Spatio-temporal reasoning in archaeology with G.I.S.

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Abstract

The aim of the project was to create a system for recording, representing, manipulating and transforming archaeological surveys using GIS technology.

The system relies on a geodatabase with administrative information of (municipalities where searches are carried out), archaeological (excavation and surveys) and documentary type Sources and documentation are associated with surveys.

The database is an archive of:

- excavations with areas, tests, stratigraphic units, tombs, individuals and finds,
- surveys with UT (zones with a higher concentration of finds),
- surveys with MS (zones with a lower concentration that does not necessarily identify a site,
- lists of the relevant finds.

In the planning stage, the data were normalized.

During the system design we focused on the spatio-temporal reasoning, because GIS technology cannot manage time and space with the same granularity.

Moreover, archaeologists often date the contexts of the materials discovered by comparing them with classifications and seriations?? that have already been processed. This dating system very rarely leads to exact chronologies (except in cases of known historical events or enclosed contexts). Besides the dating method, uncertainty is also due to dating by "cultural stages": history is subdivided into periods such as the First Republican Age or the Middle Bronze Age.

Such definitions, particularly for more ancient ages, can vary considerably in relation to geographic zone or culture. This is a crucial node in the modeling of an archaeological database, which is very much dependent on the temporal component and which is insufficiently defined. In GIS transposition of such chronologies, the main problem is the impossibility to identify one minimal unit of time – kronon – to represent the dates.

Moreover, if a find has a continuous chronology, a site or an area of finds (TU) can have a period of “no life” within its chronology. In order to meet these requirements, the dating of sites and finds is represented as a “Period”, with a beginning and an end expressed by numerical values representing the years (negative for the years before Christ and positive for those after Christ).

This solution allows one to manage continuous and discontinuous intervals of time (representing them as sequences of beginning-end periods) and temporal events (when Beginning and End are identical). Uncertainty is represented as symmetrical “tolerance” around the beginning and the end values of the period.

GIS commercial technology was integrated for this project to handle such temporal reasoning and to answer such queries. The survey described in the paper concerns the entire territory of ancient Kaulonia, what is now known as Monasterace (Reggio Calabria), Italy.

The system is currently being integrated with predictive models to locate new areas of archaeological presence in zones that have still to be surveyed.

1. Introduction

The aim of this project is to create a geographical information system (GIS) to manage, analyse and return data from archaeological surveys and excavations.

In archaeology, as in many research fields, the use of sophisticated tools, such as GIS, is becoming increasingly necessary. Such tools are needed to acquire and manage the highest volumes of data possible, not only to catalogue this information but above all to reconstruct the geomorphological and anthropic dynamics of the location of the site under study.

Using GIS technology as a data 'glue' offers a new systematic and methodological approach. It enables archaeologists to acquire an integrated point of view in relation to the application domain.

The challenge is to be able to use the knowledge stored in the system to produce further knowledge, for example predictive models for locating new archaeological sites.

The main characteristic of the system is that it should be open, so that it can be easily integrated with new types of data and so that it will enable users to be interfaced with various external databases by cross referencing data.

2. Description of the application domain

Archaeological research consists of the study of physical evidence of ancient cultures via the excavation, survey and study of their artefacts. Each of these techniques produces a huge amount of data which is normally stored in cards.

During an excavation, the relationship between natural and anthropic deposits is studied. These deposits are the result of human activity and represent a trace of a past life: pottery, money, objects, coal, and other evidence. Each of these traces is recorded and attributed to the layer (stratigraphic unit, hereafter SU) where it was found. The archaeologist then studies the physical relationships between layers and from these defines the chronological relationships, ie what came first and what came later.

For an absolute dating of the archaeological stratigraphy, the artefacts found need to be compared morphologically with finds from other known contexts. Archaeological study is not merely limited to excavation, but works on a far greater scale in the study of the surface, which often takes place before a site is excavated.

Surveying the surface is done systematically and any archaeological evidence found is recorded. The sample area may correspond to the modern administrative limits or to those of an ancient community. The former is particularly true if the survey has been commissioned by organizations that are concerned with its management. The latter is based on reconstructing the various neighbouring settlements.

