EarthByte Honours Projects 2015

Dynamic ups and downs of mountain belts

Supervisors: Nicolas Flament, Simon Williams, Dietmar Müller

The effect of the convecting mantle on the subsidence and uplift of sedimentary basins (dynamic topography) is well-established. New research suggests that mantle flow also plays a significant role in mountain-building. This effect has so far been overlooked. This project will explore the dynamic topography component related to the building of the world’s largest orogenic belt – the Alpine-Himalayan Belt. As part of this project you will build a deforming plate model of the Alpine-Himalayan Belt and use a well-established dynamic Earth models to simultaneously quantify the contributions of the deformation of the lithosphere and of mantle flow to the evolution of topography.

The project will involve analysing the topography and its rate of change predicted by global mantle flow models, and comparing them to geological constraints. This will require the use of analytical skills, basic scripting (in shell, python or other) and the use of various software skills, including GPlates and the Generic Mapping Tools (GMT). Part of a large industry collaboration (Basin Genesis Hub), this project will prepare students both for working in the exploration industry as well as for a research-oriented career in government agencies or universities.
The role of mechanical stratigraphy in the structural style of deformed sedimentary basins

Supervisors: Patrice Rey, Louis Moresi, Luke Mondy

The strong variability in the structural style (geometry of folds, fault patterns etc) of syn-rift basins and inverted basins is due, in large part, to the rheological contrasts that can exist between evaporites, shales, sandstones, limestones and volcanics. The inversion, via forward modelling, of the structural style imaged through seismic methods, can help constrain the mechanical stratigraphy which, at the scale of sedimentary basin, control the structural style. This project aims at defining, via a simple inversion protocol, the mechanical stratigraphy of major sedimentary sub-basins along Australia’s North West Shelf and PNG. It is part of, and supported by, the Basin Genesis Hub. (Photo: Ólafur Lngólfsson).

The opening of Southern Ocean gateways and their effect on Earth’s climate

Supervisors: Maria Seton, Simon Williams

Oceanic gateways are narrow, shallow, or diffuse connections between neighbouring oceans and are believed to drive large-scale changes to the entire planetary system, from global climate and ocean circulation to species diversity. The circum-Antarctic is home to two major oceanic gateways that opened in the Cenozoic: the Tasman Gateway and Drake Passage/Scotia Sea. The widening and deepening of these oceanic gateways during the early stages of continental rifting has been correlated with the inception of the Antarctic Circumpolar Current, the glaciation of Antarctica and the end of a “Greenhouse World” at the Eocene-Oligocene boundary, ~35 Myrs ago. However, the relationship between tectonic changes and abrupt climate shifts is strongly dependent on accurate dating of tectonic events and reconstructions of gateway morphology through time.

In this project, you will generate alternative plate tectonic scenarios for the Southern Ocean gateways and assess the effect of these changes on Cenozoic ocean circulation patterns. The
The tectonic evolution of Cretaceous-Cenozoic oceanic gateways and orogens of the northern Pacific rim in a palaeoclimate context

Supervisors: Maria Seton, Simon Williams, Dietmar Müller

Oceanic gateways are narrow, shallow, or diffuse connections between neighbouring oceans and focal areas for the large-scale exchange of water, heat, salinity, nutrients and genes between ocean basins. The opening and closing of these gateways are largely controlled by plate tectonic processes, eventually leading to the establishment of deep-water flow between ocean basins. On land, the rise of major orogenic belts along convergent margins may influence global climate as they act as barriers to atmospheric circulation. The northern Pacific rim and Arctic Ocean have been affected by the opening of the Bering Strait (oceanic gateway) between Eurasia and North America in the Cenozoic and the uplift of the Rocky Mountains along the western US starting in the Cretaceous.

In order to assess the relative importance of the opening of the Bering Strait to ocean circulation and the uplift of the Rocky Mountains to atmospheric circulation, we need to uncover the relative
timing of the tectonic changes associated with the evolution of these areas. As part of this project you will build a plate tectonic model of the Cretaceous-Cenozoic northern Pacific rim and Arctic Ocean, which takes into account deformation associated with continental margin extension and shortening. Your models will be used in a 3D mantle convection modeling code, CitcomS, to produce a new elevation model for the region, which will then be used as input into palaeoclimate models.

Formation of continental ribbons in the context of the North West Shelf
Supervisors: Patrice Rey, Luke Mondy, Sabin Zahirovic

During the Paleozoic and Mesozoic, three continental ribbons successively detached from Australia’s North West Shelf (NWS) via continental rifting. This fragmentation via the shedding of continental ribbons suggests that in a composite oceanic-continental plate it is the continental margin that is the weakest part. Along active continental margins, slab rollback pulling on the upper plate, as well as the rise of buoyant mantle wedge have been proposed to explain the detachment of continental ribbons. However, in the context of passive margins the dynamic of rifting leading to the detachment of continental ribbons and the formation of rift basins is still unclear. A better understanding of passive margin fragmentation may provide key insights into the evolution of the NWS. This project is part of, and supported by, the Basin Genesis Hub.

Exploring solid Earth models with machine learning
Supervisors: Simon Williams, Luke Mondy, Patrice Rey, Nicolas Flament, Dietmar Müller

Exploration for buried resources is driven by the acquisition of geological and geophysical data (boreholes, seismic, gravity, magnetics) that allow us to image the subsurface, and by geodynamic simulations that provide insights into how the subsurface is shaped by tectonic processes. Modern advances in computing and data storage give us access to huge volumes of both observational data and simulation output, providing an unprecedented opportunity to explore the relationship between the nature of structures (e.g. faulting and folding, uplift and subsidence due to mantle flow) imaged in actual data sets, and the patterns of deformation predicted by alternative simulations. This opportunity also presents new problems - how to make sense of these huge data volumes, and how to isolate the key parameters that can successfully link observations and simulations.

