Journal of Archaeological Science 38 (2011) 2017–2023

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Multitemporal analysis for preservation of obsidian sources from Melka Kunture (Ethiopia): integration of fieldwork activities, digital aerial photogrammetry and multispectral stereo-IKONOS II analysis

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ARTICLE INFO

Article history:
Received 30 April 2009
Received in revised form
24 May 2010
Accepted 27 May 2010

Keywords:
Obsidian
Melka Kunture
Remote sensing
Digital photogrammetry
Spectral signatures
Multitemporal analysis

ABSTRACT

An integrated analysis of recent satellite imageries and dated aerial photos demonstrated to be a good investigation tool (Gallo et al., 2009) for the identification of new sites and for the assessment of landscape changes of wide archaeological areas in Ethiopia.

In the Melka Kunture archaeological sequence, the obsidian exploitation represents a leitmotiv during the last 1.7 Myr and the first known example of Oldowan utilization (Piperno et al., 2009).

The primary nearest obsidian source, the site of Balchit, 7 km North from Melka Kunture, is a dome-flow dated to 4.37 ± 0.07 Myr (Chernet et al., 1998). Large areas of the Balchit site are covered by secondary obsidian debris resulting from the erosion of primary sources.

The proximity between primary and secondary Balchit obsidian sources and the high quality of this raw material, easily available in large quantity, represent a unique condition in the framework of the Oldowan and Acheulian East African sites (Piperno et al., 2009).

In order to evaluate the human impact on the multitemporal change of obsidian sources, the land use of the study area, following the CORINE Land Cover Nomenclature, has been classified from aerial photos and IKONOS II imageries, respectively dated to 1972 and 2006. The accurate positioning of the primary and secondary sources and their extent have been measured thanks to the multispectral characteristics and to the high spatial resolution of the available imageries.

Satellite scenes, covering an area of about 100 km^2, have been also utilized in stereoscopy for the creation of the new topographic map, at the scale of 1:10,000, and of the Digital Elevation Model (DEM).

Images orientation has been performed through the use of Rational Polynomial Coefficients (RPC) which accuracy has been improved by the availability of Ground Control Points (GCPs) properly measured during a DGPS survey. Then, the images have been orthorectified and radiometrically and spectrally enhanced in order to favour the recognition of obsidian presence, in respect with ground observations collected during fieldworks.

Photointerpretation and semi-automatic classification processes of images have been performed with the support of spectral signatures of obsidian samples recorded by a FieldSpec Pro spectroradiometer, ranging in the visible-short wave infrared electromagnetic interval (0.4–2.5 μm).

1. The Balchit obsidian

The site of Balchit, located 7 km North of Melka Kunture (Fig. 1), is one of the most important palaeolithic sites of the African world (Piperno et al., 2009; Poupeau et al., 2004) with an extent greater than 300 ha. Due to the extension of the site (over 100 km^2), the cultural palaeolithic sequence, dated from 1.7 to 0.2 Myr, and the variety of the archaeological remains of different chronological phases, Melka Kunture, located 50 km South of Addis Abeba in the Upper Awash River basin, represents a very important prehistoric site of high scientific value (Chavaillon and Piperno, 2004). More than 80 archaeological layers have been identified during 40 years of researches; 30 of them have been extensively excavated with surfaces ranging from 50 to 250 m^2. Several thousands of lithic tools, faunal and sometime human remains [*Homo erectus* (*sensu lato*) and archaic *Homo sapiens* (Coppens, 2004)] have been discovered for many archaeological layer.

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doi:10.1016/j.jas.2010.05.018

The area of Balchit is characterized by an obsidian primary source, dated to 4.37 $\pm$ 0.07 Myr (Chernet et al., 1998), and by the presence of obsidian debris with different size resulting from the erosion of the primary source. Obsidian cobbles and pebbles are also largely distributed in ancient, recent and present alluviums of the entire Melka Kunture region and available for prehistoric groups since Oldowan times.

