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The Geomorphological Map of Mt. Amba Aradam Southern Slope (Tigray, Ethiopia)

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Abstract

The geomorphological map described below covers an area of about 100 km^2, located on the south-eastern slope of Mt. Amba Aradam (northern Ethiopia). It has been produced within the Ethio-Italian Cooperation Programme, in order to understand the recent evolution and present-day trends of the area as a basic tool for land reclamation/rehabilitation projects. The survey was carried out in three successive work campaigns (February 1995, February-March 1996 and December 2002) following the Italian Environmental Agency guidelines. The main geomorphological processes responsible for present-day landscape modelling in the investigation area, are gravity-driven mass movements and slope erosion due to running water. They strongly affect human activities, especially in terms of agriculture and infrastructure management. This map may therefore represent a useful document for land management as well as the initial step for the assessment of geomorphological hazard and risk.

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1. Introduction

The geomorphological survey and mapping of areas highly sensitive to mass-movements and soil erosion provides baseline information for land evaluation of natural hazards and related risks assessments. In the case of the Amba Aradam area the accompanying map is the first step in this process and is of significance due to the presence of roads and communication pathways between villages that are often affected by gravity movements and runoff processes. Moreover, sustainable land-management, incorporating agricultural practices, is improved by the knowledge of soil erosion features and their distribution. The map also outlines the "Amba" landscape, one of the most common Ethiopian landscapes developed in tropical regions on horizontal and sub-horizontal terrains.

Mt. Amba Aradam is located in the Highlands of Tigray, at an elevation ranging between ca. 2000 m and 2770 m above sea level (Figure 1). The climate may be classified as warm temperate, with a mean annual temperature of ca. 10°C and an annual rainfall of ca. 1000 mm. The rainfall regime is marked by a bimodal rainfall distribution with a lesser maximum ("belg") from March to May, and a larger maximum ("kiremt") from July to October (Ethiopian Mapping Agency, 1988). The present-day spontaneous vegetation is dominated by Juniperus and Podocarpus (Ethiopian Mapping Agency, 1988), although farming and grazing have reduced it to a sparse shrub cover, except for limited areas around churches where the holy character of the places allows their preservation.

The Mt. Amba Aradam southern slope is generally bare, with very thin soil patches systematically lacking organic horizons as a consequence of run-off processes. Human settlements are scattered around the main relief, being usually located on the most favourable topographic situations, such as flat surfaces and foot slopes, where alluvial/colluvial deposits allow subsistence farming.

2. Investigation methods

The geomorphological fieldwork has been performed in different periods: February 1995 - first field survey by F. Dramis and O. Berakhi using air photographs and enlargements from the 1:250,000 "Mekelle" ND 37-11 toposheet as base map; February-March 1996 - revision and integration of the previous work by A. Asrat, M. Coltorti and P. Pieruccini using enlargements of the newly published 1:50,000 "South Mekelle" and "Dela" toposheets; December 2002, short field revision of the geomorphological map draft by M. Coltorti, F. Dramis and P. Pieruccini. The fieldwork was supported by the

Figure 1. Location of the study area (Highlands of Tigray)

interpretation of two aerial photographs covers at about 1:50,000 scale, taken in December 1964 and February 1982 respectively.

The geomorphological legend follows the guidelines of the Italian Environmental Agency (APAT (Italian Natural Environmental Agency), 1994). Bedrock lithology has been mapped with flat colours while landforms and superficial deposits have been represented by means of shades and symbols, whose colour provide information on their genesis (basic colour) and state of activity, with denser colours for active forms and paler for inactive ones. A cross section has been included on the map to better illustrate the geometry of deep-seated gravitational movements. The final map has been redrawn from the "South Mekelle" and "Dela" topographic sheets with a simplified hydrographic network and contour lines at 20 m vertical intervals.

3. Bedrock lithology and structural setting

The outcropping bedrock consists of Jurassic, sub-horizontally layered or slightly inclined, marine varicoloured marls and marly clays with interbedded limestones, sandstones and gypsum layers (Agula Shales Formation Levitte, 1970) unconformably overlain by Cretaceous continental conglomerates, sandstones and laterite levels (Amba Aradam Formation Shumburo, 1968). The unconformity is due to a planation episode which followed the pre-Cretaceous marine regression (Coltorti et al., 2007). Dolerite sills and laccolites of Oligocene age (Justin-Visentin, 1974) are interlayered within the Agula Shales. Their thickness is greatly variable from several metres to more than 100 metres in the southern part of the slope. Small dolerite necks are exposed on the westernmost edge of the upper escarpment and west of the Mt. Amba Aradam summit. Even though the investigated area is located between two major fault systems (the 'Chelekwot fault belt' to the north and the 'Samre fault belt' to the south, both trending NW-SE), only minor faults are found affecting the Agula Shales with a NE-SW trend, south-east of Hintalo and west of Mengoda Gebre Mentes Kidus. Other small fault segments have been recognised in the Belesat Maryan area. Several fracture sets with different orientation also have been observed throughout the area.

