Seismo-acoustic signals of volcanic processes

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Lecture Outline:

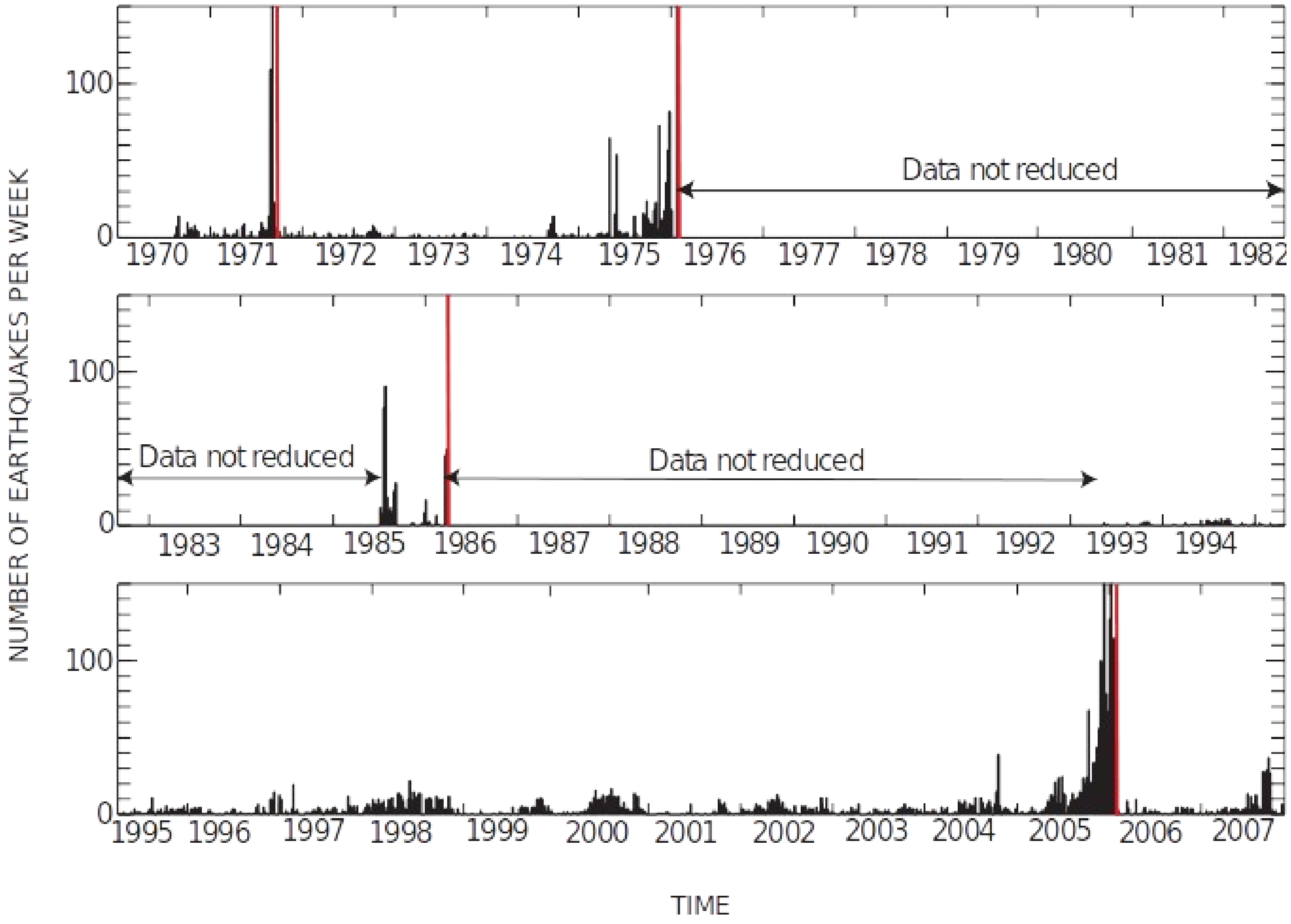
- Introduction (15 minutes)
- Volcano-seismic signals I – VTs
- Volcano-seismic signals II - LPs, VLPs, tremor
- Acoustic signals
- Recommendations for multi-disciplinary integrated research

Aims of Volcano Seismo-Acoustics

- Volcanology perspective - understand volcanic processes from seismic/ acoustic signals and patterns
- Seismology and acoustics perspective - understand seismic and acoustic source processes
- Monitoring and forecasting

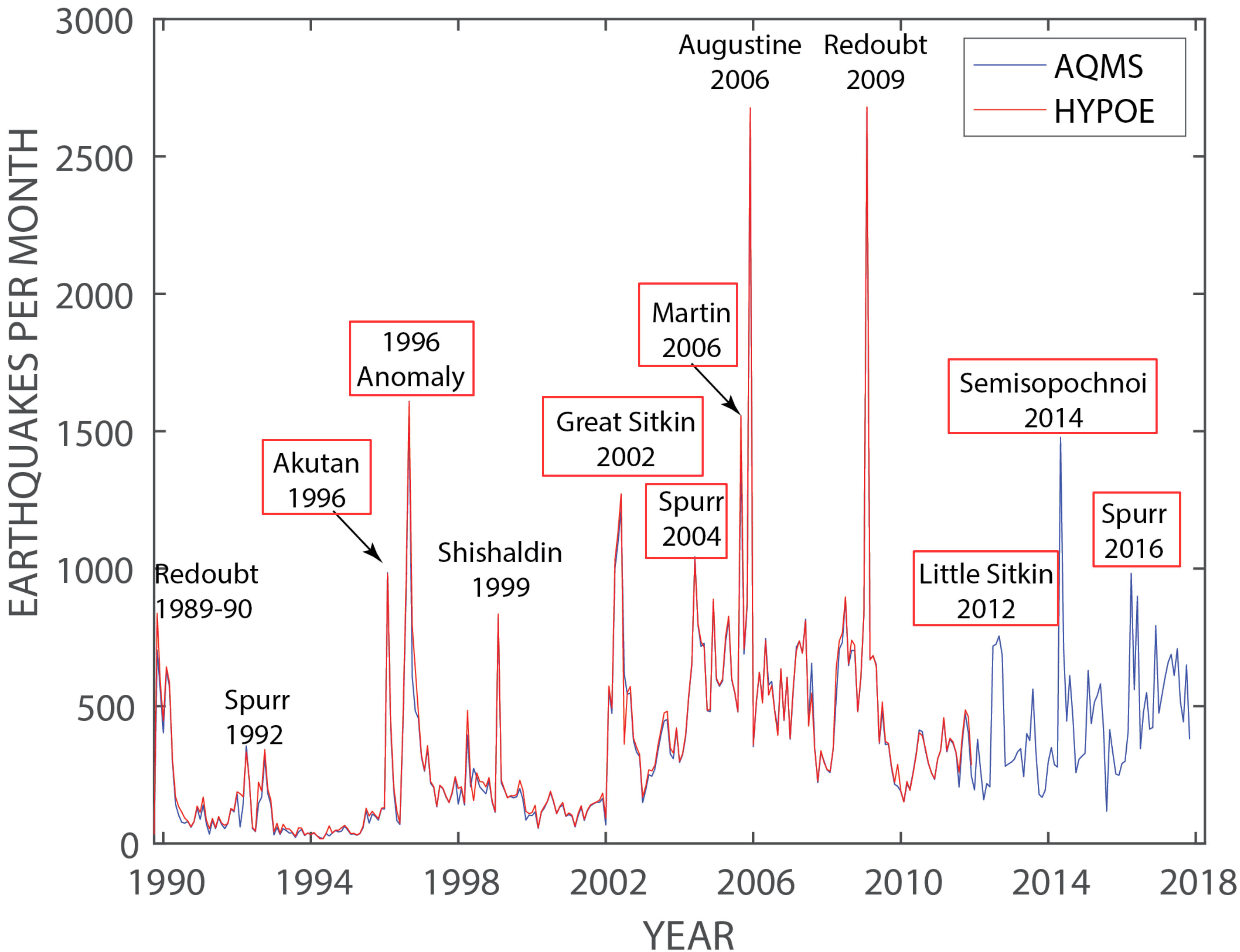
Paradigm I: Seismicity accompanies activity

- Seismicity at Augustine Volcano, Alaska, 1970-2007
  Red lines = eruptions



Power et al. 2010

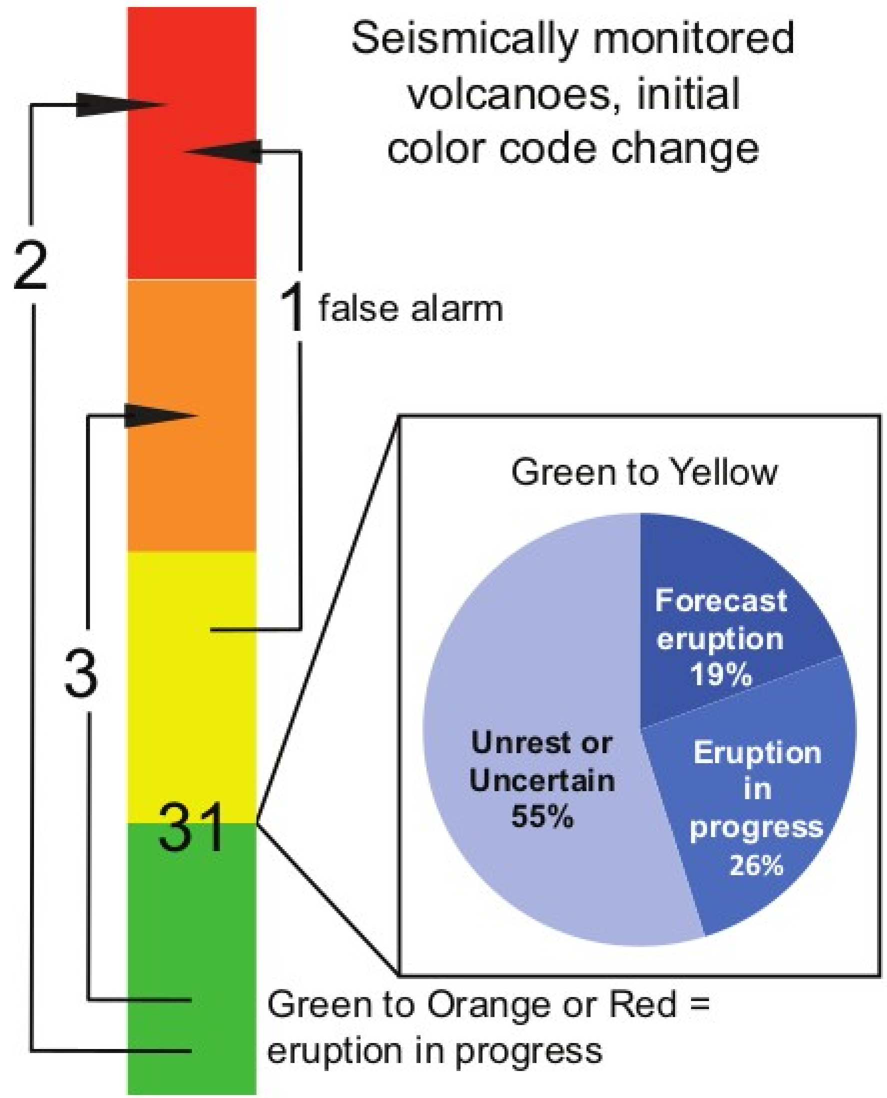
Paradigm I: Seismicity accompanies activity



After Power et al., 2019

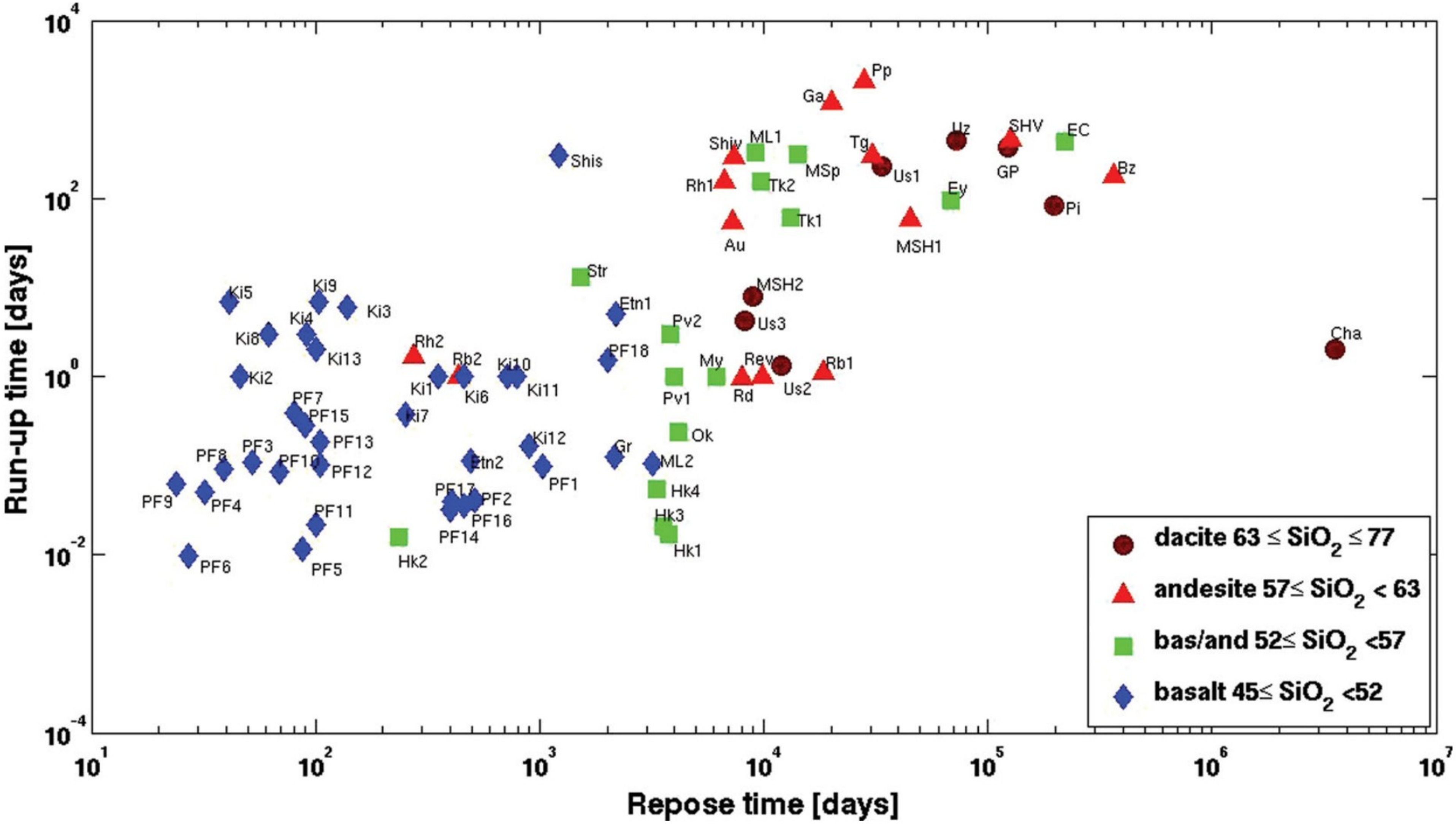
"Failed eruption" problem - see Moran et al. 2011

