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Source of the tsunami generated by the 1650 AD eruption of Kolumbo submarine volcano (Aegean Sea, Greece)

Martina Ulvrova [a], R. Paris [b,*], P. Nomikou [c], K. Kelfoun [b], S. Leibrandt [b], D.R. Tappin [d], F.W. McCoy [e]

[a] University of Lyon 1, ENS, CNRS LGL-TPE, F-69342 Lyon, France
[b] Laboratoire Magmas et Volcans, Université Blaise Pascal, CNRS, IRD, OPGC, 5 rue Kessler, F-63038 Clermont Ferrand, France
[c] University of Athens, Faculty of Geology and Geoenvironment, Panepistimioupoli Zografou, 15784 Athens, Greece
[d] British Geological Survey, Environmental Science Centre, Nicker Hill, Keyworth NG12 5GG, United Kingdom
[e] University of Hawaii — WCC, Kaneohe 96744, HI, USA

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ABSTRACT

The 1650 AD explosive eruption of Kolumbo submarine volcano (Aegean Sea, Greece) generated a destructive tsunami. In this paper we propose a source mechanism of this poorly documented tsunami using both geological investigations and numerical simulations. Sedimentary evidence of the 1650 AD tsunami was found along the coast of Santorini Island at maximum altitudes ranging between 3.5 m a.s.l. (Perissa, southern coast) and 20 m a.s.l. (Monolithos, eastern coast), corresponding to a minimum inundation of 360 and 630 m respectively. Tsunami deposits consist of an irregular 5 to 30 cm thick layer of dark grey sand that overlies pumiceous deposits erupted during the Minoan eruption and are found at depths of 30–50 cm below the surface. Composition of the tsunami sand is similar to the composition of the present-day beach sand but differs from the pumiceous gravelly deposits on which it rests. The spatial distribution of the tsunami deposits was compared to available historical records and to the results of numerical simulations of tsunami inundation. Different source mechanisms were tested: earthquakes, underwater explosions, caldera collapse, and pyroclastic flows. The most probable source of the 1650 AD Kolumbo tsunami is a 250 m high water surface displacement generated by underwater explosion with an energy of ~2×10^{16} J at water depths between 20 and 150 m. The tsunamigenic explosion (s) occurred on September 29, 1650 during the transition between submarine and subaerial phases of the eruption. Caldera subsidence is not an efficient tsunami source mechanism as short (and probably unrealistic) collapse durations (<5 min) are needed. Pyroclastic flows cannot be discarded, but the required flux (10^6 to 10^7 $m^3 \cdot s^{-1}$) is exceptionally high compared to the magnitude of the eruption.

1. Introduction

Determining the source of tsunamis generated during shallow-water and near-shore explosive eruptions is often problematic (e.g. 1883 Krakatau, 3.6 ka Santorini), because several processes might be potentially at the origin of tsunamis: pyroclastic flows, underwater explosions, earthquakes, caldera subsidence, and flank instabilities (e.g. Nomanbhoy and Satake, 1995; Maeno and Imamura, 2011; Novikova et al., 2011; Paris et al., 2014a). The 1650 eruption of Kolumbo submarine volcano, 7 km north-east of Santorini (Fig. 1), generated a destructive tsunami in the Aegean Sea (Fouqué, 1879). The source of the tsunami(s) is not clarified and its magnitude has been discussed (Dominey-Howes et al., 2000; Nomikou et al., 2014).

With a basal diameter of 3 km, Kolumbo is the largest of a SW–NE alignment of submarine volcanic cones. Kolumbo volcanic complex mostly consists of vertically stacked volcaniclastic units with a summed volume of 13–22 km^3 (Hübscher et al., 2015). Volcaniclastic deposits associated with the 1650 AD eruption cover an area of 446 km^2 around the crater (Fuller, 2015), thus representing a minimum volume of ~5 km^3, i.e. 2 km^3 dense rock equivalent (Nomikou et al., 2012; Hübscher et al., 2015). Remotely operated vehicle (ROV) exploration of the volcano revealed thick and rapidly accumulated pyroclastic deposits on the northern and southwest walls of the crater (Nomikou et al., 2012, 2014). Pumice sampled by ROV is fresh, highly vesiculated, crystal-poor, and interstitial glass has a rhyolitic composition (Cantner et al., 2014). The bedded structure of the proximal pyroclastic deposits suggests multiple explosions and collapses that led to the formation of a 1700 m large, 500 m deep crater (Nomikou et al., 2012, 2014; Cantner et al., 2014). Distal deposits are cross-bedded and preferentially accumulated in the basins at distances up to 19 km from the crater (Fuller, 2015). These deposits were emplaced by sediment gravity flows generated by submarine eruption column collapse, with a significant fine ash fraction issued from surges over the sea surface and vertical gravity currents driven by Rayleigh–Taylor instabilities (Fuller, 2015).

* Corresponding author at: Laboratoire Magmas & Volcans, Université Blaise Pascal, CNRS, IRD, OPGC, 5 rue Kessler, 63038 Clermont Ferrand, France.
E-mail address: R.Paris@opgc.univ-bpclermont.fr (R. Paris).