Balchit obsidian geologically derives from a rhyolitic rock not crystallized while setting. The rock has a black colour with a very fine fluidity, even if some facies, affected by pneumatolithic actions or by oxidations, have a greenish or reddish colour. This natural glass, easy to break, is compact and homogeneous, hard and poorly porous, vitreous or with a fine texture (Poupeau et al., 2004). The Melka Kunture obsidian exploitation, during the Oldowan, represents the first known example of utilization of this high quality raw material. Its exploitation is more or less continuous in Melka Kunture area throughout the Acheulian; only two other Acheulian examples, Kariandusi and Kilombe (Gowlett, 1993; Gowlett and Crompton, 1994) are known in Eastern Africa and dated around 0.7 Myr. From the Middle Stone Age onwards, obsidian became the major component of the Melka Kunture lithic assemblages like in almost all the East African sites (Merrick et al., 1994; Piperno et al., 2009).

Concentration of obsidian debris and artifacts as large blades, flakes and pyramidal or prismatic cores at Balchit can be considered as the waste by-products of various “chaînes opératoires” aimed at different output and belonging to different ages, at least from the Late Stone Age to the modern times.

The primary obsidian source at Balchit included within volcanic sediments, is visible in several outcrops along gullies. Three types of concentrations of obsidian debris and artifacts are distinguishable: concentrations 60 m long and 50 cm thick, concentrations 10 m long and 1 m thick, and finally more limited modern pit-like depressions of anthropic origin, excavated to reach the ground water table and successively filled by obsidian wastes.