Paradigm I: Seismicity accompanies activity



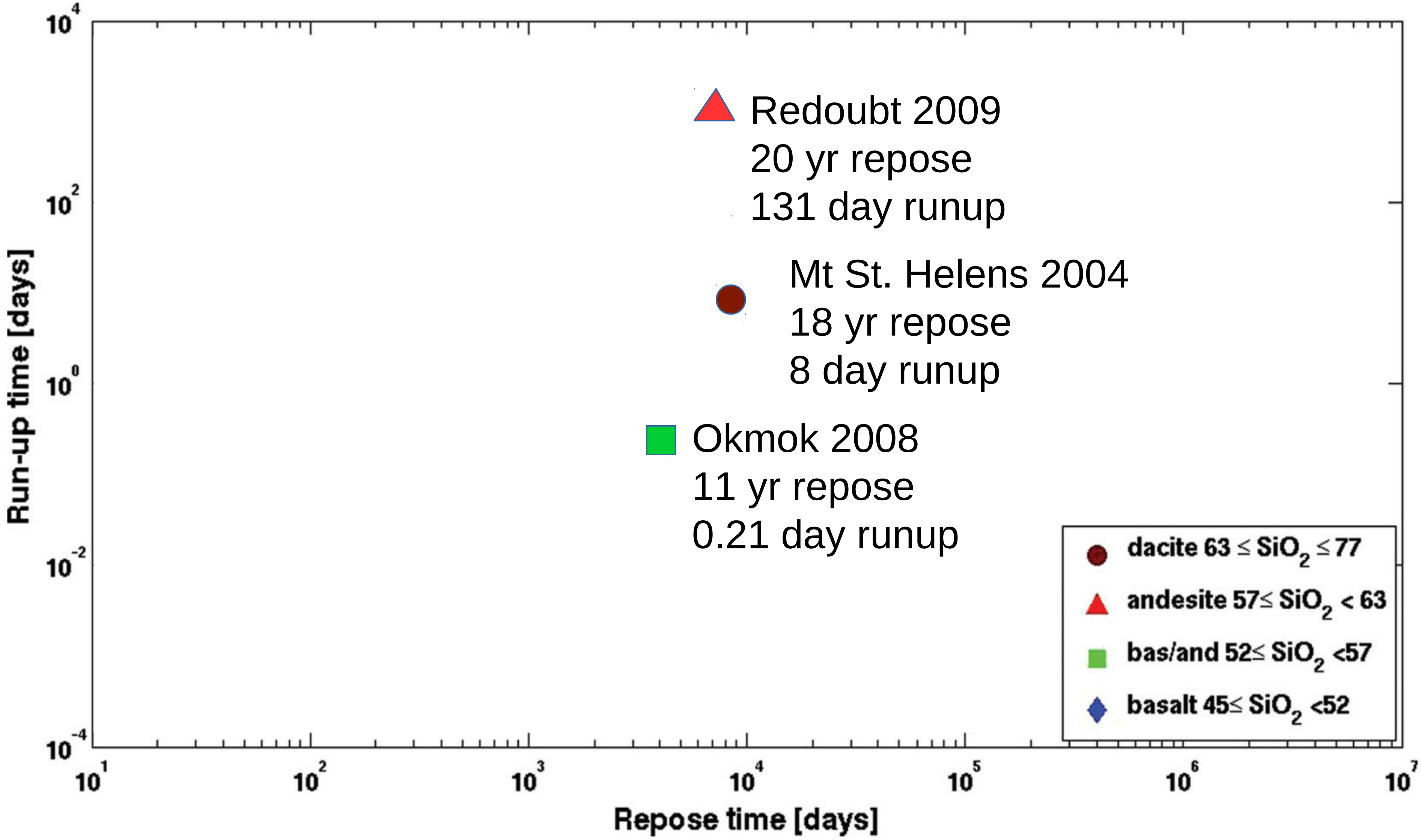
Cameron et al., 2018

Duration of Precursory Seismicity



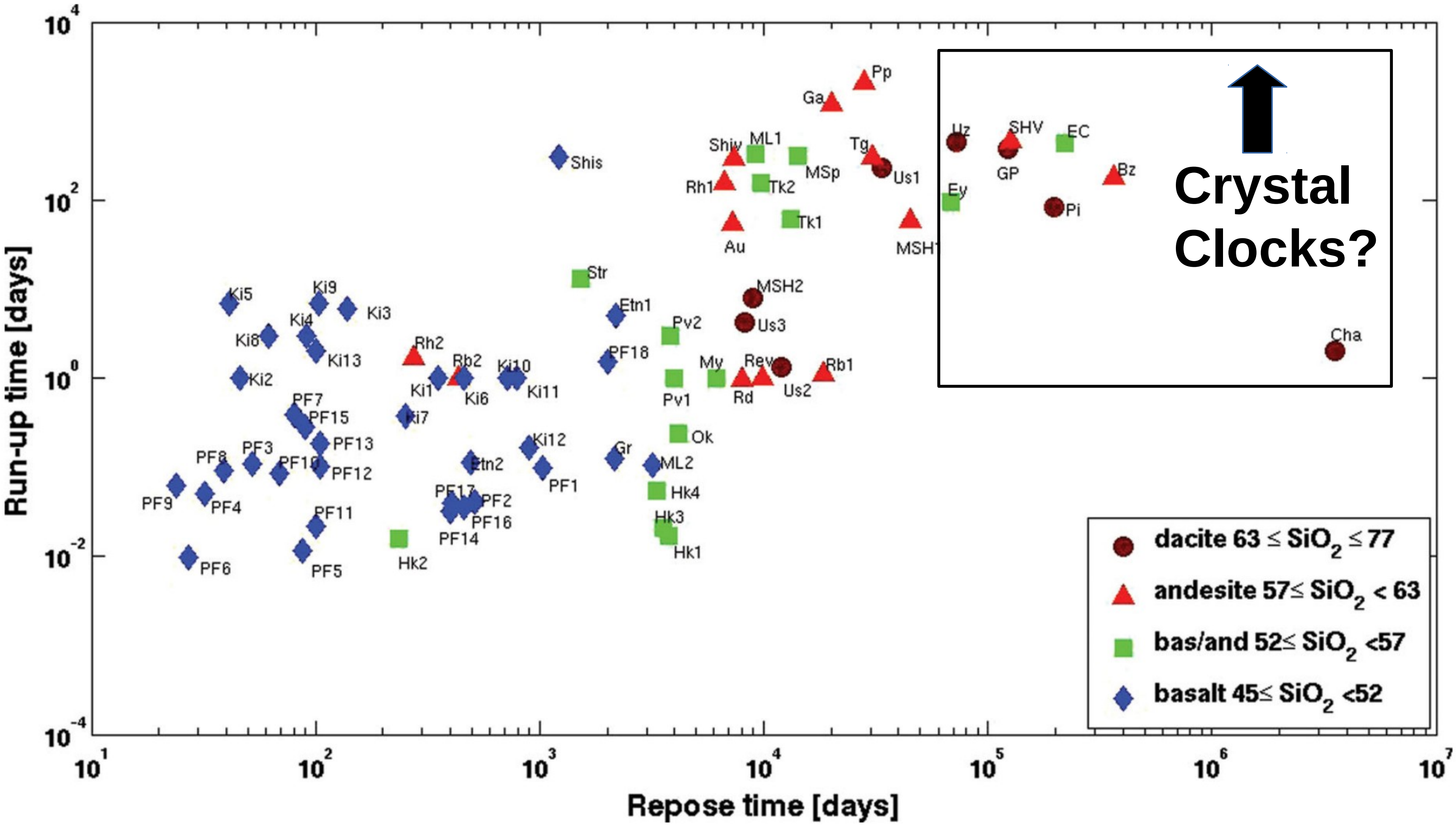
Passarelli and Brodsky 2012 (GJI)

Duration of Precursory Seismicity



After Passarelli and Brodsky 2012 (GJI)

Duration of Precursory Seismicity



Passarelli and Brodsky 2012 (GJI)

Paradigm II: Seismic Event Classes

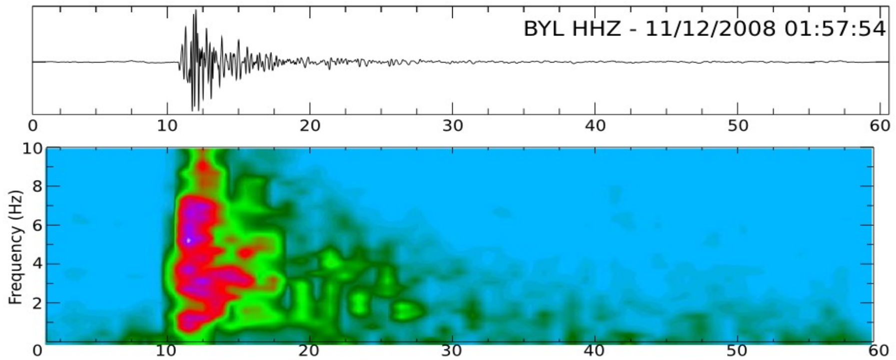
- Multiple processes produce seismic signals at volcanoes. The signals are (mostly/sometimes) distinctive and ultimately reflect the nature and underlying physics of the source process

- By looking for different event types, we can identify the processes occurring in a magmatic system and thus gain information about the state of the volcano

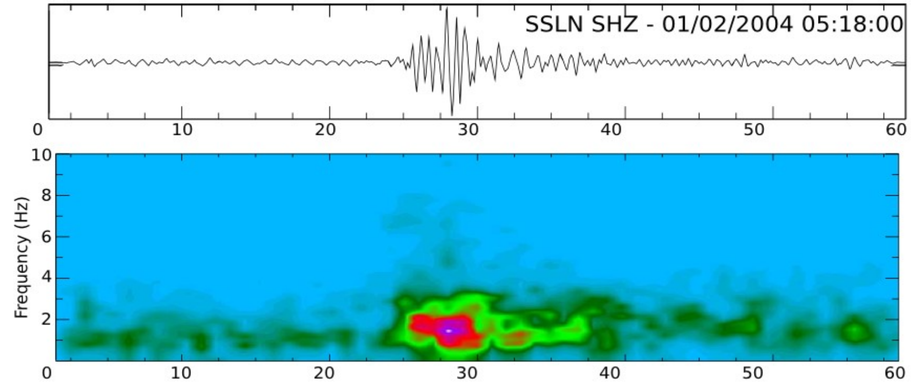
Paradigm II: Seismic Event Classes

- Distinguished by **frequency content** and shape/length

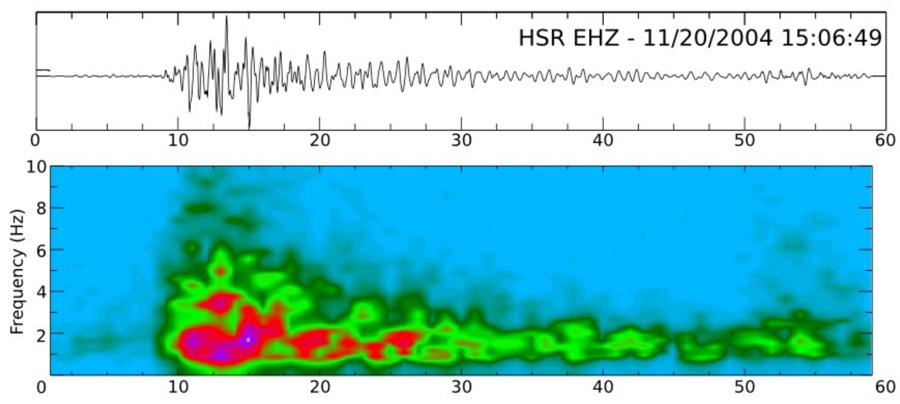
'VT' (volcano-tectonic) or 'HF' (high-frequency):



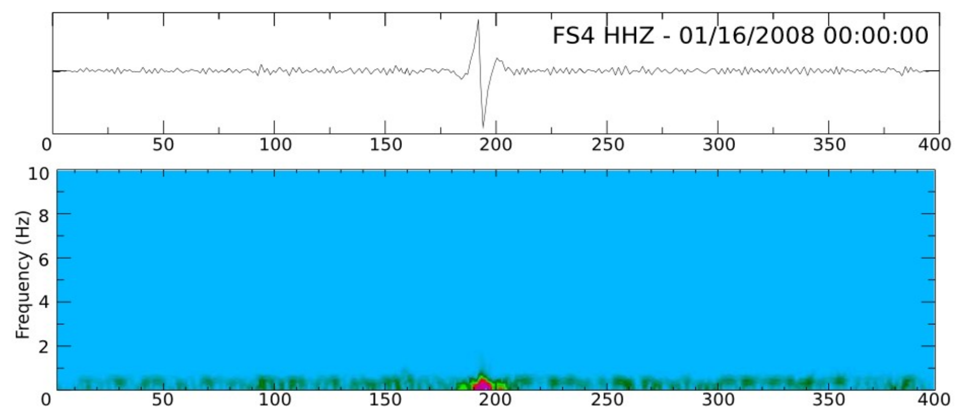
'LP' (long-period) or 'LF' (low-frequency):



Hybrid event:



'VLP' (very-long-period):

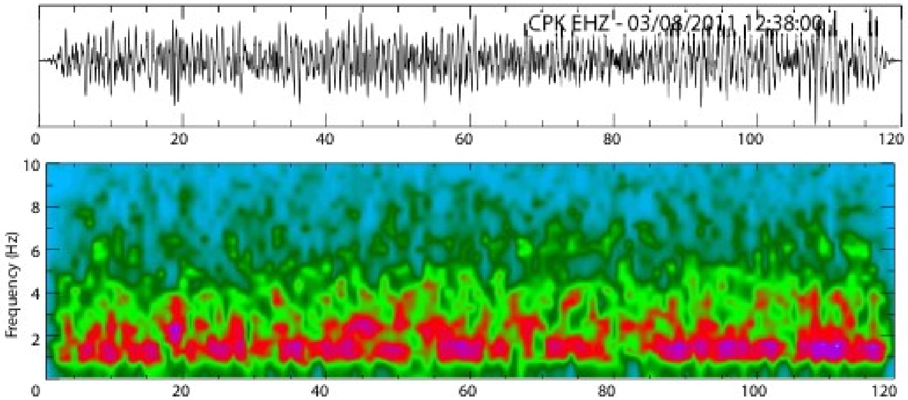


After McNutt and Roman 2015
see Minakami 1974, Lahr et al. 1994, Miller et al. 1998
for classification scheme descriptions

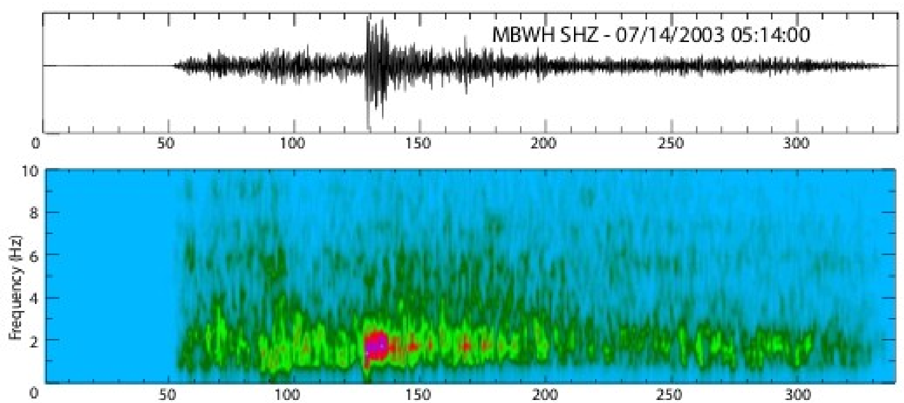
Paradigm II: Seismic Event Classes

- Distinguished by frequency content and **shape/length**

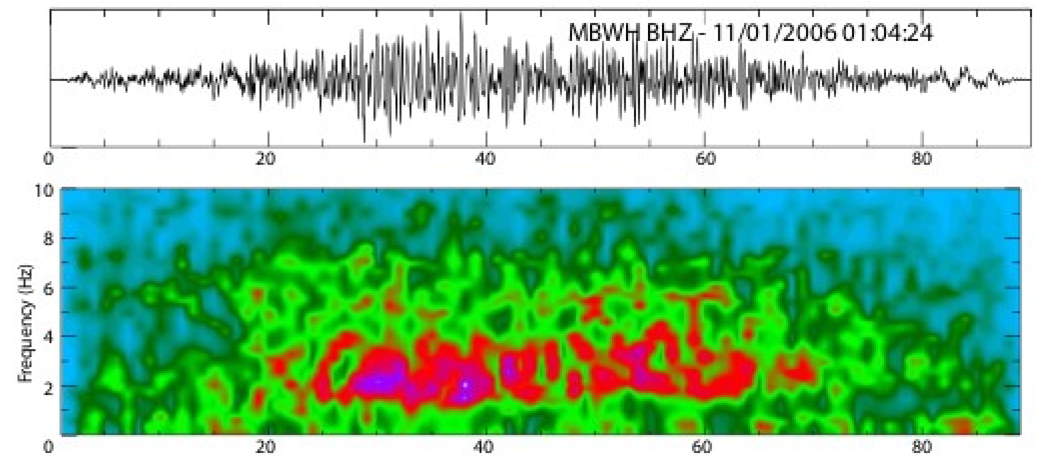
Volcanic tremor (can be harmonic or broadband):



