Coastal erosion and flexural uplift: modelling unsteady rates of shoreline migration and assessing impact on ancient shallow-marine strata and modern coastal systems

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Introduction: Coastal transgression and landward shoreline migration is a key process influencing the deposition and preservation of ancient strata, and also an increasingly important modern process globally as coastlines begin to respond to rising global sea level. In both cases, the rate and time evolution of shoreline migration is critical to understand. It is generally assumed that, the rate of landward shoreline migration is proportional to the rate of sea level rise. However, if rising sea level drives erosion of the shoreline and shelf, this will cause flexural isostatic uplift. This complex interaction may reduce or perhaps even reverse the sign of relative sea-level change. This process may have taken place throughout geological time and may be ongoing, which has very important consequences for our understanding of the ancient record and may require us to re-evaluate our long term strategy for protecting our inhabited coasts.

Project Summary: The purpose of this project is to explore the possibility of unsteady shoreline migration due to a feedback between coastal erosion and flexural isostatic uplift (Burgess, 1994). Unsteady transgression has been demonstrated already in a very simple 2D prototype model (Burgess, in prep) (Fig. 1). The model uses a simple 1D calculation of lithosphere flexure, with either an instantaneous elastic response (Watts, 2001), or a finite-duration response with an exponential decay rate based on observation of postglacial rebound (Turcotte and Schubert, 2002; Davis, 2011). The prototype modelling suggests that the wavelength of the erosion is a key control on the effect; longer wavelength erosion tends to produce higher magnitudes of uplift, as predicted by simple flexure equations (Watts, 2001). In cases with low effective elastic thickness this may be enough to outpace the rate of eustatic sea-level rise, at least for greenhouse-climate rates, and produce unsteady shoreline transgression. However, this is just a very simple 2D model, with a very basic erosion model that is largely geometric, and the simplest 1D flexure formulation. A more 3D model with more realistic representations of coastal erosion, mass redistribution and flexural response is required. Modelling of the flexure will need to account for the stress field produced by the load (Figure 2), and calculate a time-dependent response of a realistic layered lithospheric rheology. Examination of uplift rates from modern coastal setting will provide important data to constrain this model. The project will also include focussed fieldwork to apply ideas of unsteady transgression and erosion-flexure feedbacks in analysis of transgressive parasequence strata of the Cretaceous Cliff House Sandstone in the San Juan Basin, New Mexico.

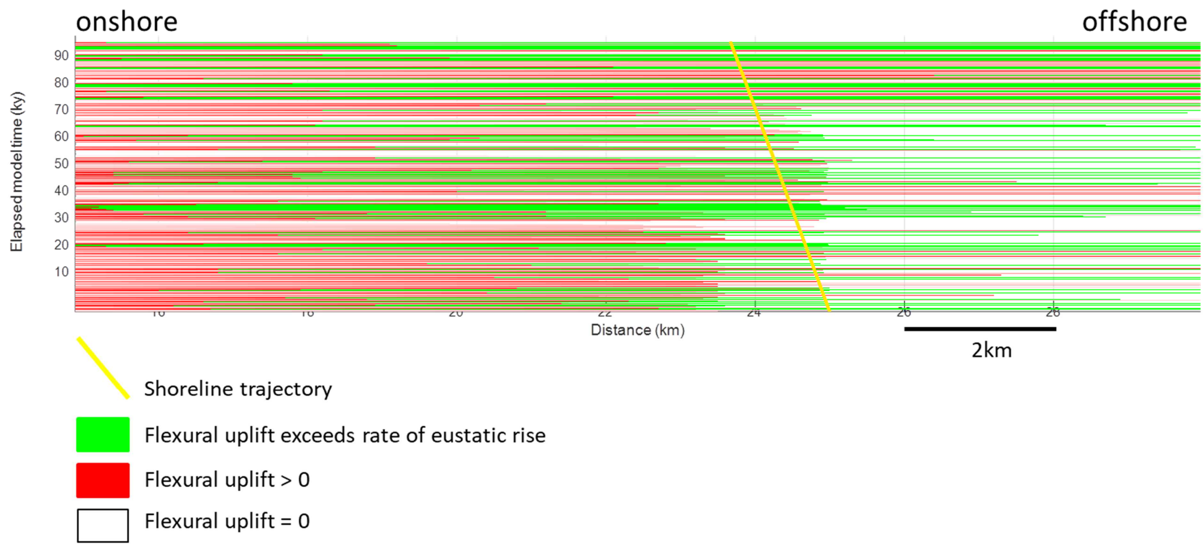

Figure 1 A chronostratigraphic diagram showing a preliminary result from the simple 2D cross-section model of flexural response to transgressive coastal erosion. Coastal erosion occurs as the shoreline (yellow) transgressed, causing periods of flexural isostatic uplift (green and red). When flexural uplift exceeds the rate of eustatic rise (red) short regressive or still-stand episodes occur. These are too small to be individually visible on the shoreline trajectory in this plot, but they decrease the mean rate of transgression by about 20%.

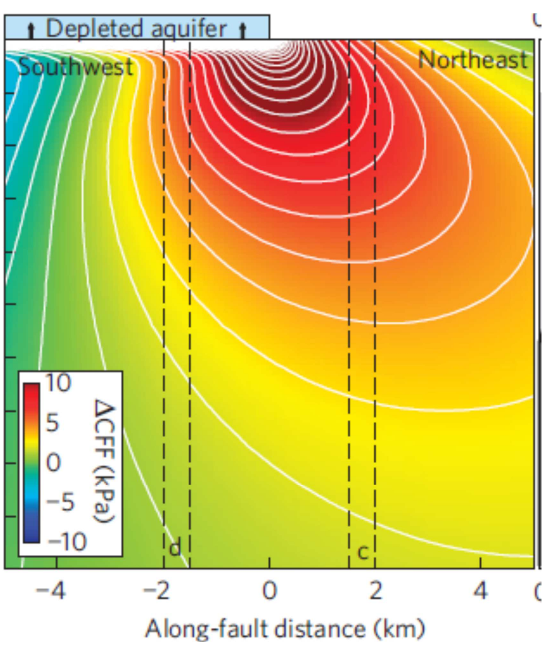

Figure 2 A calculation of the stress field generated by near-surface unloading, calculated as a homogeneous elastic half-space using the Boussinesq solution, and resolved for the Coulomb stress change (1CFF) on the a fault geometry. A similar method could be used to calculate the stress field induced by unloading due to costal erosion. From Gonzalez et al. (2012)

The aims of the project will be as follows:

- Create a simple but realistic numerical forward model of coastal erosion with three spatial dimensions that can erode mass from a transgressive coastline, and redistribute the mass offshore or alongshore.
- Calculate the stress field produced by coastal erosion unloading, and developed a simple numerical model of the likely time-dependent rheological response of a layered lithosphere.
- Derive model parameter values from modern and ancient examples to test this model. Conduct systematic sensitivity analysis to understand the parameter conditions required for unsteady shoreline transgression, and determine 1) how might this erosion-flexure feedback influence future sea-level rise driven by anthropogenic climate change, and 2) what record might unsteady shoreline migration due to an erosion-flexure feedback have produced in ancient strata
- Test the model predictions against the record of shallow-marine ancient strata and against geodetic surface uplift data in erosional coastal zones.

The student working on this project will receive training in numerical modelling using Matlab or some similar development environment, coastal geomorphology, siliciclastic sedimentology, particularly in shoreline and shallow-marine strata, and analysis of surface ground deformation from satellite data.

References

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