GIS Applications in Archaeology: Case Studies from Troy

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Introduction

For more than 130 years archaeologists have been excavating at the famous site of Troy (northwestern Turkey). Of course archaeology has changed since the 19th century, when Heinrich Schliemann attempted to discover the reality behind the myths and legends of the Trojan war, immortalized by Homer's epics. Since 1987 -more than a hundred years after Schliemann - scholars and scientists join efforts in an interdisciplinary project at Troy under the direction of Manfred Korfmann (Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, Universität et Tübingen, Germany) with different aims: They study the development of the site and the surrounding landscape from the beginnings of human settlement in the Neolithic to the present day - history, the evolution of the natural environment, and the interaction between between human societies and their environment (Korfmann ed., 1991-2004). Since Troy draws large numbers of tourists, and has been declared both a UNESCO world heritage site and the center of a "Historic National Park", archaeologists must also develop skills as cultural resource managers. Helping to protect the area and presenting the site to the public has become increasingly important.

Thus work at Troy has evolved into a typical regional archaeological project. Within this framework, Geographic Information Systems (GIS) have been used since the year 2002 to meet different needs from studies of the landscape at a regional scale down to a detailed analysis of the archaeological stratigraphy.

Landscape level: The Troad

While previous research was focused at the site of Troy itself, the surrounding landscape - since antiquity known as the Troad - has now become increasingly important both as a field of research and as a rapidly developing region containing fragile cultural and natural resources (figure 1).

Studying landscapes at a regional scale leads to a classic and straightforward GIS application, based on a collection of thematic map layers. The main task here is to develop thematic base maps, and add whatever information becomes available to facilitate research and planning.

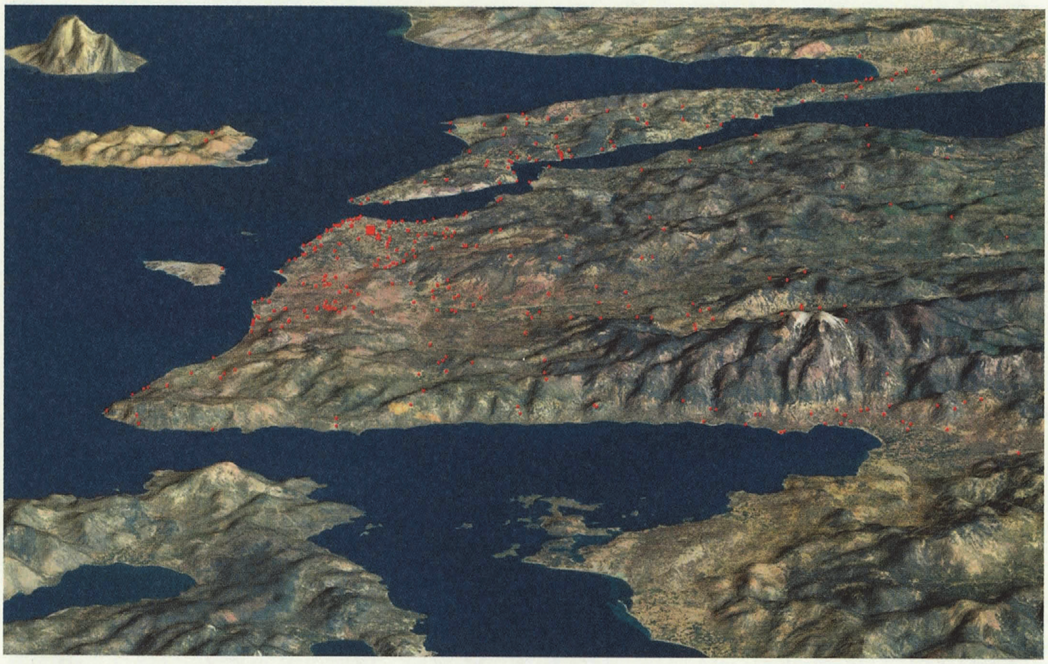

Figure 1 The Troad. 3d image created by draping Landsat TM images on GLOBE elevation model. Red dots are archaeological sites

Suitable, near-world-wide data for the creation of base maps is now available online at no cost. However, detailed, large-scale map layers must still be derived "by hand" from all available sources or obtained at high cost. In Turkey, as in several other countries, detailed maps are a military secret and will only be available for internal use, if at all.

Local excavation coordinate systems for Troy and other sites as well as several fixed points have been referenced to the WGS-84 world geodetic system with high-precision satellite geodesy (Hartmann 2001). While this remains a task for technical experts, mapping of archaeological sites and other points or areas of interest at regional scale (1:25000 to 15000) can now cheaply and easily be done with simple, hand-held GPS receivers.

The following data has been assembled for the Troad. For each layer, the largest suitable scale or raster resolution and the source are given.

