S.A.P.I.EN.S

2.2 (2009)
Vol.2 / n°2 Special issue

Matthieu Ghilardi and Stéphane Desruelles

Geoarchaeology: where human, social and earth sciences meet with technology

Electronic reference
Matthieu Ghilardi and Stéphane Desruelles, « Geoarchaeology: where human, social and earth sciences meet with technology », *S.A.P.I.EN.S* [Online], 2.2 | 2009, Online since 20 December 2008, Connection on 16 October 2012. URL : http://sapiens.revues.org/422

Publisher: Institut Veolia Environnement
http://sapiens.revues.org
http://www.revues.org

Document available online on: http://sapiens.revues.org/422
This document is a facsimile of the print edition.

INSTITUT
Veolia Environnement

S.A.P.I.EN.S
VOLUME 1 ISSUE 2 2008

Analysis

Geoarchaeology: where human, social and earth sciences meet with technology

Matthieu Ghilardi[1], Stéphane Desruelles[2]

1. Centre Franco-Egyptien d'Etude des Temples de Karnak (CFEETK), USR 3172, C.N.R.S.
matthieughilardi@orange.fr
2. J.E. 2532 Dynamiques des systèmes anthropisés, Université de Picardie — Jules Verne, Amiens, France,
stephane_desruelles@yahoo.fr

Abstract

Over the last decades, archaeologists and historians have faced the necessity to reconstruct ancient settlement history not only through the study of the material excavated, but also with the use of palaeo-environmental parameters. Geoarchaeology is a recent field of research that uses the computer cartography, the Geographic Information System (GIS) and the Digital Elevation Models (D.E.M.) in combination with disciplines from Human and Social Sciences and Earth Sciences. Satellite images, high resolution topographic surveys (Shuttle Radar Topography Mission data) and palaeo-environmental results are used to establish accurate topographic maps, palaeogeographic reconstructions and three dimensional views of the landscape, contemporaneous to the ancient site of interest. GIS is used to manage the important amount of data widely dispatched both in space and in time. This paper describes several powerful methods to infer the evolution of landscapes in the context of such multi-disciplinary/geoarchaeological programmes. The potential of Geoarchaeology is illustrated by three case-studies in Albania and Greece, where the neighbourhood of ancient settlements from the Holocene (the last 10000 years) have been reconstructed into virtual landscape. These geoarchaeological studies offer now an unprecedented level of integration between disciplines to visualize a shoreline and its displacement. Over the last 20 000 years, humans had to constantly adapt their lifestyles according to the displacement of the shoreline. Given the current threats and uncertainties related to climate change, it is predictable and desirable that many disciplines will adopt similar integrated approach to model their favourite object of research.

Keywords: Digital elevation model, geoarchaeology, geographic information systems, geomorphology, Albania, Greece, projection systems, topographic data

TABLE OF CONTENTS

Received: 2 July 2008 – Revised: 25 October 2008 – Accepted: 10 December 2008 – Published: 20 December 2008.
Edited by: Sébastien Gadal – Reviewed by two anonymous referees.

1. INTRODUCTION

Geoarchaeology is a multi-proxy approach where geographical and geoscientific concepts and methods are applied to Prehistory, Archaeology and History (Rapp and Hill, 1998).

Geoarchaeology consists in using methods and concepts of the Earth Sciences for archaeological research purposes. However, to elucidate environmental contextual issues, geoarchaeologists must be more than casual practitioners of applied science (Butzer, 1982; Fouache, 2006; Fouache and Rasse, 2007). Indeed, if archaeological excavation emerged in the 18th Century with a systematic analysis of the material excavated—notably in Herculaneum (Italy)—, stratigraphic excavation that applied environmental evolution data for the first time ever did not become established until the end of the 19th Century. Finally, to better understand environmental changes, particularly throughout the historical period, geomorphological research became an essential preliminary to the study of all archaeological sites in the 1980s.

The Geographic Information System (GIS)[1] is a digital support capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information (Marble *et al.*, 1984). GIS is well adapted to share all the information provided by different disciplines from Human and Social Sciences and from Earth Sciences. In an extended sense, GIS is a tool that allows users to create interactive queries, analyze the spatial information, edit data, create maps and present the results of all these operations for archaeological and geoarchaeological studies (Kvamme, 1999; Fletcher, 2008). This development took place in the 1970s when several methods became available: computer cartography and Computer-Aided Drafting, the linking of computer-drawn maps with relational databases, quantitative spatial analyses and their mapped by-products, views and uses of three-dimensional terrain models (Digital Elevation Models), remote sensing and image processing applications in regional simulation and modeling exercises (Kvamme, 1999). Nowadays—far from being limited to produce aesthetically pleasing cartographic material—GIS plays an important key role in archaeology and enables dynamic viewing of morphological activity. This paper presents the methods and the results derived from several case studies from Albania (Korça Basin) and Greece (ancient Methoni harbour and Thessaloniki Plain) during the Holocene—the last 10000 years (Ghilardi, 2006; 2007).

