Volcanoes in Compressional Settings (a seismological perspective)

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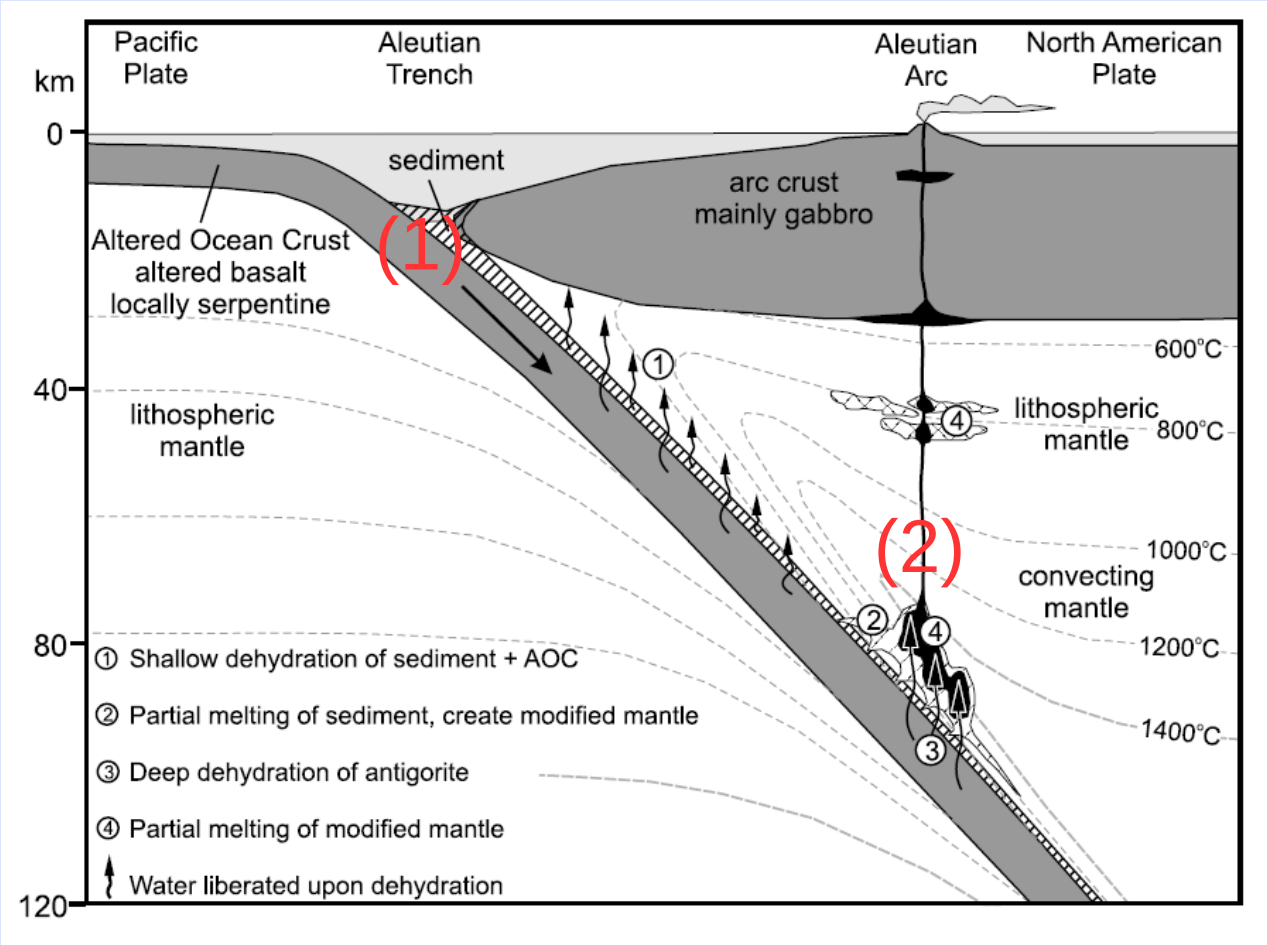
Volcanoes in Extensional and Compressional Settings

Main Points

- Why does tectonic setting matter?
- Time-depth patterns of pre-eruptive seismicity
- Case study from Redoubt Volcano, Alaska

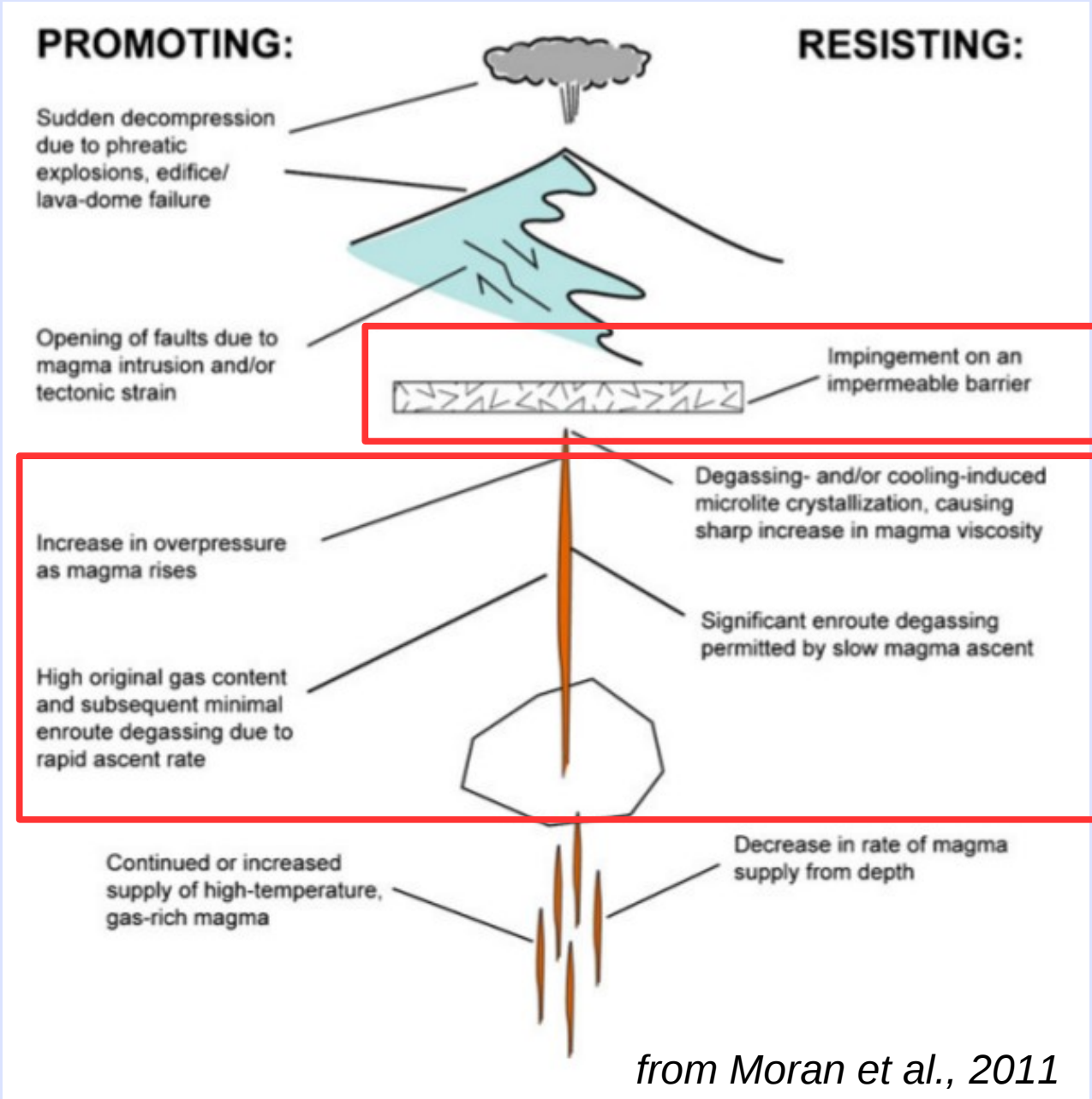
Why does tectonic setting matter?

Subduction zones are characterized by compressive stress regimes (1) and wet magmas (2)



from Singer et al., 2007

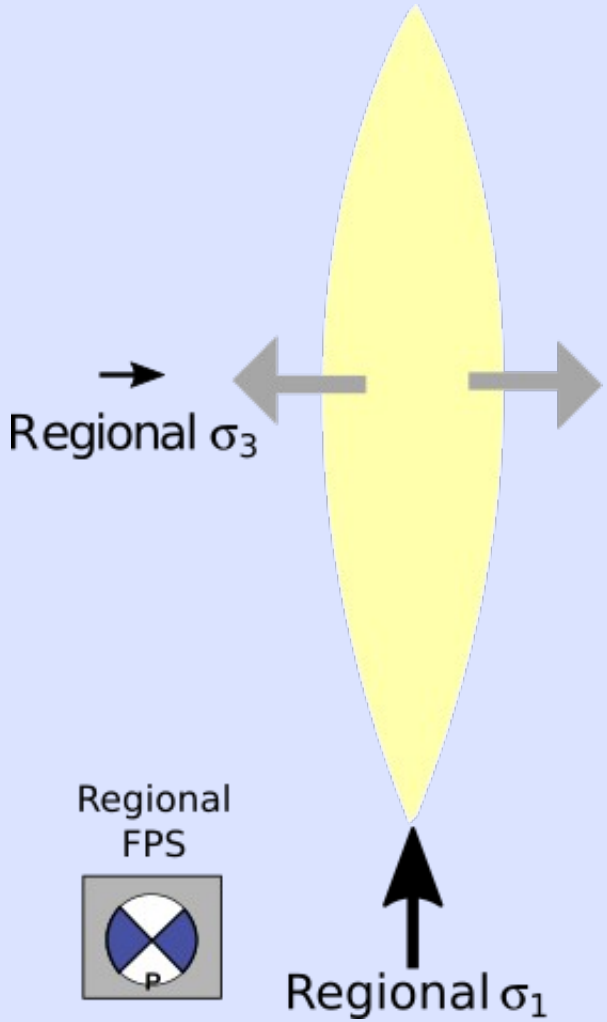
Why does tectonic setting matter?



