Journal of Geodynamics 54 (2012) 13–20

Contents lists available at SciVerse ScienceDirect

Journal of Geodynamics

journal homepage: http://www.elsevier.com/locate/jog

Stress field around the Coloumbo magma chamber, southern Aegean: Its significance for assessing volcanic and seismic hazard in Santorini

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ARTICLE INFO

Article history:
Received 27 May 2011
Received in revised form 5 September 2011
Accepted 18 September 2011
Available online 22 September 2011

Keywords:
Coloumbo
Santorini
Aegean
Magma chamber
Stress
Hazard

ABSTRACT

Coloumbo submarine volcano lies 6.5 km offshore the NE part of the Santorini island complex and exhibits high seismicity along with vigorous hydrothermal activity. This study models the local stress field around Coloumbo's magma chamber and investigates its influence on intrusion emplacement and geometry. The two components of the stress field, hoop and radial stress, are calculated using analytical formulas that take into account the depth and radius of the magma chamber as these are determined from seismological and other observations. These calculations indicate that hoop stress at the chamber walls is maximum at an angle of 74° thus favouring flank intrusions, while the radial stress switches from tensile to compressive at a critical distance of 5.7 km from the center of the magma chamber. Such estimates agree well with neotectonic and seismological observations that describe the local/regional stress field in the area. We analyse in detail the case where a flank intrusion reaches the surface very near the NE coast of Thera as this is the worst-case eruption scenario. The geometrical features of such a feeder dyke point to an average volumetric flow rate of 9.93 $m^3 s^{-1}$ which corresponds to a Volcanic Explosivity Index of 3 if a future eruption lasts about 70 days. Hazards associated with such an eruption include ashfall, ballistic ejecta and base surges due to explosive mixing of magma with seawater. Previous studies have shown that areas near erupting vents are also foci of moderate to large earthquakes that precede or accompany an eruption. Our calculations show that a shallow event (3–5 km) of moment magnitude 5.9 near the eruptive vent may cause Peak Ground Acceleration in the range 122–177 $cm\,s^{-2}$ at different locations around Santorini. These values indicate that seismic hazard even due to a moderate earthquake near Coloumbo, is not trivial and may have a significant impact especially on older buildings at Thera island.

1. Introduction

The Santorini island complex consists of five islands (Thera, Therasia, Palea and Nea Kameni, Aspronisi) that delineate a flooded caldera formed after several cycles of explosive volcanic activity over the last 400 ka (Bond and Sparks, 1976; Heiken and McCoy, 1984; Druitt and Francaviglia, 1992; Vougioukalakis and Fytikas, 2005) (Fig. 1). The last of these cycles started with the Late Bronze Age (LBA) eruption (ca. 1628 BC) which involved phreatomagmatic explosions and extended pyroclastic flows that destroyed some early human settlements near Akrotiri. The LBA event probably also triggered a tsunami that was thought to have affected the whole of the Eastern Mediterranean (Dominey-Howes, 2004 and references therein). Subsequently, many authors have contested this view mostly based on the lack of such tsunami deposits outside the southern Aegean (Dominey-Howes, 2004) and on numerical simulations (Pareschi et al., 2006). Activity after the LBA eruption continued in a diminishing trend with several smaller eruptions, the last one having occurred in the early 1950s. The small islands of Palea and Nea Kameni were created by this post-eruptive activity and presently exhibit only low-temperature (~17 °C) hydrothermal fluid venting (Sigurdsson et al., 2006).

At a distance of about 6.5 km from the NE coast of Thera island lies Coloumbo volcano, expressed by a submarine crater of 1.5 km diameter and maximum crater floor depth of 500 m. Submarine observations have revealed that the area of the Coloumbo crater exhibits vigorous hydrothermal activity manifested by high-temperature (~220 °C) gas emission plumes rising from numerous vents (Sigurdsson et al., 2006). Deployment of temporary seismic networks has revealed that the area around Coloumbo exhibits much higher seismicity than that inside the Santorini caldera (Bohnhoff et al., 2006; Dimitriadis et al., 2009). This seismicity consists mainly of microearthquakes ($M_L < 4$) that form various clusters around the Coloumbo crater at depths between 2 and 20 km. Earthquake activity is also persistent to the NE of Coloumbo delineating a tectonic zone that in 1956 generated the large (M_w 7.6) Amorgos earthquake and subsequent tsunami (Konstantinou, 2010 and references therein). The last eruption of Coloumbo occurred in 1650

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doi:10.1016/j.jog.2011.09.003

