The Aksum Project (Ethiopia): GIS, Remote Sensing Applications and Virtual Reality

Maurizio Forte

CNR-ITABC, Institute of Technologies Applied to Cultural Heritage
Via Salaria km.29, 300 C.P.10, 00016 Monterotondo St., Roma, Italy
e-mail: maurizio.forte@mlib.cnr.it

Kathryn A. Bard

Boston University
Boston University 675 Commonwealth Ave. Boston, MA 02215, USA
e-mail: kbard@bu.edu

Rodolfo Fattovich, Monica Foccillo, Andrea Manzo and Cinzia Perlingeri

Istituto Universitario Orientale, Dipartimento di Studi e Ricerche su Africa e Paesi Arabi
Piazza S. Domenico Maggiore 12, 80134, Napoli, Italy
e-mail: ybeyene@iuo.it

Abstract

Between May and June 1993 the Istituto Universitario Orientale, Naples (Italy), and Boston University, Boston (USA) archaeological expedition to Aksum (Ethiopia) resumed investigations at Bieta Giyorgis, a hill to the NW of Aksum. Six field seasons have been directed by Rodolfo Fattovich (IUO) and Kathryn A. Bard (BU) (in 1993, 1994, 1995, 1996, 1997 and 1998). The general goal of the IUO and BU Expedition is to study the development of complex societies in Tigrai from late prehistoric (3rd-2nd millennia BC) to medieval times (14th century AD). Earlier investigations have focused on the rise of complex societies in the western Sudanese lowlands (Kassala, Sudan) in the 3rd-2nd millennia BC, and the Pre-Aksumite state on the Tigrean plateau (Yeha, Tigrai) in the 1st millennium BC. The current phase of the project is investigating the rise and development of the Aksumite state (late 1st millennium BC- early 1st millennium AD). Particular emphasis has also been given to the study of the involvement of Aksum in the trade network from the Mediterranean to the Indian Ocean. Excavations at Bieta Giyorgis were aimed at testing the hypothesis, based on traditional Ethiopian sources, that the hill was an area of early development at Aksum. An important goal of this project is to investigate the origins and urban development of Aksum within its environmental setting. The project includes research in archaeology, paleo-ethnobotany, archaeo-zoology, ethno-archaeology, history, geology and geomorphology, digital technologies as well as systematic mapping and conservation. This paper will present the preliminary results of GIS and Remote Sensing applications concerning the area of Aksum, comparing 2D and in 3D digital data including aerial photos (1:60,000), satellite images (Landsat TM, SPOT XS), cartographic data and landscape documentation. Finally, some important archaeological questions will be raised: how and what can we perceive from the archaeological landscape? What are the relationships between aerial photo-interpretation, satellite imagery, and the landscape? How can 3D reconstruction help us to reconstruct and to interpret archaeological landscapes? The importance and problems of this project have been exacerbated by the "war situation" between the countries of Ethiopia and Eritrea.

Key words: Aksum, archaeological landscape, remote sensing, 3D GIS, virtual reality

1. Introduction

Field archaeology, research and work in progress in the area of Aksum in Ethiopia (figure 1), involved articulated problems that require a multidisciplinary approach. In this paper, we discuss the complex issues of the virtual reconstruction of the archaeological and diachronic landscape, starting with GIS and remote sensing applications.

The project involves the application of advanced digital technologies in order to provide a detailed reconstruction of the archaeological landscape: analysis and classification by GIS and remote sensing, as well as interpretation and communication through virtual reality and visual information systems.

The innovative component of the project is its multidisciplinary approach, starting with the acquisition of the data on the ground and, then, the creation of predictive maps of the geomorphologic and anthropic landscape, including all paleoenvironmental factors (this work is ongoing).

The possibility of interacting with the reconstructed landscape in real time produces new cognitive scenarios in visual anthropology for the scientific communication and the collective knowledge (mindscape). We have created a virtual and diachronic museum of the entire territory, on the basis of visual cultural information and of the complexity of the eco-cognitive systems.

1.1. The Aksum project (Ethiopia)

Since 1993 the Istituto Universitario Orientale, Naples (Italy), and Boston University, Boston (USA) archaeological expedition at Aksum (Ethiopia) have been conducting investigations at Bieta

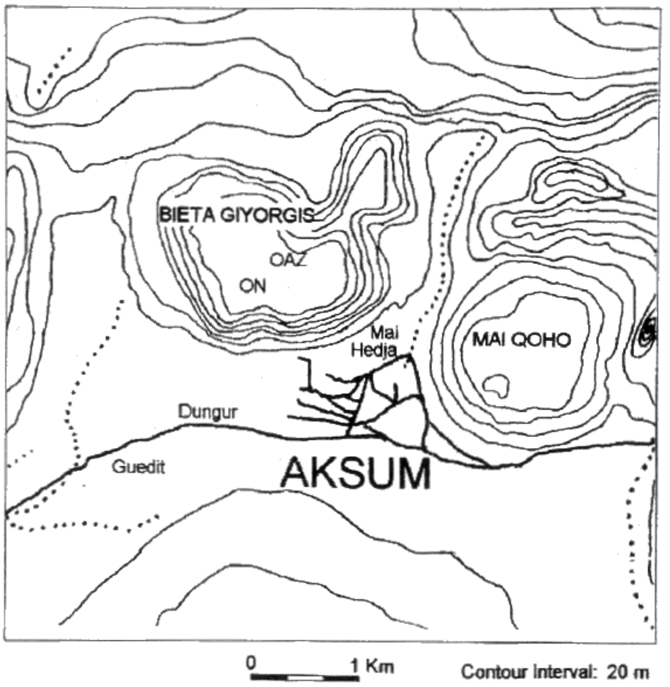


Figure 1: Map of the excavation area of Bieta Giyorgis.

Giyorgis (figure 1), a hill to the northwest of Aksum. Six field seasons have been directed by Rodolfo Fattovich (IUO) and Kathryn A. Bard (BU) (in 1993, 1994, 1995, 1996, 1997 and 1998, see: Bard et al. 2000).

The general goal of the IUO and BU Expedition is to study the rise and development of the Aksumite state (late 1st millennium BC- early 1st millennium AD). Excavations at Bieta Giyorgis have been concerned with testing the hypothesis, based on traditional Ethiopian sources, that the hill was an area of early development at Aksum, the capital city of the kingdom.

An important goal of this project is to investigate the origins and development of Aksum within its environmental setting. The project includes research in archaeology, palaeo-ethnobotany, archaeo-zoology, ethno-archaeology, history, geology and geomorphology, as well as systematic mapping and conservation.

