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Geoarchaeological Studies in Central Crete based on Remote Sensing and GIS

Abstract: Areal analysis in geoarchaeological applications can be improved by implementing a wider set of geoecological parameters in order to provide more precise results. The aim of the paper is to show how geoscientific ground-truth and techniques can be used for detailed archaeological studies using a comprehensive set of environmental variables that might have influenced ancient settlement patterns. The project focuses on spatial patterns of archaeological sites, as well as Bronze Age communication paths in Central Crete by using a multi-methodical approach (surveying, Remote Sensing, DEM-analysis, least-cost analysis, candidate site detection, predictive modelling, etc.). In contrast to conventional archaeological GIS applications this enhanced strategy offers promising prospects regarding landscape and settlement modelling.

Introduction

Geoscientific ground-truth and techniques can be used for detailed archaeological studies using a comprehensive set of environmental parameters that might have influenced ancient settlement patterns. The implementation of Remote Sensing technologies for the capture of surface and land cover structures in combination with Digital Elevation Models (DEMs) for topographical information provide detailed information for archaeological purposes.

The project focuses on the Ida Mountains in central Crete, which are characterised by several remains of the Aegean Bronze Age, especially by finds of the Neopalatial Period from about 1650 BC. In the early 1980s archaeologists discovered the Minoan settlement of Zominthos on an upland plain in the Ida-Oros. It is distinguished by its unusually large size, architecture and extremely remote location in 1187 m above sea level. Since the building is situated above the altitudinal limit of modern settlement and additionally located in the southern outskirts of the eastern Mediterranean (Sakellarakis / Panagiotopoulos 2005, 47), it seems questionable as to why and how Bronze Age people were able to settle in this climatically unfavourable place.

Hence, the main objective of our interdisciplinary collaboration is to reconstruct the palaeo landscape in the surroundings of the so far unexplored plain of Zominthos. The project focuses on spatial patterns of archaeological sites, as well as Bronze Age communication paths in Central Crete by spatial analysis (cost weight analysis, candidate site detection, etc.). A multi-methodical approach based on surveying and mapping (geology, geomorphology, vegetation, archaeological sites), Remote Sensing (land-cover classification), GIS analysis (slope, aspect, hydrologic surface analysis) was therefore applied. Our data was integrated into a GIS for modelling the settlement patterns of the investigation area in order to specify the significance of the archaeological studies and to improve the standardised methods within GIS and Geoarchaeology.

Materials and Methods

If a GIS approach to this subject is to be successful, it is indispensable to implement a large quantity of environmental and archaeological variables. For this purpose, a corresponding information system was developed, while fundamental geoecological parameters of the Ida-Oros were acquired and visualized. During several field campaigns the geomorphology (e.g. land surface, faults, karst morphology), the vegetation, the hydrology and petrographical features in the investigation area were mapped. The location of archaeological sites was tracked down with GPS for subsequent integration into the information system. In order to obtain a broad spectrum of area-wide environmental data, the project was based on a remotely sensed acquisition of geoecological information, as well as on a topographical analysis of DEMs. Land cover classifications especially provided important environmental information for further GIS analyses.

Remote Sensing

Remote Sensing applications were conducted in order to study the recent landcover in the Ida Mountains by using several different satellite images (Landsat-7 ETM+, Quickbird, Aster). Enhancement techniques had to be carried out, especially a resolution merge of the imagery and spectral modifications via ratioing for calculating iron oxide, clay mineral and infrared-red indices. Training areas were selected and compared to the collected field survey data for validation. Subsequently, the supervised classification was prepared by using all bands of the original images, the pansharpened bands and the indices (LANDSAT; classification of QUICKBIRD data was based on four bands). As the results included data errors like misclassified pixels or redundant details, postprocessing and subsequent generalisation had to be conducted. Hence, both classification rasters were majority-filtered with a 7 x 7 kernel in order to improve the quality. In order to reduce the number of thematic classes, a final reclassification into six major categories was carried out (bare rock, loose sediment, woodland, matorral, phrygana, grassland).

