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Modelling Time through GIS Technology: the Ancient Prile Lake (Tuscany, Italy)

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Abstract. This paper presents the first results of the study of the ancient Prile lake, in the modern area of Grosseto, Southern Tuscany. The modern landscape, now an area of intense agriculture, was subject to a process of land reclamation after the gradual silting of the lake that eventually drained it. This ancient inland salt water lake provided an ideal area for harbors and landing places, as it was for the Etruscan cities of Vetulonia and Rosellae. The principal aim of the research has therefore been to explore, through the use of 3-D modelling and GIS applications, the changing coastline and to establish the varying extent of the Prile lake throughout its history, integrating geological, historical and archaeological data and including time variations. The subsequent stage in this research will be the distribution of the results of this investigation through the Internet using various multimedia applications.

1 Introduction

The research presented in this paper, a part of the Prisma Project (see Niccolucci *et al.* in this volume), has the aim of reconstructing the substantial changes that have taken place throughout time in the territory surrounding the modern city of Grosseto in Southern Tuscany.

The purpose of the study is to develop new themes and directions that will help to answer current archaeological questions that have been raised in relation to the changes that took place in the coastal area of ancient Etruria, and the implications these had in the economy and the population.

Through the application of current GIS technology, it has been possible to develop reconstructions of the landscape at key moments in its history by drawing upon historical, topographical, archaeological and geological sources.

A significant part of this research involved a twofold task: constructing the models and incorporating the concept of time within them, in the attempt to create a system that is combined with a three-dimensional reconstruction of the dynamic process of the changing landscape across time.

The research approach for mapping time was to exploit the potential and the flexibility of a temporal database and modelling the changes in the landscape through digital 3D technology. This was achieved by combining cartographic modelling with animation representing the 3rd dimension. Such an approach emphasises the importance of the role of maps and terrain models as an aid in understanding of changes in time through the landscape.

The subsequent stage in this research, integrated with the overall aims of the Prisma Project, is the distribution of the results of this investigation through the Internet using various multimedia applications. Beyond Prisma's goal of knowledge dissemination to the public, data availability on the Internet by means of GIS technology has also important scientific implications (D'Andrea, Niccolucci and Crescioli 2001, Ceccarelli 2001), so both a 3D virtual model, offering interpretation to the public at large, and a GIS system, addressing scientific research, will be provided on line.

The aim of this paper is to briefly describe the principles on which the project was created and then to offer an overview of the spatial and temporal analyses carried out during the investigation and the principles on which they were based. The results obtained in this project and the proposed methodology of sharing data through different softwares can create a dynamic dialectic in the development of advanced solutions and innovative applications within cultural resource management.

2 The Study Area

The area under study lies in the south-west of Tuscany in central ancient Etruria, an area known as Maremma. It is characterised by a large flat area surrounded by hills falling between the Bruna and Ombrone rivers which encompass a study area of over 750 square kilometres which have been continually inhabited since prehistory. The morphology of the landscape varies between 630 m above sea level and half a metre below sea level.

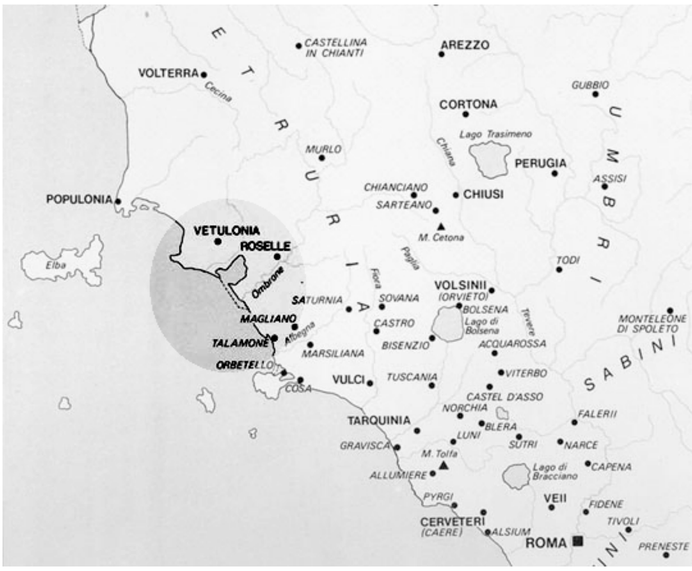

Fig. 1. The study area, in Southern Tuscany.

During the late Pleistocene the area was formed of a large gulf created by a gradual subsidence that coincided with an increase of the sea level, a consequence of the glacial era.

