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Topography, river network and recent fault activity at the margins of the Central Main Ethiopian Rift (East Africa)

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ABSTRACT

Along its length, the Main Ethiopian Rift (MER) in East Africa records a transition from early fault-dominated morphology in the South to axial magma assisted-rifting typical of continental break-up in the North. It is one of the few locations on Earth offering a complete picture of the evolution of continental rifting and thus provides a unique opportunity to directly analyze how the drainage network reorganizes under extensional tectonic forcing. In this paper we present a new analysis of the river network and relative landforms—complemented with a summary of recent geological data—at both rift margins of the Central MER, a key sector of the rift capturing the phase of drainage reorganization between incipient and mature rifting. This analysis shows that hydrography is strongly influenced by recent tectonics. Rectangular drainage patterns, windgaps, and lacustrine/swampy areas formed by structural dams document that the rivers are in continuous competition with fault activity. The irregular longitudinal profiles (with knickpoints/knickzones in correspondence with faults) also suggest that rivers are in a transient state of disequilibrium related to recent tectonic activity at rift margins, in agreement with previous geological and seismological data. A more regional analysis extended to the adjoining Northern and Southern MER indicates that rifting evolves from initial stages characterized by margins poorly incised by rivers with gentle channel gradients (except in correspondence with faults), to mature phases in which rift margins are highly incised by a well organized fluvial network composed by concave and steep rivers. Our regional analysis also indicates a stronger and/or more recent tectonic activity at the rift margins proceeding to the south, in line with previous models of rift development.

1. Introduction

Continental rifts are typically characterized by a transition from fault-dominated rift morphology in the early stages of extension toward magma assisted-rifting during continental break-up (e.g., Ebinger, 2005). Large marginal escarpments are formed during early rifting, when slips on boundary fault systems accommodate significant basin subsidence and accumulation of huge sequences of volcanic and/or sedimentary rocks. Later migration of deformation to the rift floor gives rise to axial volcano-tectonic segments where continuing extension is accommodated by small-offset normal faults controlled by magma injection at depth (e.g., Corti, 2009; Keir et al., 2006). In these phases, the axial volcano-tectonic activity almost entirely accommodates plate separation and the inactive marginal escarpments undergo erosion.

The Main Ethiopian Rift (MER) is one of the few locations on Earth where the whole rifting progression can be analyzed successfully along its length (e.g., Agostini et al., 2011a; Corti, 2009; Hayward and Ebinger, 1996; Keir et al., 2013): variations in style of extension in the three rift sectors (Southern, Central and Northern MER; Fig. 1) have been indeed interpreted as the expression of different stages in the evolutionary rift sequence. Boundary fault activity and absent axial volcano-tectonic activity are believed to mark an initial stage of rifting in the Southern MER, whereas inactive rift margins and focused tectono-magmatic deformation at the rift axis are thought to indicate an incipient break-up in the Northern MER (e.g., Agostini et al., 2011a; Corti, 2009; Hayward and Ebinger, 1996; Keir et al., 2013). Thus, this rift offers a complete picture of how rift morphology evolves through time, from fault-dominated in the Southern MER to magma-dominated in the Northern MER.

This along-axis gradient in rifting maturity from south to north provides a unique opportunity to contribute important observations on how the drainage network reorganizes under extensional tectonic forcing. Fluvial systems are indeed particularly sensitive to climatic and tectonic forcing and are the main agent in propagating regional and local perturbations to the landscape (Whipple, 2004; Whipple and Tucker, 1999). To this aim, we concentrate on the Central MER, which is believed to represent an intermediate evolutionary stage of rift evolution, with significant Quaternary activity of the boundary faults and subordinate axial faulting (Agostini et al., 2011a,b). Thus, this rift sector is of particular interest because it captures the phase of drainage reorganization between incipient and mature rifting. Its climatic conditions are

