THE APPLICATION OF DIGITAL TERRAIN ANALYSIS TO GEOARCHAEOLOGY: A CASE STUDY FROM THERA ISLAND (GREECE)

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INTRODUCTION

The main purpose of terrain analysis is to describe the morphology of the land surface (for example, distribution of altitude, slope gradient, aspect, curvature, flow lines). It provides morphometric parameters that quantify geometrical properties of the land surface or identify specific land surface features (for example, peaks, landforms). Morphometric parameters and features may be grouped according to various criteria. For example, local parameters describe land surface properties at a given point and in its surrounding area. Basic local morphometric parameters are slope, aspect, profile and tangential curvatures. These local morphometric parameters are computed using the methods of differential geometry.

Landscape processes influence landscape configuration that reflects broad-scale geometry of the terrain. The magnitude of the transporting agent affects its carrying capacity or defines the occurrence of specific phenomena such as floods or gullying. It is often related to the spatial extent of the land surface from which the transporting agent is flowing downslope. Thus, the movement may be traced by flowlines. Flow parameters are derived by flow tracing algorithms that approximate the route of water over the surface represented by a digital elevation model (DEM).

The aim of this paper is to use digital terrain analysis to study the geo-archaeology of the island of Thera. This Aegean island displays a complicated geomorphological evolution, characterised by repeated volcanic eruptions. It also preserves very important archaeological sites from the Neolithic Era. Most of these sites have been well conserved, because they are covered by fine volcanic material.

METHODOLOGY

Land surface in GIS is represented by a digital elevation model (DEM) with an array of spatially distributed values of elevation and morphometric parameters. The DEM is usually computed by spatial interpolation using input elevation data points. In our analysis, the primary elevation data source was contours from topographic maps at a scale of 1:10 000. The contours were vectorised using MapInfo Professional GIS software (ver.9.5). The raster-based DEM with a horizontal resolution of 10 m was interpolated using Regularised Spline with Tension implemented in the v.surf.rst module of GRASS GIS v. 6.3 (Neteler and Mitasova 2004). The computed morphometric parameters included slope steepness (figure 9), aspect and curvatures (Mitasova and Hofierka 1993; Hofierka et al. 2008).

The r.flow module in GRASS GIS was used to compute upslope contributing areas (figures 6 and 8). This regional morphometric parameter provides a horizontal area of upper cells from which water inflows to the given cell in a raster-based DEM. It is an approximate estimate of water flow over the land surface during rainfall events causing flash floods and erosion.
Thus the methodology we have followed can be distinguished in several steps (figure 1): Firstly digitisation of all the data concerning topography, archaeology, geology, drainage system, vegetation and field observation; secondly analysis of the input data using GIS techniques and digital terrain analysis and finally production of thematic maps interpreting the geomorphological evolution of the island based on the results of the digital terrain analysis.

A CASE STUDY: THE ISLAND OF THERA

Geographical position
Thera is situated in the Aegean Sea, and is part of Cyclades region (figure 2). Thera, along with Therassia and Aspronissi, form a circle and represent the remains of the boundary of a caldera created by past volcanic activity. The caldera is partly submerged and its centre is occupied by two volcanic islands, New Ka¬meni and Old Kameni. The caldera of Thera is one of the largest in the world: 11 km (N–S) by 7.5 km (E–W).

On Thera there is a range of different types of archaeological sites dating from the Neolithic Era onwards. Discovered under the ash and pumice, buildings, walls, graves and ceramics provide evidence of ancient settlements such as Akrotiri (ca. 7000–1670 BC). From comparative studies and spatial analysis of the available land for settlement development, it is possible that as many as 62 such sites may have existed on Thera. Though it is possible that only 39 are now still preserved; areas on the slopes north of Oia and on the western side of Therassia are likely to contain some of them.

Geological characteristics
The geological structure of Thera is characterised by a non-volcanic substratum, a complex of volcanic series and alluvial deposits. The basement of Thera is composed of Triassic crystallic limestones and dolomites, phyllites of Eocene age and a Miocene Granitic Intrusion. The second category of rocks dominating Thera is a continuous series of volcanic products dated from 1.6 million years (Ferrara et al. 1980) until modern times. The volcanic series of Thera are characterised by an alternation of volcanic lavas and pumice (Druitt et al. 1989; Pichler & Kussmaul 1980). Generally, we can distinguish three horizons of pumice: the lower, the me¬dium and the upper. The volcanic activity is probably related to the extensive tectonism, orientated in a NE–SW direction, the so-called Kameni line (Druitt et al. 1989).