During a survey areas of archaeological presence are identified in surfaces and are classified into Topographical Units (TU) and areas of Sporadic Material (SM). The first have a greater concentration of finds and are better conserved – they are areas which are more easily defined as being 'sites'. In the latter (SM), finds are scattered over vast areas and are in a very bad state of conservation. Frequently SMs are none other than areas where there are finds coming from neighbouring TUs.

Thus for an understanding of an ancient settlement, TUs tend to be more significant, whereas SMs often cannot even be dated. As with Stratigraphic Units, TUs are dated by analysing the finds. The aim of the survey is to get greater knowledge of the history of a particular area.

GISs enable archaeologists to answer numerous questions regarding the territorial relationships amongst the archaeological evidence, and to integrate archaeological data with other types of data. The aim of a survey is in fact to reconstruct an ancient land area, by analysing not only any archaeological presence but also the latter's relationship with the characteristics of the environment that must have conditioned the settlement (geomorphology, hydrography, pedology, etc).

2.1 The finds

Archaeologists often manage vast excavation and survey areas. They thus need to record, maintain and process huge amounts of data both regarding the research documentation (photographs, maps, drawings, and also SU and excavation areas cards), and the finds.

Archaeological research is made up of various preliminary activities: archives and epigraphic and numismatic sources are analysed; and historical maps and literary sources are studied. However direct hands-on knowledge of the historical background of a site is certainly gained through on-site investigation.

Obtaining an absolute dating of an SU or a TU entails a thorough analysis of the finds. Such finds are at the basis of the research, and they represent the 'minimum unit' for studying the context in which they were found.

2.2 Case study

The History, Archaeology and Topography laboratory of the Scuola Normale Superiore of Pisa set up some survey campaigns in the municipality of Contessa Entellina (Palermo, Sicily), initially in a sample area of this municipality. An information system was developed to manage the data from this research.

Later, when the research was widened to the whole municipality, the information system was complited with data from following survey campaigns. The archaeological survey of Kaulonia (Monasterace, Reggio Calabria, Italy) involved an ancient Greek colony and was aimed at bringing to light the relationship between the native inhabitants and the colonisers as well as reconstructing the settlements during various historical eras.

Another important objective was to verify the data obtained from a survey carried out in the 1970s by I. Hodder and C. Malone. This survey was never published in any exhaustive fashion, for example the TUs are shown on 1: 100000 scale maps, generically divided into prehistoric TUs and classical TUs. In addition, the materials were never published. In fact the aim of their study was to verify particular research methods rather than gain an understanding of the area.

The GIS allowed us to georeference cartographic data from the above surveys, so that we could establish whether what we found coincided with the archaeological presence found by Hodder and Malone.

3 Treatment of the archaeological data

3.1 Data typology

Designing an archaeological geodatabase involves the management of rather unstructured and normalised data. Not all archaeologists record data in the same way, the terminology used is not consistent, and datings may be uncertain. Our aim in the design phase of the information system was to 'remove' ourselves from our research environment so as to be able to design a model which would be valid whoever was doing the search.

When designing the model we examined the methodology of the survey, other examples of archaeological data formalisation, and the norms for recording archaeological data established by the Central Institute for Catalogues and Documentation . The alphanumerical database manages the data and the documentation of excavations and surveys.

Since we wanted to cover all aspects of archaeological research, we also included in the database the epigraphical, numistical and bibliographical sources. We also recorded the municipalities where the research was carried out, divided into surveys or excavations.

For the excavations, the actual excavation zones, the SUs and the finds are included. The survey is recorded by making a distinction between TUs and SMs; the TUs also have the chronology recorded. The finds (both from excavations and surveys) are divided into numismatics, pottery, metal and terracotta objects, architectonic, and various (a class including a set of objects with the same characteristics).

Each class of finds also contains a section with drawings and photographs. The base cartography is on a 1:25000 scale of the IGMI (Geographical Military Institute) in raster and vector format. There is also detailed technical cartography produced by Local Gouvernment and with a 1:5000 scale, which is normally used on site for surveys.

3.2 Georeferencing

One of the particular characteristics of archaeological research is without any doubt its connection to the geographical territory seen as the environment where man chose to live. Precisely for this reason, GIS has become a frequently used tool for managing and analysing archaeological data.

To improve the georeferencing of finds, during our last survey at Kaulonia, we used a GPS receiver to record the TUs. Using a GPS is much more precise than traditional methods consisting of manually recording on paper evidence at the moment when it is found, then digitalizing it via video in the lab. In addition, with the GPS we recorded all the grottos caves found during the survey with all the possible traces of human settlement.

