Stratigraphic Modelling of Continental Rifting

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Overview:

The interaction between surface processes and large-scale tectonics has long been recognised as a important factor in the evolution of continental rifting and rift basin development.

This project aims to quantify the relative influence of tectonic and climatic forcing on these systems by developing a new coupling between two innovative numerical modelling frameworks: Underworld and LECODE.

From the coupled models we can extract stratigraphic and geomorphic information through time to determine the impact on rift evolution and basin development.

Methodology

This project is made up of two numerical modelling frameworks and a purpose built coupling mechanism. The coupling mechanism allows communication between the two frameworks to produce high spatial and temporal resolution models.

Underworld:

Underworld is a 2/3D parallel, particle-in-cell, visco-plastic, lithospheric and mantle convection modelling framework, developed at Monash University. The coupling mechanism extracts the vertical displacement information from the surface of the model and passes it through to LECODE.

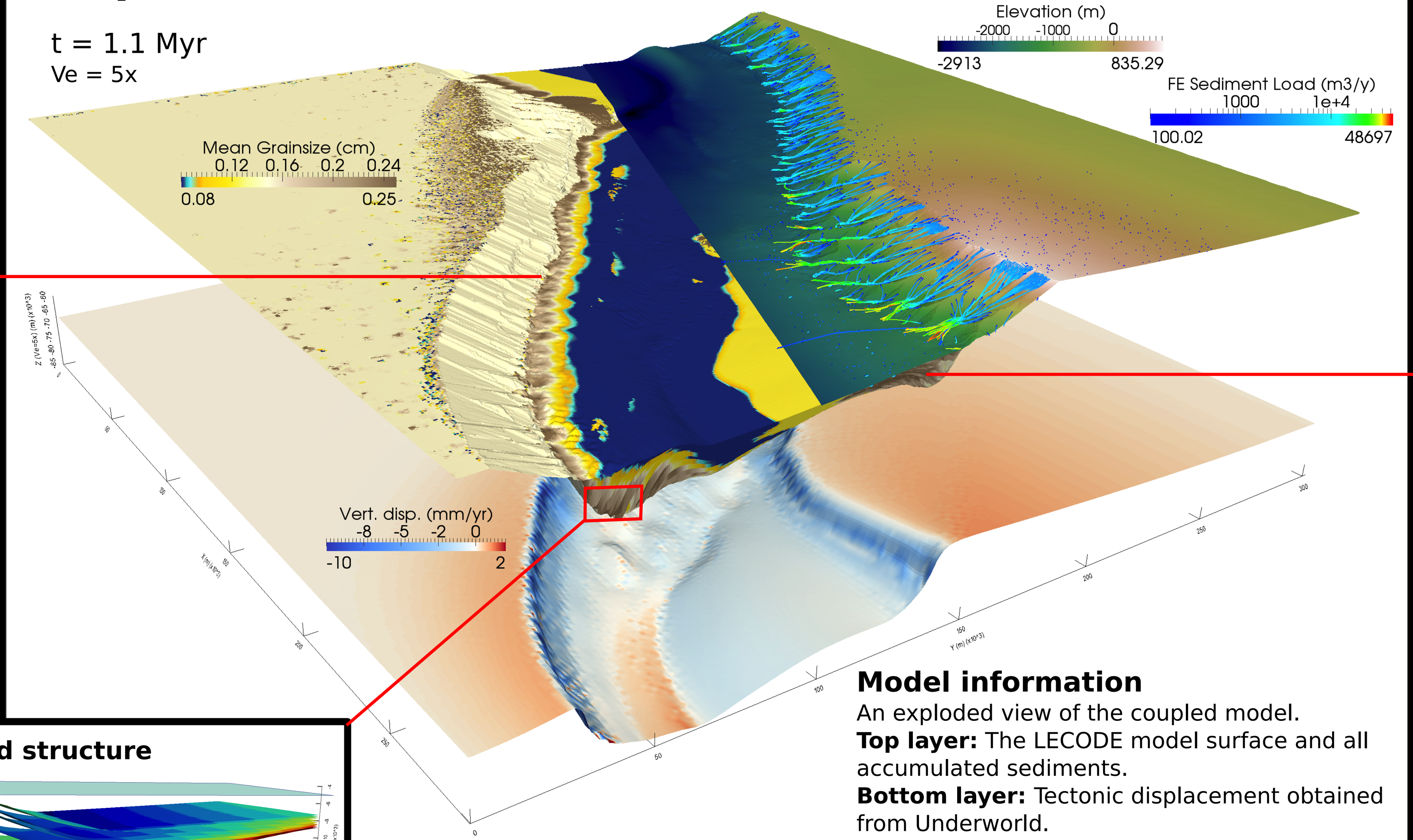
LECODE (Landscape Evolution Climate Oceans Dynamic Earth):

