

QUANTIFICATION OF HUMAN IMPACT ON NATURAL EVOLUTION PROCESSES AT A COASTAL ZONE, ADJACENT TO AN ACTIVE FAULT



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ABSTRACT

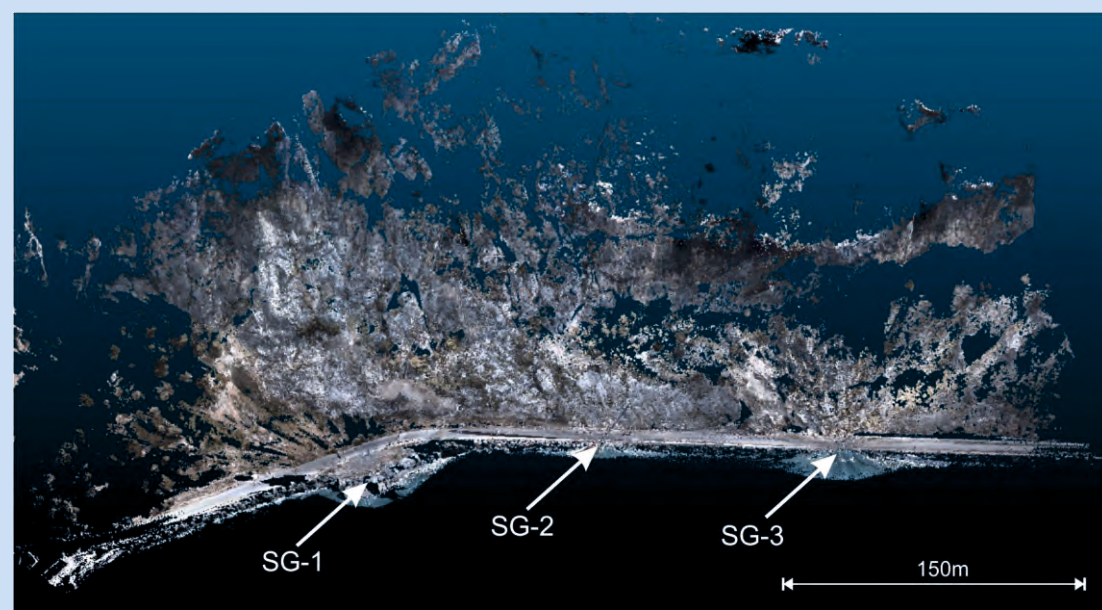
A coastal management study at areas with steep anaglyph requires detailed knowledge of the onshore surface and subsurface regime regarding the erosional procedures. Active faults produce dynamic and continuously evolving geomorphological structures, which require investigation and continuous monitoring. Detailed mapping on and adjacent to these surfaces is required in order to study the complexity of various tectonic discontinuities, which contribute significantly to erosion and rock-falls resulting rapid and significant changes on the landscape. The technology of ground-based Light Detection and Range (LiDAR) capturing devices is a powerful and valuable tool, providing detailed mapping and surface change detection of inapproachable and nearly vertical surfaces.

In this paper we introduce the diachronic monitoring and detection of alterations on the surface of the shore-side active fault of Psatha (Greece), with terrestrial LiDAR scanning, for a state of the art mapping of the almost vertical limestone fault surface. The monitoring procedure includes high-detailed topographic survey at the adjacent area using Real Time Kinematics Global Positioning System equipment (RTK-GPS), which is consisted of a large pile of brittle debris, laying on top the fault surface, by the sea.

The described methodology involved the production of a high resolution DEM based on historic topographic maps (scale 1:5,000) of the regional area and comparing it with the higher resolution DEM representing the contemporary morphology, produced by the combination of the fault wall LiDAR "point cloud" and the dense grid of the RTK-GPS measurement points. The comparison between these datasets and recently acquired high resolution IKONOS satellite images revealed impressive surface changes caused mainly by the human intervention as well as the erosional processes which were accelerated due to the absence of safety measures along the coastal zone.