2. METHODS OF GEOARCHAEOLOGY

2.1. COMPUTER CARTOGRAPHY AND COMPUTER-AIDED DRAFTING (C.A.D.) FOR WITHIN-SITE ARCHAEOLOGICAL STUDIES

Until the 1990s, archaeological studies were essentially based on two-dimensional (2D) cartographic representation developed on a local (*in situ*) scale (from 0.1 to 10 km^2). Computer cartography and computer-aided drafting helped to make within-site geoarchaeological studies, a rather limited technique compared to GIS. For example, vector outlines showing the locations of walls, pits, middens, ditches, post holes, etc., are generally colour coded by feature type, cultural affiliation or temporal period: various artefact distributions were similarly portrayed (Kvamme, 1999). Using C.A.D., ground observations, chart interpretations (topography, geology, etc.) aerial photographs and satellite image treatments can all be combined into environmental maps (geomorphological and vegetation maps, pedological charts, etc.). Until recently, different layers corresponding to points, lines, and polygons were created using *Adobe Illustrator©* software. This method lacked the possibility to associate graphic elements with geographic coordinates and to access dynamic geodatabases. These limitations are now addressed using GIS.

2.2. GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND DIGITAL ELEVATION MODELS (D.E.M.) AS IMPORTANT TOOLS FOR MANAGEMENT OF GEOARCHAEOLOGICAL STUDIES

The use of the GIS in archaeology is essential:

At the site level (from 0.1 to 10 km^2), extensive data about excavation and surface mappings of artifacts, topography and other features are collected. It is necessary to efficiently manage these data and address fundamental research and spatial analysis questions (Kvamme, 1999). Three-dimensional GIS allows deposits, features, and artifacts to be visualized in their proper 3D contexts (Katsianis *et al.*, 2008). A volume may be rotated, sliced, diced, or "exploded" to yield virtually any possible view of internal relationships. These systems allow better understanding of complex deposits and greatly help in the interpretation of intrasite spatial relationships, site structure, and formation processes (Kvamme, 1999).

At the regional scale (areas of more than 10 km^2), GIS is frequently used to analyse the spatial distribution of settlements using statistical methods (Kvamme, 1999; Anschuetz *et al.*, 2001). Archaeological predictive modelling—one of the earliest applications made possible by GIS—continues to grow in importance as a tool for cultural resource management and planning (Kvamme, 1999; Fry *et al.*, 2004). GIS can support other information derived from:

- 3D modelling of present and past environments (relief, hydrology, shorelines, vegetation cover, etc.) and of their evolution.
- the cross comparison of environmental, palaeo-environmental and archaeological data. For example, GIS can be used to quantify changes in water volume of ancient reservoirs caused by the rise or fall of the water level (Desruelles and Cosandey, 2005).

To create the GIS, various data sources are used, integrated with the main steps presented below.

2.2.1. GEOREFERENCING PROCESS OF THE CARTOGRAPHICAL DATABASE

The georeferencing phase of a cartographical study can be difficult in countries that do not use a single cartographic

1 Abbreviations and acronyms used in the article are listed in Annex 1.

projection system to serve as a unique referential. In Greece for example, four systems are in use since the beginning of the 20th Century[2] that can not be converted into each other. Polynomial equation (Ghilardi, 2006) and/or freeware (software) can help significantly to convert geographic coordinates. It is now crucial to use a single international reference for GIS such as the World Geodetic System (W.G.S.) 84 cartographic projection.

2.2.2. DERIVATION OF THE D.E.M.

The common definition of a D.E.M. can be presented as follows: a Digital Elevation Model is the digital image of altitudes for a topographical surface set in a geographical marker and a 3D representation of the territory without vegetation or buildings (Hubert, 2001; Ghilardi, 2006). Two methods of D.E.M are in usage depending on the community: the first employs the digitalisation of points on contour lines in order to create a Triangular Irregular Network (T.I.N.) type D.E.M.: points make up the mesh of the digital elevation modelling in which all the points are linked together by lines forming flat triangles that never intersect. These triangles are contiguous by their sides and form a continuous surface in space (Hubert, 2001). Raster D.E.M. has a lower quality of representation but file created by the GIS—which uses mass points and provides a smooth view in 2D—is smaller.

The topographic data for the derivation of the D.E.M. can be obtained from several sources: contour lines (reported on maps), S.O.N.A.R. records, S.R.T.M. (Shuttle Radar Topography Mission) data and D.G.P.S. (Differential Global Positioning System) surveys:

2.2.2.1. DIGITALIZATION OF CONTOUR LINES

The georeferenced topographic maps have often the major drawback of presenting an "artificialised" topography due to the numerous anthropogenic installations (construction of roads, railway tracks). Such installations usually imply the excavation of materials in very high quantity and/or the accumulation of the excavated materials over significant thickness to produce more rectilinear layouts and milder gradients in favour of establishing communication routes. Before GIS, contour lines on topographic maps were digitalized using lines. Today, GIS contour lines are deduced from a grid of points that gives a much better modelling of the landscape (Ghilardi, 2006). To create more realistic palaeo-topographic reconstructions throughout the different periods of the site's occupation, the contour lines must be re-interpreted manually in the GIS whilst ensuring that the overall aspect of map contour lines is respected as much as possible (Ghilardi, 2006; Ghilardi *et al.*, 2007).