LECODE is a new 3D parallel, stratigraphic and geomorphic modelling framework, developed within the CSIRO. LECODE uses Lagrangian fluid elements over an Eulerian adaptive mesh to dynamically model erosion, sediment transport, and deposition. The vertical displacement information from the coupling mechanism is applied to the basement of the model. The surface is then allowed to evolve in response to regional rain-fall and eustatic sea-level changes.

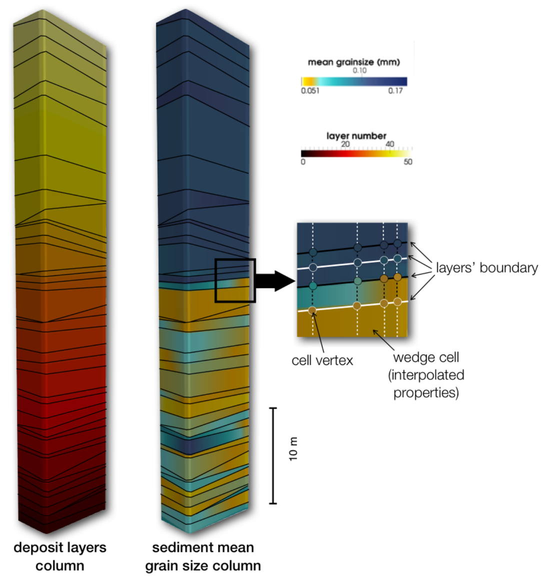
Surface Lithology

The coupled model begins with a homogeneous layer with a relative hardness of 10 compared to loose sediments. Materials are defined by combining different materials (e.g. gravels, sands, silts), and their relative proportions are recorded in subsequent sedimentary units. Deltaic structures and paleo-shore lines can be seen along the rift axis as changes in material composition and geomorphology.

Coupled Underworld/LECODE Model



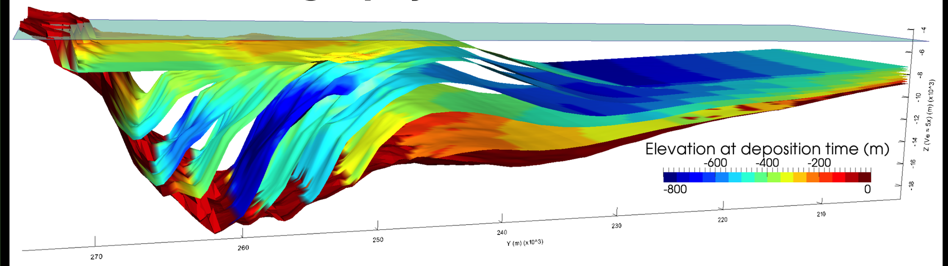
Model information
An exploded view of the coupled model.
Top layer: The LECODE model surface and all accumulated sediments.
Bottom layer: Tectonic displacement obtained from Underworld.



Stratigraphic columns

Stratigraphic columns are able to be extracted from anywhere in the model. Material type, grain-size, deposition age, and porosity can all be visualised.

3D basin stratigraphy and structure



A 3D section of a basin extracted from the coupled model, formed from a mix of bounding fault subsidence and clino-form-like sediment build up. Layers are 100 Kyr isochrons.