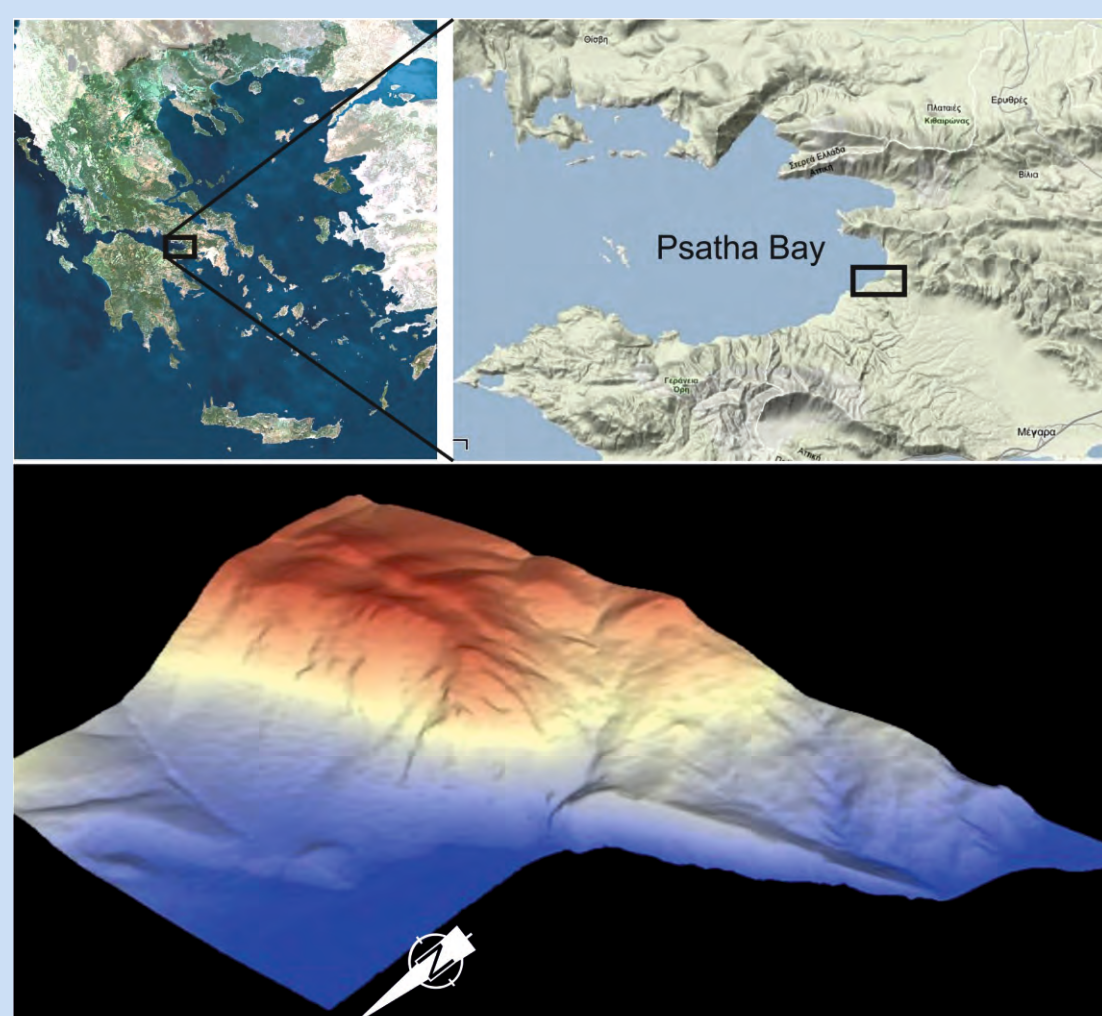
Furthermore, the regional subsurface of the hanging wall zone area was also investigated, especially underneath the brittle debris formation, applying the high-resolution near surface geophysical technique of Electrical Resistivity Tomography (ERT). Several sections were conducted aiming to represent the subsurface extension of the visible structures in three dimensions and combine it with the aforementioned datasets.

The successful combination of different techniques revealed and quantified the landscape evolution involving the surface alternations at the fault adjacent coastal zone, the sea intrusion and even the coastline displacement, during the last four decades. Most of these yielded to the anthropogenic interference on the brittle debris formation and even the construction of the coastal road.



Locations of the local control network stations on a true color 3-D view produced by the point cloud acquired from the ground-based laser scanning. The high relief of coastal area required a combination of several surveying methods for succeeding high accuracy topography at the largest possible scale. Initially an establishment of a local control network was designed, which comprise the basic reference for different kind of measurements. This network consists of three base stations (SG-1, SG-2, SG-3), which were selected based on the visibility of the entire coastal area, especially at places where the debris are cropping out.

