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Seismicity accompanying the 1999 eruptive episode at Telica Volcano, Nicaragua

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ABSTRACT

Telica Volcano, Nicaragua, is a 'persistently restless' basaltic-andesite stratovolcano located in the Central American volcanic front. A high rate of low-frequency seismic events (LFs) has been recorded at Telica since the installation of a single, vertical-component 1 Hz seismic sensor (TELN) near its summit in 1993. Due to the high rate of LFs at Telica, traditional methods of forecasting volcanic activity based on increases in the overall rate of seismicity are not applicable; therefore an understanding of the nature of precursory changes in Telica's seismicity is necessary to forecast future volcanic activity. In May 1999 a nine-month eruptive episode started at Telica, consisting of phreatic to phreatomagmatic explosions. Here we analyse over 29,000 seismic events recorded during a fifteen-month period of seismicity bracketing this eruptive episode, in an attempt to retrospectively identify precursory changes in seismicity. Seismic event rates between January 1999 and March 2000 show a reduction in the LF event rate three months before the onset of eruptive activity, closely followed by a short-lived swarm of high-frequency (HF) (>5 Hz) events. After a three month data gap a second reduction in the LF event rate started in August 1999, directly following eruptive activity in August and approximately two months before a series of explosions in October 1999. This reduction in the LF event rate was closely followed by a short-lived swarm of HF events that was coincident with the onset of numerous (22) short-lived, but populous, LF multiplets. A further reduction in event rate for both LFs and HFs is evident in the months between the October 1999 explosions and explosions on the 29th of December 1999. We suggest that these changes in seismicity reflect a transition from open-system degassing to closed-system degassing at Telica and could signify a change in the volcanic system preceding future episodes of phreatic to phreatomagmatic activity at Telica and similar persistently restless volcanic systems worldwide. We note that these signals are for phreatic to phreatomagmatic activity and thus may not pertain to magmatic volcanism or to other persistently restless volcanoes prior to their magmatic activity.

1. Introduction

Current paradigms in eruption forecasting interpret the onset of low-frequency seismic events (LFs), or the appearance of LF swarms, as a short-term indication of impending eruption (Chouet, 1996). For example, the generic volcanic earthquake swarm model of McNutt (1996) outlines a 'generic' precursory seismic sequence starting with a swarm of high-frequency (HF) earthquakes, followed by a peak rate in HF seismicity, a period of relative seismic quiescence, the onset of LF events, the onset of volcanic tremor (a sustained long-period signal), eruption, then post-eruption deep HF seismicity and then a decrease in seismicity. One of the key aspects of this model is the appearance of LF events as a short-term precursor, and such precursory LF activity has often been observed immediately prior to many eruptions. For example, the 1989–90 eruption of Redoubt Volcano, Alaska, was preceded by 23 h of LF seismicity (Stephens and Chouet, 2001), and the 1991 eruption of Mount Pinatubo, Philippines, was preceded by three days of increased LF seismicity (Harlow et al., 1996; Ramos et al., 1999). However, LF swarms that do not culminate in eruptions are also observed, for example, the 1998 seismic swarm at Iwate Volcano, Japan (Nishimura and Ueki, 2011) and the 2006 LF swarm at the Campi Flegrei Caldera, Italy (Saccorotti et al., 2007), yet they are less commonly documented (perhaps due in part to observational bias (Moran et al., 2011)). Despite the occurrence of LF swarms that do not culminate in eruptions, the observation of LF events, or LF swarms, remains crucial to many aspects of volcano monitoring and forecasting of eruptions.

A recognised style of volcanic activity, here termed 'persistent restlessness', is characterised by sustained high levels of geophysical

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and volcanic activity, including high or variable seismicity rates, strong degassing, and sporadic explosions. Volcanoes that exhibit persistent restlessness, here termed 'persistently restless volcanoes' (PRVs; also referred to as quiescently active volcanoes (Stix, 2007)), do not appear to experience the more typical distinct 'background' and 'unrest' states, but do experience distinct non-eruptive and eruptive phases that do not show a clear correlation with geophysical measurements. Based on the paradigm that high levels of LF seismic activity indicate an elevated short-term probability of eruption, PRVs present a challenge for forecasting because their varying level of seismicity makes traditional models of forecasting inapplicable. Hence understanding the nature of seismic precursors to eruptive episodes at PRVs is critical.

