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Review

Volcanic processes detected by tiltmeters: A review of experience on Sicilian volcanoes

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ABSTRACT

A review of the experience gained in the use of tiltmeters on Mt. Etna, Stromboli and Vulcano during the last 30 years is reported here.
Tilt data represent a fundamental contribution towards understanding volcanic processes such as dike intrusions, fracture propagation, lava fountains and volume changes in magmatic or hydrothermal systems causing a deflation/inflation of the edifice.
Intrusive processes preceding lateral eruptions show large variations (up to over 100 microradians), while minor variations (not exceeding 2.5 microradians) are linked to lava fountains that form ash plumes and lead to fallout deposits that cause severe hazards to aviation. High precision tilt also allows detecting the slight ground deformation linked to strombolian activity (0.01–0.2 microradians) as well as co-seismic variations (0.1–1.5 microradians) and tidal effects (0.1–0.2 microradians) that may have a role in the evolution of a volcanic system.
Time–amplitude tilt ranges linked to each process are generally different allowing to discriminate, in real time, between a signal associated to one process and another one.
This fact is important in terms of early warning particularly during the first phases of dikes propagation that precede a lateral eruption by hours–days.

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1. Introduction

Ground deformation on volcanoes is fundamental to better understand magmatic processes and for eruption forecasting. In order to detect both spatial and temporal patterns of ground deformation different techniques are undertaken: InSAR, GPS, leveling, strainmeters and tiltmeters (Dzurisin, 2003).

Tiltmeters measure angular movements by using borehole bi-axial electronic sensors and long-base devices. Borehole instruments use high precision electrolytic bubble sensors and each one comprises two perpendicular axes; long-base devices have two orthogonal fluid-filled tubes that are generally positioned inside tunnels where fluid levels are measured at the ends of the tubes.

Continuous tilt measurements are able to measure small variations on volcanoes over a broad time span, though excelling over the short-term. Weeks to months variations could indicate the inflation/deflation of the edifice caused by volume changes in shallow-middle depth magma reservoirs (e.g. Murray and Wooller, 2002; Zeeuw-van Dalfsen et al, 2005) or from movements of geothermal fluids (e.g. Battaglia et al., 2006 at Campi Flegrei; Waite and Smith, 2002 at Yellowstone Caldera).

Faster tilt variations (minutes to days) may be linked to different processes, the most common of which are the rapid rise of magma and propagation of dikes and eruptive fissures (e.g. Toutain et al., 1992; Peltier et al., 2011 at Piton de La Fournaise, Ueda et al., 2005 at Miyakejima, Montgomery-Brown et al., 2010 at Kīlauea) and dome growth (e.g. Anderson et al, 2010 at St. Helens, Costa et al., 2007 at Soufrière Hills).

This paper focuses on tilt feature related to different volcanic processes that have been detected by tilt networks installed on Mt. Etna, Stromboli and Vulcano over the last 30 years and reports both published and unpublished data.

1.1. Volcanological settings of Mt. Etna, Stromboli and Vulcano

Mt. Etna, Stromboli and Vulcano are the most active and highly monitored of the Sicilian volcanoes (Fig. 1).

Mt. Etna is a basaltic volcano situated on the eastern coast of Sicily and is one of the most active volcanoes in the world. The volcanic edifice is high over 3300 m, has a basal diameter of about 40 km and at present exhibits four active summit craters.

Mt. Etna's activity may be grouped into two types: lateral flank eruptions occurring along fracture systems and persistent activity comprising phases of degassing alternating with strombolian activity, which may evolve into lava fountains and effusive events.

Flank eruptions at Etna are more hazardous than the more continuous summit activity and may have serious consequences in terms of material damage and/or the loss-of-life; the interval between two such eruptions spans from several months to few decades. Some of these eruptions, such as the 1991–93 event, have produced major lava flows and in some cases lava flows have covered both main flanks of the volcano, as during the 2001 and 2002–03 eruptions (e.g. Allard et al., 2006).

The continuous summit activity is also characterized by lava fountain episodes, i.e. paroxysmal activity causing the formation of dispersal ash plumes and fall-out deposits, which may entail severe aviation hazards (e.g. Alparone et al., 2007; Bonaccorso et al., 2011a).

Stromboli, an approximately 3 km high strato-volcano rising 924 m above sea level, is the northernmost island of the Aeolian Archipelago, a

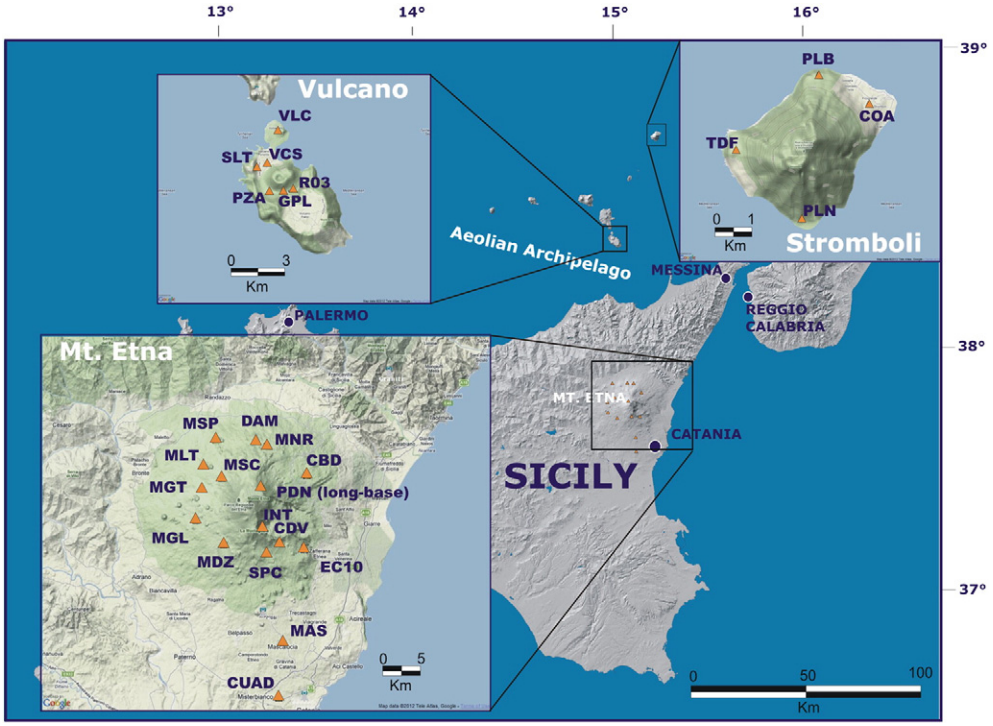

Fig. 1. Map of permanent tilt networks in operation on Sicilian volcanoes.