In the future we intend to use the receiver not only for recording evidence, but also to use some cartography on site that we would otherwise not have available during the survey itself (traces by aerial photos, sites already identified by other on-site research, the walls of Kaulonia, etc).

3.3 Spatial-temporal reseasoning

As described by Stine and Lanter in "Interpreting space: GIS and archaeology", one can imagine an archaeological database as a three dimensional object. The first dimension corresponds to the features (finds, TUs, excavation areas), the second to their attributes, and the third to the chronology that the individual features have.

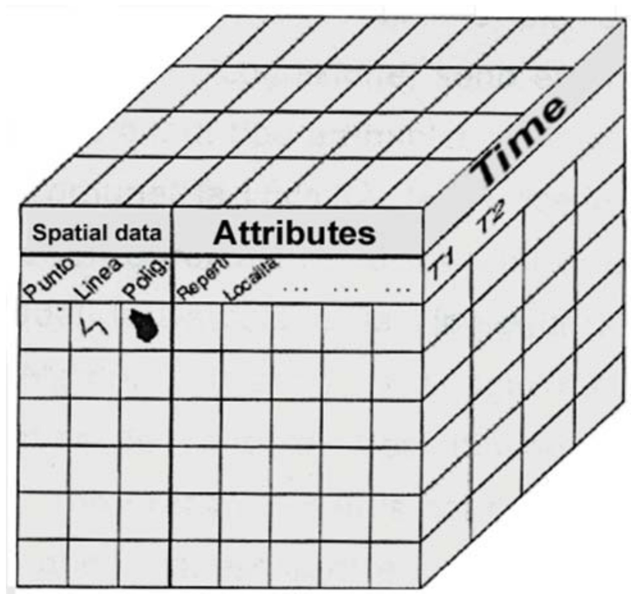

Fig. 1 An archaeological database

The chronological data are determined by the often problematic management of an archaeological archive. The main difficulty is inherent in the methodology used by archaeologists to date the finds. The finds are dated using morphological comparisons with classes and serations of similar materials from known contexts. This type of dating prevents us from defining a minimum unit of time (one kronon), nor can we have dates which are 'certain'. In most cases there are datings represented by time intervals that are very uncertain, in fact rather vague expressions such as 'the end of the third century before Christ' are used. Moreover, in other cases, such time intervals are identified with cultural periods (eg the Hellenistic age) which do not correspond to an age which has a chronologically defined beginning and end, and nor are they universally valid.

If it is already difficult to implement a temporal dimension in an information system, it is even more so if the chronological date is the result of those methods of dating which do not have either a fixed unit of measure or limits which are certain. For excavations we can have other data (eg historical sources make reference to the site in question) which help us to understand the chronological horizon of the site. However, in an archaeological survey, the finds made on the surface belong to different contexts and often represent the only trace of the settlement, thus becoming the only means for dating the 'site'. Furthermore, such areas of archaeological materials may have a discontinuous life for a wide arc of time. For example, we may have surface finds from prehistoric and medieval times without having any trace of the intervening period. So we cannot assign a site with a chronology that has just one beginning and end, but rather we should assess individual intervals of existence.

For this reason, it was necessary to define the temporal component of such areas by using one or more 'periods', each of which with a beginning and an end. Since the materials brought to light do not allow us to make an exact dating, these periods of life are further characterised by an 'uncertainty' which is symmetrical to the beginning and end, expressed in years (each period will be defined by a "Beginning" ± x and by an "End" ± x).

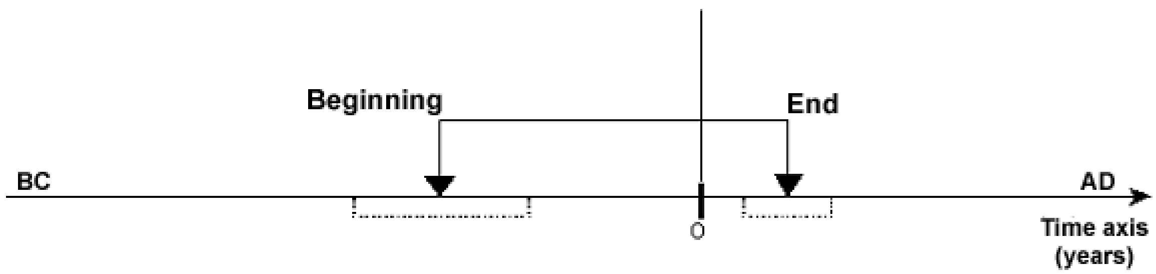

Fig. 2 Chronology

Using this method we can represent any dating, irrespectively of its precision and with a unit of measurement, a year, which corresponds to the minimum unit of measurement in the dating of archaeological finds. By combining the time periods of the settlement with the quantitative data of finds it is also possible to understand how intensely each site was used during each period.