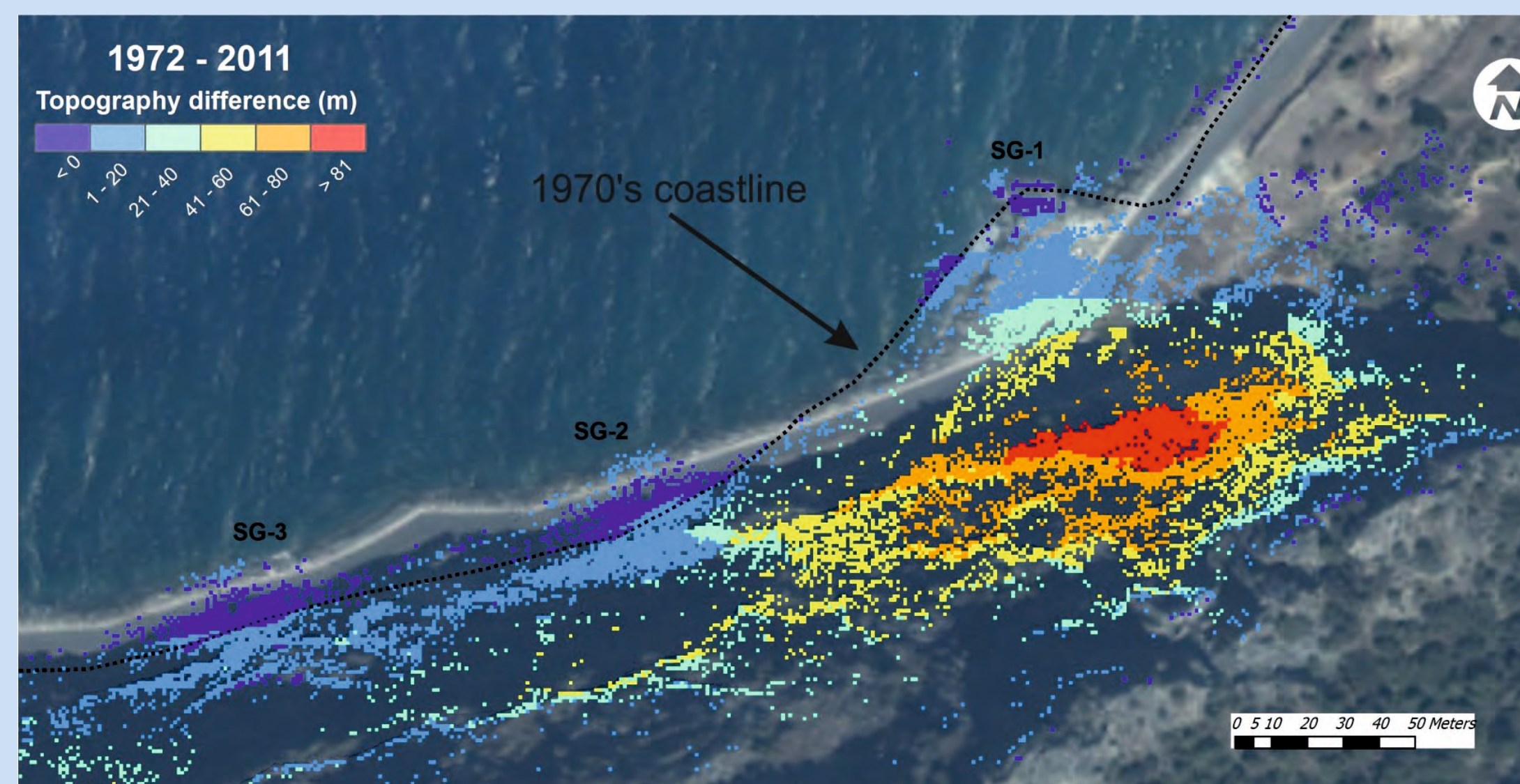
The SG-1 station was placed on a large limestone block which was naturally fallen on the beach area, in order to have good visibility at the debris outcrop, whilst the next two (SG-2 and SG-3) were placed on the sidewalk along the road next to the coastline. The latter were placed opposite from the vertical cliffs, which have been formed by the fault activity, in order to acquire the largest possible relief information of the fault surface during the laser scanning. Finally, the surveying methodology was completed by laser scanning of the onshore coastal area. A terrestrial laser scanner was used (Leica ScanStation C-10) and placed on the three established stations. Three point clouds with 2-5cm measurement spacing and ±6mm precision were merged in a single point cloud covering the entire coastal area and minimizing the shadow effect due to the roughness of the cliff. The same technique was repeated after seven months in order to capture the changes caused by rock falling and erosion due to wet period, but no significant changes were detected.