The Expedition has been funded by the Italian Ministry of Foreign Affairs (Rome), CNR (Rome), the Ministry of University, Scientific and Technological Research (Rome), the National Geographic Society (Washington DC). Minor contributions were also provided by the African Studies Center, BU (Boston), Michigan State University (for ethnohistorical and ethnoarchaeological research), and NASA, Langley Research Center, Atmospheric Sciences Division, Hampton, VA (for geological investigation).

1.2. The Kingdom of Aksum: historical outline

Aksum is the site of the capital city of the ancient Aksumite kingdom that dominated the southern Red Sea in the early through mid-1st millennium AD. At its height, Aksum was one of the great kingdoms of the ancient world, involved in a trading network that stretched from the Mediterranean to India. At that time, the Aksumite kingdom was a partner of the Roman/Byzantine Empire onhe Red Sea trade route to the Indian Ocean. Recent excavations at Bieta Giyorgis hill indicate that the kingdom emerged from a local complex society of the late 1st millennium BC (the Proto-Aksumite Phase, approx. 400/300-100 BC).

The Aksumite kingdom began to decline in the 7th century AD, largely due to Islamic expansion along the African coast of the Red Sea. The Aksumite kingdom eventually disappeared by the 10th century AD (Late Aksumite Phase, ca. AD 700-900).

1.3. The Capital city

Aksum is located at the edge of a broad plain, and is dominated by the hills of Bieta Giyorgis and Mai Qoho, which are separated by a seasonal stream, Mai Hedja. At present, the ancient settlement is partially covered by the modern town. Aksum is one of the major archaeological areas in Ethiopia, and one of the most impressive sites in sub-Saharan Africa. The town is the main religious centre of the Ethiopian Orthodox Church, and is included in the UNESCO World Heritage List.

The archaeological area of Aksum includes (figure 1):

1. The settlement area of the ancient capital city, at the base of Bieta Giyorgis hill, and in the valley between Mai Qoho and Bieta Giyorgis (figures 1, 2).
2. Cemetery areas with stelae fields, along the Mai Hedja, at the base of Mai Qoho hill, and to the south-west and west of the settlement area.
3. Bieta Giyorgis hill, with a large settlement (Ona Nagast), a cemetery with stelae (Ona Enda Aboi Zewgè), and the remains of two Aksumite churches.
4. Two monumental subterranean tombs (Enda Kaleb and Gabra Masqal), and some pit-tombs on the top of Mai Qoho hill.

Many smaller sites have also been recorded around the main archaeological area. They form the rural hinterland of Aksum. The occurrence of archaeological sites in the area is usually indicated on the surface by concentrations of stone rubble left behind from collapsed structures.

1.4. The excavated sites

The IUO/BU expedition has conducted excavations at the sites of Ona Enda Aboi Zewgè, a large stelae field and cemetery, and Ona Nagast, the settlement associated with the cemetery.

The site of Ona Enda Aboi Zewgè (OAZ) extends over an area of about 17 hectares, and is partly covered by a modern village. Over 100 stelae (possibly up to 300) are now visible on the surface, including both roughly hewn monoliths and ones which were more carefully carved, with rounded tops, and are up to 10 m high. The largest stelae are mainly concentrated on the southern side of the site.

The site of Ona Nagast (ON) is located on a slope of Bieta Giyorgis hill about 500 m to the west of OAZ. The site covers an area exceeding 12 hectares. Part of the ancient settlement is covered by a modern village, and in the centre of the site stands a large rock-cut cistern, it is of unknown age but most likely ancient.

The general topography of Ona Nagast, and particularly the three terraces to the east sloping down to the Mai Lahlah, suggests a carefully planned complex. Results of excavations, which have unearthed substantial monumental structures, specialised functional areas, and non-elite domestic areas, suggest that the site was occupied for at least 1000 years.

1.5. Environmental setting

Aksum is located on the Tigrean Plateau in northern Tigray about 22 km to the west of Adwa at an average elevation of 2200 m. The geographical co-ordinates are 14° 7’ 8” N, 38° 43’ 46” E. The hills of Bieta Giyorgis and Mai Qoho dominate the present town to the north-west and east, respectively. Some hills, with an average elevation ranging between 2406 m and 2289 m, surround Aksum, delimiting a roughly circular plain approximately 10 km in diameter, which gently slopes from north to south and south-east.

Two main eco zones can be distinguished within the region;

1. The plain around Aksum, with a low gradient and highly fertile land, which is optimal for plough cultivation;
2. Hills with a steep gradient or naturally terraced land, which are less favourable for ox-plough cultivation.

The rock sequence exposed in the Aksum area includes;

1. Variegated sandstone in bedding sets 2 m thick (Takkaza Sandstone), with a total thickness of at least 320 m.
2. Flood basalts (Emba Ayba Basalts), with a maximum thickness of about 600 m, and rare tuffs that form extensive outcrops.
3. Blocky trachtyc lavas, and large platforms of basalts elevated by subsurface intrusions and plug domes (Hyperalkaline Silicic Lavas).
4. Unconsolidated or semi-consolidated clays, silts, sands, and gravels deposited in fluvial or colluvial environmental settings at the top of the rock sequence in the area (Quaternary Sediments).

1.5.1. Bieta Giyorgis

Bieta Giyorgis rises 200 to 250 m above the surrounding terrain (figure 7). The hill itself is comprised of three distinct physiographic sections: the steep flanks; the horse-shoe shaped, gently sloping Ona Nagast plain; and the central uplands of Beta Giyorgis. The drainage pattern on the hill is radial and streams are intermittent.

The flanks of Bieta Giyorgis include the very steep slopes and cliffs that form the perimeter of the mountain. These slopes are littered with a discontinuous cover of large boulder colluvium.

The Ona Nagast plain is of a horseshoe-shape, a gently undulating plain that surrounds the central uplands on three sides. The plain, which is about 175 m above the Aksumite plain, is bounded on its outer edge by a knobby rim. The knobs are underlain by bare to thinly veneered fine-grained igneous rock. The south-eastern part of the plain is underlain by stratified sedimentary rock. Elsewhere the plain appears to be formed directly on the igneous rock. The streams generally follow the joint pattern in the igneous rock or zones of weaker metamorphic rock. The central uplands consist of a rolling terrain underlain by relatively homogeneous, but jointed, igneous rock.

1.5.3. Environmental history of the Aksum region

Paleo-environmental evidence for the Aksum region is very scarce. Four major aggradation episodes occurred during the last millennium and may represent periods with increasing soil erosion due to heavier rains and/or more intense human disturbance. These episodes are tentatively dated to;

1. AD 100-350 (heavy rainfall with strong periodic floods, on a landscape already partially deforested and degraded because of intense land-use).
2. AD 650-800 (a period of deep soil erosion due to very intense land-use and very heavy periodic rains, combined with a progressive abandonment of settlement).
3. Late 1st millennium AD (more soil erosion due to a late abandonment or eventual destruction of settlement).
4. 19th-20th centuries (recent soil erosion due to more intense land use on a greatly denuded landscape).