This project will aim to develop new approaches to the exploration of geodynamic simulations; generating synthetic geophysical data volumes from simulation output, and creating innovative
techniques to allow quantitative comparisons between simulations and observations. The project may tackle a range of scales, from global mantle convection simulations to models of individual rift basins. The project will develop skills and experience in state-of-the-art computational tools for geophysical and geodynamic data analysis and machine learning.

The evolution of proto-Atlantic/Indian ocean basins and marginal seas in the Cambrian to Devonian

Supervisors: Dietmar Müller, Kayla Maloney, Kara Matthews, Nicolas Flament

Continents and sedimentary basins through time have recorded fundamental Earth system cycles, reflecting environmental change, migration of fauna and flora and shifting coastlines. It was originally thought that successive advances and retreats of shallow inland seas mainly reflect global sea level variations (eustasy). However, it is now well established that large-scale surface morphology such as the high topography of the East African Rift, the low-lying Amazon River Basin and the southwest to northeast tilt of the Australian continent are strongly controlled by processes deep within the Earth. Quantifying the magnitude and time-dependence of mantle-driven topography requires integrating geological data with coupled models of the plate-mantle system. In turn, these models need to be validated with observational data, such as published paleogeographic maps and paleobiology data.

The overarching aim of this project is to understand the deep-seated driving forces of large-scale topographic change, providing dynamic models of the Earth’s subduction history, deep plume sources and dynamic topography for the Paleozoic-Mesozoic periods. The early Paleozoic follows the breakup of the supercontinent Rodinia after the end of the so-called Snowball Earth period. Throughout the early Paleozoic, the Earth’s landmass was broken up into a substantial number of continents. This Honours project focussed on building models for the early Paleozoic Earth using the software GPlates, and using geological observations, especially thermochronology, to test geodynamic models, which predict mantle convection patterns and surface uplift/subsidence through time.
Tectonic reconstruction at 455 million years ago (Late Ordovician) centered on the ancient Iapetus and Rheic oceans that once existed between Laurentia and Gondwana, and have since been destroyed. Present-day topography is shown for the continents.

This project will address the following questions:

- How were ocean basins, including back-arc basins, created and destroyed between the Cambrian and Devonian periods?
- How have the fundamentally different plate tectonic configurations before and during/after the assembly of the supercontinent Rodinia affected subduction history, the history of mid-ocean ridge system evolution, mantle convection patterns and ultimately regional sea level fluctuations/subsidence/uplift?

The projects will involve acquiring various software and database skills, including GPlates, including spatio-temporal data mining, ArcGIS, the Generic Mapping Tools, shell scripting, dealing with the paleobiology database, as well as learning the basics of geodynamic modelling. These projects will prepare students both for working in the exploration industry as well as for a research-oriented career in government agencies or universities.
Sequence stratigraphy 2.0: Sea level change & dynamic topography

Supervisors: Patrice Rey, Dietmar Müller, Nicolas Flament, Luke Mondy

At the global scale, sea level highstands limit erosion power, favouring the transfer and deposition of small sized particles over increasingly larger sedimentary basins. In contrast, sea level lowstands increase erosion power, favouring the mobilisation and deposition of coarser particles over retreating basins. Hence, the nature of sediments, the volume of sediment, and their sequential deposition is controlled by global sea level changes through time. This has led to the concept of sequence stratigraphy, the principles according to which basin stratigraphy and stratigraphic architecture are interpreted in terms of global sea level changes. To the first order, this theory predicts that the stratigraphy of sedimentary basins of similar ages should be correlatable. However, at regional scales, dynamic topography, tectonic topography and climate change interfere with sea level change, by influencing surface processes controlling the evolution of sedimentary basin. This project aims at transforming the concept of sequence stratigraphy by exploring the impact of dynamic topography. Part of a large industry collaboration (Basin Genesis Hub), this project will prepare students both for working in the exploration industry as well as for a research-oriented career in government agencies or universities.
Feedback lithospheric extension - surface processes, and climatic forcing

Supervisors: Patrice Rey, Luke Mondy, Guillaume Duclaux, Tristan Salles

This project investigates the interplay between extensional tectonics, and mass transfer at the Earth’s surface through erosion, sediment transportation and deposition. The weight of sediments has an important amplification effect on the surface subsidence, while in the meantime modulating the Moho upwarping during extension. This loading impacts also on the evolving deviatoric stress field, and therefore the tectonic evolution of basins. Sediments - which commonly have a low thermal conductivity - have also an important effect on the long term thermal structure and therefore rheology of the underlying lithosphere, and its response to deviatoric stresses. The rate of accumulation is also key to the burial of organic matter, and evolution of good source rocks. Being able to map through time the optimum accumulation rate in an evolving basin is therefore important. This project is part of, and supported by, the Basin Genesis Hub.

Continental rifting mantle melting and hyper-extended continental crust

Supervisors: Patrice Rey, Luke Mondy, Sascha Brune

The formation of continental margins through the processes of continental rifting often leads to strong vertical strain partitioning during which, the upper crust, the lower crust and the lithospheric mantle record contrasting style of extension. Because these layers have contrasting densities and thermal properties, vertical strain partitioning can lead to contrasting subsidence patterns and thermal evolutions. In addition, contrasting style of extension in the lithospheric mantle could explain the development of magmatic and a-magmatic continental margins. This project will specifically investigate the role of the mantle and mantle processes, including edge-driven mantle convection, in the evolution of continental margins. This project is part of, and supported by, the Basin Genesis Hub.