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Maximum horizontal range of volcanic ballistic projectiles ejected during explosive eruptions at Santorini caldera

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ABSTRACT

This study investigates the hazard posed by Volcanic Ballistic Projectiles (VBPs) to the Santorini islands considering eruption scenarios that include low (VEI = 2–3) and higher energy (VEI >3) eruptions. A model that describes rapid decompression of pressurized magma below a caprock along with its fragmentation and acceleration of particles is utilized for estimating initial velocities during vulcanian-style eruptions. These initial velocities are inserted into the ballistic equations assuming that VBPs have a cube-like shape, are subjected to gravity/drag forces and are launched into a zone of reduced drag. Four different diameters of VBPs are considered (0.35 m, 1.0 m, 2.0 m, 3.0 m) and also different values of gas fractions and extent of the reduced drag zone are investigated. The results of these calculations show that an area of 1–2 km width along the western coast of Thera will be within the maximum range of VBPs, provided that the eruptive vent will develop either on Nea Kameni or between Nea Kameni and Thera. Initial velocities for higher energy eruptions are estimated by considering the conversion efficiency of thermal to kinetic energy. For the case of an eruption with VEI = 4 and a number of vents centered between Nea and Palea Kameni, calculations show that the coastal areas of Thera and Therasia are within the maximum horizontal range of VBPs with diameter larger than 0.35 m. As the exact position of the eruptive vent seems to be of crucial importance for determining the areas at risk, continuous seismic and geodetic monitoring of the caldera is needed in order to decipher its likely location.

1. Introduction

Volcanic Ballistic Projectiles (hereafter called VBPs) can be defined as particles above a certain diameter (>0.1 m) of any origin that tend to separate rapidly from the eruptive column, following nearly parabolic trajectories before they impact the Earth's surface (Alatorre-Ibargüengoitia et al., 2012). VBPs represent a significant volcanic hazard that can potentially cause damage to man-made structures and serious injury to the inhabitants of the area around the eruption site. These hazardous effects stem from two properties that VBPs have, namely their high impact energy and elevated temperature. The former property accounts for the fact that large projectiles are capable of penetrating building materials such as cement and the latter one is responsible for triggering fires should VBPs fall within a vegetated area. Observations from volcanoes worldwide suggest that VBPs attain ejection velocities in the range of 50–600 m/s, they have diameters of few centimeters to several meters and their maximum horizontal range may vary from hundreds of meters to several kilometers (Nairn and Self, 1978; Yamagishi and Feebrey, 1994; Kilgour et al., 2010; Harris et al., 2012; Maeno et al., 2013). In an effort to mitigate the risks posed by VBPs, volcanologists have taken advantage of the rather predictable trajectories that VBPs follow and have tried to delineate their impact locations. Such calculations take into account that VBPs are subjected to gravity and drag forces and that their trajectories depend on the initial conditions at the time when they were ejected from the eruption vent (Walker et al., 1971; Wilson, 1972; Fagents and Wilson, 1993; Bower and Woods, 1996).

Volcanism in the southern Aegean is the consequence of the subduction of the African slab beneath the Eurasian plate which results in the formation of a well-developed volcanic arc (Vougioukalakis and Fytikas, 2005). Santorini caldera is a very active volcanic center of this arc, having produced numerous explosive eruptions over the last 250 ka, the most famous of these being the Late Bronze Age (ca. 1613 BC, VEI = 7) Minoan eruption (Bond and Sparks, 1976; Heiken and McCoy, 1984; Druitt and Francaviglia, 1992; Vougioukalakis and Fytikas, 2005; Friedrich, 2013). Subsequently, several smaller eruptions with VEI between 2 and 3 occurred in the time period from 197 BC to 1950 AD, and the small islands of Palea and Nea Kameni that lie in the center of the caldera were created by this activity. For the last 60 years, the volcanic system had been relatively quiet with only minor hydrothermal and seismic activity (Dimitriadis et al., 2009). However, this situation changed in 2011 when significant uplift and increased seismicity rates were detected within the caldera (Newman et al., 2012; Parks et al., 2012; Foumelis et al., 2013; Konstantinou et al., 2013; Lagios et al., 2013; Papoutsis et al., 2013). Even though

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this unrest did not culminate into an eruption, it did put forward the issue of the volcanic hazards posed by future eruptive activity and how authorities should plan to cope with them. Vougioukalakis and Fytikas (2005) have published a zonation map (Fig. 1) for different volcanic hazards that are expected to affect the Santorini island complex and especially Thera island, whose population is greatly increased by a large influx of tourists every summer. The delineation of the hazard area due to VBPs impact is mostly based on observations of the effects from previous eruptions (even though the authors do not refer explicitly to these observations) and implies that the most populated areas on Thera are out of VBPs range.

