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Isostatic origin of longitudinal rivers on passive margins

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The break-up of continents commonly leads to a large topographic relief between the continental regions that have experienced stretching and subsidence and the more stable, interior parts of the two continents that have rifted apart. These topographic steps or escarpments are now located several tens to hundreds of kilometers inland from their original positions. The coastal erosion that accompanies the escarpment retreat produces unloading and subsequent isostatic rebound of the margin, including the coastal plain and the escarpment itself, but also results in a low amplitude subsidence of the continental area inland of the escarpment. This may lead to the formation of a longitudinal valley landward of the escarpment striking in a direction parallel to the orientation of the margin. Assuming a finite flexural strength for the lithosphere, one can predict that the distance from the original margin position to the flexural depression increases in proportion to the flexural rigidity of the continental lithosphere, which is often parameterized by an effective elastic thickness (T_e).

We tested this hypothesis using a two dimensional numerical model simulating surface erosion by solving the stream power law and assuming linear hillslope diffusion, combined with an isostatic model representing the flexural behavior of the lithosphere by a thin elastic plate of uniform thickness/rigidity. Model results support our explanation for the formation of a longitudinal river of high stream order at the location of the flexural depression of the lithosphere landward of the escarpment. We also observe that after the establishment of this longitudinal river both the course and the location of the major confluence with the seaward draining channel/river are relatively stationary in space. The presence of the longitudinal river, in turn, helps to stabilize the position of the coastal escarpment and slows down its landward retreat.

We examined rivers flowing towards current passive margins around the world, and found that the locations of many longitudinal rivers are consistent with the prediction of our model. This is especially true for large rivers along the South Atlantic margin of Africa, the east coast of Australia, the Arabian Peninsula, India and Madagascar. Outliers however exist along the North Atlantic margin of North Africa and southwestern Europe, the east coast of Africa, southern Australia and South America, where we suspect that the geometry of the drainage network may have been affected by vertical movement of the lithosphere well after the continental rifting, often associated with post-rift orogenic systems such as the Pyrenees, the Atlas Mountains, the opening of the East African Rift or dynamic topography resulting from mantle flow such as along the southeastern margin of Australia, and the Atlantic margin of South America.