Digital elevation models:
GLOBE (elevation), 30 arc seconds (1 km) (GLOBE Task team and others eds. 1999);
ETOPO2 (elevation, bathymetry), 2 minutes (4 km) (National Geophysical Data Center 2002);
GTOPO-30 (elevation), 30 arc seconds (1 km) (U.S. Geological Survey 1996);
SRTM-3 (elevation) 3 arc seconds (90 m) (U.S. Geological Survey 2004).
Vector data:
VMAP0 (Vector base map), ca. 1:1000000 (National Imaging and Mapping Agency 2000).
Satellite image data:

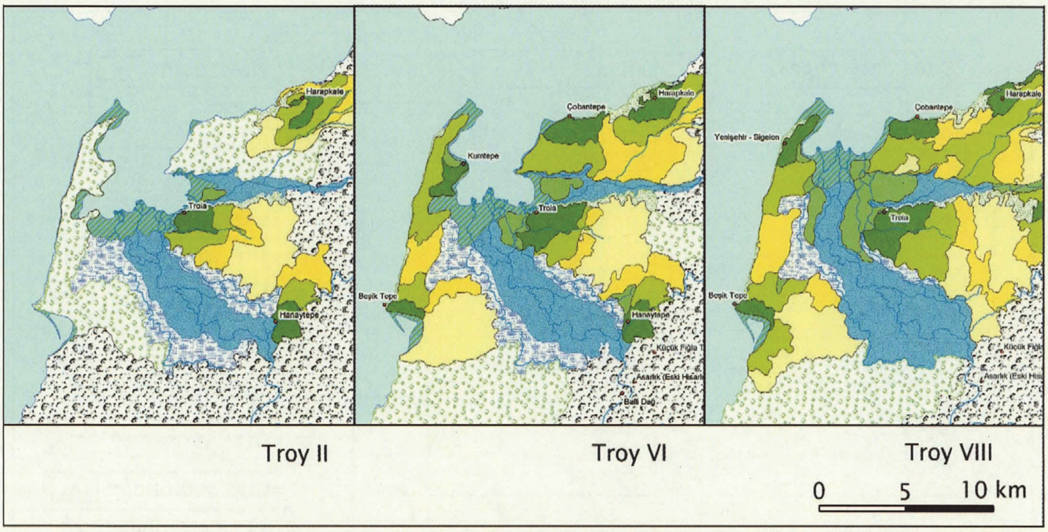

Figure 2 Time slice representations of palaeolandscapes for Troy II (ca. 2300 BC), Troy VI (ca. 1300 BC) and Troy VIII (ca. 300 BC), showing changing coastlines and watercourses, probable land use, and archaeological sites

Landsat5 TM, 28,5 m (U.S. Geological Survey 1984-2004);
Landsat7 ETM+, up to 14,25 m (U.S. Geological Survey 1984-2004);
IKONOS, up to 1 m (courtesy Compton J. Tucker, NASA and Space Imaging, Inc.).
Scanned maps:
Turkish maps, 1:25000, 1:5000 (classified, copies for internal use only);
Geological Map of Turkey, 1:500000 (T.C. Maden Tektik ve Arastirma Enstitütesi 1964);
Historic map of the Troad, 1:25000 (Forchhammer and Spratt 1850).
Research results:
Detailed vector base map from all available sources, 1:5000 (Troy project);
Locations of drill core sites, 1:5000 (Troy project);
Results of detailed hydrological and geological study, 1:5000 (Troy project);
Reconstructed vector maps of palaeoenvironment (3 time slices), 1:10000 (Troy project);
Archaeology, 1:5000 (Troy project, unpublished).

The palaeoenvironment maps (figure 2) consist of a polyline layer with attributes for period (Troy II, VI, VIII) and type (river, coastline), and a polygon layer with attributes for period (Troy II, VI, VIII), type (sea, lagoon, swamp, dry land, ...) and land use (agriculture, forest, ...). These maps are interpretations of the available data which have been drawn consulting the relevant literature and specialists from different fields - geology, palaeobotany - working at Troy.

Figure 3 shows a data model for archaeological sites. It consists of point layers for site midpoints. For each site, features in a polygon (site areas), line (for "sites" like aqueducts or