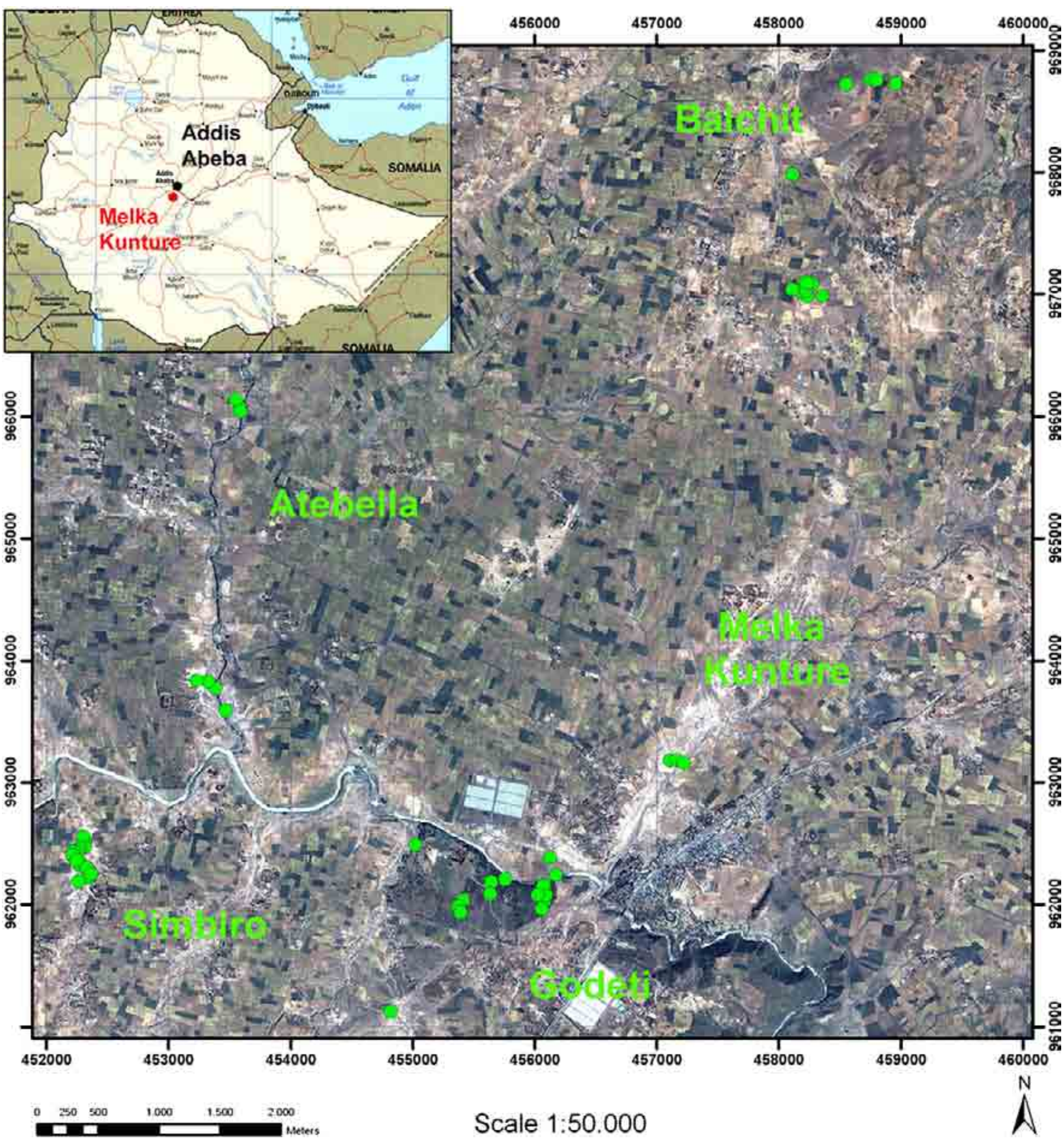

Fig. 1. Study area.

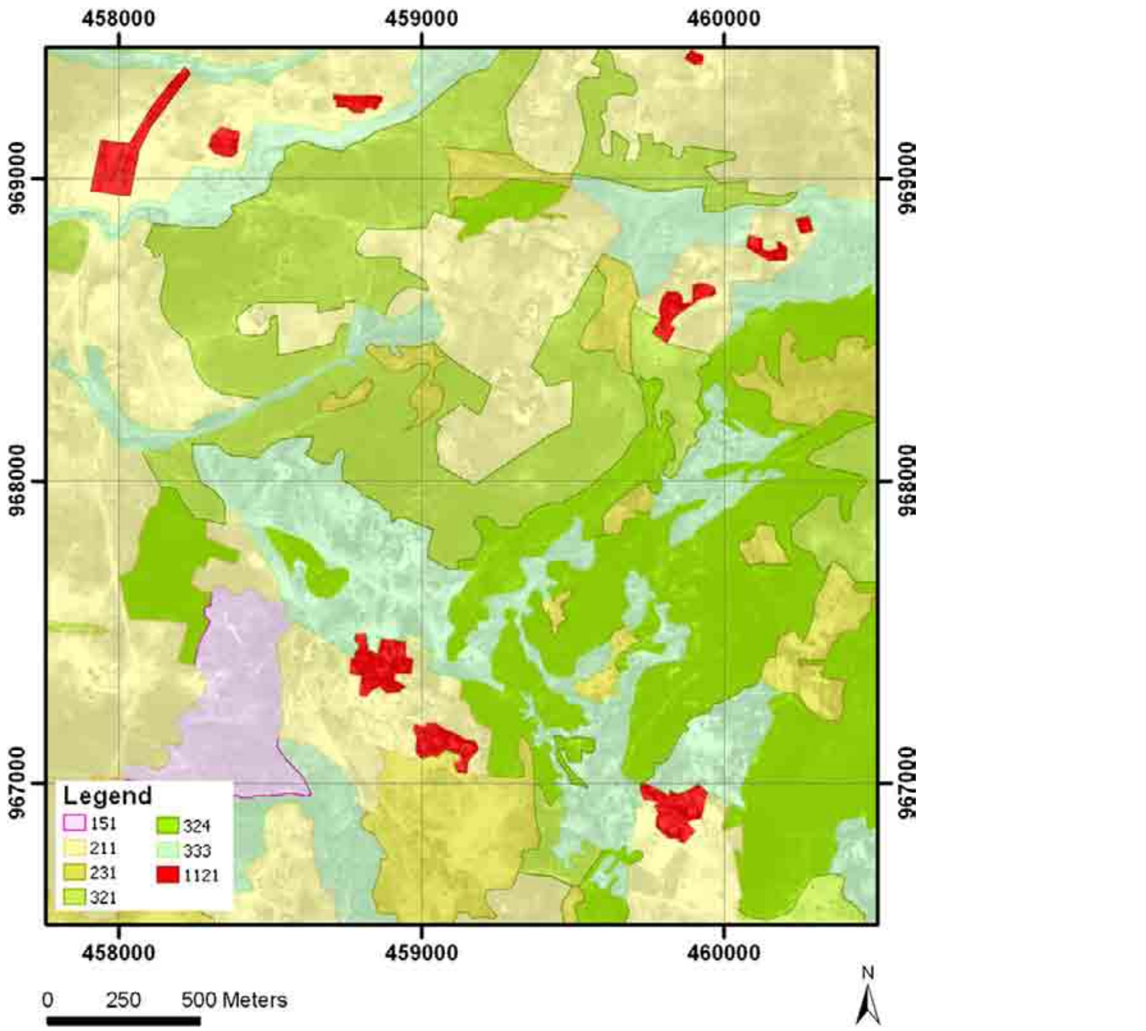

Fig. 2. Land use 1972 overlapped to the aerial orthophoto. Legend: 151. Archaeological area; 211. Non-irrigated arable land; 231. Pastures; 321. Natural grasslands; 324. Transitional woodland-shrub; 333. Sparsely vegetated areas; 1121. Discontinuous urban fabric.

