Cratonic basins: an archive of lithosphere-mantle interaction

***Project Report:* Summary Description of the Project Objectives**

Topography is generated by tectonic forces in the lithosphere, extension and compression, and as a response to movement of rock in the deeper mantle. The latter is commonly referred to as dynamic topography. However, the long-term preservation of dynamic topography has never been fully addressed. In this project we explored how deep mantle dynamics is recorded in the rock record by exploring the relationship between lithosphere destabilisation, subsidence and sediment accumulation within the continental interior, with a focus on cratonic basins[1]. The objectives were, (1) To develop a numerical model that couples large-scale Earth surface processes with mantle convection. (2) To understand the stability / destabilisation of continental lithosphere at the continent to ocean transition. (3) To explore the relationship between intra-continental subsidence and mantle convection.

Overview of results, *Stability or destabilisation of the continental lithosphere:*

1. The upper mantle, lithosphere, beneath the continents is thicker than the lithosphere beneath the oceans. Continental lithosphere is has a different chemical composition, causing it to be less dense that the mantle below. This change in structure creates lateral changes in density (e.g. Figure 1a, inset), which leads to lateral motion of the transition region and the associated topography at the surface. From the models developed, it was found that the predicted lateral motion of lithosphere rock explains the observed landward migration of the coast line of Eastern North America over the last 100 million years (*Armitage et al., 2013a*).

2. The movement of the transition in lithosphere structure at the continent to ocean transition is also potentially observed as sharp or broad transitions in observed surface heat flow, depending on the chemical composition of the continental lithosphere and width of the transition in lithosphere structure (*Armitage et al., 2013a*).

3. Episodic subsidence, vertical movement of the surface of the Earth, is also predicted as a consequence to the interaction between flow driven by both lateral density contrasts and the convective break-down of the lithosphere (Figure 1a). Such episodic subsidence is observed within the cratonic basins of North America, the Congo Basin in Africa (Figure 1b) and the eastern margin of North America (*Armitage et al., 2013a; Lucazeau et al., in press*).

Relationship between deep mantle flow, surface processes and the sedimentary record:

4. The accumulation of sediment due to the erosion of mountain landscape is insensitive to short-term, of a period of less than one million years, change in precipitation rates. The implication is that the sediment flux out of continental landmasses is temporally damped to Milankovitch-band oscillations in climate. Therefore the sedimentary system that delivers sediment from source (catchment) to sink (basin) acts as a quasi-steady conveyor, being only sensitive to long-lived change in uplift or climate

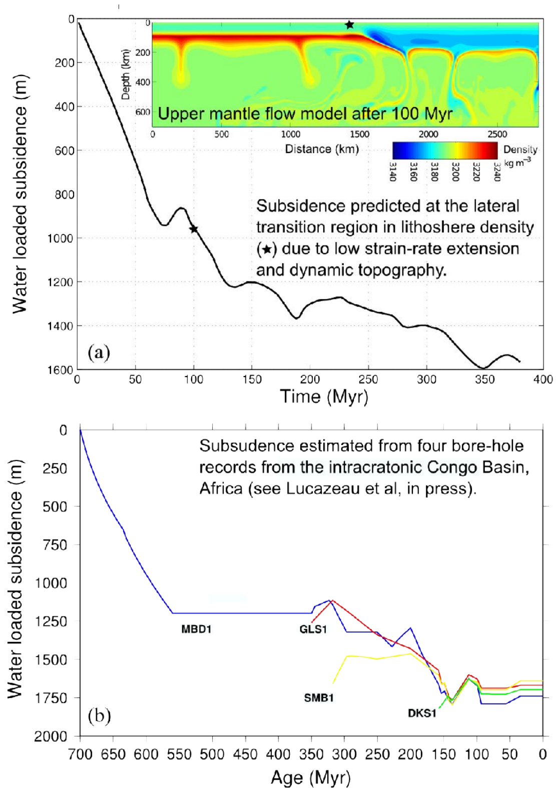

***Figure 1:** Prediction and observed subsidence at the transition from thin young to thick and buoyant old lithosphere. **(a)** Predicted subsidence due to the combined effects of extension during continental break-up and destabilisation of the lithosphere. Inset is the density structure of the modelled upper mantle after 100 Myrs of evolution. **(b)** Observed subsidence records of the Congo Basin taken from four bore-holes. The subsidence records displays an episodic change in susbidence that is very similar to that predicted by the model.*

1 Cratonic basins are large 1000 km diameter sedimentary basins that exist within all continental landmasses. These basins form over hundreds of millions of years. Classic examples are the Michigan Basin and Hudson Bay in North America.

(*Armitage et al., 2013b*).