Explosion with ground-coupled airwave:



Rockfall signal (note cigar shape):



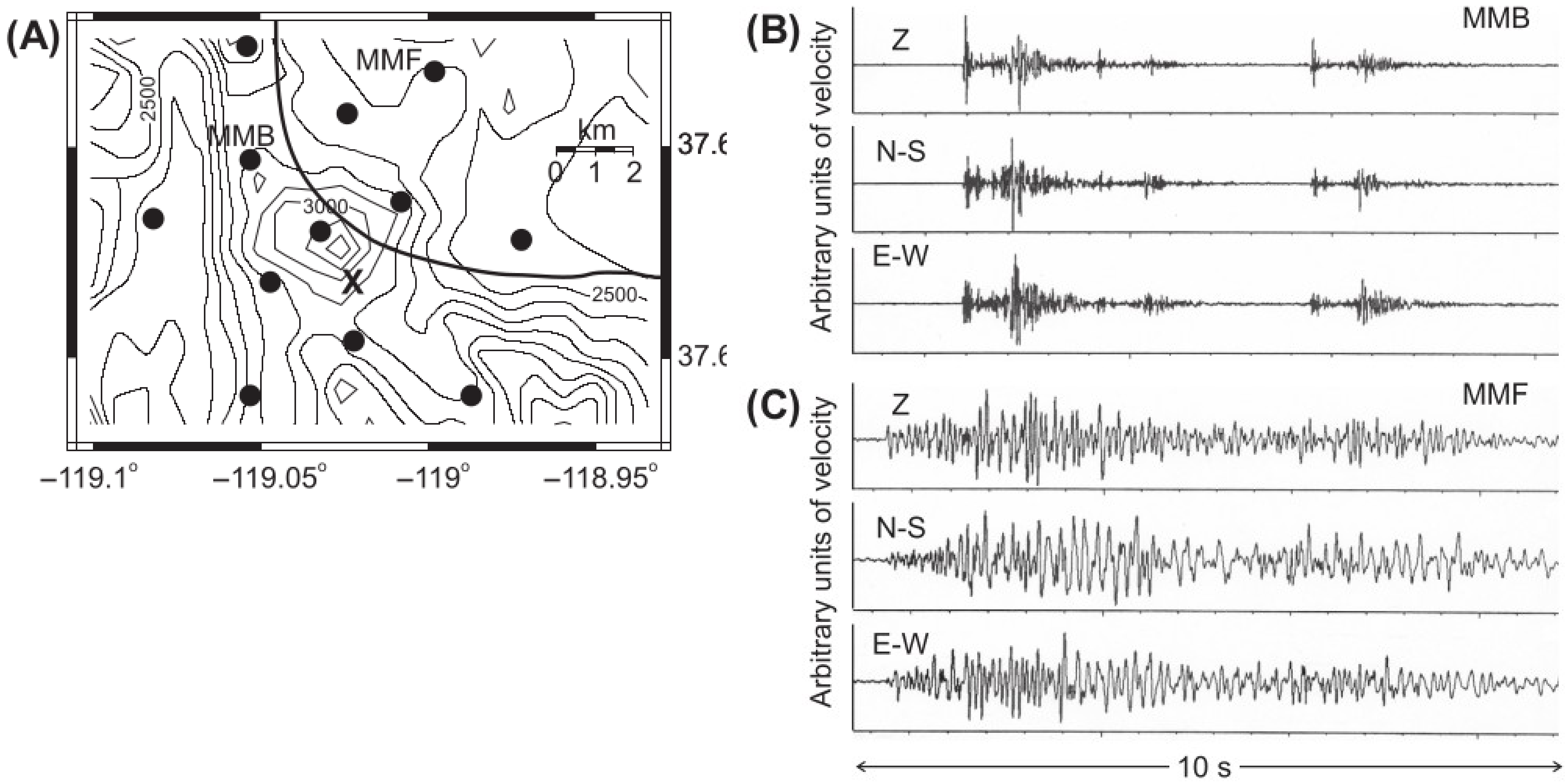
After McNutt and Roman 2015

Event Classification Issues

Utility and appropriateness of a universal event classification scheme?

- Implies the existence of clearly distinct classes rather than a spectrum of event characteristics
- Implies that event classes are uniquely linked to a particular source process
- Implies that events do not interfere/interact with each other

Station-to-station variations: Mammoth 1989



After Julian et al., 1998

Automated Event Detection/Classification

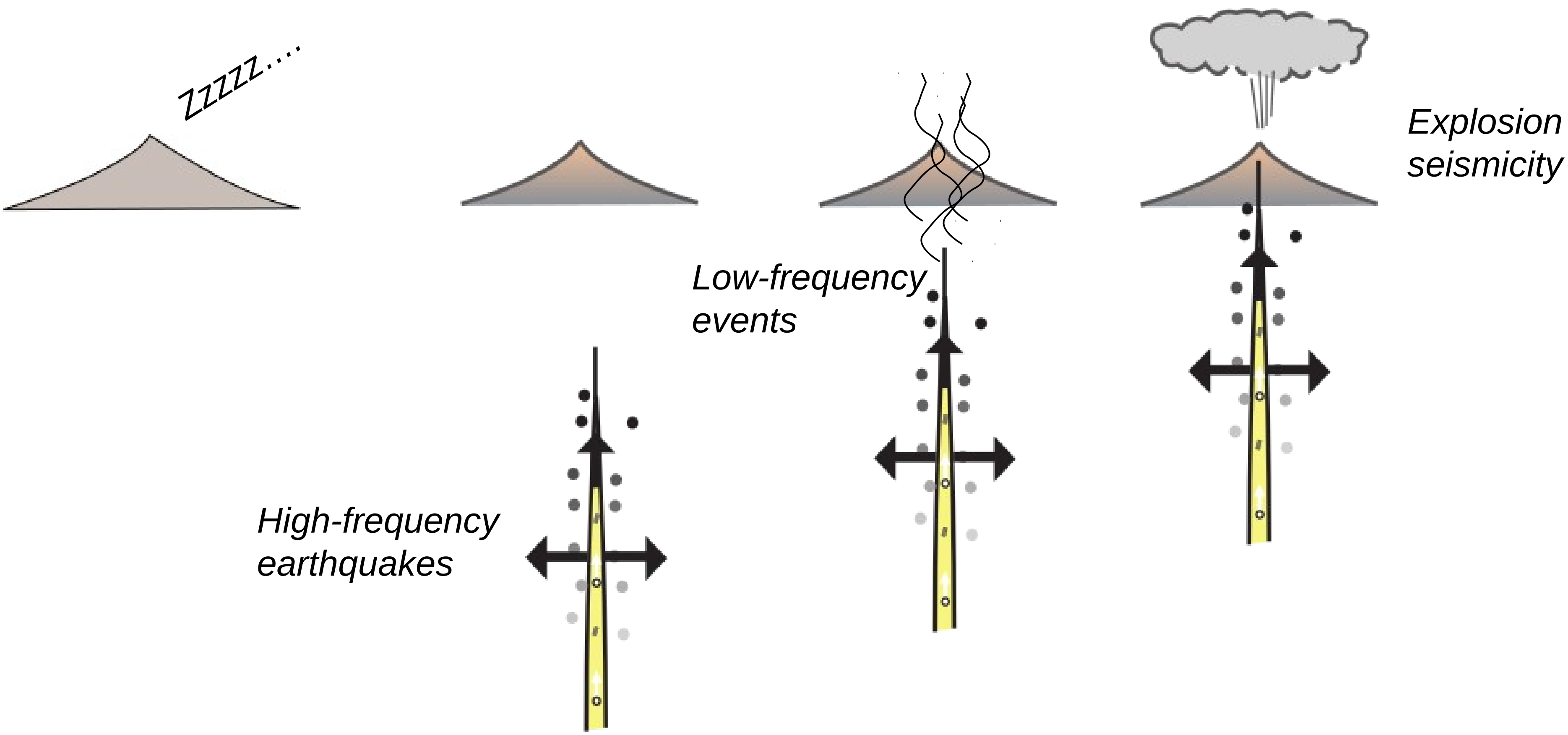
- Bueno et al. 2019, Seismol Res Lett
  https://github.com/srsudo/remos

- Malfante et al. 2018, IEEE Signal Proc Mag
  https://github.com/malfante/AAA

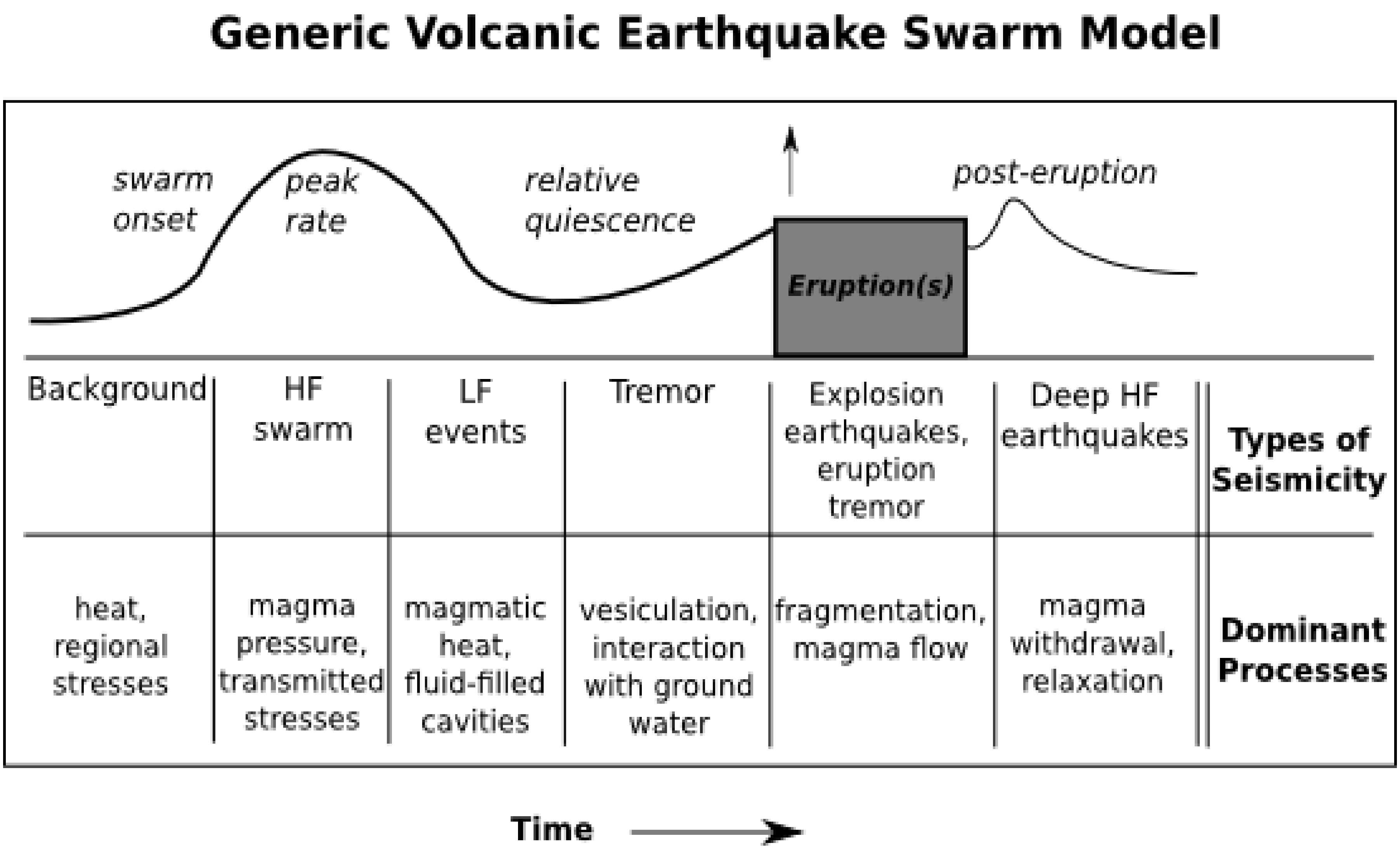
- Roman 2017, Geophys Res Lett
  https://github.com/dcroman/Tremometer
  (harmonic tremor detection)

- Wech and Creager 2008, Geophys Res Lett
  https://github.com/awech/AVO-alarms
  (broadband tremor detection)

Precursory Seismicity Patterns



Precursory Seismicity Patterns



McNutt and Benoit (1995)

Precursory Seismicity Patterns: MSH 2004

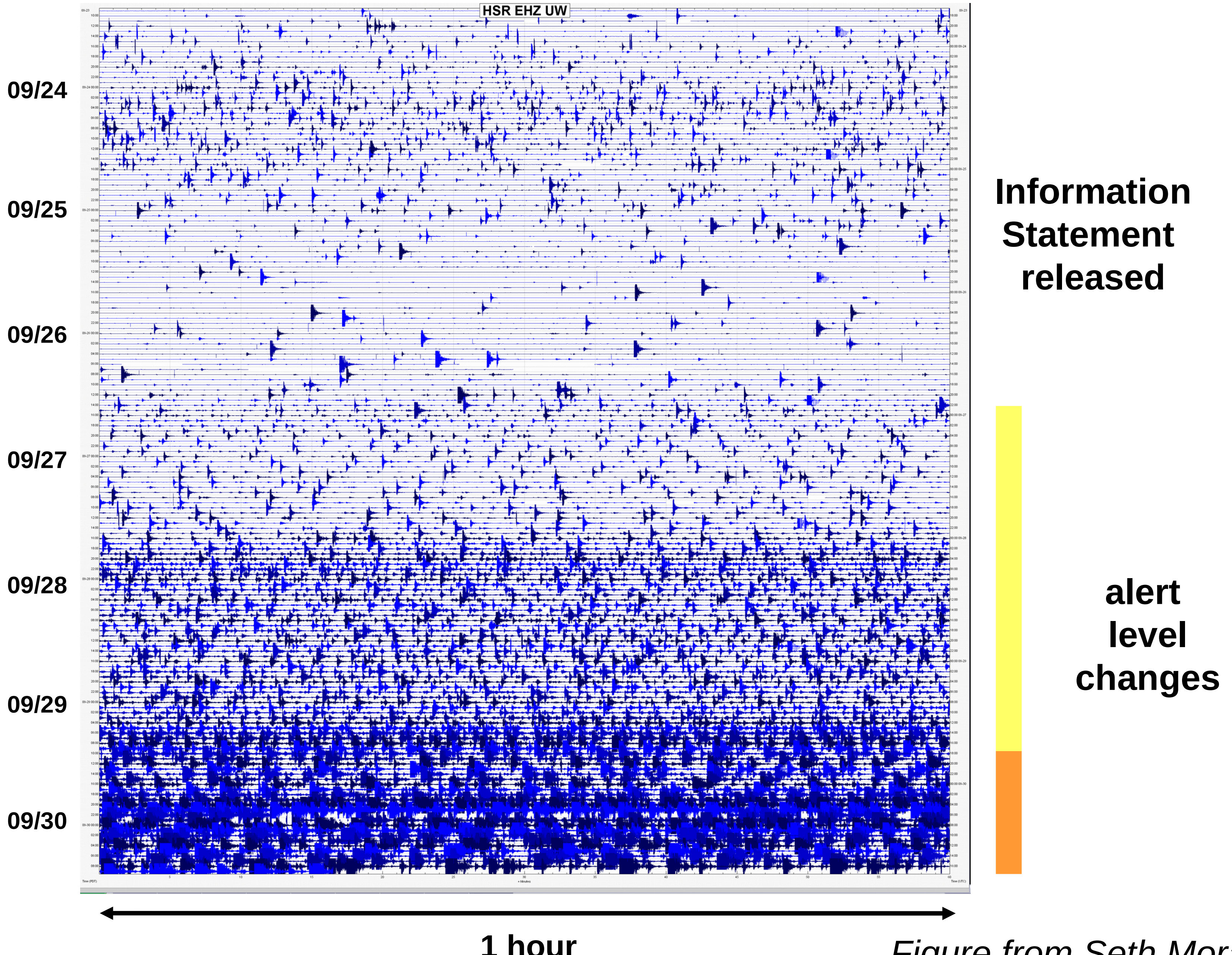
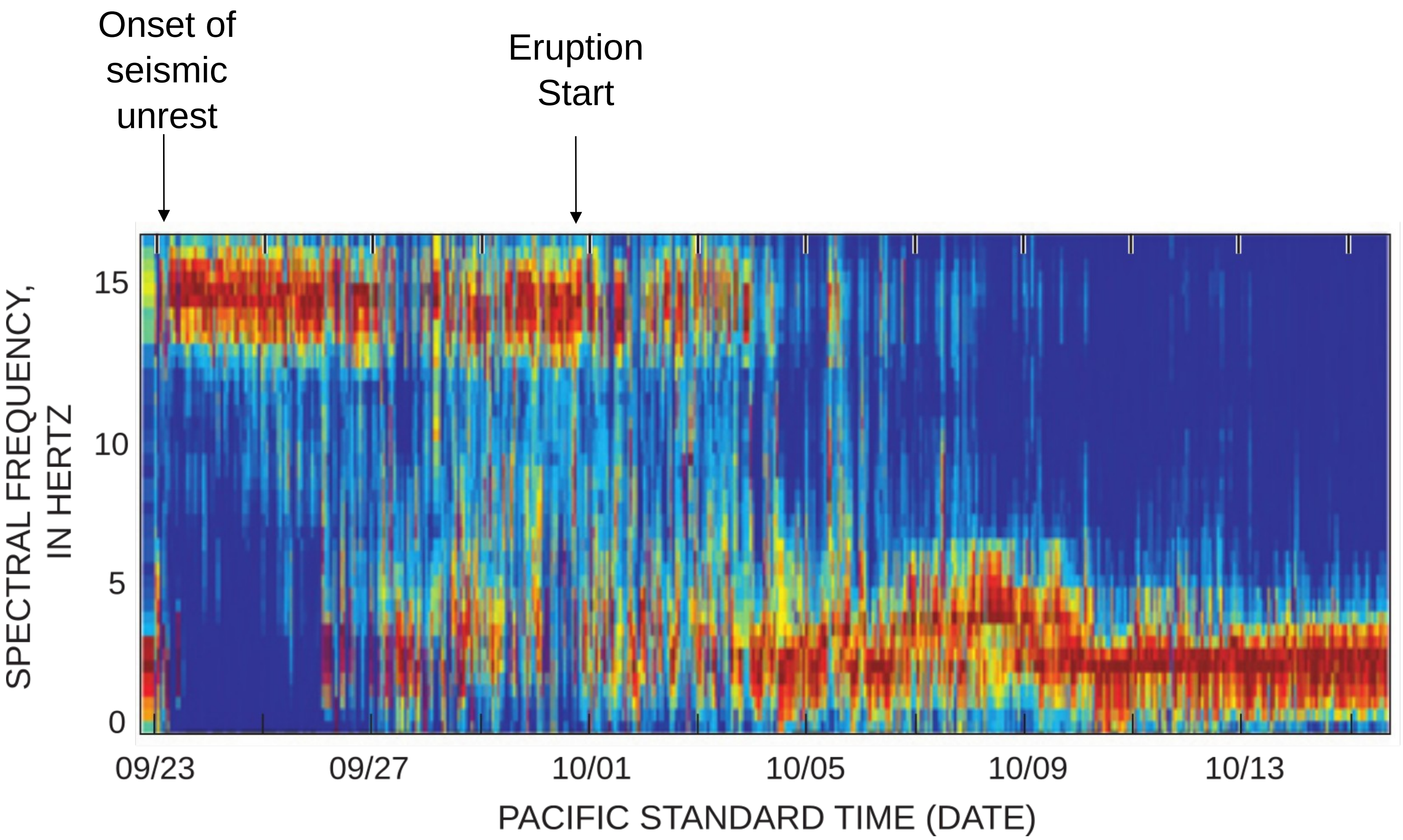