2. Methods and results

Goals of the work were the multitemporal identification of primary obsidian source and the evaluation of superficial extension of obsidian concentrations in Balchit locality with the purpose of suggesting suitable measures of safeguard to protect the cultural heritage.

The objective of assessing the multitemporal changes of obsidian presence was reached by the use of integrated techniques of Remote Sensing and GIS (Siart et al., 2008). Input data for the multitemporal analysis has been a series of panchromatic aerial photos at a nominal scale of 1:60,000, dated 1972 (Read et al., 1973), and two couples of satellite stereoscopic IKONOS II imageries dated 2006, November. The use of high resolution satellite imageries (1 m spatial resolution), characterized by good radiometric quality and geometric accuracy (Dial and Grodecki, 2003; Holland et al., 2006), allows to obtain accurate results (De Laet et al., 2007) with remarkable costs saving in this kind of landscapes, especially if compared with aerial photos utilization (Jacobsen et al., 2008); recent aerial photos of developing countries are frequently either unavailable or characterised by inadequate scale for archaeological applications.

Two couples of Standard Stereo-IKONOS II 1 m pan-sharpened satellite imageries, covering an area of 102 km^2, have been acquired with the aim of studying the archaeological area and to create, from the stereoscopic digital restitution, a new topographic map of Melka Kunture at a scale of 1:10,000. For images orientation and aerial triangulation, together with the RPC, additional GCPs collected during a DGPS survey have been utilized. In order to guarantee a high accuracy on the GCPs positioning, the coordinates measurements have been done both in differential static modality and in Real Time Kynematic (RTK) way. The static modality, with acquisition times long up to 3 h, has been adopted to measure the BNP 267 trigonometrical station located few kilometres North-East to the archaeological site; its coordinates and description cards were made available by the Addis Abeba Mapping Agency. Nine new reference stations, uniformly distributed over the area, have been properly built and measured in a static way; then, they have been utilized as reference stations during the RTK acquisition of the remaining GCPs through radio modems; such a survey method has permitted accuracy, short observation times and quick moving.

According to the Ethiopian 1:50,000 topographic maps reference system, the collected GPS data have been reprojected from the geographic WGS84 coordinate system of acquisition to the national UTM system, (Spheroid Clarke 1880 – Datum Adindan – Zone 37 N).

The satellite imageries have been externally oriented. From the stereorestitution of the oriented stereopairs a DEM 10 m groundel