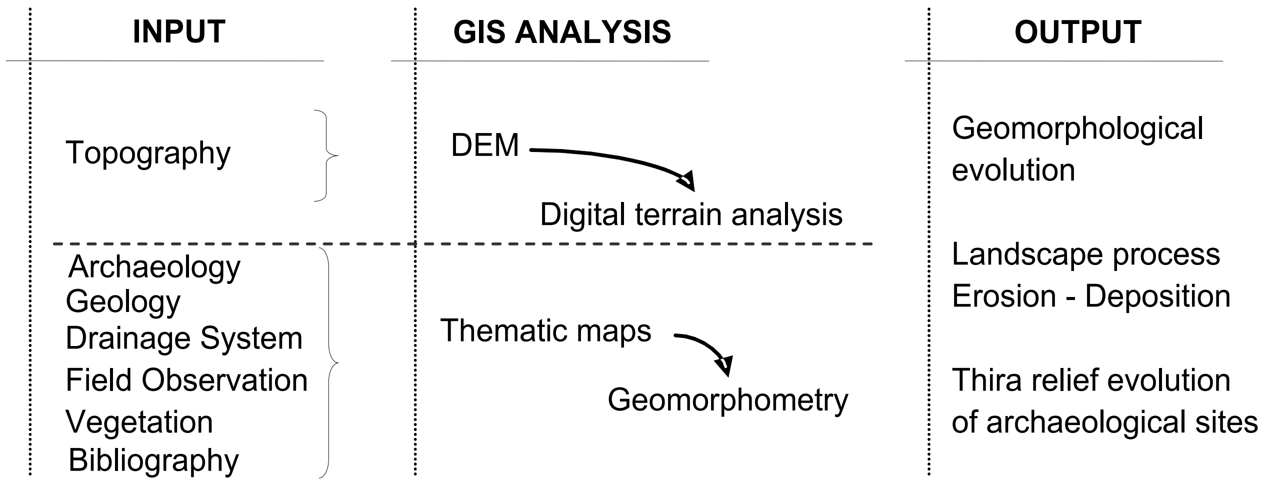

Figure 1 Flow diagram

Geomorphological characteristics

The volcano has erupted numerous times during the Quaternary, forming a distinctive landscape which can be characterised by major geomorphological events. The topography of Minoan Thera has been modified through the deposition of volcanic tuffs, both in the valleys and on the coastline, radically reshaping the island.

Many projects in a wide spectrum of sciences have studied the island of Thera (Friedrich 1980 and 1990; Fytikas et al. 1984; Galanopoulos 1958 and 1971; Heiken & McCoy 1984; Lagios et al. 1990; Lohmann 1998 and 2005; Marinatos 1968 and 1972; Ninkovich and Heezen 1965; Skarpelis and Liati 1990; Velitzelos 1990 and 1991). Despite the aforementioned studies, the geomorphologi¬cal references are relatively rare (Gournelos et al. 1995; Gournelos et al. 2009).

The present relief of Thira is the result of intense tectonic and volcanic, as well as erosional-depositional, processes. The drainage network of the islands of Thera and Therassia is generally radial. Secondary watersheds are also of the same orientation, apart from the area of Prophet Ilia.

Five geomorphological units have been distinguished in the Thera Island (figure 3) (Gournelos et al. 2009). The first unit is the Limestone-schist one (Prophet Ilia – Vlychada) which is found in the south-eastern part of the island and mainly constitutes crystalic limestones, dolomites and phyllites that represent the pre-volcanic relief of Thera. The second unit is the volcanic clusters (M. Vouno – Small Prophet Ilias – Skarou) which are located in the Northern part of the island and are mainly formed by andesitic lavas. The third unit is the Minoan volcanic relief, which has a crescent form in Thera as well as in Therassia. This unit may be further divided in two sub-units, the one having a smooth relief and the other presenting a rough relief. The forth unit is the caldera, which is the most impressive landform in Thera and has attracted many researchers over time. Lastly, the fifth unit is the one of the newer volcanic islands, Old and New Kammeni, whose recent creation expresses the most recent volcanic activity.

