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LATE HOLOCENE ENVIRONMENTAL CHANGES AND PRESENT-DAY GEOMORPHIC PROCESSES IN THE WURGO CATCHMENT (WOLLO, ETHIOPIA)

ABSTRACT: COLTORTI M., CINQUE A., FUBELLI G., DRAMIS F., ABEBE B. & ASRAT A., *Late Holocene environmental changes and present-day geomorphic processes in the Wurgo catchment (Wollo, Ethiopia)*. (IT ISSN 0391-9838, 2009).

The recent geomorphic evolution of a river catchment, located in Wollo (Ethiopia) between 2794 and 3374 m a.s.l., is outlined. The catchment is carved in Tertiary volcanics, intruded by felsic and mafic dikes. The slopes are bare and widely affected by erosion. At the slope toes thick colluvial deposits are found. Deep gullies cut these deposits, showing buried soils overlying alluvial gravels, likely emplaced during the last «Glacial». Most gullies have developed during the last decades, probably due to minor climatic fluctuations. A sequence of colluvial/alluvial deposits and buried soils, the lowest of which is dated 3900 yr ^{14}C BP (2570-2145 cal. BC), suggests a progressive reduction of vegetation cover likely due to climate change to drier conditions and man-made forest clearing.

KEY WORDS: Geomorphology, Climate change, Human impact, Holocene, Ethiopia.

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Questa nota prende in esame l'evoluzione geomorfologica di un bacino fluviale ubicato nella regione del Wollo (Etiopia), tra 2794 a 3374 m s.l.m. Il bacino è modellato in rocce vulcaniche del Terziario, intruse da dicchi sialici e femici. I versanti sono denudati e diffusamente interessati da processi erosivi che hanno accumulato alla loro base spessi depositi colluviali. Questi sono incisi da profondi fossi di erosione sulle cui pareti si rinvengono suoli sepolti sovrapposti a ghiaie fluviali messi in posto con ogni probabilità nell'ultimo «Glaciale». Molti di questi fossi si sono sviluppati negli ultimi decenni, probabilmente in conseguenza di minori fluttuazioni climatiche. Una sequenza di depositi alluvio-colluviali e suoli sepolti, il più basso dei quali datato a 3900 yr ^{14}C BP (2570-2145 cal. BC), suggerisce una riduzione progressiva della copertura vegetale dovuta verosimilmente a uno spostamento del clima verso condizioni aride e a deforestazione antropica.

TERMINI CHIAVE: Geomorfologia, Cambiamento climatico, Impatto antropico, Olocene, Etiopia.

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INTRODUCTION

Geomorphological research has been carried out in the Ethiopian highlands within the framework of the Ethio-Italian Cooperation Programme in order to understand the recent geomorphological evolution of landscape and its present-day trends as a basic tool for land reclamation/rehabilitation projects. In this perspective, the upper Wurgo catchment (ca. 15 km^2), a tributary of the Abbai (Blue Nile) River has been investigated.

The study area is located in the highlands of Wollo at elevations ranging between 2794 and 3374 m a.s.l. Its climate falls within the cool subtropical summer rainfall zone of FAO/UNESCO (1990) classification: the mean annual temperature is estimated to range between 8.0 °C and 11.0 °C; the annual rainfall is more than 1200 mm (Tegene, 1997). The rainfall regime is marked by a bimodal rainfall distribution, with a lesser maximum («*belg*» season) from March to May, and a larger maximum («*meher*» season) from July to October (Ethiopian Mapping Authority, 1988).

The potential vegetation of the area is that of *Juniperus* and *Podocarpus* woodlands passing to ericaceous woodland at the higher altitudes (Ethiopian Mapping Authority, 1988). However, as for a large part of the Ethiopian highlands (Pankhurst, 1990; Nyssen & *alii*, 2004), the study area has been extensively deforested in historical times. As a consequence, the original vegetation cover has disappeared and most slopes are bare or covered with scrub vegetation.

The Akesta village, with ca. 1000 inhabitants belonging the Amhara ethnic group, is located on the hydrographic left of the catchments at about 3100 m a.s.l.

INVESTIGATION METHODS

The investigation methods included detailed geological/geomorphological field survey and mapping (fig. 1), supported by air-photo interpretation (air-photographs ET2:S11/26, 323-326 at ca. 1:42,000 scale) and stratigraphical analysis of superficial deposits. The 1:50,000 Akesta topo-sheet (1039 A1) has been used as base work map.