Preceding GIS Analyses

Preceding analyses for further data acquisition had to be performed in order to carry out the intended geoarchaeological investigations. First of all, DEMs were used for generating derivatives, and the land cover classification was utilised for further applications. All results were integrated into our GIS database.

Topographical information was derived from analysis with DEMs by using an SRTM-model with a 90 m grid size and an ASTER-model (15 m grid). Besides contours of altitudinal zones (100 m, 50 m, 20 m and 10 m spacing), a slope raster of each DEM was calculated in degree units. Mean-filtering and majority-filtering with 3 x 3 kernels was applied before reclassifying the slope-rasters into ten continuous categories. Additionally, depth contours were calculated by performing hydrologic-surface analysis, indicating both valley bottoms and basin floors.

The land cover classification was used for generating new thematic layers into the database. Due to the fact that agricultural areas are especially of enormous interest for geoarchaeological work, corresponding locations had to be extracted from the raster. Since sediment accumulations and areas filled with thick soils represent presently favoured areas for agriculture, because they are the only locations with approximately flat surfaces, they were also classified within the scope of Remote Sensing applications.

In the following step, a raster-calculation was performed to select these accumulations. Point like and small scaled areas were outlined and thus required a generalisation by majority-filtering (7 x 7 kernel). Each site's surface area was calculated in ArcGIS, before zones smaller than 150 m² were separated out due to lacking representation.

Spatial GIS Analysis

In the light of the project's objective of reconstructing a geoarchaeological landscape, the spatial distribution of Bronze Age communication paths and of traffic routing was firstly analysed. Then a second detection of potential archaeological candidate sites was conducted. In both cases preliminary strategies for the following proceedings had to be taken into consideration.

Bronze Age Infrastructures in Central Crete

The investigation of potential Minoan communication paths and their traffic routing in central Crete was based on spatial information about the location of several archaeological sites such as buildings, necropolises, and peak sanctuaries. It is assumed that a sophisticated network of infrastructures connected the sites as early as the Bronze Age (Panagiotopoulos 2007, pers. comm.). The known locations were surveyed and mapped with high precision GPS. It became necessary to analyse the spatial distribution of these roads, because they serve as an important influencing factor for the location of settlements. The reconstructed communication paths then allow the detection of potential candidate sites.

The villa of Zominthos is located close to several ancient traffic routes, which lead from the Neopalatial centres in the lowlands to settlements and peak sanctuaries like the Idaean Cave above the Nida plateau (1509 m above sea level) in the Ida Mountains (Rehak / Younger 2001, 383–473; Warren 1994, 189–210). Archaeologists emphasize the spiritual connection with the Minoan building that might have served as an interstation for pilgrims (Sakellarakis / Panagiotopoulos 2005, 56). Along these roads it is possible to find numerous indicators for Minoan colonisation, such as a Bronze Age cave near Kylistria or peak sanctuaries in Gonies and Keria (Rutkowski 1988, 71–99). Nevertheless, it is still uncertain if Zominthos must be considered as a unique object or if, with regard to the environmental setting, there are some additional locations that could have been very favourable for human settlement since the third millennium BC. According to numerous archaeological findings, the Ida-Oros was most likely densely populated during that period, based on an assumed communication network linking settlements and agricultural areas.

Concerning our investigations, a cost-distance analysis was considered as the best tool for verifying the ancient transit roads, as it allows the identification of spatial correlations which are based on a least cost connection of Minoan sites (see also Soetens et al. 2003). Quite similar to modern traffic planning, we can suppose that the Minoans predominantly chose routes with a low cost effort. In this regard, a cost weight analysis helped to elicit an approximate concentric matrix of spatial expense for travelling. As it was not only intended to create an area-wide cost raster file, a calculation of the shortest absolute distance between several Minoan remains that had been surveyed and mapped with GPS in advance was performed. Cost direction rasters were computed and finally integrated in the cost path function to generate the desired linear sections of roads.