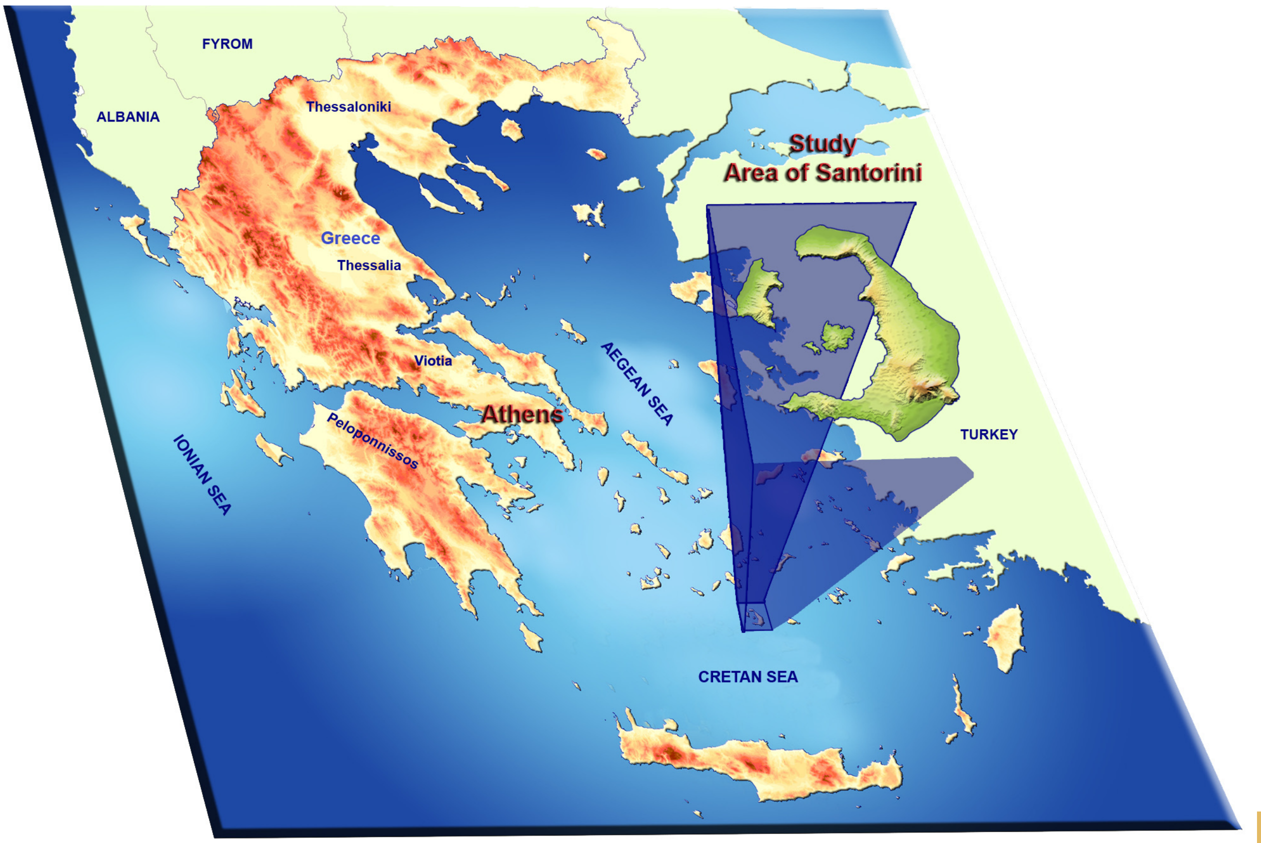

Figure 2 The study area

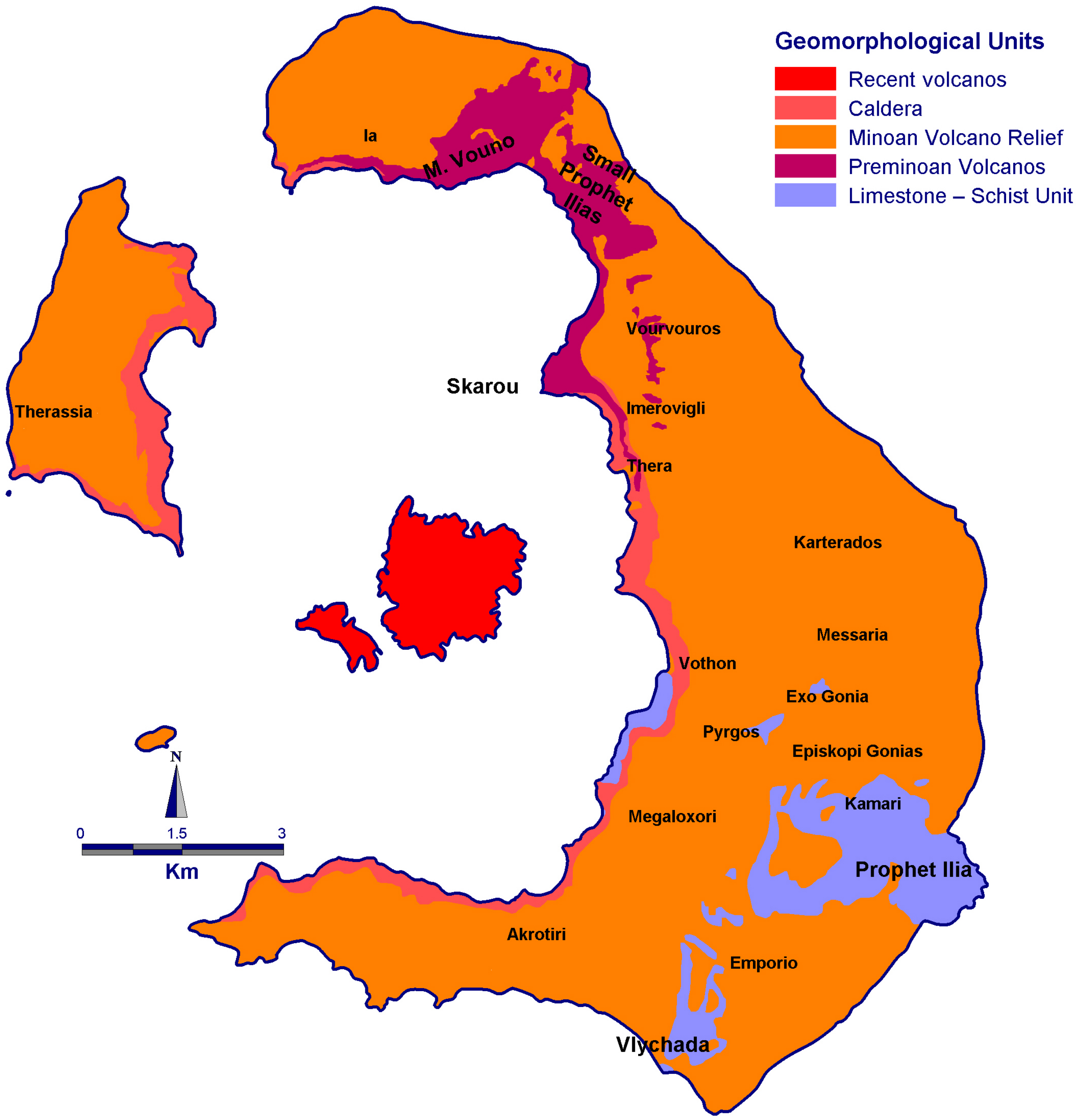

Figure 3 Geomorphological units of Thera

The digital terrain analysis of Thera island

The digital terrain analysis of the island of Thera has been focused on the estimation of the mean morphometric parameters such as slope, aspect, profile, plan, tangential and mean curvature (figures 7 and 8) and altitudinal analysis.
The analysis of the above morphometric parameters in combination with the geological map and the erosion processes, indicate the geomorphological evolution of the island. Thus the Pre-Minoan landscape evolution and the Post-Minoan one can be distinguished.
Slope analysis primarily defines relatively flat areas favorable to settlement installations (figure 9). The relatively low slopes are located in the coastal zone and around the caldera areas, where many archaeological sites have been discovered. Also, deeper soil formations are to be found in lower topographic areas and these

