Safeguard of the Archaeological Heritage in Ethiopia: Satellite Photogrammetry for the Archaeological Map of Melka Kunture Palaeolithic Site

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Abstract

Melka Kunture (Ethiopia) represents one of the most important Palaeolithic archaeological site of the African world. To protect and to safeguard this cultural heritage, advanced technologies such as the satellite photogrammetry and the Geographic Information Systems (GIS) have been applied.

The use of IKONOS II stereoscopic images and ground control points from a DGPS survey allowed the creation of the new topographic-archaeological map of Melka Kunture at a scale of 1:10,000. This map will constitute an useful tool for the preservation of several archaeological sites spread over a 100km² area. Moreover, thanks to the creation of full three-dimensional data, spatial analyses on archaeological and palaeo-environmental data in respect with palaeo-geography have been executed.

Keywords

Archaeological map, IKONOS II, satellite photogrammetry, GIS

1. Introduction

The creation of a topographic-archaeological map of the archaeological area at a scale of 1:10,000 from remote sensed imageries, was one of the goals in the framework of EU Culture 2000 project "From the Past to the Present in Ethiopian Prehistory. An Interactive Museum for the Archaeological Park of Melka Kunture". The project derives from the will to increase the knowledge in respect of one of the most important sites of the ancients phases of the Prehistory.

The creation of a large scale map resulted necessary to locate old and new excavation sites, characterized by detail, completeness and high positional accuracy, considering that the actual available topographic map, deriving from the photogrammetric restitution of aerial photographs at a nominal scale of 1:60,000 dated 1971, is at a scale of 1:50,000 (Read *et al.* 1973, 649–661).

Besides, the new topography, together with the availability of recent satellite multispectral orthorectified imageries, will represent a fundamental tool aiming to monitor, to preserve and to study the archaeological area (Lock 2000).

During recent years the availability of high spatial resolution sensors has made satellite photogrammetry valid alternative to aerial photogrammetry, maintaining satisfactory values of radiometric quality, spatial resolution and geometric accuracy (Dial and Grodecki 2003; Holland *et al.* 2006, 212–223; Sperti and Galanti 2006, 229–243). Furthermore, especially in developing countries, it permits remarkable cost efficiency over aerial photos production (Jacobsen *et al.* 2008), that, even when available, are dated and present an inadequate scale for archaeological excavation applications.

2. Study area

Melka Kunture, located 50km South of Addis Ababa, in the upper valley of the Awash River, the cultural palaeolithic sequence dated from 1.7 to 0.2 myr and the variety of the archaeological remains of different phases, represents a very important prehistoric site

of elevated scientific value, due to the extension of the site (Chaivallon and Piperno 2004).

Melka Kunture is the name of a ford of the Awash: the site extends for 5km on both banks of the river. The main sites are located in the old fluviolacustrine terraces and in the volcanic rock of the Melka Kunture Formation (Bardin *et al.* 2004, 3–23; Kieffer *et al.* 2004, 83–92).

Melka Kunture was discovered in 1963 by the hydrogeologist G. Dekker, and in the same year the prehistorian G. Bailloud organized a survey in the region, collecting many Lower and Middle Palaeolithic remains on the surface. Several archaeological project were conducted by a French-Ethiopian team directed by J. Chavaillon in the time span 1965–1981 and 1992–1995. Subsequently, since 1999 an Italian projects directed by M. Piperno from La Sapienza University of Rome is continuing the systematic study, through a series of extensive excavations, the survey of areas interested by the prehistoric settlements and the chronostratigraphic definition of the site.

Over 80 archaeological layers have been identified; 30 of them have been extensively excavated with surfaces ranging from 50 to 250m² permitting to discover, for every archaeological layer, several thousand of lithic tools, faunal and occasionally human remains (*Homo Erectus* and *Homo Sapiens*) (Berthelet *et al.* 2001).

3. Methods and results

Two sets of *Standard Stereo* IKONOS II *1m Pansharpened* satellite imageries have been purchased, acquired the November 6, 2006 for the EU project, covering an area of 102km², with the aim of creating new topographic map of Melka Kunture at a scale of 1: 10,000 from the stereoscopic digital photography.

The scenes, distributed together with the RPC (Rational Polynomial Coefficients) necessary for stereopairs orientation, have a CE90 horizontal accuracy of 25 meters and a LE90 vertical accuracy of 22 meters.

