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Source mechanisms of persistent shallow earthquakes during eruptive and non-eruptive periods between 1981 and 2011 at Mount St. Helens, Washington

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ABSTRACT

Shallow seismicity between 0 and 3-km depth has persisted at Mount St. Helens, Washington (MSH) during both eruptive and non-eruptive periods for at least the past thirty years. In this study we investigate the source mechanisms of shallow volcano-tectonic (VT) earthquakes at MSH by calculating high-quality hypocenter locations and fault plane solutions (FPS) for all VT events recorded during two eruptive periods (1981–1986 and 2004–2008) and two non-eruptive periods (1987–2004 and 2008–2011). FPS show a mixture of normal, reverse, and strike-slip faulting during all periods, with a sharp increase in strike-slip faulting observed in 1987–1997 and an increase in normal faulting in 1998–2004. FPS *P*-axis orientations show a ~90° rotation with respect to regional σ_1 (N23°E) during 1981–1986 and 2004–2008, bimodal orientations (~N-S and ~E-W) during 1987–2004, and bimodal orientations at ~N-E and ~S-W from 2008–2011. We interpret these orientations to likely be due to pressurization accompanying the shallow intrusion and subsequent eruption of magma as domes during 1981–1986 and 2004–2008 and the buildup of pore pressure beneath a seismogenic volume (located at 0–1 km) with a smaller component due to the buildup of tectonic forces during 1987–2004 and 2008–2011.

1. Introduction

Mount St. Helens (MSH; Fig. 1) has been monitored by a dense seismic network since 1980, a time period spanning over thirty years. During this time MSH has experienced two eruptive (1980–86 and 2004–2008) and two non-eruptive periods (1987–2004, 2008–2011). Few stratovolcanoes have such long monitoring time histories that span eruptive & non-eruptive periods. Those that do often show background levels of seismic activity during non-eruptive periods, with up to a few earthquakes per day (McNutt, 2000). Examples include Redoubt Volcano, Alaska, (1989–2009, Power et al., in review) and Augustine Volcano, Alaska, (1986–2006, Power et al., 2010), where 20-year-long inter-eruptive periods were characterized by background levels of seismic activity (~5–10 events per week). Like Redoubt and Augustine volcanoes, Mount St. Helens, Washington (MSH, Fig. 1), showed background levels of seismic activity of ~5–10 events per week during a 17-year-long inter-eruptive period from 1987–2004 (Fig. 2a). In the case of MSH, the background rate of non-eruptive seismicity is likely related to post-eruptive processes and/or slow recharge of the magmatic system (Barker and Malone, 1991; Mastin, 1994; Moran, 1994; Musumeci et al., 2000). It is therefore imperative for accurate future assessment of eruption likelihood that we understand the source processes behind the persistent background seismicity at MSH.

One means of investigating the source processes behind the persistent, elevated VT seismicity recorded at MSH involves examining how fault plane solutions (FPS) vary over time. Changes in the orientation of maximum compressive stress (σ_1) recorded by *P*- and *T*-axes, which serve as a proxy for the maximum and minimum compressive stresses, have been observed at a number of volcanoes worldwide prior to eruptions (Soufriere Hills Volcano, Montserrat, Roman et al., 2006; Roman et al., 2008; Mount Spurr, and Redoubt volcano, Alaska, Roman et al., 2004; Gardine and Roman, 2010; respectively; and Mount Etna, Italy, Cocina et al., 1997), and most studies link this rotation to magmatic activity. In this study we compute FPS for shallow VTs (0–3 km depth, relative to a datum of 2.2 km ASL, the altitude of the highest seismic station (Thelen et al., 2008) from 1981–2004 and 2008–2011 to complement previous studies that have focused on deeper seismicity (4–20 km, Barker and Malone, 1991; Musumeci et al., 2000; Moran, 1994) or shallow seismicity for the early vent clearing phase of the 2004–2008 eruption (Lehto et al., 2010). We use the resultant FPS along with relocated hypocenters to constrain models for generation of shallow VTs so as to better understand how these earthquakes relate to the eruptive cycle at MSH.

