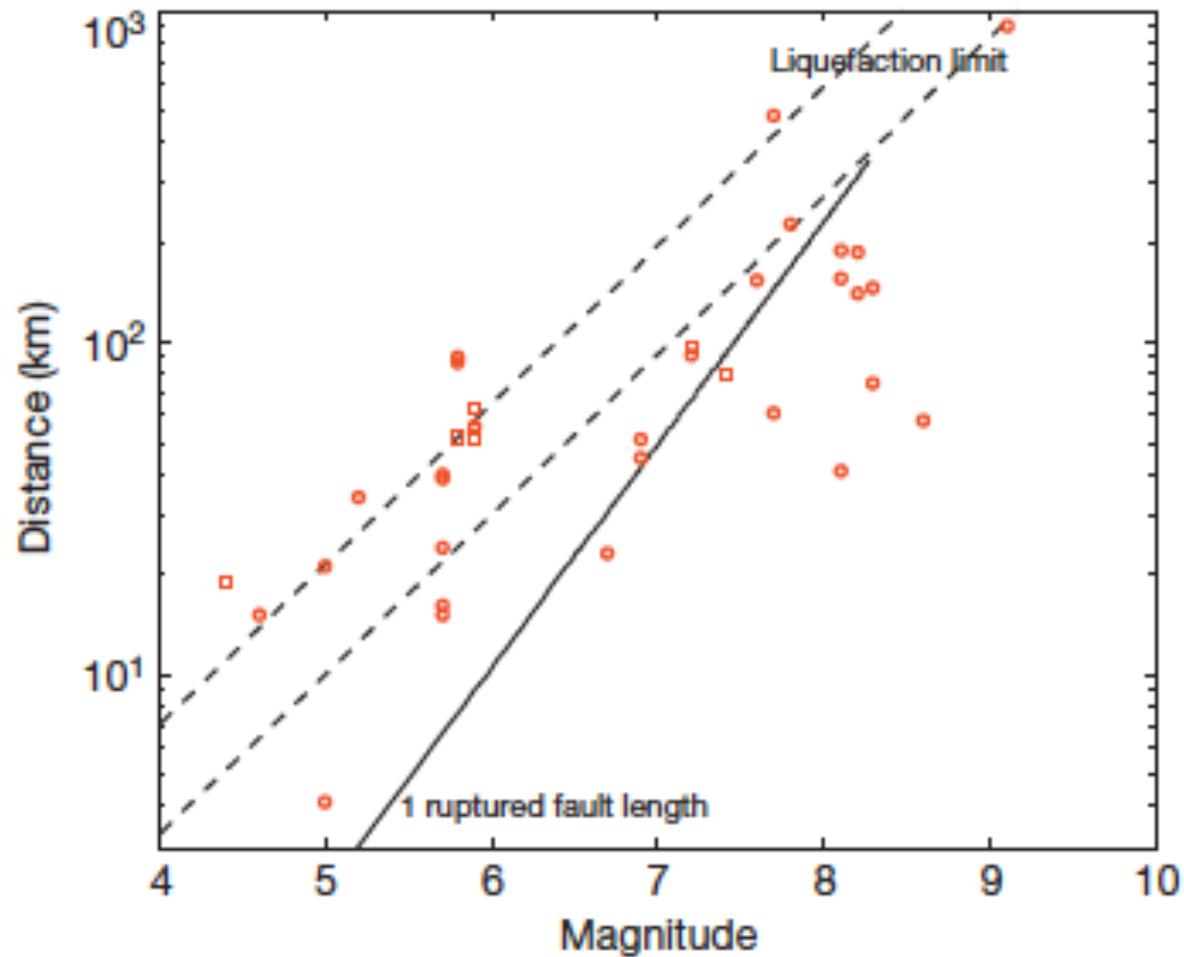
Manga and Brodsky, AREPS (2006)

