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

Regional $\sigma_3$

Regional FPS

Regional $\sigma_1$
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
Most instances of hypocenter propagation are lateral and tend to involve low-viscosity basalts.
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

Onset of seismic unrest
Eruptions

from Power et al. 2001
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

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

Other examples:

Mt. St. Helens 2004 (Moran et al. 2007)
Soufriere Hills 1995 (Roman et al., 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
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
Analysis of shear-wave splitting in regional earthquakes:

• **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)
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

The diagram shows the activity of Redoubt Volcano from June 2008 to April 2009. The AVO Color Code indicates the level of activity: Weak tremor, Strong tremor, LP Swarm, Phreatic event, and Eruption. The plot on the bottom left shows the catalog depths in kilometers below sea level (km BSL) for the same period.
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?