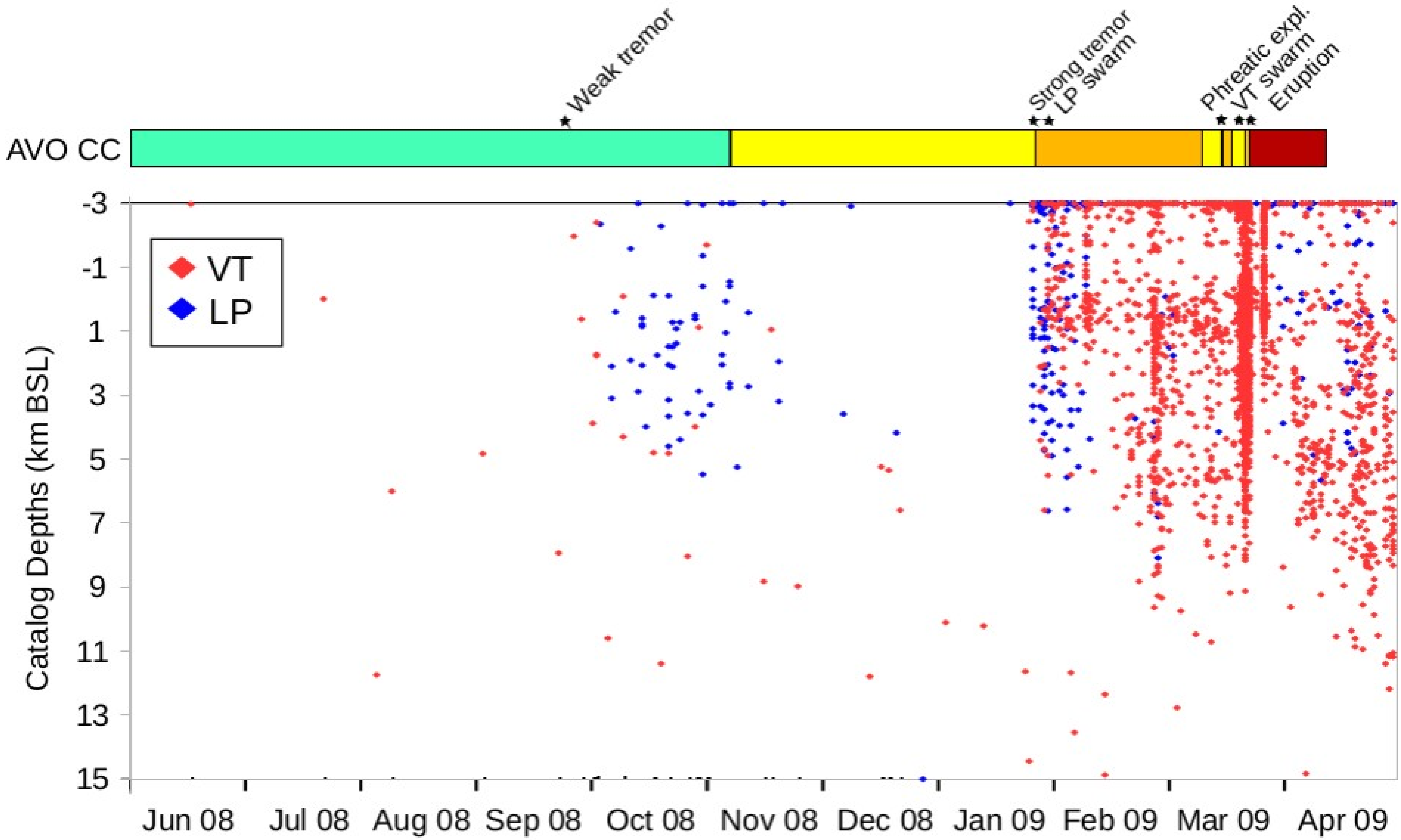
Figure from Seth Moran

Precursory Seismicity Patterns: MSH 2004



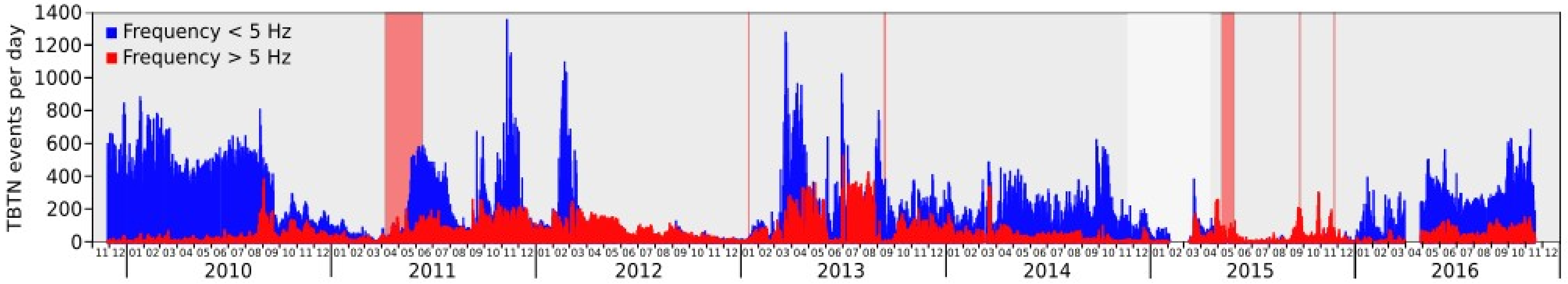
Moran et al., 2008

Precursory Seismicity Patterns: Redoubt 2009



After Roman and Gardine 2013 and Roman and Cashman 2018

Precursory (phreatic) Seismicity Patterns: Telica

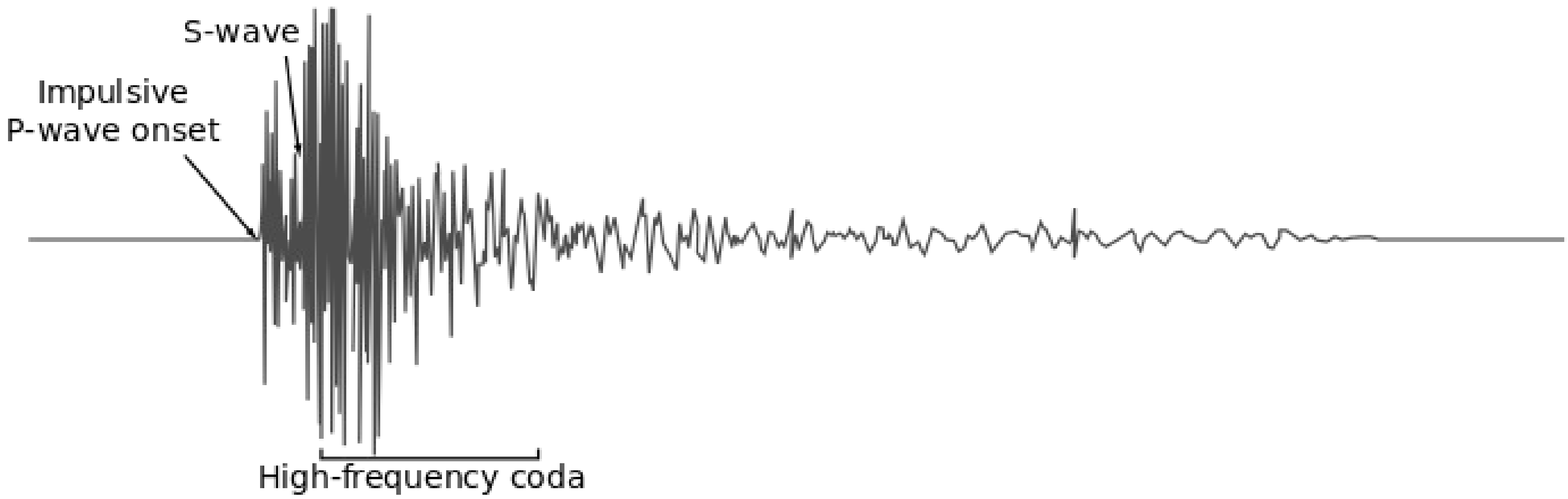


Geirsson et al., 2014
Rodgers et al., 2015
Roman et al., in review

Volcanotectonic (VT) (aka “HF”) earthquake:

- Clear high-frequency P and S waves, peak frequencies above 5 Hz, short coda

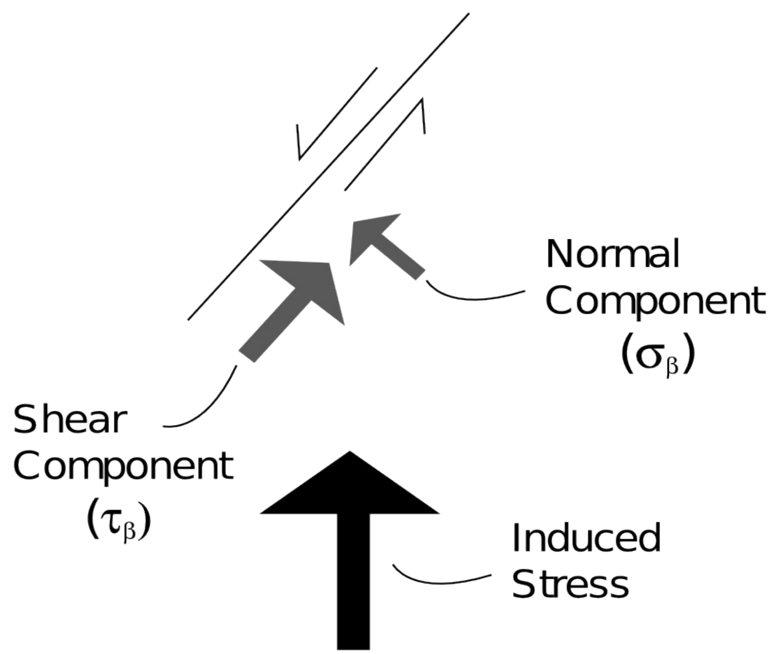
- Brittle response of host rock to processes in the magmatic system

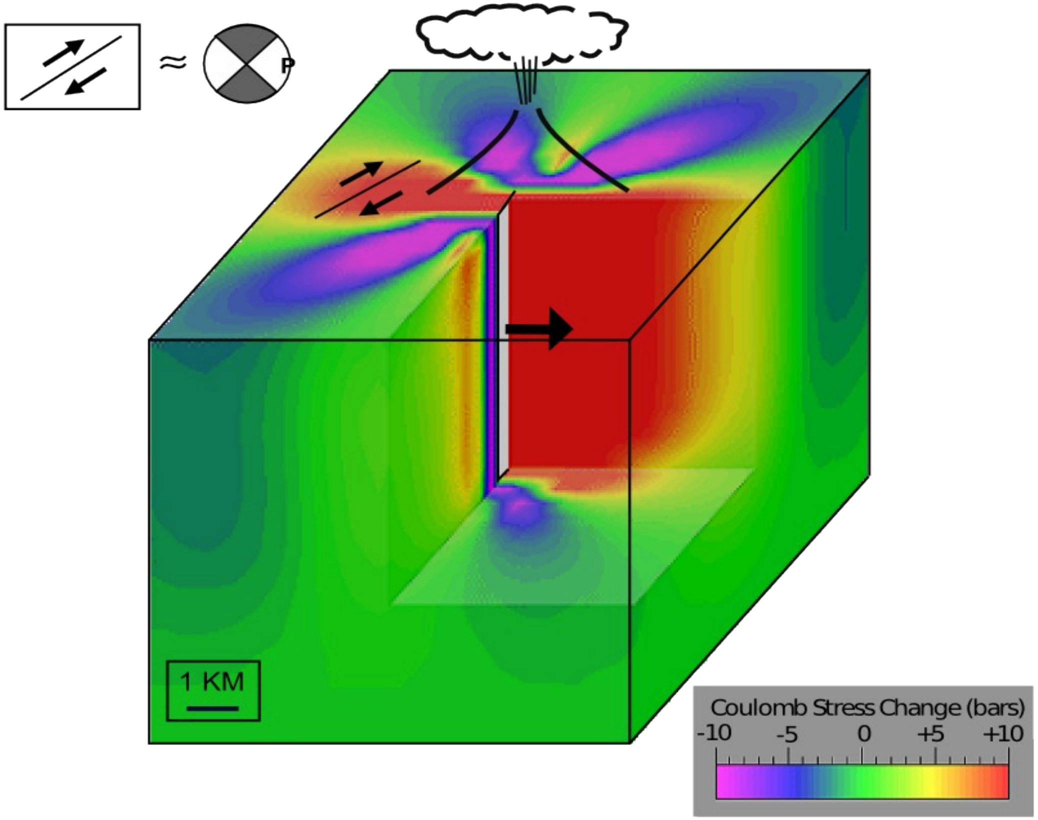


VTs: Theory

Coulomb stress change:

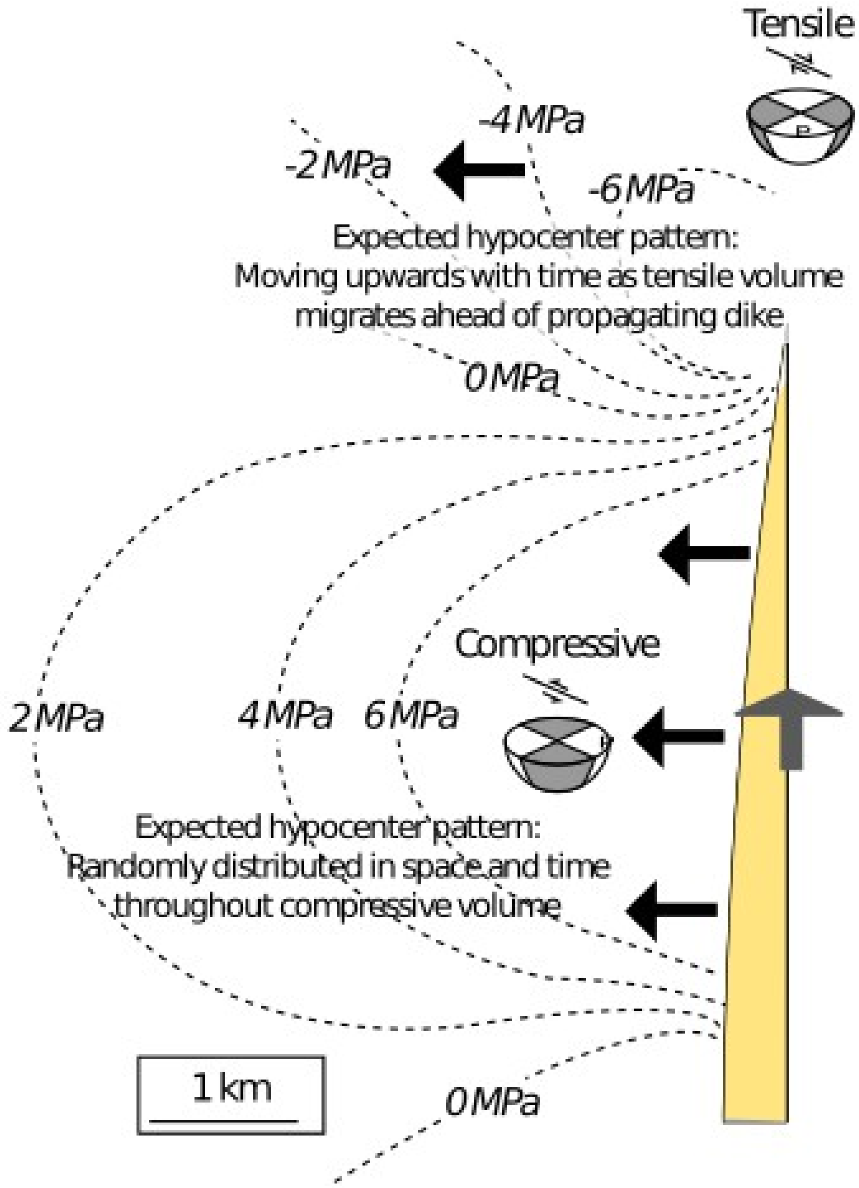
$$\Delta\sigma_f = \tau_\beta - \mu\,(\Delta\sigma_\beta - \Delta p)$$





See Toda et al., 2002; Segall et al. 2013;
Coulomb 3.3: https://earthquake.usgs.gov/research/software/coulomb/

Dike-induced stress regimes



Numerical models show
two induced stress regimes:

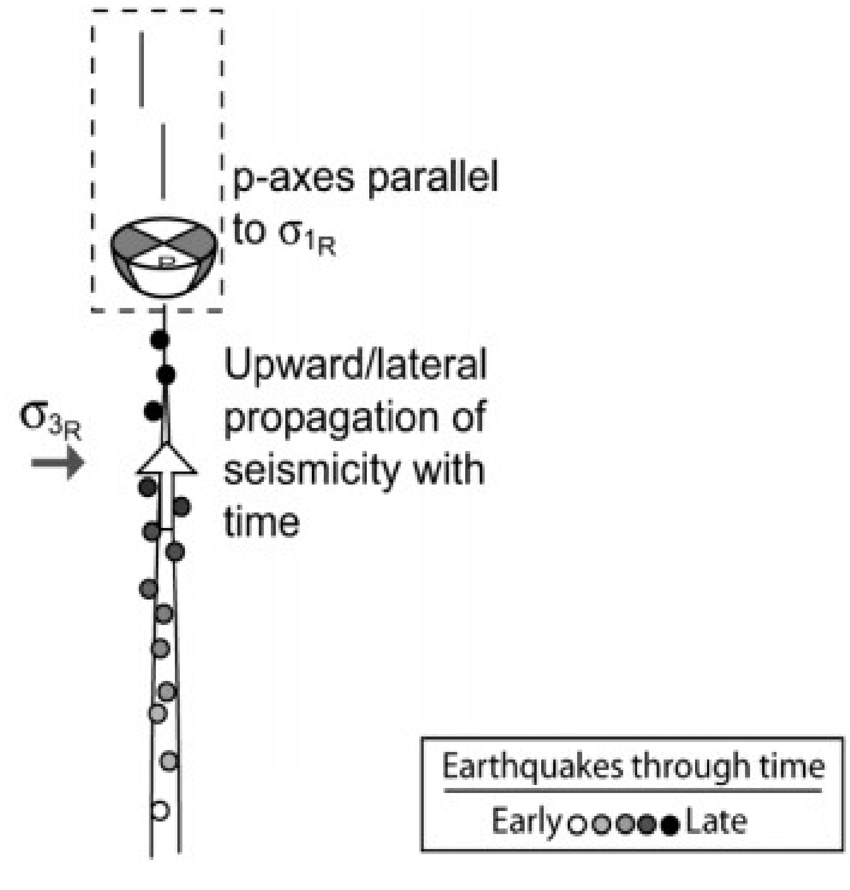
- Compression in walls of dike (perpendicular to dike strike)
- Tension above propagating dike

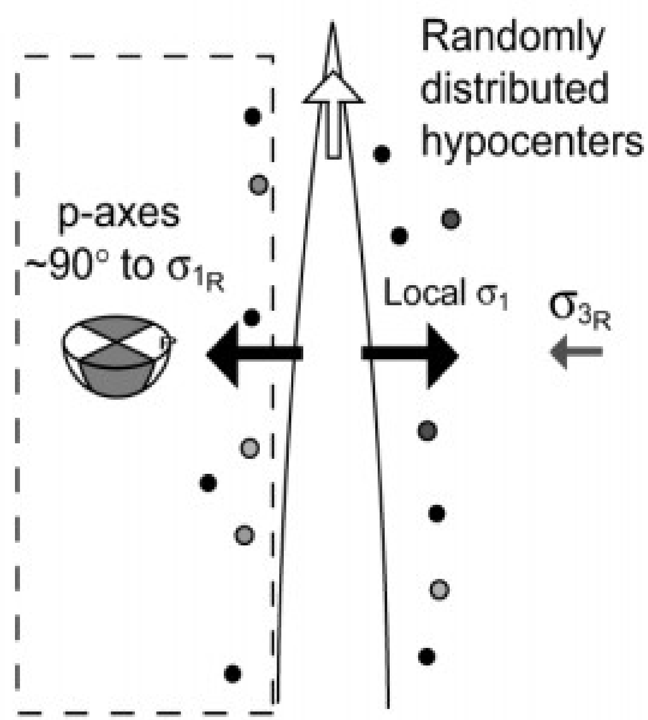
After Rubin and Pollard 1988

VTs: Theory

Low-viscosity magmas

High-viscosity magmas



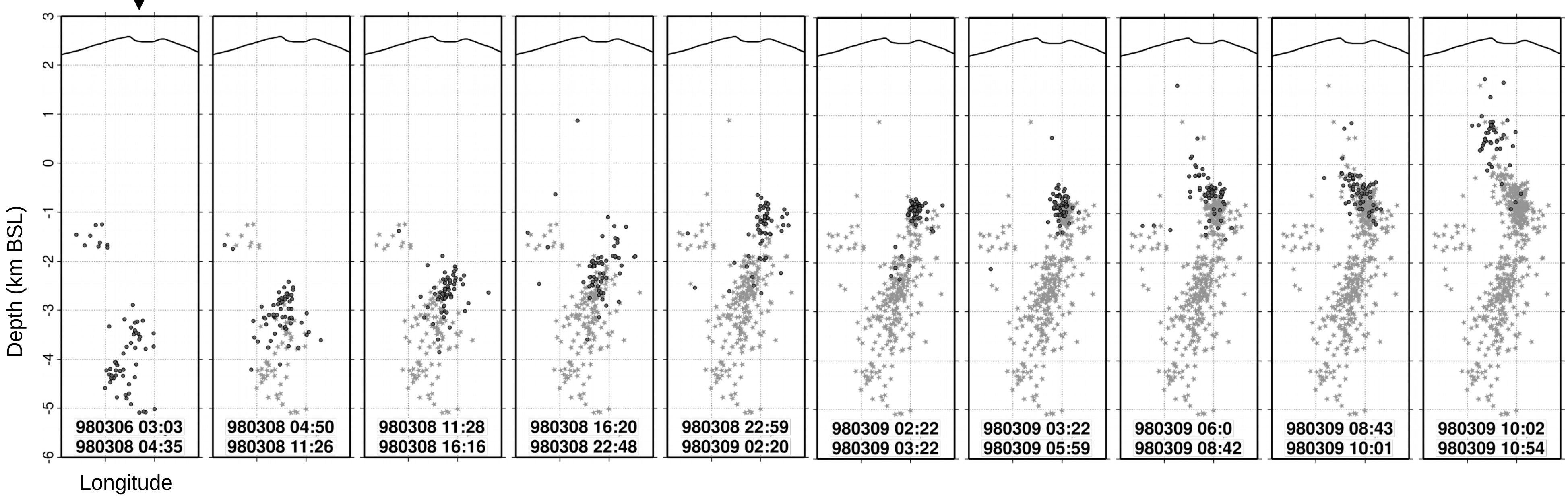


After Roman and Cashman (2006)