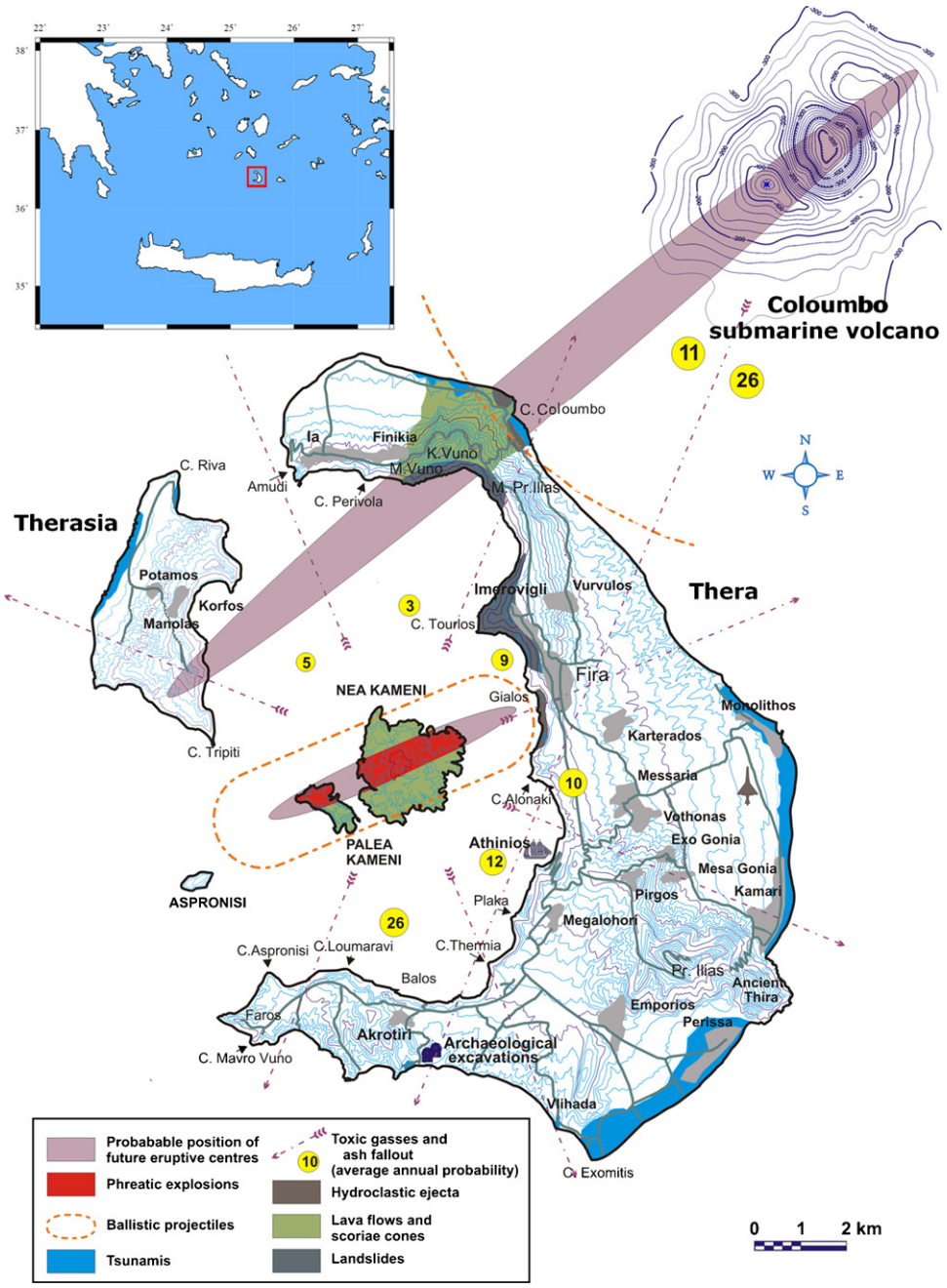

Fig. 1. Map of the Santorini island complex also depicting the volcanic hazards zonation due to a future eruption within the caldera or at Coloumbo (map compiled by G. Vougioukalakis also available from http://ismosav.santorini.net). Contours show the bathymetry in meters around the Coloumbo crater. The inset at the upper left-hand side shows the position of the island complex in the southern Aegean with a red square. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

AD and involved the formation of pumice rafts as well as subaerial tephra fallout while eruptive activity was preceded/accompanied by strong earthquakes (Dominey-Howes et al., 2000). Historical accounts also mention that this eruption generated a large tsunami that inundated the eastern coast of Thera to a distance of 2 miles, depositing large submarine boulders and sediments (see Dominey-Howes et al., 2000 and references therein). Table 1 summarizes the volcanological characteristics of this eruption as listed in the Global Volcanism database of the Smithsonian Institution.

The Greek Institute of Geological and Mineral Exploration (IGME) has compiled a map of volcanic hazard zones for Santorini based mostly on information taken from historical sources about past eruptive activity (Fig. 1). This map identifies five different potential hazards and their corresponding zonation: (a) phreatic explosions, (b) ballistic projectiles, (c) tsunamis, (d) toxic gas/ashfall, and (e) landslides. As far as Coloumbo is concerned, the map delineates a zone of probable eruptive centers that extends from the Coloumbo crater up to Therasia. It also considers possible that ballistic projectiles from Coloumbo may affect the NE coast of Thera, while toxic gases and ashfall are expected to affect the whole of the Santorini area. In this work, we aim at improving the understanding of hazards stemming from future eruptive activity of Coloumbo by considering the stress field around its magma chamber and how this affects intrusion emplacement and geometry. First we give an overview of the available information about the Coloumbo magma chamber derived from seismological and