Long-term rift evolution

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Rift systems represent one of the most remarkable geomorphological features on Earth. Hydrocarbon resources can be found within deep rift basins, whereas rift flanks form high morphological ridges influencing climate, vegetation, and fauna (Rosendahl 1987; Ziegler 1992; Ruppel 1995; Ziegler and Cloetingh 2004; Sepulchre et al. 2006; Trauth et al. 2007). Rift systems are the perfect laboratory to understand how our planet is changing dynamically through time and how mantle processes, volcanism, rock and surface uplift, erosion and sedimentation, climate, and fauna are ultimately linked.

This special issue arises from a session at the EGU 2008 and presents a broad range of papers on long-term rift evolution spanning from the Asthenosphere through the Lithosphere all the way to climate-related processes. Seven papers focus on the evolution of the Albertine Rift System situated in the western branch of the East African Rift System and are the outcome of a DFG (Deutsche Forschungsgemeinschaft) funded Forschergruppe “RiftLink”. Another six contributions focus on the Cheb basin, the Brazilian continental margin, the East Barents Sea Basin, the East African Rift System or on rifting processes in general. The contributions consider mantle to climate models: contributions by Semprich et al., Wallner and Schmeling, and Stamps et al. present mantle and lithospheric modelling studies of extensional environments;

contributions by Babuska et al., Wölbern et al., and Link et al. treat mantle-crust relations and interactions; contributions by Bauer et al., Franco-Magalhaes et al., Sachau and Koehn, Koehn et al., and Roller et al. study crustal tectonics, rock and surface uplift histories and sedimentary environments; and the contributions by Brachert et al. and Kaspar et al. investigate climate proxies and climate models.

Semprich et al. show with a systematic series of density diagrams, which are based on thermodynamic calculations that density changes are crucial for isostatic models in geodynamics. These authors illustrate that buried metapelitic rocks rich in Fe and Mg experience much larger density changes than dry basalt indicating that metamorphism of a hydrous lower crust leads to significant subsidence. The implications of these calculations are discussed in detail for different geodynamic settings.

Wallner and Schmeling present a geodynamic modelling study of rift-induced delamination of Mantle Lithosphere (RID) in order to explain the extreme elevation of the Rwenzori Mountains in the western branch of the East African Rift System. These authors argue that the rift systems that surround the mountains trigger the delamination and that they are reducing the viscosity and strength of the lower crust around the horst. In the model, the weakened zone becomes unstable and a block of mantle material and lower crust sinks into the Asthenosphere leading to isostatic uplift of the overlying continental crust. A variation of modelling parameters is presented in order to illustrate under what conditions delamination takes place.

Stamps et al. present a modelling study in order to determine if gravitational stresses are large enough to break the continental lithosphere in East Africa. They use a thin sheet approach to compute vertically averaged deviatoric

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stresses and show that the results match stress indicators from the World Stress Map project and earthquake focal mechanisms. A comparison with the integrated strength of the lithosphere shows that gravitational potential energy accounts for a significant part of forces that induce continental rifting but that they are likely insufficient to rupture the cold and thick lithosphere in East Africa.

Babuska et al. present a study of the mantle lithosphere below the Cheb Basin in the western part of the Eger Rift. These authors show a triple junction in the lithosphere where three Variscan tectonic units, the Saxothuringian, Tepla-Barrandian and Moldanubian meet. The deepest parts of the Cheb Basin and the Eger Rift lie on top of the Variscan mantle junction indicating that the mantle lithosphere has a very long memory and is still controlling the evolution of the crust above.

Wölbern et al. show results of a temporary seismic network that was installed on the Ugandan side of the Rwenzori Mountains in the western part of the East African Rift System. These authors illustrate that the Moho depth along the eastern flank of the Lake George rift is about 30 km but that the crustal thickness varies significantly below the Rwenzori horst where it is thinned up to 28–20 km. The authors conclude that the Rwenzori Mountains have no crustal root. In addition, reduced S-wave velocities are found in a layer at 15 km depth between Lake Edward and Lake George basins indicating the existence of partial melts.

Link et al. study the metamorphic basement in Western Uganda in the vicinity of the Albertine rift system. Based on field-work and new Laser-ICP-MS U–Pb ages these authors show that the Rwenzori Mountains present a WSW to ENE trending fold and thrust belt where Archaean basement units with Paleoproterozoic cover are thrust northwards onto a thick craton. In addition, the authors show that the composition of volcanics in the western branch of the East African Rift System indicates that the Rwenzori area is made up of thick lithosphere (>140 km) and that the lithosphere is thinning southwards towards the Virunga region.

Bauer et al. study the rock and surface uplift history of the Rwenzori Mountains in the western part of the East African Rift System based on low-temperature thermochronology. These authors show that samples from the central and northern Rwenzoris reveal apatite fission-track ages between 195.0 (± 8.4) and 85.3 (± 5.3) Ma and apatite (U–Th–Sm)/He ages between 210.0 (± 6.0) and 24.9 (± 0.5) Ma. A modelling study of the authors indicates that the ages reflect a cooling history with accelerated cooling in Permo-Triassic and Jurassic times followed by a long period of slow cooling and a renewed accelerated cooling in the Neogene. The authors favour a differentiated surface uplift of the Rwenzori Mountains during the last 10 Ma

and a final surface uplift in the near past that led to the recent topography.