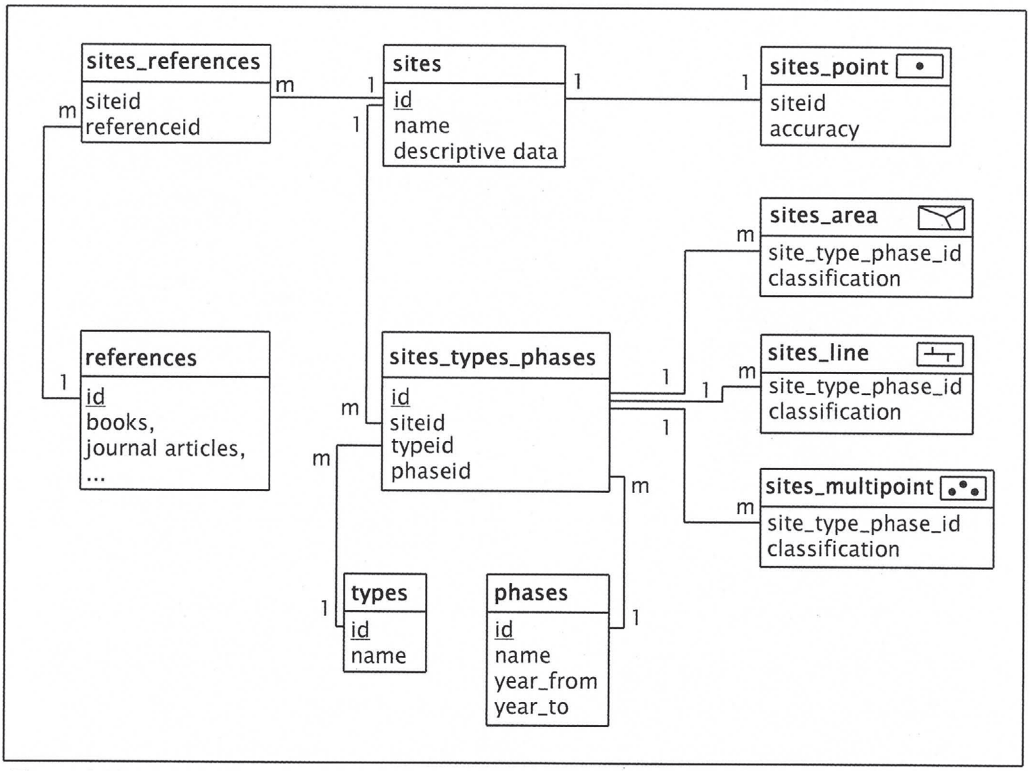

Figure 3 Simplified data model for archaeological sites (entities, GIS entities with geometry indicated as symbol, selected attributes, relationships with cardinality)

ancient roads) or multipoint (for dispersed remains like ancient inscriptions within a site) layer can be present. Attributes specify accuracy and classify site locations and extents (e.g. accuracy 10 meters, maximum extent, derived from surface find scatter). In addition to spatial features, the database consists of several non-spatial tables for sites (names, descriptive information), references (bibliography), site types (e.g. cemetery, settlement, ...), phases (e.g. TroyI, Hellenistic, ...), a list linking sites, site types and phases, and a list linking sites and bibliography. Phases have "from" and "to" attributes in years to add a time dimension. With systems like ESRI ArcView spatial and non-spatial data can conveniently be handled within a single database. Individual types and phases present at any particular site can be filtered, symbolized, or displayed using different styles, colours or symbols (figure 4).

Site level: Troy

For the site of Troy itself another set of thematic layers has been assembled. It comprises modern topography, background 1m resolution satellite image, generalized plans of excavated remains, excavation areas, and gridded data from magnetic prospection.

Since 2002 a systematic surface find collection (archaeological survey) is being carried

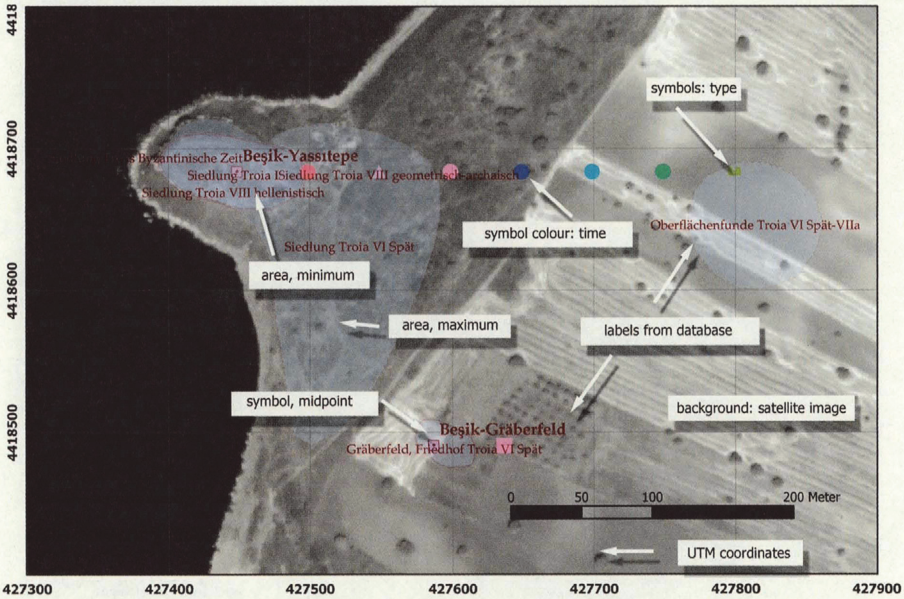

Figure 4 Example GIS map showing background satellite image and archaeological sites, with explanation of symbols

out at Troy. Details of survey methodologies can best be found in Banning (2002). At 20 m intervals all finds from the uppermost 5-10cm of topsoil are collected from 5 m^2 sampling areas. The finds are classified according to find type and phase. Find counts and statistic summaries can then be displayed as dot density distribution maps (figure 5). This is accomplished with the help of another GIS and database application (figure 6). A main table holds descriptive information on sampling points and- redundant but convenient - their coordinates. This is linked to a GIS point layer. Find counts and classifications by type and phase are stored in a related table, which is in turn linked to tables for types and phases.

Site detail: Stratigraphy of Troy

The central mound of Troy consists of 15meters of settlement deposits accumulated over a period of 3500 years. For the past 130 years, the greater part of it has been dug away by archaeologists. Documentation of this work consists of a library of published and unpublished sources. The daunting task remains to bring thousands of excavation contexts into one consistent set of plans, describe and classify them, and devise an ordered chronological sequence with the help of stratigraphic analysis (according to the principles outlined by Harris 1989).