Other triggered fluid phenomena: mud volcanoes

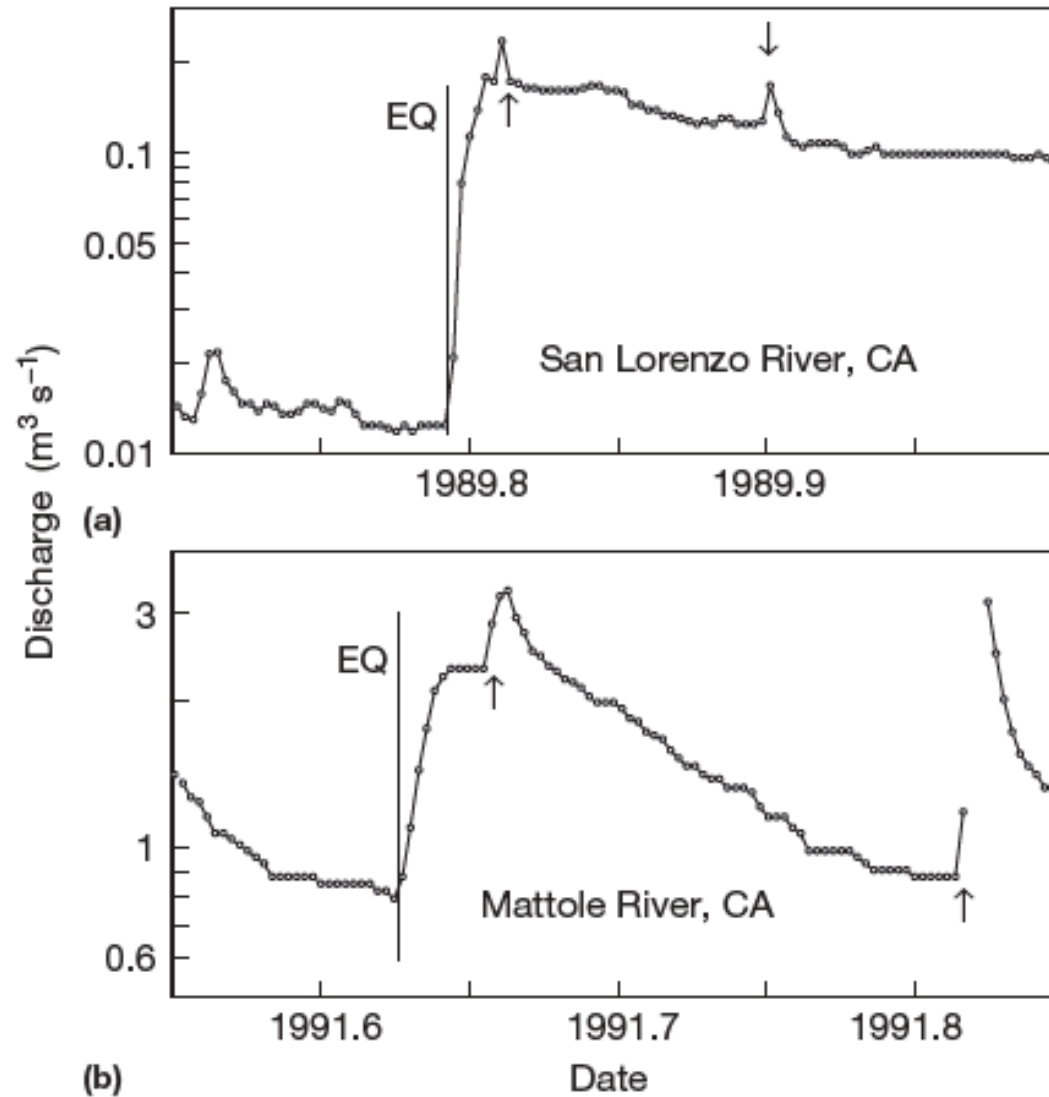


Bonini et al.,
Tetonophysics (2016)