This system of representing the temporal component can also be applied not only to finds but also to historical events. Historical data don't require a division into those which occurred either at a particular moment within a net interval (ie with a precise date, eg battles, or wars with a known beginning and end), or gradually (eg historical phenomena that began slowly or with transition phases, with an uncertain beginning and end). What does vary, however, is the type of 'period' that describes them. In the first case, the chronology of the event will be described by a period with a beginning and end that coincide and that have no uncertainty. In the second case, the beginning and end will be different, but with no uncertainty. The gradual events can be described by one or more periods with uncertainties that indicate transition periods.

Alongside this system we still use a traditional dating system for cultural periods. The period is chosen from a predefined list of words. This was necessary since for archaeologists this is the most straightforward dating system from which they can then proceed to a more accurate analysis of the finds. Each cultural period is delimited by numerical dates defined on the basis of the events that are commonly considered to represent cultural change in the Mediterranean area, and in some cases, in the actual location where we carried out our research (Magna Graecia and Sicily).

4. System architecture

The difficulty in predicting and analysing the data sources, along with the need to leave the door open to new data with different typologies, led us to design a system with two main requirements:

- Open architecture
- Interoperability

An architectural model was designed that is not constrained by an individual application to a survey campaign and, as far as possible, not constrained by methods used on the field either.

Analysing the data available was only the first step towards an understanding of the thematic domain in order to be able to identify and design a conceptual model of the database, leaving ample room for integrating any further data.

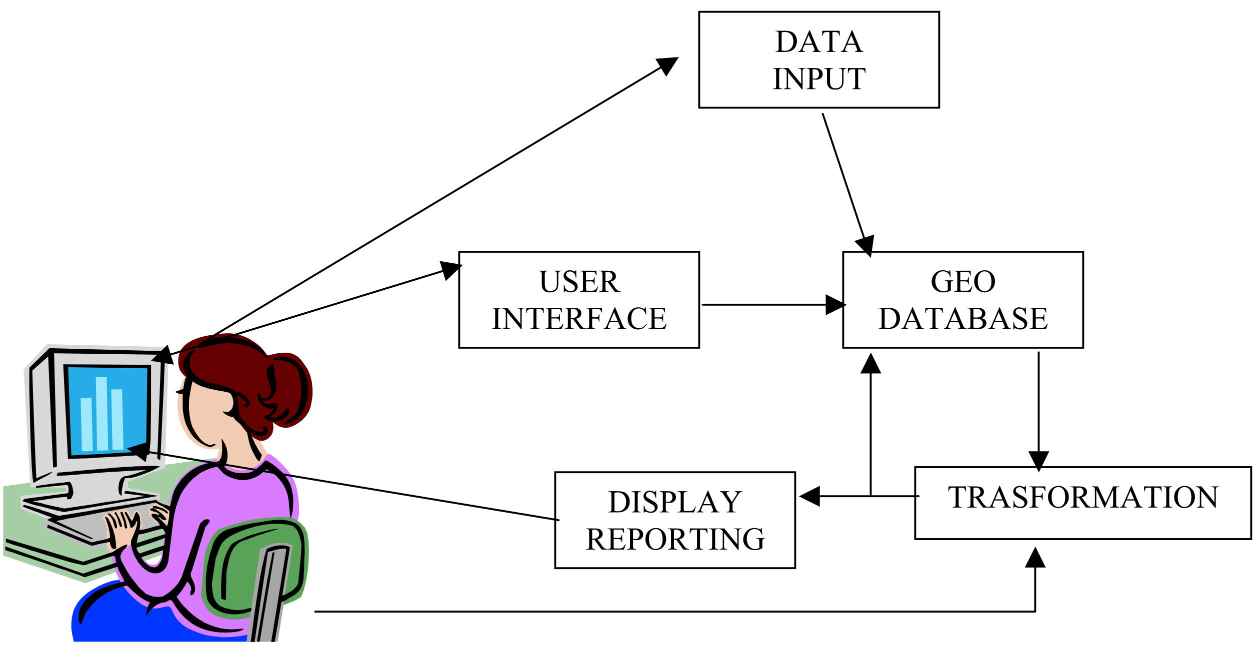

Fig. 3 The main software components of a geographical information system (Barrough, 1998)

The best architectural solution also takes into account how much has already been done in terms of computerization of archeological data, thus allowing for integration with relational databases outside the system.