Paper maps and plans from publications are scanned and then digitized. Both plans and section drawings are treated as flat, two-dimensional objects with optional height attribute fields or spot (point) elevations since true 3d data has not been recorded at Troy. All

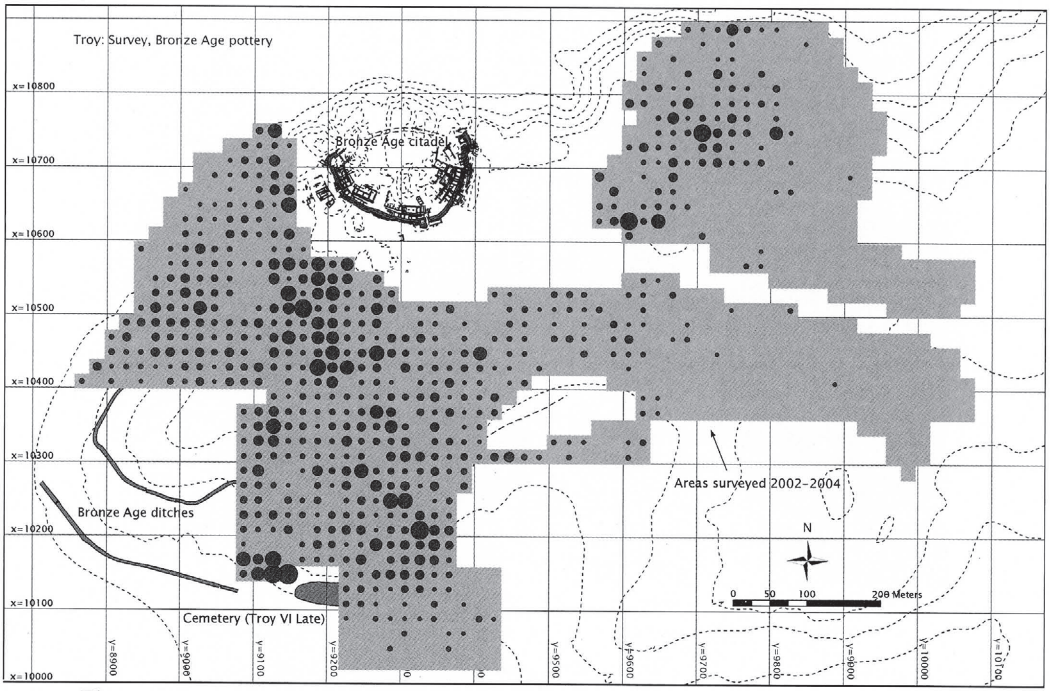

Figure 5 Example dot density distribution map showing Bronze Age pottery scatter at Troy and main buildings as background

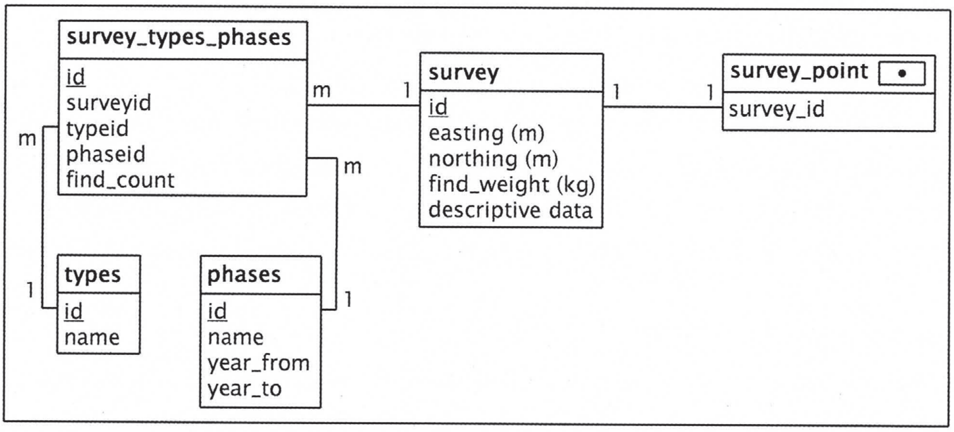

Figure 6 Simplified data model for systematic surface collection (archaeological survey) of Troy

contexts are represented as both outlines (classified into extant, reconstructed, or cut) and areas. In addition, heights or finds can be displayed as points or symbols. Spatial features are linked to a database table describing and classifying (e.g. wall built, wall destroyed, pit fill, street surface; Troy I, Late Bronze Age, ...) contexts. For each context, a list of its stratigraphic relationships is maintained. Valid relationships (according to Herzog 2004) are: "earlier than", "later than", "contemporary with", "equal to", and "part of" (to group contexts, e.g. all walls belonging to one building are "part of" that building). Contexts and