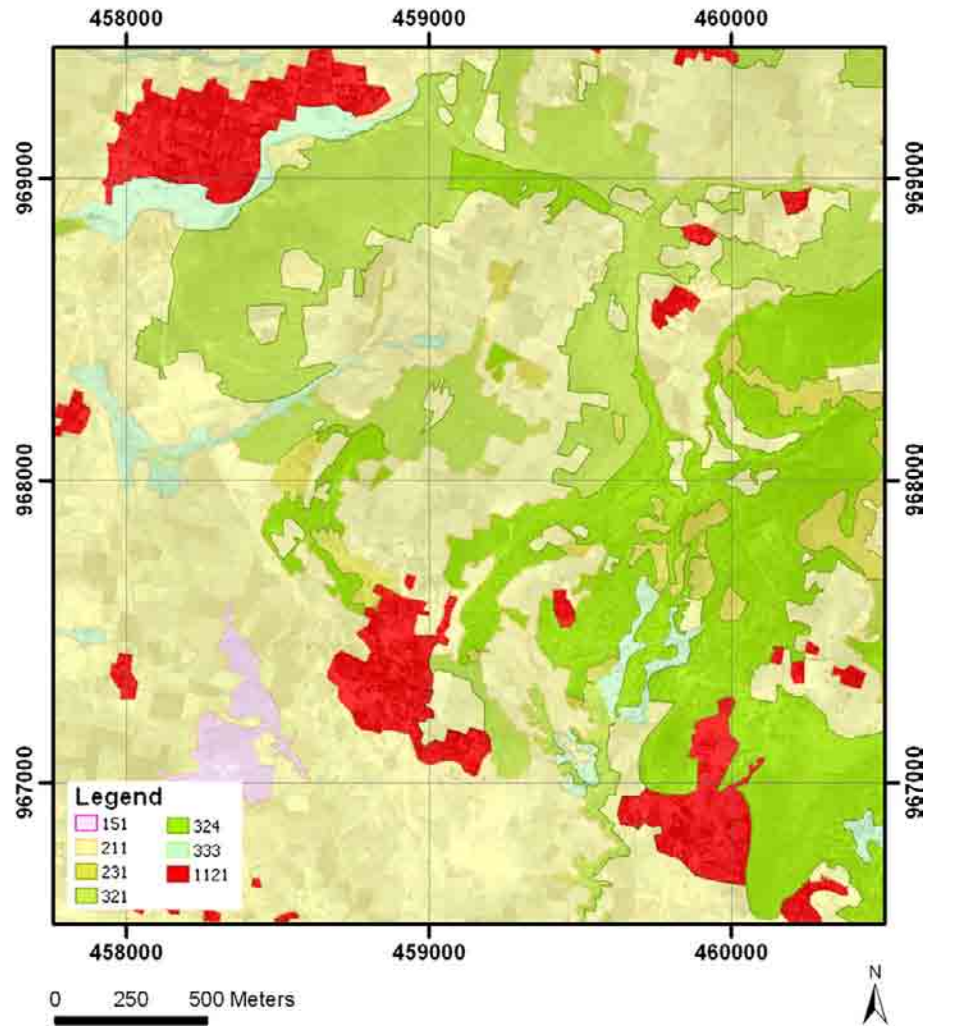

Fig. 3. Land use 2006 overlapped to the satellite IKONOS II orthoimage. Legend: 151. Archaeological area; 211. Non-irrigated arable land; 231. Pastures; 321. Natural grasslands; 324. Transitional woodland-shrub; 333. Sparsely vegetated areas; 1121. Discontinuous urban fabric.

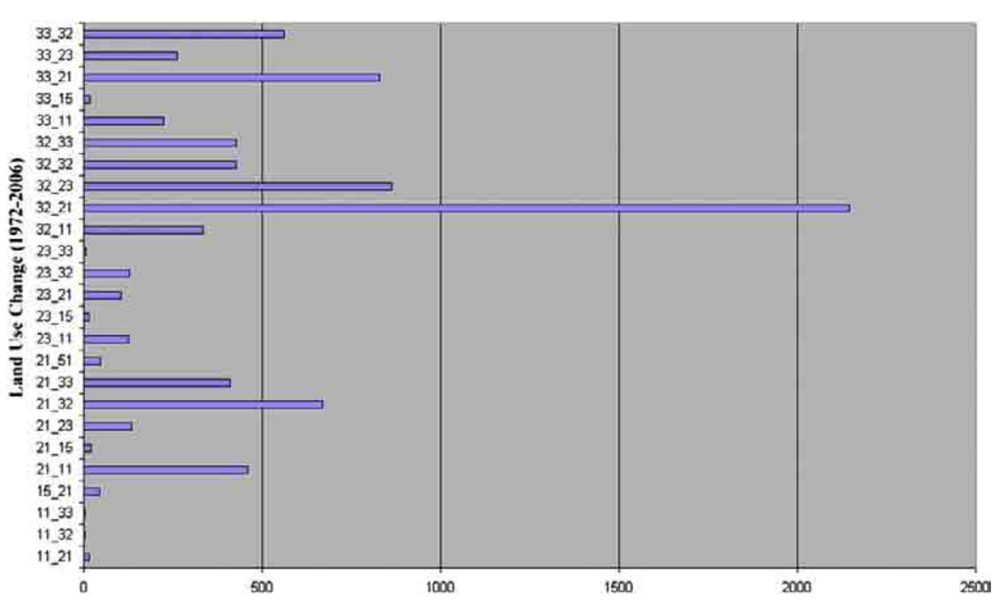

Fig. 4. Land use changes. CORINE nomenclature level 2.

