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The role of inherited crustal structures and magmatism in the development of rift segments: Insights from the Kivu basin, western branch of the East African Rift

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ABSTRACT

The study of rift basin's morphology can provide good insights into geological features influencing the development of rift valleys and the distribution of volcanism. The Kivu rift segment represents the central section of the western branch of the East African Rift and displays morphological characteristics contrasting with other rift segments. Differences and contradictions between several structural maps of the Kivu rift make it difficult to interpret the local geodynamic setting. In the present work, we use topographic and bathymetric data to map active fault networks and study the geomorphology of the Kivu basin. This relief-based fault lineament mapping appears as a good complement for field mapping or mapping using seismic reflection profiles. Results suggest that rifting reactivated NE-SW oriented structures probably related to the Precambrian basement, creating transfer zones and influencing the location and distribution of volcanism. Both volcanic provinces, north and south of the Kivu basin, extend into Lake Kivu and are connected to each other with a series of eruptive vents along the western rift escarpment. The complex morphology of this rift basin, characterized by a double synthetic half-graben structure, might result from the combined action of normal faulting, magmatic underplating, volcanism and erosion processes.

1. Introduction

The western branch of the EARS consists of a series of elongated half-graben basins, which developed in a Precambrian basement and which are separated from each other by transfer zones (e.g., Ebinger, 1989a,b; Morley, 1989; Lærdal and Talbot, 2002; Corti et al., 2007). The Kivu rift, corresponding to the central part of the western branch of the East African Rift System (EARS), differs from other rift segments. First, it is flanked by large volcanic provinces, namely the Virunga Volcanic Province (VVP), in the north, and the South Kivu Volcanic Province (SKVP), in the south (Fig. 1). Next, Lake Kivu shows a complex shape subdivided into five basins, including two elongated ones separated by the central Idjwi Island. Additionally, irregular shorelines are observed, along which several minor islands extend topographic ridges into the basin. This complex lake shape is assumed to result from the combination of a rift depression and a former hydrologic system that flowed northward. The system was flooded due to natural damming by the Virunga lavas (Boutakoff, 1933; Peeters, 1957), triggering a lake-level rise and a southward flowing of the Kivu waters, towards Lake Tanganyika (Hecky, 1978; Ross et al., 2014). As highlighted by Wood et al. (2015), this latest stage in the evolution of the Kivu basin is very recent. Recent studies date the main lake level rise at 12.2 ka BP (Zhang et al., 2014) and the first deposition, in Lake Tanganyika, of sediments coming from Lake Kivu at 10.6 ka BP (Felton et al., 2007). Finally, the Kivu rift segment is located in the centre of a regional topographic uplift called the Kivu dome (Fig. 1b), which is possibly related to melting and lithospheric thinning processes in the mantle (Chorowicz, 2005; Wallner and Schmeling, 2010; Schmeling and Wallner, 2012) or to a local effect of the mantle upwelling located beneath the Tanzanian craton (Furman and Graham, 1999).

Several geological and structural maps of the Kivu rift exist in the scientific literature (Boutakoff, 1939; Degens et al., 1973; Pouclet, 1977; Villeneuve, 1978, 1980; Ebinger, 1989b; Yamba, 1993; Wood et al.,

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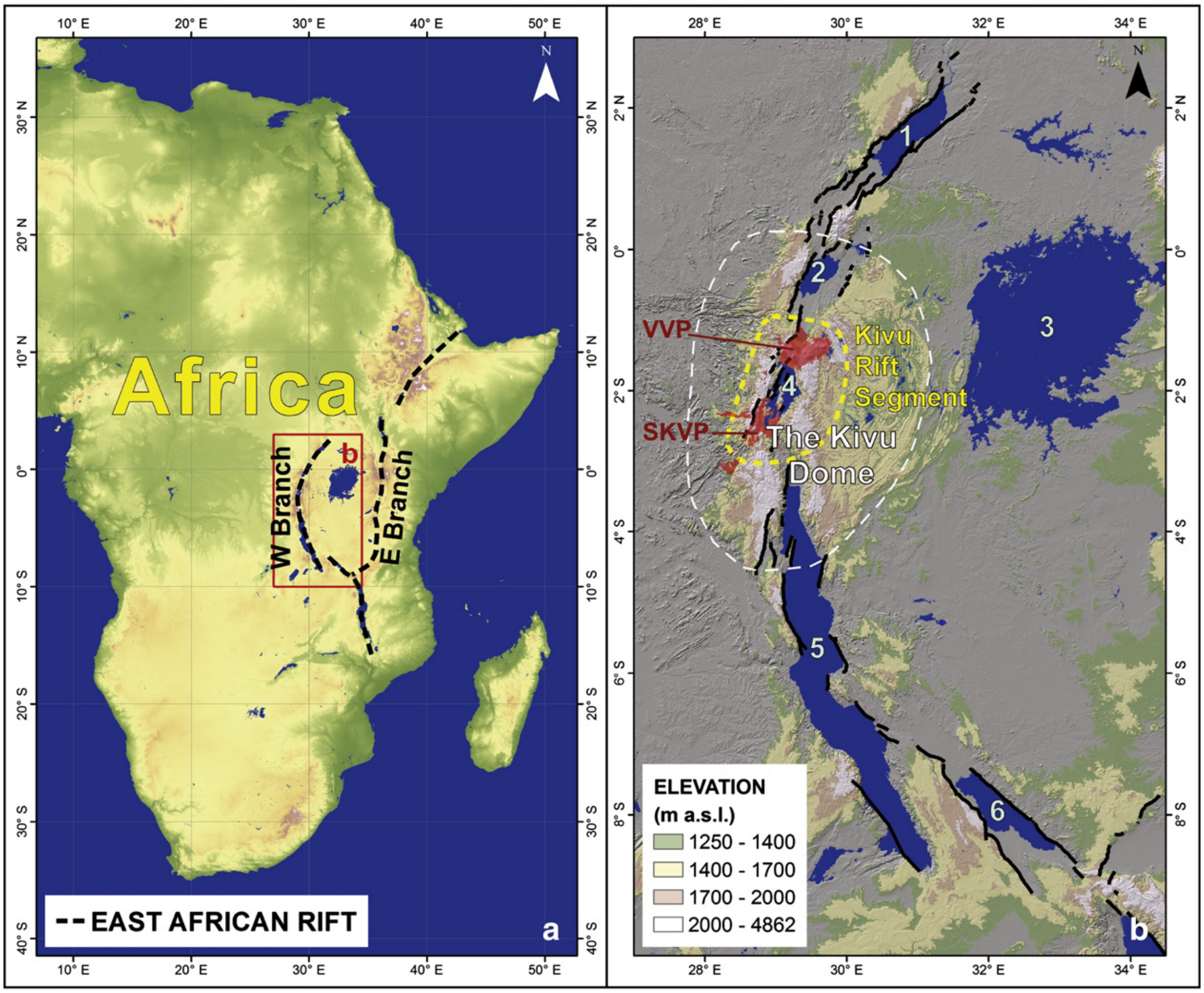