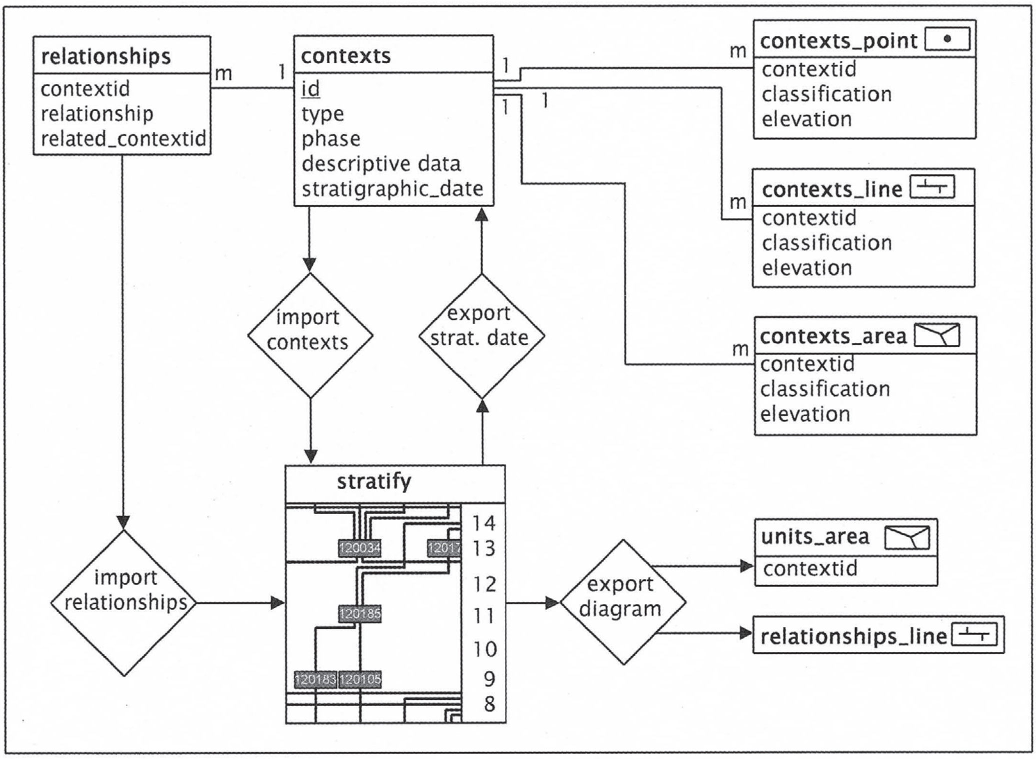

Figure 7 Simplified data model for stratigraphy

their stratigraphic relationships are then exported to a program that performs error and consistency checks, removes redundancies, and calculates the optimal layout of a graph ("Harris diagram") showing the complete stratigraphic sequence ("Stratify" by Irmela Herzog: Herzog 2004a). The vertical position of each context in this graph ("stratigraphic date") is then re-imported into the database. The "Harris diagram" can also be exported to GIS format and linked with the context plans and database.

This system (figure 7) allows for dynamic construction of the stratigraphy of complex sites. Changes and additions can be made as work progresses. After each run of the stratigraphy program contexts are automatically assigned to the current chronological sequence. This will update all phase plans joined with the context database. By visual inspection of plans and section drawings gaps or mistakes are easily detected. In addition, contexts can be filtered, symbolized or colour-coded according to type and phase. The "stratigraphic date" can be used as a pseudo-height attribute to display contexts in order from old (bottom) to young (top) (figure 8). The basic idea goes back to work published by Alvey 1993 and has in part be described in Jablonka (2004).

The future of GIS applications at Troy

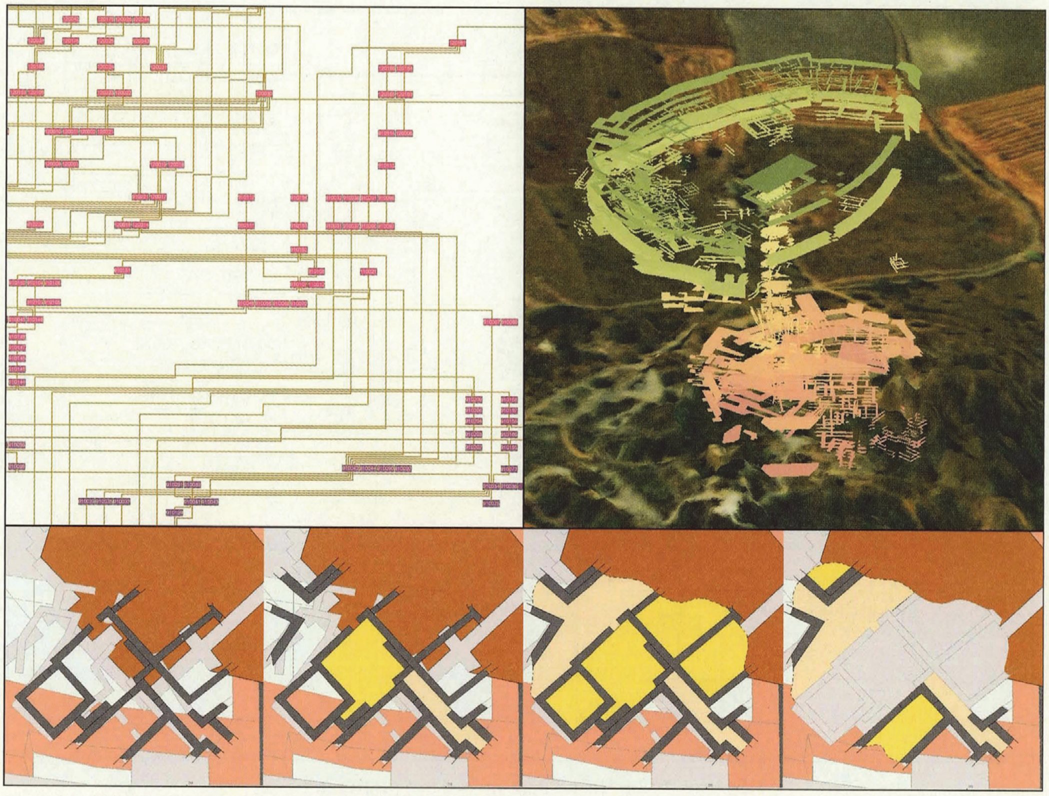

Figure 8 Example output from stratigraphy GIS system, showing part of Harris diagram, pseudo-3d-representation of stratigraphy (bottom = oldest to top = youngest buildings), and automatically generated phase plans (colours: context type, youngest contexts always displayed on top of older ones)

It has been said that creation, checking, editing, and documention of suitable GIS data will consume the greater part of all time spent with any GIS project (Wheatley and Gillings 2002: 59). Consequently, until now GIS work at Troy concentrated on the creaton of a "data rich environment" (Lock 2003: 8-9) to facilitate research and management of cultural resources.