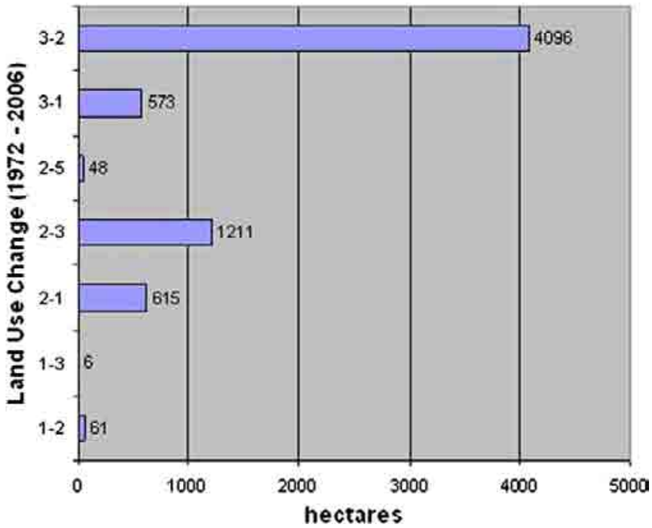

Fig. 5. Land use changes. CORINE nomenclature level 1.

has been created and it has been utilized, together with the exterior orientation parameters, in the creation process of orthoimageries with a spatial resolution of 1 m both for the years 1972 and 2006.

The orthocorrected scenes have been radiometrically and spectrally enhanced in order to favour the identification of obsidian presence in respect with ground data collected during fieldworks. The principal component transformation has been applied to the orthocorrected pan-sharpened IKONOS II scene, in a way to obtain non-correlated synthetics layers useful, especially the first, to recognize some obsidian sources not evident in the natural light bands and to remove doubts in cases of uncertain attribution.

The identification of obsidian outcrops and dispersion areas has been obtained from the photointerpretation and from the semi-automatic classification of images. Moreover, multitemporal land use geodatabases have been created (Figs. 2 and 3) in order to quantify human impact on the sources and possible lost of obsidian sites during the last 35 years. Then, a post-classification comparison has been executed between the two geodatabases. The selected land use codes are related to the 3rd level of the CORINE Land Cover Nomenclature (Heymann et al., 1994), with some widening to the 4th level in areas of particular interest. The nomenclature of such widening follows the guidelines dictate by the ETC-L.C. (European Topic Centre on Corine Land Cover) and by the Italian Ministry of the Environment, in relationship to the Management Planes of the SIC (Community Importance Sites).

The identified land use classes are the following: 151 "Archaeological areas", 211 "Non-irrigated arable lands", 231 "Pastures", 321 "Natural grasslands", 324 "Transitional woodland-shrub areas", 333 "Sparsely vegetated areas", 1121 "Discontinuous urban fabric".

Figs. 4 and 5 highlight two of the main trends in the land use modifications: a large area classified 32 "Scrub and/or herbaceous vegetation associations" and 33 "Open spaces with little or no vegetation" in 1972 has changed to the class 21 "Arable land" and 23 "Permanent crops" in 2006, for a total area of about 4100 ha. Almost 1200 ha of agricultural or natural land (class 2 and 3), classified in the year 1972, have converted their use to "Urban fabric" (class 11) in 2006.

These changes testify the social and economical development of the area potentially dangerous for the preservation of the archaeological sites related to obsidian sources.

The multitemporal change detection on the obsidian sources extent and localization, carried out as already mentioned by photointerpretation and supervised classification techniques, has been aided by spectral signatures (Fig. 6) collected on obsidian samples by the use of a FieldSpec Pro spectroradiometer ranging in the 0.4–2.5 μm electromagnetic interval.

The photointerpretation of spectrally corrected images has allowed the recognition of known source areas that have been used as reference signatures; then, a non parametric rule was applied for the semi-automatic classification of the whole area. Post-classification procedures have been successively applied in order to improve the informative contents of the classified data: a statistical majority 3×3 filter has been twice applied to the classified image while areas smaller than 9 m^2 have been erased in order to enhance model's reliability. The results from the semi-automatic classification have been converted from raster to vector format, checked and improved by the photointerpretation of the corrected 1972 and 2006 images.