Preliminary studies of pollen samples taken from archaeological sediments at Ona Enda Aboy Zewgè and Ona Nagast indicate that:

- In the middle to late 1st millennium BC the vegetation cover on Bieta Giyorgis hill was dominated by shrubs and herbaceous plants characteristic of open vegetation and areas of human settlement. The very low arboreal frequency in the samples (and virtual absence of tree pollen normally transported long distances by wind) suggests that trees were not common components of the vegetation pattern in the general area of Aksum.
- In the second half of the first millennium AD the general vegetation pattern on Bieta Giyorgis was very similar to the pattern of today: a predominance of grasses and shrubs with only a few isolated trees near structures, in gorges along seasonal streams, and on rocky slopes (13: BG).

At present we do not have pollen data for the first half of the first millennium AD.

2. Remote sensing and GIS applications

2.1. The digital Project

The Aksum Project is a work in progress but, in order to obtain good results from the outset, we have constructed a “conceptual model” of the project (figure 2) on the basis of the available data which includes;

- Vector and raster digitalisation (maps, aerial photos, morphological features, etc.)
- DEMs creation (micro-macro scale).
- Satellite image classification (multi-spectral).
- Integration and overlay of raster and vector data: aerial photos, satellite images, DEM, multi-layered surfaces.
- 3D processing and VR navigation through the archaeological landscape.
- Multi-spectral classification of Landsat TM and SPOT XS images.
- Predictive archaeological maps on the basis of satellite training regions.
- GIS applications (spatial analyses).
- Creation of landscape virtual models in OpenGL (format Openflight, .flt) for the visualisation and navigation on the

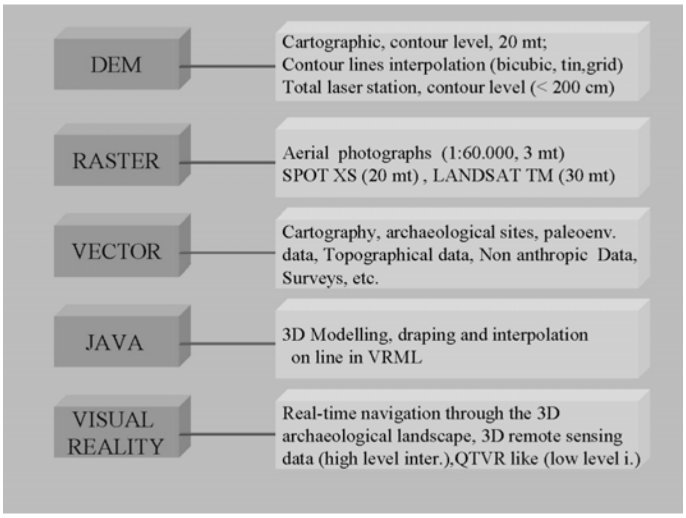


Figure 2: The scheme of the project.

workstation in real time (by the Audition freeware viewer, www.cg2.com) and for the virtual theatre (using the Multigen software on SGI Onyx 2).

- 2D-3D spatial analysis with GIS applications (Arcview and Idrisi).
- Creation of digital mosaics of aerial photos and satellite images (with histogram matching of the images for obtaining homogeneous results in grey levels and in RGB components)
- Virtual reconstruction of cognitive archaeological landscapes.
- VR applications through remote sensing data and archaeological landscapes reconstructed by OpenGl applications.
- VR reconstruction and visualisation of the archaeological landscape through the virtual theatre.

In a few words remote sensing techniques and GIS applications are used for the virtual reconstruction of the archaeological landscape at the micro and macro-scale. Indeed, the 3D exploration and navigation of the virtual landscape allows us to suggest new and unexplored hypotheses and interpretations.

2.2. Data-entry

The choice of the sources has been very important because of the difficulties to obtain, first of all, detailed and useful cartographic documentation (these difficulties increased following the war between Ethiopia and Eritrea). Furthermore, it has been fundamental to integrate different data sources, such as printed documentation and digital data. Therefore, we have used the following principal data-sets:

- Landsat TM 7 bands (30 m resolution, multi-spectral**,** figure 3).
- SPOT XS, 3 bands (20 m resolution, multi-spectral, figures 3, 5).
- Aerial photos (1951, 1964, 3 m resolution, 1:60,000, figure 4).
- DEMs (by total laser station, 1:500 and by cartographic contour lines, 1:25,000).

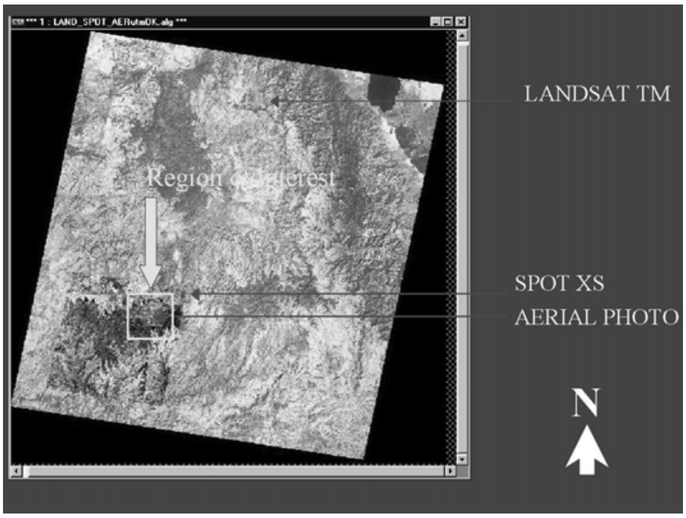


Figure 3: Landsat TM, SPOT XS and aerial photos (1964) geo referenced and mosaiced.

Figure 4: Identification of an archaeological site by an aerial photo.

- Aerial photo-interpretation (feature identification, cropmarks, vector thematic layers).
- Archaeological excavation maps (vector thematic layers, figure 1).
- Archaeological survey maps (vector thematic layers).
- Territorial databases.
- Geological and paleoenvironmental data (vector thematic layers, soil maps, digital classifications).