Detection of Potential Archaeological Candidate Sites

The spatial distribution of prehistorical sites in the Ida Mountains is of fundamental interest, as it raises the question of a potential regularity in its layout as well as in the dispersal of other similar remains. While analysing as many of the environmental parameters as possible and examining their transferability, the area of Zominthos serves as a central point of reference. In this regard, the potential Minoan transit roads must be seen as a crucial parameter, because they let us predict a proximate set-up of buildings and other infrastructures. Though the Minoans sometimes built their rural villas far from urban areas, they always selected strategic locations in order to control fertile pastures or traffic routes and places that allowed a relatively easy exchange of goods with lowland areas. The fact of Bronze Age pilgrimage from the palatial centres up into the mountains indicates once more a spatial connection and a mobility related to settlement location. As Zominthos certainly was an interstation for travellers, its position along one or several roads appears to be doubtlessly coherent.

Besides all these anthropogenic determinants, the relief-related influencing factors were also very important for the spatial flow of traffic. Slopes must be considered as an essential component, because heavily inclined areas are generally unsuitable for human colonisation. Also the exceptionally high altitude of 1187 m above sea level is one of the most outstanding characteristics of Zominthos. It enables the definition of an important variable for the detection of potential Minoan candidate sites. In this context, it is quite certain that further locations within a similar altitudinal zone or even in higher elevations in the Ida-Oros were used by Minoans. First and foremost the Idaean Cave above the Nida plateau can be seen as an indicator for human activities in the high mountains. According to the prevailing opinion, there was an economic focus on agriculture as far back as prehistoric times (Chaniotis 1999, 181–220), which makes a colonisation of the mountainous areas very likely.

Linked to the investigation of settlement patterns in the Ida-Oros, the sediment-filled depressions are of prime importance, because they could have served as agriculturally favoured areas for thousands of years, and thus have to be regarded as another spatial impact in the site detection. The decision of where to settle down might have been significantly influenced by the existence of spacious useful areas close-by.

The facet of water supply is yet another influencing parameter for the choice of location and has to be considered within the candidate site identification. Humid altitudinal zones in the karstic Ida Mountains are only of value, if water is available through springs. The remarkable size of Zominthos (ca. 200 m^2) indicates a large permanent population and high water consumption. In addition, the proximity of springs was absolutely necessary for the livestock. Hence, all Bronze Age settlements and useful areas were located as close to springs or subterranean water access as possible. In the Ida Mountains these waters only appear in the boundary zone between Tripolitza limestones and platy limestones, where schists form an acquiclude with a line of springs (Jacobshagen 1986, 131).

Within the scope of our geoarchaeological GIS analysis, a buffer was generated in relation to the potential communication paths. The result shows an area along the roads with a maximum distance of 500 meters in which Minoan settlements might have been located. Based on the slope DEM-derivative, a hypothetical maximum value of 7° was defined for detecting all areas with lower inclinations by raster calculation. Furthermore, the input of the elevation as an influencing factor was considered by selecting a predefined altitudinal zone between 1000–1500 m above sea level. The corresponding areas were selected and extracted by a raster calculation. In addition to the discussed topographic variables, we incorporated the geographical input of our GIS database into the following proceedings. A primary selection of the digital documented sediment areas subject to size was conducted, defining a minimum value of 10,000 m² as a hypothetical minimum limit for agricultural profitability (Siart 2006, 60). Concerning the proximity of Minoan settlements to springs, tectonic faults and overthrusts were extracted from the digital geological map in the GIS. Similar to the processing of potential transit roads a buffer of 300m was calculated around these structures, representing a plausible zone around the geological elements contemptible for human colonisation. After preparing all determinants, the final analysis of spatial relationships and correlations between the influencing variables was carried out by calculating a layer intersection of spatial attributes.

Results and Discussion

Until now, the current archaeological discourse only focused on sporadic Bronze Age infrastructures on Crete. In the scope of new GIS applications, a sound geographic input can be especially considered as the key to the identification of spatial settlement activities and thus be of great use for archaeology.

