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Quantitative hazard assessment of phreatomagmatic eruptions at Vulcano (Aeolian Islands, Southern Italy) as obtained by combining stratigraphy, event statistics and physical modelling

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ABSTRACT

The detailed analysis of stratigraphy allowed the reconstruction of the complex volcanic history of La Fossa di Vulcano. An eruptive activity mainly driven by superficial phreatomagmatic explosions emerged. A statistical analysis of the pyroclastic Successions led to the identification of dilute pyroclastic density currents (base surges) as the most recurrent events, followed by fallout of dense ballistic blocks. The scale of events is related to the amount of magma involved in each explosion. Events involving about 1 million cm^3 of magma occurred during recent eruptions. They led to the formation of hundreds of meters thick dilute pyroclastic density currents, moving down the volcano slope at velocities exceeding 50 m/s. The dispersion of density currents affected the whole Vulcano Porto area, the Vulcanello area. They also overrode the Fossa Caldera's rim, spreading over the Piano area. For the aim of hazard assessment, deposits from La Fossa Cone and La Fossa Caldera were studied in detail, to depict the eruptive scenarios at short-term and at long-term. By means of physical models that make use of deposit particle features, the impact parameters have been calculated. They are dynamic pressure and particle volumetric concentration of density currents, and impact energy of ballistic blocks. A quantitative hazard map, based on these impact parameters, is presented. It could be useful for territory planning and for the calculation of the expected damage.

1. Introduction

The most impressive events of volcanology are Plinian eruptions, which lead to the formation of thick fallout and pyroclastic flow deposits (e.g. Cioni et al., 2000). They are variable in energy, size and distribution (but always highly destructive in the volcanoes surrounding). Most of the fatal eruptions occurred recently worldwide were, however, of scales and styles different from a Plinian type. As an example, it suffices to remember some recent or ongoing eruptions at Mount Peleè (1902; Fisher and Heiken, 1982), Montserrat (1995–present day; Druitt and Kokelaar, 2002), Unzen (1990–1995; Miyabuchi, 1999), and Merapi (2006; Charbonnier and Gertisser, 2008). In many cases the eruptive regime was quite complex and characterized by multiple events of variable intensity, with the eruption lasting for months up to years. In these cases, an extreme detail in the study of the geological record is needed to assess hazard. This is the approach we used in the study of past eruptions at La Fossa di Vulcano. When we consider that the majority of houses and tourist activities (population increases up to over 10,000 people during summer) are located at the foot of the western flank of La Fossa Cone (Fig. 1), we understand that even a very small eruption could have very serious impacts at Vulcano.

As it is deduced from the stratigraphic record, eruptions were characterized by explosive events mainly driven by phreatomagmatic processes. Dilute pyroclastic density currents of the type of base surges formed in rapid succession, during pulsatory eruptions. For such currents, the hazard is related to the dynamic pressure (Valentine, 1998) acting on buildings, and to the volumetric concentration of hot particles, which is a threat to people, because of the toxicity of hot, fine ash (Baxter et al., 1998; Horwell and Baxter, 2006).

Our final aim was to obtain a quantitative hazard map that, on one side was to be based on a solid geological background, and on the other would represent quantitative data, to be used for territory planning and Civil Protection actions.

2. Geological and volcanological background

Vulcano Island (Fig. 1) covers an area of about 23 km^2, with a length of 5.5–6 km along NS and 4.5 along EO direction. It represents

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Fig. 1. Panoramic view of Vulcano Island. Locations referred to in the text are marked.

the emerged part of a volcanic edifice whose base level is at about 1 km below sea level. The subaerial eruptive history started at about 125 ka.

