SPATIAL ANALYSIS OF LAND COVER PROPERTIES FOR AN ARCHAELOGICAL AREA IN AKSUM, ETHIOPIA, APPLYING HIGH AND MEDIUM RESOLUTION DATA

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INTRODUCTION

Aksum, in the Tigray highlands of northern Ethiopia, was the political, cultural and commercial centre of the Aksumite state in the first millennium A.D. (Butzer, 1981; Bard *et al.*, 2000). Aksumite urban centres, towns, and villages were established throughout the region, and large areas were used for agriculture and livestock grazing. These anthropogenic activities have continued to the present time and have caused landscape transformations affecting soil, lithology and vegetation. As a result, land degradation is a major problem and affects the natural resources as well as social and economic conditions for living in this region (Feoli *et al.*, 2002; Nyssen *et al.*, 2004).

The Aksum region has so far not been systematically mapped in terms of its geo-environmental history. The first geologic map was compiled at a scale of 1:250,000 by Tadesse (1997) and published by the Geological Survey of Ethiopia in 1999. Geomorphologic and pedologic maps at an equivalent or smaller scale of the study area are non-existent or unpublished. Thus, this region remains largely unmapped and its environmental history poorly understood.

This work presents a preliminary investigation of the geologic and pedologic characteristics of Bieta Giyorgis hill and its surroundings in Aksum and is based on two field trips conducted in May 2001 and May 2006. The investigation consisted of mapping main landscape units and land cover classes from field surveys, aerial photographs and high- and medium resolution images (IKONOS, ASTER); collecting soil samples for laboratory analysis; and creating a digital elevation map (DEM) from topographic maps for terrain analysis. An important objective is to establish the relationship between environmental setting and archaeological site distribution.

Figure 1. Volcanic plugs in the study area

The Aksum area is composed of two main lithologic units of Tertiary age. The Koyetsa volcanics (stratified flood basalts) form a gently undulating plateau surface that is intruded by numerous volcanic necks belonging to the Adwa trachyte formation (trachytic and phonolitc plugs). These plugs stand out as circular hills *(Figure1)* due to their rock composition that is more resistant to erosion than the surrounding plateau basalts. Bieta Giyorgis hill is one such plug. Widespread volcanic activity in the early Cenozoic covered large parts of the Tigray highland with a thick layer of Tertiary basalts (flood basalts). Beneath the basalt layer is a sequence of Paleozoic and Mesozoic sedimentary rocks that overlay unconformably the Precambrian basement rocks.

DATA AQUISITION AND METHODOLOGY

Field survey in and around Bieta Giyorgis:

- In 2001, a joint archaeological expedition was conducted as part of a project carried out by the University of Naples “L’Orientale” (Italy) and Boston University (USA).
- In 2006, Boston University in collaboration with Mekelle University and the Geological Survey of Ethiopia conducted a survey.
- Soil surface cover samples and field observations of abiotic and biotic characteristics were taken and complemented with soil and mineralogical analyses of the samples.

Satellite data:

- Medium resolution data from ASTER image of 21 May 2001.
- High spatial resolution data from IKONOS image of 12 December 2000.
- Pre-processing of the data included system, geometric and atmospheric corrections.

Geographic Information System (GIS) database:

- Topographic maps (1:50 000), Digital Elevation Map (DEM) and derived products.
- Archaeological sites with attribute data.

The following classification procedure was carried out:

ASTER

- Numerous training sites were first selected through visual interpretation of the ASTER image and subsequently inspected in the field during the May 2006 survey.
- Representative training sites were utilized to test several supervised classification methods of which the maximum likelihood classifier gave the best result in terms of distinguishing main lithologic and pedologic groups.
- Fifteen training sites or Regions Of Interest (ROIs) and a probability threshold setting of 95% were used to create the classification output map in *Figure 2*.
- The spectral separability of the selected ROIs was further verified using a statistical method based on Jeffries-Matusita and Transformed Divergence separability measures (Richards, 1999). A majority/minority filter with a kernel size of 3x3 was utilized to remove spurious pixels and to render a smoother image.

IKONOS

- A vegetation mask was built using a common vegetation index algorithm (NDVI) and applied to the image bands to separate vegetated from non-vegetated pixels.
- An unsupervised classification ISODATA method was implemented.
- Post-classification labeling was performed where individual classes were related to field observation points and photographs as well as to a digital elevation model (DEM) in order to determine their nature and label them (*Figure 4*).

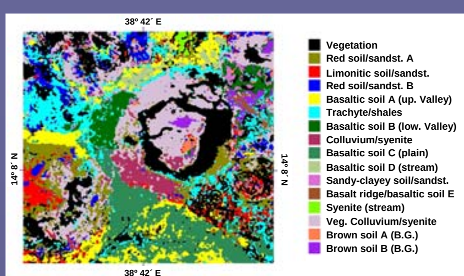
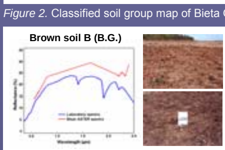


Figure 2. Classified soil group map of Bieta Giyorgis and surroundings based on ASTER.

Brown soil B (B.G.)

