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Interplay of lower crustal metamorphism and continental lithosphere dynamics

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Crustal rocks densify if they are subjected to higher pressures, consistent with the common perception of compressibility of solid materials, direct observations and simple and more sophisticated calculations. The response of typical lower crustal rocks to heating, however, is 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 – it contracts upon heating at certain P-T conditions if it contains some water. 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. Systematic calculations of phase relations and densities using internally consistent thermodynamic data and Gibb's free energy minimization show that 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 pushed into the mantle 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 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. In addition, we predict a higher than usually assumed density increase in the initially hydrated oceanic crust during subduction.

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. Differences in the late stage evolution of orogens may be due to variations in bulk lower crustal compositions. Mafic lower crust becomes very dense if buried to sub-Moho conditions and may delaminate on a timescale that is determined by the initial level of hydration (in addition to rheological paramters). Dry basaltic crust is densest at high-P, but low-T conditions while wet mafic rocks reach densities higher than those of the mantle at high-P and high-T conditions. Lower crustal rocks with more felsic compositions are slightly lighter than mantle under high-P, high-T conditions and may stabilize basins and orogenic roots. However, some water-bearing felsic rocks (meta-pelitic restites) display larger density variations than mafic rocks along a wide range of P-T-paths and consequently cause larger isostatic vertical motions.