Piton de la Fournaise, La Reunion - 1998

Onset of seismic unrest

Eruption Start

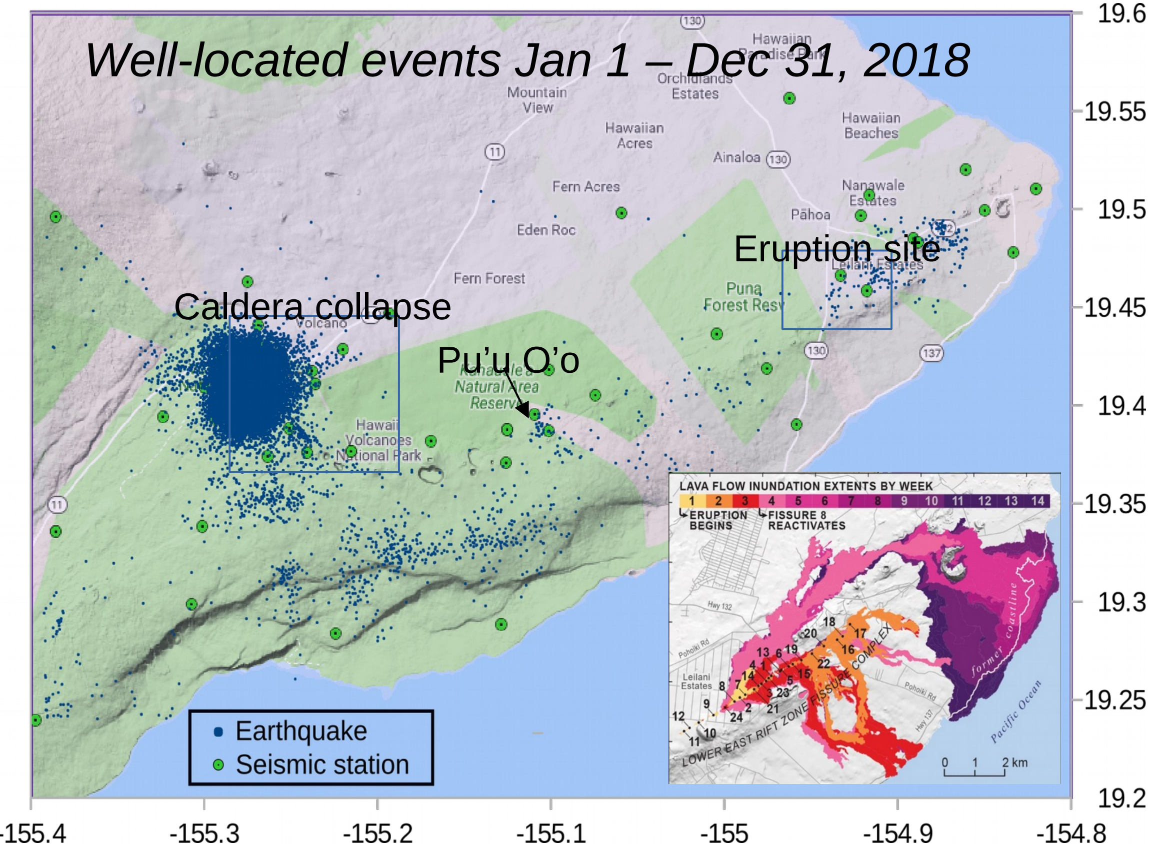


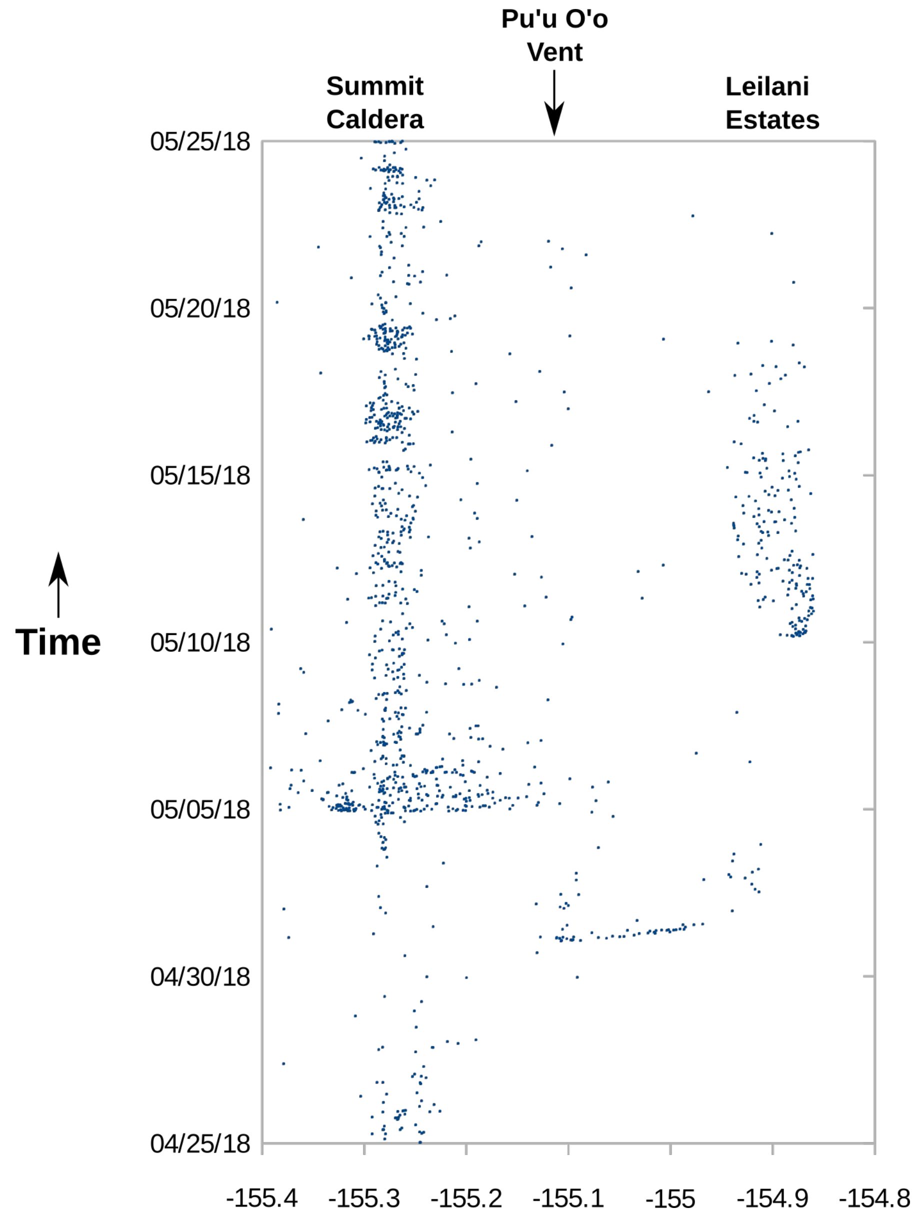
Time →

Battaglia et al., 2005

VTs: Low-Viscosity Magmas

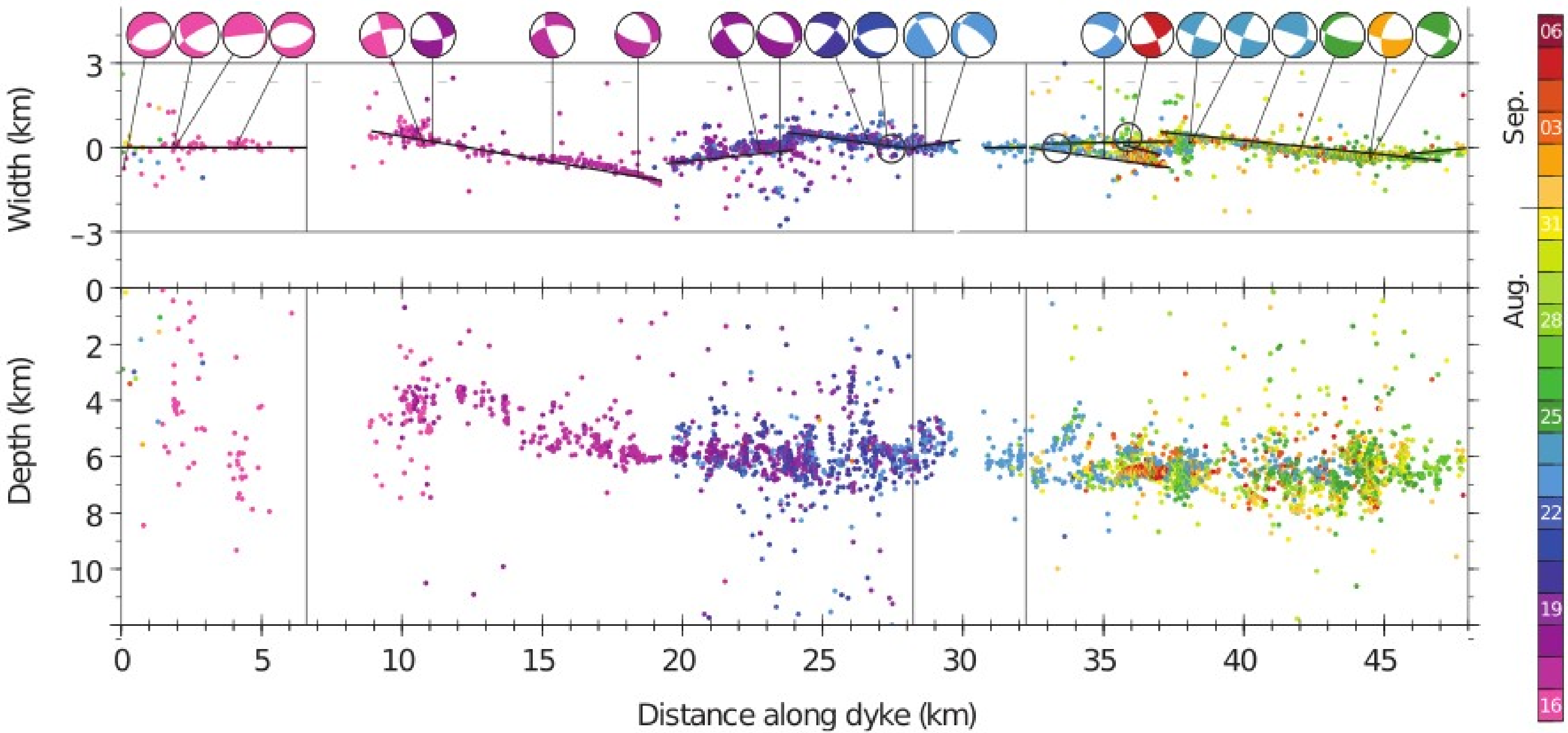
Kilauea, Hawai’i - 2018





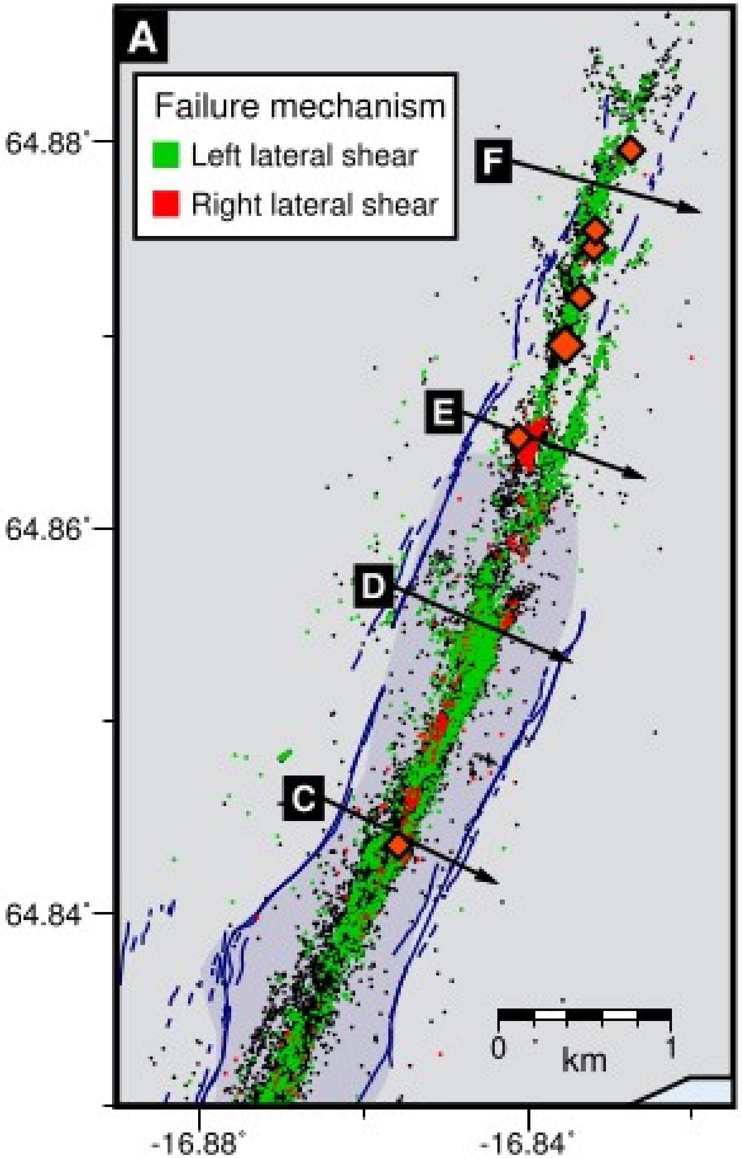
Inset: Neal et al. (2018)