In the future, more sophisticated spatial and geostatistical analysis (Wheatley and Gillings 2002: 165-216) must be applied to data on archaeological sites and on-site find distributions. Predictive modeling and related methods can be used to test hypotheses on site and find distributions and help in managing the cultural resources of the landscape.

Stratigraphy is at present analyzed in the non-spatial part of the database and with the help of a software component external to the system. In theory it is possible to detect excavation contexts sharing a common border, and establish stratigraphic relationships, with a GIS. The ordered stratigraphic sequence and its display ("Harris diagram") can be perceived as a topological network, a concept implemented in several GIS systems. A pure GIS solution to the problem of archaeological stratigraphy seems therefore possible.

An important point is the dissemination of GIS data and results both within the research community and for the wider public. Good practices to deliver and share this information with an audience having little or no expertise in GIS need to be found. There is a wide range of possible ways to achieve this: Printed or online publication of maps and data in non-GIS formats, distribution of GIS maps and data with a viewer software, or online map servers.

The future of GIS in archaeology

Archaeologists will probably never fully utilize the whole array of techniques and functions any modern GIS software package has to offer. As far as spatial analysis is concerned, only a fraction of the possibilities of any standard GIS package have been explored by archaeologists. Nevertheless there are inherent limitations in the extent GIS can be used within archaeology due to the fact that GIS technology is not tailor-made for archaeologists, but has been developed for other fields and purposes.

Very prominent on any archaeologist's "wish list" of additional GIS functionality are full 3d capabilities. GIS packages are attempts to translate the concept of a map - not a view of our planet as a sphere, or three-dimensional coordinate space - into a computer system. At present, most GIS systems must therefore still be called "2.5d". Heights can be represented as an attribute field, vector features can be given one height for the feature as a whole or draped over a surface representing topography. Simple surfaces, e.g. terrain models, are usually supported both in raster format and as polygon meshes. However, this does not allow for 3d-representations of complex shapes like the outlines of archaeological layers, not to speak of the interior of a cave, or 3d-models of buildings. On the other hand, 3d-modeling software lacks essential GIS functionality like geographic reference frames and projections, or database links. Consequently, a large collection of 3d reconstructions of Troy (Jablonka et al. 2003) can at present not be integrated with GIS applications.

To fully integrate 3d-data into GIS software the concept of a two-dimensional pixel raster can be extended to a three-dimensional "voxel" volume (Barcelo et al. 2003). Attempts to tackle similar problems in geology - the modeling of complex geological layers - might be of interest here (GOCAD 2004). Surfaces of three-dimensional shapes of arbitrary complexity can also be represented as polygon meshes, as most 3d modeling software does. With the arrival of new technologies for 3d data acquisition - 3d laser scanners, image-based devices - there will be an increasing need for software to process large amounts of 3d data. Depending on the application, archaeologists need to work both with raster and vector representations of three-dimensional objects.

It is frequently remarked that GIS lack a time dimension, whereas archaeological information needs to represent both space and time. However, it is relatively straightforward to give GIS entities and other data a time attribute, and to calibrate different time scales, for instance archaeological phases, into years. The issue of time can therefore be addressed at the level of data models and analysis design. There is not necessarily a need for new technology here, although "temporal" GIS solutions are currently being developed in several areas (for example, analysis of traffic flow, or tracking of objects in time and space).

Every GIS application needs to publish GIS datasets and provide spatial information to non-expert audiences. Both this issue and the time dimension of GIS are addressed in an exemplary manner by the TimeMap system (developed by Ian Johnson: TimeMap 2004). However, this system requires users to download and run a Java applet, and register data with a central metadata clearinghouse. Although this seems like a small price for what it does, many archaeologists will prefer a "thin client" approach to provide online access to their own GIS data stored on a server, assuming that users will not install or run any software apart from their web browsers on client machines. Here GIS users who are not willing or able to purchase a proprietary, commercial product are at present left with programming their own solution around the University of Minnesota map server (MapServer 1996-2004). Simple, as far as possible ready-to-use, browser-based interfaces to GIS data using open source software on the server side would certainly be welcomed.

Here and in the area of desktop GIS open source software and open data formats are becoming increasingly important. Even commercial GIS companies seem to move from being software vendors to becoming data and service providers. It will be hard for any archaeological project to sustain funding of software licenses and computer hardware over a longer period of time. Most commercial software supports data export to open, published formats. Long-term data storage should make use of such formats, and deposit data (including metadata and documentation) with reliable institutions such as a university computer center or library.