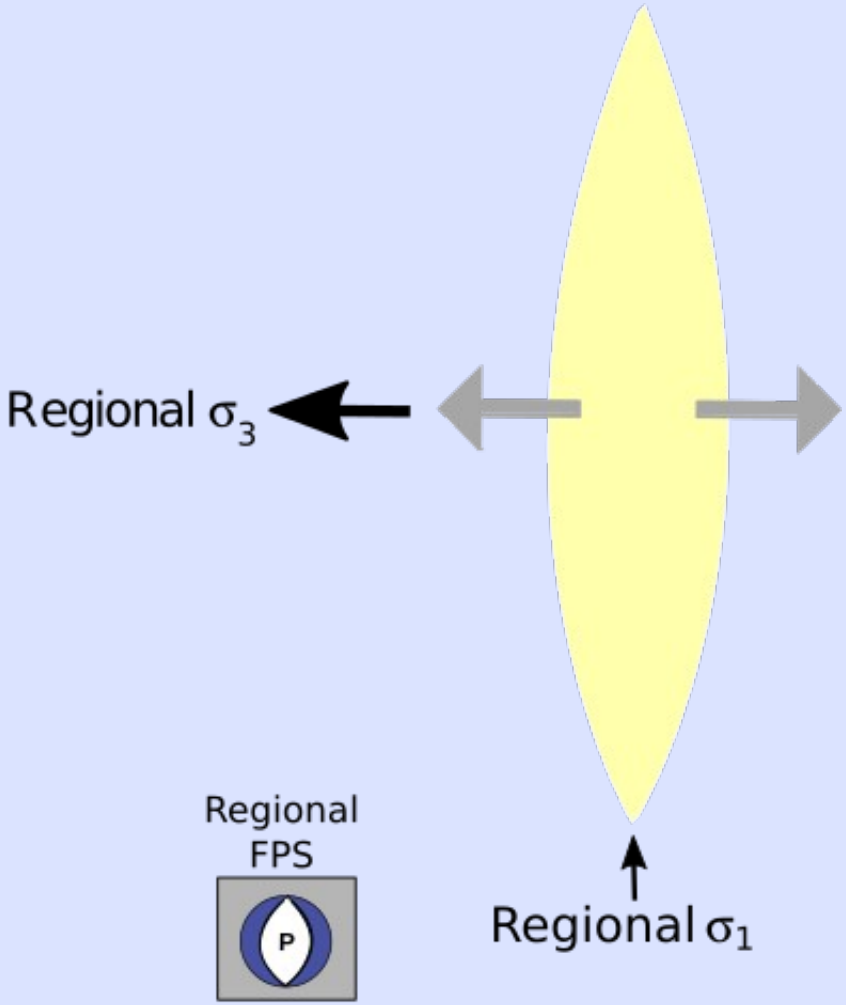
from Moran et al., 2011

Why does tectonic setting matter?

Compressional environment



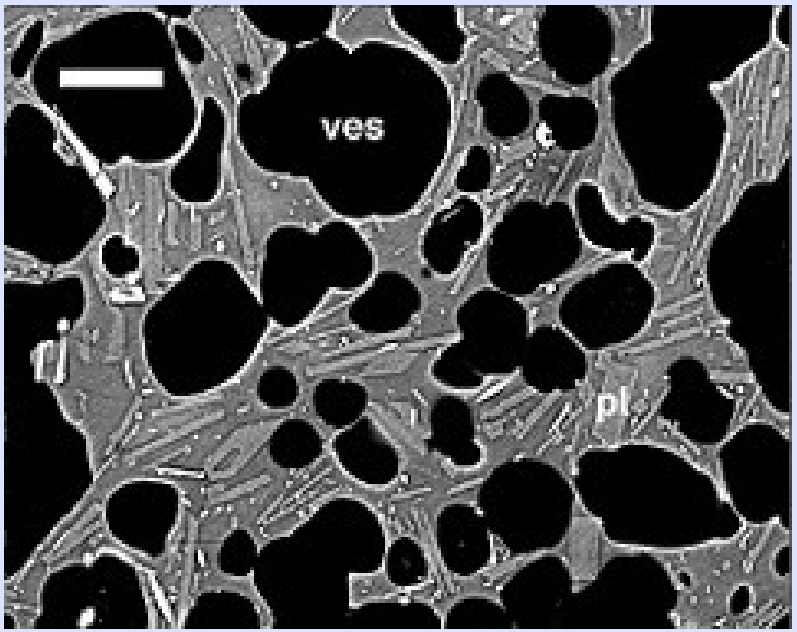
Extensional environment

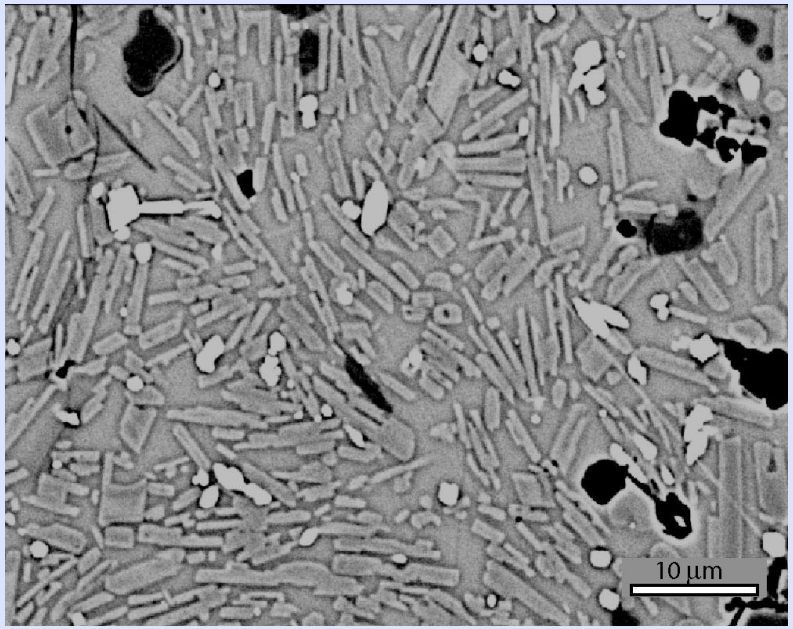


Why does tectonic setting matter?

Wet magmas experience significant and sometimes competing rheological changes during ascent:

- Degassing-induced crystallization increases effective viscosity
- Volatile exsolution reduces bulk density and may increase or decrease effective viscosity





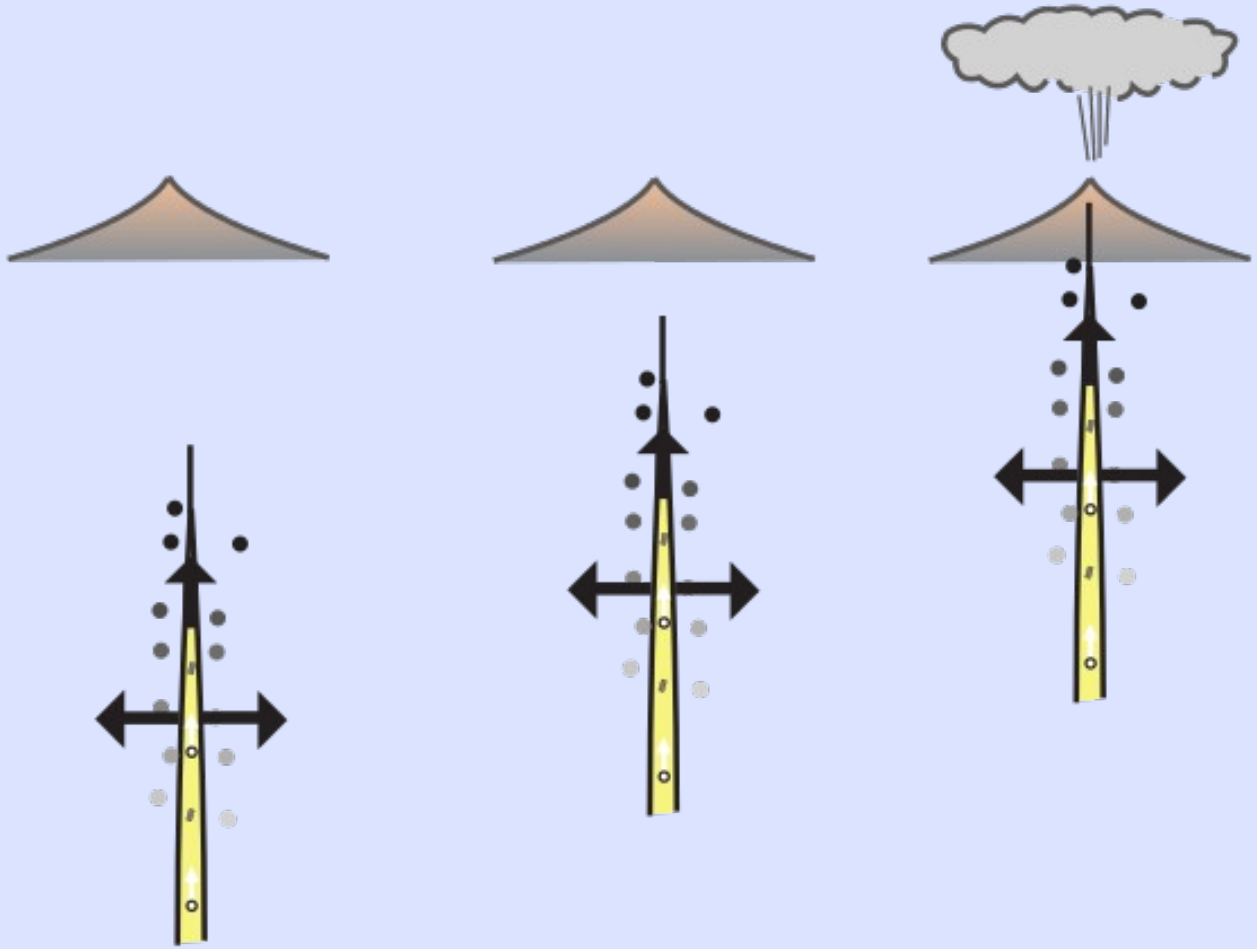
SEM images of MSH 1980 dacite from K. Cashman