Coupling Mechanism

Vertical displacement - No feedback to tectonics

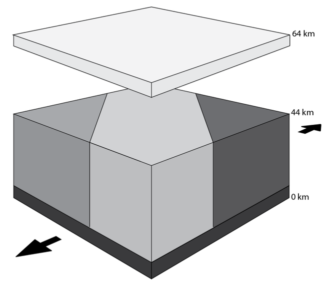
Vertical surface displacement

Surface process modelling

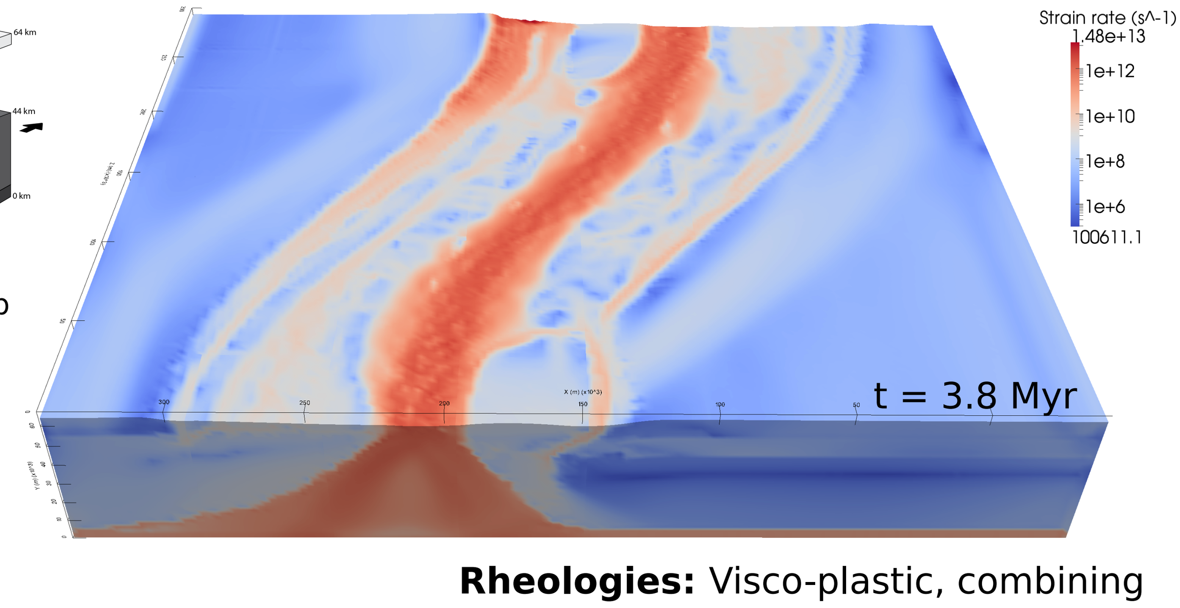
Future work

The coupling mechanism will be upgraded in two stages:
1) Vertical feedback to Underworld
2) Full lateral and vertical feedback.

Thermo-Mechanical Oblique Rifting Model



Initial model setup



Model: Oblique rifting with heterogeneous sub-continental lithospheric mantle. Two cratons of differing rheologies are rifted apart at ~1cm/yr on each boundary.

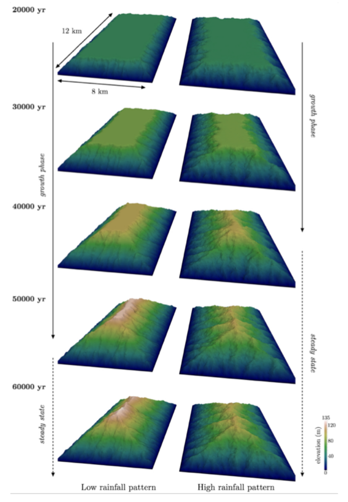
Rheologies: Visco-plastic, combining Drucker-Prager yielding and temperature and strain-rate dependent viscosity.

