Tectonic stress field in rift systems – a comparison of Rhinegraben, Baikal Rift and East African Rift

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Abstract

Crustal stress pattern provide important information for the understanding of regional tectonics and for the modelling of seismic hazard. Especially for small rifts (e.g. Upper Rhine Graben) and beside larger rift structures (e.g. Baikal Rift, East African Rift System) only limited information on the stress orientations is available. We refine existing stress models by using new focal mechanisms combined with existing solutions to perform a formal stress inversion. We review the first-order stress pattern given by previous models for the Upper Rhine Graben, the Baikal Rift, and the East African Rift System. Due to the new focal mechanisms we resolve second-order features in areas of high data density. The resulting stress orientations show dominant extensional stress regimes along the Baikal and East African Rift but strike-slip regimes in the Upper Rhine Graben and the interior of the Amurian plate.

Introduction

Stress field orientations are valuable constraints for understanding rift kinematics and rift development. They can be used to deduce boundary conditions for kinematic models (Buchmann & Connolly, 2007; Petit & Fournier, 2005). Moreover, data from regions adjacent to rift structures can reveal spatial changes from the rift-related stress field. Stress data from the inversion of focal mechanism solutions (FMS) of light earthquakes can improve the data coverage especially for intraplate regions with a low seismicity. We use new FMS from earthquakes with $M_W \geq 3.9$ that were determined using the Frequency Sensitive Moment Tensor Inversion (FMTI, Barth et al., 2007). The FMTI allows to invert regional waveform data for automatically determined frequency pass-bands based on a 1D earth model. Combining the new FMS with known FMS, we perform the formal stress inversion (Michael, 1987). After using both nodal planes for inversion, the best fitted plane is chosen for the final inversion. First-order stress pattern are a consequence of sub-lithospheric processes and plate boundary forces, that partly are related to gravitational potential energy as discussed by several authors (Zoback, 1992; Coblentz and Sandiford, 1994). However, this alone cannot explain second and third order pattern as discussed in this work, that result from three-dimensional density variations and deep mantle processes in some cases.

East African Rift System (EARS)

The EARS is a complex example of active continental rifting. Passing for nearly 3000 km through the continent, the EARS separates the Nubian subplate to the west from the Somalian subplate to the east. The eastern part of the African plate, which is dominated by the EARS, is affected by extensional stresses with a general E-W orientation of the minimum horizontal stress S_h, while the Nubian plate is affected by a compressional regime with the maximum horizontal stress S_H oriented E-W (Fig. 1). Barth et al. (2007) determined 38 new focal mechanisms using the FMTI. Delvaux & Barth (2009) combined these solutions with others to a total dataset of 332 FMS and performed stress inversions for 24 bins. For 12 bins we obtained quality A and B following the *World-Stress-Map (WSM)* quality ranking scheme (Heidbach et al., 2008). They showed that the rift basins that surround the Tanzanian craton mostly have S_h