In this study, we investigate the seismic characteristics of the 1999 eruptive episode at the persistently restless Telica Volcano, Nicaragua (Fig. 1). Telica is one of the most active volcanoes in Nicaragua and its historical activity has been dominated by Volcanic Explosivity Index (VEI) 0–2 eruptions (Siebert and Simkin, 2002). A phreatic to phreatomagmatic eruptive episode started in May 1999; explosions occurred intermittently throughout 1999 and 2000, and the eruptive episode ended in February 2000. Here we document pre-eruptive and

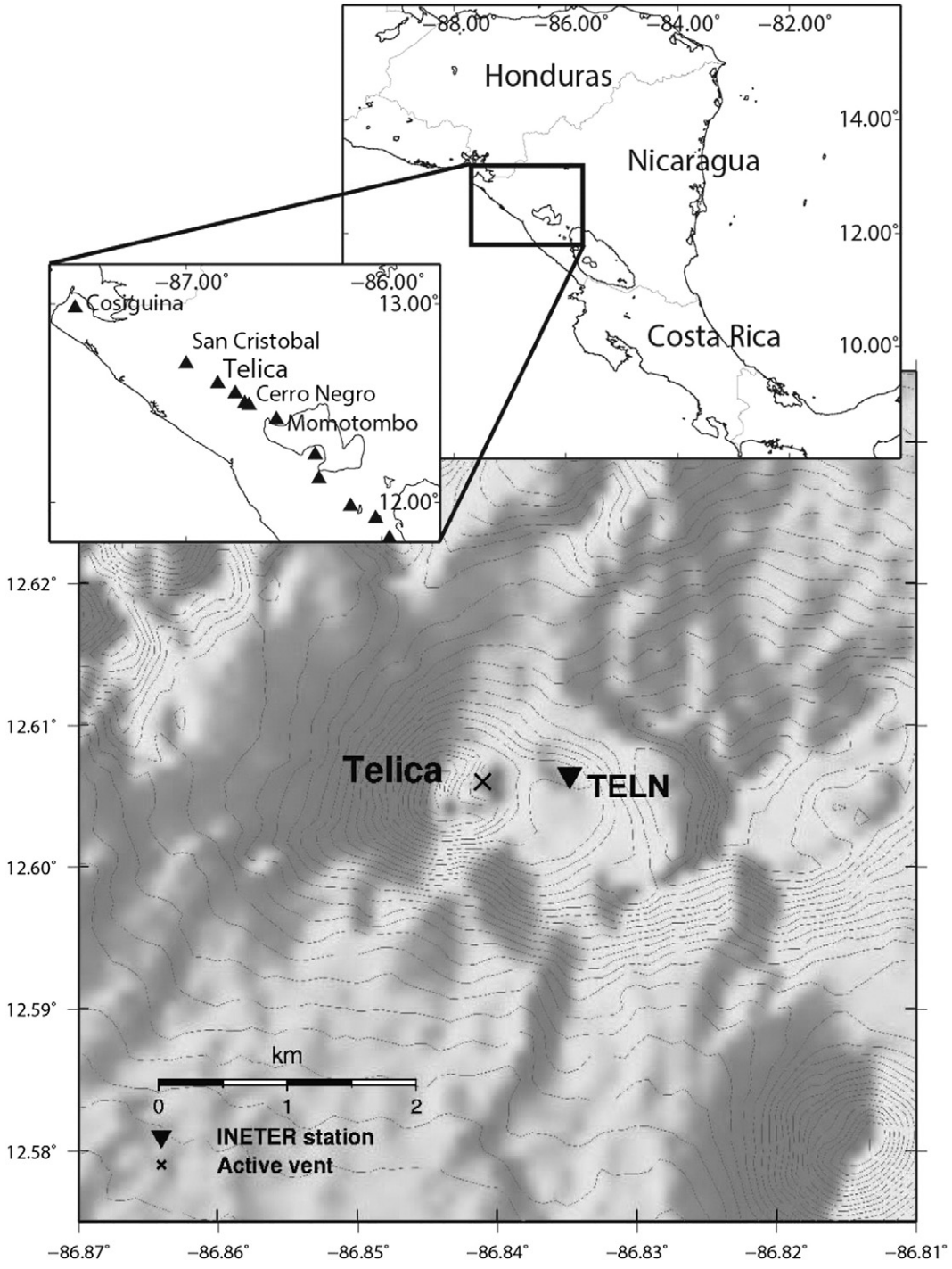

Fig. 1. Location of Telica and of INETER seismic station TELN. Inset maps: (right) Central America and (left) major volcanic centres of Nicaragua.