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Late-stage stretching and subsidence rates in the Danakil Depression, evidenced from borehole records and seismic reflection data

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The Ethiopian and Afar Rift systems provide a globally unique opportunity to study the incipient transition from continental rifting to sea-floor spreading. A consensus has emerged that a considerable proportion of plate extension in Ethiopia is accommodated by dyke intrusion, with smaller contributions from crustal thinning. However, observations of thinned crust and a pulse in Quaternary-Recent basaltic volcanism within Ethiopia's Danakil Depression have been cited (Bastow and Keir, 2011) as evidence that localised plate stretching may mark the final stages of continent-ocean transition. We explore this hypothesis using an archive of five 2-D seismic reflection profiles, each between 7-10 km in length, and $\sim$120 borehole records distributed over an area of 225 km^2. From depth and age relationships of key marker horizons, we also suggest local subsidence and extension rates.

The borehole archive reveals extensive evaporite sequences deposited in and around an asymmetric basin, bounded to the west by a network of east-dipping normal faults. West of the basin, the maximum observed thickness of evaporites is 150 m, beneath which are deposits of clastic sediment, but a sequence of evaporites at least 900 m thick is observed at the basin centre. The sedimentary architecture of these sequences suggests deposition in a shallow salt-pan environment, with seasonal – potentially diurnal – freshening of the brine supply (Warren, 2012). Isotopic analysis of reef carbonates in the basin flank dates the last marine incursion into the Danakil Depression at 24-230ka (Lalou et al., 1970; Bonatti et al., 1971; Bannert et al., 1971), therefore the evaporite sequence must be younger than this. A key marker horizon within the evaporites is the potash-bearing Houston Formation, also distinct in borehole records given its high porosity (25-40%) and radioactivity (50-250 API units). The elevation of the Houston Formation is $\sim$500 m deeper in the centre of the basin than on the flank. This depth change corresponds to a plausible vertical subsidence rate of between 2-20 mma^{-1} and, assuming a 60° fault dip, a horizontal extension rate of 1-12 mma^{-1} during the deposition of the Houston Formation, consistent with recent geodetic constraints offered by Ar Rajehi et al. (2010).

The borehole archive shows no evidence of significant magmatism anywhere in the survey area, and the characteristic reflectivity of igneous bodies is absent in the seismic data. Extension of this basin is, therefore, not obviously explained by dyke intrusion. We consider that the $\sim$500 m change in elevation of the Houston Formation is instead diagnostic of rapid stretching, possibly indicating a late period of non-magmatic extension in the transition to sea-floor spreading in the Danakil Depression.