Why does tectonic setting matter?

- How do these factors combine to affect magma ascent? On balance, which are more important?
- Some clues from volcano seismology….bottom-up vs. top-down propagation of precursory seismicity...

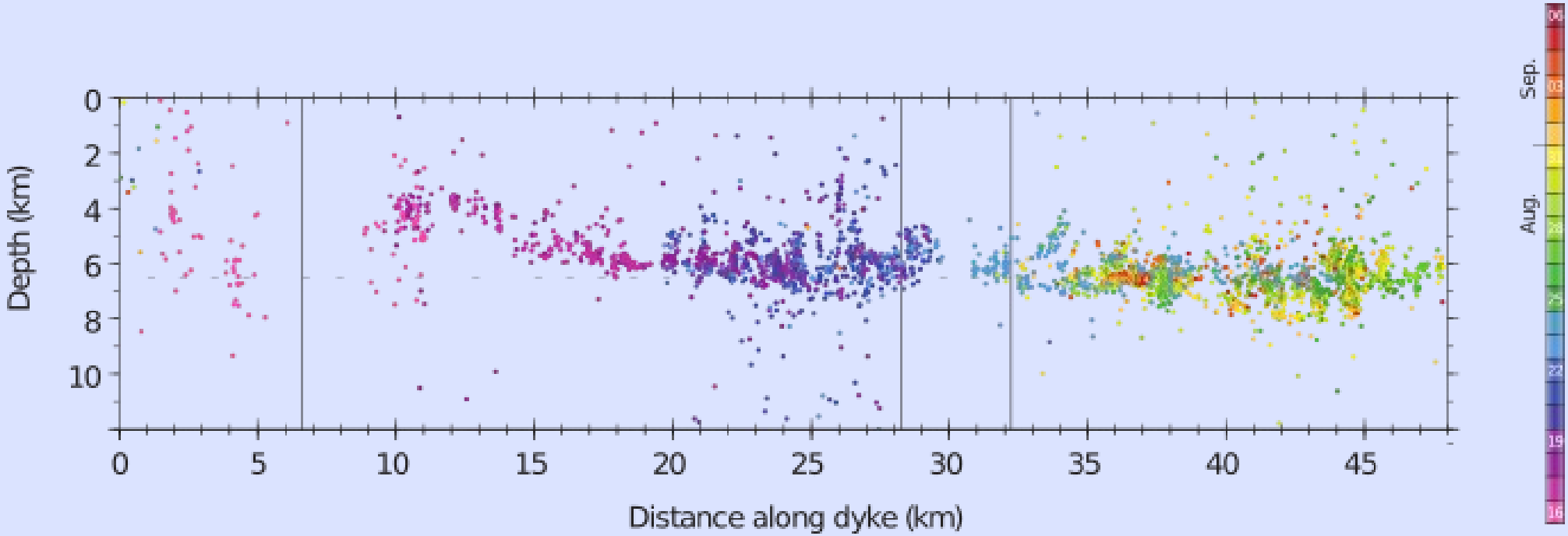
Precursory seismicity patterns

The 101 view….rarely observed in reality



Precursory seismicity patterns

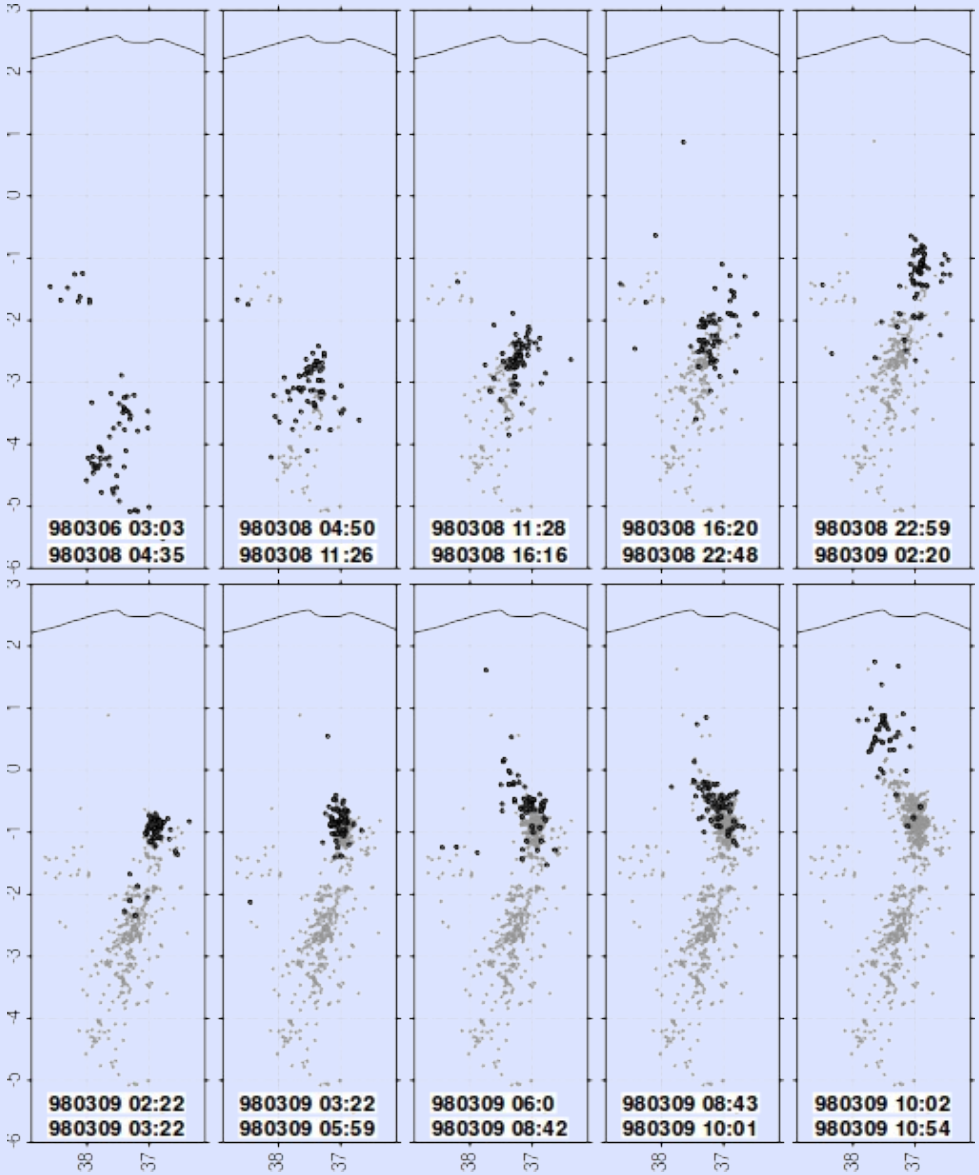
Most instances of hypocenter propagation are lateral and tend to involve low-viscosity basalts