Subsequently, a DPGS survey has been executed in order to collect additional GCPs (Ground Control Points) to be utilized in the orientation and aerial triangulation phases. For this reason, the GCPs have been selected in the way to be uniformly distributed over the study area and in zones easily distinguishable on the imageries (edge of metal roof, tukul enclosures, etc). The topographic survey has been carried out by n.2 GPS Leica™ SR530, n.1 Leica™ 1200 and n.1 Leica™ GS20 receivers. To guarantee high accuracy and simultaneously appropriate acquisition times, the measures have been recorded both in differential static modality and in Real Time Kinematic (RTK) way. The static modality, with a long acquisition (up to three hours) times has been referred to measure the BNP 267 trigonometrical station located few kilometres North-East to the archaeological site, whose coordinates and description cards were made available by the Addis Ababa Mapping Agency. Nine new reference stations, uniformly distributed over the area, have been properly built and measured for the project as rover.

The remaining GPS points have been acquired using the Real Time Kinematic procedure, utilizing the nine new stations as reference, and getting the correction through a Radio Modem; such a survey method permitted short observation times and quick station set-ups.

Besides the GCPs, all the survey archaeological points, the main archaeological and geological sites present in the satellite images have been measured, for a total of 171 records.

According to the Ethiopian 1:50,000 topographic maps reference system, the collected GPS data were converted from the WGS84 coordinate system of acquisition to the national UTM system, spheroid Clarke 1880, datum Adindan, zone 37 N.

The scenes, external orientation carried out by the RCPs has been improved utilizing the GCP coordinates measured by the GPS survey (16 GCPs in North^{ern} couple, 27 GCPs in the South^{ern} one) (Fraser *et al.* 2006, 182–194; Jacobsen, 2002). The photogrammetric process has been executed by LPS module of Leica GeoSystems™ Erdas Imagine 9.1 software.

Together with the GCPs, with the aim of increasing the orientation accuracy and to support the stereoscopic vision, respectively 114 and 74 tie points from the North^{ern} and South^{ern} model have been utilized. Starting from the Standard original format of the scenes, the orientation has been refined through Rational Functions with a second level polynomial order. The resulting 0.25 and 0.6 pixel RMSE (Root Mean Square Error), according to 1 meter spatial resolution of IKONOS II imageries, corresponds to 0.25 and to 0.6 meters at the ground. Such an error, considering the reference scale, was

deemed satisfactory. The two sets of IKONOS II scenes were oriented separately and not as a group because of the lack of sufficient overlap.

From the oriented scenes, a preliminary Digital Elevation Model (DEM) of the area has been extracted by utilizing automatic "Image-Matching" algorithms, integrated with stereo-restituted information. The smooth morphology of the area and the rare presence of tall trees and big villages, favoured the production of an accurate DEM.

After the accomplishment of interior and absolute orientation, the stereoscopic view and the topographic stereo restitution have been possible. The restitution concerned punctual, linear and polygonal features such as buildings, roads, paths, streams, rivers and escarpments. The contours and the spot eights, preliminarily generated by automated extraction, have been checked and corrected in stereoscopy. Through the use of all elevation and morphological data, such as contours, spot eights, roads, stream, rivers and escarpments, a new DEM 10m cell size has been created. From this DEM, orthorectified 1m pixel size images have been generated; they constitutes the basis of the GIS and permitted the creation of the ortophotomap of the area at a scale of 1:10,000 (*Fig. 1*).

For the creation of the topographic geodatabase, the Tuscany Region Guidelines (year 2007) related to graphic contents and codes for the production of numeric cartography at a scale of 1:5,000 / 1:10,000, level 3 Version 3.5 (Regione Toscana, 2007), have been utilized. In this way the resulting GIS, to be delivered to the Ethiopian Archaeological Service, constitutes a technical reference for the creation of possible additional maps at a similar scale.

The attribution of the proper symbology to topographic elements in the topographic map, in terms of size, thickness and spacing was done according to the Tuscan Region Guidelines (2007), while the limits and the rules of representation and generalization were chosen following Slocum (Slocum *et al.* 2005, 201–212) and of the Swiss Society of Cartography (*Swiss Society of Cartography* 2005).

For the attribution of the colours to the features, it was decided to follow the scheme utilized for the Italian national cartography, along with the pantone colours.

Looking to the future, it has seemed useful to create the land use geodatabase, in the way to monitor and safeguard the area. The chosen codes derive from the Corine Land Cover Nomenclature, 3 level (Heyman *et al* 1994), with widening to the 4 level, when possible, thanks to the high spatial resolution of the imageries.

Such widening follows the guidelines for the compilation of the Management Planes of the SIC (Community Importance Sites) of the ETC-L.C. (European Topic Centre on Corine Land Cover) and of the Italian Ministry of the Environment.