(5) The interaction between the lithosphere and surface processes, erosion and deposition, will modulate the signal of change in climate or uplift recorded in the sedimentary archive: In regions of strong lithosphere, where cratonic basins typically exist, the predicted response to an increase in precipitation rates is of an initial increase in sediment delivery to the basin that subsequently reduces through time. This is in agreement with previous models (*Armitage et al., 2011*). The response to an increase in uplift is of an increase to a new steady sediment flux. However, if the lithosphere strength is low, the response of the system to both an increase in precipitation rates and uplift is for the sediment flux to increase to a new state. The implication is that sediment accumulations in regions of thick lithosphere may provide a strong record of past change in climate that is differentiable from uplift.

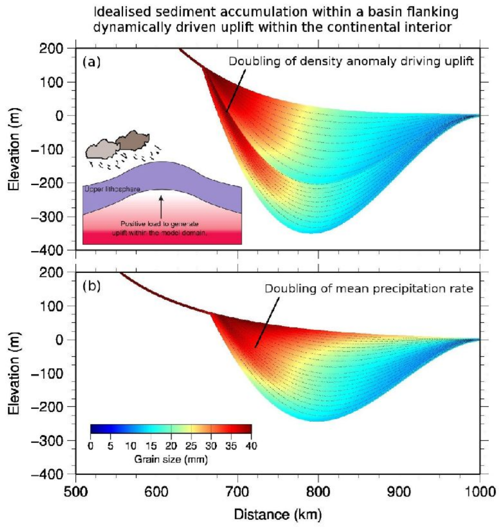

Figure 2: *Predicted change in stratigraphy over a 2 Myr period due to a change in topography cause by a density anomaly in the mantle or a prolonged change in climate.* ***(a)*** *Stratigraphy at 100 kyr intervals and grain-size for a hypothetical landscape (inset) responding to a doubling in uplift.* ***(b)*** *Stratigraphy and grain-size for the same landscape responding to a doupling in precipitation rates.*

(6) By combining the model of surface and lithosphere processes with predictions of the sediment grain size of the basin fill we find that, even in regions of weaker lithosphere, there may remain diagnostically different responses in the sediment accumulations to change in precipitation and uplift. An increase in uplift within the continental interior would lead to an increase in sediment thickness accompanied by a reduction in the grain size of deposit (Figure 2a). An increase in precipitation rates, would cause an increase in sediment accumulation accompanied by a gradual increase in the grain size of deposits (Figure 2b). This idealised model is in line with observations from the Great Planes, North America, where change in climate lead to the deposition of larger sediment grains during the Pliocene. (4 to 2 Myr ago; *Duller et al., 2012; Armitage & Duller, 2012; Armitage & Schmalholz, 2013*).

Conclusions

Cratonic basins are enigmatic, large, and very long-lived sedimentary basins that exits across all the continental landmasses. After formation, subsidence continues for hundreds of millions of years, providing a potential archive of change in climate and mantle dynamics. The long-lived subsidence history contains episodic periods of uplift and subsidence at intervals of 20 to 50 Myr that is driven by the lateral density contrast at the transition from oceanic to continental lithosphere at the passive margin. The sedimentary fill of these basins records both change in climate and uplift within the continental interior, with diagnostically different styles of deposition depending on the forcing mechanism, change in precipitation or uplift. To understand what sort of rocks fill a sedimentary basin, and how the basin is formed are crucial for hydrocarbon exploration. Furthermore, the results of this project will enable the sedimentary archive within these basins to be interrogated to explore past climate and mantle dynamics.

References

Armitage, J.J., Schmalholz, S., (2013) Is their a distinctive difference between climate and tectonically driven increases in sediment flux? EGU General Assembly, Abstract EGU2013-5920

Armitage J.J., Dunkley Jones, T., Duller, R.A., Whittaker, A.C., Allen, P.A., (2013) Temporal buffering of climate-driven sediment flux cycles by transient catchment response. Earth and Planetary Science Letters, doi: 10.1016/j.epsl.2013.03.020

Armitage J.J., Jaupart, C., Fourel, L., Allen, P.A. (2013) The instability of continental passive margins and its effect on continental topography and heat flow. Journal of Geophysical Research – Solid Earth, doi: 10.1002/jgrb.50097

Armitage, J.J., Duller, R.A., (2012) Towards a stratigraphic record of dynamic topography. AGU Fall Meeting, Abstract T33C-2668

Duller, R.A., Whittaker, A.C., Swinehart, J.B., **Armitage, J.J.**, Sinclair, H.D., Bair, A.R., Allen, P.A., (2012) Abrupt landscape change post-6 Ma on the Central Great Plains, U.S.A. Geology, 40, 871-874.

Armitage, J.J., Duller, R.A., Whittaker, A.C. & Allen, P.A., (2011) Transformation of tectonic and climatic signals from source to sedimentary archive. Nature Geoscience, 4, 231-235, doi: 10.1038/ngeo1087.

Lucazeau,F., **Armitage J.J.**, Kadima Kabongo, E., (in press) Thermal regime and evolution of the Congo Basin as an intracratonic basin, Chapter 7, in "The geology and resource potential of the Congo Basin", Editors: M.J. de Wit, F. Guillocheau, M. Fernandez-Alonso, N. Kanda, M.CJ De Wit.