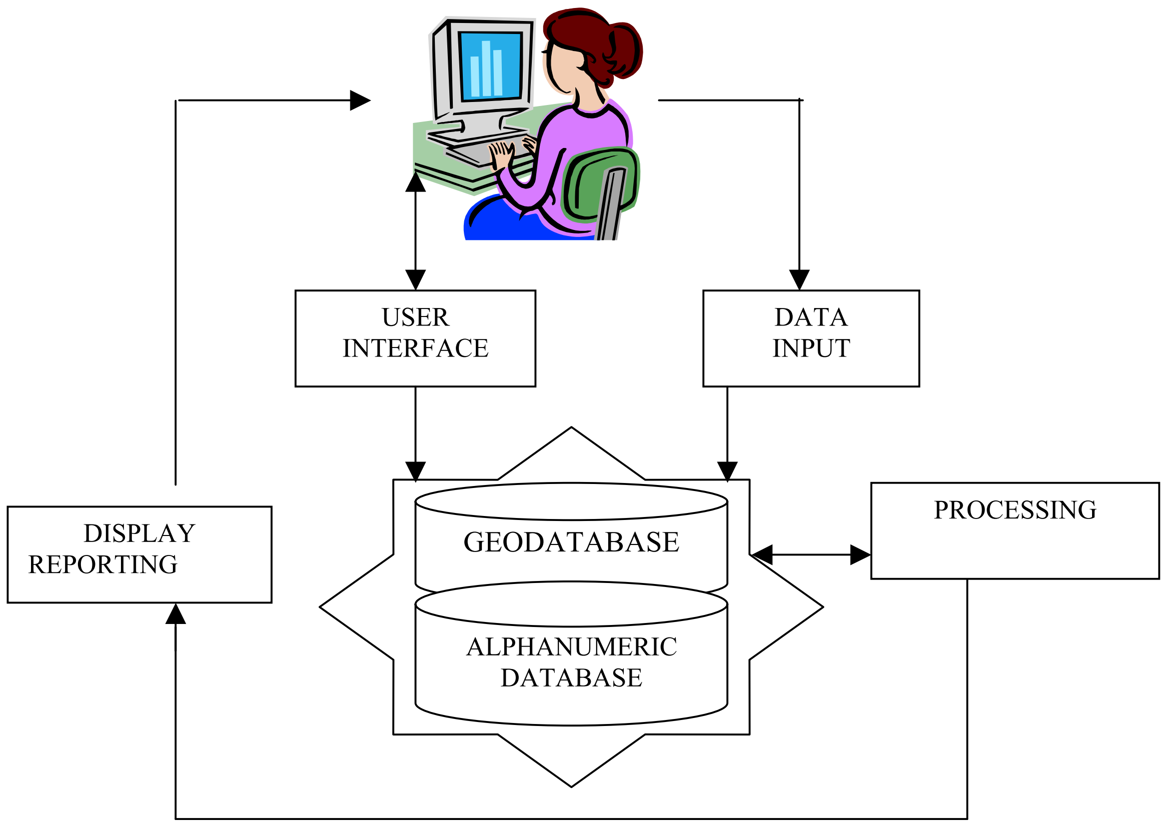

Fig. 4 The main components of an Archaeological GIS

Current GIS technology allows one to build a system that can be interfaced both with different types of software (eg CAD) and with non proprietary format.

The geodatabase is the heart of the system (Figure X). The GIS bases its own efficiency on the data contained in the geodatabase and on the conceptual model which described the types of data and their relationship during the design phase.

In the specific case of this application to the field of archaeology, the geodatabase is just one of the databases with which the system is interfaced.

The need to integrate information stored in different databases, both for the conceptual model and for the software with which they have been built, is thus one of the main driving points.

