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A new and detailed structural interpretation of a developing passive margin along the western margin of Afar, Ethiopia

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The Afar Depression in Ethiopia forms the northernmost segment of the East African Rift System, representing a unique location where active continental break-up and passive margin formation can be examined. A key element in the system is the poorly studied Western Afar Margin (WAM), which marks a sharp decrease in altitude and crustal thickness from the Ethiopian Plateau towards the main rift axis in Afar. This developing passive margin along the western edge of Afar is marked by a series of marginal grabens associated with dominant antithetic faulting, as well as ongoing seismicity that pose severe risks to the local population. How the WAM and its marginal grabens were formed, as well as why it is still actively deforming remains unclear. In this study we aim to establish the first detailed structural map of the whole margin, which may serve as a basis for future studies on the evolution of Afar and passive margins in general.

We apply various methods to chart the structures in the study area. Firstly, earthquake analysis of two datasets retrieved between 2007-2009 and 2011-2013 provides insights into the current tectonic situation. Mapping the spatial distribution of seismic events and associated seismic moment release shows significant active deformation focused at both the Afar rift axes and the WAM. Focal mechanisms indicate general normal faulting, which is in accordance with the extensional nature of the Afar Depression. Secondly, satellite imagery and digital elevation models allow the drafting of new and detailed fault maps covering the whole margin. The NNW-SSE oriented marginal grabens are bounded by large faults and are arranged in a right-stepping fashion, separated by transfer zones with high fault densities. Faults have generally the same NNW-SSE strike, except for the southernmost part of the margin, which exhibits a NNE-SSW orientation, parallel to the Main Ethiopian Rift to the south.

By studying geomorphological indicators such as slope breaks, hanging wall features and basin geometry, we determine fault vergence and recent fault activity. In addition, plotting the best constrained earthquake locations on detailed maps and sections provides an impression of present fault activity, associated fault vergence, as well as the presence of actively deforming basement structures. Furthermore, a recent extensive field campaign along much of the WAM has provided valuable structural, kinematic, lithological and geomorphological data on crucial localities, such as the main boundary faults of the marginal grabens, providing further verification and refining of our initial structural interpretation.

We find that the large-scale structures of the WAM are relatively well-defined. Yet there are distinct differences in structural style along the margin, which seem to be related to factors such as lithology, lithospheric thickness, distance to the main rift axes, volcanism as well as the uplift and erosion of the Ethiopian Plateau, calling for further study of this intriguing part of the world and the processes that shaped its geology.