2.2.2.2. BATHYMETRIC SURVEYS

In addition to terrestrial data, it is appropriate to complete the D.E.M. in marine environment to produce an overall topographical view of the concerned areas, both above and below sea level. Bathymetric data provide particularly precious information concerning the topography of the seabed in areas recently affected by the last post-glacial sea-level rise. Bathymetric points, produced using S.O.N.A.R. technique, can be included to the GIS and added to the D.E.M. (Ghilardi, 2006). In addition, L.I.D.A.R. technique is currently employed in the framework of shallow bathymetric surveys (Li, 2005). Photogrammetry and L.I.D.A.R. data complement each other: photogrammetry is more accurate in the x and y direction while L.I.D.A.R. is more accurate in the z direction.

2.2.2.3. INTEGRATION OF S.R.T.M. DATA.

Conventional topographic mapping technologies have produced maps of uneven quality—some with astounding accuracy, some far less adequate. Most industrial countries

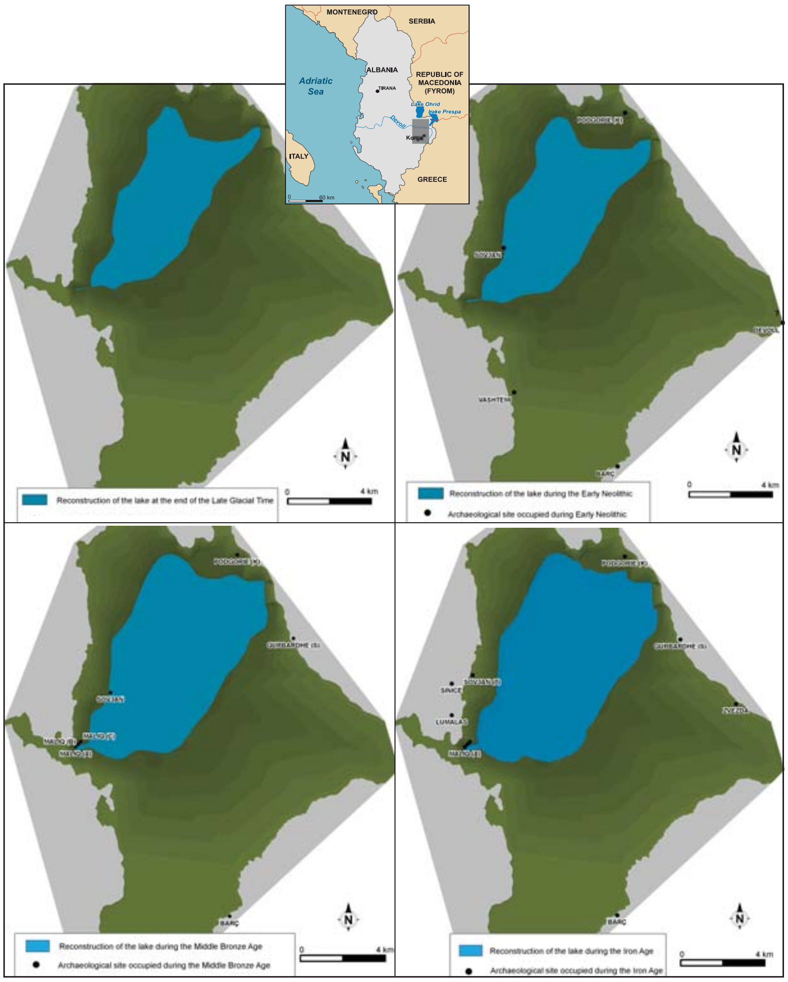

FIGURE 1: Four palaeogeographical reconstructions of palaeo-lake Maliq. a: Last Glacial Times; b: Early Neolithic; c: Middle Bronze Age; d: Roman Times. The four lake dwelling sites (Sovjan, Maliq A, Maliq B and Maliq C) discovered by the archaeological team are on the nearby reconstructed lake shores.

2 Hatt, Transverse Mercator 3 degrees, Hellenic Geodetic Reference System (H.G.R.S.) 87 and U.T.M. European Datum (E.D.) 50 (Mugnier, 2002; Ghilardi, 2006).

maintain national cartographic databases. The map products derived from these databases vary greatly in scale and resolution, and are often referenced with country-specific data and are thus inconsistent across national boundaries. The Shuttle Radar Topography Mission produced elevation data on a near-global scale and generated the most complete high-resolution digital topographic database of Earth (Farr, 2007; Rabus *et al.*, 2003). The new S.R.T.M. D.E.Ms. have probably had the largest impact on studies of regions in the developing world for which reliable, high-resolution digital topography was not previously available. With relatively few exceptions, a nearly complete topographic coverage is now available for most of the nonpolar world and provides a foundation for a new analysis of diverse landscapes (Farr *et al.*, 2007).

2.2.2.4. 3D TOPOGRAPHY USING D.G.P.S. SURVEYS

G.P.S. is an excellent data collection tool for creating and maintaining a GIS. It provides accurate positions for point, line, and polygon features. By verifying the location of previously recorded sites, G.P.S. can be used for inspecting, maintaining and updating GIS data. G.P.S. provides a tool for validating features, updating attributes and collecting new features. Differential correction techniques are used to enhance the quality of location data gathered using G.P.S. receivers. The underlying premise of D.G.P.S. is that any two receivers that are relatively close together will experience similar atmospheric errors.