In the Holocene period, eroded sand sediments from internal sea streams were deposited on a rock crest to form a sediment spit, a so-called "tombolo". Such a natural dam during the Etruscan period (7th-6th century BC) altered completely the landscape closing the gulf to form a natural lagoon (Stea and Tenerini 1996). The gradual subsidence of the internal lake was also caused by the sediments carried by the Ombrone River, which has significantly altered its course several times.

As the lake slowly receded, inhabitants followed the retreating shoreline as is attested by the archaeological data. A GIS can be extremely useful in modelling the complex relationships between humans and this changing environment but it has to keep into account the time variation of the latter to be really useful. This implies a varying geographical base, while in common GIS applications it is generally assumed that the geographical layer is constant and different settlement periods are simulated by means of different GIS layers.

In the Palaeolithic period there have been discovered scattered lithic material mostly in caves located at a height between 10 and 90 m above sea level (all heights, here and below, are referred to present position).

In Etruria, the period of time between the 12th and l0th centuries BC (late Bronze Age) coincided with the phenomenon of proto-urbanisation: nucleated settlements and necropolises seems to originate in the Final Bronze Age around the hills. In the Villanovan period (9th-8th century BC) occupation began on the surrounding hills (190 – 100 m above sea level), some settlements disappeared during the later 8th century BC, while others begun to flourish, including *Vetulonia*, on the north side of the lake, and *Rosellae*, located on the east coast (Celuzza 1993), near the modern village of Roselle. The Etruscan sites developed along the shoreline of the lake, many of which were at 4 – 5 m above sea level.

The Ombrone river and the ancient inland salt water lake provided an ideal area for harbours and landing places, as it was so used by the previously mentioned Etruscan cities, while the lake maintained its connection with the sea. The presence of the lake undoubtedly played a pivotal role in the commerce and economy of the surrounding territory, as is witnessed at Vetulonia, that controlled the entire area in the 7th and 6th century, subsequently losing power during the mid 6th century in favour of the ascending *Rosellae* (Celuzza 1991). From its high position (150 m above sea level) above the plain of Grosseto, *Rosellae* dominated lake Prile and also had control over the river Ombrone. The city had a flourishing economy based on agricultural activities and commerce until it was conquered by Romans in 294 BC.

The romanisation of the area was completed in the 2nd century BC. The Romans continued to exploit the economic activities of agriculture, stock breeding, and fishing that had already distinguished the zone in the past, as well as the extraction and working of minerals. They created a road network taking advantages of the changed landscape, as the lake become a lagoon as the tombolo was completely joined to the mainland, as it is attested by the construction of a road on it (Citter 1996).

During the Roman period the lake was still navigable as it is attested by ancient sources, as Pliny "*Hinc amnes Prile, mox Umbro, navigiorum capax*", (Nat Hist, III, 51). Archaeological records have revealed that a large number of villas were located around the lake until the 4th century AD (Curri 1978, Citter1 996). The area continued to prosper until the 2nd century AD, when a crisis assailed above all trade and agriculture, decreeing the failure of the economy of land estates; it was also related to the silting up of the Prile lake and the consequent swamping of the zone, in addition with the neglect of the territory formerly controlled by an efficient drainage system. Despite the economical and social crisis in the territory in the 4th century AD, attested by historical sources, archaeological records reveal that flat areas, which became marshland, were abandoned, but hills were still inhabited until the medieval period (Citter 1996).

The landscape was subject to a process of partial land reclamation after the gradual silting of the lake that eventually drained it. The process continued throughout the roman and medieval periods until the gradual demise of the lake and its complete disappearance at the end of the 15th century. Marshes remained a typical feature of the area, which in the 18th and 19th century was famous for being infested by anopheles mosquito causing malaria.

However, substantial changes in the landscape took place in the first half of the 20th century with reclamation, when the soil of the plains was drained and its level was increased by nearly 3 meters, covering any archaeological evidence in the plain.

3 The Research Methodology

The research focused on the importance of the spatial component of the data, to discover whether significant patterns and arrangements can be revealed in the relationship to the geographical and historical context. GIS technology has been used in answering these questions, as this platform is the most appropriate for performing a complete analysis of the data.

The method chosen to represent the changing landscape was the construction of a 3D model conceived as:

- reconstructing the ancient landscape in the light of archaeological data;
- developing a methodology of incorporating time in a GIS;
- creating a product that can be distributed to the public through the Internet.

