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Geoarchaeological tsunami deposits at Palaikastro (Crete) and the Late Minoan IA eruption of Santorini

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Abstract

The explosive eruption at Santorini in the Aegean Sea during the second millennium BCE was the largest Holocene volcanic upheaval in the Eastern Mediterranean region. The eruption was disastrous for the Minoan settlements at Santorini, but the effect on human society in the neighbouring islands and regions is still clouded in uncertainty. Tsunami generation was suggested, but comparatively little evidence was found. The lack of firm tsunami traces is particularly puzzling in Crete with its coastal settlements of the Late Minoan IA period, during which the Santorini eruption occurred. Here, we report the discovery of extensive geoarchaeological tsunami deposits at Palaikastro in north-eastern Crete. These deposits are characterized by a mixture of geological materials, including volcanic Santorini ash, and archaeological settlement debris. Various tsunami signatures were identified: (1) erosional contact with the underlying strata, (2) volcanic ash intraclasts in the lower part of the deposit, (3) reworked building stone material in the lower part of the deposit, (4) individual marine shells, (5) marine micro-fauna, (6) imbrication of rounded beach pebbles, settlement debris, ceramic sherds and even bones, (7) multi-modal chaotic composition. Late Minoan human settlement activities at Palaikastro provided architectural and stratigraphic frameworks in space and time that recorded and preserved tsunami evidence as geoarchaeological deposits. Such stratigraphic resolution and preservation may not occur in the natural landscape. Volcanic ash transported by wind from Santorini south-east to Crete preceded the tsunami. Geological, archaeological and radiocarbon dating criteria all converge, indicating that the tsunami deposits are coeval with the Minoan Santorini eruption. Field evidence suggests that tsunami waves at Palaikastro were at least 9 m high. Inverse tsunami modeling was attempted, based on these newly discovered tsunamigenic deposits. The initial wave in the generation region at Santorini that best fits the stratigraphic data is a wave with +35 to −15 m initial amplitude and a crest length of about 15 km.

Keywords: Minoan Santorini eruption; Crete; Geoarchaeological tsunami deposits; Micromorphology; Volcanic ash geochemistry; Radiocarbon dating; Tsunami modeling

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1. Introduction

The explosive eruption of the Santorini volcano in the Aegean Sea (Fig. 1) during the Late Minoan IA period (LM IA) is of great significance as a regional stratigraphic and chronological marker in the Eastern Mediterranean region (Bond and Sparks, 1976; Doumas, 1983; Keller et al., 1978, 1990; Sparks and Wilson, 1990; Druitt et al., 1999; Friedrich, 2000). Reassessment of the total volume of discharged tephra (McCoy and Dunn, 2002) and particularly the discovery by Sigurdsson et al. (2006) of massive pyroclastic deposits below sea level around Santorini indicate that the eruption was significantly larger than previous estimates. The Minoan Santorini eruption is now considered comparable to the 'super-colossal' Tambora eruption in Indonesia in 1815 (Sigurdsson et al., 2006), the largest volcanic eruption known in historical times (Sigurdsson and Carey, 1989), classified with a volcanic explosivity index (VEI) of 7 (maximum defined VEI = 8).

The well-known Krakatau eruption of 1883 (Simkin and Fiske, 1983), which occurred on a volcanic island in between Java and Sumatra, had a VEI of 6, *i.e.* 'colossal'. The eruption began on 20 May 1883 and volcanic activity continued for a few months until the final cataclysmic explosive events on August 26 and 27. Tsunamis were generated by emplacement of pyroclastic flow deposits, caldera collapse of the northern part of Krakatau Island and a huge submarine explosion (Nomanbhoy and Satake, 1995). The main catastrophic tsunami occurred on 27 August 1883 and caused the death of more than 36,000 people, as 295 villages and towns were destroyed or damaged in Java and Sumatra along the Sunda Strait (Simkin and Fiske, 1983). Pumice-bearing tsunami deposits of the Krakatau eruption were studied by Carey et al. (2001). The dramatic effects of the 1883 Krakatau catastrophe inspired Marinatos (1939) to suggest that widespread Late Minoan archaeological destruction levels in Crete may have been caused by the Santorini eruption, including tsunami impact along the coast.