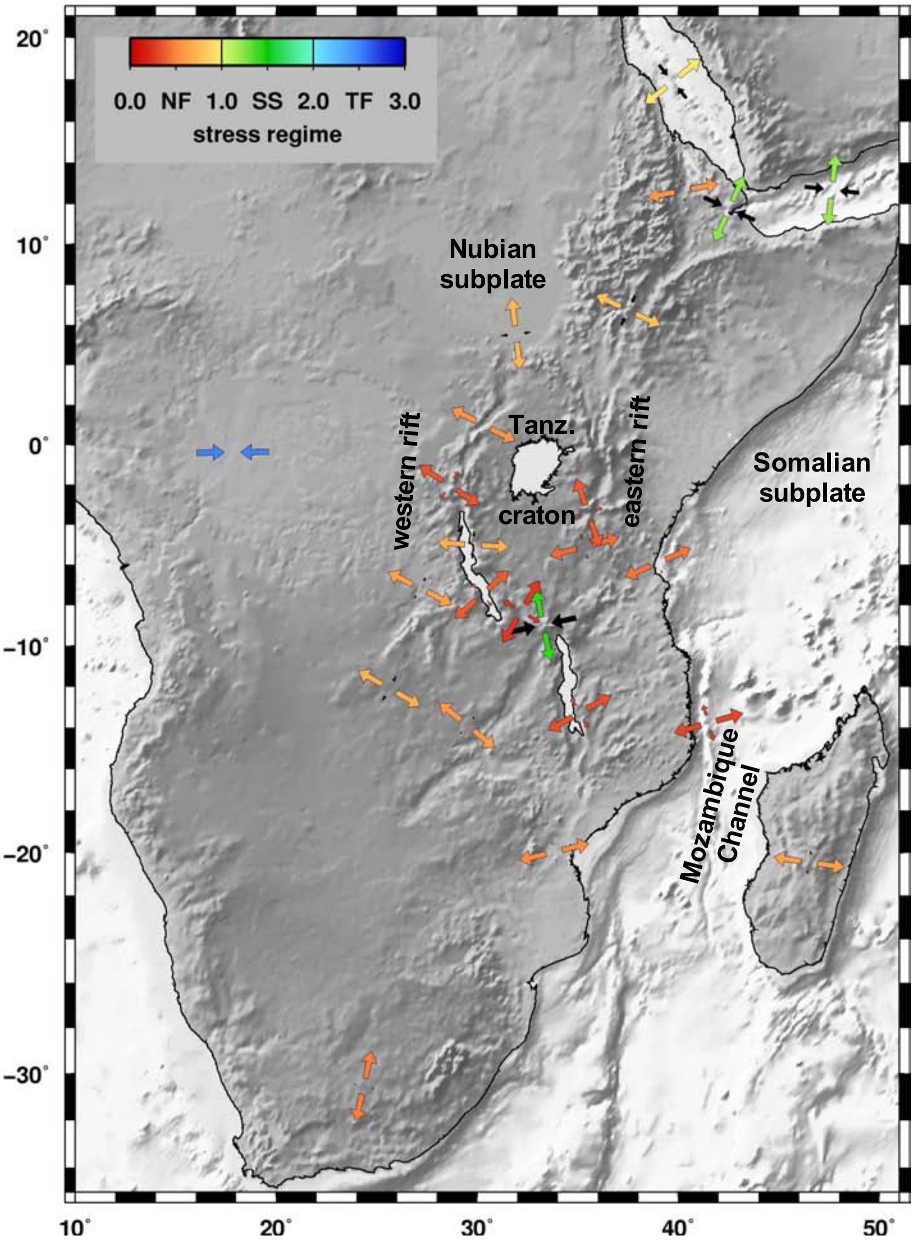

Figure 1: Formal stress inversion of 332 FMS in Africa (Delvaux & Barth, 2009). Colours indicate the stress regime. Vectors give the orientations of max. and min. horizontal compressional stress S_H and S_h, respectively. Stress symbols after Delvaux et al. (1997).

orientations roughly orthogonal to their trend. Two dominant orientations of S_h arise: WNW-ESE extension in the north-western segments of the EARS and in the south-western high plateau region and ENE-WSW extension in the central part of the western rift branch, the southern extremity of the eastern rift branch, the southernmost rift segment and the continental margin. The overall extensional regime mainly results from plate boundary forces combined with lithospheric gravitational potential energy of the African high plateaus. As the lowlands of the Indian Coast and the Mozambique Channel seem also affected by extensional faulting, the extension might also reflect a combination of complex 3-dimensional crustal structure and deep processes like the spreading of a mantle plume head beneath the Tanzanian craton or mantle flow at the base of the lithosphere (Delvaux & Barth, 2009).

Baikal Rift and Amurian plate

The Amurian plate is situated between the Eurasian and Pacific plates and spans approximately 2500 km in both the north-south and the east-west directions. Since Zonenshain and Savostin (1981) suggested the existence of a distinct Amurian plate, its development, plate kinematics as well as the location of its plate boundaries have been matters of debate (e.g. Petit & Fournier, 2005; Delvaux et al., 1997). Barth & Wenzel (2009) used the (FMTI) to calculated 41 focal mechanism solutions for earthquakes with magnitudes of $M_W \geq 3.9$ that have not been determined before. Here we combine it with additional data to a set of 272 FMS. Stress inversion is performed for 13 bins along the Baikal Rift, the Transbaikal and the Amurian plate (6 quality A and B). Along the rift itself we obtain normal faulting regimes with S_h oriented NW-SE, mostly orthogonal to the rift trend. For the Transbaikal and interior of the Amurian plate we obtain a strike-slip regime with an NE-SW to ENE-WSW orientation of S_H (Fig. 2). The stress field at the Stanovoy foldbelt shows a slight rotation with respect to the more southern regions and might be influenced by the Baikal Rift extension. The transpressive regime in the eastern part of the Amurian plate responds to far field plate boundary forces from the Pacific plate subducting at the Kuril trench and northern Japan (Barth & Wenzel, 2009).