Figure 2. Mt. Amba Aradam, a typical mesa (amba) landform. On the right side, the main scarp is affected by a local rock slump

4. Geomorphology

4.1 Structural landforms

The slopes of Mt. Amba Aradam are characterised by a structurally controlled mesa morphology (“amba” in the Ethiopian language) which has resulted from selective erosion of sub-horizontal bedrock layers and dolerite sills (Figure 2). Selective erosion scarps have been mapped according to their height (< 5 m; > 5 m). The higher ones are related to dolerite sills and thicker limestones layers whereas the smaller ones correspond to thinner gypsum and limestone layers. The most striking structural landform is the high escarpment, modelled on the Amba Aradam Formation in the upper part of the slope. Flat structural surfaces, up to 1 km^2 in areal extent, have been made by selective erosion of dolerite sills and stiff limestone layers.

4.2 Landforms due to gravity

Landslides of various size and typology affect the Mt. Amba Aradam southern slope. Large dormant rotational landslides involving bedrock and debris cover characterise the foot of the upper escarpment. Rotational slides and mudflows affect the marly-clayey levels of the Agula Shales. Evidence suggesting deep-seated gravitational movements (DSGM) have been mapped in large sectors of the investigated slope. They can be recognised by the occurrence of small to medium scale deformations of the bedrock, associated with counterslopes and trenches, sometimes filled with slope-waste and colluvial material in the head zone. There are typical features for DSGM, such as rotational single saggings (Hutchinson, 1988; Dramis and Sorriso-Valvo, 1994, sensu), that, being in an embryonic stage, do not require a defined shear surface at depth. Rock slumps of different size also affect the south-eastern slope of Mt. Amba Aradam (Figure 2). A continuous mantle of chaotic boulder-dominated reddish debris (Hintalo Giyorgis Unit), emplaced by slope wash and mass movements, is found at the base of the upper escarpment down to 2450 m. Remnants of the same materials are also present on top of isolated small hills down to 2150 m. Their distribution along the slope suggests the existence of an ancient depositional glacis overlying a pediment-like surface, formed by retreat of the Amba Aradam Formation escarpment and later dissected by the present drainage network. Due to their morpho-stratigraphic position, these materials constitute the oldest geomorphic-sedimentary unit of the area, deposited after erosion associated with the late Tertiary-Quaternary uplift (Almond, 1986) and can be generically referred to the Early-Middle Pleistocene. More recent slope-waste deposits and debris cones, made of poorly sorted angular and sub-angular, locally stratified debris fragments, are largely present in the western sector of the slopes and at the foot of the main escarpment. Colluvial deposits consisting of massive sands and silts with scattered debris fragments, are widespread in the investigated area at the foot of shaly-clayey slopes. Rounded blocks produced by weathering typically cover the dolerite hillslopes (Figure 3).

Figure 3. Sub-rounded blocks produced by weathering on a dolerite hillslope

4.3 Landforms due to the running water

Two well-developed alluvial terraces are present in the lower sector of the investigated slope. The higher terrace (Samre Road Unit) is made of unsorted, loose uncemented, reddish and often chaotic gravely beds with boulders and sandy matrix filling shallow and broad channels (Figure 4). The deposits are found up to ca. 40 m above the present-day thalweg. Elsewhere the upper surface is not well preserved due to runoff processes and, in the easternmost part of the map, it is a strath terrace with scattered gravels on top. The accumulation of these materials may be reasonably related to cold periods of the late Pleistocene, as suggested for other areas of the country (Osmaston and Harrison, 2005). The younger terrace (Bet Gebriel Unit), entrenched by a few metres in the older one, has been incised down to the bedrock, enabling observation of a stratigraphic sequence up to 20 m thick made of sands, silts and clays with rare gravely beds (Figure 5). A number of buried paleosoils with ^{14}C ages ranging from 4990±60 yr BP to 1950±50 yr BP provide a reliable record of slope stability and erosion phases during the last 6000 yr (Brancaccio et al., 1997; Machado et al., 1998; Dramis et al., 2003; Coltorti et al., 2003). The older phases might represent the effects of climatic changes or, similar to the younger ones (<3000 yr BP) could also be related to human impact as suggested by the presence of archaeological remains.

Both bedload and bedforms of watercourses change according to the distance from the source areas. Boulder-sized armoured beds are common in the upper parts of the streams whereas nearly planar sandy beds are typical of their distal portions. Abandoned channels have been observed on top of the Holocene terrace and in the southern part of the map, ephemeral swampy areas containing silty/clayey deposits are also present. Deep gullies characterise both the hillslopes and the alluvial plain (Figure 6). Their evolution is conditioned by minor climate fluctuations (air temperature and rainfall regimes) as well as by human activities (Billi and Dramis, 2001; 2003).