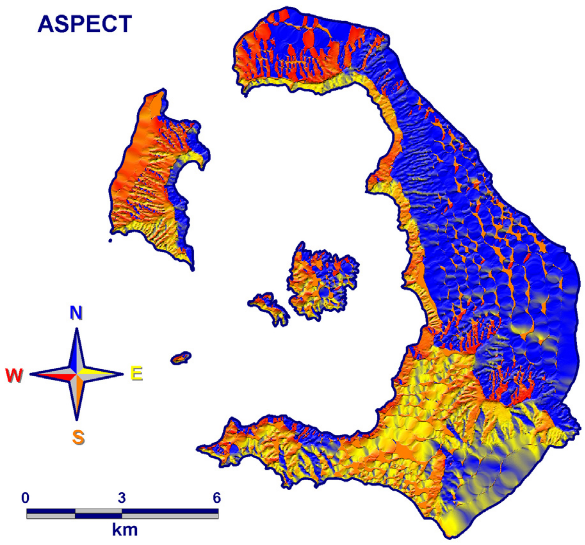

Figure 4 Thematic map of the Thera aspect parameter

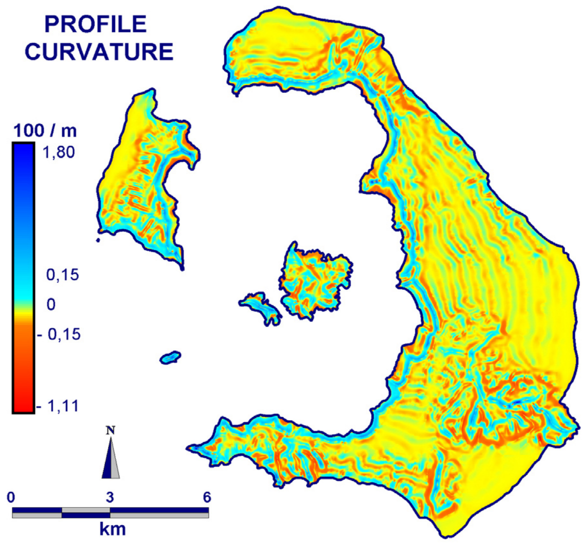

Figure 5 Thematic map of Thera profile curvature

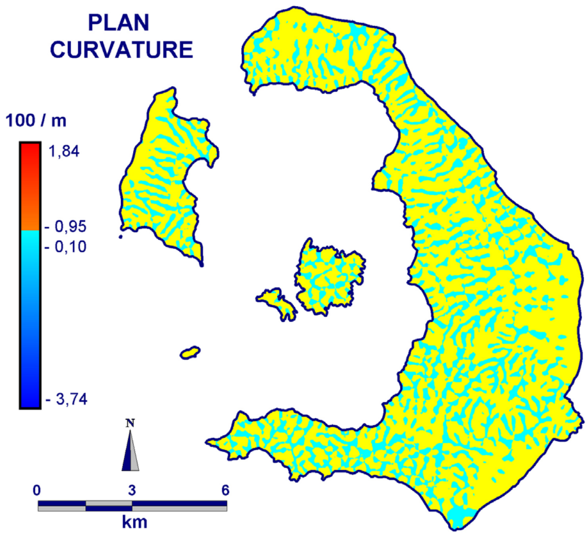

Figure 6 Thematic map of Thera plan curvature

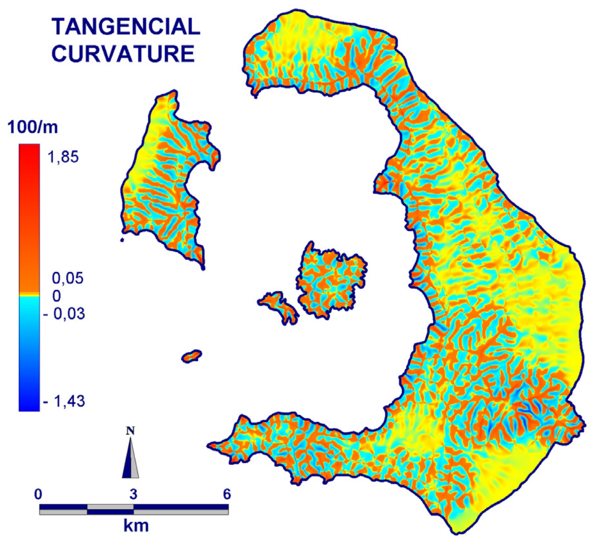

Figure 7 Thematic map of tangential curvature of Thera

zones consequently have an enhanced potential for agricultural activities. This is also apparent in relation to the spatial distributions of aspect or the orientation of slope segments (figure 4). It is expected that south and southeastern facing slopes are sunnier while the north and northwest slope are wetter. All these factors in combination with the lithology and the soil development influence the vegetative cover.

Finally, by analysing profile and plan curvature (figures 5 and 6) it is possible to define palaeodrainage characteristics and depositions, since these attributes control disperse, surface or linear water flows. Another very significant factor after the Minoan erosion was the intensity and direction of the winds.

