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Statistical analysis of the historical activity of Mount Etna, aimed at the evaluation of volcanic hazard

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Abstract

We analyzed the space–time distribution of the lateral eruptions of Mt Etna during the last 5 centuries aimed at the definition of the probability of eruption, and proposed a method to make quantitative estimate of lava flow hazard.

The time series analysis shows that, on average, the temporal distribution of flank eruptions follows a non-homogeneous Poisson distribution. The last 20 years of activity point out to an increasing number of eruptions with time.

The lava flows can be divided into two classes: those with a short duration and high effusion rate (type I flows), and those with relatively lower effusion rates, but longer durations (type II flows). Type I flows attain the longest lengths. We evaluate the probability of a given lava flow length for Type I events, based on the distribution of historical lava flow fields, and the duration and effusion rate of the corresponding eruption. We propose a methodology for the evaluation of hazard from lava flow, taking into account the worst-case scenario of a type I lava flow, and the probability that it can reach a certain area, basing on the probability of occurrence of eruption, of location of the vent, and of flow length.

Keywords: Etna; lava; hazard

1. Introduction

The evaluation of volcanic hazard is a primary goal of scientific research on volcanoes, especially for those located in densely inhabited areas. Quantification of the hazard is not an easy task, as it requires a deep knowledge of the volcano's history and of the style of eruptions. Italian volcanoes have an uncommonly long historical record of activity (10^2–10^3 yr, Scandone et al., 1993; Simkin and Siebert, 1994), which permits statistical estimates of hazard for events whose return period is shorter than ˜100 years. On longer time scales, our knowledge of the record of activity is based on geological investigations, which lack the sufficient detail to gather the fine structure of volcanic activity. The record of smaller events is often lost, and, for the oldest period, the catalogue is not complete. This problem is known as the completeness threshold of a catalogue.

Records of activity on Etna go back to the period of Greek colonization. The first modern description of eruptions dates back to Thucydides in his History of the Peloponnesian War, reporting the eruption of 425 BC, and mentioning another from 475 BC.

Although there are accounts of numerous eruptions dating back to the Roman and the medieval times, a reliable historical catalogue of eruptions is available only since 1500. Different catalogues are presently

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available (Tanguy, 1981; Romano and Sturiale, 1982; Chester et al., 1985); and we complemented these data for the most recent activity, making use of the Smithsonian Institution database of recent eruptions starting in 1971, which is particularly reliable for Etna (Global Volcanism Program/Etna). The spatial analysis was also based on the available geological maps (Romano, 1975, 1989), and the GIS data (Favalli et al., 1999; Pareschi et al., 2000). When necessary, we complemented this information with original historical sources and geological informations.

It must be emphasized that historical catalogues of Etna are reliable mostly for flank eruptions; summit activity has a reliable record only since the late 1900s. In terms of hazard, summit activity poses relatively minor problems to inhabited areas, and for this reason has not been taken into account in our analysis.

Previous statistical analyses of Etna's activity have been used mostly to infer the temporal patterns of volcanic activity (Mulargia et al., 1985, 1987, 1992; Marzocchi, 1996). In this paper, we perform a similar analysis for the temporal distribution of eruptions on a longer record including also the most recent activity. For the statistical analysis of hazardous eruptions, we will concentrate on flank events and limit our statistical evaluation to the space–time distribution of this class of eruptions.

We make also an analysis of the spatial distribution of lateral vents as well as of the morphology of lava flows. The length of Etnean lava flows mostly depends on the morphology of the volcano (slope), rheology of magmas, and magma discharge rate (Walker, 1973; Kilburn, 1990). Different dynamical regimes characterize AA and Pahoehoe flow fields (Macdonald, 1953). Most lava fields on Etna are of the AA type and so we apply our analysis only to this variety.

After this analysis, we provide the guidelines necessary for the construction of quantitative hazard maps for invasion of lava flows.

2. Styles of activity at Etna

Etna displays a wide range of eruption styles from effusion and mild, strombolian to violent, plinian explosive eruptions such as what occurred in 122 BC (Coltelli et al., 1998). Since 1500 AD, the activity has been dominated by effusive eruptions from the central craters or from lateral vents on the flanks of the volcano. Occasionally, these eruptions were accompanied by minor explosive activity that formed an eruption plume rarely exceeding a few kilometers in height. The volume of erupted magma ranges from a few millions of cubic meters to approximately 1 km^3 (e.g. the voluminous flank eruptions of 1614–24 and 1669).

Flank eruptions may be fed from the central feeding system (Wadge, 1977; Bousquet and Lanzafame, 2001) or directly from a deep feeding system not intercepting the central one (eccentric eruptions); (Romano and Sturiale, 1982). In the first case, it is assumed that the rocks surrounding the central conduit fracture at a level where the lithostatic load of the magma column overcomes the strength of the wall rocks (Wadge, 1977). Often, this process is accompanied by a rapid drainage of magma with an exponential decrease of the magma discharge (Wadge, 1981). The initial rapid phase might be followed by a longer period of almost constant but low magma discharge.

Occasionally both the central conduit system and an eccentric system may be active at the same time, as inferred for the eruptions in 2001 and 2002–2003. (Taddeucci et al., 2002; Patanè et al., 2002).

Only flank eruptions pose a major treat to inhabited areas. During the last century, the village of Mascali was reached in 1928 by a lava flow whose vents opened as low as 1200 m asl; in 1971, a lava narrowly missed the village of Fornazzo; in 1981, a lava reached the outskirts of the village of Randazzo; and in 1991–1993 a voluminous lava flow menaced the village of Zafferana (Barberi et al., 1993). During the last 300 years, the lowest vent of the 1669 eruption opened at 900 m asl on

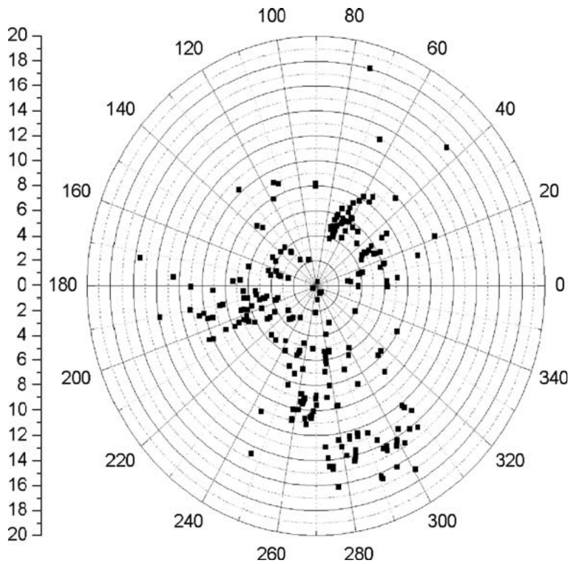

Fig. 1. Azimuthal distribution of cones of lateral eruption on Etna. The center is located on "La Voragine" central crater. The cones are all those identified on the geological map of Romano (1975, 1989) and the DEM model of Pareschi et al. (2000), Favalli et al. (1999). The scale on the left is in km from the center.