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A phase transition model for basins

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In general, rocks densify when they are subjected to higher pressures and swell when they are heated, consistent with the common perception of compressibility and thermal expansion of solid materials, direct observations and simple and more sophisticated calculations. As a first approximation, the density of rocks can be calculated as a linear function of temperature using a constant thermal expansion coefficient. This solely temperature dependent approximation is widely used in modelling of geological processes and interpretation of geophysical data. However, mineralogical reactions, or phase transitions, lead to a more complicated non-linear response of density to pressurization and heating. Densities of mantle peridotites hardly change along a normal continental geotherm due to the pressure dependence of mineral reactions, while the solely temperature dependent formulation predicts a density decrease of 2.6 %. In contrast, upper mantle phase transitions amplify the effect of thermal expansion by up to a factor of two, which can lead to significant basin uplift in strongly stretched lithosphere (Simon and Podladchikov, 2008).

The response of typical lower crustal rocks to heating is much more complicated. While the crust expands with increasing temperature at some pressure-temperature conditions, in line with conventional use of a positive thermal expansion coefficient, the crust contracts upon heating at certain P-T conditions if it contains some water (Semprich et al., 2010). The loss of volume due to dehydration reactions can be larger than the tendency of the solid to swell upon heating, leading to an effective negative coefficient of thermal expansion for these rocks under those conditions. This negative thermal expansion (densification upon heating) is most pronounced at pressures larger 1 GPa and temperatures between 500 and 800 ºC. These conditions prevail in lower continental crust that is deepened due to flexure and loading (e.g. in foreland basins) or due to thickening (e.g. in the crustal root of a mountain range), and in subducted oceanic crust.

We propose that the density increase of the lower crust due to dehydration reactions may be the driving force for the subsidence in many cratonic basins, and can explain the larger than predicted subsidence of foreland basins as well as the preservation of orogenic roots over long periods of time in eroded mountain chains. Simple isostatic modelling predicts that intra-cratonic basins will subside rapidly as a response to pressure increase, followed by slow subsidence on the time-scale of thermal equilibration.

References:

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