2.2.3. ENVIRONMENTAL, PALAEO-ENVIRONMENTAL AND ARCHAEOLOGICAL INFORMATIONS INTEGRATION

The different shapes (points, lines, polygons) are georeferenced and connected with databases. Regarding the present and the past environments, stratigraphic, sedimentological, palynological and/or chronological (^{14}C datings) information can be collected. The archaeological databases can integrate information concerning the architecture, the function and the dating of buildings constituting the archaeological sites. The cross-comparison of these informations into the GIS allows palaeo-landscapes (hydrology and vegetation, in particular) and palaeo-topographies reconstruction.

3. THREE CASE STUDIES FROM ALBANIA AND GREECE

3.1. HOLOCENE PALAEOGEOGRAPHICAL RECONSTRUCTIONS AND PREDICTIVE MODELS OF ARCHAEOLOGICAL SITE LOCATION

The Korça Basin, located in southern Albania, is a plain at 818 m surrounded by high mountain ranges which culminate at 2028 m. The northwestern part of this basin was occupied by Maliq Lake until drainage works in the 1950s. Probably due to climatic variability and, since the second half of the Holocene, to anthropogenic forest clearances in the catchment area (Bordon *et al.*, in press), the surface of the palaeo-lake varied between a minimum of 40 km^2 during periods of low level to a maximum of 80 km^2 (Fouache *et al.*, 2001). From the Early Neolithic period (around 9000 B.P.) to the Early Iron Age (2300 B.P.), and especially during the Middle Bronze Age (around 4500 B.P.), the nearby lake shore was occupied by several settlements like Maliq (Prendi, 1966) or Sovjan (Touchais *et al.*, 2005). These settlements were studied by a French-Albanian archaeological team to elaborate a model of human implantation around the palaeo-lake Maliq. To perform surveys, palaeogeographical reconstructions of the palaeo-lake were established using GIS and D.E.M. taking into account archaeological, geological and new palaeo-environmental data[3]. Then, geological, palaeo-environmental and archaeological records have been included to a GIS and connected to the S.R.T.M. topographic data controlled with D.G.P.S. measurements. Figure 1 presents a 3D modelling of four stages of palaeogeographic reconstruction of the Maliq Lake along the Holocene period.

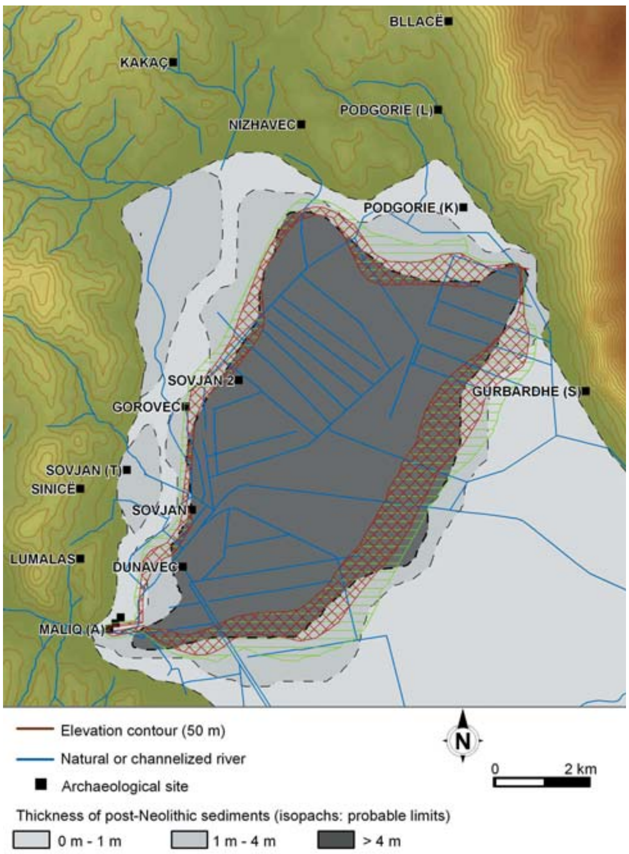

FIGURE 2: Predictive map for surface archaeological surveys of the Korça Basin and thickness of post-Neolithic sediments. The thickness of sediments covering archaeological layers is inferred from boreholes studies.

The reconstruction of the extension of the palaeo-lake during high levels, together with the knowledge of the thickness of the sediment (accumulation of colluvial deposits) covering settlements allowed us to design a predictive map of the potential archaeological layers for the Neolithic, the Bronze Age and the Iron Age (Fig. 2). Since the

3 The thickness of post-Neolithic sediments (peat deposits at the location of present dried up lake and colluvial deposits at the foot of the hill slopes) was determined by geomorphological observation in the whole basin.
The geometry of the palaeo-lake Maliq was reconstructed using unpublished data from the Geological Institute in Korça (101 logs obtained in 1974 by core-drilling, E/W and N/S profiles) A 150m long core transect from the archaeological site to the lake basin was drilled in 2005. Lithostratigraphy description, palynological analyses and A.M.S. ^{14}C datings from cores were used to characterize the sedimentary deposits of Lake Maliq and infer palaeo-environmental changes.