Several problems were encountered in following this process, firstly in constructing the model and secondly in the representation of the temporal changes, where a suitable solution was eventually identified in a time database combined with GIS spatial modelling. The capability of this information system has been expanded through the adoption of a range of widespread software, including AutoCAD, Access, ArcGIS, in the process of building the models, then converting the result to Grass and PostgreSQL RDBMS to allow on line access, and to 3D Studio Max to create the time animation. The latter will be viewed as a QuickTime movie and/or a QTVR. It is planned to create a QTVR navigable object, in which the horizontal movement will change the spatial perspective while moving vertically will visualize different historical periods. Thus the final result will address issues of multimedia data storage and presentation, and also will allow the possibility of exploiting the GIS capabilities across the Internet.

4 The Concept of Time

The definition of time is a challenging task to which many scientists or philosophers have suggested an answer. However, it is not the aim of this paper to discuss the philosophical concept of time throughout history or its interpretation in archaeology. The temporal framework of this project is one formulated upon the linear time of the western culture and is using a position relative to a sequence of events. In the confines of this research, more than the theoretical approach of the nature of time and space, concern has focused on the representation of temporal and spatial entities.

There exists a significant amount of research and debate on the subject of time and GIS during the last decade, in particular a significant contribution by Langran (1992). In the discipline of archaeology, the issue of time can be addressed in different ways. For instance, much temporal information can not be addressed by certain date, days or hours as in other fields, as transformations happened over centuries. This complex issue was investigated by Castleford in 1992, where he provided the framework and the foundation for the adoption of the time component in an archaeological GIS. The topic was further developed within the Time Map Project, by Johnson (Johnson and North 1997, Johnson and Wilson 1998). A recent overview of the conceptual issues in Daly and Lock 1999 reveal that there have been many design proposals and even some intriguing software solutions. Yet little has been accomplished in the field of archaeology, because the main problem currently encountered is that commercial GIS software still lacks the capability to adequately represent the temporal dimension and to perform a temporal analysis of spatial data, which has been on the contrary developed, at least at theoretical level, for DBMS and SQL.

In this project, a possible solution to the problem has been identified as a time database combined with spatial modelling. The cartographic modelling has been connected with animation, thus representing the 3rd dimension, in order to explore questions of change over time, stressing the importance of the terrain models.

5 The Concept of Modelling

This concept has a twofold meaning:

1. a model of real world phenomena, which implies a simplification of reality, which is characteristic of the GIS. Hence, the algorithm that is used to create the model is fundamental.
2. a model as a study of an object or an event "…believed to have the structure and the behaviours which will be the guide to investigate the same attributes of something else which can not be tested directly" (Doran 1990: 94).

In the project it was necessary to produce models of the terrain representing the change in the coastline thus used to approximate the phenomena in the real world, creating a simulation, which is a methodology that describes the behaviour of complex systems (Barcelo 2001).

The main data source for the landscape reconstruction were modern topographical and archaeological data, the majority of which derived from field walking surveys, as few excavation have been conducted in the area except within the Etruscan cities. The cartographic base has been a vector map generated from aerial photographs by Regione Toscana, from which a set of 25000 spotheights was derived. A further source of information for the creation of the lake models derived also from a geological study conducted in the past years in the Grosseto area (Stea and Tenerini 1996), which provided information of the nature of the soil and permitted to formulate hypotheses on the extension of the shore-line in relation to the topography.

The research models were created on the basis that a landscape can be interpreted as a three-dimensional space in continuous evolution, where the fourth dimension is time. In a GIS all the data (archaeological, physical, spatial) are palimpsest in a bi-dimensional space. In addition, there are limits of the GIS modelling capabilities as the neat limits, such as the shorelines, are based on contours and in reality they may not have been so definite. In our model, the changes of the coastal line and the shore of the lake are represented as "shots" taken at the main settlement periods: Palaeolithic (35.000 BP), Final Bronze Age (2nd millennium BC), Etruscan (7th – 3rd century BC), Roman (2nd century BC – 4th century AD). The changes in the sea level and the retreating shoreline are therefore indicated through four time slices rather than one continuous change, as levels rose or fell by small amounts over long periods of time, changes which are impossible to indicate. For instance, between the 6th and the 4th century BC the level of the Tyrrenian sea changed by 20 cm. (Antonioli-Leoni 1998, 63) As such small, continuous changes are invisible at the model scale, it was chosen to visualize time fragments related to the major phases of the archaeological data.

Considerable attention and research has been paid to choose the most suitable interpolation algorithm to model the terrain.

This issue is often ignored as attention is merely focused on the results of the analyses (D'Andrea and Niccolucci 2001, Wheatley and Gillings 2002: 113).

Different software packages were used, with considerable focus on the ESRI ArcGIS spatial analysis extensions.