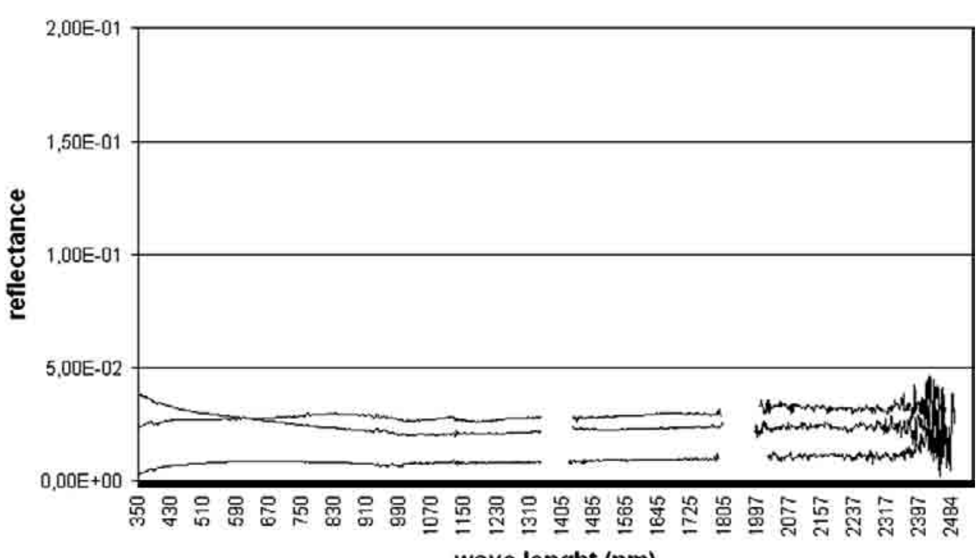

Fig. 6. Spectral signatures on three Balchit obsidian samples.

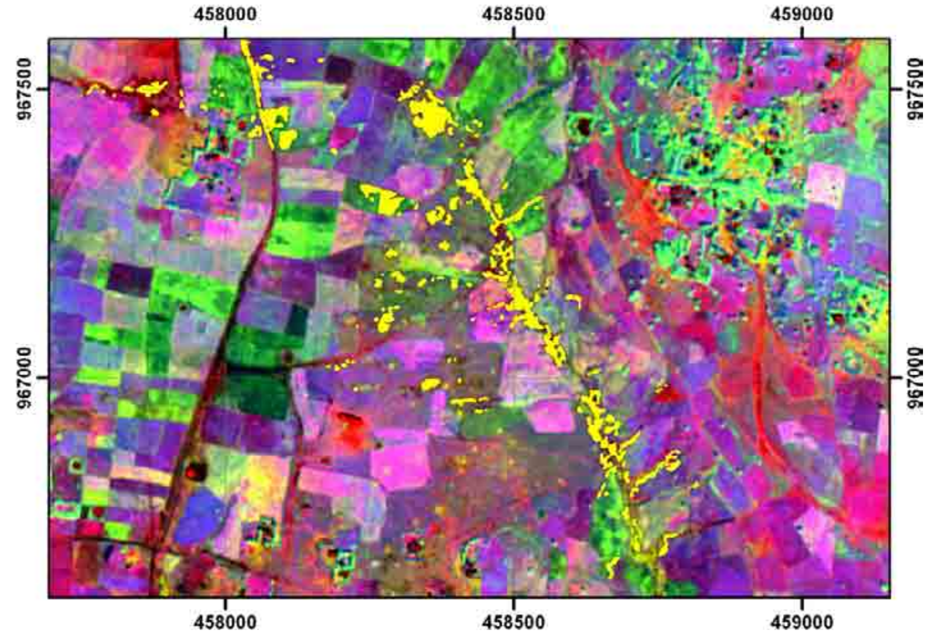

Fig. 7. 2006 Obsidian evidences overlapped to the IKONOS II Principal Components (321 RGB).