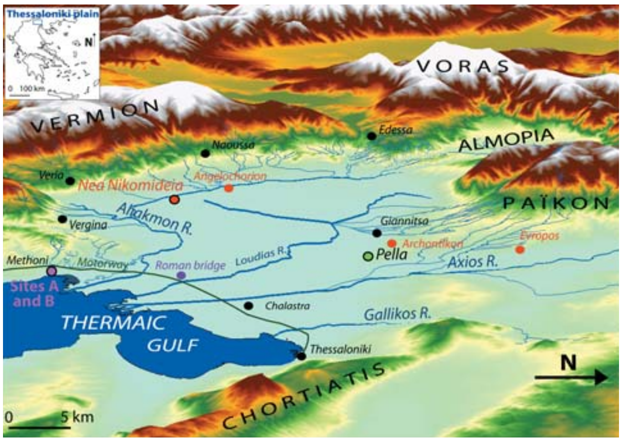

FIGURE 3: 3D view of Thessaloniki Plain using S.R.T.M. data. Superimposition of the archaeological settlements and hydrographical network with the SRTM data. The topography of the Thessaloniki Plain varies between 0 and 10 meters from the actual shoreline to the north, close to Ancient Pella (a maximum length of 32 km), and between 0 and 10 meters to the west, close to the Neolithic settlement of Nea Nikomedia. The city of Methoni is located along the Pierian coast on the meridional border of the delta (Ghilardi *et al.*, 2007). Red dots indicate Neolithic settlements, green dot indicates the capital Pella, light pink dot indicates the ancient settlement of Methoni (Sites A and B correspond to the sites identified by Hatzopolous *et al.*, 1990). The dots circled in black colour are described in this article.

lake level rised between the Neolithic and the Iron Age, the increase of the extension was taken into account to determine potential areas where sites could be fossilized. The preliminary results of the prospecting carried out in August 2007 confirmed the predictive map: lacustrine sites were actually found in the areas designated by the GIS-based predictions.

3.2. SECOND CASE STUDY: GEOARCHAEOLOGICAL STUDIES OF HIGH RESOLUTION ALTIMETRIC MAP FOR A DELTAIC AREA

The Thessaloniki Plain is the largest deltaic complex in Greece, covering an area of approximately 2000 km² (Fig. 3). This vast deltaic complex presents a flat relief-topography and originates mainly from the coalescence of alluvial deposits from Aliakmon and Axios Rivers, over the past 6000 years (Ghilardi, 2007; Ghilardi *et al.*, 2008a; 2008b). The palaeo-environmental study allowed reconstructing the landscape evolution for six millennia (Ghilardi, 2007). Based on chronostratigraphic sequence (^{14}C A.M.S. datings performed on marine shells and peat episodes), derived from borehole analysis, this important work for the area highlighted the rapid infilling of a shallow bay from the Neolithic period. Up to a maximum depth of 11 meters, eight boreholes recorded deltaic sediments, ranging from marine environment (the lower part) to lagoonal deposition (the middle part) and finally to fluvial deposits (upper part); the microfaunal helped in differentiating the different environmental conditions. Subsequently, sedimentological analysis helped in classifying the grain-size distribution (clays, silts, sands, coarse sands) and in identifying the contribution of the different drainage-basins. The rather flat appearance of deltaic areas does not reflect a lack of morphological processes. The three-dimensional display of minor relief forms (deltaic lobes, debris flow, alluvial fans…) often transpires to be difficult to implement due to the inaccuracy of available cartographic documents and also due to the fact that research scales are often oversized (Ghilardi, 2006). The different landforms (former levees, alluvial fans, etc.) are identified on satellite image as false colour composite objects. To obtain altimetric information, high-resolution topographic data derived from S.R.T.M. surveys are added in a GIS and superimposed on the satellite imagery. Subsequently, topographic information is linked to the palaeo-environmental results derived from borehole stratigraphy. This combination allows a spatial interpretation and a palaeo-geographic reconstruction of the whole area, including location of settlements (see Fig. 4 for a palaeogeographic reconstruction over the last 6000 years).

3.3. THIRD CASE STUDY: POTENTIAL LOCATION OF AN ANCIENT HARBOUR

The ancient settlement of Methoni was an important harbour closely affiliated with the Athenian Alliance (5th Century B.C.). According to historical manuscripts, the urban settlement was distant from the

