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Modeling along-axis variations in fault architecture in the Main Ethiopian Rift: Implications for Nubia-Somalia kinematics

Asfaw Erbello[a], Giacomo Corti[b,*], Andrea Agostini[b], Federico Sani[c], Tesfaye Kidane[d], Antonella Buccianti[c]

[a] Adama Science and Technology University, School of Applied Natural Sciences, Department of Applied Geology, P.O. Box 1888, Adama, Ethiopia
[b] Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse, Via G. La Pira, 4, 50121 Florence Italy
[c] Università degli Studi di Firenze, Dipartimento di Scienze della Terra, Via G. La Pira, 4, 50121 Florence Italy
[d] School of Earth Sciences, Faculty of Science, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia

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ABSTRACT

In this contribution, analogue modeling is used to provide new insights into the Nubia-Somalia kinematics responsible for development and evolution of the Main Ethiopian Rift (MER), at the northern termination of the East African Rift system. In particular, we performed new crustal-scale, brittle models to analyze the along-strike variations in fault architecture in the MER and their relations with the rift trend, plate motion and the resulting Miocene-recent kinematics of rifting. The models reproduced the overall geometry of the ~600 km-long MER with its along-strike variation in orientation to test different hypothesis proposed to explain rift evolution. Analysis of model results in terms of statistics of fault length and orientation, as well as deformation architecture, and its comparison with the MER suggest that models of two-phase rifting (with a first phase of NW-SE extension followed by E-W rifting) or constant NW-SE extension, as well as models of constant ENE-WSW rifting are not able to reproduce the fault architecture observed in nature. Model results suggest instead that the rift has likely developed under a constant, post-11 Ma extension oriented roughly ESE-WNW (N97.5°E), consistent with recent plate kinematics models.
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1. Introduction

The Main Ethiopian Rift (MER) is part of the East African Rift System, a region of rifting that accommodates the active extension between the Nubia and Somalia plates (Fig. 1). It is a key locale to study continental rifting and break-up since it records – along strike – the different stages of continental rifting, from initiation to incipient break-up (e.g. Ebinger, 2005; Corti, 2009). Since the MER is one of the few places along the incipient plate boundary between Nubia and Somalia where the deformation is narrow, it also thus represents an ideal place where to get insights into the long-term plate motion. However, despite this strategic location, the evolution of Nubian-Somalia motion responsible for rift development and evolution remains unclear. Specifically, whereas the Quaternary-present kinematics of rifting is rather well constrained, the kinematics driving the initial, Mio-Pliocene stages of extension is still not clear, and different hypothesis have been put forward (see below Section 2).

To shed additional light on these processes, in this contribution we use new rift-scale analogue models to analyze the along-strike variations in fault architecture in the MER and their relations with the rift trend, plate motion and the resulting kinematics of rifting. The extension direction is indeed one of the most important parameters controlling the architecture of continental rifts (e.g., Corti, 2012 for a review). Whereas orthogonal rifting (i.e., extension direction orthogonal to the rift trend) results in simple fault patterns dominated by normal faults orthogonal to the extension direction (i.e., parallel to the rift trend), oblique rifting (i.e., extension direction oblique to the rift trend, resulting in a combination of extensional and strike-slip deformation) gives rise to a more complex rift architecture. The fault pattern in oblique rifts is indeed characterized by different fault systems typically composed of: boundary faults oblique to both the rift trend and the direction of extension, extension-orthogonal fault segments at the rift axis and rift-parallel faults connecting these segments (e.g., Corti, 2012 and references therein). The relative abundance and orientation of these different fault sets is a function of the obliquity angle α (the angle between the extension direction and the orthogonal to the rift trend). Thus, rift architecture and rift-related fault patterns have been widely used to define the kinematics of rifting. Since the

* Corresponding author.
E-mail address: giacomo.corti@igg.cnr.it (G. Corti).

