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A new model for the development of the active Afar volcanic margin

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Volcanic passive margins, that represent more than the three quarters of continental margins worldwide, are privileged witnesses of the lithospheric extension processes thatform new oceanic basins. They are characterized by voluminous amounts of underplated, intruded and extruded magmas, under the form of massive lavas prisms (seaward-dipping reflectors, or SDR) during the course of thinning and stretching of the lithosphere, that eventually form the ocean-continent transition. The origin and mechanisms of formation of these objects are still largely debated today. We have focussed our attention in the last few years on the Afar volcanic province which represents an active analogue of such volcanic margins.

We explored the structural and temporal relationships that exist between the development of the major thinning and stretching structures and the magmatic production in Central Afar. Conjugate precise fieldwork analysis along with lavas geochronology allowed us to revisit the timing and style of the rift formation, since the early syn-rift period of time in the W-Afar marginal area to present days. Extension is primarily accommodated over a wide area at the surface since the very initial periods of extension ($\sim$ 25 Ma) following the emplacement of Oligocene CFBs. We propose in our reconstruction of central Afar margin history that extension has been associated with important volumes of underplated mafic material that compensate crustal thinning. This has been facilitated by major crustal-scale detachments that help localize the thinning and underplating at depth. In line with this 'magmatic wide-rift' mode of extension, we demonstrate that episodic extension steps alternate with more protracted magmatic phases. The production of syn-rift massive flood basalts ($\sim$ 4 Ma) occurs after early thinning of both the crust and the lithosphere, which suggests that SDR formation, is controlled by previous tectonic event. We determined how the melting regime evolved in response to the deformation of the lithosphere, through a petrological and geochemical study of the pre- to syn-rift lavas and concluded that the lithospheric mantle experienced the combined effect of post-plume cooling, but also thinning during the Miocene. This is accompanied by the early channelization of the plume head into narrower zones, which helped focus extension at the future volcanic margins location. The anomalous mantle potential temperature increased during the very last localization phase ($<$ 1 Ma), which leads us to argue in favor of the focussed activity of a plume stem below the volcanic margin, instead of purely passive adiabatic decompression. Our new interpretation of the regional isotopic signatures of lavas depicts a clear framework of the Afar plume and lithospheric mantle relationships to on going extension and segmentation of these margins, and allow us to propose new contrasted models for their development.