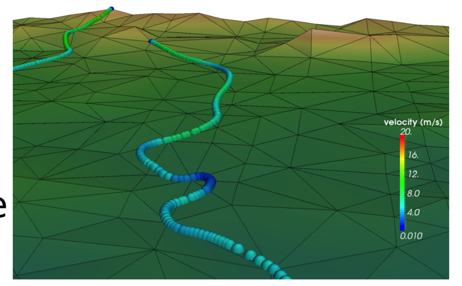
Geotherm: Constant top and basal temperature with radiogenic heat production in the crust.

Stratigraphic and Surface Processes Model

Tectonic & climatic inputs

LECODE allows input of the spatial and temporal distribution of:
- Tectonic uplift or subsidence
- Rainfall
- Eustatism
- Lithologies



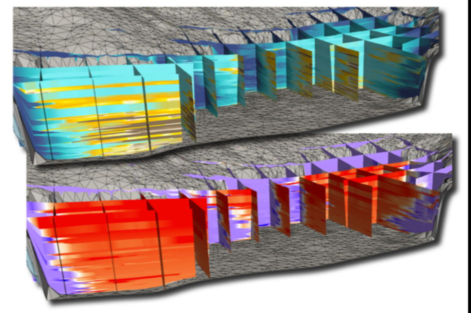


Stratigraphy

Recorded across the entire domain, LECODE tracks sediment type, age, grain size, and porosity.

Fluid elements

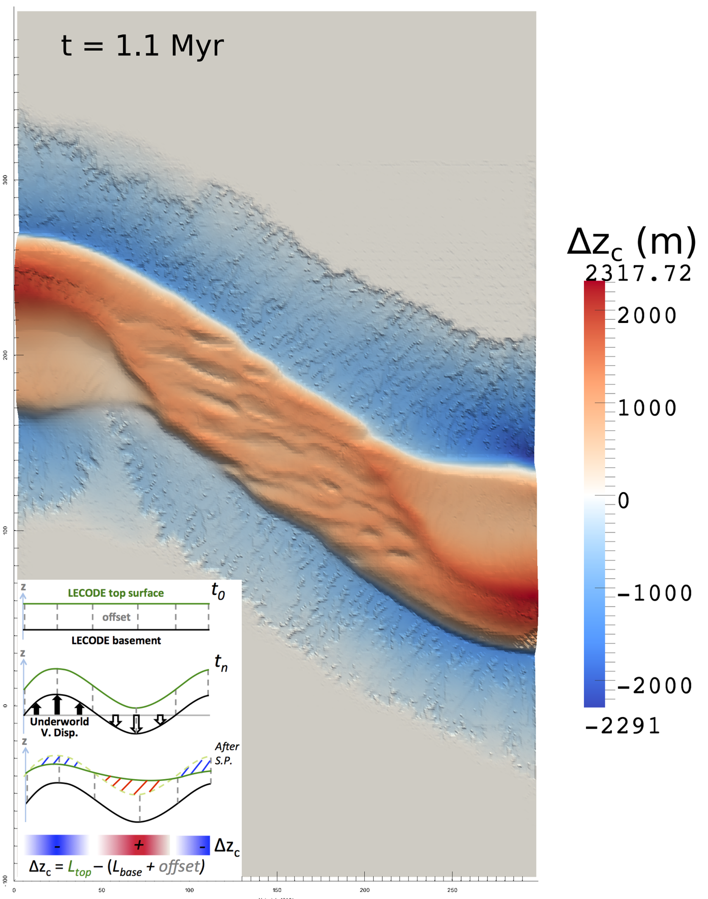
Representing fluid from rivers, rain or slope failure. They flow over an adaptive mesh to erode, transport, and deposit material. They track flow paths, velocity, sediment load, and flow type.

