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Contrasted seismogenic and rheological behaviours from shallow and deep earthquake sequences in the North Tanzanian Divergence, East Africa

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ABSTRACT

We report preliminary results of a seismological experiment, SEISMO-TANZ' 07, which consisted in the deployment of a local network (35 stations) in the East African Rift System (EARS), North Tanzania, during 6 months in 2007. We compare two earthquake sequences (Gelai and Manyara) occurring, respectively, in the southern end of the Kenya rift and in the North Tanzanian Divergence (NTD). Only distant of ~150 km, their triggering mechanisms are different. None of the sequences depicts typical swarm or mainshock–aftershock patterns. They highlight the change in the magmatic/tectonic nature of the rift where the eastern branch of the EARS enters the Tanzanian craton. The similar shape and long-axis of the elongate sequences emphasize the preferred locus of active strain release along NE–SW discontinuities which probably root at depth into steep Proterozoic shear zones. At Gelai, the deformation is dominated by aseismic process involving slow slip on normal fault and dyke intrusion within the upper crust (Calais et al., 2008). The spatial and temporal earthquake distribution indicates a possible correlation between the Gelai crisis and the eruption of the nearby Oldoinyo Lengai volcano. At Manyara, the sequence is more uncommon, revealing a long-lasting seismic activity deeply rooted (~20–35 km depth) possibly related to stress loading transmitted laterally. The yield strength envelope modelled from the depth frequency distribution of earthquakes in the NTD is consistent with the presence of a mafic lower crust and further supports the strength increase of the rifted crust from south Kenya to the NTD.

1. Introduction

Earthquake sequences are common features in many active rift settings. The space and time distribution of earthquakes are widely used to highlight the mechanisms that trigger them and to discuss which processes may explain their occurrences. Whereas the type of sequence is generally easily determined and often referred as swarms, aftershocks, clusters or bursts (e.g., Mogi, 1963; Sherburn, 1992; Benoit and McNutt, 1996; Vidale and Shearer, 2006; Ibs-von Seht et al., 2008; Parsons, 2008), determining their cause is not straightforward. The spatial and temporal variability of seismic deformation and its relationship with aseismic processes such as magma injections, slow slip, static or dynamic stress triggering are generally poorly understood owing to the lack of accuracy on spatial and temporal evolution of deformation and on the rheological setting. An open question is also whether and how long earthquake clustering is expected to persist, with important consequences on seismic hazard forecasting.

Continental rifts are known to provide evidence since long for various types of earthquake sequences, either as mainshock–aftershock sequences or as swarms. From earthquake series captured in various modern rift systems (Rio Grande, Kenya and Eger), Ibs-von Seht et al. (2008) have recently suggested that swarm activity is mostly restricted to rift valleys at shallow depth and are influenced by large-scale fracture or shear zones intersecting the rifts, which are assumed to favour intrusions of upper mantle into the crust. A similar pattern is reported in the Baikal rift, but some "swarm-like" sequences identified there depict even much longer time series (several years) and develop off the main rift axis and at depth as large as 23 km (Déverchère et al., 1993; Solonenko et al., 1997).

In 2007, a French–Tanzanian seismic experiment (SEISMO-TANZ' 07) took place from June 1st to November 20, in the North

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Tanzanian rift, at the southern end of the eastern branch of the East African Rift System (EARS) (Fig. 1A). This branch depicts a general, large scale southerly-propagating rift pattern (Le Gall et al., 2008, and references therein). At about 2.5°S, the main axial valley splits into several zones of deformation of different strikes, forming the so-called North Tanzanian Divergence (NTD) (Dawson, 1992). Fortuitously, the SEISMO-TANZ' 07 temporal seismic network has captured simultaneously two earthquake sequences, called hereafter Gelai and Manyara, located, respectively, in the volcanic area of the Natron Valley and at the contact of the Tanzanian Archaean craton near Lake Manyara (Fig. 1A). The aim of this study is to take advantage of this exceptional opportunity to contrast deformation mechanisms and rheological settings during synchronous, yet spatially discrete magma-rich and magma-poor continental rifting episodes. We intend to describe the main spatial and temporal patterns of these two sequences, to underline their specificities, similarities and differences, and to compare them to other sequences captured in continental rifts in order to infer rheological implications and possible triggering mechanisms.