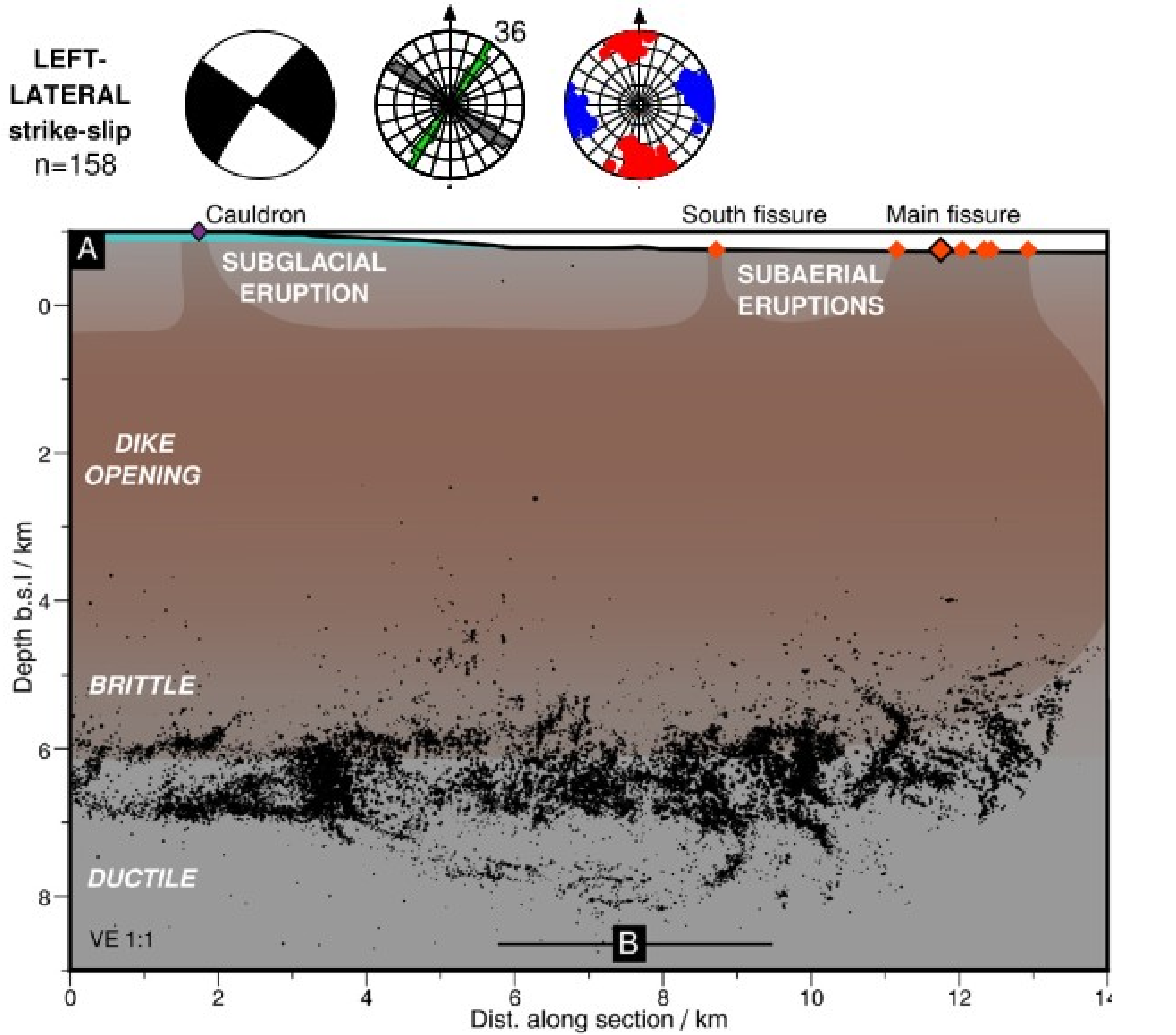
Holuhraun, Iceland - 2014



After Sigmundsson et al., 2015

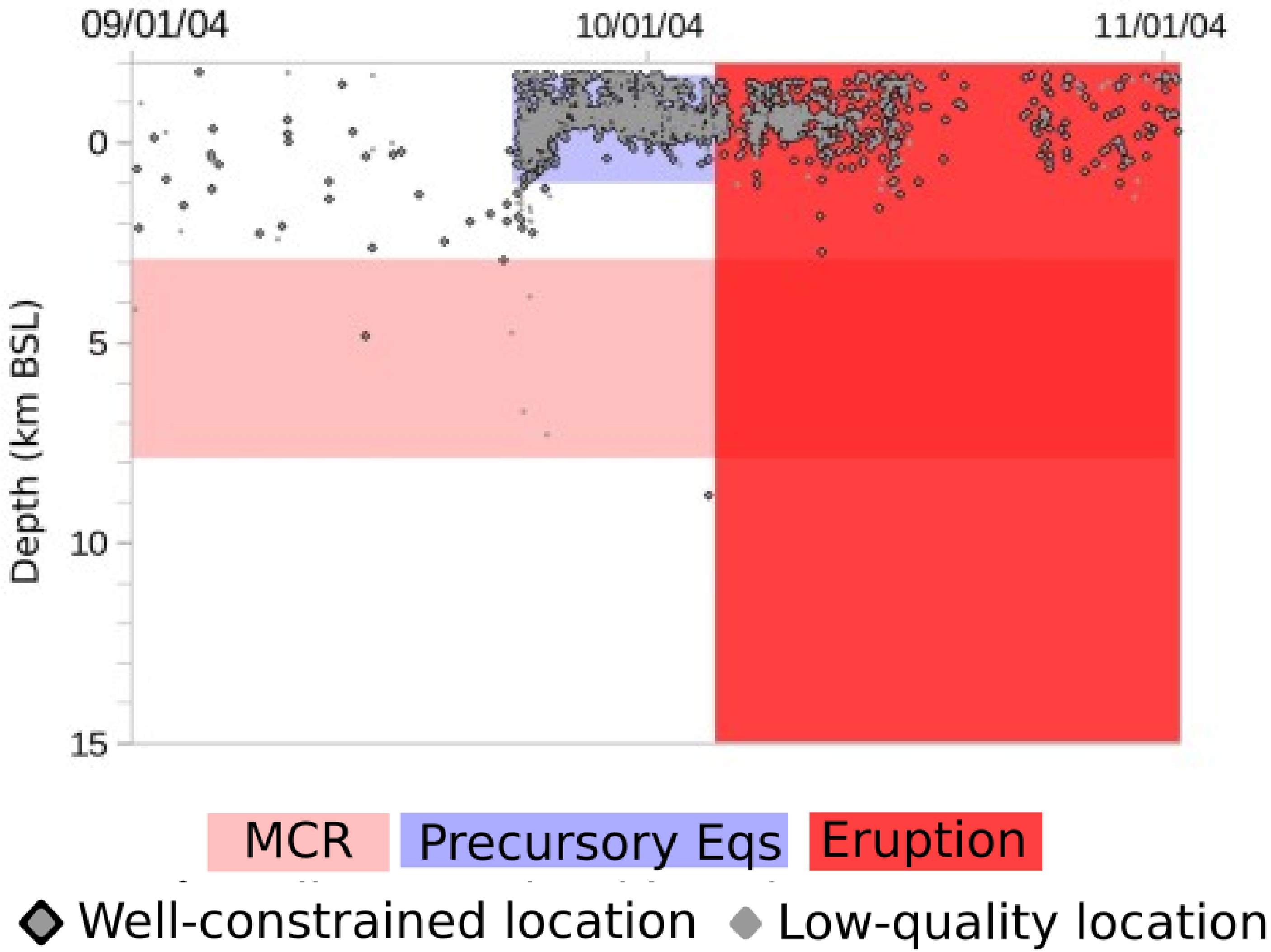
Holuhraun, Iceland - 2014





Agustsdottir et al., 2016; Woods et al., 2019

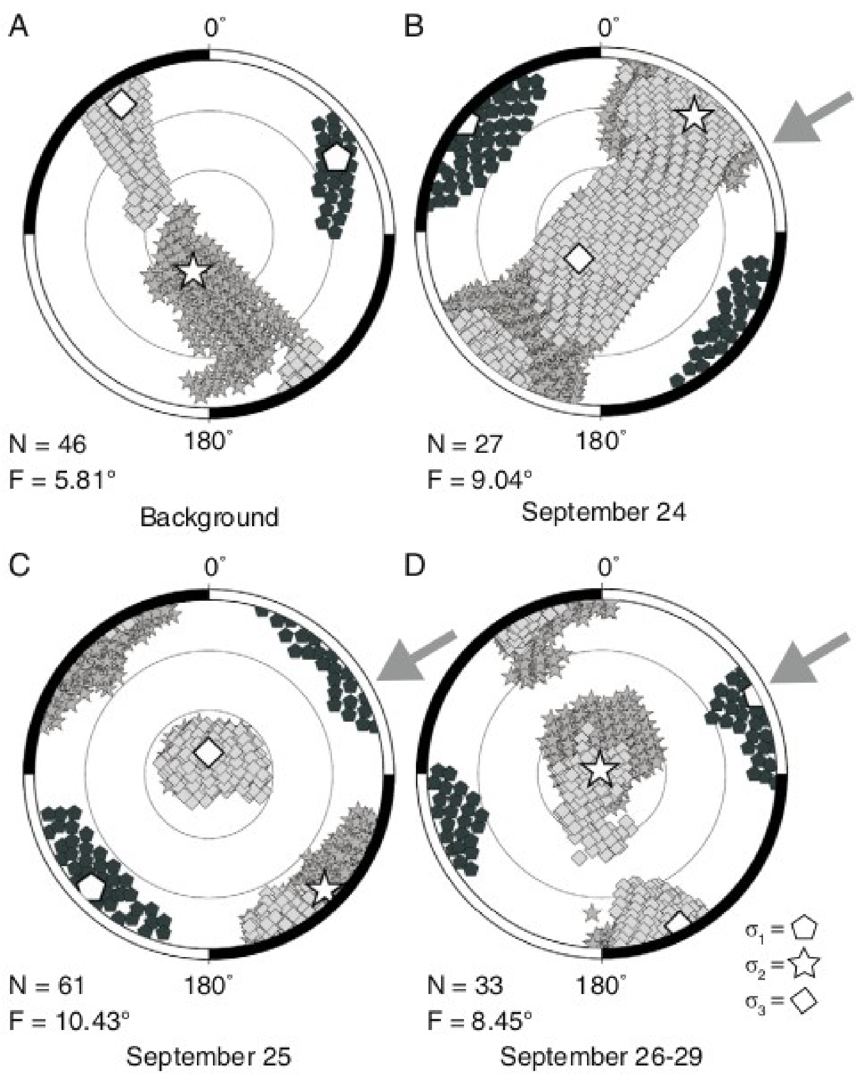
Mt. St. Helens, Washington - 2004

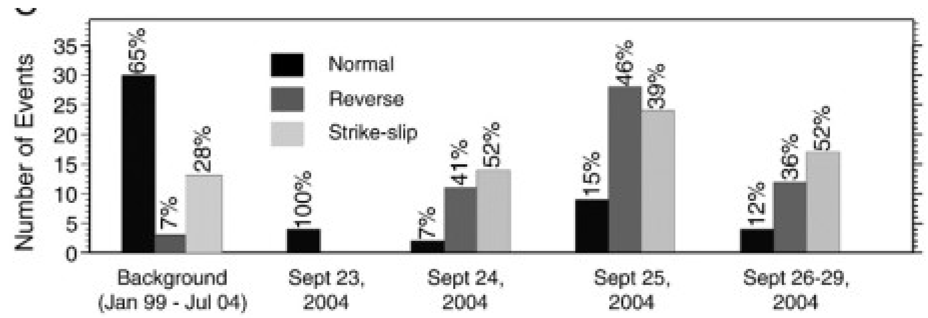


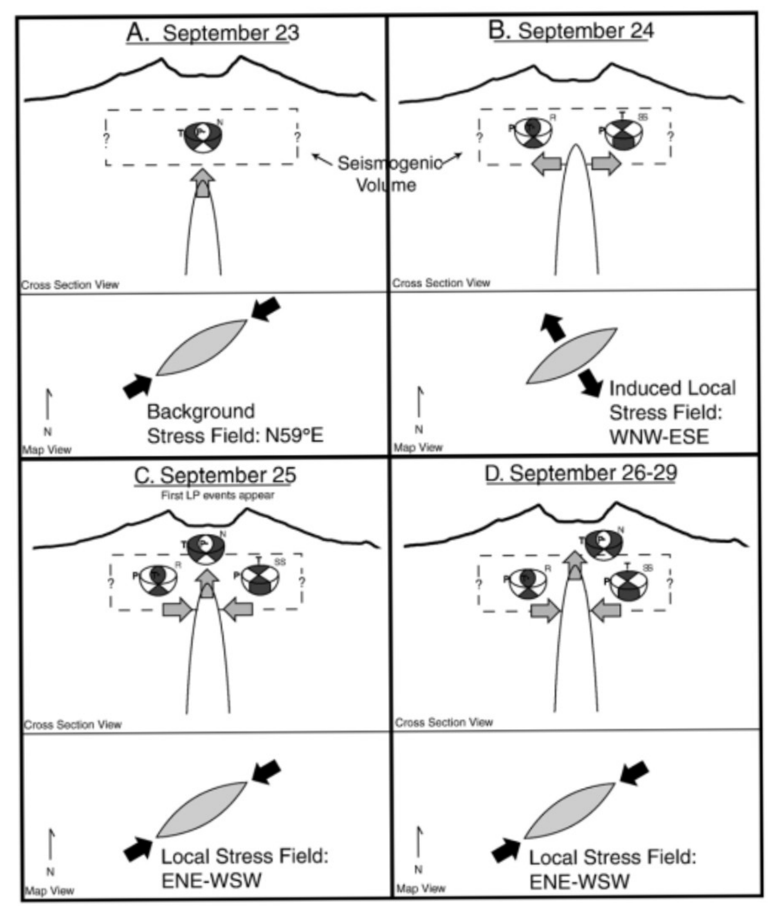
Roman and Cashman (2018)

Seismic: Moran et al. 2008; Geodesy: Dzurisin et al. 2008; Petrology: Pallister et al. 2008

Mt. St. Helens, Washington - 2004

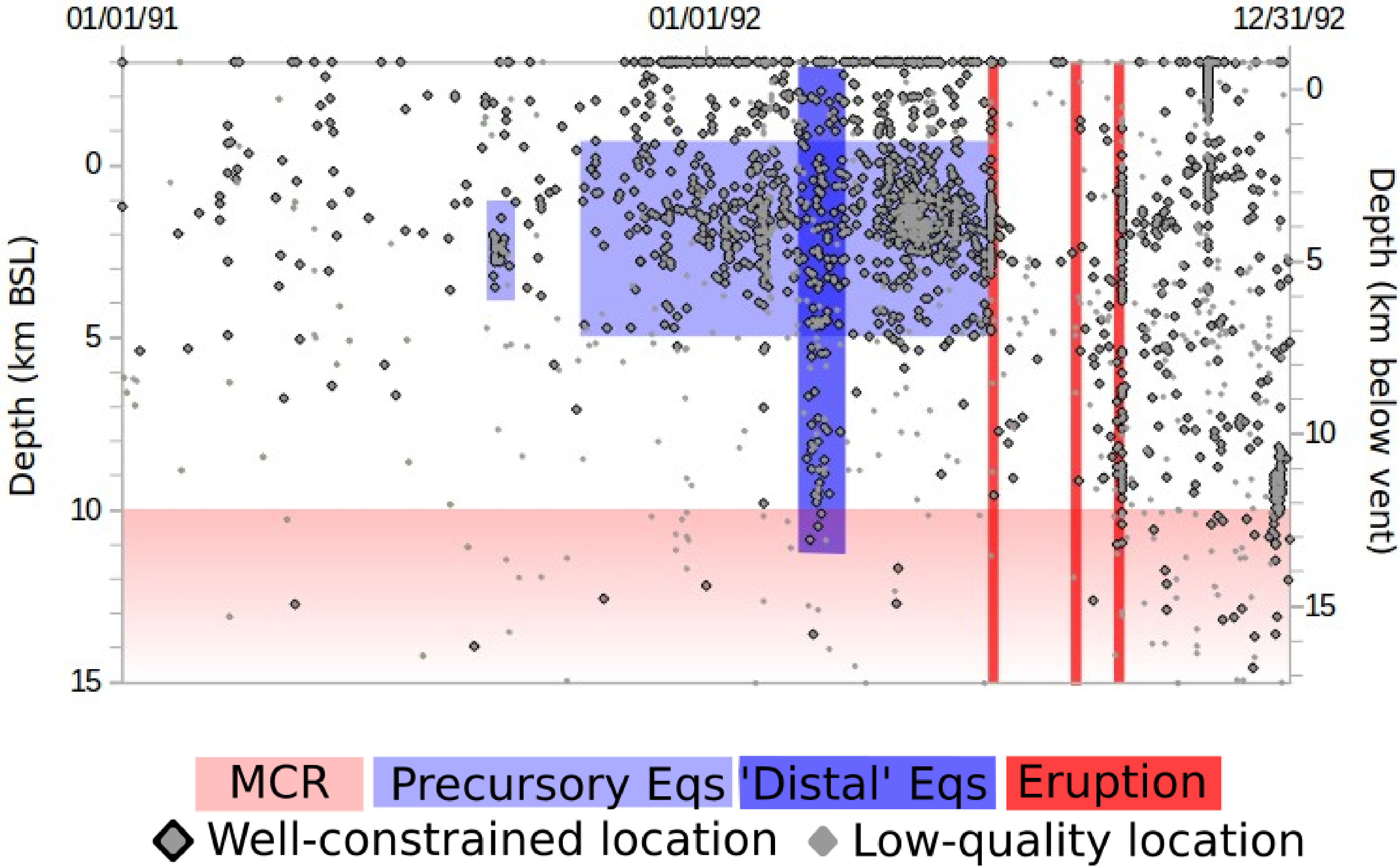






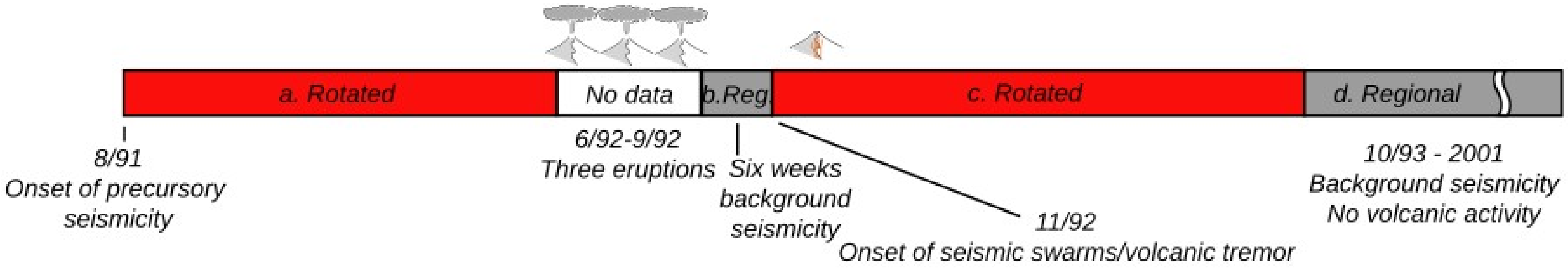
Lehto et al., 2010

Mt. Spurr/Crater Peak, Alaska - 1992

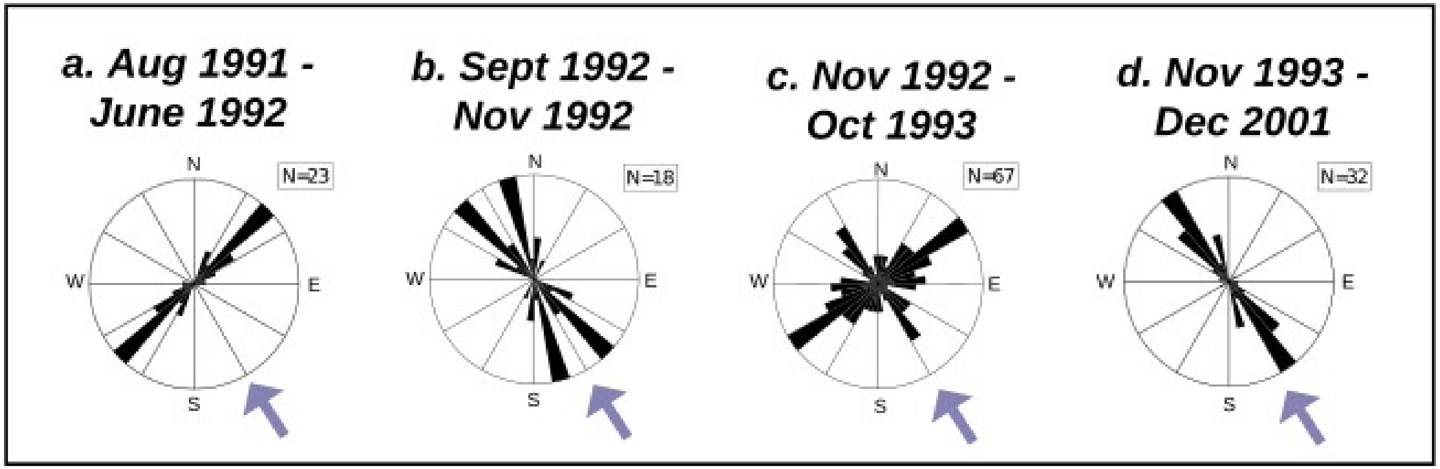


Roman and Cashman (2018)
Seismic: Power et al. 1995; Petrology: Harbin et al. 1995 and Power et al. 2002

