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Landslides in the Ethiopian highlands and the Rift margins

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ABSTRACT

Landslide hazard is one of the crucial environmental constraints for the development of Ethiopia, representing a limiting factor for urbanization and infrastructures. The high relief and the rugged topography induced by a strong Plio-Quaternary uplift, the occurrence of clayey horizons within the sedimentary sequences, the dense network of tectonic fractures and faults, the thick eluvial mantles on volcanic outcrops, and the thick colluvial–alluvial deposits at the foot of steep slopes are the predisposing factors for a large variety of mass movements. Heavy summer rainfall is the main triggering factor of most landslides, some of which undergo a step-like evolution with long-lasting quiescence intervals. First generation movements are commonly restricted to shallow phenomena, such as soil slips or mud flows in eluvial–colluvial material. Fast moving slope failures, such as rock slides, topplings and falls, are also triggered by earthquakes. To mitigate the landslide risk, any first priority measure should include adequate drainage of slopes in order to reduce water infiltration. On the other hand, appropriate site selection for buildings, transferring risky settlements, accurate geological control of works, and education campaigns are all strongly recommended.

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1. Introduction

Landslide hazard is, without any doubt, one of the crucial environmental problems for the development of Ethiopia, representing a limiting factor for urbanization and infrastructural projects and, generally, for all the activities performed on and at the foot of slopes. The damage produced by landslides in Ethiopia is relevant: from 1993 to 1998 alone, more than 200 houses were destroyed, more than 500 km of roads were interrupted and about 300 people were killed (Ayalew, 1999).

The widespread distribution of landslides in Ethiopia is mainly related to the occurrence of several predisposing factors such as rugged morphology, high relief energy, and the nature of the outcropping rocks. The triggering factors are essentially connected with the rainfall regime and, to a minor extent, with seismicity. The role played by human impact within the context of the country's socio-economic development is being of increasing importance in causing slope instability.

The northern Omo River basin, the lower Wabe-Shebele River valley, the Wendo Genet slope, the Blue Nile Gorge, the town of Dessie, the Wudmen area in Weldiya, the Gilgel Gibe River, the Uba Dema village in Sawla, and parts of Tigray are some of the areas where imposing landslide events have been reported in the last decade (Fig. 1).

Notwithstanding the growing information on landslide occurrence in the country and the valuable papers published on the topic (Ethiopian Institute of Geological Surveys, 1994, 1995; Asrat et al., 1996; Gezahegn, 1998; Ayalew, 1999, 2000; Ayalew and Vernier, 1999; Temesgen et al., 1999, 2001; Ayalew and Yamagishi, 2002, 2004; Nyssen et al., 2002, 2003; Fubelli et al., 2008; Moeyersons et al., 2008), the sensitivity of public administrators and decision makers is still weak and only few research projects have been launched on the assessment of landslide susceptibility, hazard and risk (IUGS WGL-CRA, 1997) on a regional scale.

The authors hope that the general overview of landslides in Ethiopia presented in this paper could help making people aware of their widespread environmental/social impact all around the country and, possibly, stimulating further investigation and public intervention on potentially unstable areas.

2. Geological background

The most ancient geological unit of Ethiopia is the Precambrian–Archean crystalline-metamorphic basement (Katzmin, 1972; Tefera et al., 1996). It is made of two sub-units: the "*Upper Complex*" (Precambrian), consisting of a more than 1500 m thick sequence of low grade metamorphosed pyroclastics and rhyolithic lavas (*Tsaliet Metavolcanics*) unconformably overlain by a 2000-m thick sequence of metasediments (*Tembien Group*), and the highly

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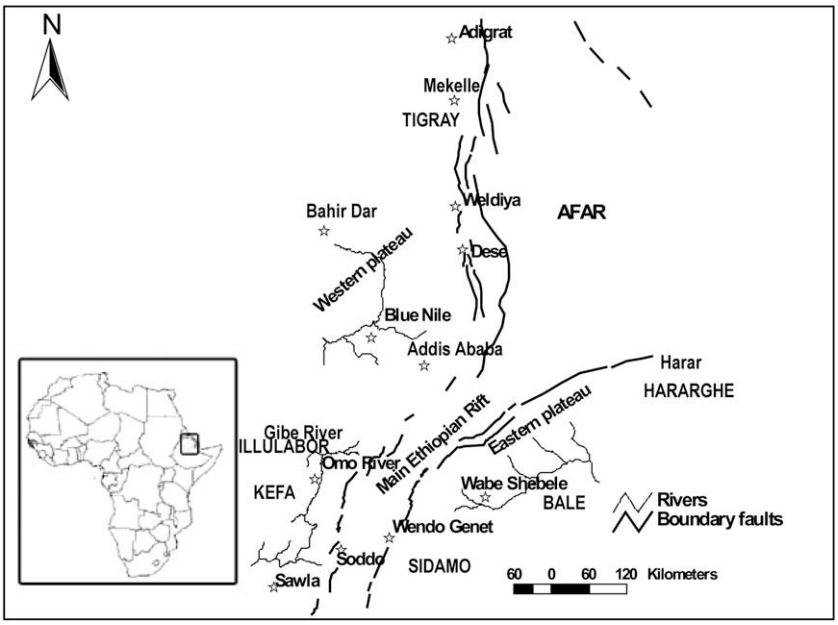

Fig. 1. Sketch map of Ethiopia showing the localities mentioned in the text.

metamorphosed "*Lower Complex*" (Archean), cropping out only in western and southern Ethiopia. At places, Late-Precambrian to Early Paleozoic granitic–dioritic batholiths and stocks cross the basement rocks.