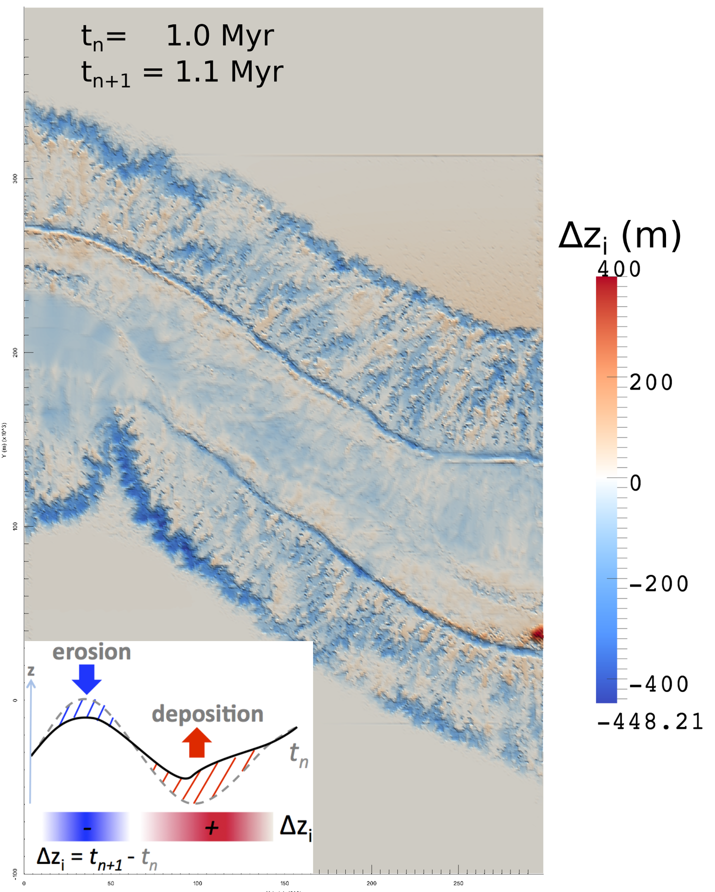


Model exploration and visualisation

Cumulative (Δz_c) & Instantaneous (Δz_i) erosion/deposition:

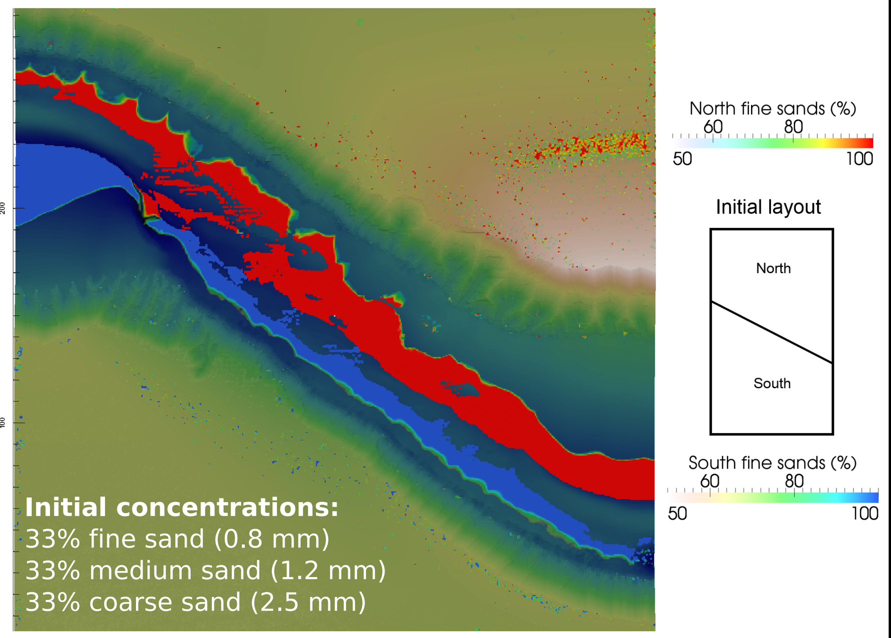
Visualising Δz_c and Δz_i through time highlights periods and locations that are critical to basin formation and evolution.





Sediment dispersion:

Eroded and reworked material can be visualised across the domain. Shown is the asymmetry in fine sand distribution from the north and south of the model, driven by the asymmetric flank uplift.



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Underworld: http://www.underworldproject.org/

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