2. Background

Shortly after the May 18, 1980, Plinian eruption, MSH entered an extended period of sporadic dome-building in which 0.074 km^3 of magma (bulk volume) was erupted in discrete eruptive episodes between 1981

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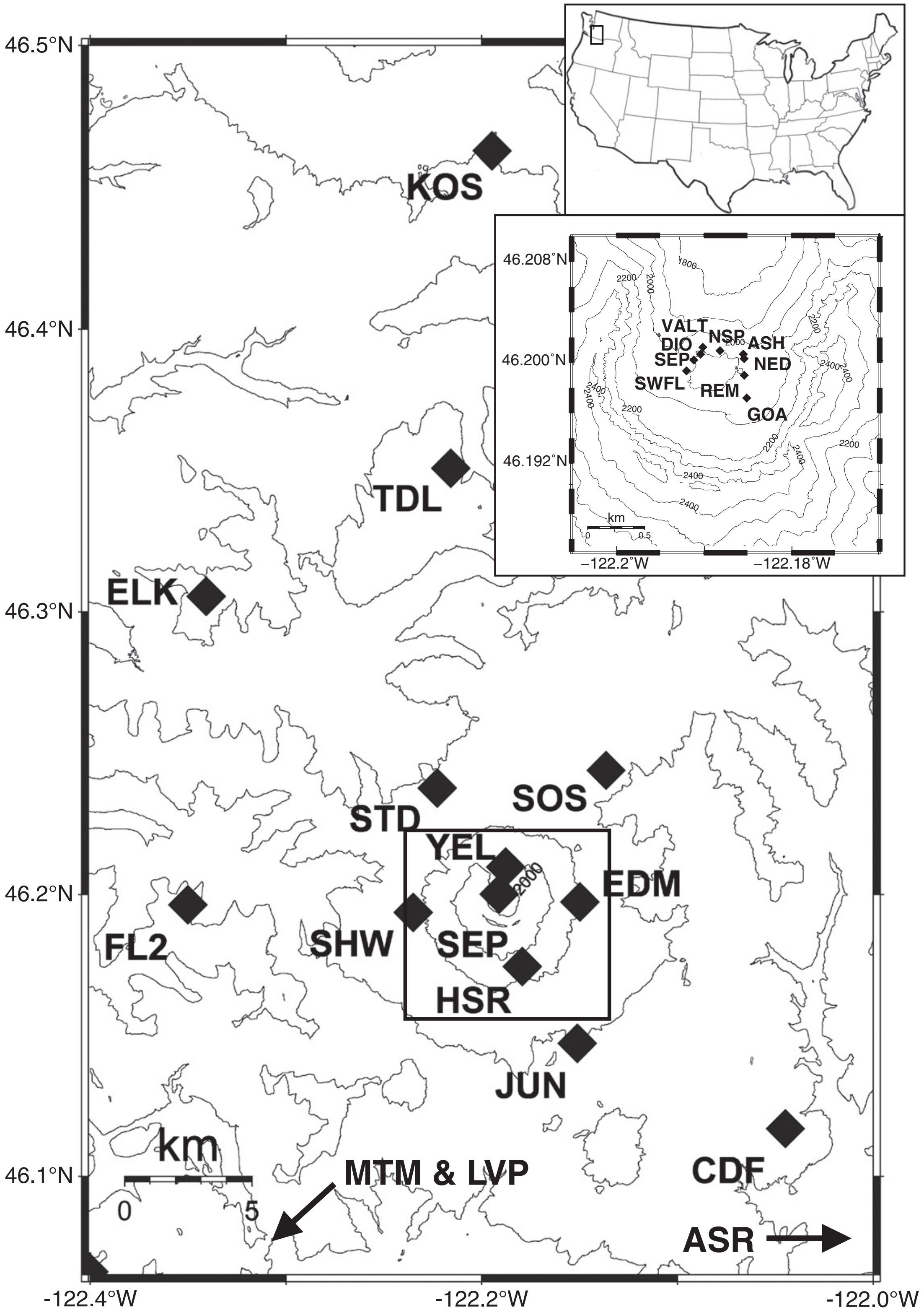

Fig. 1. Map of station locations for crater stations (inset, bottom) and larger network and location map (inset, top). Dates of network changes can be found in Table 1.

and 1986 (Swanson and Holcomb, 1990). After an almost 18-year period without eruption, dome-building recommenced in September 2004 with a continuous dacitic lava-dome-building eruption (Scott et al., 2008) that produced a new dome complex with a total volume of 0.0917 km^3 (bulk volume) by early 2008 (Steve Schilling, personal communication, 2012).

MSH seismicity has been monitored at a basic level since 1972, when the first seismic station was installed by the Pacific Northwest Seismic Network (PNSN). A multi-station short-period, vertical components network was installed in March–April of 1980 in response to the 1980 MSH precursory sequence and eruption, and was slightly expanded in response to the 2004 eruption. The seismic network currently comprises 19 stations within 20 km of MSH (Table 1, Fig. 1) (Moran et al., 2008). Stations located within the crater, which are particularly critical for depth control but which are also more susceptible