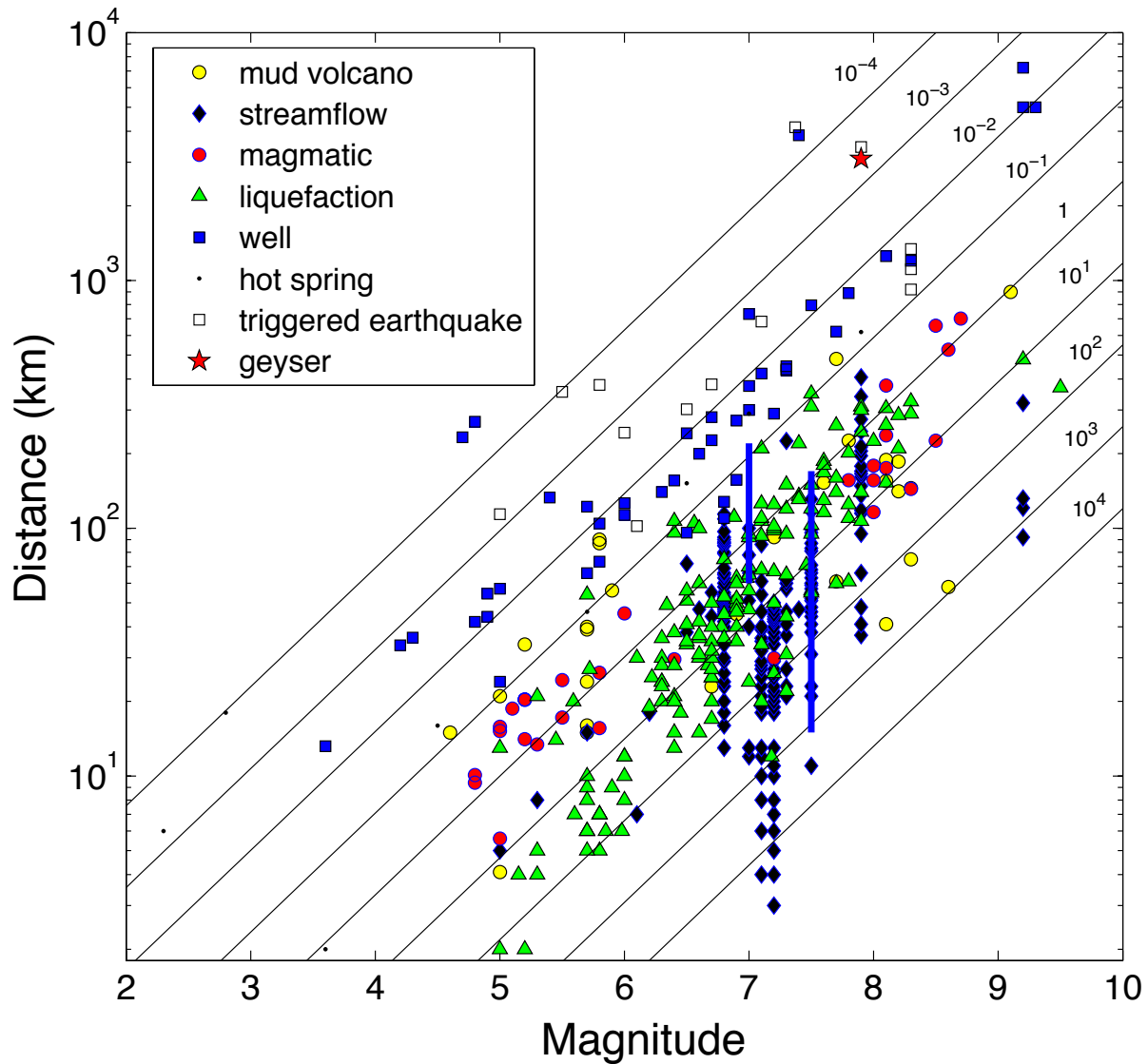
Other triggered fluid phenomena: mud volcanoes



Other triggered fluid phenomena: streams



Space-time relationships



Compilation from Wang and Manga, Geofluids (2010)

Why?

- Probe some of the processes that initiate eruptions?
- Determine critical thresholds
- Are relationships real?
- What is the mechanism or mechanisms?