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Mapping the Bronze Age settlement of Akrotiri on Santorini: digital documentation and archaeological prospection

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The Bronze Age settlement of Akrotiri on the Greek island of Santorini/Thera was covered by thick layers of volcanic pumice during the massive eruption of the Thera volcano in approximately 1613 BC. Archaeological excavations conducted since 1967 have revealed the archaeological remains of an affluent prehistoric society, living in up to three-storey-high buildings that were richly decorated with vivid frescoes and furnished with sophisticated sewer systems. To date, three buildings have been excavated completely and approximately seven buildings have been partly uncovered in an area measuring some 90 m by 120 m (Doumas 1983). Archaeological excavation at Akrotiri inevitably exposes the archaeological remains and often fragile prehistoric architecture to the risk of destruction in case of stronger seismic events, which are very likely to occur at some point in the future, since the site is located in one of the world's seismically most active regions (Chouliaras *et al.* 2012), being located on an active volcano. Additionally, gradual decay caused, for example, by mud wasps and accidental damage threatens with the collapse of exposed architecture at this unique site.

While it is impossible to prevent partial or total destruction of the excavated architecture in case of a larger earthquake, and while the long-term preservation of this cultural heritage is an extremely difficult challenge, it is possible to document the site digitally in three dimensions and in great detail. In 2013 and 2014, the LBI ArchPro documented the excavated areas in very high resolution, using laser scanning and latest photogrammetric methods. Within this project, which has been supported by the Conservation Trust of the National Geographic Society, additional geophysical archaeological prospection techniques have been tested in the vicinity of the archaeological site of Akrotiri in order to evaluate their potential to map still buried archaeological remains without exposing them to the risk of destruction.

With exception of the location Kokkino Vouno (Red Mountain) west of the archaeological site, all other nearby areas are covered by more or less thick layers of volcanic ash and pumice, rendering the application of standard near surface geophysical archaeological prospection approaches challenging. The volcanic geology and the mostly large distance between the surface and the target structures renders the use of the otherwise commonly used magnetic prospection method less than promising. Early magnetic measurements were conducted in the area by Dr. Elizabeth Ralph from the University of Pennsylvania Museum in 1967 using a caesium magnetometer, still prior to the substantial archaeological discoveries made by Spyridon Marinatos (Mavor 1969).

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Fig. 1. Ground penetrating radar measurements with a 250 MHz antenna system and 25 cm profile spacing on top of Kokkino Vouno (Red Mountain) near the archaeological site of Akrotiri. Photo: LBI ArchPro, Klaus Löcker

However, the magnetically highly inhomogeneous volcanic subsurface prevented any positive results. Sledge-hammer seismic measurements for archaeological prospection were attempted at that time, yet without any great success (Vermeule 1967).

Ground penetrating radar (GPR) measurements were to our knowledge first attempted at Akrotiri by Gregory Tsokas and colleagues in September 1996 (The Thera Foundation 1996), using a 225 MHz PulseEkko antenna as well as an EPRIS system from Coleman Research. The published results indicate limited signal penetrating depths between two and three metres in case of the 225 MHz PulseEkko, thus not yet reaching layers containing antiquities. However, these tests conclude that GPR can be successfully used, if the alluvium layer, which is the medium causing greatest signal loss, is removed. Further GPR tests conducted at Akrotiri by Russel and Stasiuk (2000), using a PulseEkko 100 system and 50 and 100 MHz antennae with large trace stacking numbers (256 respectively 128), resulted in reflectors successfully mapped at depths as large as 22 m. A geoelectrical tomography test was also conducted by Tsokas and colleagues in 1996 (The Thera Foundation 1996), resulting in the mapping of a resistive layer between two higher conductive ones, possibly imaging the volcanic basement at 6 m depth.