2.3. Analysis and classification

Having such a complex archaeological data-set, digital applications have been oriented towards a construction of multi-layered models, i.e. a 2D and 3D representation through GIS overlay and

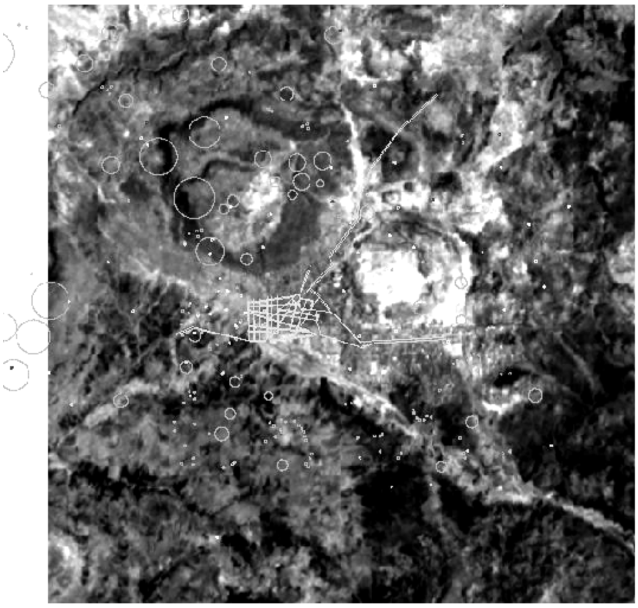


Figure 5: SPOT XS with vector themes corresponding to archaeological sites, roads and urban areas.

remote sensing applications at a micro- and macro-scale. In this first phase, research mainly involved the following methodological applications: multi-spectral satellite classification, panchromatic classification, DEM construction, overlay of raster and vector data, and 3D multi-layered visualisations.

Multi-spectral classification is aimed primarily at classifying the landscapes into macro-classes, and, in particular, at suggesting predictive models for the identification of the archaeological sites and cultural features. The combination of all these information layers is providing new interpretations of archaeological evidence on the basis of the diachronic visibility of the territory and the ancient settlements. Then, the integration of 2D with 3D data and real time visualisation allows the construction of cognitive models of the landscape, with analysis of spatial features and an overlay of all the information acquired during fieldwork, as well as by remote sensing data. In fact, dynamic perception, acquired through 3D virtual models, can open different directions to research on the basis of draping and DEM resolution. This work is only at the initial stage but, by combining all paleo-environmental data, we have obtained a diachronic reconstruction of the archaeological landscape. Problems concern the availability of data. Ongoing research must provide more detailed description of the territory, i.e., through soil maps, geomorphologic and pedological analyses, palynological data etc. Thus, knowledge of the anthropic landscape is at an early stage and new archaeological and geo-archaeological surveys must be included in future fieldwork.

2.3.1. Multi-spectral classification and image processing

In remote sensing applications thematic information can be extracted from imagery through multi-spectral classification; the results of the classifications depend mainly on the image resolution and on the number of spectral bands. Classification is a statistical process which groups homogeneous pixels into areas of interest based upon a concept referred to as spectral pattern recognition. It can be categorised into two methods: supervised (human assisted), or unsupervised (clustering) techniques. Each classification serves a particular purpose, and the two methods are often used in conjunction. Supervised classification uses ‘training’ regions drawn on the image (typically with vector polygons), then finds all other pixels with similar spectral characteristics. Unsupervised classification works with a nominal class and categorises all pixels into classes with similar spectral signatures, creating classes according to semi-automatic parameters. Results from the process are typically in the form of a thematic map that can be used to solve a particular problem or to provide important data unobtainable from other sources. Several classification algorithms are used in image processing, such as parallelepiped, minimum distance to means, and maximum likelihood. In our project the processed satellite data is taken from a Landsat TM (7 bands, for first processing see Bard, Fattovich, Petrassi, and Pisano 2000, figure 5, 6), and from a SPOT XS (3 bands). Landsat TM is a second generation earth resources satellite, and combines reasonable spatial resolution (cell size of 30 meters by 30 meters) with a range of spectral bands (7 bands in visible and near, short and mid infrared wavelengths). The first band covers the range from 450 nm to 520 nm, which roughly corresponds to blue light in the visible spectrum. The abbreviation “TM” refers to the Landsat Thematic Mapper which has six bands of interest:

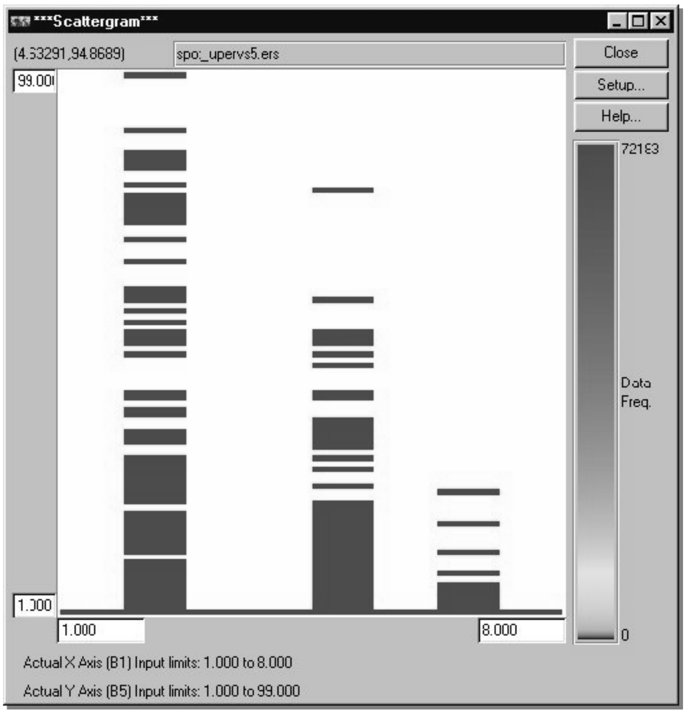
- TM1 covers 450-520 nm
- TM2 covers 520-600 nm
- TM3 covers 630-690 nm
- TM4 covers 760-900 nm
- TM5 covers 1550-1750 nm
- TM7 covers 2080-2350 nm

Detailed information of the SPOT image (SPOT5 covers 1580-1750) is as follows:

- Scene ID 2 135-322 93/03/23 08:05:32 1X
- K-J identification 135-322
- Date 93/03/23
- Processing level 1B
- Spectral mode XS
- N134756/E0381029 N134257/E0384306
- Azim.: 120.0 Elev.: 64.5 Gains: 454
- N. of lines 3003
- N. of pixels per line 3182
- 14°8’ N 38°43’ E (Aksum)

The first step of processing multi-spectral data is to combine the sequences of the spectral bands in order to provide a good visualisation of the territory with respect to research goals (i.e. visibility of soils, vegetation, geomorphology, etc.). For the Landsat TM, the following sequences of bands were chosen: 7, 4, 1 and 5, 3, 1; while for the SPOT XS, we have used the following different combinations: 3, 2, 1 and 1, 2, 3. The combination of spectral bands in pseudo colour is very important because it greatly influences interpretation of the imagery.