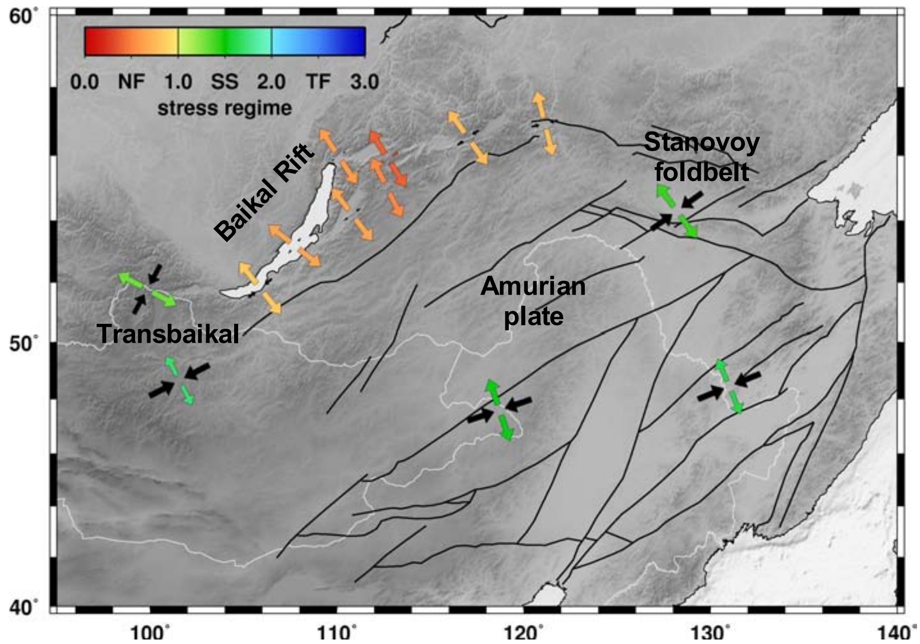

Figure 2: Formal stress inversion of 272 FMS along the Baikal Rift and within the Amurian plate. Symbols as in Fig. 1.

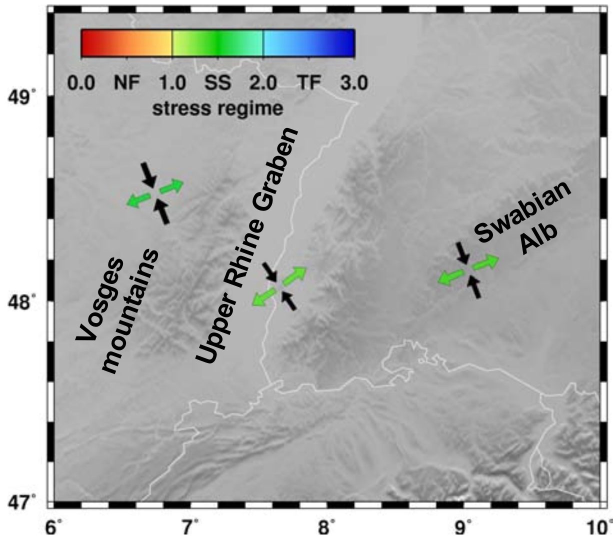

Figure 3: Formal stress inversion of 83 FMS for the URG and adjacent regions. Symbols as in Fig. 1.

Upper Rhine Graben (URG)

The URG is part of the European Cenozoic Rift System (ECRS) that extends from the Mediterranean Sea to the North Sea. Within the last 100 years five events of magnitude 4.7 took place in the URG and the largest historic event dates from 1352 when in Basel/Switzerland a major earthquake of maximum intensity IX killed 300 people (Leydecker, 2008). Several studies focused on the stress field in the seismically more active southern part of the URG and its connection to the southern parts of the ECRS (Plenefisch & Bonjer, 1997; Cardozo & Behrmann, 2006; Delacou et al., 2004). However, for the adjacent seismic active regions of the Vosges Mountains and the Swabian Alb no stress inversion of focal mechanism data has been performed so far. In this study we group 83 FMS (Swiss Seismological Service; Bonjer, 1997) in three bins: Southern URG (SURG: 47 FMS), Vosges Mountains (VS: 8 FMS), Swabian Alb (SW: 28 FMS). Figure 3 shows that the stress field of SURG (S_H = 146°, B quality) is slightly rotated compared to S_H = 159° of both, VS (B quality) and SW (A quality). While SURG and SW show transtensional strike-slip regimes, VS has a tendency to a transpression. Besides the strong influence of the African-Eurasian collision the regional stress field might be a consequence of the strong gradients in local topography.

Discussion & Conclusion

Both active rifts, the Baikal and the East African Rift System (EARS) show extensional regimes along the main rifts. The adjacent regions to the Baikal Rift reveal strike-slip regimes as a consequence of plate boundary forces. However, the extensional regime of the EARS in combination with topography effects of the high plateaus dominates the stress field in eastern Africa, although local stress variation indicate structural heterogeneities and/or deep processes. In the URG a strike-slip regime has reactivated the main structures that is also apparent in the adjacent Vosges mountains and Swabian Alb. The first-order stress pattern of the presented rifts are in general supported by data of the *WSM Project* (Heidbach et al., 2008), while second and third order effects reveal the influence of local heterogeneities.

We showed that the FMTI (Barth et al., 2007) can be used for the determination of focal mechanisms of earthquakes $M_W \geq 3.9$ and that it is applicable world-wide. It can improve the knowledge of active tectonics and may allow stress inversions in regions where it was not possible before.

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