As the potential Minoan transit roads were calculated by cost-weight analysis, they respectively indicate the most cost-effective connection between the mapped sites. The results are based on topographical variables, showinging in paths of communication within depth contours while avoiding steep slopes. From today's perspective, the indicated course of the routes can therefore be interpreted as economically efficient too. Current archaeological studies show as well that the assumption of slope and topography might have been of enormous

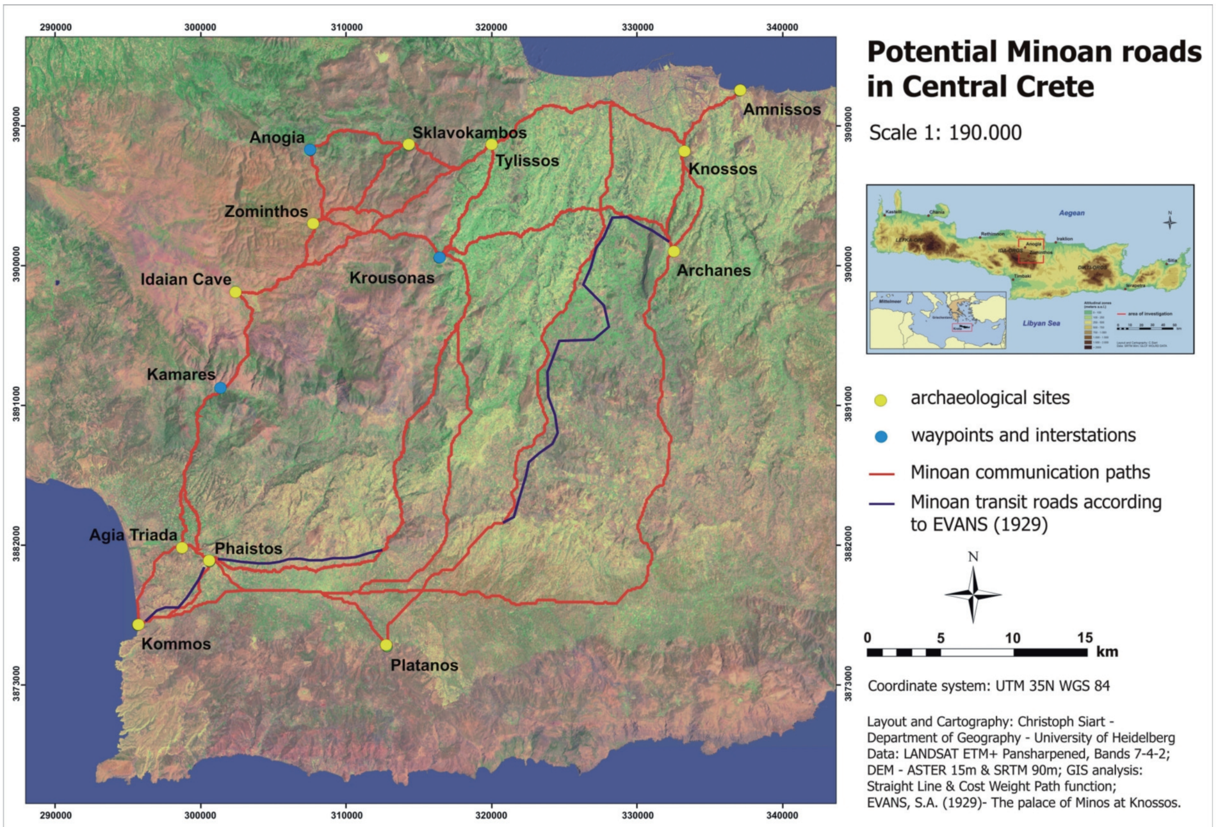

Fig. 1. Potential Minoan transit roads in Central Crete

importance and have been the crucial determinants for the choice of traffic routing in ancient times (see also Tomkins et al. 2004, 2–4).

There are also other possible determinants like land use, vegetation or hydrology that had a remarkable impact on transit roads, but for want of explicit corresponding data, we can not yet draw an explicit conclusion for former times. Since exceedingly controversial opinions complicate specifying the environmental setting of the Ida-Oros in prehistoric times (Rackham / Moody 1996, 15), our investigations are based on a minimum set of the most persistent influencing parameters. The topographical conditions can thus be considered as one of the most perpetual impacts on spatial mobility without being modified during following millennia. It is also necessary to remember that anthropogenic preferences and influences, e.g. settlements, necropolises or spiritual places modified the course of human infrastructure and possibly even outweighed topographical determinants in the cost value ratio. In this regard, reference should be especially made to the numerous Bronze Age peak sanctuaries and sacred landscapes that might have led to a wilful routing into rough terrain in prehistoric times.