Classification and analysis of the raster data have been directed toward the integrated digital processing of the remote sensed (panchromatic and multi-spectral) data, and considering the significant potential of integration of multi-spectral Landsat TM (30 m)



Actual X Axis (B1) Input limits: 1.000 to 8.000

Actual Y Axis (B5) Input limits: 1.000 to 99.000

Figure 6: Digital histograms (multi-spectral signatures) corresponding to possible archaeological sites.

data with SPOT XS imagery (20 m), and, finally, with panchromatic data (aerial photos, 3 m, 1:60,000). Whereas the progress of the project will permit a detailed multi-layered classification, the following final data should be produced:

- Classification of soils, vertisoils and erosion areas;
- Classification of damp areas;
- Classification of vegetation, cultivation and crop-marks;
- Classification of archaeological sites on the basis of visible anthropic structures;
- Geomorphologic classifications;
- Classification of anthropic features by aerial photo-interpretation;
- Predictive maps derived from digital sampling of known surface structures;
- Image draping (satellite, aerial photos) over the DEMs in micro and macro-scale for analysis of connections between spectral signatures and digital elevation models;
- Multi-layer visualisation of all geo referenced raster data;
- Data-entry of all digital data in GIS.

At this stage of our work the potential of a multi-spectral classification is reduced by the lack of information on the Aksum regional landscape with respect to soils, rocks, vegetation and cultivation. However, preliminary results of the supervised classification of the Landsat TM imagery have been obtained from two different processes, with samples of 7 and 10 training regions.

In the first instance, seven classes have been distinguished on the basis of the spectral signature: vegetation (unspecified), forests, damp areas, type 1 sites (circular anthropic features), type 2 sites (terraced sites), urban areas, unclassified. In the second case, ten regions have been classified: 4 types of vegetation, forests, damp areas, urban areas, 3 types of anthropic features (2 types of features corresponding to probable archaeological sites, figure 6). In the case of archaeological sites or of anthropic features used to identify probable ancient settlements, several known areas have been sampled (figure 6). For these supervised classifications maximum likelihood algorithms have been used, but it is impossible to categorise these results as definitive, because the training regions have been chosen mainly through cartographic processes and without detailed ground truthing (this activity is planned for 2001). At a preliminary level, the identification of some anthropic features and probable archaeological sites (figure 5) is encouraging. The use of the maximum likelihood algorithm has allowed the identification of two different anthropic features (figure 5), specifically identification of features with circular shapes. In fact, with the superimposition of thematic maps created from supervised classification over the aerial photos (3 m resolution) it is possible to calculate that over 60% of the pixels belong to circular anthropic shapes (features 1), although the final analyses are still in progress.

Other important results have been obtained by data fusion, probably the best method for combining multiple types of data into a single view (for example, sharpening a Landsat TM image with a SPOT XS image). Thus, in our case, data fusion allows the integration of spectral properties (not available for panchromatic data, such as aerial photos) with panchromatic high resolution aerial photos of Aksum: the final result corresponds to “multi-spectral” imagery of 3 m of resolution. Furthermore, using this process it is also possible to superimpose thematic layers classified by supervised algorithms over the aerial grey scale photos. It is then possible to verify in overlay and in detail the correspondence between classified pixels (spectral information) with traces, crop-marks and anomalies visible from on aerial photos (analogue information).

Other interesting results have been obtained using the Brovey transform, a method to fuse different data together using one image (for example Landsat TM) for spectral or colour information, and another image for spatial or sharpness. During processing the Brovey transform has been applied with a panchromatic aerial photo and Landsat TM 7 band imagery and with a panchromatic aerial photo (1964) and SPOT XS (figure 3).

Despite the difficulties, this first attempt to classify regions of interest through a multi-layered approach provides interesting results through its potential to overlay all available information layers including:

- Overlay of vector and raster data (topography, contour levels, archaeological sites, geo-archaeological and paleo-environmental data).
- Diachronic analysis of raster data in transparency and on different layers.
- Overlay and multidimensional visualisation of all classified data.
- Creation of thematic maps and predictive models of ancient settlements systems.
- Aerial photos of the top of Beta Giyorgis hill with possible features identified in the aerial photos.
- Data fusion of panchromatic and multi-spectral data.

2.3.2. DEMs processing and 3D remote sensed data visualisation

DEM processing is currently still in progress because new topographic survey is still planned for Beta Giyorgis hill. A micro-scale and a macro-scale DEMs have been processed: the micro-scale DEM has been created from mapping at a 1:500 scale; while the macro-scale DEM has been created digitising contour levels at a 1:25,000 scale. One of the principal activities of the project involves the draping of the raster and vector data over the DEMs in order to construct 3D and multi-layered models of the landscape: each draped layer can represent different types of data (real or interpreted) and only in 3D is its level of information visible (virtual dynamic perception). Furthermore, by integrating all 2D data within 3D visualisations it has been possible to plan the following applications:

- Different interpolation methods for DEM creation: kriging, cubic-spline, nearest neighbour, grid, TIN.
- Structural filters for micro-topographic visualisation of the DEMs.
- Digital segmentation techniques for identification of archaeological and geomorphologic structures.
- Digital enhancement filtering (colour drape algorithm).
- 3D visualisation of the SPOT and Landsat images draped over the DEM.
- 3D visualisation of the DEM created by total station survey (excavation area, figure 7)
- 3D visualisation of excavation areas (micro-DEM) and aerial photos draped over the micro-DEM.

3.1. Cognitive archaeological landscapes: toward the virtual mindscape

“The map is not the territory…” (Bateson 1973, Bateson 1980), and, in digital language, a GIS is not the landscape, because it cannot represent such a complex data set as a landscape. In recent years the relationships between landscape and cognitive archaeology has been studied with two significant contributions: *The ancient mind* (Renfrew and Zubrow 1994) and *Semiotics of Landscape: Archaeology of Mind* (Nash 1997). Otherwise, post-processualist archaeologist are now studying GIS spatial applications (Forte and Cremaschi 1999, Gaffney and Van Leusen 1995, Gaffney et al. 1996, Johnston 1995, Van Leusen 1999) in order to reconstruct past landscapes (mainly “resource landscapes”) on the basis of viewshed and cost surface analyses (see Van Leusen 1999). Since 1987 a significant number of these spatial applications have been undertaken with cognitive aims (Gaffney and Van Leusen 1995). The problem is very complex because it involves methodological, epistemological and technological aspects: how can we represent archaeological landscapes? What is the perception of the landscape? What is the difference between the real and imaginary landscape? How is it possible to describe an archaeological landscape? The complexity of the problem is evident when analysing, describing and representing an ancient landscape, and spatial techniques as well as epistemological and anthropological approaches are needed.