The first algorithm used to generate the model was kriging, a procedure that optimises the interpolation function assuming that the pattern of spatial variation between sample points can be observed at all locations on the surface. This pattern is estimated by using variograms models such as: spherical, exponential, linear and Gaussian. The best estimation method for generating the output surface is then based on an interactive examination of the variogram that describes the weighting factors that will be applied for the interpolation and can calculate the expected error of estimation of the interpolation of the points (Burrough and McDonnel 1998; see also Hagemann and Bennet 2000 for an interesting comparison of the error estimation in terrain model with kriging). Two possibilities were exploited using ordinary kriging and simple kriging, The latter uses the average of the entire data-set, producing a less accurate model of the area characterised by flat plain surrounded by hills. Ordinary kriging utilises the local average, creating a more accurate model. It resulted, however, that, due to the large number of data points for the area, the technique was computationally very intensive without offering substantial advantage in comparison with simpler techniques as TIN. Thus another set of models was generated using TIN. Although little control on the interpolation method is possible, it proved more suitable for the available data-set due to the morphology of the landscape.

To permit visualization of these models to a large number of users with no specific software, several trials were performed to export them to various format to be used for animation. The first attempt was to export the models in VRML format, but it was found, as expected, that it produced a huge file. As an alternative, exporting the 3D models to GRASS (with NVIZ 3-D application) was also tested; finally we chose the solution using 3D Studio to create a movie, to be then imported into Quick Time to generate QT movies and virtual models. It appears that if the aim is simply to create a 3D "fly-through" animation, the DTM created is unnecessarily detailed to be easily generated and rendered as a photorealistic panorama in a 3D modelling package, where only a smaller portion of the landscape can be generated with a reasonable amount of computational resources. Therefore we chose the simpler solution to obtain immediate results, easy to display on a PC and over the Internet with satisfactory quality, since one of the research aims is the creation of an application for display in the Grosseto archaeological museum, as a part of the Prisma project (see Niccolucci *et al.* this volume). Further investigation will subsequently be carried out to exploit the vast amount of information included in the available detailed DTM to obtain a 3D model suitable for scientific research.

6 Mapping the Time

The type of model suggested to visualise and measure changes in time is that of spatio-temporal intersection model, which combines a database with a snap-shot model, using a series of 2D data. The basic idea of this model is to take advantage of the possibility of layer division in a GIS, which permits us to combine different sets of data referring to the same spatial domain, using boolean operators such as present/absent and SQL applied to the same spatial location (Bagg and Ryan 1997). The inclusion of a DBMS ensures data integrity. The database was built accordingly to the type of the data, the majority of which were derived from field-walking surveys as very few excavations have been conducted in the area.

In the database, time is treated as a categorical rather than continuous variable, because time, according to an archaeology conceptual model, can be divided in a series of periods (see Lock and Harris 2000). Whilst it is realised that there is a substantial oversimplification, it appears to be a suitable solution for both the historical and technical aspects.

7 The models

As always, it is difficult for authors to explain and for readers to appreciate (or criticize) a GIS when this is explained only on paper. For this reason, we are going to make it available on line, together with the 3D models as far as these are compatible with an ordinary bandwidth. So interested readers will soon be able to access both at the VAST Lab web site, under the Prisma heading: http://www.vast-lab.it/prisma/.

However, we reproduce here some of the models produced by the application. Even if the reproduction is in greyscale and images are necessarily small, in our opinion they clarify the result of our work and may help in imagining the museum display and its effect on visitors.

Below are presented four 2D models of the study area, referring to different historical periods, archaeological sites are indicated by small circles, while main centers are shown with their modern names for reference.

8 Conclusions

The project discussed here is a preliminary attempt to model temporal changes in a GIS environment. The results achieved represent an important step forward in the knowledge of the area as no similar research, utilising GIS modelling and analysing capabilities, has previously been conducted and important archaeological conclusions can be drawn, which will be presented at a later stage.

Further interesting field to extend this research will be the application of fuzzy logic in the GIS spatial representation of archaeological sites, in order to interpret their evolutionary changes and to define their boundaries (fuzzy time) in order to study other archaeological aspects.