The system was implemented with ARC Gis 8.1 and can be integrated with Access and Excel databases.

ArcGIS is a complete, single, integrated system for geographic data creation, management, integration, and analysis. It provides flexibility when configuring a system since it is modular and scalable.

ArcGIS consists of ArcView, ArcEditor, ArcInfo, ArcIMS, and ArcSDE. ArcGIS extends ArcView by providing multi-user editing, advanced analysis, Internet services, and high performance spatial database services.

It was precisely modularity that led to it being chosen. In fact, while the developer has all the platform, the end user will only be able to use the displayer, with considerable savings in cost.

The result of two queries made to the database in ArcGIS is shown below. In the first (Fig. 5) we selected all the topographical units containing the class of ceramics known as ‘Terra Sigillata Africana’. This is a class of Roman pottery, which was very common from the second half of the second century BC to the end of the fifth century AD.

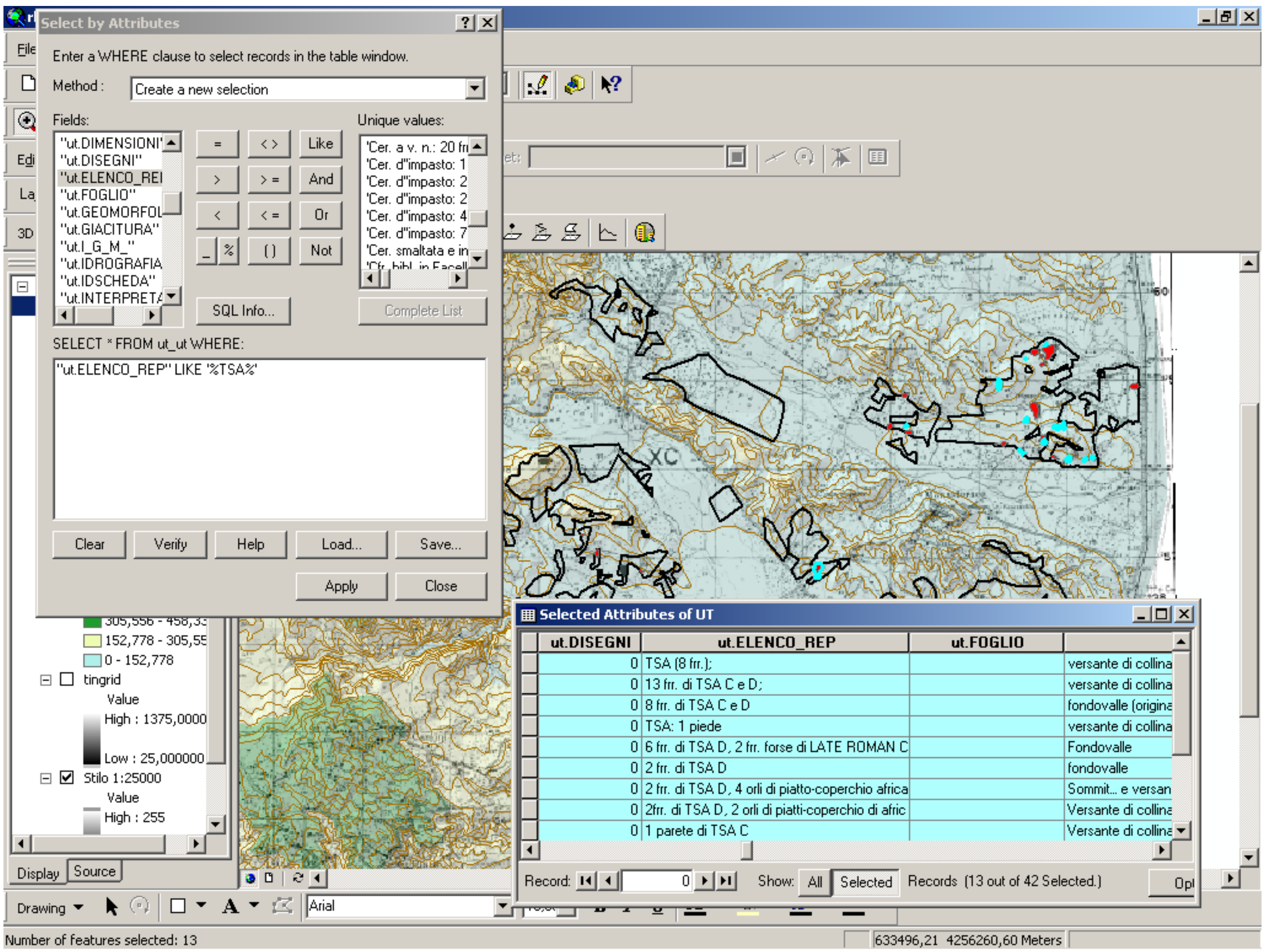

Fig. 5 Topographical units containing the class of ceramics known as ‘Terra Sigillata Africana’

