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Flow of material under compression in the weak layers of continental crust can cause post-rift uplift of passive continental margins

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Many passive continental margins are flanked by a mountain range up to more than 2 km high (e.g. Norway, eastern Australia, eastern Brazil, SE and SW Africa, east and west Greenland etc.), dubbed Elevated Passive Continental Margins (EPCMs). There are increasing numbers of observations that uplift of these margins took place long after continental break-up, but lack of a geodynamical mechanism has meant that there has been considerable difficulty in getting the community to accept the observational evidence. Explanations for these uplifted margins have been ad hoc, but there has hitherto been no explanation that accounts for their presence at both volcanic and non-volcanic margins and in both polar and tropical climatic environments.

A continent breaks up by extension and pure shear thinning of the continental crust, a conclusion effectively confirmed by the innumerable successful applications of McKenzie's (1978) theory to model the subsidence of continental margin basins. The thinning increases from small amounts in the proximal rift to perhaps a factor of 5-10 in the distal area adjacent to oceanic crust, resulting in continental crust only a few km thick there. All likely compositions of continental crust more than 25 km thick imply that there are two weak layers, one separating strong upper (quartz-rich) and lower (dioritic) crust and the other separating strong lower crust and strong mantle. Those parts of the rift that have extended to thicknesses less than about 25 km are too thin for there to be weak layers and the strong layers of continental crust become effectively annealed to one another and to the underlying strong mantle.

Formation of a passive continental margin by rifting must take place under conditions of tension.
After rifting ceases, however, the margin can come under compression from forces originating elsewhere on or below its plate, e.g. collision of the continent with other continental plates or from the excess lithostatic load from any mountain range formed from such a collision. The World Stress Map (www.world-stress-mp.org) shows that, where data exists, all EPCMs are currently under compression.

Under suitable conditions of stress, flow can develop in the crust's weak layers. If sufficient compression develops, material can flow in the weak layers towards the rift margin from the continental side. The annealing of the extended crust and mantle under the rift means, however, that flow cannot continue towards the ocean. Mid- and lower crustal material therefore accumulates in the proximal rift and rift margin, thickening them and lifting them by isostatic response to the thickening.

Analysis of the parameters necessary for flow to occur at sufficient rates to cause uplift of EPCMs shows that it can do so only if the lower crust is either quartz-rich or if it consists of dry diorite, but not of wet diorite. Because the rate of flow is proportional to $\sigma 3$ where σ is the difference between the principal (vertical) stress and the imposed (horizontal) compressional stress, the flow rate increases very rapidly with increasing stress difference. Flow into the rift margin is opposed by uplift and bending of the upper, strong crust, which imposes an additional normal stress, reducing σ, so flow into the already thickened crust is reduced substantially because of the strong dependence of flow on $\sigma 3$. Thickening continues 'upstream' on the continental side, however, widening the thickened and uplifted area. Flow and uplift can continue until a reduction in imposed far-field compressive stress causes a consequent large reduction in inflow, thereby 'freezing' the thickened crust in place. Erosion of the uplifted area will lead to further uplift because of the isostatic response to the erosion.