Detailed geological studies date back to the '70 and '80 decades (Keller, 1980, Frazzetta et al., 1983), and recently led to a new geological map (De Astis et al., 2006). This map provides a synthesis of the various articles published since recently (De Astis et al., 1997a; Dellino and La Volpe, 1997; Del Moro et al.; 1998; Ventura et al., 1999; De Astis et al., 2003), which allowed the reconstruction of the evolution of volcanism of the island. The early eruptive activities went throughout effusive and mild explosive eruptions, which led to the growth of a strombolian strato volcano (~127–100 ka). Products are of almost constant composition, ranging between HKCA and SHO suites, with basaltic–andesitic to latitic compositions. At about 100 ka, a collapse of this old edifice occurred, due to volcano-tectonic activities related to a strike–slip tectonic regime, and the Piano Caldera formed. Intra-caldera and ring-faults volcanism – mainly driven by NNE–SSW normal faults – developed until about 50 ka, also producing the early (southern) collapse of the present multi-stage La Fossa Caldera. Magma compositions during this time-span were basically similar to the previous ones, but some high-K to shoshonitic basalts were erupted, displaying the most primitive magma composition observed in the whole Volcano history (De Astis et al., 1997a). At the end of this period, a shifting of the eruptive vents towards the NW sector of the island occurred, together with further partial collapse events connected to the formation of La Fossa Caldera structure. It has been suggested (De Astis et al., 2006) that a major eruptive vent was active within the morphologic depression of La Fossa Caldera structure. It was characterized by a strombolian to phreatomagmatic eruptive style, which produced an alternance of fallout deposits and base surges. The most energetic events were able to override the topographic obstacles represented by La Fossa Caldera walls, and to infill the central and southern sectors of the Piano Caldera morphologic depression. Lucchi et al. (2008) suggest that part of these caldera-filling pyroclastic sequences represent the proximal counterpart of the so-called Intermediate Brown Tuff deposits, which are documented on most of the Aeolian archipelago. New eruptive vents, located along the present western collapse rims of il Piano and La Fossa Caldera structures, rejuvenated the volcanism on the Island, following a N–S to NW–SE alignment and a ~20 ka-long period of quiescence (Fig. 2A). In particular, the growth of trachy-rhyolitic lava domes and the emplacement of subordinate pyroclastic products affected, at various times, the Mt. Lentia area (~28–13 ka). It is to note that, after 30 ka, the eruptive activities were concentrated in the wide area presently corresponding to La Fossa Caldera, whose present polycyclic configuration was reached through the partial collapse of the Lentia lava-domes (Fossa Caldera western sector). This last volcano-tectonic event is probably due to some of the biggest explosive eruptions occurred at Vulcano (from 21 to 7.7 ka), which led to the emplacement of the Piano di Grotte dei Rossi unit (i.e. the TGR Inf. and TGR Sup. by De Astis et al., 1997b). It represents the proximal expression of the Upper Brown Tuff deposits on most of the Aeolian archipelago (Lucchi et al., 2008). These products are the result of intense phreatomagmatic eruptions, driving the generation of dilute density currents, and are sometimes associated to thin co-ignimbritic fallout deposits. They were able to get over La Fossa caldera walls, and led to the deposition of ash layers on wide sectors of Vulcano Island and the entire Aeolian archipelago (as far as the northern coast of Sicily, at Capo Milazzo).

The presently active tuff cone, named La Fossa Cone, was built over the last 5.5 ka, in the middle of La Fossa Caldera structure (Frazzetta et al., 1983). Its activity was mainly phreatomagmatic and drove to the emplacement of multiple overlapping beds, emplaced along rather long time-spans, as it is inferred by considering the patterns of the activities occurred and observed in the last centuries (Mercalli, 1879; Mercalli and Silvestri, 1891 and references therein). These pyroclastic products mostly crop out along the flanks of the cone, with scattered outcrops on the flat area of il Piano, on Vulcanello and along the southern flank of the Primordial Vulcano, close to Gelso. During the last 3 ka, explosive eruptions at La Fossa Cone alternated with some effusive episodes generating viscous lava flows, with lati-trachytic or rhyolitic compositions (Fig. 2B). The Vulcanello lava shield, consisting of a shoshonitic lava platform encircling three small coalescent, NE–SW aligned scoria cones, was entirely built during the last 2 ka (last eruption 1550 AD). It is the result of three distinct phases of activity from an eruptive vent most probably localized along the northern border of La Fossa caldera. Explosive activity at Vulcanello was similar to that of La Fossa cone, but of smaller scale.

The last eruption on Vulcano occurred in the years between 1888 and 1890 AD, from La Fossa Cone, and produced “pulsating” outbursts of pyroclastic material and bread-crust bombs, which description gave origin to the definition of the Vulcanian-type eruptions in the volcanological literature (Mercalli and Silvestri 1891). In the last century, La Fossa Cone has been the site of intense gas emissions