In the second figure (Figure 6) we made a query on coarse ware (which was typical in prehistory). The system returns both a table and a thematic map which displays a subset of topographical units on the basis of the class of the finds.

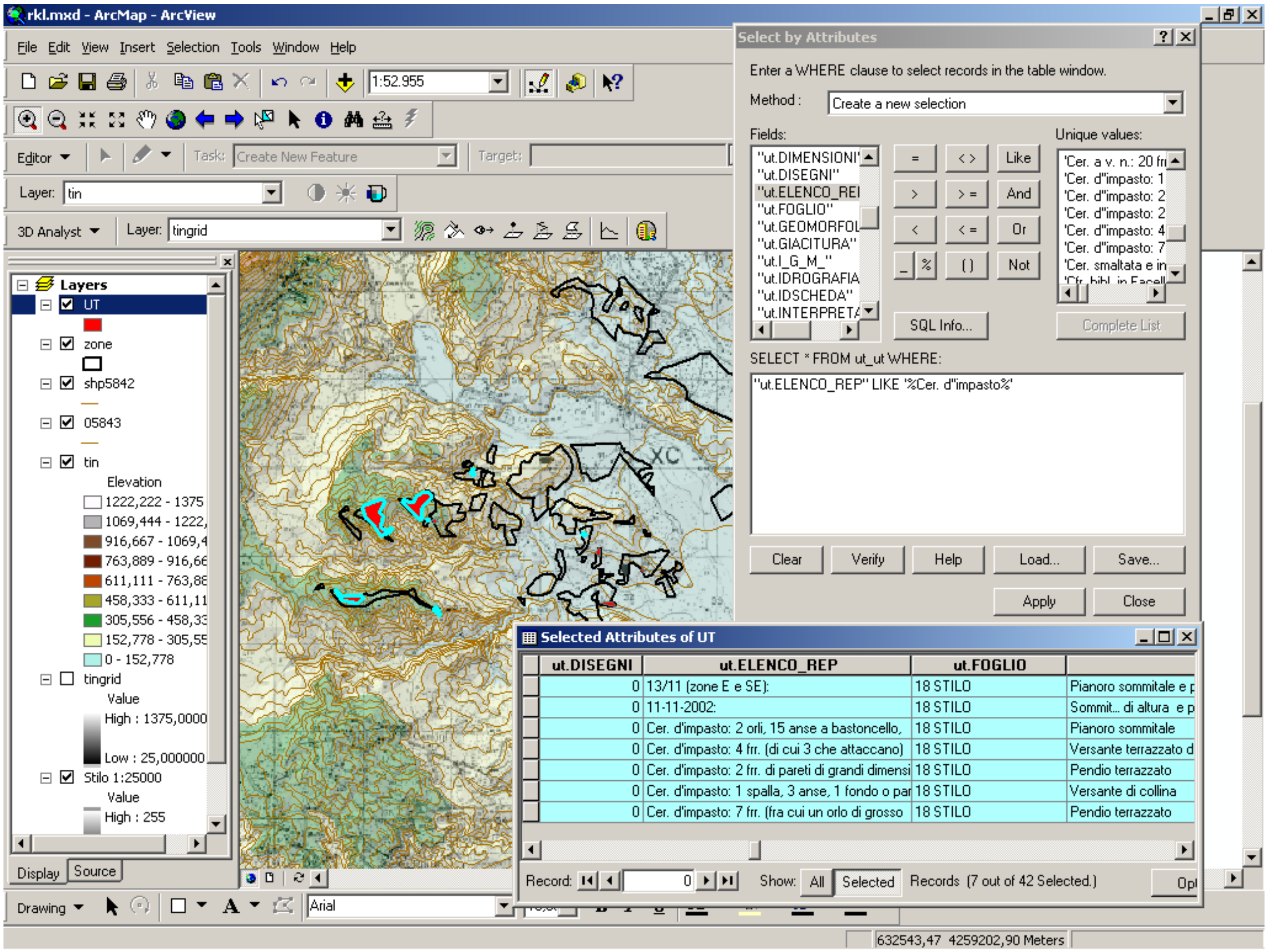

Fig. 6 Coarse ware

5 Future work

In archaeology GISs are used above all to produce maps: maps showing the distribution of artefacts in terms of excavations and surveys, maps showing the distribution of the sites in terms of surveys. Archaeologists have always wanted to understand the spatial relationships between archaeological objects. In fact, the study of archaeological stratigraphy is none other than the analysis of spatial relationships between anthropic deposits. Archaeology has always used spatial statistical analysis to study human settlements, in fact there is much literature on statistical analysis in archaeology. The use of statistical techniques has evolved with the introduction of GISs. This has meant that vast quantities of data could be managed and new geostatistical analyses could be applied.

As far as infrasite analysis is concerned, a new approach to studying ancient sites is to formulate settlement patterns by creating a model of the site based on the features of presences on the surface revealed during surveys and on environmental data that may have conditioned the settlement. The next step is to apply this pattern to areas that have not yet been investigated. Maps can thus be produced which predict the areas where archaeological sites are most likely to be located. Such tools are particularly useful for planning public works that are likely to significantly affect a particular locality.

We are currently studying the feasibility of integrating an archaeological data system with an expert system so as to formulate a ‘model of finds’ relating to the various classes of materials. In the design of such a model we will take into consideration archaeological data and other ‘environmental’ factors (nearness to water, altimetry, distance from water supplies) shown on modern maps. The next step, which would require a higher level of archaeological analysis, is to formulate ‘settlement models’ for chronology. To develop such models we will need to create cartography which shows the morphological features which would have been present at the time the site was used in a particular historical period, in order to understand what environmental factors led man to choose that site for a settlement.

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GLOSSARIO

From the Southeast Archeological Center Website (http://www.cr.nps.gov/seac/seac.htm)