Fig. 1. Location of the Kivu rift segment within the East African Rift System (EARS). Frame "a" shows the location of the EARS in the African continent and its separation into two branches. The black dashed lines highlight the rift valleys. Frame "b" zooms into the western branch of the EARS. The Kivu rift segment is surrounded by a yellow dashed line. Red areas are volcanic provinces surrounding the Kivu basin, namely the Virunga Volcanic Province (VVP) and the South Kivu Volcanic Province (SKVP). The white dashed line highlights the presence of a topographic zone, called the Kivu Dome; centred on the Kivu rift segment. The black lines are the main rift fault escarpments mapped according to the topography on the SRTM-3 DEM (NASA) and the mapping of Ebinger (1989a). 1 = Lake Albert; 2 = Lake Edward; 3 = Lake Victoria; 4 = Lake Kivu; 5 = Lake Tanganyika; 6 = Lake Rukwa.

2015). Rift faults on these maps were mostly mapped using photo-interpretation of aerial and satellite optical images, sometimes complemented with field observations. However, these fault maps often differ from each other (e.g., Fig. 2), which makes difficult to interpret the geodynamic context. Besides insecurity and recurrent civil unrests, which most of the time prevent ground-truthing of observed fault lineaments, the main difficulties in neotectonic fault mapping in the Kivu region are the strong weathering and erosion rates, landslides along rift flanks and sometimes vegetation. In addition, faults in the Kivu rift depression are mostly hidden by the presence of Lake Kivu's waters and recurrent lava flows resurfacing in the VVP. Hence, the contact between these surfaces and the main highly eroded rift escarpments does not necessarily represent the exact position and orientation of the main rift faults.

A better understanding of the fault distribution in the Kivu segment is however required, as active faults play a role in the distribution and occurrence of the main natural hazards encountered in this region, i.e. landslides (e.g., Moeyersons et al., 2004; Trefois et al., 2007), earthquakes (e.g., d'Oreye et al., 2010; Mavonga et al., 2010) and volcanism (e.g., Wadge and Burt, 2011; Smets et al., 2015). In the present work, we propose a new mapping of fault escarpments, as well as a geomorphological and structural analysis of the Kivu rift segment. Fault lineament mapping was realized independently of existing mappings, using digital elevation models (DEM) and two sets of bathymetric data. This mapping was restricted to straight escarpments that clearly suggest the existence of faults. However, we preferred the term "fault lineament", which is here defined as the surface expression of a potential or confirmed fault at depth. The main lithologies were locally mapped using field data available in the scientific literature and changes in the topographic texture. The fault mapping technique was validated in the southern lake Edward basin and in the eastern part of Lake Kivu using mappings of Nicholas et al. (2015) and Wood et al. (2015), respectively. Results were compared with other existing fault maps, with the aim of re-interpreting active fault networks and the local geomorphology that characterize the Kivu rift. Finally, implications for rifting processes and volcanism are discussed.

2. Material and methods

2.1. Topographic analysis

In this work, we used the SRTM-1 DEM (~30 m/pixel; NASA/NGA; Farr et al., 2007), and two sets of bathymetric data. In the vicinity of the Kabuno Bay, a DEM derived from the TanDEM-X SAR imagery (Albino et al., 2015) was used to interpret topographic features missing in the SRTM-1 DEM. The first bathymetric dataset was acquired between March and October 1998 over the entire Lake Kivu (blue area in Fig. 3)