Journal of Volcanology and Geothermal Research 178 (2008) 787–794

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Swarms of similar long-period earthquakes in the mantle beneath Mauna Loa Volcano

Paul G. Okubo [a], Cecily J. Wolfe [b,*]

[a] Hawaiian Volcano Observatory, US Geological Survey, Hawai'i National Park, HI 96718, USA
[b] Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa, 1680 East West Road, Honolulu, HI 96822, USA

ARTICLE INFO

Article history:
Received 21 April 2008
Accepted 9 September 2008
Available online 23 September 2008

Keywords:
Mauna Loa
long-period earthquakes
mantle
magma system

ABSTRACT

We present analyses of two swarms of long-period (LP) earthquakes at >30 km depth that accompanied the geodetically observed 2002–2005 Mauna Loa intrusion. The first LP earthquake swarm in 2002 consisted of 31 events that were precursory and preceded the start of Mauna Loa inflation; the second LP swarm of two thousand events occurred from 2004–2005. The rate of LP earthquakes slowed significantly coincident with the occurrence of the December 26, 2004 M_w 9.3 Sumatra earthquake, suggesting that the seismic waves from this great earthquake may have had a dynamic triggering effect on the behavior of Mauna Loa's deep magma system. Using waveform cross correlation and double difference relocation, we find that a large number of earthquakes in each swarm are weakly similar and can be classified into two families. The relocated hypocenters for each family collapse to compact point source regions almost directly beneath the Mauna Loa intrusion. We suggest that the observed waveform characteristics are compatible with each family being associated with the resonance of a single fluid filled vertical crack of fixed geometry, with differences in waveforms between events being produced by slight variations in the trigger mechanism. If these LP earthquakes are part of the primary magma system that fed the 2002–2005 intrusion, as indicated by the spatial and temporal associations between mantle seismicity and surface deformation, then our results raise the possibility that this magma system may be quite focused at these depths as opposed to being a diffuse network. It is likely that only a few locations of Mauna Loa's deep magma system met the geometric and fluid dynamic conditions for generating LP earthquakes that were large enough to be recorded at the surface, and that much of the deep magma transfer associated with the 2002–2005 intrusion occurred aseismically.

1. Introduction

Long-period (LP) earthquake swarms in volcanic systems are often associated with eruptions or intrusions, and are believed to be due to processes such as pressure-induced vibrations of fluid-filled cracks in magmatic and hydrothermal systems (e.g., Chouet, 1996) (however, note that in non-volcanic systems, Ide et al. (2007) have recently suggested that deep LP earthquakes may be due to shear failure). In many cases, LP swarms contain similar repeating events or multiplets indicating a family of earthquakes that have similar source processes and location (e.g., Stephens and Chouet, 2001; Battaglia et al., 2003; Green and Neuberg, 2006; Saccorotti et al., 2007; Petersen, 2007). Regularly occurring deep tremor and LP earthquakes in the mantle beneath Hawai'i have long been recognized and studied (Aki and Koyanagi, 1981; Koyanagi et al., 1987; Eaton et al., 1987). But the interpretations in these studies may have been limited by possible errors in event locations. Deep LP earthquakes are not unique to Hawai'i and have been observed at numerous volcanic centers: for example, in the mid and lower crust at Mammoth Mountain (Pitt and Hill, 1994), Mount Pinatubo (White, 1996), and Aleutian arc volcanoes (Power et al., 2004).

Mauna Loa volcano is one of the most active volcanoes on Earth. Its lava flows cover over half of the surface area of the island and it represents a major hazard for the island of Hawai'i. Following a relatively active first half of the 20th century featuring frequent eruptions, eruptions at Mauna Loa have been rare since. The most recent Mauna Loa eruptions occurred in 1984, 1975, and 1950, but only the 1975 and 1984 eruptions and associated seismicity were recorded in the era of high quality, modern, digitally recorded seismic instrumentation (c.f. Okubo, 1995; Baher et al., 2003).

Around May 12, 2002, after almost a decade of very slow rates of deformation, Mauna Loa began a period of geodetically constrained inflation (Miklius and Cervelli, 2003; Miklius et al., 2005) that was accompanied by renewed seismic activity. Analyses of InSAR and GPS data indicates that the deformation was due to a combination of magma chamber inflation southeast of the caldera and dike intrusion in the upper southwest rift zone that occurred during the 2002–2005 time period (Yun et al., 2005; Amelung et al., 2007). The deformation slowed thereafter, and has nearly stopped in early 2008.

* Corresponding author. Tel.:+1 808 956 6347; fax: +1 808 956 3188.
E-mail address: cecily@soest.hawaii.edu (C.J. Wolfe).

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doi:10.1016/j.jvolgeores.2008.09.007