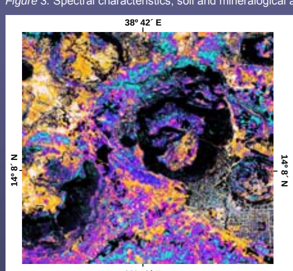


Soil analyses		Mineralogy*	
Clay (%)	19.4	Quartz	+
Silt (%)	37.3	Feldspars-K	Tr.
Sand (%)	43.3	Feldspars-Na	Tr.
Texture	Lloam	Phylosillicate**	+++(S,K)
Colour (Dry)	10YR4/3		
Colour (Wet)	10YR3/3		
Organic material (%)	1.0		
pH (satuated paste)	6.6		
Fe_2O_3 (%)	2.4		
Al_2O_3 (%)	0.63		
CEC (%)	36.23		
C/N	11.1		

*Tr. - trace; + - present, ++ - abundant; +++ - very abundant

**Phyllosilicates In order of decreasing presence: S: Smectite; K: Kaolinite.

Figure 3. Spectral characteristics, soil and mineralogical analyses for a soil surface.



Key

Black
Vegetated areas as well as shadows and water bodies.

White/Light Pink
Areas of anthropogenic activity where soil surface is compact and eroded mixed with dry vegetation fragments (e.g. paths and village square).

Cyan
Freshly ploughed areas. Soil has a dark appearance in contrast to surrounding areas and a rough surface texture.

Yellow/Orange
Brown or dark yellowish brown soil are mainly concentrated in central part of Bieta Giyorgis and on peripheral area.

Magenta
Dark brown soil with an increase in phyllosilicates on the soil surface.

Blue
Soil with high percentage of rock fragment on the surface. Areas of weathered igneous rock outcrops.

Figure 4. Classified soil group map of Bieta Giyorgis and surroundings based on IKONOS.

RESULTS AND DISCUSSION

The ASTER classification (*Figure 2*) shows that the parent material of the soils is directly related to the geology of the area, where the chemical and mineralogical compositions of the igneous rocks are mainly responsible for the soil formation. A diversity of soil types is found in this area due to the physical and chemical weathering of the rocks and minerals. In this case, soil properties such as clay minerals reflect this diversity and form an important role in the soil-forming processes of the area.

Spectral characteristics of a selected soil cover (*Figure 3*) obtained in the laboratory represent iron oxide and phyllosilicate absorption features (0.87 µm and 2.2 µm, respectively). The latter feature is clearly identifiable with the ASTER spectra and the corresponding mineralogical analysis (X-ray diffraction) indicates very abundant phyllosilicates with smectite and kaolite in decreasing order of abundance.

The IKONOS classification result (*Figure 4*) shows six distinctive color groups, which correspond to main surface classes and their respective color shades represent slight variations within a surface class. Because the classification procedure was designed to detect and classify mainly soil/rock surfaces, all class colors except the color black represent soil groupings that are spectrally distinguishable by the IKONOS sensor.

These image-based lithologic and pedologic classification maps are the first of their kind to be presented for the study area and can be further used as a valuable information layer in a Geographic Information System (GIS) for correlation analysis of settlement patterns, land and soil types as shown in *Figure 5*.

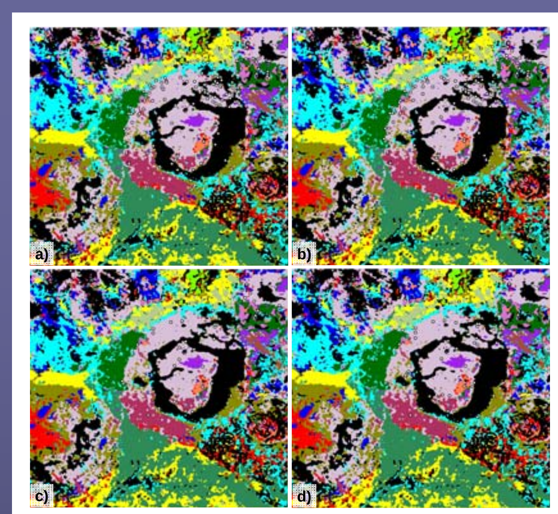


Figure 5. Soil group map of *Figure 2* with the corresponding archaeological site distribution (white dots) from a) Early, b) Classic, c) Middle and Late Aksumite. Map area and legend is the same as in *Figure 2*.

Figure 5 displays the distribution of archaeological sites in the study region from Early to Late Aksumite times (ca. 150 BC – AD 750). For all periods, the general pattern of ancient settlement is similar to that of today: structures were built on well drained, high relief terrain near the vertisols and related vertic soils of the surrounding plains, which were used for agriculture and grazing. Although the density of settlement changed significantly through time, these physiographic correlates of settlement location remained constant. As our research continues, we will explore the impact this long history of settlement had on the evolution of the regional landscape.

CONCLUSIONS

This study represents the first image-based lithologic and pedologic characterization of the greater Aksum area. Our goal is to map the physical environment of this region in order to understand the dynamics of human-environment relationships in Aksumite times, and to understand how the impact of human activities has affected the evolution of the landscape up to the present time.

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