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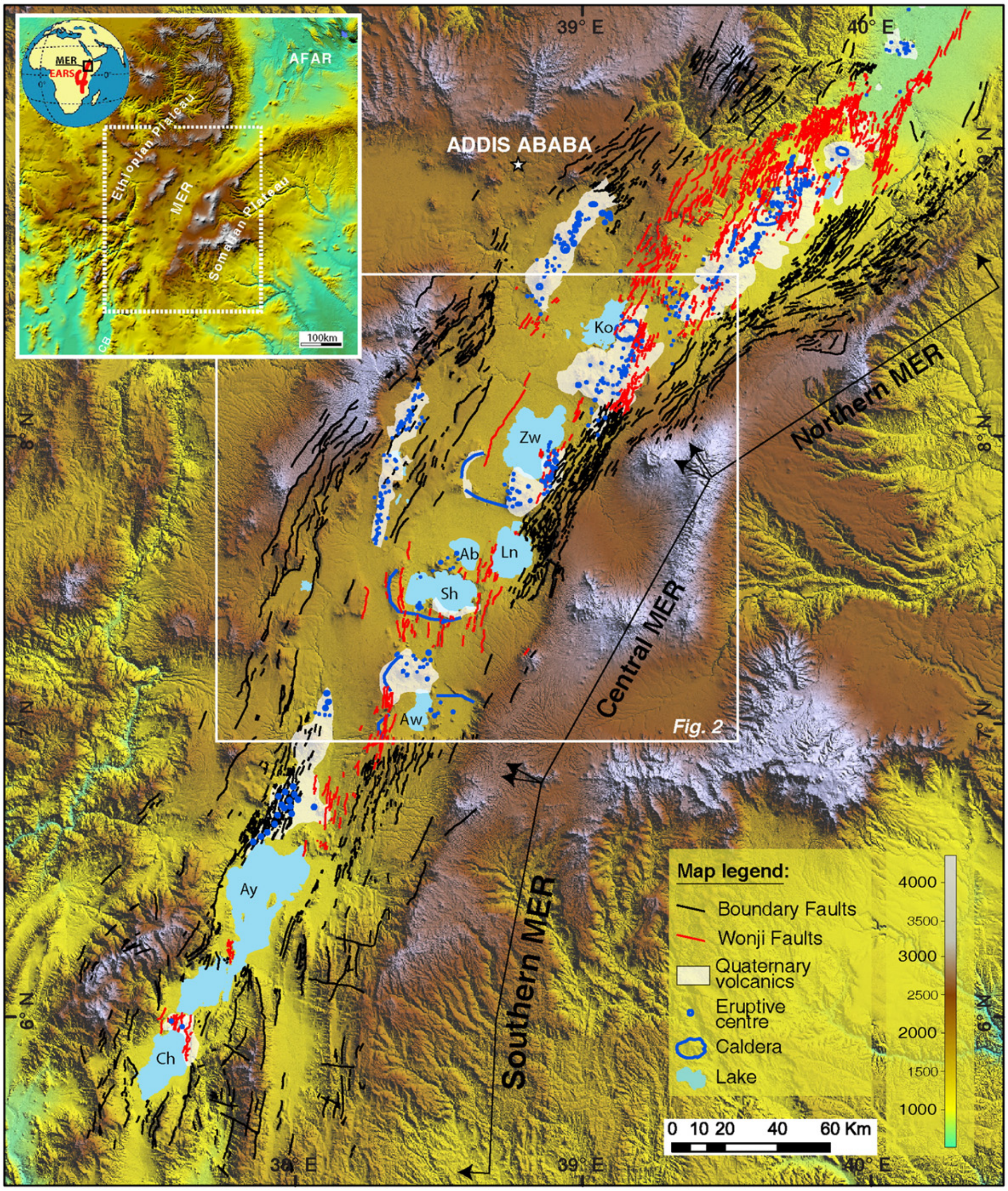

Fig. 1. Tectonic setting of the Main Ethiopian Rift (MER).

particularly suited to study the influence of local tectonic structures on hydrography, since the semiarid climate allows the generation of little vegetation—making the landforms more apparent—and the abundance of surface running water during the rainy season lets fluvial network and relative morphology to develop. So the possible tectonic perturbations on river network, for example recorded by variation in channel slope or orientation, could provide important information on fault activity, offering the opportunity to identify active faults or get information on their evolution when not accessible by other means like stratigraphy or radiometric datings (Goldsworthy and Jackson, 2000 and references therein). We present an analysis of morphology and hydrography of the rift margins, combined with a summary of recent geological data on fault activity, to improve the knowledge of the pattern of fluvial response to the different phases of rifting and of the best approaches to derive quantitative constraints on tectonics from the landscape.

2. Regional setting and along-axis variations in rift morphology and evolution

The MER represents the northern termination of the East African Rift System and extends from the Afar Triangle in the north, to the Turkana Rift in the south (Fig. 1). This rift accommodates the active extension between the major Nubia and Somalia Plates (e.g. Corti, 2009; Ebinger, 2005), which is now occurring in a roughly N100°E direction at rates of 4–6 mm/yr (e.g., Saria et al., 2014).

The MER is traditionally subdivided into three main sectors (Southern MER; Central MER and Northern MER) differing in terms of fault timing and patterns, and lithospheric characteristics (Fig. 1; e.g., Mohr, 1983; WoldeGabriel et al., 1990; Hayward and Ebinger, 1996; Bonini et al., 2005; Corti, 2009). In the Southern MER, a few major boundary faults accommodate the largest part of recent and active deformation