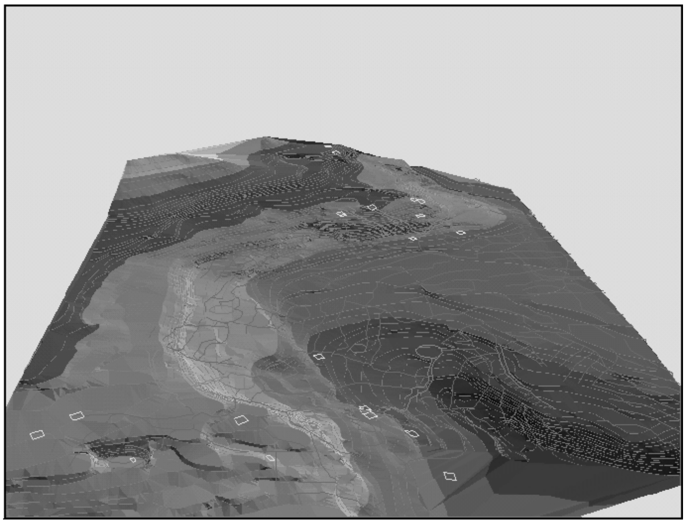


Figure 7: 3D visualisation (TIN model) of the archaeological region with data interpolated by a total laser station.

We are aware that these interesting problems need much discussion and in this paper, we would like to present a brief contribution relating to the problems of virtual digital technologies and their use for restoration of the archaeological landscape. Moreover, we believe that a cognitive landscape reconstruction needs an integrated methodology consisting of spatial digital technologies (GIS, remote sensing, virtual reality) and epistemological discussion.

The conditions for interpreting an archaeological landscape depend on many factors of visual representation. Visibility, perception, cognition and communication are the most important factors in the knowledge of landscape, especially ancient landscapes. A distinction between perception and cognition has been suggested by Van Leusen (1999) where perception is “the simple act of being aware of the landscape…” and cognitive archaeology, “the study of past ways of thought as inferred from material remains” (Renfrew and Zubrow 1994). According to Nash (1997) the “landscape, comprising natural features, is a series of stories that are constructed through time and space and formulate a series of histories; not history”. Therefore, with respect to the reconstruction of cognitive archaeological landscapes these questions should be raised**:**

- What is the present landscape? (today).
- What is the landscape we perceive? (today and through our mind).
- What was the ancient landscape? (in the past).
- What was the landscape to the ancient people? (in the past, through the ancient mind).
- *What is the ancient landscape we perceive?* (at present, but also through ancient minds and mental maps).

A first attempt to classify the archaeological landscapes on the basis of a cognitive approach is given below (obviously all terms interact each other).

Cognitive qualities of the archaeological landscape / Description - Significance

Social-symbolic:

Socio-ritual knowledge and the consciousness and manner in which people perceive objects within their surroundings is fundamental to the formulation of a sense of belonging.

Geometrical:

The geometry of the landscape is the property used to describe (intervisibility, DEMs, viewshed, panoramas) surfaces and volumes.

Power-hierarchical:

In many cases the ancient construction of archaeological landscapes follows the rules of power, thus the perception is through hierarchical passes (layers of importance).

Visual:

The visibility is the condition to view territories (own and other peoples) without mental maps (in theory).

Artefact:

"Landscape employs a language of artefact, an object which is created by people and embodies the principles of organisation and categorisation within the human experience" (Nash 1997).

Mental:

Perception of the landscape through mental maps constitutes the grammar of the visual anthropology.

Narrative:

The preservation of a memory of the landscape means the preservation of a cultural identity. A narrative landscape describes the quality of a collective memory (i.e., through myths, imaginary places, places of memory).

Semiotic:

Any landscape is understandable by different languages and grammars. The construction of anthropic landscape involves the use of a common language for expressing the mind of the community.

Connected-inter-connected:

Landscape is a context where the whole is more significant than the sum of each component. Connections belong to the context.

Natural:

The quality of the natural in the perception of landscape is purely theoretical, including a neutral knowledge without giving hierarchical values.

Spatial-temporal:

"Landscape is a series of spaces which become places, thus establishing territory… although we perceive ideas and place them within our minds, our body too becomes a part of the landscape - it interacts with and becomes a component of the landscape, forming a sense of space" (Nash 1997:1-2).

Simulated:

Within a virtual reality reconstruction there is a passive interaction (the user navigates and visualises the model) and an active interaction (with behavioural exchange between the environment and the events).

Virtual-dynamic:

Our perception of landscape can be through the dynamic perception/interpretation of virtual models (virtual walkthrough, flythrough), requiring 3D navigation.

Mindscape:

Mind of landscape: the way to read the landscape through cognitive representations.

In our project virtual reality applications are important for the presentation of data because through virtual models the landscape becomes a cognitive landscape. We are aware that we are only at the beginning of this experiment, but we think that cognitive interaction increases the level of knowledge and communication (Forte and Beltrami in press, Barceló et al. 2000, Forte 2000).

Following this approach, three levels of interaction have been chosen for the project:

- Level 1 (2D) - QTVR applications used in order to generate virtual panoramas within the 3D models of reconstructed landscape (with different textures);
- Level 2 (3D) - VR navigation through the remote sensing data (using the OpenGl flythrough of Er Mapper);
- Level 3 - Virtual navigation through the reconstructed landscape with billboards, vegetation, paleoenvironmental data, architectonic and extruded models (made with Terravista, see below, figure10).

4. Terravista

The last stage of the project is to complete the reconstruction of the archaeological landscape, converting the GIS data into a new environment for virtual reality applications; this is possible with specific software (Terravista 2.1).

In January 2000, a program for scientific co-operation was established between ITABC (Institute of Technologies Applied to Cultural Heritage) and the American software company Terrex (www.terrex.com) for the application of the Terravista 2.1 software (ITABC is the only reliable user for cultural heritage in Europe for this kind of license). Terravista is a high level and high performance software for virtual 3D reconstruction of geo referenced landscapes starting from GIS data, and is capable of generating models by OpenGL libraries (www.opengl.org). The OpenGL working environment provides high quality graphics on inexpensive PCs, because accelerated graphic cards are used. OpenGL is the premier environment for developing portable, interactive 2D and 3D graphics applications. Since its introduction in 1992, OpenGL has become the industry's most widely used and supported 2D and 3D graphics application programming interface (API), bringing thousands of applications to a wide variety of computers. OpenGL fosters innovation and speeds application development by incorporating a broad set of rendering, texture mappings, special effects, and other powerful visualisation functions.

Encouraging experiments performed with Terravista have demonstrated a high level of interactivity and practicality for OpenGL models (combined with accelerated graphic cards API-OPENGL). These results open new perspectives for versatility of applications for non-immersive virtual reality, mainly in connection with virtual reconstruction of territorial contexts and with three-dimensional visualisation of geo-referenced data.