However, subsequent research did not yield conclusive evidence to substantiate this hypothesis. The effect of the Minoan Santorini eruption on Crete (Fig. 1) is thought to have been limited in terms of the effect of volcanic ash deposition, while tsunami evidence has remained elusive (Thorarinsson, 1978; Keller, 1980a; Doumas and Papazoglou, 1980; Driessen and Macdonald, 1997, 2000; Dominey-Howes, 2004). Yet the 'super-colossal' magnitude of the eruption must have had consequences for the Aegean civilizations and their eastern Mediterranean neighbours. The decline of the Minoan civilization on Crete is thought to be related to the eruption (Driessen and Macdonald, 1997).

Various tsunami models have been developed in relation to the Minoan Santorini eruption (Yokoyama, 1978; Antonopoulos, 1992; McCoy et al., 2000; Pareschi et al., 2006). But surprisingly little robust onshore field evidence for Minoan tsunami deposits has been found so far in the Aegean specifically and the eastern Mediterranean region in general; see Dominey-Howes (2004) for a comprehensive review. Deep-sea homogenite deposits in the Ionian Sea were attributed, however, to a possible LM IA Santorini tsunami (Cita et al., 1984). The most important onshore evidence is a 3.5 m thick reworked tephra deposit along the east coast of Thera (Santorini) near Pori, discovered by McCoy and Heiken (2000). They interpreted the make-up and spatial distribution of these layers as tsunami evidence during the later stages of

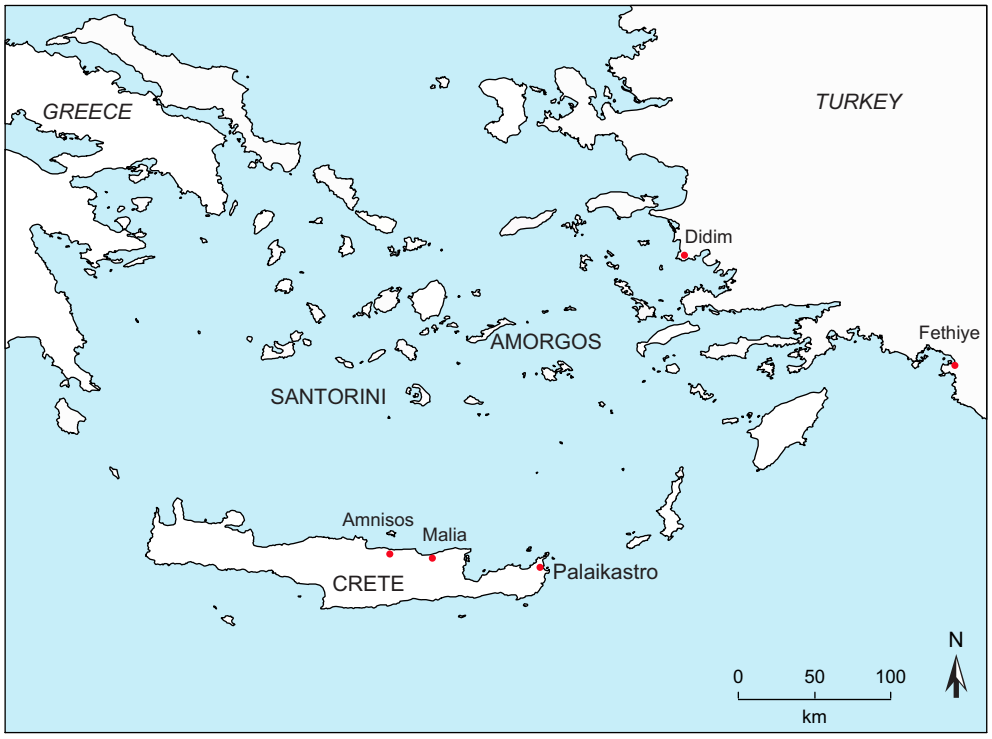

Fig. 1. Location map of the Aegean region, showing the main sites mentioned in the text.