Distribution of faults and volcanic centers in the early stages of continental breakup: Natron Basin, Tanzania

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1 Introduction

We present preliminary findings of a study characterizing faults and volcanic products in the <5 Ma Natron rift basin. The nature and behavior of these faults has implications for how strain is actively accommodated along the rift, and will provide insights into the evolving contributions of magmatic and tectonic processes during early-stage rifting. The current study looks to address:

1) The distribution and nature of faulting
2) Spatial relationships between faults and volcanoes
3) The distribution of observable strain (i.e. fault throw) at sub-kilometer scales
4) The relative timing of border and intra-rift faulting
5) Potential rheological influences on fault behavior

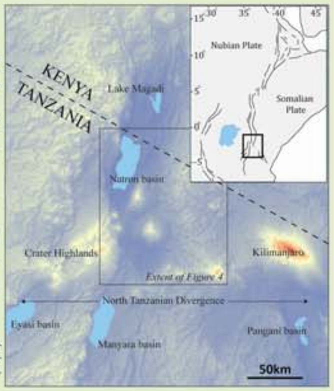

Figure 1: Location map of the Natron Basin and North Tanzanian Divergence to the south. Inset map in the top right illustrates the extent of the eastern arm of the East African rift.

2 Methods

Fieldwork: Fault scarps were identified and measured, and dissected lavas and other volcanic deposits were sampled for Ar-Ar dating (currently being analyzed at Rutgers University, New Jersey.

Broad-scale fault mapping: Mapping was performed using a combination of LandSat imagery (12 m resolution), high resolution aerial photography (0.5-2 m resolution), and hillshade functions on the newly available ASTER GDEM v.2 (horizontal resolution of 30 m; vertical accuracy of 14.6m (LE90)).

Strain analysis: Fault throw has been analyzed using a novel technique combining the ASTER DEM v.2 with a newly designed, automated fault measuring program. The program measures fault throw using a slope-break method at 30 m intervals along fault traces.

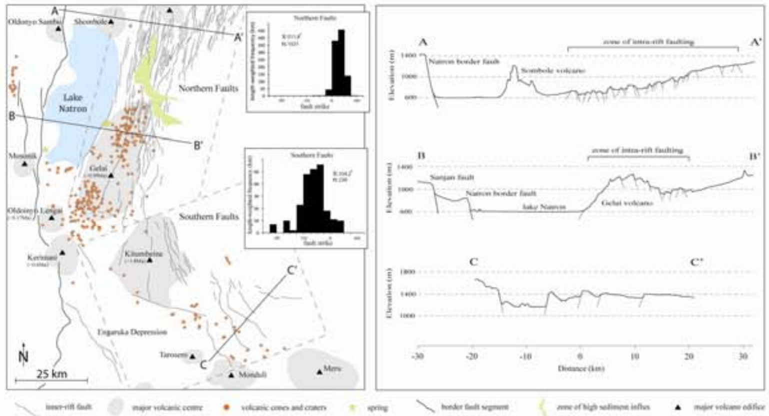

Figure 4: Structural map the Natron Basin showing the broad distribution of faults and volcanic centers (left). The extent of the northern and southern faults are indicated by the dashed boxes. Histogram frequency graphs of fault strikes are provided for each fault set. Dates below volcanoes represent maximum ages from Le Gall et al. (2008, and references therein). Topographic cross sections are provided on the right of the image. Fault planes are inferred from scarps observed on the surface. Actual depth of the faults is unknown.

4 Interpretation of intra-rift fault patterns

The short lengths and tight clustering of the northern faults is suggestive of a zone of focused (magmatic?) strain above a thermally weakened lithosphere. Strain is primarily concentrated in the centre of this fault array (Fig. 5), indicating a potential transition from border fault- to rift axial-dominated strain accommodation in the Natron region. Further work, however, will need to consider how tension from crustal flexure due to border fault activity has affected the distribution of faulting in the north.

The greater lengths and throws exhibited by southern faults highlights the potential influence of stronger, thicker crust on fault geometry, where higher stresses are required for fault activation. The general fault trend is also oblique to the far-field least principal stress direction (~E-W); these faults are either exploiting pre-existing basement fractures (cf. Le Gall et al., 2008), or accommodating the gradual widening of the rift south into the North Tanzanian Divergence.

3 Field Observations and Fault Data

Dividing faults into sub-populations allows an assessment of (1) variations in the style of strain accommodation across the rift, (2) potential rheological influences on the nature of faulting, and (3) temporal variations in fault activity, with implications for the evolution of the Natron rift. The faults are divided into three sub-populations based on mean length, throw, and spacing: northern faults, southern faults, and the border fault. The ~120 km-long, 1.8-3.5 Ma (Le Gall et al., 2008, and references therein) Natron border fault is the oldest feature forming the current expression of the Natron rift. Intra-rift faults (i.e. fault arrays ~20km east of the border fault) began to form at ~1.2 Ma (cf. Le Gall et al., 2008, and references therein). These faults differ in mean length, throw, and spacing from north to south (Table 1) and have therefore been sub-divided. Of these faults, the border fault and northern faults were measured and sampled in the field.

Table 1: Fault data collected from northern and southern faults (outlined in Figure 4). Ages from Le Gall et al. (2008, and references therein)

	number of faults	mean orientation	total length (km)	mean length (m)	mean throw (m)	maximum throw (m)	mean spacing (m)	maximum age (Ma)
Northern Faults	220	012°	1031	4600	39	249	2200	1.2
Southern Faults	28	334°	239	8500	64	293	5300	1.2

Northern faults: general appearance in the field

The northern fault array extends approximately 10 km east and 40 km north of Gelai volcano (Fig. 4). The faults are arranged en echelon, with both hard and soft-linked segments, and the footwalls of faults typically displace basalt lavas. Northern faults observed in the field have shallow slopes and in general appear largely degraded, suggesting that slip rates are low. We believe there is only limited evidence for recent ground-rupturing events, although some scarps are partially exposed in places (Fig. 2). Lavas dissected by 5 northern faults will be dated using Ar-Ar analyses.