The minimum unit to be interpreted must correspond to a surface of at least 1 ha. For the linear elements, infrastructures and water courses, the minimum unit to be represented must be 20m wide and 250m long, except infrastructural features (e.g the roads), that must be displayed.

The colours of the polygons indicating the landuse of the represented area have been assigned on the base of the official chromatic codification proposed by the Corine Land Cover 2000 Project (CLC2000).

The landuse constituted the background for the produced topographic-archaeological map (*Fig. 2*).

4. Conclusions and future developments

The archaeological map of Melka Kunture will constitute an useful instrument aiming to preserve several sites distributed on a wide area. To achieve this objective, it will be delivered to the Ethiopian Archaeological Service, permitting to propose Melka Kunture as future UNESCO World Heritage Centre. Moreover, it could be possible to promote it in a tourist circuit, favouring some economic benefits in developing country.

In a scientific view, basing on the satellite images multispectral data and on the GIS, every archaeological element will be analyzed in relation with the palaeo-geographic characteristics of the territory. The data could be processed, by means of dedicated software, aiming the proposal of a settlement model based on the relation among contemporary sites and the distance from specific environmental variables (i.e. distance from water, from raw material) (Clevis *et al.* 2006, 843–874; Llobera 2001, 1005–1014; Wheatley and Gillings 2002).

Starting from the analyzed variables, the future research activities could be oriented to the excavation of unexplored remains, in a way to support the conservation and the protection for this invaluable heritage.

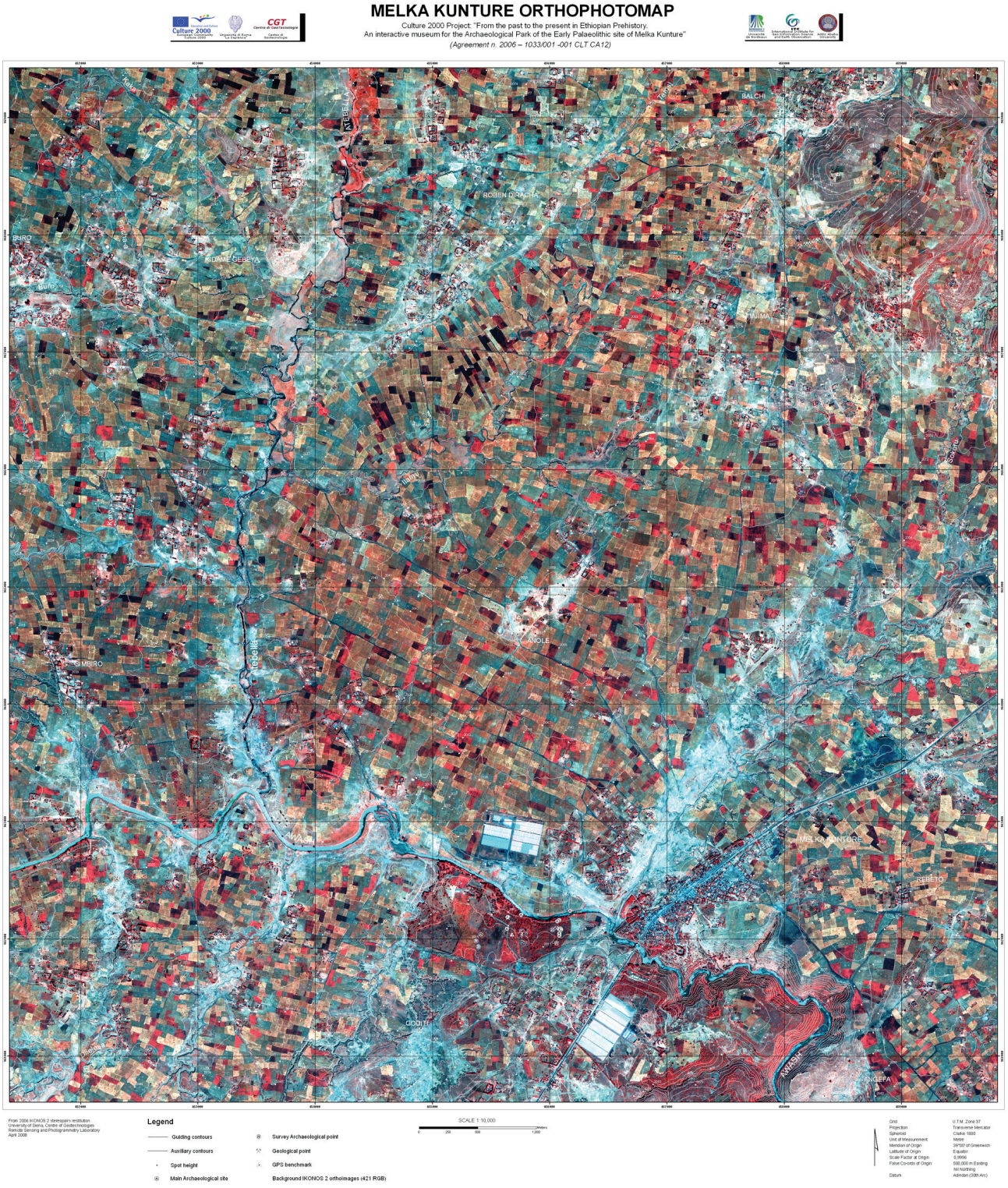

Fig. 1. Melka Kunture Ortophotomap.

