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Multiphase rotational extension and marginal flexure along a developing passive margin: the Western Afar Margin, East Africa

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This multidisciplinary study focuses on the tectonics of the Western Afar Margin (WAM), which is situated between the Ethiopian Plateau and Afar Depression in East Africa. The WAM represents a developing passive margin in a highly volcanic setting, thus offering unique opportunities for the study of rifting and (magma-rich) continental break-up, and our results have both regional and global implications.

Earthquake analysis shows that the margin is still deforming under a ca. E-W extension regime (a result also obtained by analysis on fault measurements from recent field campaigns), whereas Afar itself undergoes a more SW-NE extension. Together with GPS data, we see Afar currently opening in a rotational fashion. This opening is however a relatively recent and local phenomenon, due to the rotation of the Danakil microcontinent modifying the regional stress field (since 11 Ma). Regional tectonics is otherwise dominated by the rotation of Arabia since 25 Ma and should cause SW-NE (oblique) extension along the WAM. This oblique motion is indeed recorded in the large-scale en echelon fault patterns along the margin, which were reactivated in the current E-W extension regime. We thus have good evidence of a multiphase rotational history of the WAM and Afar.

Furthermore, analysis of the margin's structural architecture reveals large-scale flexure towards Afar, likely representing the developing seaward-dipping reflectors that are typical for magma-rich margins. Detailed fault mapping and earthquake analysis show that recent faulting is dominantly antithetic (dipping away from the rift), bounding remarkable marginal grabens, although a large but older synthetic escarpment fault system is present as well. By means of analogue modelling efforts we find that marginal flexure indeed initially develops a large escarpment, whereas the currently active structures only form after significant flexure. Moreover, these models show that marginal grabens do not develop under oblique extension conditions. Instead, the latter model boundary conditions create the large-scale en echelon fault arrangement typical of the WAM. We derive that the recent structures of the margin could have developed only after a shift to local

orthogonal extension. These modeling results support the multiphase extension scenario as described above.

Altogether, our findings are highly relevant for our understanding of the structural evolution of (magma-rich) passive margins. Indeed, seismic sections of such margins show very similar structures to those of the WAM. However, the general lack of marginal grabens, which are so obvious along the WAM, can be explained by the fact that most rift systems undergo or have undergone oblique extension, often in multiple phases during which structures from older phases control subsequent deformation.