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The influence of laterally varying crustal strength on rift physiography – Combining 3D numerical models and geological observations

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Continental rifts form across a mosaic of crustal units, each unit displaying properties that reflect their own unique tectonic evolution and lithology. The physiography of rift systems is largely reflective of this underlying crustal substrate, which may change over short distances along-strike of the rift. Pervasive, well-developed structural heterogeneities represent sites where strain may localise and may thus weaken a crustal volume. In contrast, relatively pristine areas of crust, such as igneous batholiths, contain few heterogeneities and may be considered relatively strong. Characteristic rift physiographies associated with these 'strong' and 'weak' crustal units, and how rift physiography changes across areas where these units are juxtaposed remain elusive.

In this study we use the 3D thermo-mechanical numerical code ASPECT to investigate how areas of differing upper crustal strength influence rift physiography. We extend a 500x500x100km volume, within which we define four 125km wide upper crustal domains of either 'strong', 'normal' or 'weak' crust. Crustal strength is determined by varying the initial plastic strain in the model across 5km blocks, producing a static-like pattern. Weak domains contain weakened blocks with large initial plastic strain values, creating large contrasts with adjacent blocks. In contrast, 5 km blocks within the strong domain have relatively low values of initial plastic strain, producing little variation between adjacent blocks.

Our modelling simulations reveal that strain rapidly localises onto high-displacement structures (equivalent to faults) in the weak domain. Fault spacing and the strain accommodated by each fault decreases in the normal domain, with the strong domain characterised by closely-spaced, low displacement faults approximating uniform strain. When heterogeneities are incorporated into the strong domain, we find that these rapidly localise strain, effectively partitioning the domain into a series of smaller, strong areas separated by faults. Faults are initially inhibited at the boundaries with adjacent stronger domains; as extension progresses, these faults break through the barrier and propagate into the stronger domains.

Our observations have important implications for rift system development, particularly in areas of highly heterogeneous basement. Studies have shown that the Tanganyika rift developed at high angles to cratonic and mobile belt basement terranes, with localisation inhibted in the stronger cratonic areas. Similarly, extension in the Great South Basin (GSB), New Zealand, initially localised in weak, dominantly sedimentary, terranes, compared to stronger, more homogenous granitic areas. Terrane boundaries in the GSB also inhibit the lateral propagation of faults. Comparing our model results with observations from these and other systems globally, we determine characteristic structural styles and examine how rift physiography varies across ‘strong’ and ‘weak’ crustal volumes.