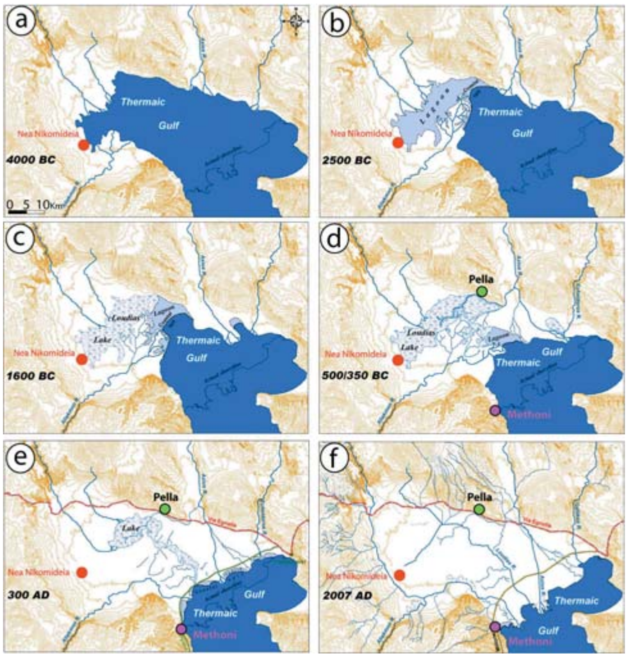

FIGURE 4: Palaeogeographic reconstruction of Thessaloniki Plain from Neolithic period to the present-day. Panel 4a: the actual plain of Thessaloniki is occupied by a large marine gulf circa 4000 B.C. This period corresponds to the maximum shoreline extension during the last post glacial sea level rise. Panel 4b: in 2500 B.C., the bay starts to be infilled by terrestrial deposits coming from Aliakmon and Axios rivers mainly. The rapid growth of their respective deltas created some levee gradually transformed into natural dams and lagoon—brackish environments around the margins of the bay. Panel 4c: the novel feature of the plain is the appearance of a lake, confined to the western part of the bay, around 1600 B.C. In the area of the Ancient Pella, at these times, shallow marine conditions appear. Panel 4d: around the 4th century B.C. the Aliakmon and Axios deltas grew. The probable narrowing of the bay is from this epoch: the junction between the two main rivers draining the plain is not efficient, but there is a very small strait which permits the passage of boats until Pella. Panel 4e: gradual silting up of the harbour of Pella around 300 A.D. and the lacustrine occupation. Panel 4f: morphology of the plain nowadays.

harbour even though neither the distance nor the potential location of the harbour are documented. Using the D.E.M[4] (digitalization of points on contour lines, integration of bathymetric surveys: the different shape files were integrated in a GIS) key landforms were identified indicative of the infrastructure of the ancient harbour (natural bays fossilized by intense sediment transfers in a deltaic context; Ghilardi, 2007). In addition to terrestrial data, a D.E.M. in marine environment was performed to produce an overall topographical view of the Methoni region both above and below sea level. Bathymetric data[5] enabled completion of this marine D.E.M. and precised the topography of the Methoni bay:

The three-dimensional view of landscapes revealed signs of the intense morphological activity. In the North of the archaeological settlement, there is a sector in which contour lines are represented in a concentric manner, representing a mild and regular gradient. The hypothesis of the presence of an alluvial fan can be made. On the digital elevation modelling, slope transfer activity (transfer of sediments along slopes that have not been transported by river flow) is visible along the former active cliff of Methoni. Indeed, where the escarpment meets the low zone (made up of deltaic sediments), we observe that the contour lines are "disharmonic", showing no concentricity. This is a telltale sign of an impermanent runoff that has been subjected to irregular phases of material transfer along slopes.

Today, we propose two candidate sites for the ancient harbour infrastructure away from the city (Fig. 5): two natural bays that remained unfilled by sediments after the classical period (Ghilardi, 2007). Further palaeo-environmental investigations, based on boreholes analysis and chronostratigraphic sequence could help significantly in reconstructing the sedimentary history along the Pierian coastline. Archaeological excavations in the two former bays will provide important results to confirm or not the presence of these harbour infrastructures.

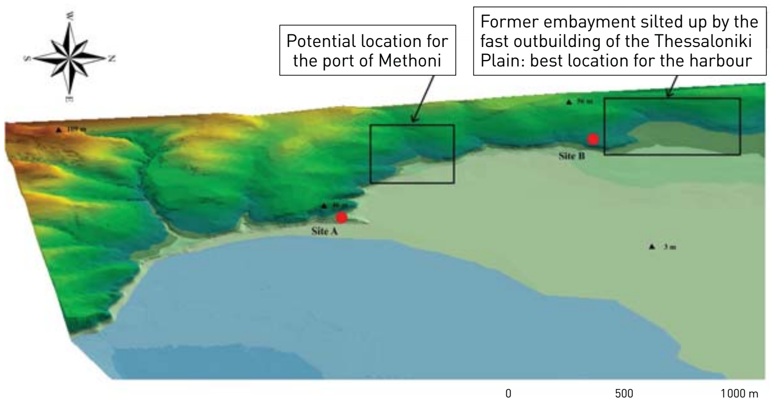

FIGURE 5: Proposal of location of two port sites for the city of Methoni (3D view of the sector). If two sites of occupation have been identified for the ancient city of Methoni—Sites A (archaic and classical periods) and B (Roman Times) (Hatzopoulos *et al.*, 1990)—the locations of the respective harbours are still unknown. Two natural bays that remained unfilled by sediments during historical times have the potential to be those ancient harbour sites.

4. CONCLUSION

Over the last decades, archaeologists and historians have faced the necessity to reconstruct ancient settlements history not only through the study of the material excavated, but also with the use of palaeo-environmental parameters. For this reason, geographers were invited to collaborate and include their results in georeferenced maps allowing a spatial interpretation of the laboratory analyses. This paper describes several powerful methods to infer the evolution of landscapes in the context of such multi-disciplinary/geoarchaeological programmes.

GIS is now the main digital support for scientists from various disciplines to reconstruct landscape around ancient settlements. The layers created in a digital format can have topics developed in Human and Social Sciences (Archaeology, Geography, History) as well as in Earth Sciences (Geology, Geochemistry, etc.). The main aim is to develop techniques and tools for multidisciplinary programmes dealing with the historical reconstructions of the landscape frequented by the Human societies since the last glacial period (circa 17500 BP).

When combined with Digital Elevation Models, GIS represents an essential preliminary step for all geoarchaeological research. Information concerning relief forms provides insight into the morphological evolution of landscapes and gives a basis for selecting potential sites for future excavation campaigns. Today, the three-dimensional reconstruction of environments is the best available method to produce a common reference. Dynamic and three-dimensional thematic maps using the Digital Elevation Model as a reference document must be used in the framework of multidisciplinary programs. The gain in time and resources is also substantial.