After Sigmundsson et al., 2014

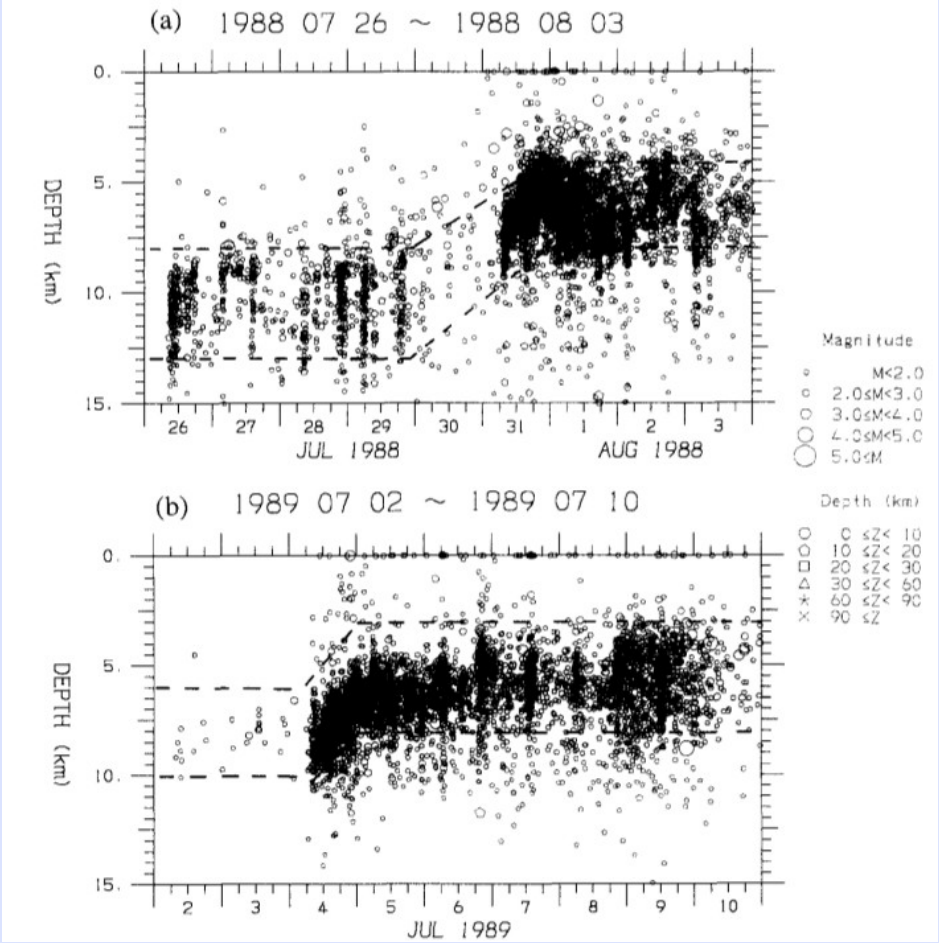
Precursory seismicity patterns

Piton de la Fournaise, la Reunion - 1998



from Battaglia et al., 2005

Teishi Knoll (Ito-Oki), Japan - 1989

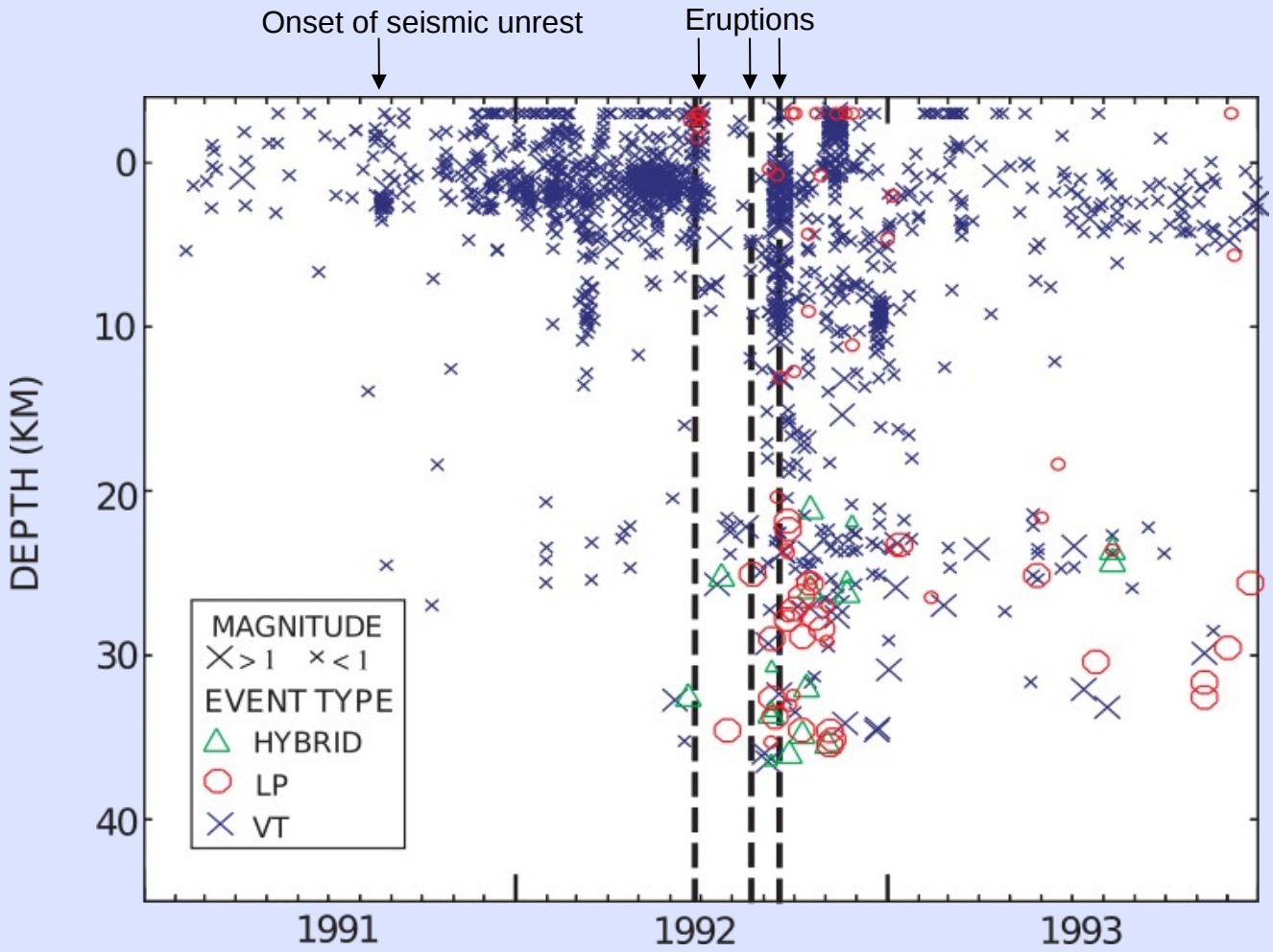


From Ukawa and Tsukahara 1996

Precursory seismicity patterns

Crater Peak, Alaska

Initial seismic activity at ~1-3 km depth
Source of magma for the eruption – 10km BSL

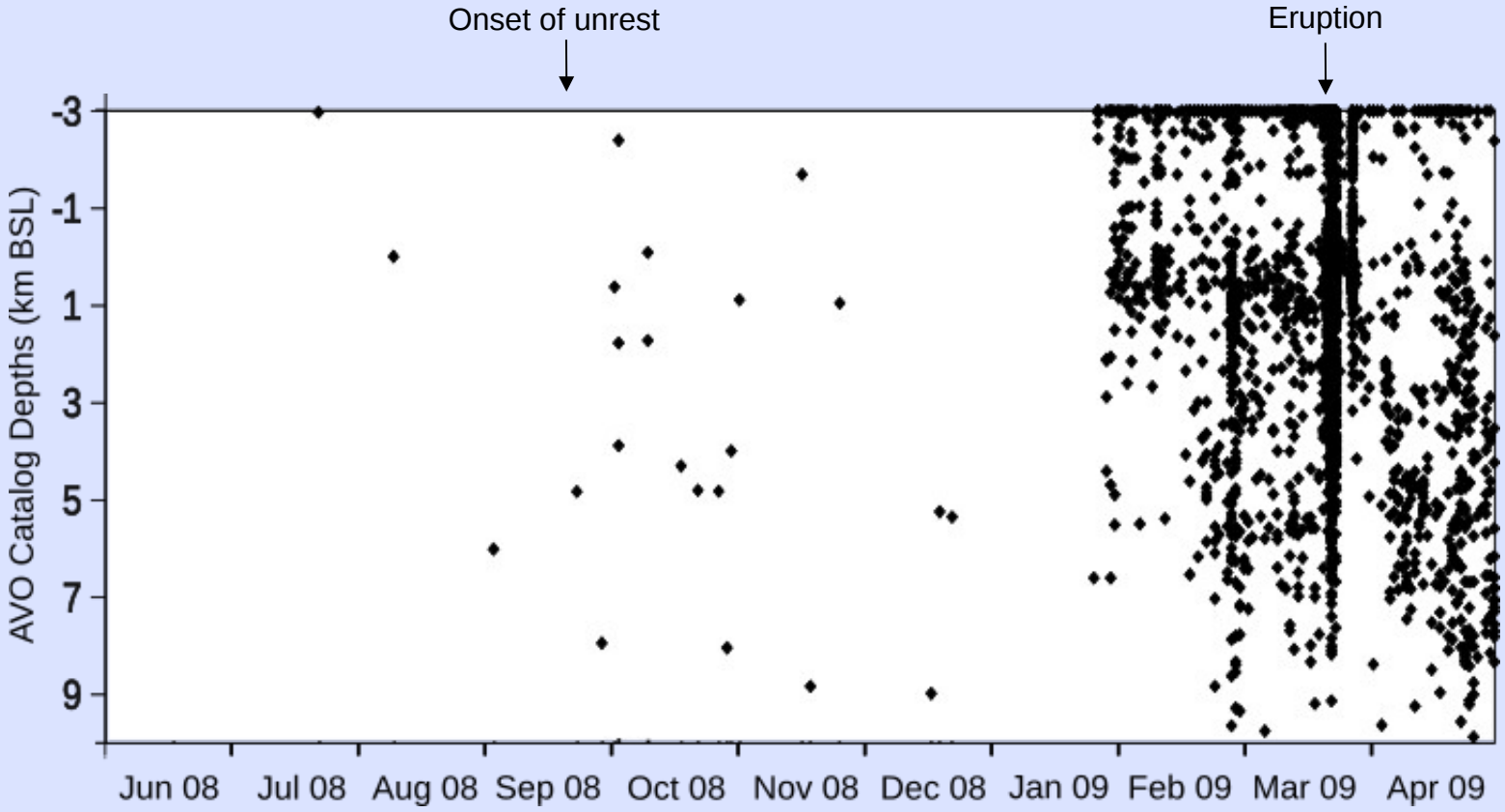


from Power et al. *2001*

Precursory seismicity patterns

Redoubt Volcano, Alaska

Initial seismic activity at ~-3-1 km depth
Source of magma for the eruption – 4-6 km BSL



