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Dynamics of continental lithosphere

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Although ancient continental interiors are commonly described as stable, many have been subjected to major perturbations, not just on their margins, but also within their interiors. In North America, for example, continental lithosphere was perturbed by the Keweenawan rift of 1.1 billion years ago, and later by the formation of four intracratonic basins (Williston, Hudson Bay, Illinois and Michigan) about 500 million years ago. Most interpretations rely on analogies with plate tectonics, such that events within continents are processes responding to remotely applied forces to their boundaries or mantle plumes. In this presentation, I would like to challenge this framework.

Chemical differences seem to have played a crucial role in the preservation of continental regions. Continental lithosphere of various ages, compositions, and thicknesses appears to be stable, which suggests the existence of multiple stable states. The intrinsic buoyancy of continental lithosphere, however, is not sufficient to guarantee its stability: lithosphere is cooled from above and hence develops a negative buoyancy. Both theoretical analysis and laboratory experiments show that stability depends on the buoyancy number, B, the ratio of the intrinsic density difference between the fluids and the maximum density difference due to thermal expansion.

For small buoyancy number, $B<0.5$, the lithosphere can undergo oscillatory instability, whereby perturbations to the interface between the fluids rise and fall periodically. For $B>\sim0.5$, a second form of instability develops, in which convection is confined to the lithosphere. In the oscillatory regime, downwellings reach maximum depths and then rise back, folding on themselves and entraining some of the lower fluid. In contrast to delamination, unstable lithopsheric material is not lost to the underlying mantle.

The lithosphere may have developed in a state near that of instability with different thicknesses depending on its intrinsic buoyancy. It may have grown by oscillatory convection entraining chemically denser material from the asthenosphere. During instability events, downwelling plumes of cold, but intrinsically light material should sink into the underlying asthenosphere, and asthenospheric material should upwell where the lithosphere thins. Upwelling implies decompression of hot asthenosphere, which in turn implies melting and basaltic eruption, and the mantle residue left by the extraction of melt should become part of a lithospheric root. Where the lithosphere is stretched and thinned, the continental crust should be subjected to subsidence. Above downwelling flow, the continental crust should undergo convergent flow, which leads to compressive features. These ideas can be applied to the consolidation of Archean (age $>$2.5 Ga) lithosphere in South Africa.