One of the limits encountered in the geomatic approach for geoarchaeology is the choice of the geographic scale of study: archaeologists focus on small structures (walls, etc.) or on simple pottery shards (sometimes no more than 10 cm in length) while geographers and specialists of Earth Sciences (Geology, etc.) employ different working scales which can be extended to hundreds of squared kilometres. Therefore, GIS can be used with difficulties by the different disciplines and need to be well adapted at a spatial level. Other problems can be observed within a discipline: source documents can be more or less reliable, for example it is still difficult to georeference maps older than the beginning of the 20th Century, and to adapt archaeological charts without spatial references in a GIS.

Perspectives for the use of GIS in geo-archaeological studies seem limitless and encompass: surface microtopography surveys, mapped surface finds, data from test pits and

4 for the D.E.M, we chose a series of topographic maps scaled to 1:5000. The digitalization of points on contour lines required the use of 15144 topography points.
5 1770 bathymetric points have been produced using S.O.N.A.R. The recorded sector, corresponding to the approximate boundaries of the bay, extends from the west of the Thermaic Gulf, to the meridional sector of the current city of Methoni and to the distal part of the Aliakmon Delta, further east.

excavations, and many multispectral and geophysical remote sensing data. All applications combined in one place, should yield tremendous potential for understanding site content, organization and structure. Multimedia presentations could offer video, sound, photographs, drawings and animated 3D views. In doing so, free Internet-based Software, such as *Google Earth©* and *Geoportail©*, which use 3D views could be implemented with additional data. Indeed, palaeo-environmental results provided by a large amount of international scientific programmes could be added and sea level rise since the last glacial period could be modelled, allowing not only 3D landscape reconstruction but also 4D modelling that relates long term evolution of shorelines displacement.

As presented in this article, geoarchaeological studies offer now an unprecedented level of integration between disciplines to visualize a shoreline and its displacement. Over the last 20 000 years, humans had to constantly adapt their lifestyle according to the displacement of the shoreline. Given the current threats and uncertainties related to climate change, it is predictable and desirable that many disciplines will adopt similar integrated approach to model their favourite object of research. More generally, GIS offers a tremendous opportunity for scientific outreach and its international common databases are now ready to be shared for new purposes and adapted to create new usages beyond scientific communities.

Acknowledgements are addressed to the CNRS for financial support through the ECLIPSE project "Variations climatiques et dynamique des écosystèmes au Sud des Balkans au cours du dernier cycle climatique", coordinated by A.M. Lézine and E. Fouache. Special thanks to the members of the Franco-Albanian cooperative project including the French School of Athens (Greece) and the Archaeological Museum of Korçë (Albania). Fruitful remarks from Theodoros Paraschou (Anafi) and David Psomiadis (University of Dimokritos, Athens, Greece) were highly appreciated. Finally, special thanks to the Ecole Pratique des Hautes Etudes (Paris-France) for technical support.

References

Anschuetz K. F. *et al.* (2001). An Archaeology of Landscapes: Perspectives and Directions, Journal of Archaeological Research, 9 (2).

Bordon A. *et al.* (in press). Pollen-inferred Late-Glacial and Holocene climate in southern Balkans (lake Maliq), Quaternary International.

Butzer K.W. (1982). Archaeology as Human Ecology, Cambridge University Press, 364 p.

Desruelles S. & C. Cosandey (2005). The water resources in the insular group of Mykonos, Delos and Rhenia (Cyclades, Greece) and their management in the antique city of Delos, In Stournaras, G., Pavlopoulos, K., and Bellos, T., Eds., 7th Hellenic hydrogeological conference and 2nd Mem Workshop on fissured rocks hydrology; Vol. II, key lectures, workshop proceedings, Athens, The Geological society of Greece, 101-104.

Farr T. G. *et al.* (2007). The Shuttle Radar Topography Mission, Rev. Geo-phys., 45. RG2004, doi:10.1029/2005RG000183.

http://www2.jpl.nasa.gov/srtm/srtmBibliography.html

Fletcher R. (2008). Some spatial analyses of Chalcolithic settlement in Southern Israel, Journal of Archaeological Science, 35, 2048-2058.

Fouache É. (2001). Man and environement around lake Maliq (southern Albania) during the Late Holocene, Vegetation History and Archaeobotany, 10, 79-86.

Fouache É. (2006). 10000 ans d'évolution des paysages en Adriatique et en Méditerranée Orientale. Géomorphologie, Paléoenvironnements, Histoire, De Boccard éditions, Travaux de la Maison de l'Orient et de la Méditerranée, 45.

Fouache É., & M. Rasse (2007). Geoarchéologie. Avant-propos, Bulletin de l'Association des Géographes Français, (1), 115-118.

Fry G.L. *et al.* (2004). Locating archaeological sites in the landscape: a hierarchical approach based on landscape indicators, Landscape and Urban Planning, 67, 97-107.

Ghilardi M. (2006). Apport et intérêt de la Modélisation Numérique de Terrain en géomorphologie, étude du site antique de Méthoni (Piérie—Grèce), Dinard, Mémoire du laboratoire de géomorphologie et d'environnement littoral de l'Ecole Pratique des Hautes Etudes, 114 p.