In such a physical environment another determining factor for cultural development has been proximity to the sea. Thus GIS procedures of digital terrain analysis and knowledge of geomorphological evolution can serve to highlight possible zones of ancient settlements and explain the existence of the already excavated ones.

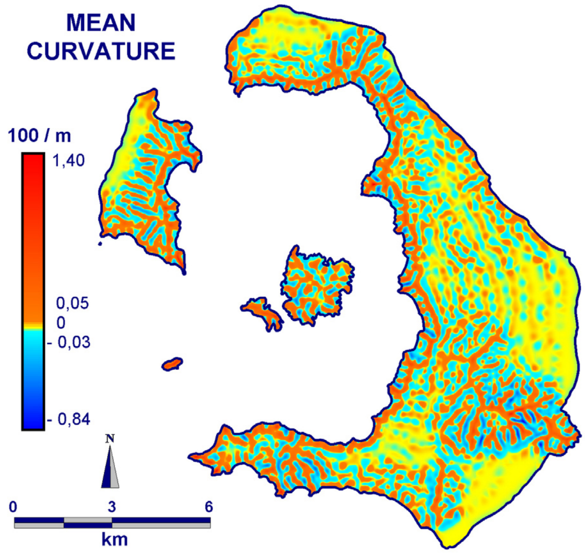

Figure 8 Thematic map of mean curvature of Thera

The geomorphological evolution and the archaeological sites of Thera

The main prehistoric site of Thera is situated in the Akrotiri area, where a whole settlement has been excavated with multifloor houses. Apart from this, several settlements have also been found in the areas of Phira (Ptellos, Agios Ioannis, Karterados, Imerovigli), Kamari, Perissa, Exomitis, Therassia and the island of Christiana (figure 9).

All these archaeological sites were found buried under the fine products of the Minoan volcanic expulsion. The thickness of the upper volcanic deposits depends on the previous microtopography of these settlements and the proximity to the volcanic crater. Thus ancient settlements in the main divide of the island such as the Phira area and Thirasia has been buried under very thick deposits.

Sites located in concave slopes close to the drainage system have also received relatively thick volcanic deposits such as in the case of the Akrotiri area.Finally, the classical Doric settlement of M. Vouno was created after the Minoan eruption in a flat area in a relatively high altitude. Subsequently, the processes of erosion have modified the most vulnerable part of this volcanic island.

CONCLUSIONS

The methodology included the digitisation and analysis of all input data concerning geology, geomorphology and archaeology, with GIS techniques and digital terrain analysis, and the interpretation of Thera relief evolution in relation to its archaeological sites.

The digital terrain analysis of Thera was focused on the estimation of morphometric parameters, such as slope steepness, aspect and curvatures. Through the slope analysis, flat areas and low slopes, prosperous for settlement installations are determined. Many archaeological sites were found in the coastal zone and around the caldera areas. The spatial distribution of slope aspect is found to be related to areas favorable for agricultural activities. Therefore, it can be seen that the use of GIS techniques in digital terrain analysis may offer significant help in geoarchaeological studies of ancient landscapes.