Index map of the study area and high resolution painted shaded relief of the coastal area (below). The area of interest is located at the easternmost coastal zone of the Corinth Gulf in Greece. Psatha Bay is one of the most seismogenic regions which hosts neotectonic faults that have been recently activated (1981) and produced disastrous earthquakes. The coastal zone along the Psatha active fault escarpment was chosen for developing a multi parametric methodology involving high resolution remote sensing and near surface applied geophysics techniques, in order to gain detailed knowledge of the onshore surface and subsurface regime regarding the erosional procedures. Along the sub-vertical fault scarp various tectonic kinematic features reveal several displacements during the post-alpine period causing a total visible throw of 185m and forming a steep coast. This activity produces a dynamic relief, which continuously alters the coastal zone that is also suffering the human intervention for more than the last two decades.

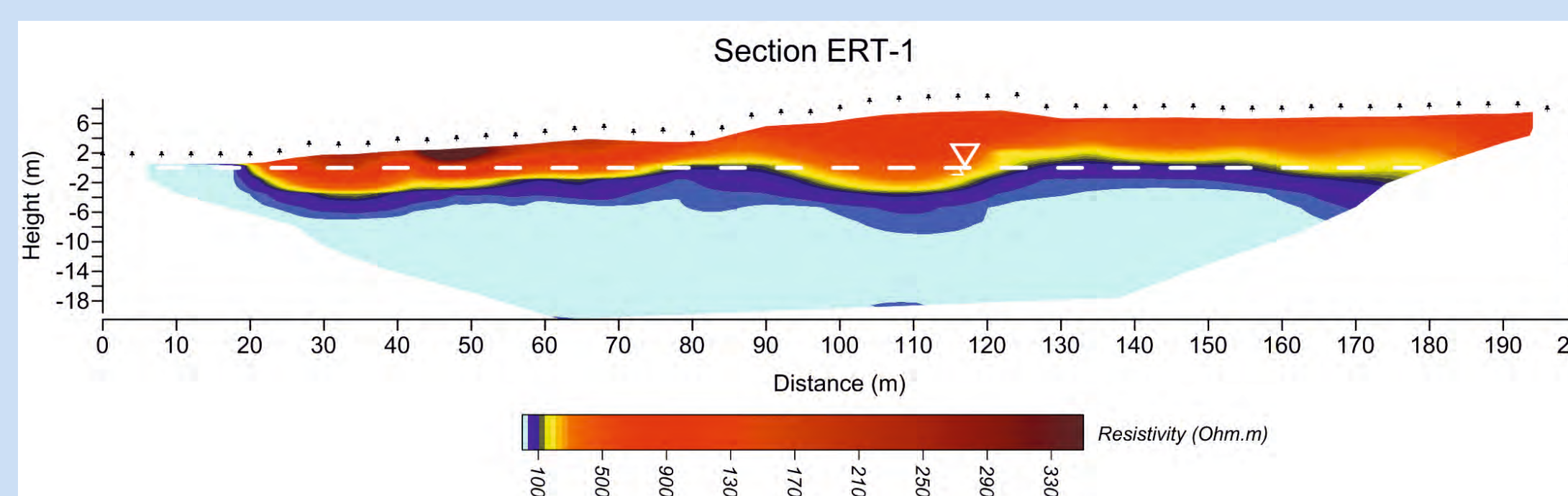


Field work data acquisition by surveying with the terrestrial laser scanner at the station SG-2 (a) and geophysical tomography along the ERT-1 section above the debris formation (b). The fault scarp is visible at the top right of figure (a).