This work aims at estimating the maximum horizontal range of VBPs at Santorini caldera for different eruption scenarios that range from small eruptions with Volcanic Explosivity Index (Newhall and Self, 1982) (hereafter called VEI) between 2 and 3, as well as larger ones (VEI > 3). First, a caprock model proposed by Alatorre-Ibargüengoitia et al. (2010) approximating conditions during small volume explosive eruptions is used in order to estimate initial velocities of ejected VBPs. Initial velocities for higher energy eruptions are calculated by using an approach based on the conversion efficiency of thermal to kinetic energy (Sato and Taniguchi, 1997). The calculated ejection velocities are then coupled to a ballistic model that describes the trajectories of

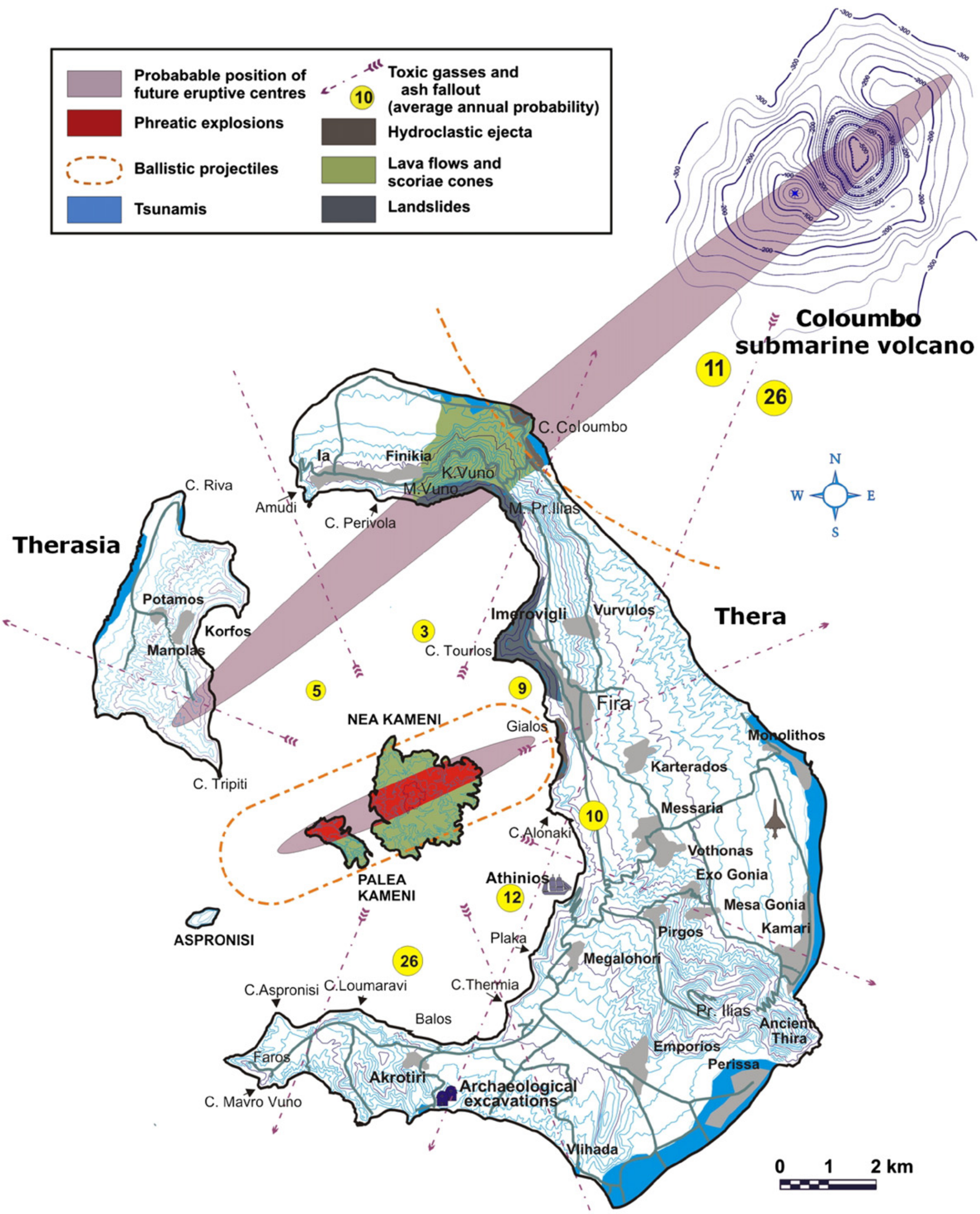

Fig. 1. Map of the Santorini island complex also depicting the volcanic hazards zonation due to a future eruption within the caldera or at Coloumbo submarine volcano. Contours show the bathymetry in meters around the Coloumbo crater. The map has been published by Vougioukalakis and Fytikas (2005) and is also available from http://ismosav.santorini.net website.