In the Early Paleozoic extensive denudational processes affected the Precambrian relief, generating a wide planated surface (Coltorti et al., 2007) over which continental sandstones (*Enticho Sandstone*) and tillites (*Edaga Arbi Glacials*) of Ordovician age were deposited (Katzmin, 1972; Tefera et al., 1996). These sediments crop out in Tigray, in the Blue Nile Gorge, in the Illulabor, in the Kefa regions, and in the Bale area with a maximum total thickness of a few hundred meters.

After a long-lasting sedimentary gap, the *Adigrat Sandstone* (Triassic-Callovian), made of quartz sandstones with laterite layers and conglomerates, were emplaced (Bosellini et al., 1997). The upper part of the sequence includes 20–30 m of shales. The *Adigrat Sandstone* crops out all around the Mekelle Outlier, in the middle Blue Nile valley as well as in the Illubabor, Kefa, Bale, Harar, and Hararghe regions, with a thickness varying from a few meters to several hundred meters.

The following *Antalo Supersequence* (Bosellini et al., 1997) is a thick (up to more than 700 m) marly-carbonatic marine successionn of Upper Oxfordian – Kimmeridgian age, cropping out in the Mekelle Outlier, around Adigrat, in the Blue Nile Valley, and in the Harar-Dire Dawa area. The lower part of the *Antalo Supersequence* includes the *Antalo Limestone* (Blanford, 1870; Merla and Minucci, 1938), a stratified limestone unit with variable intercalations of marly-shaly layers. In the Blue Nile Valley, the *Antalo Limestone* overlays the *Goha Tsion Formation* (Assefa, 1991), a 580 m thick Early Jurassic sequence of sandy limestone, calcareous sandstone, gypsum and shales. The upper part of the *Antalo Supersequence* includes the *Agula Shales* (Merla and Minucci, 1938) consisting of shales with alternating marls, coquina limestones, quartz–arenites and gypsum. Early Tertiary dolerite sills and dykes, up to 300 m thick, cut across the stratigraphic succession in the Mekelle area. A comparable sedimentary sequence of Jurassic age, including, from the base, the *Hamanilei Formation* (limestone and dolomite), the *Urandab Formation* (shales, marls and gypsiferous limestone), and the Gabredarre Formation (marly limestone and shaly limestone), occurs in Hararghe, Sidamo and Bale.

The *Amba Aradam Formation*, a continental sequence of sandstone and conglomerate with shaly and laterite horizons of Cretaceous age (Katzmin, 1972) unconformably covers the previous units south and east of Mekelle (Coltorti et al., 2007), in the Blue Nile valley (where it reaches a thickness of 600 meters), and in the Hararghe region.

The *Amba Aradam Formation* is overlain almost everywhere by the *Traps*, a pile of lava flows, up to more than 2000 m thick, emplaced during the Oligocene, in the first stages of the East African rifting. Their lower part (*Ashangi Group*) is composed almost entirely of basalts while the upper part (*Magdala Group*) includes some rhyolites. Some volcanoes, mainly basaltic but also rhyolitic, trachytic and phonolitic, erupted during the Pliocene and the Quaternary (Zanettin and Justin-Visentin, 1973). Some of them, located in the Rift Valley, are still active.

From a structural point of view, the Ethiopian highlands include two main uplifted blocks divided by the Main Ethiopian Rift: the Western plateau and the Eastern plateau (Fig. 2). Different fault systems cross the highlands giving rise to horsts, tectonic depressions, and fault scarps (Korme et al., 2004 and references therein). Particularly striking among these are the high scarps built up by the faults which border the Rift Valley and the marginal basins. The recent activity of these faults is testified by the displacement of Tertiary-Quaternary volcanics and Quaternary alluvial deposits.

3. Landslide types and the main predisposing and triggering factors

The main predisposing factors of landsliding in the Ethiopian highlands include the high relief (on average between 2000 and 3000 m), induced by the large-scale Pliocene-Quaternary uplift (Almond, 1986; Mohr, 1986), and the resulting rugged morphology, characterized by very deep valleys and gorges with high steep slopes. Active river incision is widespread and causes further slope steepening and instability. Steep escarpments, up to several hundred meters high, are also produced by faulting which is still active on the Rift margins (Gouin, 1979).

According to the bedrock lithology and slope morphology, different types of landslides are generated in the country.

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