BEDROCK GEOLOGY

The catchment bedrock consists of horizontally layered alkali basalt agglomerates, tuffs and lava flows of Middle Miocene age (Termaber-Megegez Formation; Ethiopian Institute of Geological Surveys, 1996). In the study area the following rock groups have been recognized: *basaltic*

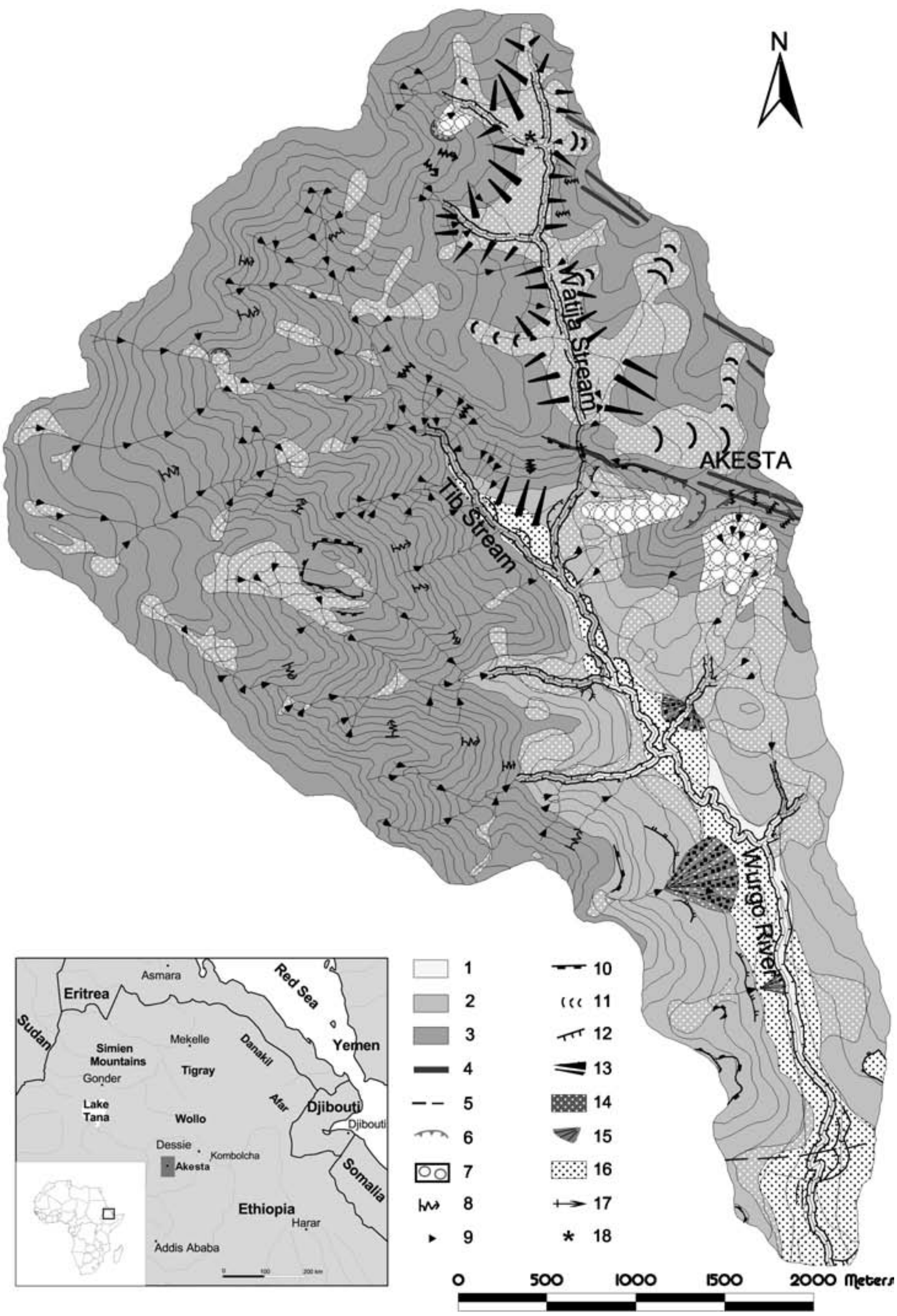

FIG. 1 - Geomorphological map of the Wurgo River catchment. Legend: 1. amygdaloidal basalt; 2. aphyric basalt; 3. basaltic agglomerates; 4. dyke; 5. fault/fracture; 6. landslide scar; 7. landslide; 8. slope erosion; 9. channel incision/gully; 10. structural escarpment; 11. trough floored small valley; 12. fluvial erosion scarp; 13. erosion glacis; 14. slope debris; 15. alluvial fan; 16. alluvial terrace; 17. waterfall; 18. investigated section.

agglomerates (basalt blocks with big crystals of pyroxenes, amphiboles and plagioclase); *aphyric basalt* (highly fine-alcaline olivine-basalts with micro-phenocrystals of fresh olivine and plagioclase in a ground mass of plagioclase and clinopyroxene; in some places, the basalt becomes porphyric with pyroxene and plagioclase phenocrystals); *amygdaloidal basalt* (characterized by the presence of big amygdales of calcite and quartz). This extrusive complex is cut by a swarm of subvertical rhyolitic-trachytic and basaltic dikes of variable thickness (from 1 m to 30 m) and spacing, mostly oriented N40W, NE and NNE.