from Roman and Gardine 2013

Precursory seismicity patterns

Redoubt Volcano, Alaska

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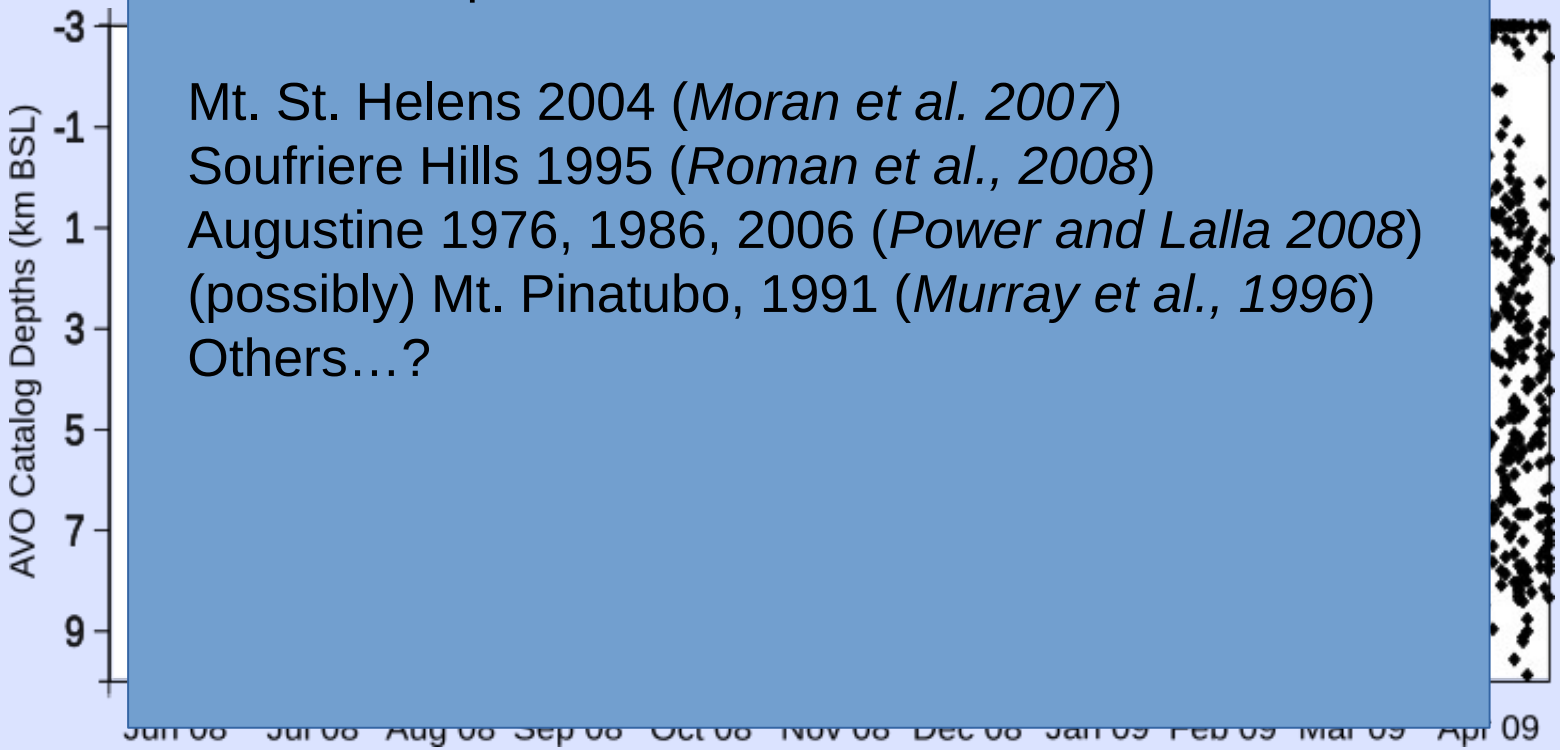


Other examples:

Mt. St. Helens 2004 (*Moran et al. 2007*)
Soufriere Hills 1995 (*Roman et al., 2008*)
Augustine 1976, 1986, 2006 (*Power and Lalla 2008*)
(possibly) Mt. Pinatubo, 1991 (*Murray et al., 1996*)
Others…?

from Roman and Gardine 2013

Precursory seismicity patterns

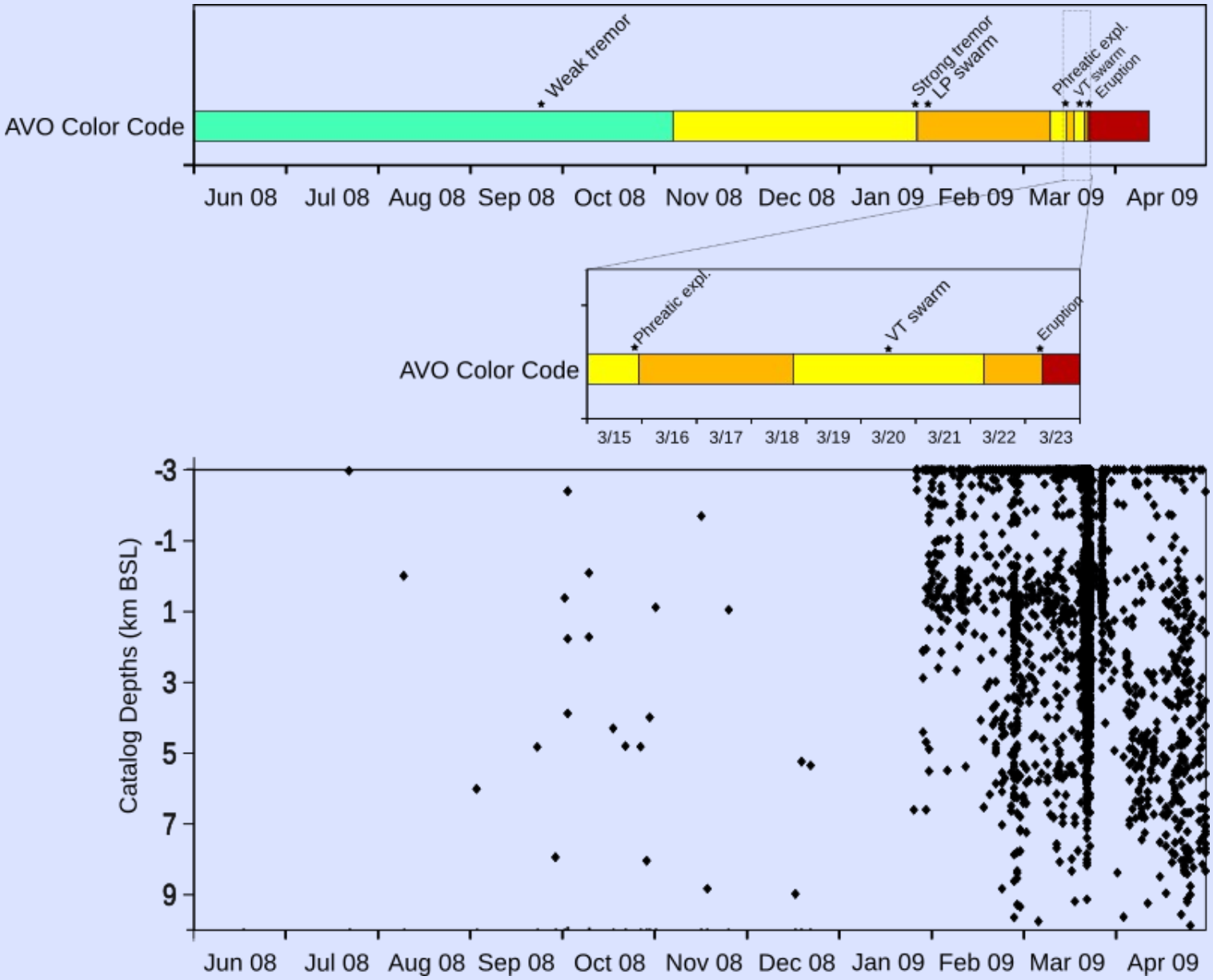
What factors control which pattern is observed?
Not really enough observations to say, but maybe….

- Tectonic setting/ambient stress conditions?
- Magma rheology?
- Magma volume?
- Other factors?