Natron border fault: general appearance in the field

The main segments of the Natron border fault are highly eroded with no observable fresh scarps or ruptures; these segments are either inactive or have experienced a reduced slip rate and higher recurrence interval between surface-breaking events. An exception is a ~2 km-long fault segment, 1 km east of the main border fault escarpment, and in close proximity (< 5 km) to Oldoinyo Lengai. Here, ~10 m of seemingly recent throw is observed in volcaniclastic deposits. Constraining the behaviour of faults like these has implications for how strain is accommodated presently on the flanks of the rift. Pyroclastic deposits draping the main fault segments were sampled for Ar-Ar analyses. These dates will give a minimum age of the last faulting event in the region on the main border fault escarpment.

Figure 2: Photo of a typical northern fault observed east of Gelai volcano.

Figure 3: Photos of the Natron border fault. Left: view to the north from the slopes of the fault above the Engaresero township. Right: view to the north from the western slopes of Oldoinyo Lengai. Pyroclastic flows draping the fault have been sample for Ar-Ar analysis.

Photos of our 2012 field season. Top left: Nice and clean and ready to head out into the field. Top right: Professor Simon Kattenhorn standing in the way of Oldoinyo Lengai from the top of the Natron border fault. Bottom left: Sunrise over Engaresero village. Bottom right: Our driver, William, gives us another demonstration on how to change a tire.

Acknowledgments

This work is funded by the NSF-EAR grant 1113677. ASTER DEM data was acquired through the NASA Land Processes Distributed Active Archive Center. Additional support for JDM has been provided by Fulbright New Zealand. Darin Schwartz and Matt Pendleton helped process remote sensing data, and Alexa Van Eaton is thanked for her thoughtful contributions to the poster.

References

Le Gall, B., Nonnotte, P., Rolet, J., Benoit, M., Guillou, H., Mousseau-Nonnote, M., Albaric, J., and Deverchere, J., 2008, Rift propagation at craton margin. Distribution of faulting and volcanism in the North Tanzania Divergence (East Africa) during Neogene times: Tectonophysics, 448, 1-19.

5 Broad distribution of fault-related strain and magmatic centers: observations and limitations

Two broad observations from our preliminary strain analysis are:

- Cumulative fault throw is greatest in the north and steadily decreases to the south towards Kitumbeine volcano, with a corresponding increase in the aerial distribution of volcanoes.
- In the northern fault array, strain is localized towards a central axis.

Limitations with the current approach

- The fault program is susceptible to artifacts when analysing faults on volcanic slopes or in the vicinity of smaller volcanic cones.
- An unknown quantity of faults may be hidden below the surface, either buried under sediment (particularly near Lake Natron) or recent lava flows. The inverse relationship between cumulative fault throw and the distribution of volcanoes may therefore be a consequence of lava flow coverage.

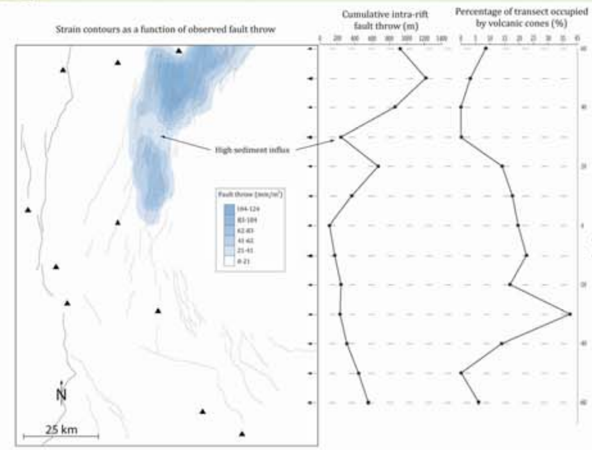

Figure 5: Distribution of fault-related strain in the Natron basin measured from observable fault throws. Cumulative fault throw, and the percent of the transect occupied by volcanoes was measured along twelve E-W transects (indicated by arrows). Strain contours (blue polygons) in the center of the figure reresent the average fault throw per square meter measured in 8 x 8 km neghbourhoods.

6 Conclusions

- There is a shift in the nature and distribution of faults from north to south. This transition is likely related to a change in the mechanical properties of the crust. Northern faults are forming in a thermally weakened lithosphere, whereas the southern faults are likely contained in thicker, stronger crust.
- The distribution of fault throw and volcanic centers indicates a possible interplay between magma- and fault-related strain accommodation in the Natron rift basin.
- The observed focusing of strain in the centre of the rift is suggestive of a transition to rift axial-dominated strain accommodation, and the potential termination of border fault activity.

7 Future Work

- Ar-Ar ages of volcanic deposits disturbed by faults to better constrain the timing and evolution of the fault sub-populations.
- Fine-tuning the automated fault measuring program and performing error analyses.
- Estimate the contribution of crustal flexure on the distribution of faulting.
- An analysis of faults in Magadi Basin to the north using a similar approach.

- Combine our results with those of two studies: (1) a seismic study (co-PIs Cindy Ebinger and Steve Roecker) imaging the crust and upper mantle structure in the Natron, Magadi, and Manyara rift basins; and (2) a geochemical study of local springs (PI Tobias Fischer) addressing whether fluid chemistries reflect magmatic or asthenospheric fluids that may be contributing to the rifting process by weakening the lithosphere.