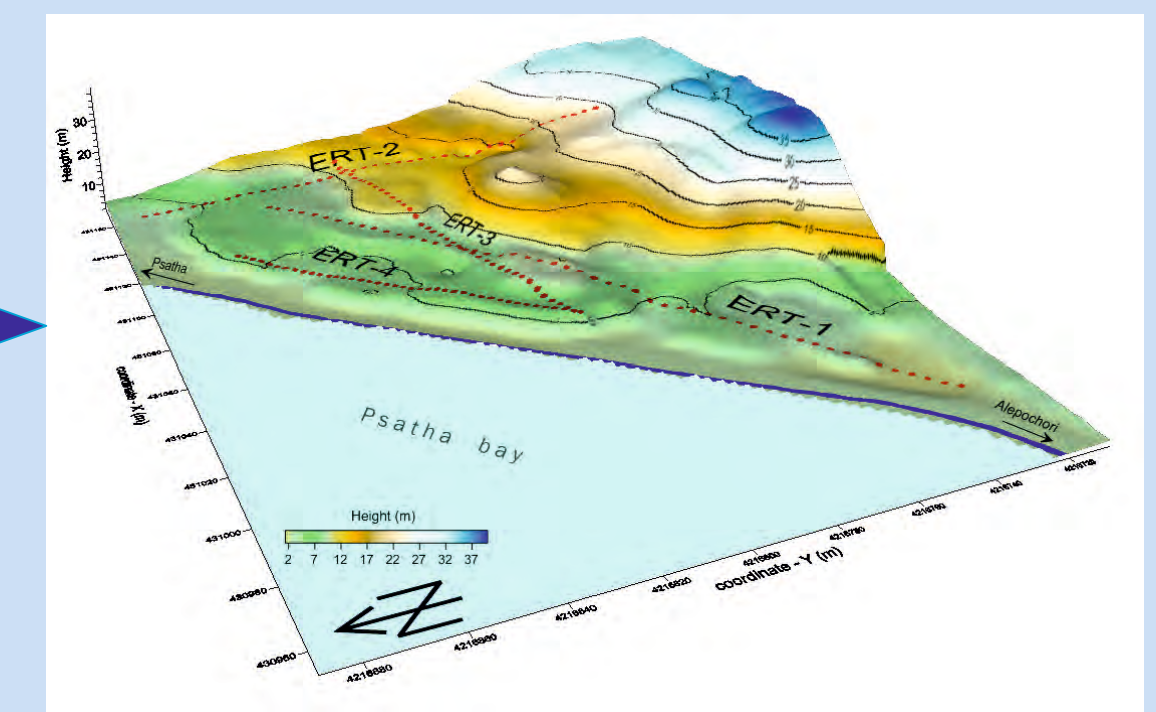
Surface changes along the coastline for the period 1972-2011. The alteration of the coastal zone during the 40 year period is clear as well as the impressive decrease of the volume of the debris next to the fault scarp. The original data that were used for producing the terrain morphology during the 1970's were analog topographic maps of scale 1:5,000, which were scanned, georectified and the 4m contours were digitized. These maps cover the entire onshore coastal area and a 0.25m spatial resolution digital elevation model was created representing the historic relief (see Figure 1). It was used as a reference dataset on which temporal change detection was based on. A combination of ground based LiDAR data and RTK-GPS measurements led to the production of a dense point cloud of high accuracy x,y,z coordinates. More than 30 million points were acquired and interpreted for the production of a 0.05 spatial resolution digital elevation model, which was also filtered for reducing the artifacts, the noise effects and the vegetation cover.

The two DEMs were co-registered and subtracted by using raster calculations in a Geographic Information System (ArcGIS v.10) and the resulted image was draped over a recently acquired pansharpened orthorectified IKONOS-2 satellite image (1m spatial resolution) for further interpretation. The changes along the coastal zone were impressive as the road along the shoreline was constructed after the production of the historic maps, as well as the on shore section of the coast suffered severe alteration by erosion and human interference. It seems that the most of the debris were removed from the hanging wall, which was used as an improvised quarry for building material. The overall elevation change was quantified and at certain areas the total soil loss exceeded the 80 meters.