Regardless, examples of top-down seismic propagation imply initially-aseismic ascent to shallow levels at arc volcanoes

- Aseismic ascent implies initially slow magma ascent
- Redoubt case study *(also preliminary results from Shishaldin 1999 – Rasmussen pop-up talk/poster*)

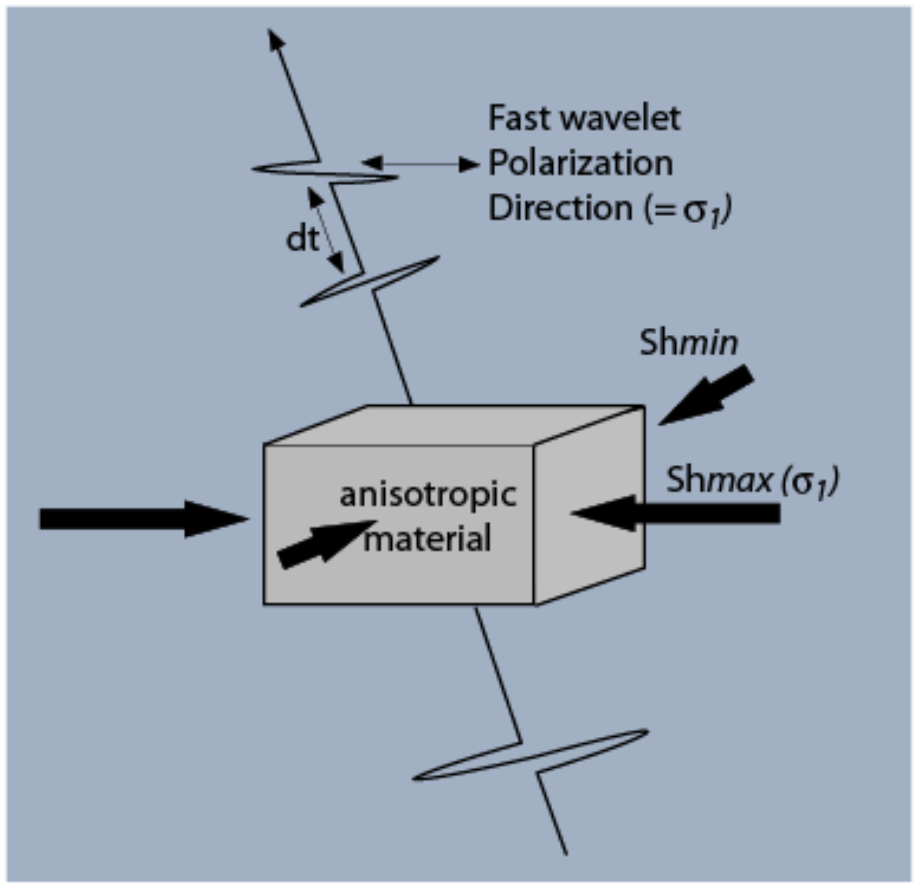
Redoubt Volcano, Alaska



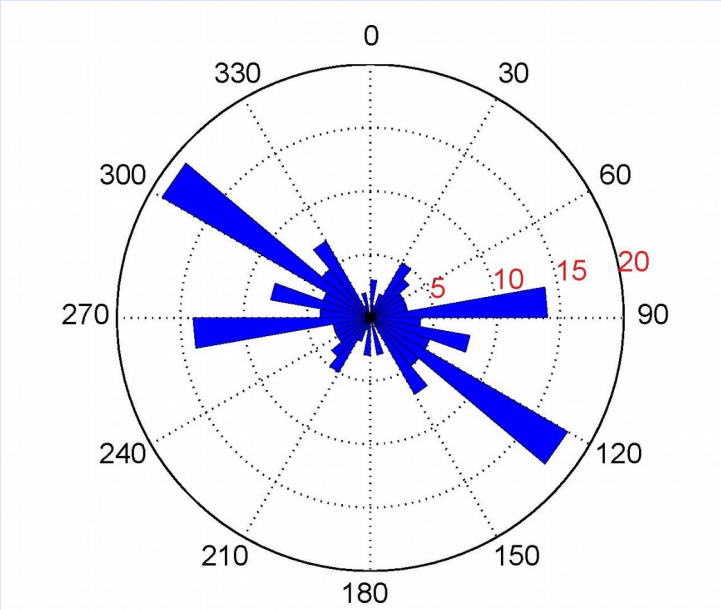
from Roman and Gardine 2013

Redoubt Volcano, Alaska

Analysis of shear-wave splitting in regional earthquakes:



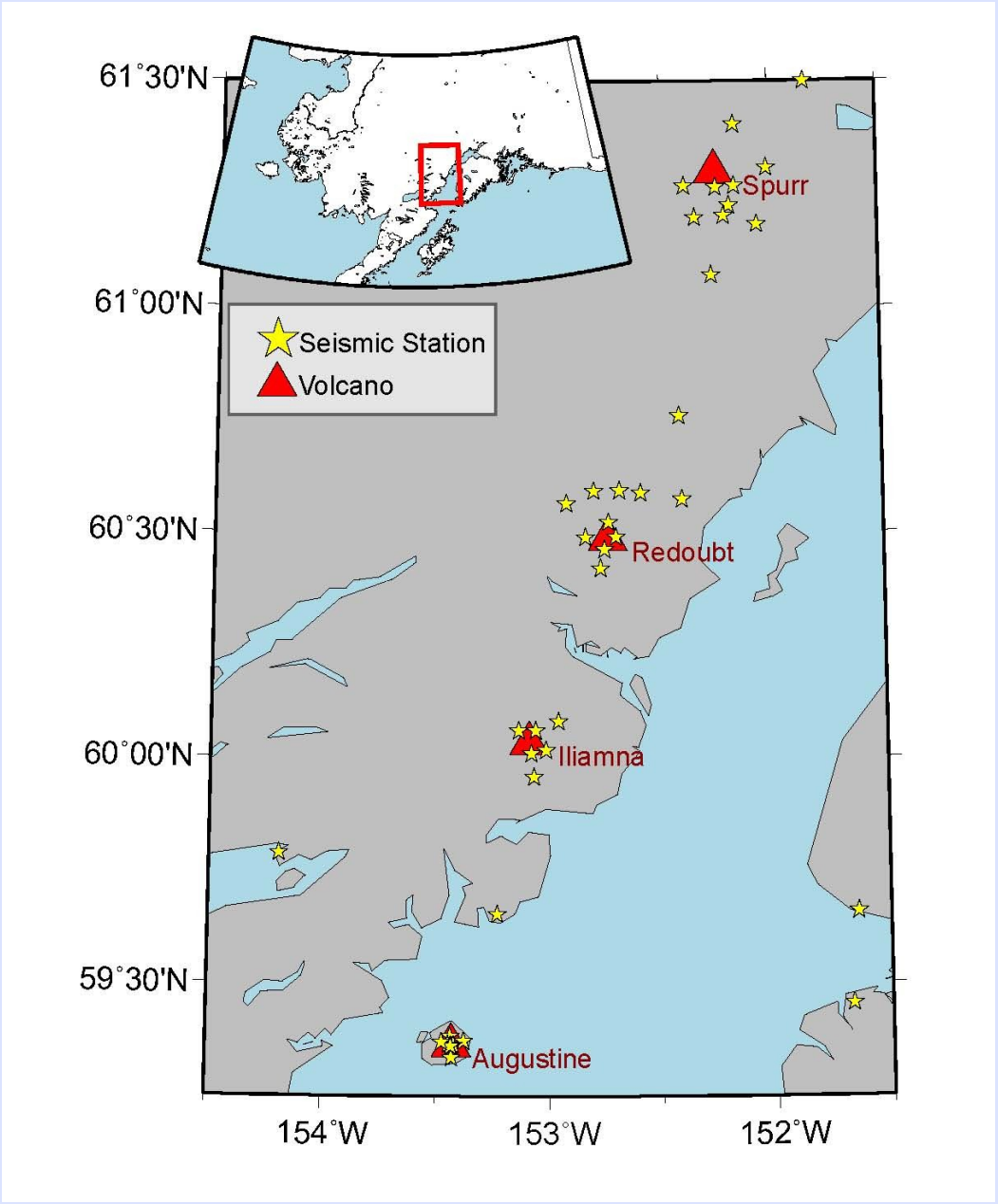
Azimuth of FWPD
(Multiple events)
Jan 2005-Dec 2006



N=89

from Roman and Gardine 2013

Redoubt Volcano, Alaska



Redoubt Volcano, Alaska

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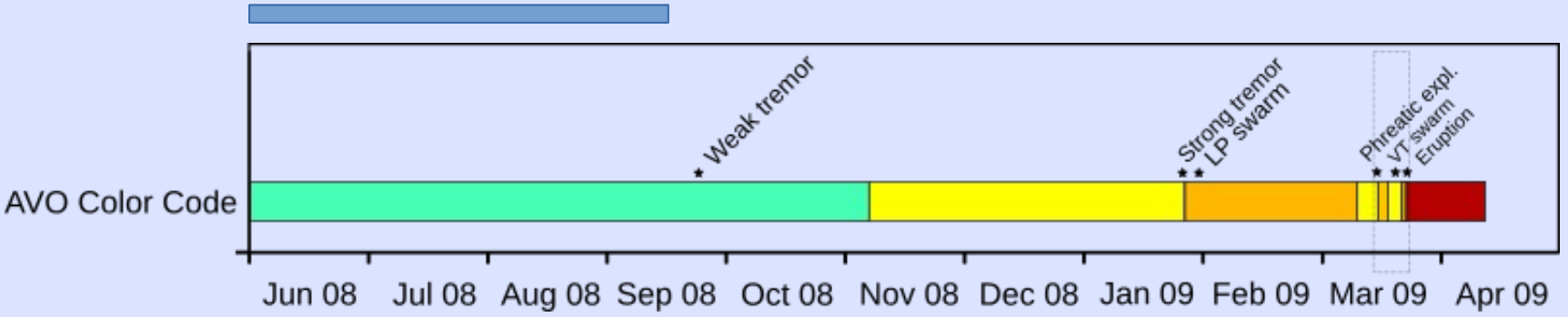
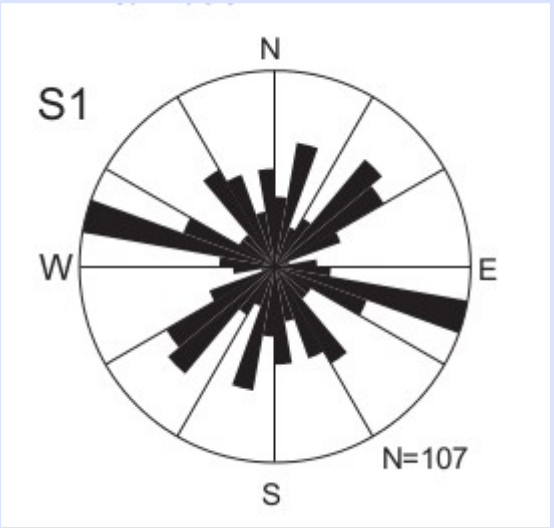