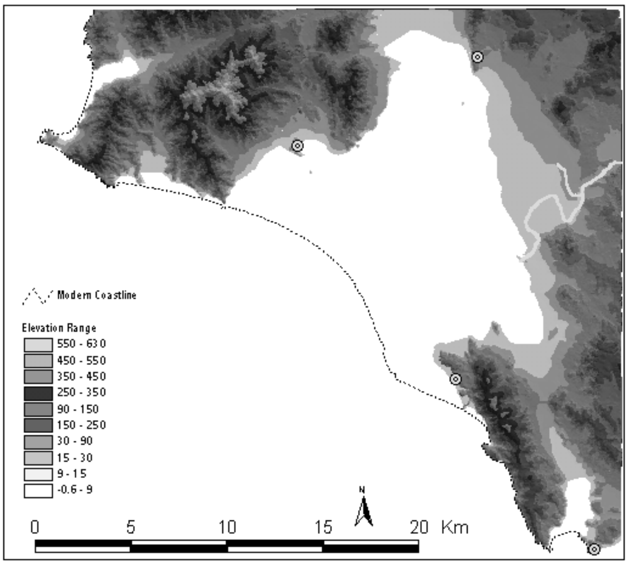

Fig. 2.*.The lake in the Palaeolithic (actually, still a gulf).*

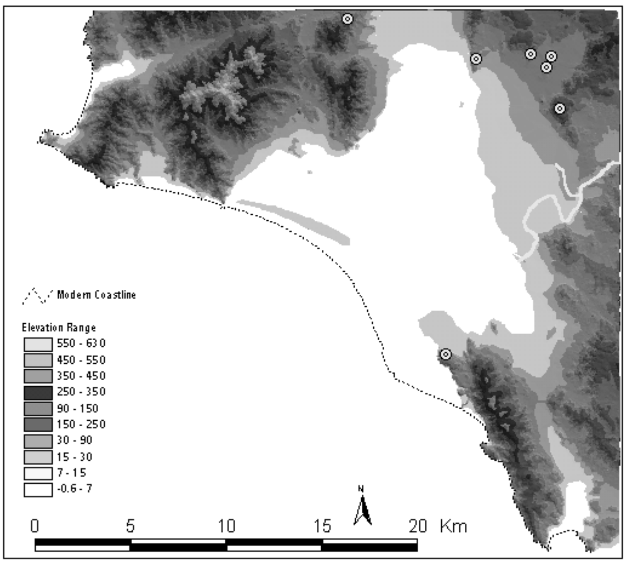

Fig. 3. *The lake in the Bronze Age (2nd millennium BC).*

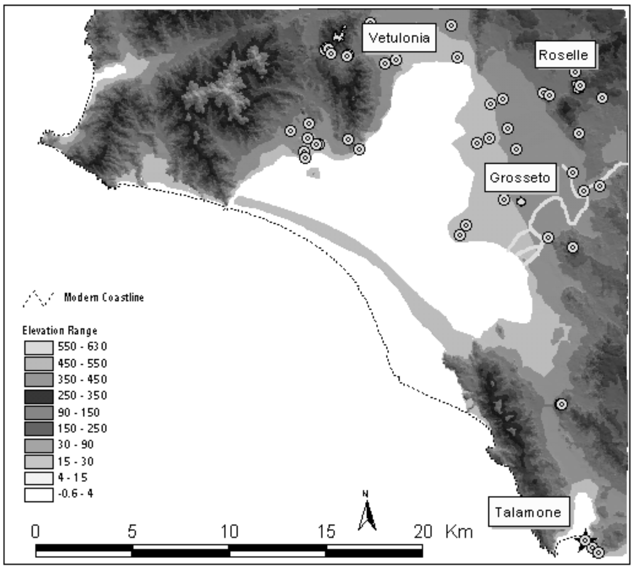

Fig. 4. *The lake in the Etruscan period (8th to 6th century BC).*

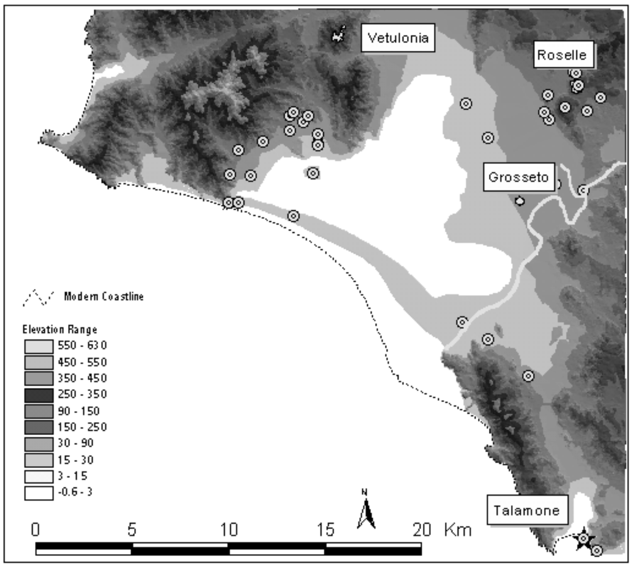

Fig. 5. *The lake in the Roman period (2nd century BC to 4th century AD). Note the closure of the coastline.*

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