Bibliography

Alvey, Bryan A.P. 1993. Interpreting archaeology with Hindsight. The use of three dimensions in graphic recording and site analysis. In: Harris, Edward. C., Marley R. Brown and Gregory J. Brown eds. *Practices of Archaeological Stratigraphy*. London - San Diego: Academic Press. 218-228.

Banning, E.B. 2002. *Archaeological Survey*. Manuals in archaeological method, theory, and technique. New York: Kluwer Academic/Plenum Publishers.

Barcelo, Juan A., Oscar de Castro, David Travet and Oriol Vicente. 2003. A 3D Model of an Archaeological Excavation. In: In: Doerr, Martin and Apostolos Sarris. *CAA 2002. The Digital Heritage in Archaeology. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 30th Conference, Heraklion, Crete, April 2002*. Athens: Hellenic Ministry of Culture. 85-89.

Forchhammer, Peter W. and Thomas A.B. Spratt. 1850. B*eschreibung der Ebene von Troia mit einer Karte* *von T. A. B. Spratt*. Frankfurt am Main.

GOCAD. 2005. GOCAD Project. *An original approach for geomodeling*. URL: http://gocad.ensg.inpl-nancy.fr/ [Accessed: 2005-01-11]

GLOBE Task Team and others (Hastings, David A., Paula K. Dunbar, Gerald M. Elphingstone, Mark Bootz, Hiroshi Murakami, Hiroshi Maruyama, Hiroshi Masaharu, Peter Holland, John Payne, Nevin A. Bryant, Thomas L. Logan, J.-P. Muller, Gunter Schreier, and John MacDonald) eds. 1999. *The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0*. National Oceanic and Atmospheric Administration, National Geophysical Data Center, Boulder, Colorado, USA. URL: http://www.ngdc.noaa.gov/seg/topo/globe.shtml [Accessed: 2005-01-11]

Harris, Edward C. 1989. *Principles of Archaeological Stratigraphy*. 2nd edition. London - San Diego: Academic Press.

Hartmann, Christian. 2001. *ITRF-basierter Aufbau und Integration präziser archäologischer und geowissenschaftlicher Grundlagennetze*. Civil engineer thesis, Technical university, Karlsruhe.

Herzog, Irmela. 2004. Group and conquer. A method for displaying large stratigraphic datasets. In: Magistrat der Stadt Wien - Referat Kulturelles Erbe - Stadtarchäologie Wien ed. *Enter the Past. The E-way into the Four Dimensions of Cultural Heritage. Proceedings of the 31st CAA (Computer Applications and Quantitative Methods in Archaeology) conference, Vienna, Austria, April 2003*. BAR International Series 1227. Oxford: Archaeopress. 423-426.

Herzog, Irmela. 2004a. Stratify. Check and Layout of Stratigraphic Data. Version 1.3. URL: http://www.stratify.privat.t-online.de/ [Accessed: 2005-01-11]

Jablonka, Peter. 2004. Reconstructing sites and archives: information and presentation systems at Troy. In: Magistrat der Stadt Wien - Referat Kulturelles Erbe - Stadtarchäologie Wien ed. *Enter the Past. The E-way into the Four Dimensions of Cultural Heritage. Proceedings of the 31st CAA (Computer Applications and Quantitative Methods in Archaeology) conference, Vienna, Austria, April 2003.* BAR International Series 1227. Oxford: Archaeopress. 281-285

Jablonka, Peter, Steffen Kirchner and Jordi Serangeli. 2003. TroiaVR: a virtual reality model of Troy and the Troad. In: Doerr, Martin and Apostolos Sarris. *CAA 2002. The Digital Heritage in Archaeology. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 30th Conference, Heraklion, Crete, April 2002.* Athens: Hellenic Ministry of Culture. 13-18.

Korfmann 1991-2004. *Studia Troica*. Vol. 1-14. Mainz: Verlag Philipp von Zabern.

Lock, Gary. 2003. *Using Computers in Archaeology*. Towards Virtual Pasts. London - New York: Routledge.

MapServer. 1996-2004. University of Minnesota. URL: http://mapserver.gis.umn.edu/ [Accessed: 2005-01-12]

National Geophysical Data Center (NGDC). 2001. *ETOPO2 Global 2'Elevations*. Boulder, Colorado: NGDC. URL: http://www.ngdc.noaa.gov/mgg/global/relief/ETOPO2/ [Accessed: 2005-01-11]

National Imaging and Mapping Agency. 2000. *Vector Map Level 0 (Digital Chart of the World)*. 5th edition. Bethesda, Maryland: NIMA. URL: http://www.geoengine.nima.mil/geospatial/SW_TOOLS/NIMAMUSE/

webinter/rast_roam.html [Accessed: 2004-11-26]

T.C. Maden Tektik ve Arastirma Enstitütesi [Republic of Turkey, Insitute of Mineral Research and Exploration]. 1964. Türkiye Jeoloji Haritasi [Geological Map of Turkey]. Izmir; Denizli. Ankara: Harita Genel Müdürlügü.