2. Geological and seismological settings

2.1. Tectono-magmatic framework

The Gelai and Manyara sequences take place at the southern end of the southerly-propagating eastern branch of the EARS (Fig. 1A) where faulting and magmatism initiated at around 15 Ma (Baker and Mitchell, 1976). They occur in two contrasted rift settings, resulting from the splay of the axial rift valley southwards into the 400 km-wide NTD (Dawson, 1992):

(1) To the north, the Gelai earthquakes lie within the Natron axial trough which forms a 50- to 60-km wide westerly-facing half-graben, slightly offset to the SW with respect to the Magadi linear N–S rift valley in south Kenya (Fig. 1A). There, strain history over the last 15 Myr is marked by repeated episodes of extensional faulting and magmatism (Cerling and Powers, 1977; Crossley and Knight, 1981), producing a limited extension (<15–20%) and little crustal thinning,

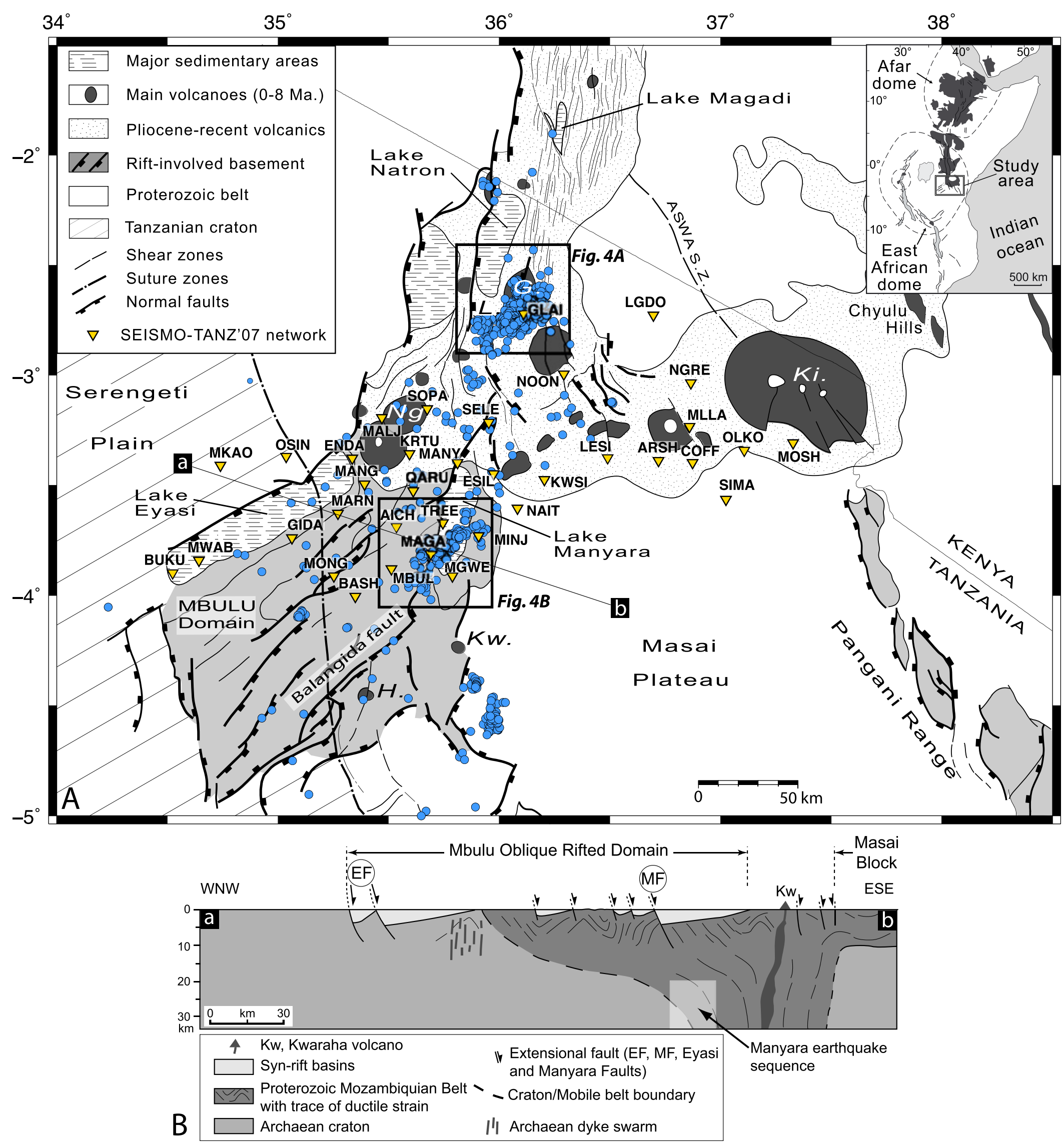

Fig. 1. (A) Structural sketch map of the NTD (modified from Le Gall et al., 2008) with SEISMO-TANZ' 07 network and seismicity (blue circles) recorded from June to November 2007. NOON and GLAI were only installed in August. (B) 2D-cross-section (a–b on A) of the western arm of the NTD showing the root of the frontal Mozambiquian Belt along a suture zone deepening between two cratonic blocks. The approximate location of the root zone does not permit to definitely assess whether the Manyara sequence occurs within the craton or in the Mozambiquian Belt. The Kwaraha volcano and its inferred magma conduits are projected from their southern location. ASWA SZ, ASWA shear zone; G., Gelai; H., Hanang; Ki., Kilimanjaro; Kw., Kwaraha; L., Oldoinyo Lengai; Ng., Ngorongoro; EF, Eyasi fault; MF, Manyara fault.