As far as the actual existence of such infrastructure is archaeologically provable, the GIS results can be verified. For instance, Evans (1929) presumed a so called "Minoan Highway" leading from Knossos to Kommos via Archanes and Phaistos. Our output dataset traces the archaeologist's notional road network with slight deviations and shows strong correlations between the digital detection and the hypothesis *(see Fig. 1)*. The only difference is Evans' traffic routing nearby Archanes, where he described a path to the north of Mt. Jouchtas while our least-cost analysis indicates a southern course. Such variations can be justified by the limited utilisation of DEM based parameters.

Concerning the detection of archaeological candidate sites, the Minoan settlement of Zominthos was used as a point of reference within the process of predictive modelling, because its especially remote and unusually high location raises the question of colonisation history BC. We hence based our investigations on an inductive strategy (see van Leusen 2002, 5/4; Posluschny 2002, 108). Falling back on a much more comprehensive data set of influencing factors than in our traffic route analysis proved to be very advantageous, being less limited and yielding more detailed results within spatial GIS analysis.

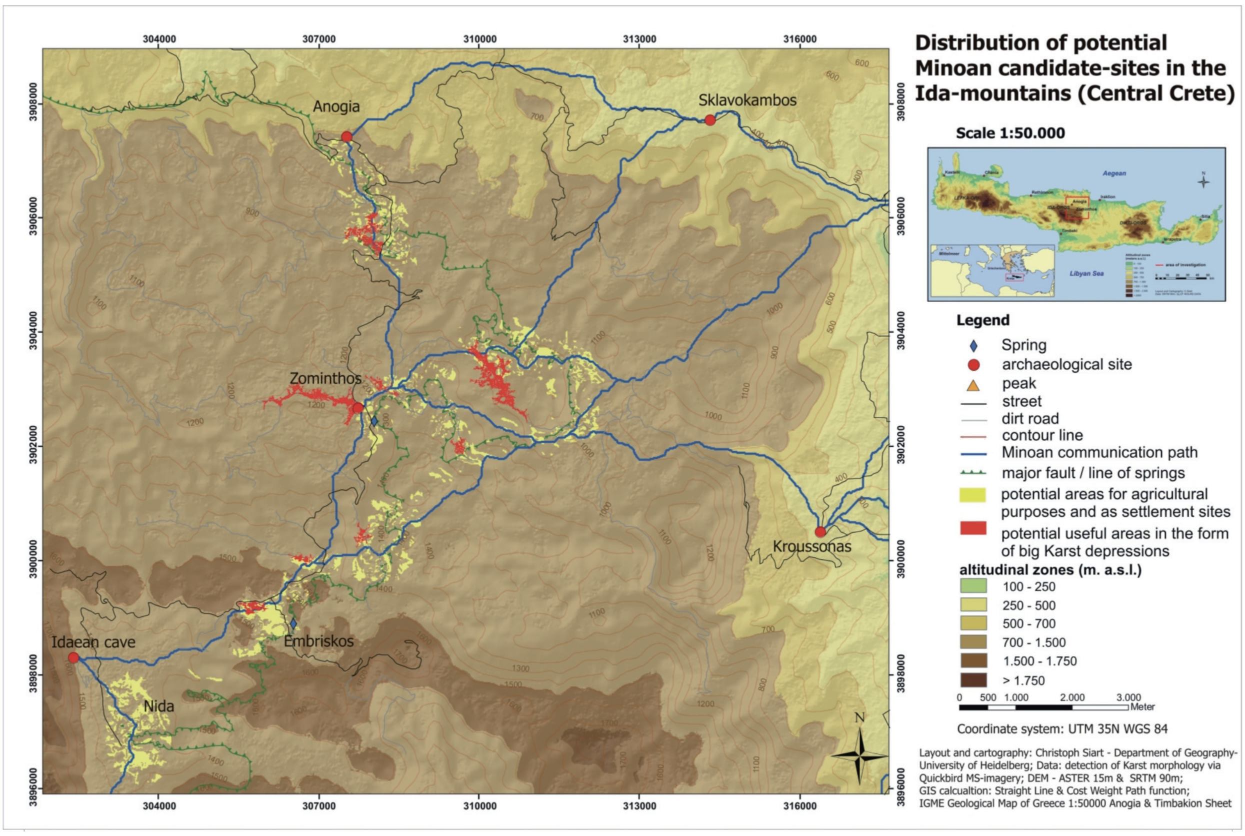

Fig. 2. Distribution of potential Minoan candidate sites in the Ida Mountains (Central Crete).

Here, the interdisciplinary geoarchaeological approach is important, because the preceding environmental mapping and surveying enables us to analyse the major objective of crucial determinants of Bronze Age settlement.

The results of the candidate site detection were cartographically visualised, showing probable areas which were potentially favoured for agriculture during the Bronze Age *(see Fig. 2)*. Consequently, seven particularly suitable candidate sites remain in the investigation area. All detected locations can be described as well qualified pastures and even correlate with current agricultural areas, doubtlessly constituting persistently favoured places. If we interpret this fact with regard to a chronological distance of 4000 years, the environmental requirements for agriculture of human beings have apparently hardly changed over the millennia. However, the fact the existence of a potential all-season residence in the high mountain areas during the Bronze Age is the major difference to the present. This evokes new research interest in settlement history of such a hidden and remote area.