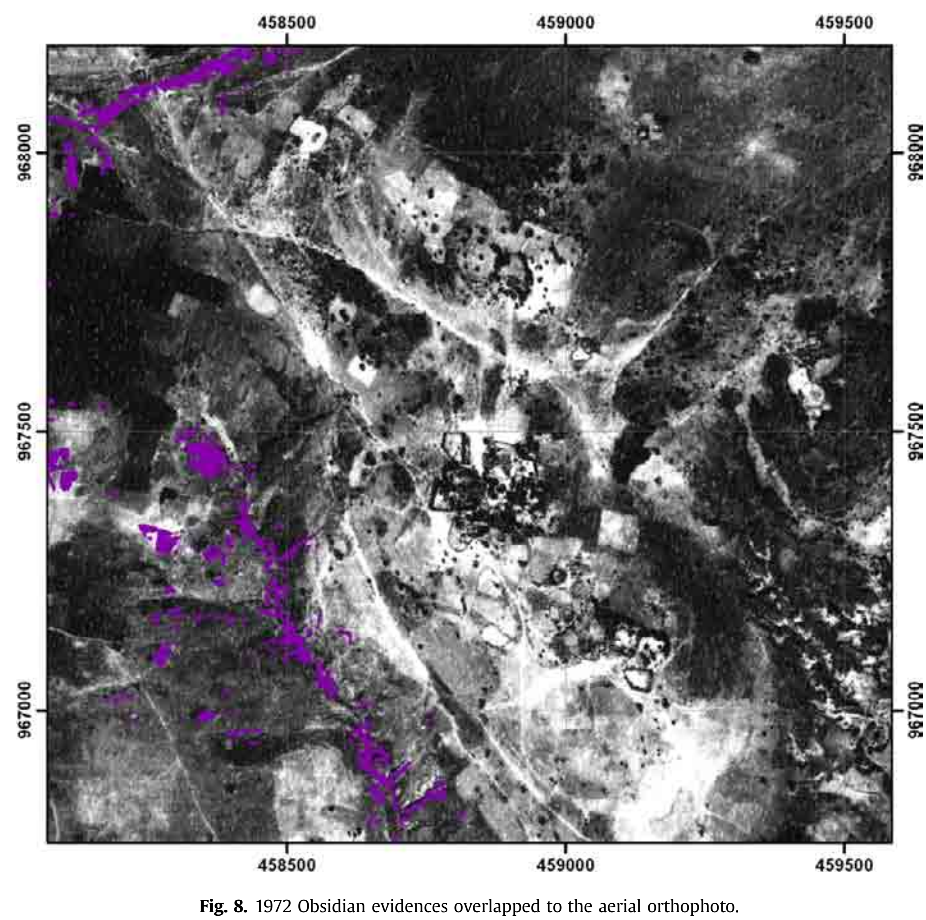

Fig. 8. 1972 Obsidian evidences overlapped to the aerial orthophoto.

The primary and secondary sources of obsidian have an extent of 12,156 ha in 2006 (Fig. 7) and of 11,584 ha in 1972 (Fig. 8).

All the produced data has been organised into a Geographic Information System (GIS) and showed on the Melka Kunture archaeo-topographic map at a scale of 1:10,000.

3. Conclusions

Despite large land use changes, results about multitemporal extent of primary and secondary obsidian sources at Balchit site show a nonsignificant variation. Agricultural activities are rapidly increasing but the utilized tools, tractors and methods for farming have been still not invasive and they have not penetrated the soil up to remove and to scatter the obsidian rock.

Up to now, agriculture do not represent a menace for the archaeological site conservation, but the multitemporal land use analysis highlights an urban development increase and the introduction of the mechanized agriculture that, without adequate policies of development and management, are a documented threat for any archaeological site (Beck et al., 2007).

In order to avoid this risk, the area of Balchit has already been included in the archaeological park of Melka Kunture, proposed to UNESCO as future World Heritage Centre, in a way to permit safeguard activities and monitoring of its cultural value.

The approach of studying the landscape combining several methods of remote sensing analysis has offered numerous and accurate results useful to monitor the land use and the state of archaeological sites and to plan the safeguard of the cultural heritage.

Acknowledgements

The researches at Melka Kunture and Balchit have been carried out thank to the permission of The Ministry of Culture & Tourism – Authority for Research & Conservation of Cultural Heritage – and the Oromia Culture and Tourism Bureau. The field and laboratory activities have been financially supported by the Italian Ministry of Foreign Affairs, the Sapienza University of Roma, and the Aquitania Region.

The construction of the Melka Kunture archaeological park and the elaboration of the topographic archaeological map have been financially supported by the Oromia Culture and Tourism Bureau and by the Culture 2000 project of the European Commission "From the Past to the Present in Ethiopian Prehistory. An Interactive Museum for the Archaeological Park of the Early Palaeolithic site of Melka Kunture", Agreement n. 2006 – 1033/001 – 001 CLT CA12.

The authors thank R. La Saponara, N. Masini and T. Farr for the opportunity to publish this paper. We would like to thank the reviewers for their useful comments.

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