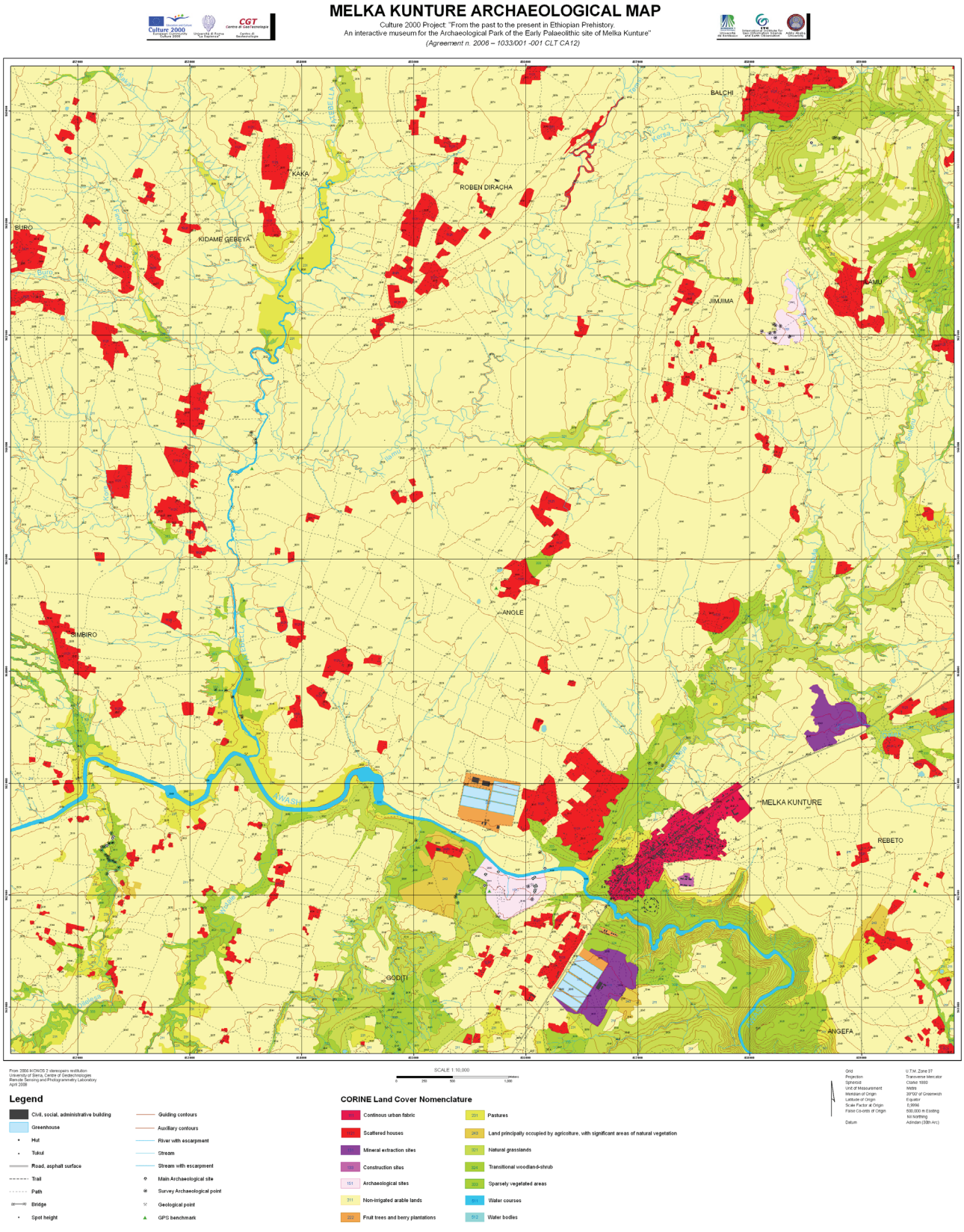

Fig. 2. Melka Kunture Archaeological Map.

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