The seven sectors, lying within the predefined altitudinal belt between 1000–1500 m above sea level, are not unequally distributed, so potential Minoan sites could have been located in any place in the studied region. For instance, there is a big plain south of Anogia at an altitude of 900 m above sea level, as well as some extensive areas on the second plateau (1200 m above sea level). Furthermore, several smaller locations can be found nearby Axi Kefala and Embriskos. This fact consequently raises the question of why exactly the Minoans chose Zominthos and none of the other sites for constructing such a huge villa. Potentially, the answer might be found in the function of the building as an interstation for pilgrims, being situated half way up from the lowlands to the Ideaen Cave. A construction close to Embriskos or even on the Nida plateau instead of Zominthos seems implausible, because of the proximity to the peak sanctuary. Regarding the great distance to the cave, the detected areas close to Anogia might have been unsuitable for Minoans as well. Conversely, Zominthos can be considered as an ecologically and strategically favoured place. Extensive pastures, several springs, immediate adjacency to the most likely route for crossing the Ida-Oros and an advantageous topography with high visibility of the surroundings make it an outstanding location in an otherwise hidden and uncommon landscape. Concerning the indispensable intervisibility between Minoan sites, the latter argument is especially of major importance in the archaeological discourse (see Tomkins et al. 2004, 2).

To sum up, Zominthos does not exhibit an environmental uniqueness in consideration of the conducted GIS analyses, and thus also other locations in the Ida Mountains could have been potentially used by Minoans during the Bronze Age. The remaining question for the reason for building this huge settlement precisely in Zominthos can be answered by referring to the almost perfect combination of favouring factors: No other location in the investigation area is so hydrologically, geomorphologically and topographically qualified. In the past as well as nowadays, the choice of this site thus seems evident and totally convincing.

Conclusions

GIS based analyses in archaeological studies show that in most cases only few environmental variables were included in the investigations. As "obtaining and developing useful environmental data can be the most time consuming and costly aspect of a predictive modelling project" (Hill / Devitt / Sergeyeva 2005), there is a huge demand for detailed knowledge about the environment. This exactly poses a future challenge, as better understanding of space and intensified analysis based on the input of more environmental data will offer more precise and comprehensive results. These tasks explicitly represent the strengths of geosciences, which could support archaeological research significantly. Concerning geographical information systems, cooperation between Archaeology and Geography is still uncommon, but recent research points out the steadily increasing interest in this topic. In addition to geophysical and cartographical collaboration, GIS-based prospection is surely one of the most promising tasks among interdisciplinary geoarchaeological research.

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