Mt. Spurr/Crater Peak, Alaska - 1992

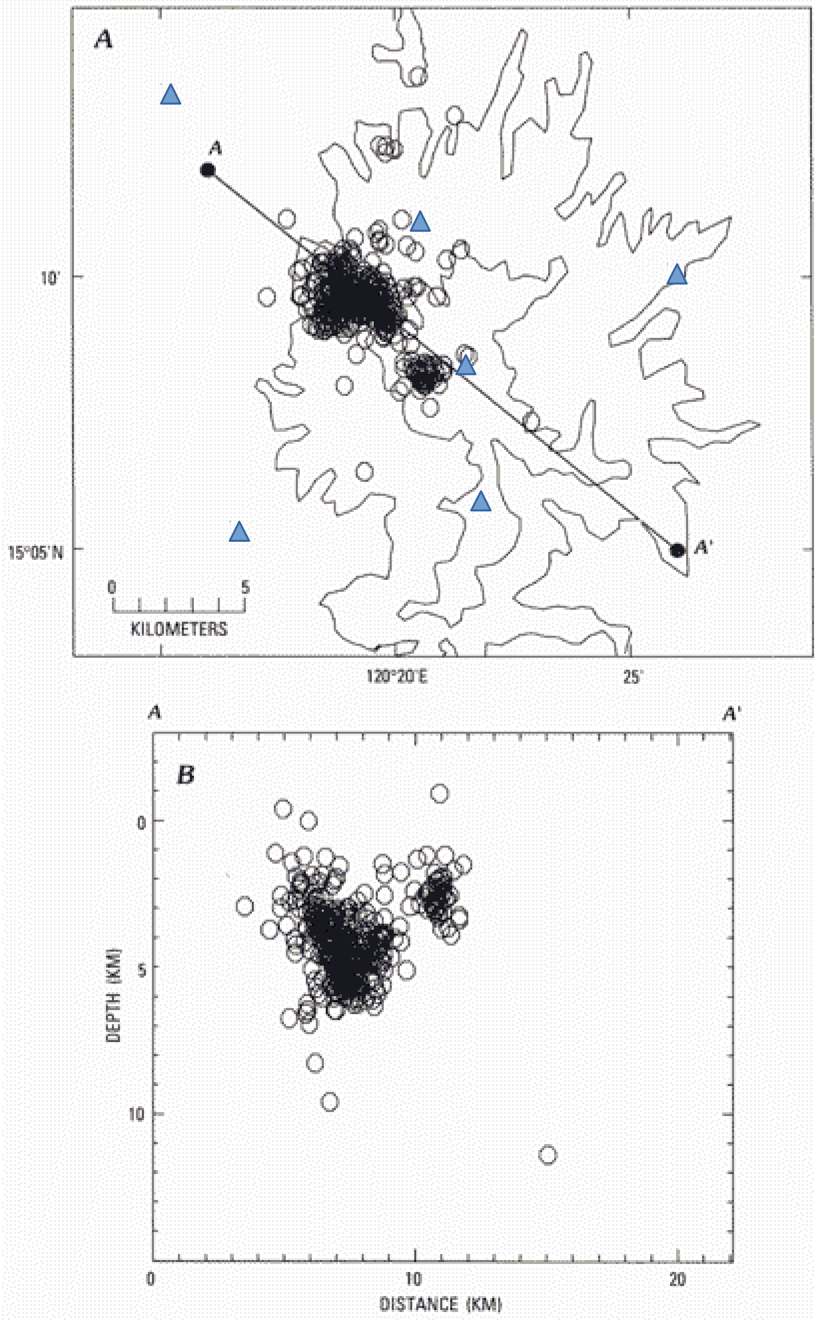


Fault-plane solution P-Axis azimuths



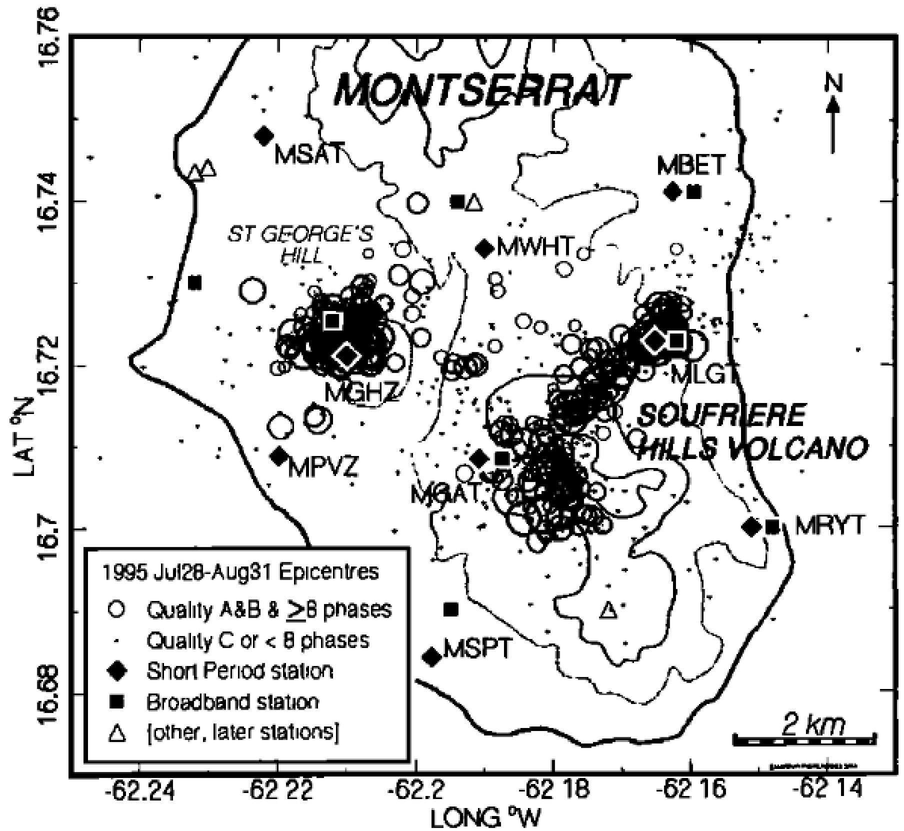
Roman et al. (2004)

Distal VT Earthquakes



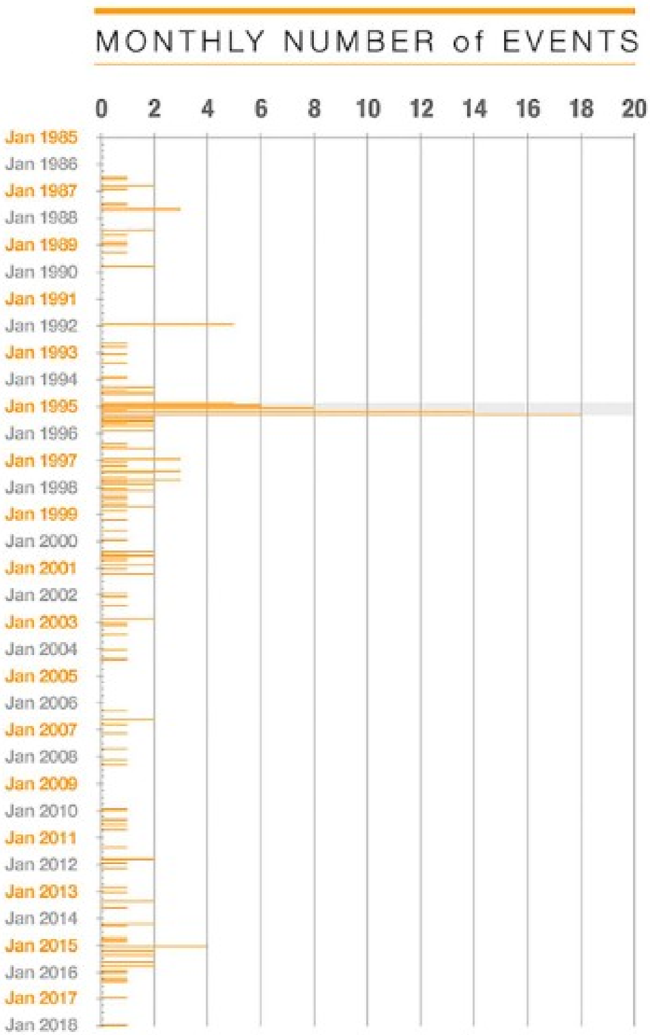
Harlow et al., 1996

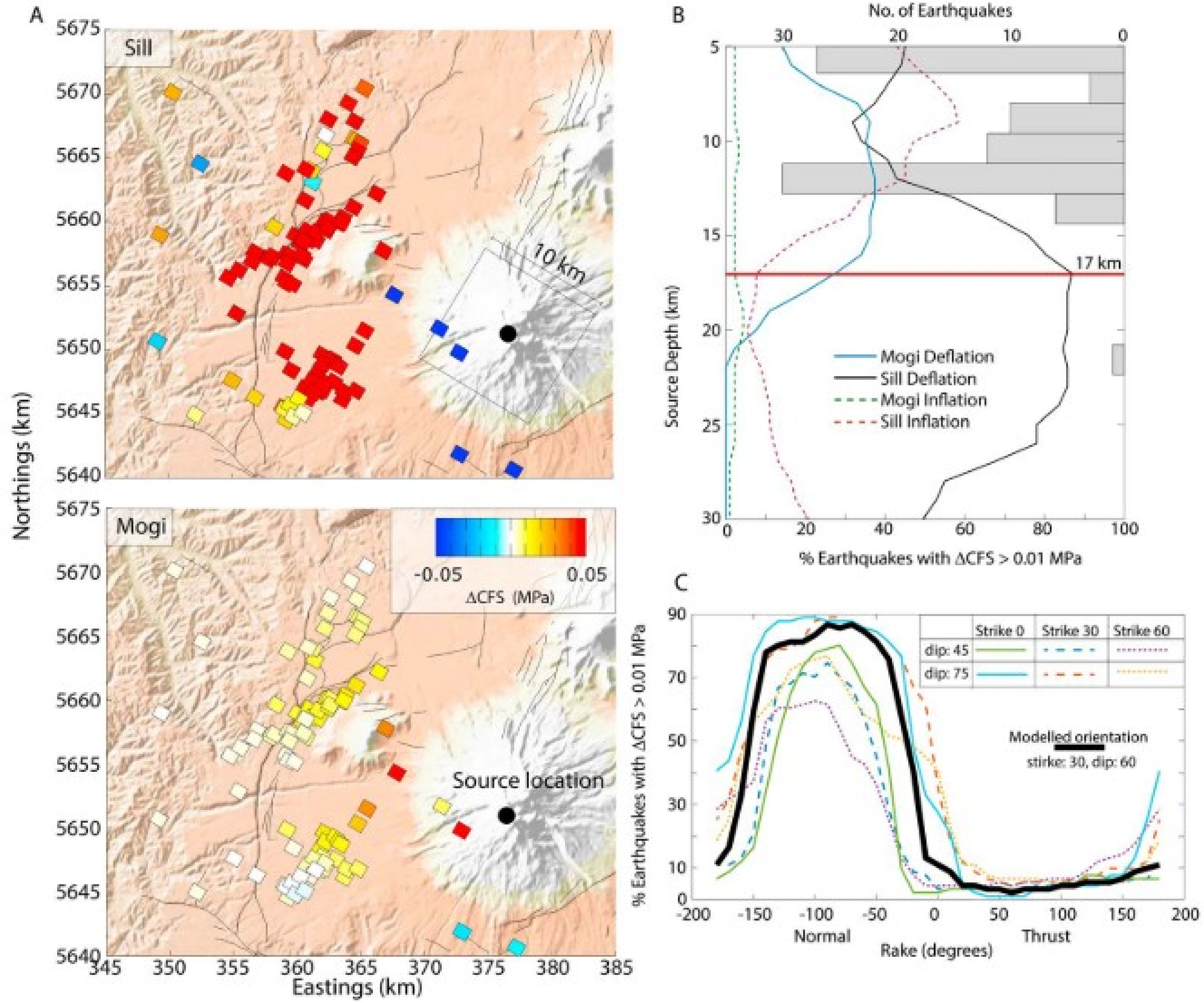
Left: Pinatubo 1991
Below: Soufriere Hills 1995



Aspinall et al., 1998

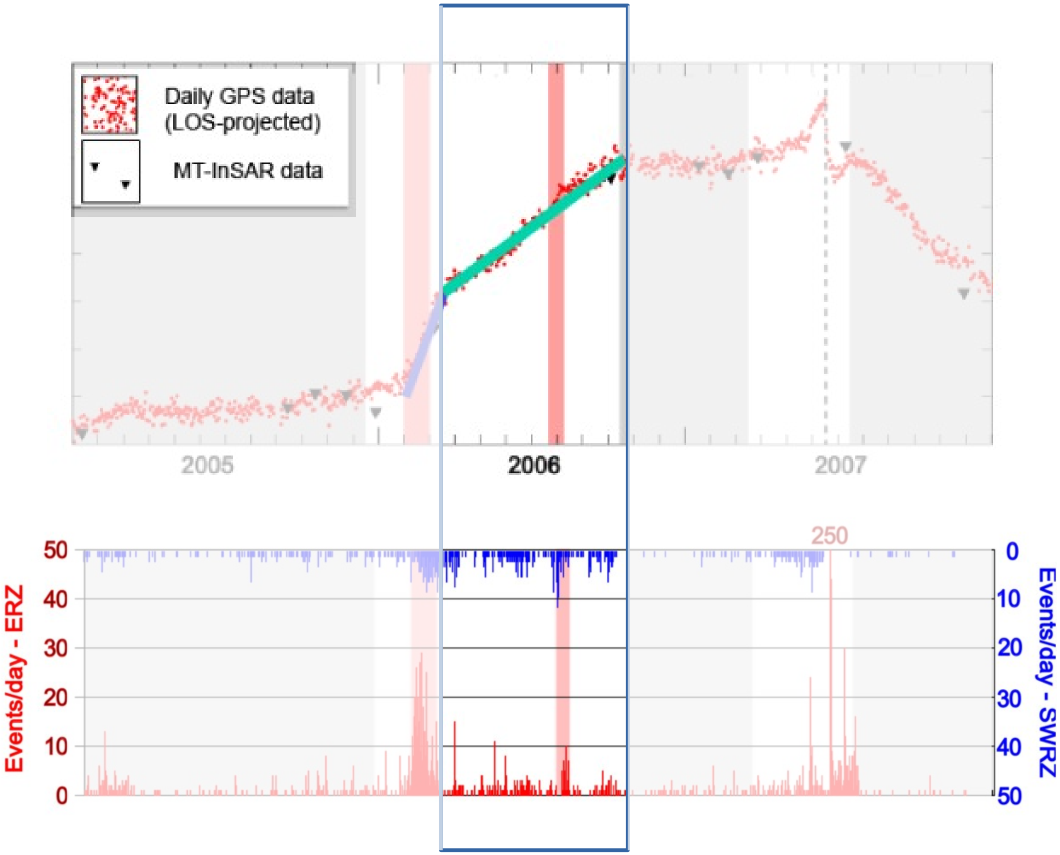
Ruapehu, New Zealand - 1995

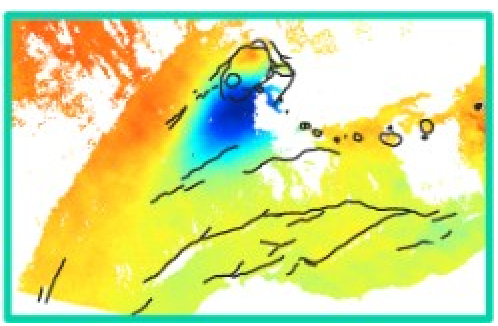


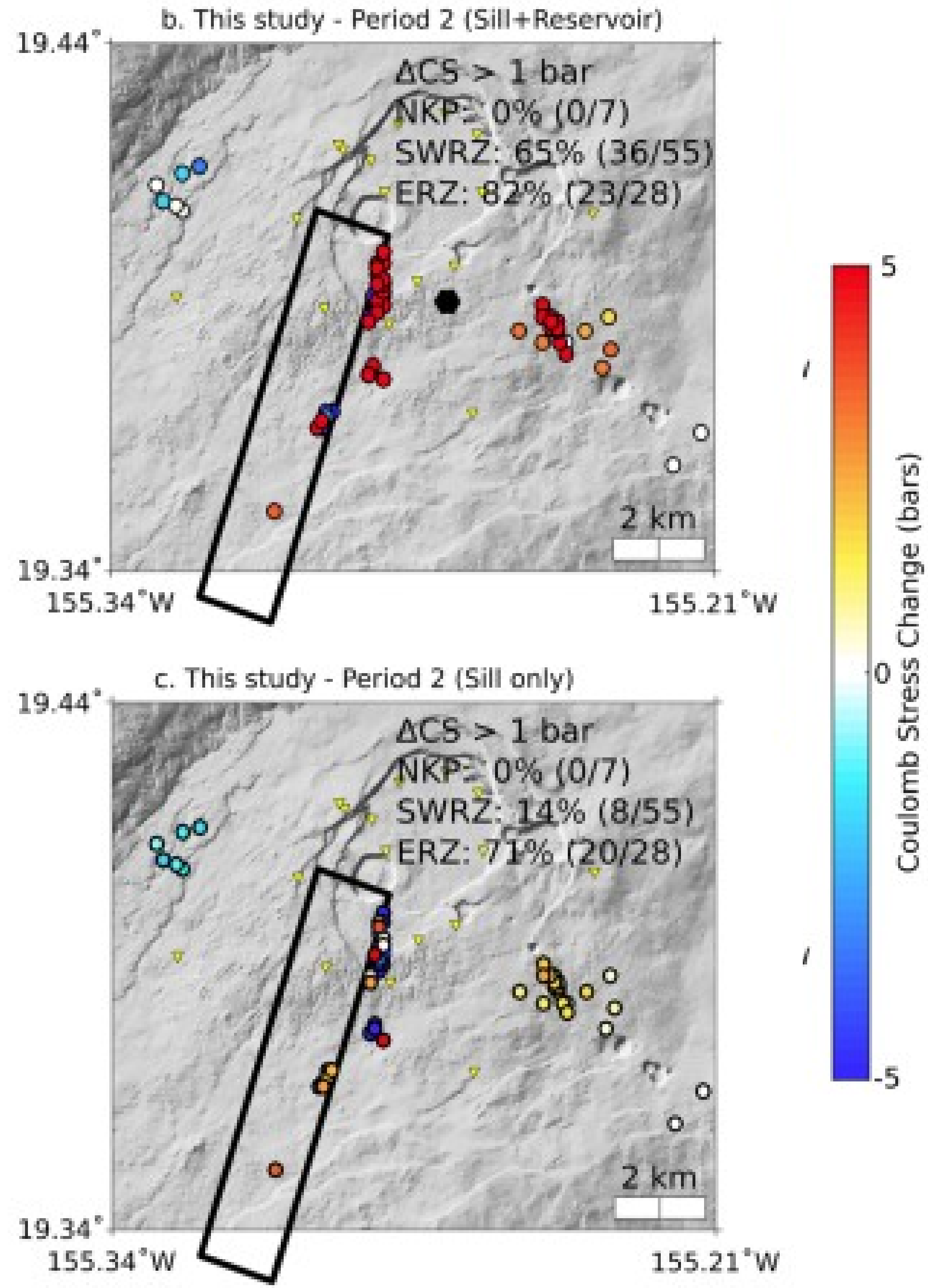


Hurst et al., 2018

Distal VT Earthquakes







Wauthier et al., 2016