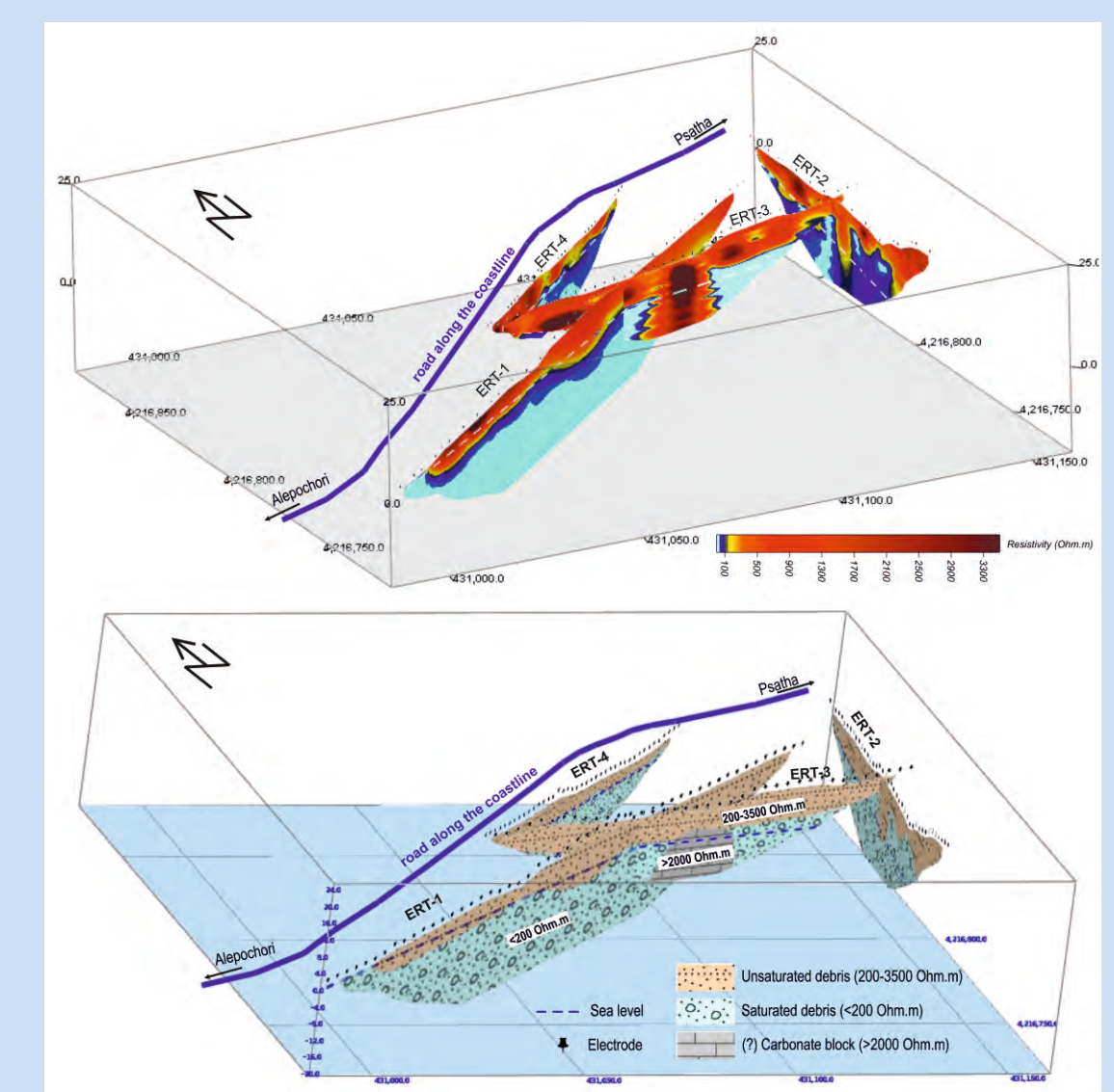


Field measurements processing was performed with the RES2DINV software by GeoTomo. Afterwards, the results of the 2-D inversions were homogenized using a common color scale of the electrical resistivity in order to construct the four (4) sections.

Above, ERT-1 is displayed corrected with topographic relief (5th iter., RMS 4.37%). At the geoelectrical-geological sections, the sea level is depicted with a dashed line.



The high resolution field work for the geophysical investigation was completed in two phases. The first held in November 2011, during which the geoelectrical section ERT-1 of 200m length was completed, whilst during the second in June 2012, the ERT-2, ERT-3 and ERT-4, with a total length of 360m were carried out. The data were recorded with the automatic 41-electrode Lund system (ABEM), along with the geoelectrical instrument Terrameter SAS 300B. A set of 810 measurements of subsurface electrical resistivity was concentrated, applying the Wenner array. Along with the geophysical measurements, precise topographic surveying of the electrodes positions was carried out, with the RTK-GPS technique.



For a realistic illustration of the evaluation of the geophysical results and of the imprint of subsurface structure, a three-dimensional illustration was constructed. In sections ERT-1 and ERT-3, that were developed close to the coast line of Psatha bay, even up to the altitude of the sea, an almost horizontal resistive geoelectrical layer of 200-3500 Ohm.m corresponds to unsaturated and slightly welded debris was investigated, while the underlying conductive geoelectrical formation of 5-200 Ohm.m relates to saturated debris. A particular feature in the geoelectrical-geological section ERT-3 was identified in the middle (60m) and for approximately 20m range. It was a highly resistive structure (> 2000 Ohm.m), which appears to be continued below the sea level. This geoelectrical formation is attributed either to the existence of a 'buried' carbonate block fallen from the foot wall, or to a powerful welded debris with calcite carbonate material. In either case it is more than a proof that material of various sizes keeps falling for a long time period at this zone.

ACKNOWLEDGMENTS

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