Standardisation of software procedures and increasing use of OpenGL graphic libraries for archaeological applications will direct research towards the organisation of specific multidisciplinary databases (2D-3D). Virtual reality applications will also be undertaken for visualisation of classified remote sensing data.

Terra Vista™ is a software that rapidly constructs digital landscapes representing both real and imaginary worlds. These landscapes are optimised for drawing, which makes them suitable for use in applications such as visual simulation, where a scene must be updated very quickly. The approach for constructing virtual worlds differs from other modelling systems in two ways:

1. A high degree of automation allows the creation of potentially huge worlds.
2. Existing sources of digital cartographic data is used as an input to its automatic processes (Terravista User's Guide).

The combination of these two features allows the program to quickly create virtual worlds that are highly representative of the real world. So, simulation is achieved through three processests: (1) Data Acquisition, (2) Terrain Database Generation, and (3) Visualisation of the Generated Terrain.

The three main types of data used by Terra Vista are as follows:

- Elevation data (DEMs), which constitutes the basis for starting the reconstruction;
- *Geospecific* imagery (raster data such as satellite imagery, aerial photos or textures created by the archaeological researches), which are the first "drape" of the landscape;
- Cultural data, including man-made structures such as buildings, roads, bridges, etc.; or natural features, such as lakes, oceans, rivers, forests, soils, vegetation. Vector files contain these features in the form of points, lines, and areas.

Additional data (textures and 3D Models) used by Terra Vista to create a terrain database are included in powerful graphic libraries. Generic or repeating textures can be used where geospecific imagery is not available. Moreover, Terra Vista supplies a library of textures that can be used on the terrain.

With respect to the features of these 3D models it is important to stress that they are constructed as LOD (levels-of-detail) models, i.e., each tile has multiple levels-of-detail (LOD, figure 8). Each LOD represents the tile at a different polygon density: less detailed for when the tile is far from the viewer; or more detailed when the tile is close to the viewer. Whether the terrain is displayed in a flight simulator or shown in a corporate boardroom on a notebook computer, the hardware on which it is rendered will determine some of the parameters for the terrain generation. The number of polygons that can be drawn per second along with the desired frame rate will determine how many polygons can be drawn per frame (texture memory can limit the amount of geospecific imagery used).

Finally, the *fly-through* visualisation is optimised for OpenGl, thus real time movement is very fast. It is also possible to set up various navigation parameters (altitude, fog, velocity, panorama, visibility).

5. Virtual Theatre

Thanks to scientific co-operation with the CINECA Visual Information Lab (Interuniversity Supercomputing Consortium, http://www.cineca.it/visit/virtualtheatre.html) the first virtual models of archaeological landscapes (created with Terravista in Openflight format) have been implemented for the Virtual Theatre (figure 9).

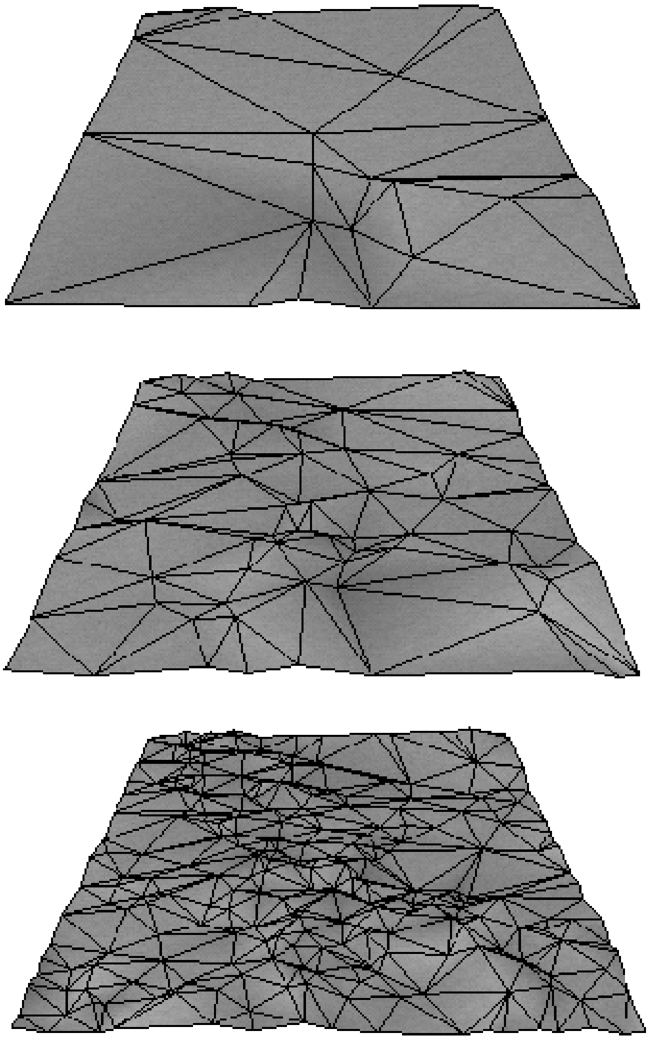


Figure 8: Terravista software: representation of 3 LOD (level of details) for different types of visualisation.

These simulations may benefit especially from viewing on a large scale in the CINECA Virtual Theatre, which aids the visualisation of scenarios through its size and "immersiveness". The Virtual Theatre is a structure for immersive three-dimensional computerised visualisation with a surround sound system and a semicircular screen that allows the spectator to experience the illusion of three-dimensional vision. The CINECA Virtual Theatre hardware platform consists of a SGI Onyx2 system with 8 R10000 processors, 4 Gigabytes of RAM, 3 "Infinite Reality2" graphic pipelines with 8 raster managers, 3 Barco projectors and a switching system integrated directly into the graphic computer system (figure 9).

Applied to research, the Virtual Theatre therefore becomes an instrument that enhances understanding. The availability of these technologies opens up new perspectives and a new way of interpreting well known data, re-appropriating he original sense of the word "theatre", in which the Greek intended a space for observing in order to understand.

Visualisation obtainable through VR crystal eyes (with stereoscopic view) enhances the level of the viewers' perception as generated virtual models can be experienced as holograms.

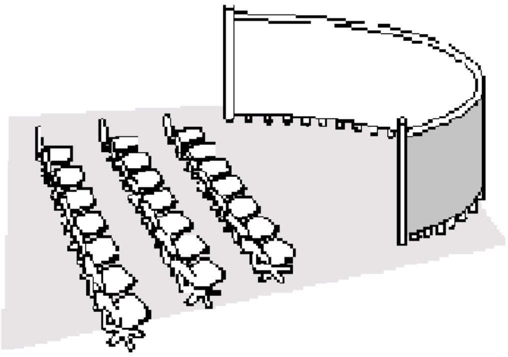


Figure 9: The virtual theatre.

