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Fault architecture in the Main Ethiopian Rift and comparison with experimental models: Implications for rift evolution and Nubia–Somalia kinematics

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ABSTRACT

The Main Ethiopian Rift (MER) offers a complete record of the time–space evolution of a continental rift. We have characterized the brittle deformation in different rift sectors through the statistical analysis of a new database of faults obtained from the integration between satellite images and digital elevation models, and implemented with field controls. This analysis has been compared with the results of lithospheric-scale analogue models reproducing the kinematical conditions of orthogonal and oblique rifting. Integration of these approaches suggests substantial differences in fault architecture in the different rift sectors that in turn reflect an along-axis variation of the rift development and southward decrease in rift evolution. The northernmost MER sector is in a mature stage of incipient continental rupture, with deformation localised within the rift floor along discrete tectono-magmatic segments and almost inactive boundary faults. The central MER sector records a transitional stage in which migration of deformation from boundary faults to faults internal to the rift valley is in an incipient phase. The southernmost MER sector is instead in an early continental stage, with the largest part of deformation being accommodated by boundary faults and almost absent internal faults. The MER thus records along its axis the typical evolution of continental rifting, from fault-dominated rift morphology in the early stages of extension toward magma-dominated extension during break-up. The extrapolation of modelling results suggests that a variable rift obliquity contributes to the observed along-axis variations in rift architecture and evolutionary stage, being oblique rifting conditions controlling the MER evolution since its birth in the Late Miocene in relation to a constant post ca. 11 Ma ~N100°E Nubia–Somalia motion.

1. Introduction

Continental rifting represents one of the most important geodynamical processes affecting the lithosphere–asthenosphere system. If successful, the process leads to continental break-up with typical evolution characterized by the progressive focusing of deformation in a narrow straining region that eventually evolves into oceanic spreading centres (e.g. Ziegler and Cloetingh, 2004).

The Main Ethiopian Rift (MER) has been suggested to be in the break-up stage and to record all the main different evolutionary stages (e.g. Corti, 2009; Ebinger, 2005), and thus is one of the few locations on Earth where the whole rifting progression can be analysed successfully. Geological and geophysical data have evidenced different MER sectors characterized by distinctive volcano-tectonic characters and geophysical signatures, interpreted as the expression of different stages in an evolutionary rift sequence (e.g. Bonini et al., 2005; Hayward and Ebinger, 1996). In particular, an overall north to south decrease in crustal thinning and tectono-magmatic modifications of the crust and lithosphere (e.g. Keranen and Klemperer, 2008), together with the southward increase in fault length and effective elastic thickness (Hayward and Ebinger, 1996), point to an along-axis variation in rift evolution.

In this study the fault architecture of the MER has been quantitatively characterized to define the spatial variation of rift evolution. We approached this problem by producing a new detailed fault database from satellite images and digital elevation model analysis. The data, verified during different field surveys, have been statistically analysed and compared with the results of lithospheric-scale analogue models of orthogonal and oblique rifting. The results of this approach have allowed better characterizing the fault architecture in the MER, providing new constrains on the spatial variation of the rifting evolution in Ethiopia as well as new insights into the plate kinematics controlling the rift process. These results highlight the importance of rift obliquity on the extension process, and thus involve general implications for the evolutionary model of continental rifting.

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2. Tectonic setting

The MER is part of the East African Rift System (EARS), a region of rifting that accommodates the active extension between the Nubia and Somalia Plates (e.g. Corti, 2009; Ebinger, 2005). The MER extends from the Afar triple junction in the north, to the northern Kenya Rift to the south (Fig. 1).

The MER is traditionally differentiated into three main sectors differing in terms of rift trend, fault patterns and lithospheric characteristics (Fig. 1; e.g. Bonini et al., 2005; Hayward and Ebinger, 1996; Mohr, 1983): (1) the ~N50°–55°E-trending Northern MER (NMER), (2) the ~N30°–40°E Central MER (CMER), and (3) the Southern MER (SMER) further subdivided into two sub-sectors: (3a) a ~N20°–25°E-trending northern sub-sector (SMERn) and (3b) a ~N0°–10°E-trending southern sub-sector (SMERs).