Coarse ware: this represents the first technological level reached by the community in protostoric Italy. It is characterised by recipients modelled by hand in mixed clays and other elements.

Archaeological evidence: any trace material that identifies an ancient human presence in a particular location.

Terra Sigillata Africana: pottery used for eating purposes, characterised by quite a fine fabric and by being compact, and a red orange outer surface. The name derives from sigillum (Latin for 'seal' and a sort of brand) used by ateliers and potters.

ARCHAEOLOGICAL CONTEXT: The physical setting, location, and cultural association of artefacts and features within an archaeological site.

ARCHAEOLOGICAL SITE: A location where human activities once took place and left some form of material evidence behind.

ARCHAEOLOGY (also spelled **ARCHEOLOGY**): The scientific study of the physical evidence of past human societies recovered through collection, artefact analysis, and excavation. Archaeologists not only attempt to discover and describe past cultures but also to formulate explanations for the development of cultures. Conclusions drawn from study and analyses provide answers and predictions about human behavior that add, complement, and sometimes correct the written accounts of history and prehistory.

CULTURE: Common beliefs and practices of a group of people. The integrated pattern of human knowledge, belief, and behavior that depends upon man's capacity for learning and transmitting knowledge to succeeding generations.

EXCAVATION: Digging up and removing artefacts and features from an archaeological site in order to analyze and predict past human behavior.

SITE SURVEY: A non-intrusive method of observing a site without excavation. There are many types of surveys, including pedestrian walkovers, controlled collection, and a number of remote sensing procedures such as resistivity, magnetic, radar, side-scan sonar, and metal detection surveys. These surveys allow archaeologists to "see" a buried site or feature without disturbing the ground and guide any needed follow-up investigations such as test excavations, block excavations, and other kinds of data retrieval.

SERIATION: Technique in which artefacts are dated relatively to each other without any strict assigning of age.

STRATA: The layers of sediment or rock revealed after excavation or through natural weathering.

STRATIGRAPHY: The study of layers sequentially deposited over time. This is very helpful for land archaeology. Under water, it can also be useful, but it is more complicated and often confusing because of current and sea movement.

TOPOGRAPHY: Study of land features at a site. This can be useful in determining the potential of an archaeological site for excavation.