Figure 4. Channels cut on the bedrock and filled with gravels and sands at the base of the higher terrace (Samre Road Unit)

5. Conclusions

The Mt. Amba Aradam southern slope has a typical mesa morphology made by selective erosion of a horizontally stratified sedimentary sequence intruded by dolerite sills. The evolution of the landscape is constrained by the presence of the Hintalo Gyorgis Unit (Early? -Middle Pleistocene) that suggest the modelling of a pediment-like surface buried under debris material produced by the retreat of the Mt. Amba Aradam upper escarpment. Late Pleistocene alluvial terraces have formed within the older landscape incisions. The Holocene evolution of the area indicates the occurrence of repeated

Figure 5. The younger terrace (Bet Gebriel Unit) stratigraphic sequence made of sands, silts and clays with rare gravely beds and buried paleosoils

phases of slope stability (paleosoils formation) and disturbance (paleosoils erosion and burial).

The high escarpments bounding the upper mesa-like landform and the major dolerite sills drive most landslides and debris/colluvium deposition as well as large-scale, deep-seated gravity movements. Overland flow erosion and gullies are widespread, significantly affecting the soils. The detailed survey revealed no evidence for the glacial landforms and deposits suggested by Panizza (2002). The geomorphological map may be used as a base document for land management and planning as well as for any further assessment of geomorphological hazard and risk in the view of land reclamation/rehabilitation projects.

Software

The topographic base, the geomorphological features map and related layout has been drafted with Macromedia Freehand 10.

Figure 6. A deep gully incised in the Mt. Amba Aradam footslope

References

ALMOND, D. C. (1986) Geological evolution of the Afro-Arabian dome, Tectonophysics, 131, 301–332.

APAT (ITALIAN NATURAL ENVIRONMENTAL AGENCY) (1994) Carta Geomorfologica d'Italia - 1:50,000 - Guida al rilevamento, Servizio Geologico Nazionale, Quaderni serie III, 4, Istituto Poligrafico dello Stato.

BILLI, P. and DRAMIS, F. (2001) Recent climatic changes and the spreading of gully erosion in Ethiopia, UNESCO-IHP CNR, Grifo Publications, Perugia, pp. 131–141.

BILLI, P. and DRAMIS, F. (2003) Geomorphological investigation on gully erosion in the Rift Valley and northern highlands of Ethiopia, Catena, 50, 353–368.

BRANCACCIO, L., CALDERONI, G., COLTORTI, M., DRAMIS, F. and OGBAGHEBRIEL, B. (1997) Phases of soil erosion during the Holocene in the highlands of western Tigray (northern Ethiopia): a preliminary report, Istituto Universitario Orientale, Naples, pp. 29–44.

COLTORTI, M., DRAMIS, F. and OLLIER, C. D. (2007) Planation surfaces in Northern Ethiopia, Geomorpology, 89, 287–296.

COLTORTI, M., DRAMIS, F. and PIERUCCINI, P. (2003) Holocene soil erosion phases in the Amba Aradom area (Tigray, Ethiopia), Università Roma Tre, pp. 104–111.

DRAMIS, F. and SORRISO-VALVO, M. (1994) Deep-seated graviattional slope deformations, related landslides and tectonics, Engineering Geology, 38, 231–243.

DRAMIS, F., UMER, M., CALDERONI, G. and HAILE, M. (2003) Holocene climate phases from buried soils in Tigray (northern Ethiopia): comparison with lake level fluctuations in the Main Ethiopian Rift, Quaternary Research, 60, 274–283.

ETHIOPIAN MAPPING AGENCY (1988) National Atlas of Ethiopia, Addis Ababa.

HUTCHINSON, J. N. (1988) General Report: Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology, vol. 1, Balkema, Rotterdam, pp. 3–36.

JUSTIN-VISENTIN, E. (1974) Petrografia, chimismo e petrogenesi dei corpi subvulcanici di Macallè (Tigrai Etiopia), Memorie dell'Istituto di Geologia e Mineralogia, Universitá di Padova, 31, 1–33.

LEVITTE, D. (1970) The geology of Mekele. Report on the geology of the central part of sheet ND 37-11, Geological Survey of Ethiopia, Addis Ababa.

MACHADO, J. M., PEREZ-GONZALES, A. and BENITO, G. (1998) Palaeoenvironmental changes during the last 4000 yr in the Tigray, Northern Ethiopia, Quaternary Research, 49, 312–321.

NYSSEN, J., MOEYERSONS, J., POESEN, J., DECKERS, J. and HAILE, M. (2002) The environmental significance of the remobilisation of ancient mass movements in the AtbaraTekeze headwaters, Northern Ethiopia, Geomorpology, 49, 303–322.

OSMASTON, H. A. and HARRISON, S. P. (2005) The Late Quaternary glaciation of Africa: A regional synthesis, Quaternary International, 138-139, 32–54.

PANIZZA, M. (2002) Report on "Glacial" forms observed on Amba Aradam Mountain (Northern Ethiopia), Il Quaternario, 2, 275–278.

SHUMBURO, M. M. (1968) The Amba Aradam formation (formerly the Upper Sandstone), Mobil Petroleum Ethiopia Inc., unpublished.