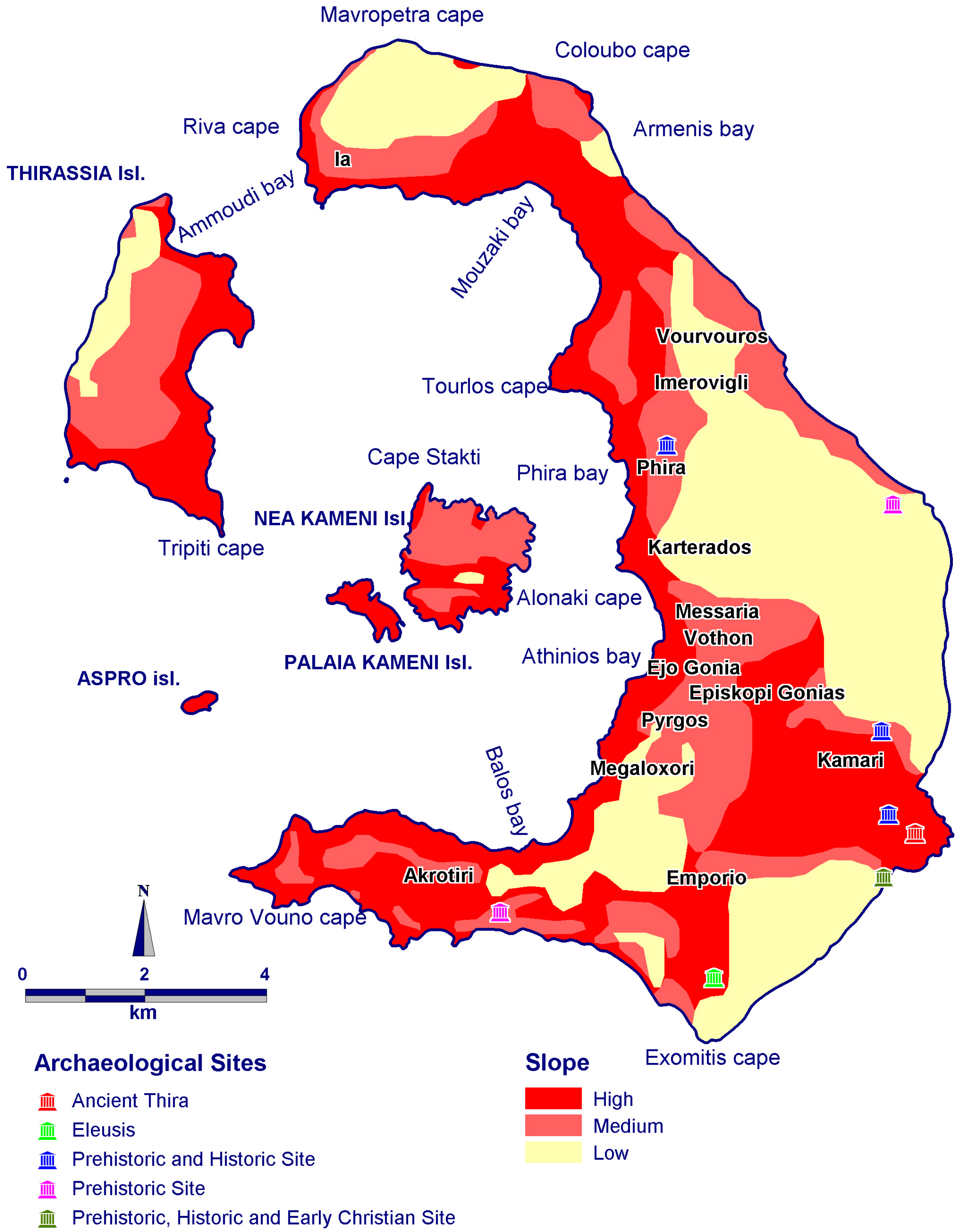

Figure 9 The archaeological sites of Thera

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Résumé

Cet article examine les résultats de l'analyse digitale de terrain dans les recherches géoarchéologiques utilisant une plateforme SIG. En important des ensembles de données digitales et en mettant en oeuvre des techniques modernes d'analyse spatiale, il est possible de calculer les différents caractères du relief comme le gradient de pente, les orientations, le profil des courbes, et également de définir les zones de pente élevée ou d'évaluer les variables de drainage. Ces caractères sont ensuite analysés au sein d'un SIG en croisant des ensembles de données géologiques, géomorphologiques ou archéologiques. L'objectif final de cette étude est la recherche sur l'évolution du paysage et sur le poids qu'elle a pu avoir sur le développement culturel. Cette méthodologie a été appliquée à l'île de Théra qui a un intérêt archéologique significatif et qui présente une evolution géomorphologique complexe, caractérisée par une activité volcanique destructive.

Resumen

En este texto se consideran las posibilidades del análisis digital del terreno en investigaciones geoarqueológicas usando una plataforma SIG. Importando conjuntos de datos digitales y usando modernas técnicas de análisis espacial, es posible calcular diferentes atributos del relieve, tales como gradientes de pendientes, mapas de orientaciones y perfil de curvaturas, y también definir áreas de pendiente elevada o estimar variables de drenaje. Estos atributos son posteriormente analizados mediante SIG junto con conjuntos de datos relativos a geología, geomorfología y arqueología. El objetivo final del estudio es la investigación de la evolución del paisaje y su influencia en el desarrollo cultural. Esta metodología ha sido aplicada en la isla de Thera, que posee un particular interés arqueológico y presenta una compleja evolución geomorfológica, caracterizada por una actividad volcánica destructiva.