Ghilardi M. (2007). Dynamiques spatiales et reconstitutions paléogéographiques de la plaine de Thessalonique (Grèce) à l'Holocène récent. PhD thesis, University of Paris 12, 475 p.

Ghilardi M. *et al.* (2007). Localisation de sites portuaires pour la cité antique de Methoni (Piérie—Grèce) via l'utilisation des Modèles Numériques de Terrain, Travaux archéologiques en Macédoine et en Thrace AEMTh, 19, 317-321.

Ghilardi M. *et al.* (2008a). Reconstruction of Mid-Holocene sedimentary environments in the central part of the Thessaloniki Plain (Greece), based on microfaunal identification, magnetic susceptibility and grain-size analyses, Geomorphology, 97 (3-4), 617-630.

Ghilardi M. *et al.* (2008b). Human occupation and geomorphological evolution of the Thessaloniki Plain (Greece) since Mid Holocene, Journal of Archaeological Science, 35 (1), 111-125.

Hatzopoulos M.V. (1990). Deux sites pour Méthone de Macédoine, Bulletin de Correspondance Hellénique, 114.2, 639-668.

Hubert S. (2001). Modélisation Numérique de Terrain et analyse spatiale pour une aide à l'évaluation des risques d'inondation dans la région de Nouakchott (Mauritanie), Mémoire de DESS, ENSG—Univ. Pierre et Marie Curie, 50.

Katsianis M. *et al*. (2008). A 3D digital workflow for archaeological intra-site, Journal of Archaeological Science, 35, 655-667.

Kvamme K. L. (1999). Recent directions and developments in geographical information systems, Journal of Archaeological Research, 7 (2), 164-167.

Li X. (2005). Contribution à la mise en place d'une base de données à référence spatiale en baie du Mont Saint-Michel, Mémoire de l'Ecole Pratique des Hautes Etudes.

Marble D. F. *et al*. (1984). Basic readings in geographic information systems, SPAD Systems Ltd., Williamsville, New York.

Mugnier C. (2002). The Hellenic republic—Grids and datums, Photogrammetric engineering and remote sensing, 1237-1238.

Prendi F. (1966). La civilisation préhistorique de Maliq, Studia Albanica, 3 (1), 255-280.

Rabus B. *et al*. (2003). The shuttle radar topography mission- a new class of digital elevation models acquired by spaceborne radar, Photogrammetric Engineering & Remote Sensing, 57, 241-262.

Rapp Jr. G. R. & C.L. Hill (1998). Geoarchaeology: The Earth-science approach to archaeological interpretation, Yale University Press, New Haven.

Touchais G., P. Lera & C. Oberweiler. (2005). L'habitat préhistorique lacustre de Sovjan (Albanie): dix ans de recherches franco-albanaises (1993-2003), In Della Casa, P., and Trachsel, M., Eds., WES '04. Wetlands Economies and Societies, Proceedings of the International Conference, Zurich, 10-13 march 2004, 255-258.

Abbreviations and Acronyms

A.D.: Anno Domini

A.M.S.: Accelerator Mass Spectrometry radiocarbon dating is a way to obtain radiocarbon dates from samples that are far tinier than that needed for standard radiocarbon dating. Standard 14C dates require amounts of between 1 and 10 grams of charcoal; A.M.S. can use as little as 1-2 milligrams, and under special circumstances to samples as small as 50-100 micrograms.

B.C.: Before Christ

B.P.: Before Present. Before Present years are a time scale used in Archaeology, Geology, and other scientific disciplines to specify when events in the past occurred. Because the "present" time changes, standard practice is to use 1950 as the arbitrary origin of the age scale. For example, 1500 B.P. means 1500 years before 1950 (that is in the year 450).

C.A.D.: Computer-Aided Drafting (Design). It is the use of computer technology to aid in the design and especially the drafting (technical drawing and engineering drawing) of a part or product, including entire buildings. It is both a visual (or drawing) and symbol-based method of communication whose conventions are particular to a specific technical field.

D.E.M.: Digital Elevation Model. It is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (D.T.M.). A D.E.M. can be represented as a raster (a grid of squares) or as a triangular irregular network. D.E.Ms. are commonly built using remote sensing techniques; however, they may also be built from land surveying.

D.G.P.S.: Differential Global Positioning System. It is an enhancement to Global Positioning System that uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions.

E.D.: European Datum

GIS: Geographic Information System. This system integrates hardware, software, and data for capturing, managing, analyzing and displaying all forms of geographically referenced information.

G.P.S.: Global Positioning System, is a system of satellites in space which are circling the Earth. The system has more than 24 satellites circling the Earth, all of them working together to tell people where they are.

L.I.D.A.R.: Light Detection And Ranging. It is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses.
H.M.G.S.: Hellenic Military Geographical Service

H.G.R.S.: Hellenic Geodetic Reference System

S.O.N.A.R.: SOund Navigation And Ranging. It is a technique that uses sound propagation (usually underwater) to navigate, communicate or to detect other vessels.

S.R.T.M.: Shuttle Radar Topography Mission: elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth.

T.I.N.: Triangular Irregular Network. It is a digital data structure used in a Geographic Information System (GIS) for the representation of a surface. A T.I.N. is a vector based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (x, y, and z) that are arranged in a network of non-overlapping triangles.

U.T.M.: Universal Transverse Mercator

W.G.S.: World Geodetic System