In February 2014, we tested several GPR antennae systems in the vicinity of Akrotiri, including a shielded 80 MHz MALÅ Geoscience GroundExplorer prototype antenna, as well as unshielded 100 MHz, and shielded 250 MHz and 500 MHz PulseEkko Pro antennae with 25 cm profile spacing. The latter two antennae were used to map an area on top of the Red

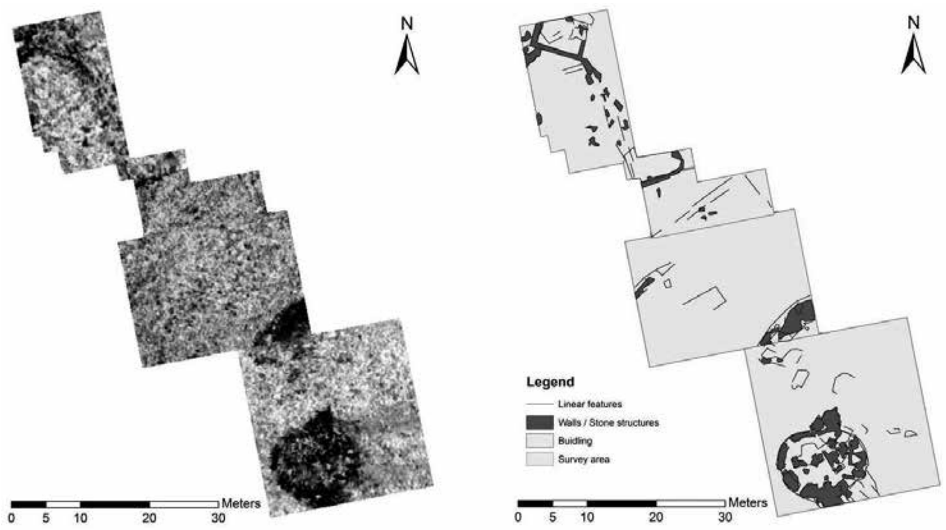

Fig. 2. GPR depth-slice from the Red Mountain (approx. 30 cm depth) and corresponding data interpretation

Mountain west of the Akrotiri excavation site. Georeferenced GPR depth-slices were generated after basic processing of the GPR traces. The GPR data shows anomalies caused by the buried remains of three buildings of great archaeological interest.

Additionally, electric resistance tomography (ERT) measurements were conducted using a 48-channel IRIS SYSCAL Pro system on the Red Mountain in two adjacent areas (grids) that had also been covered with GPR measurements. Each grid comprised a set of several 2D ERT lines, which were processed in full 3D mode. The inter-line and inter-electrode spacing was set to 0.75 m and every ERT line had 24 electrodes, resulting in a total line length of 17.25 m. Data were collected using an automated 10-channel resistivity meter using the dipole–dipole array with dipole separation up to n=8 and dipole spacings of a=0.75 m and 2a=1.5 m. Due to the generally very high resistivity environment, the signal-to-noise-ratio was very high, resulting in high quality measurements.

Each ERT line was initially processed using a standard 2D smoothness constrained inversion algorithm (Tsourlos 1995) to test the overall data quality and to reject possible outliers. Subsequently, all individual 2D ERT data were merged in a single dataset that was processed in full 3D mode: 3D inversion results were obtained after six iterations and the total RMS error was below 2%. Subsurface resistivity images produced from the 3D inversion are presented in the form of depth-slices.

Two buildings were located on the top of Red Mountain, where a trial excavation conducted by S. Marinatos in 1968 and surface finds of fresco fragments had indicated remains of Bronze Age architecture. There was also a circular structure of uncertain date, roughly 12 m in diameter. Both results of the GPR and ERT measurements are in good agreement.

For the first time it was possible to map substantial new archaeological structures in the vicinity of the archaeological excavation site of Akrotiri, using high-resolution GPR as well as ERT measurements. State-of-the-art non-invasive near-surface geophysical prospection has the potential to generate important new archaeological information about this fascinating archaeological site.

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