The different MER sectors are characterized by two distinct systems of normal faults that differ in terms of orientation, structural characteristics (e.g. length, vertical throw), timing of activation and

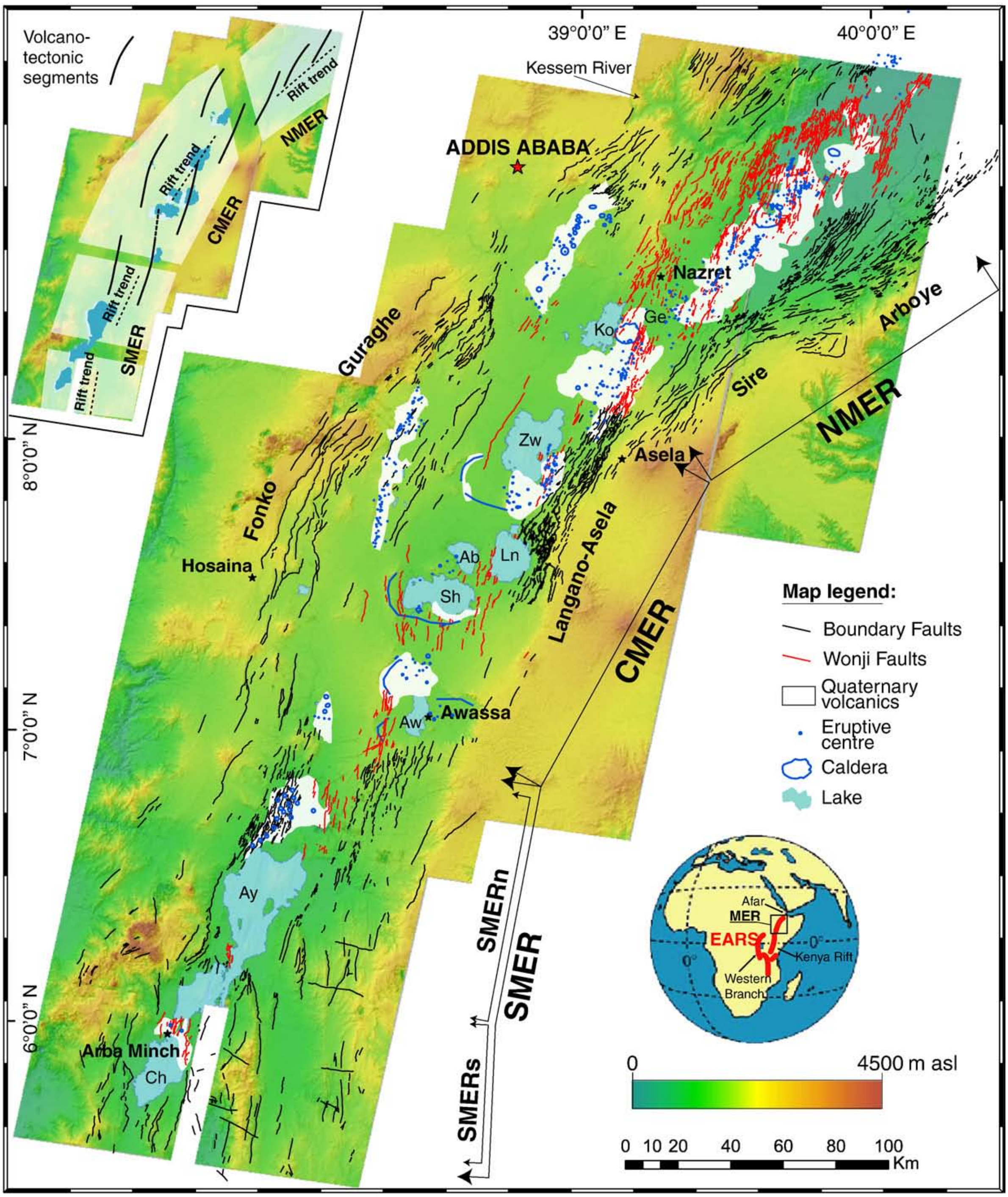

Fig. 1. New database of faults of the Main Ethiopian Rift (currently available online as Google Earth® kmz file at http://www.mna.it/MER/utilities.htm) superimposed onto a digital elevation model obtained from the elaboration of the Aster images (see text for details). NMER, Northern MER; CMER, Central MER; SMER, Southern MER (SMERn, northern subsector; SMERn, southern subsector). The small inset to top-left hand side shows the en-echelon right stepping arrangement of the volcano-tectonic Wonji Fault Belt segments (from Corti, 2009), and the different MER sectors. Ko: Lake Koka; Ge: Gedemsa Caldera; Zw: Lake Ziway; Ln: Lake Langano; Ab: Lake Abyata; Sh: Lake Shala; Aw: Lake Awasa; Ay: Lake Abaya; Ch: Lake Chamo.