Franco-Magalhaes et al. worked on the Brazilian passive continental margin and applied low-temperature thermochronology in order to understand the post-rift evolution of the margin. Apatite fission-track ages from the Ponta Grossa Arch indicate a post-rift reactivation of margin perpendicular fracture zones during the late Cretaceous and Paleogene. The authors show that two distinct age groups can be found, separated by a NW–SE trending fault zone that can be followed offshore into the Santos basin indicating a segmentation of the margin. In addition, the authors show that differential exhumation causes a change in transport directions of sediments through time.

Sachau and Koehn present new numerical simulations of passive rifting and related rift-flank uplift. The simulations show that the highest rift flanks develop when the deformation is localized, the lower crust is strong, and movement takes place along single faults. They present an analytical solution of their problem and show that stretching of a layered crust, cut by faults produces a moment that leads to active rift-flank uplift due to an elastic strain mismatch within the layers. The authors discuss the implications of these new ideas for real rift systems and the current rifting theory in general.

Koehn et al. present a structural and seismological study of the Rwenzori Mountains in the northern part of the western branch of the East African Rift System and compare the results with numerical simulations. These authors argue that the Rwenzori block was captured by propagating rift segments and that it is rotating clockwise at the moment. Seismological and structural data indicate that the block is currently detaching from the larger Victoria plate along a large-scale 20-km long transection fault. The numerical model of the authors illustrates how propagating rift segments capture and rotate the block and indicates that the majority of the vertical uplift has taken place within the last 8 Ma.

Roller et al. present a sedimentological study of a middle Miocene to Pleistocene sequence of synrift sediments that were deposited in the southern Lake Albert rift in the western branch of the East African Rift System. The studied siliciclastic sediments are clays to coarse gravels and indicate alluvial plain, delta plain, nearshore, delta front, and lacustrine depositional environments. The authors distinguish four evolutionary phases that include a first phase between 14.5 and 10.0 Ma where sediments indicate a bedload-dominated fluvial environment, a second phase from 10.0 to 4.5 Ma where fine-grained material was deposited in a distal fluvial plain to lacustrine setting followed by a third phase between 4.5 and 2 Ma with delta plain and nearshore deposits and a last interval from 2.0 to 1.5 Ma that shows gravel units and arkosic sandstones. The

first phase is interpreted to represent a pre and early synrift sedimentation under a semiarid climate, the second phase shows an increase in tectonic activity and a more humid climate, the third phase represents an acceleration of subsidence and a humid climate, and the fourth phase is interpreted to indicate drier climate and an increase in differential surface uplift.

Brachert et al. present a study of stable isotope proxy data from tooth enamel of hippopotamids in order to understand Late Neogene climate and watershed dynamics in a paleolake system in the Lake Albert region in the western branch of the East African Rift System. These authors show that an increase in $\delta^{18}\text{O}$ of hippopotamid tooth enamel reflects an increase in evaporation of the lake water, which is argued to be an effect of rift basin segmentation and rift-flank surface uplift. The authors argue that climate data from valley floors are generally biased by rift dynamics or relative valley subsidence, a relation that has to be included when such proxies are used to monitor regional climate change.

Kaspar et al. (this issue) use a global atmosphere-ocean model and vary topographic as well as orbital scenarios in order to study the relative roles of these factors for the past climate of East Africa. These authors show that reduced topography leads to an increase in moisture transport from the Indian Ocean towards East Africa and thus an increase in precipitation. A step-wise increasing topography that

simulates plateau and rift-flank uplift shows a continuous change in climate. Orbital forcing shows changes in climate of similar order of magnitude but with different spatial and seasonal structure.

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References

- Rosendahl BR (1987) Architecture of continental rifts with special reference to East Africa. *Ann Rev Earth Planet Sci* 15:445–503
- Ruppel C (1995) Extensional processes in continental lithosphere. *JGR-Solid Earth* 100(B12):24187–24215
- Sepulchre P, Ramstein G, Fluteau F, Schuster M, Tiercelin JJ, Brunet M (2006) Tectonic uplift and Eastern Africa aridification. *Science* 313:1419–1423
- Trauth MH, Maslin MA, Deino AL, Strecker MR, Bergner AGN, Dühnforth M (2007) High- and low-latitude forcing of Plio-Pleistocene East African climate and human evolution. *J Hum Evol* 53:475–486
- Ziegler PA (1992) Geodynamics of rifting and implications for hydrocarbon habitat. *Tectonophysics* 215:221–253
- Ziegler PA, Cloetingh S (2004) Dynamic processes controlling evolution of rifted basins. *Earth-Sci Rev* 64(1–2):1–50