6. Perspectives and conclusions

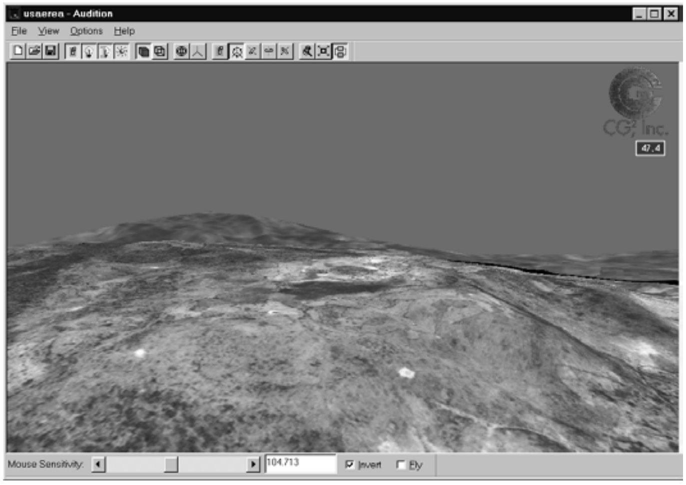
In the above-discussion the importance of reconstructing the archaeological landscape (figure 10) through remote sensing applications has been highlighted. However, for a cognitive landscape we need to add other facets of simulation. Therefore, in the Aksum project, the archaeological landscape data will be supplied to CINECA in Multigen OpenFlight format (.flt, the same format used by the Terravista models). Using IRIS Performer libraries and the developing environment software of the MultiGen-Paradigm Vega, archaeological landscape models will be integrated with real-time dynamic behaviour and multimedia data, producing visual simulations such as:

- geomorphological simulation (e.g.,. landslides, terrain morphology variation, terraces),
- paleo-environmental events (former water courses),
- settlement simulation (population expansion, settlement planning)**,**
- other dynamics (deforestation processes, cultivation, irrigation, etc).

In conclusion, the 3D reconstruction of archaeological landscapes through virtual reality experience (with the addition of remote sensing classification) can provide a fundamental contribution to the development of the project and to the construction of cognitive models. In fact landscape patterns are the results of economic experience, mental maps, cultural ideas and topographic reality (Renfrew and Zubrow 1994, Forte 2000). Furthermore, it is important to acquire new tools for understanding the past, including spatial techniques (GIS) and visual information dynamic systems (VR). Finally, the multi-layered perception of 3D archaeological models through advanced virtual environments (virtual theatres and mindscapes) opens new perspectives for cognitive landscape archaeology, perhaps as a first step for restoring what “ancient collective memories” represented.

Acknowledgements

Special thanks are due to all members of the IUO/BU joint archaeological expedition to Aksum, and in particular to Dr Livio Crescenzi, (Soprintendenza Archeologica. per il Lazio, Roma.), Mr. Antonio Sollazzi (Soprintendenza Archeologica per il Lazio, Roma), and Mr. Franco Cioffi, (Soprintendenza Archeologica per il Lazio, Cassino). This project has been supported by funds from the Ministero Affari Esteri, CNR, Ministero per l’Università e la Ricerca Scientifica, Rome (Italy), and the National Geographic Society, Washington DC (USA). Other thanks are also due to the Visual Information Lab of the CINECA and particularly to Eng. Antonella Guidazzoli.



Mouse Sensitivity: 104.713 ☑ Invert ☐ Fly

Figure 10: Virtual reconstruction of the Aksum archaeological landscape (real time navigation).

References

BARCELÓ J., FORTE, M. and SANDERS, D. (eds.), 2000. *Virtual reality in archaeology*, Oxford, ArcheoPress (BAR International Series S 843).

BARD, K.A., FATTOVICH, R., PETRASSI, L. and PISANO, V., 2000. *The Aksum archaeological area: a preliminary assessment*, Istituto Universitario Orientale, Napoli.

BATESON, G**.**, 1973. *Steps to an Ecology of Mind*. Paladin Books.

BATESON, G. 1980. *Mind and Nature - A Necessary Unity*. Bantam Books.

FORTE, M., 2000. About virtual archaeology: disorders, cognitive interactions and virtuality. In Barceló, J., Forte, M. and Sanders, D. (eds.), *Virtual reality in archaeology*, Oxford, ArcheoPress (BAR International Series S 843).

FORTE, M., 2000. Archaeology and virtual microtopography: the creation of DEMs for reconstructing fossil landscapes by Remote Sensing and GIS applications. In Lock, G. (ed.), *Beyond the Map: Archaeology and Spatial Technologies*. NATO Science Series, IOS Press Amsterdam: 199-214.

FORTE, M. and BELTRAMI, R., in press. A proposito di virtual archaeology: disordini, interazioni cognitive e virtualità, *Archeologia e Calcolatori*, 11.

FORTE, M. and CREMASCHI, M., 1999. Reconstructing a fossil landscape by remote sensing and GIS applications: sites, virtual models and territory during the Middle Bronze Age in the Po Plain (Northern Italy), *Archeologia e Calcolatori*, 10.

GAFFNEY, V. and Van LEUSEN, P.M., 1995. Postscript – GIS, Environmental Determinism and Archaeology. In Lock, G. and Stančič, Z. (eds.), *Archaeology and Geographical information Systems: A European perspective*, Taylor and Francis: 367-382, London.

GAFFNEY, V., OŠTIR, K., PODOBNIKAR, T. and STANČIČ, Z., 1996. Spatial analyses, field survey, territories and mental maps on the Island of Brac, *Archeologia e Calcolatori*, 7: 27-41.

NASH, G. (ed.), 1997, *Semiotics of Landscape: Archaeology of Mind*, Oxford.

MALINA, J. and VASICEK, Z., 1997. *Archeologia. Storia, problemi, metodi*, Electa, Milano.

RENFREW, C., ZUBROW, E. (eds.), 1994. *The Ancient Mind: elements of cognitive archaeology*, Cambridge UP.

TAYLOR, P.J. and JOHNSTON, R.J., 1995. GIS and Geography. In Pickles, J. (ed.), *Ground Truth. The social implications of Geographic Information Systems*, 51-63, New York, London.

Van LEUSEN, M., 1999. Viewshed and Cost Surface Analysis Using GIS (Cartographic Modelling in a Cell-Based GIS II). In *New Techniques for Old Times*, Computer Applications and Quantitative Methods in Archaeology, Proceedings of the 26th Conference, Barcelona, 1998, BAR 757.