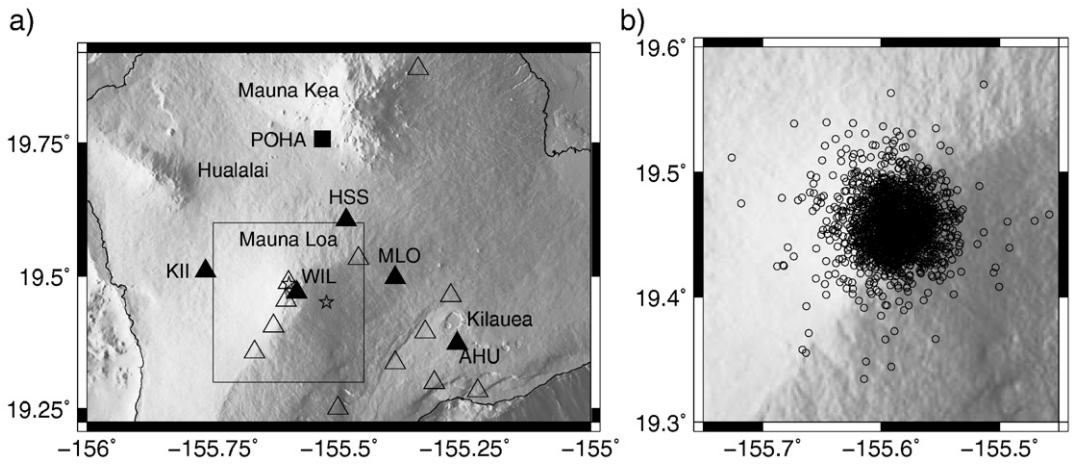

Fig. 1. a) Map of Hawai'i, with shaded topography. The subset of the best 17 HVO seismic network stations used for waveform cross correlation are shown: vertical component stations are open triangles; 3-component stations are filled triangles. Names of 3-component stations are also shown. Global Seismographic Network station POHA is plotted as a filled square. Two open stars show locations of GPS stations ELEP and MOKP. b) HVO locations at Mauna Loa from 8/2004–12/2005 (depths>20 km).

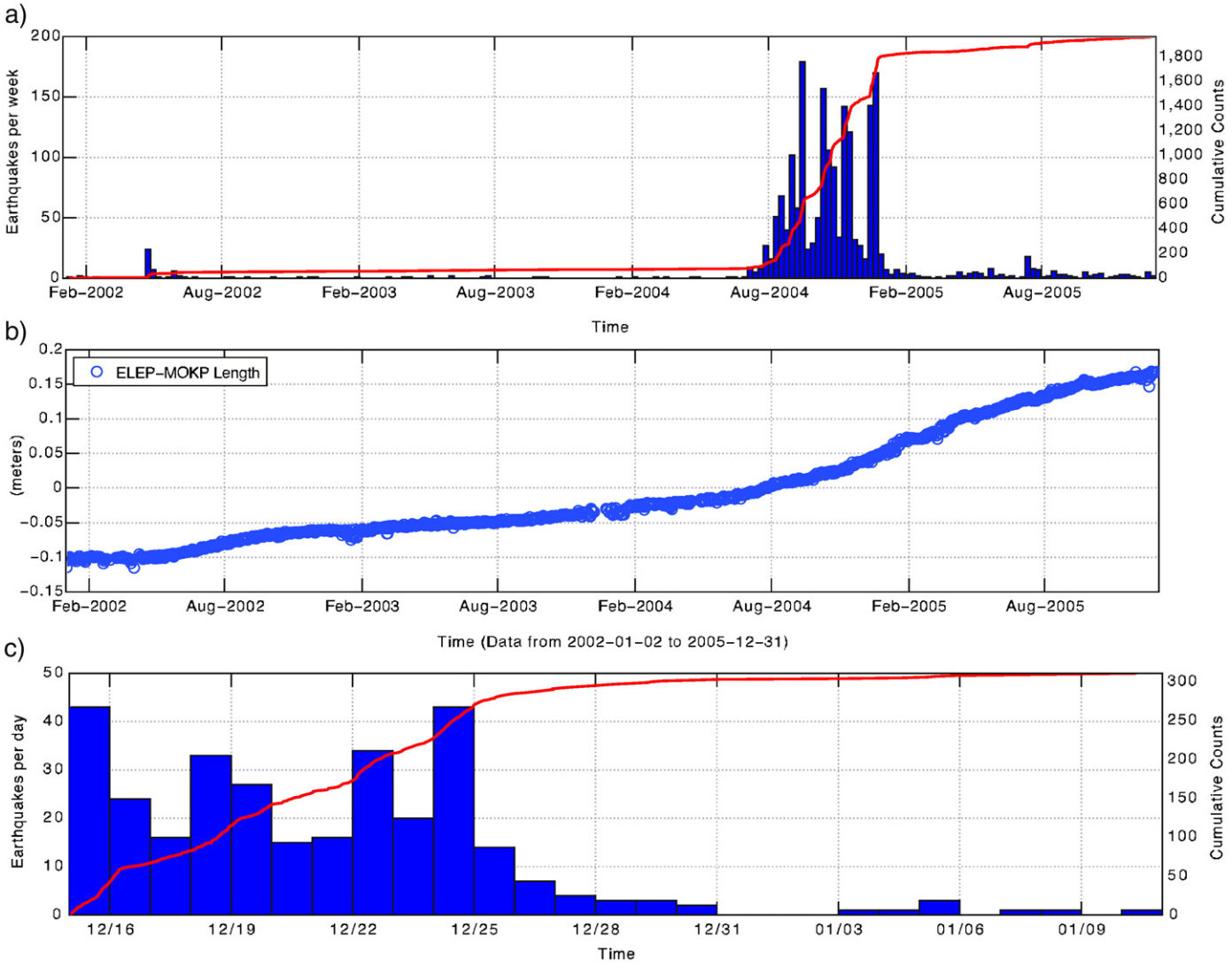

Fig. 2. a) Blue histogram displays numbers of deeper (>20 km) earthquakes per week located by HVO beneath Mauna Loa and red line displays cumulative numbers of earthquakes. b) GPS measurement of line length across Mauna Loa's summit. The increased line length between GPS stations ELEP and MOKP with time is related to the inflation from the 2002–2005 intrusion. See also Miklius and Cervelli (2003). c) Blue histogram displays numbers of deeper earthquakes per day beneath Mauna Loa around the time of the 2004 Sumatra earthquake and red line displays cumulative numbers. Because data are here presented in Hawaii-Aleutian Standard Time (HST), on this plot the Sumatra earthquake origin time would correspond to December 25th at 14:58:53 (HST), rather than to December 26th at 00:58:53 (UTC).