GEOMORPHOLOGICAL SETTING

The study area is dominated by erosional landforms which started to develop by the end of the Tertiary through the progressive incision of the former volcanic surface following the Pliocene-Quaternary uplift of the Ethiopian Plateau (Almond, 1986; Coltorti & *alii*, 2007). Due to the horizontally layered bedrock, structure-controlled landforms are widespread. The cross profile of valley sides has a stepped aspect caused by the different competence of bedrock levels (lava flows, agglomerates, tuffaceous layers, deeply weathered volcanics). The overall slope angle is higher (up to 50°) in the deeply incised basaltic agglomerates of the western catchment sector, and definitely lower (up to 35°) in the aphyric basalt. The long-profiles of streams are segmented into a structure-controlled series of broad-gently sloping sectors, cut in deeply weathered and/or densely stratified lavas and tuffaceous layers, and steep-sided V-shaped sectors, cut through harder basalt layers or dikes. These latter sectors slowly retreat backward by regressive erosion dissecting the next upstream broad-gently sloping valley floors. A thick resistant felsic dike, over which the Watija Stream forms a 120 m high waterfall (fig. 2), allowed the generation upstream of a broad hanging valley (the upper sector of the Watija sub-catchment), whose gently-sloping topography strongly contrasts with the rugged aspect of the catchment remaining part.

Two alluvial terraces, respectively located at ca 25 m and 10 above the valley floor, are present along the Tib Stream and the lower Wurgo River. The alluvial deposits, generally thin, are made of gravels and boulders (gravel bars and channel filling), inter-layered with silty and sandy layers and lenses (local channel filling or overbank fines). Cross-bedding and cut-and-fill structures are common. Inactive alluvial fans are also present at the outlet of tributary valleys.

Slope deposits deriving from basaltic agglomerates, are mostly made of massive or crudely stratified, fine-grained colluvial materials with scattered rock fragments, and fine to medium-grained laminated sheet-wash sediments. Coarse-grained debris deposits, locally including weathering spheroids, are commonly found at the base of basalt escarpments.

LATE HOLOCENE GEOMORPHIC-STRATIGRAPHIC EVOLUTION

A stratigraphic section of alluvial/colluvial sediments and buried soils has been investigated in the upper sector of the Watija basin (figs. 1 and 3). The basal part of the section (layer 4) is made of ca. 50 cm thick silty-clayey level overlain by a buried dark brown eutric vertisol (Tegene, 1997), dated 3900 ± 70 yr 14C BP / 2570-2145

FIG. 2 - The Watija Stream waterfall.

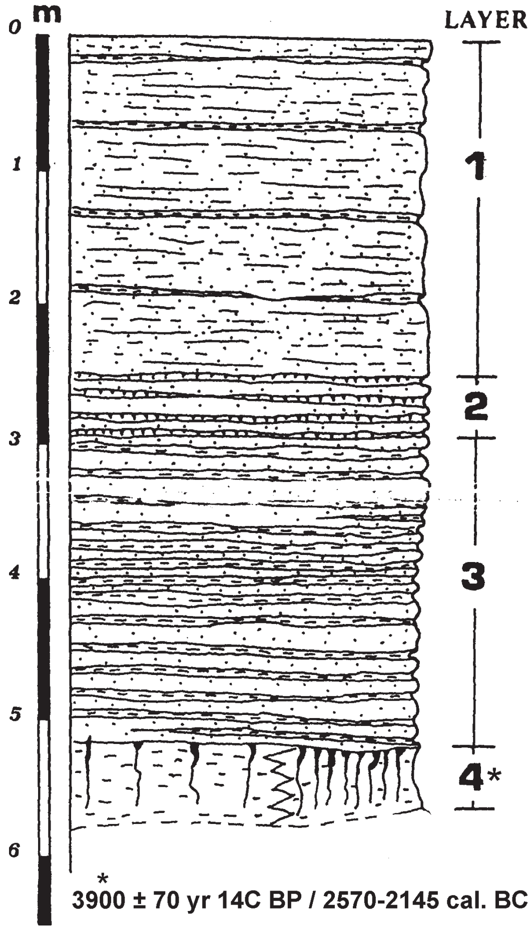

FIG. 3 - The investigated section in the upper Watija sub-catchment.

cal. BC (Beta 89713). The lower limit of the unit is not reached but, further downstream, it is clearly visible that the section overlays alluvial gravels. The buried soil is covered by alternating of silty-clayey and sandy-clayey layers and lenses with scattered gravels (layer 3). A thickening and coarsening upward trend is recognisable in the sandy layers. Between 2.5 and 3.0 m below the top surface, the intercalated silty-clayey layers are weathered by weakly-developed discontinuous soils (layer 2). The upper part of the section (layer 1) is dominated by coarse sands, interlayered with thin discontinuous silty-clayey levels and topped by coarser gravely fragments.