TimeMap. 2004. *TimeMap*: Time-based Interactive Mapping. URL: http://timemap.net/ [Accessed: 2005-01-11]

U.S. Geological Survey. 1984-2004. *Landsat ETM+, TM*. Sioux Falls, South Dakota: USGS. Data Source: Global Land Cover Facilitiy. URL: http://www.landcover.org [Accessed: 2005-01-11]

U.S. Geological Survey, EROS Data Center Distributed Active Archive Center (EDC DAAC). 1996. *GTOPO30 - Global Topographic Data*. Sioux Falls, South Dakota: USGS. URL: http://edcdaac.usgs.gov/gtopo30/gtopo30.asp [Accessed: 2005-01-11]

U.S. Geological Survey. Reprocessing by the GLCF. 2004. *3 Arc Second SRTM Elevation, Reprocessed to GeoTIFF*. Version 1.0. College Park, Maryland: Global Land Cover Facility. URL: http://www.landcover.org [Accessed: 2005-01-11]

Wheatley, David and Mark Gillings. 2002. *Spatial Technology and Archaeology*. The Archaeological Applications of GIS. London - New York: Taylor & Francis.

考古学におけるGISの応用：トロイの事例

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トロイ戦争で有名なトロイ遺跡（トルコ北西部）は世界でも最も有名な遺跡の１つで，その発掘は19世紀にまでさかのぼる。1987年、この遺跡に関する大規模な考古学プロジェクトが組織され、周辺地域から遺跡内にいたるような様々な空間のスケールでGISが適用された。こうした背景もあり、トロイ遺跡での事例を紹介することは、研究の問題を明確にでき、また考古学研究にGISを応用しようとしている人々にとっても有意義だろう。

景観研究は，主題図集成に基づいた比較的簡単なGISの応用へと導く。トロイ遺跡では、基本図の利用が難しかったため、リモートセンシングデータ（衛星画像とDEM）から主題図が作成された。遺跡はGPSによって位置情報が取得され、点や区画あるいは他の幾何学的な形状としてデータ化された。遺跡の立地と範囲に関する精度と確度については属性データ項目に格納された。

以上のような多様な情報や属性をあつかうため連携データベースを構築した。例えば、ある１遺跡でも、新石器時代の集落、青銅器時代の墓域、ローマ時代の市域などが見出される。この連携データベースでは、その１遺跡について、遺跡の種別、期間（時期)、組み合わせなどと幾何学的な形状を結びつけ、相互に参照できるようになっている。考古学的な時代や時期については、時間属性をすべてのGIS内の遺構情報に簡単に関連させ、その遺跡のおおよその存続期間を地図化できるよう構築した。

分析においては、遺跡景観と現在の景観とを比較する必要がある。そのため、GISには各地点のボーリングコアから知ることができる景観の変化に関するローデータを格納し、“時間スライス”という時系列での異なった地点情報を利用して古景観地図を再構築した。

また、トロイ遺跡についてはもう１つの主題図レイヤーのセットが構成された。この主題図セットは、地球物理調査（地磁気探査）や調査区概要、最重要建造物の一般的な平面形状情報などから得られた詳細な地形情報が格納された。トロイ遺跡で実施された組織的な表面採集の結果については、他の連携データベースとGISアプリケーションによって処理される。異なった遺物の検出地点の頻度分布図なども容易に地図化、解析され、他の遺構や遺物などとの比較が可能となる。

さらに、本遺跡のように複数の文化層で形成される場合、個別の発掘調査成果

に焦点を合わせるには、複雑な層位を組み立て記述できるような非標準的GISソリューションが必要となる。基本的な発掘成果は、主に平面図・断面図と紙に記載された記録から成り立っており、これらは発掘のコンテクストに関するGISの平面図と断面図に変換される。これらの幾何学的なオブジェクトはコンテクストデータベースと、いわゆるハリス・マトリクス・ダイアグラムなどの層位を計算するプログラムと関連づけられる。各コンテクストに関わる垂直方向での位置づけもデータベース内に格納される。これにより、調査が進み新しいデータが入力あるいは古いデータが改変されるのに連動して、各遺跡時期の平面図は自動的に生成・改変される。もちろん、コンテクストについても、種別や時期、機能などの様々な属性により同じようにフィルタリングされる。また、それらの座標系によるデータベースに格納された発見物も各種の平面図にプロットすることができる。また，層位もコンテクストとの連携で表現できるので、ネットワークトポロジーを利用したGISソリューションが可能となる。

一方、データを集成し構造化することから空間分析へと進むことはGIS応用の目的である。だが、経験的には、GISに投資されたすべての時間と労力の大部分は、データの作成、維持、分類などに費やされるにちがいない。おそらく考古学者は、提供されているGIS技術のすべての機能を完全に使いこなすことはないだろうが、別にGISは考古学にとって特別あつらえなものでもないことも事実である。以下は、ある考古学者のGISの機能性について追加して欲しい「要望リスト」である。

－完全な３D機能

ピクセルラスターデータの拡張として３Dボクセル、また３Dラインやポリゴン、メッシュなどを扱える３D幾何ベクターデータなどが処理できるもの。これはGISを使った３Dの再構築の統合のためにも、考古学上の層位構造などの表現、あるいは近代的な測量機器（３Dレーザースキャニング）からのデータインプット処理のためにも必要である。

－時間GISソリューションへの時間データのよりよい統合技術

－異なった精度レベルのデータを取り扱う機能

例えば、異なったスケールの地図を利用するような場合。このようなものをうまく編集したり、自動化したりするような機能はまだ実装されている例は少ない。

－専門家以外に対するデータに富んだGISアプリケーションを公開する簡単なツール

例えば、ブラウザベースのユーザーインターフェースなど。より広くそして容易に利用可能になるべきだろう。