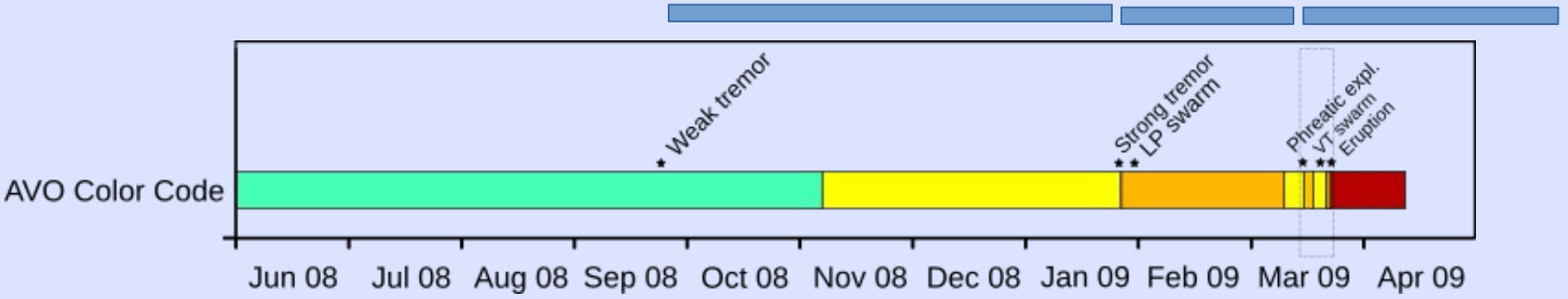
•**Group S1 (3/98-9/98)**
Background – prior to weak tremor onset (earliest known precursor)



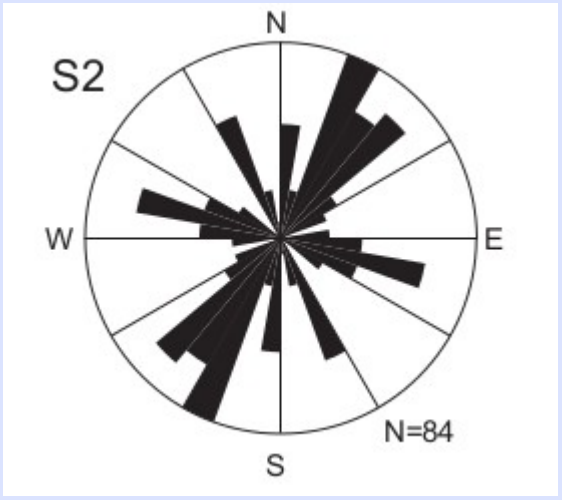
from Roman and Gardine 2013

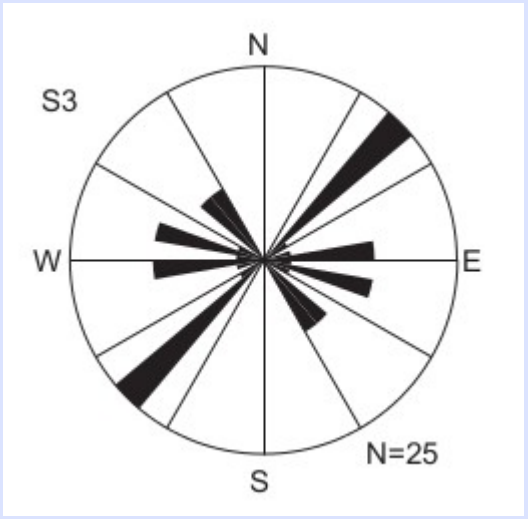
Redoubt Volcano, Alaska

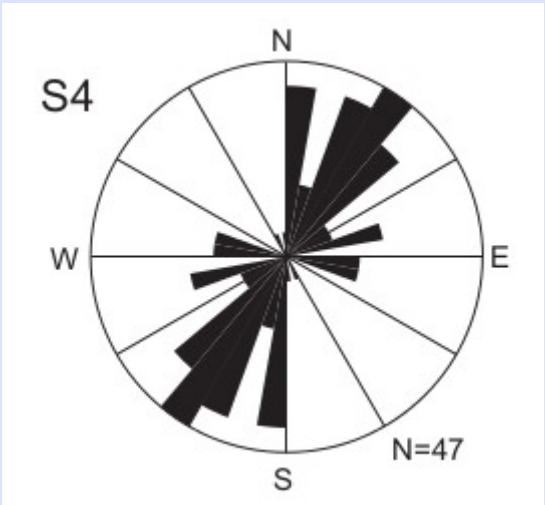
Analysis of shear-wave splitting in regional earthquakes:



- **Groups S2-S4 (9/08-end of eruption)**



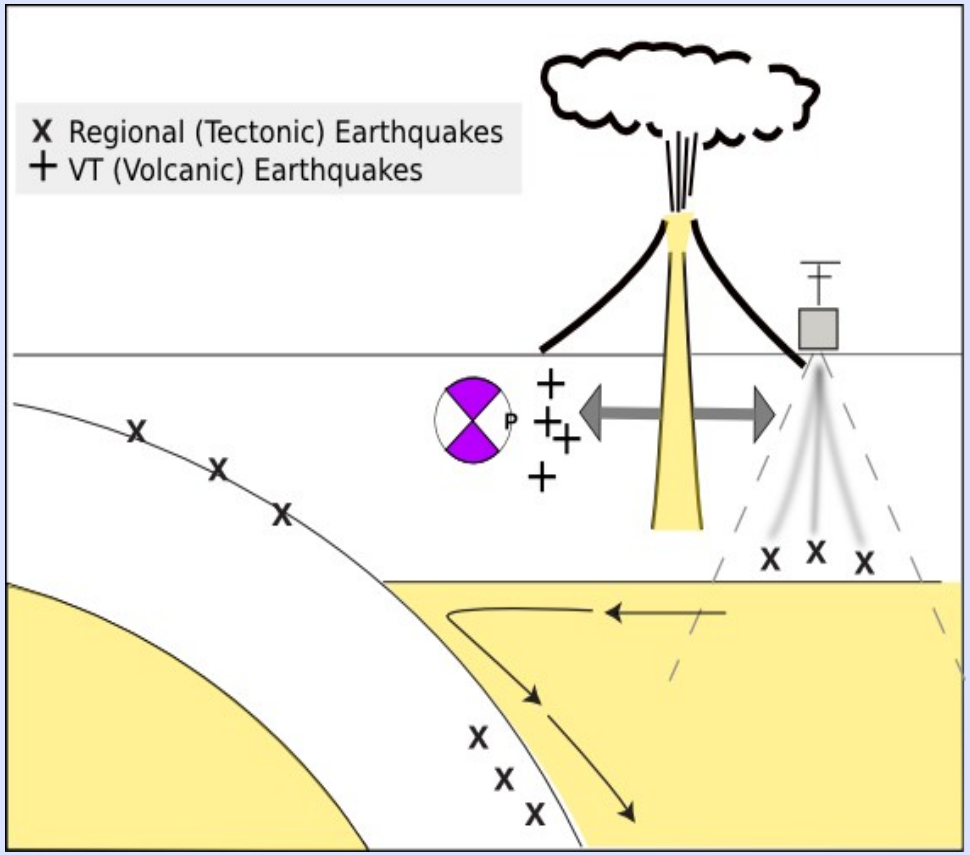


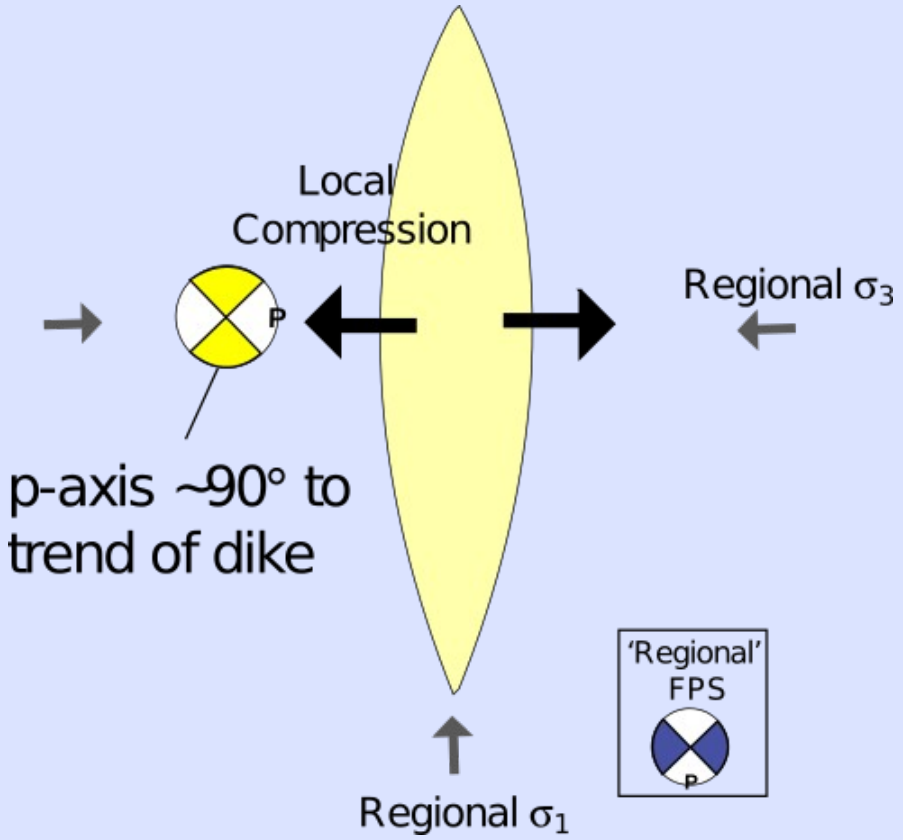


from Roman and Gardine 2013

Redoubt Volcano, Alaska

Geometric relationship of inflation-induced stress field to regional stress field:



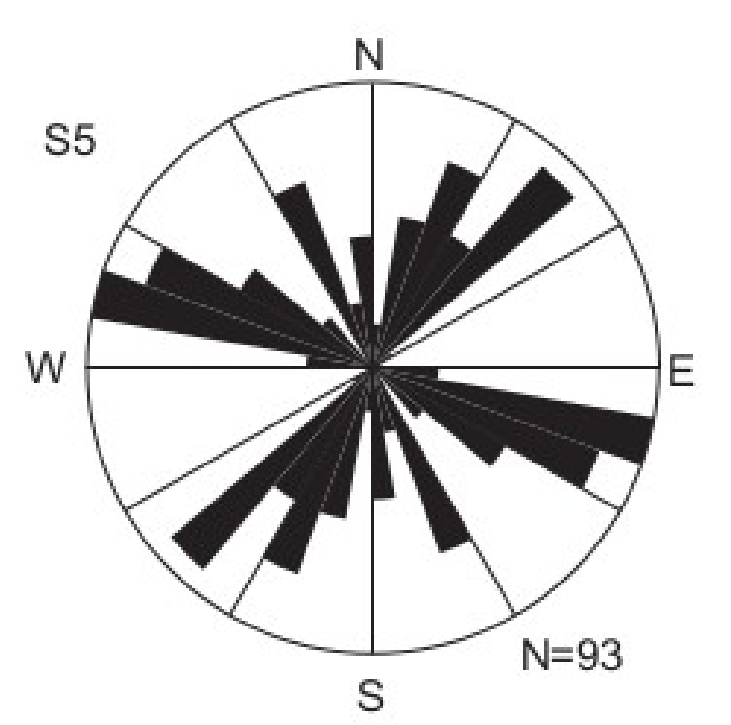


from Roman and Cashman (2006)

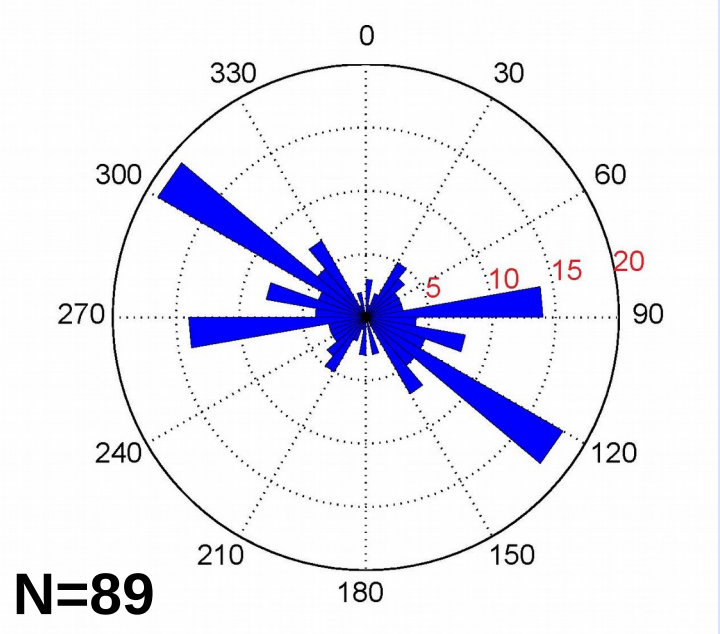
Redoubt Volcano, Alaska

Analysis of shear-wave splitting in regional earthquakes:

- **Group S5 (End of eruption to 12/09)**

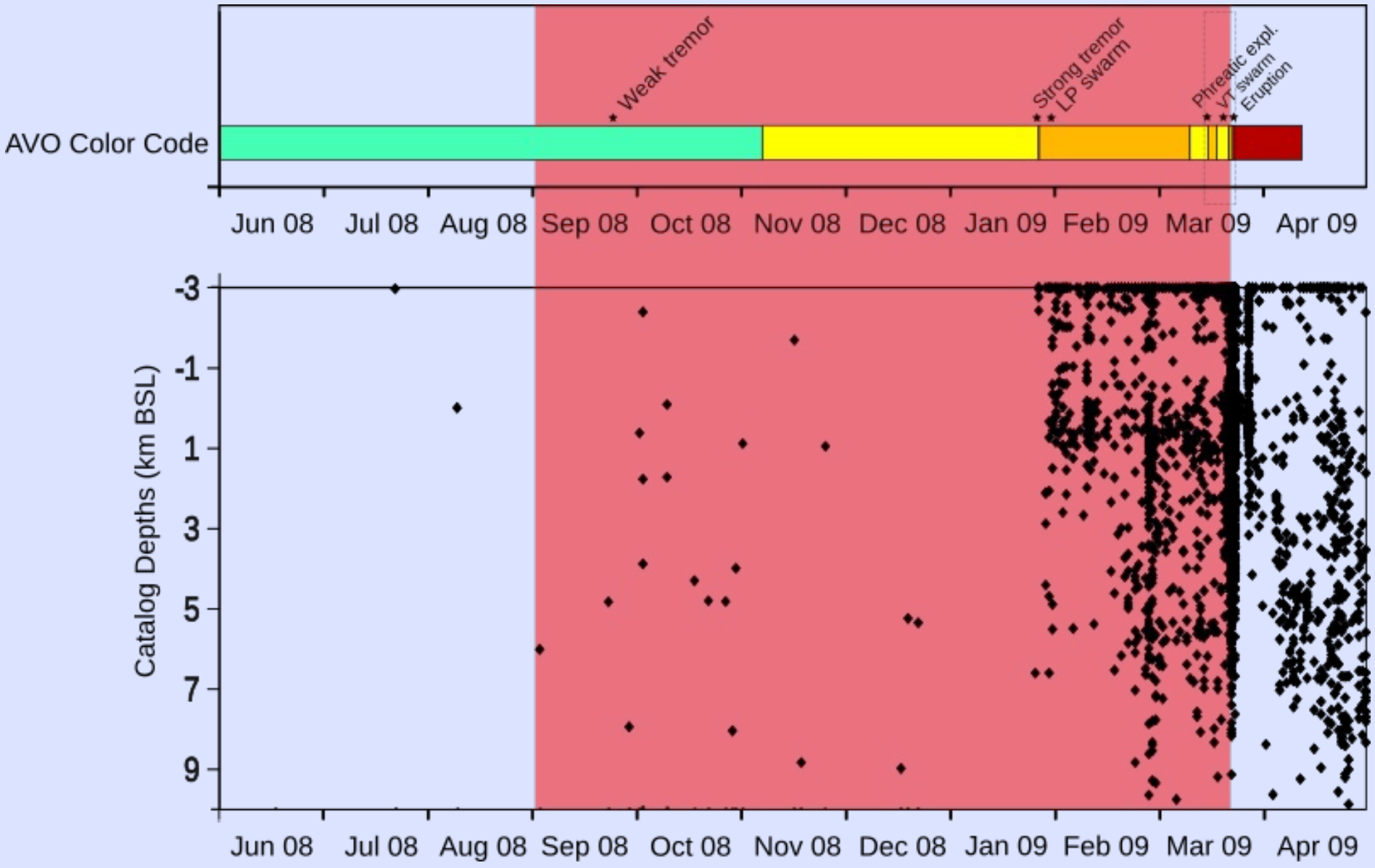


Compare to background (Jan 2005-Dec 2006)



from Roman and Gardine 2013

Redoubt Volcano, Alaska



Questions for Discussion

- How does ambient stress (tectonic setting) affect magma ascent and eruption?
- How does magma composition (dissolved/exsolved volatiles, crystal content, melt composition) affect magma ascent and eruption?
- What are the implications for volcano monitoring and eruption forecasting?