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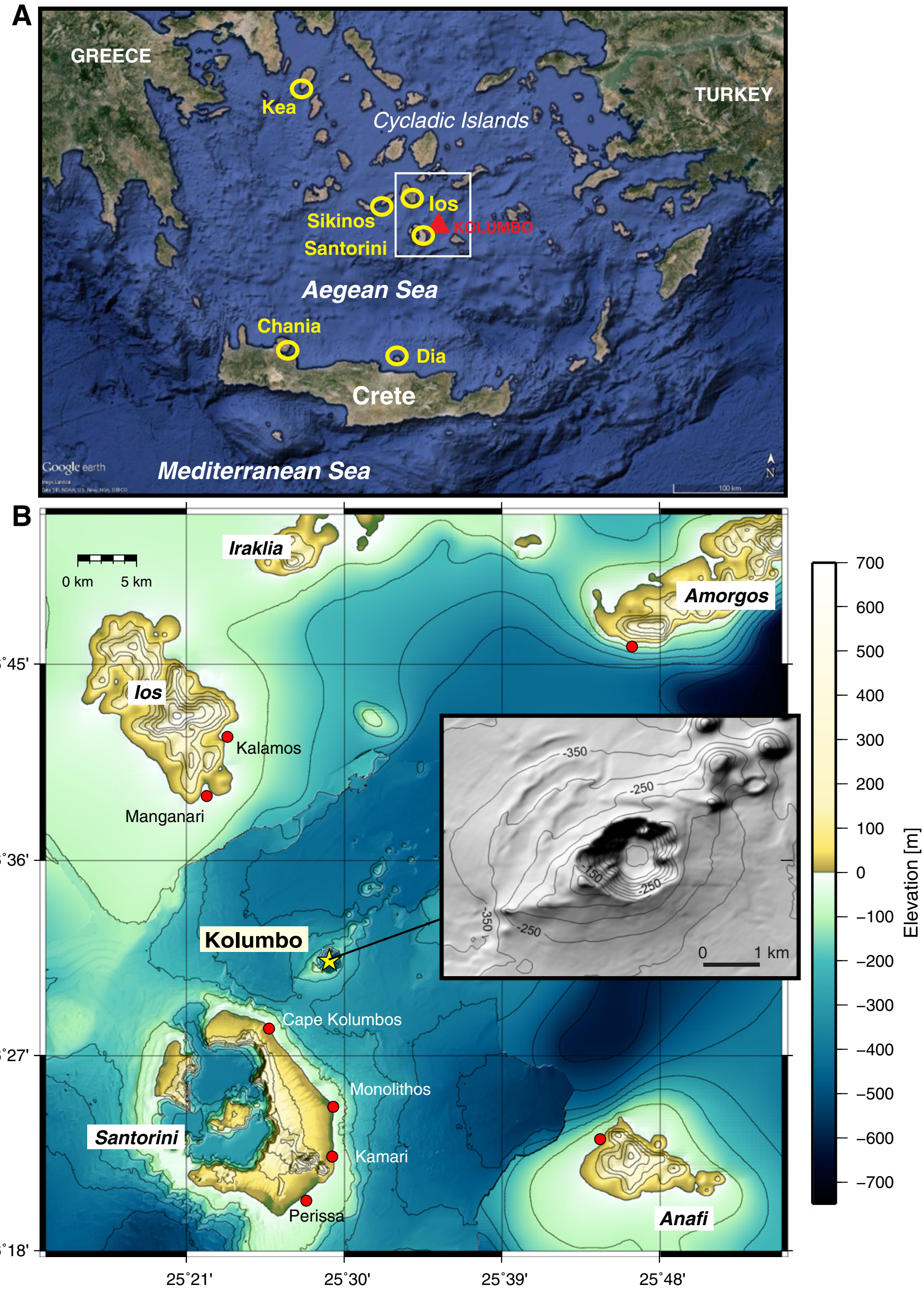

Fig. 1. Location map of Kolumbo submarine volcano (Aegean Sea, Greece). Yellow circles on map A indicate locations where the 1650 tsunami was observed. Shaded relief view depicts the edifice with its central crater and peripheral cones to the northeast.

Dominey-Howes et al. (2000) did not identify field evidence of the 1650 AD tsunami along the shores of Santorini, and thus considered problems related to the poor preservation and discontinuity of onshore high-energy deposits, and a possible overestimation of the magnitude of the tsunami. The aim of this paper is to re-investigate sedimentary evidence for the 1650 Kolumbo tsunami along the coast of Santorini and test different source mechanisms (earthquakes, underwater explosions, caldera collapse, and pyroclastic flows) through numerical simulations. Note that the high-resolution bathymetry of the studied area (Nomikou et al., 2012; 2013) did not reveal any evidence of hummocky or irregular topography that could be interpreted as a debris-avalanche deposit which would suggest flank instability that could be associated to the 1650 AD eruption. Thus, we decided not to consider a submarine slope failure of the edifice as a possible tsunami source.

2. Historical observations of the eruption

The aftermath of the 1650 AD eruption of Kolumbo volcano was described mostly by priests and travellers, and these testimonies were later summarised by Stefanou (1878), Fouqué (1879) and Mindrinos (2001). Precursory earthquakes were felt on Santorini Island in 1649 and in March 1650, and persisted during the eruption that started in