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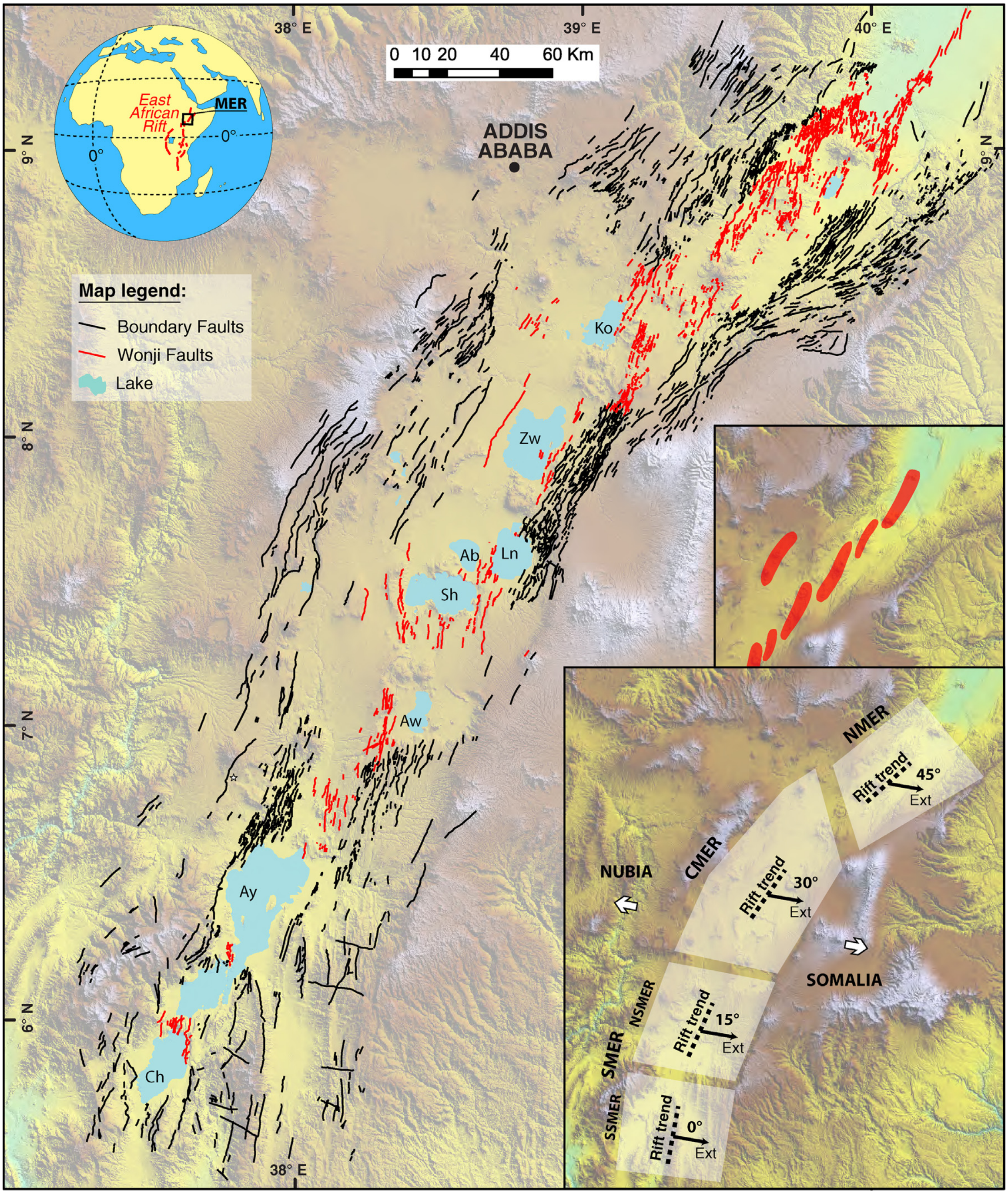

Fig. 1. Fault pattern in the Main Ethiopian Rift superimposed on a SRTM (Nasa Shuttle Radar Topography Mission) digital elevation model. Insets show the en-echelon, right-stepping arrangement of the Wonji segments in the Northern MER (upper panel, modified from Corti, 2008) and the obliquity of the four rift segments with respect to the current extension direction (lower panel, modified from Agostini et al., 2011).

trend of the MER varies along strike, and consequently it is characterized by a variable obliquity angle α (i.e., kinematics) along its length (e.g., Agostini et al., 2011; Keir et al., 2015), the analysis of fault architecture and its variations are able to provide significant insights into the plate kinematics responsible for rift development and evolution.

Differently from previous analogue modeling works (e.g., Corti, 2008; Agostini et al., 2011) where different MER sectors with different orientation where reproduced separately in different models, these new experimental series is novel in that each model reproduces the complex geometry of the entire MER with its characteristic along-axis variations in rift trend. This new approach allows to more adequately simulate the propagation and interaction of structures between adjacent rift sectors and to better visualize how rift architecture varies along-strike under a constant far-field stress. These new models also improve the existing literature by providing a systematic test for all the different hypothesis of Miocene-recent Nubia-Somalia kinematics.

2. Tectonics setting

The MER is traditionally differentiated into three main sectors differing in terms of rift trend, fault patterns and lithospheric characteristics (Fig. 1; e.g. Mohr, 1983; Hayward and Ebinger, 1996;

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