The top surface of the sequence forms a wide terrace (fig. 4 a) cut by shallow (up to 6 m deep) valleys whose floors host a thin and discontinuous sandy-gravelly alluvial fill, subsequently incised to form a small terrace (fig. 4 b). These two terraces are likely correlable with those present along the Tib Stream and the lower Wurgo River.

The geomorphological-stratigraphical analysis of the section provides a preliminary window on the late Holocene environmental evolution of the study area. The dated buried soil at the base of the sequence (layer 4) indicates substantial slope stability associated to a relatively warm/wet climate and a continuous cover of soils and vegetation. The underlying alluvial gravels can be associated to a phase of cold/arid climate and intense slope degradation, likely referable to the Late Pleistocene (Hurni, 1989) when coarse frost-shattered fragments were transported from the slopes into the valley floors. Pebbly-gravely alluvial plains, later incised by streams, were formed during this period. A phase of slope degradation is testified by layer 3, which suggests an increasing sediment supply by slope wash on a stagnant valley bottom.

FIG. 4 - The geomorphological context of the investigated section: a. upper terrace; b. lower terrace; * section site.

The relatively abundance of organic matter of layer 2 seems to indicate a period of relatively longer soil formation/slope stability interrupting the slope erosion processes. Finally, the abundant coarse fraction of layer 1 indicates a periods of dominating slope wash and sheet flood processes. The horizontal layering characterising the various units indicates an increased supply of slope debris that periodically buried the marshy environment. The absence of buried channels in the section indicates that no major episodes of linear erosion occurred before the main incision of the terrace, representing a break in the previous aggradation trend.

Comparable sequences of events were reported by Machado & *alii* (1998), and Dramis & *alii* (2003) from the highlands of Tigray, where a long lasting phase (from ca. 5800 ± 70 yr 14C BP / 4742-4499 cal. BC to ca. 3450 ± 50 yr 14C BP / 1829-1639 cal. BC) of soil formation occurred, followed by a period of soil erosion with two minor stages of soil formation (at ca. 2380 ± 50 yr 14C BP / 454-349 cal. BC and from ca. 1250 ± 60 yr 14C BP / 731-926 cal. AD to ca. 970 ± 60 yr 14C BP / 1051-1206 cal. AD). According to the same authors, these environmental changes were essentially related to the wet-dry climate fluctuations that have affected the Horn of Africa during the same period (Gillespie & *alii*, 1983; Umer & *alii*, 2007) with wet climate more favourable to soil formation/fluvial incision and dry climate associated to soil erosion, slope degradation and stream bed aggradation. Also human activities, such as deforestation, removal of grass cover and ox-plough cultivation, likely contributed to trigger soil erosion and slope degradation processes (Brancaccio & *alii*, 1997; Berakhi & *alii*, 1998; Nyssen & *alii*, 2004), especially in historical times (Hamilton, 1982; Pankhurst, 1990).

PRESENT-DAY MORPHODYNAMICS

The most visible effects of present slope morphodynamics are deep gullies incised in the colluvial/alluvial footslopes (fig. 5). Field observations, aerial-photo interpretation and interviews with residents allowed to give an age, in terms of few decades, to many of these features. This very recent phase of gullying could have been favoured by minor changes of climatic parameters (increase up to 1 °C of annual temperature, modification of rainfall regime; Billi & Dramis, 2001; 2003) even if, in many cases, the initiation or acceleration of gully erosion followed the complete man-made depletion of vegetation cover from the upper slopes. In some cases, gullies started as a consequence of the diversion and concentration of run-off water for the construction of agricultural channels, footpaths or roads. Stone bunds and check dams seem not always able to succeed in controlling erosion processes.

Moreover, in the present times, exception made for the sectors immediately upstream of structural thresholds, where some overbank deposition may occur during floods, all the catchment streams are presently affected by channel entrenchment. The recent entrenchment of stream channels could be explained with the almost complete depletion of weathered materials from the slopes (Brancaccio & *alii*, 1997) and the absence of weathering processes able to produce coarse fragments from the outcropping bedrock.

FIG. 5 - A recently incised gully in the Akesta village.

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