EarthByte Honours Projects 2016

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).
Understanding the formation Earth’s largest continental ribbon: The Lord Howe Rise

Supervisors: Patrice Rey, Simon Williams and Dietmar Müller

Lying submerged beneath the sea east of Australia is the world’s largest submerged continental fragment, the Lord Howe Rise (LHR). The LHR is part of the continent of Zealandia, which separated from eastern Australia in the Cretaceous during the final phase of Gondwana breakup. The LHR is of critical importance both scientifically and economically. The region represents a large gap in our knowledge of the Mesozoic geological history of pre-breakup Australia, New Zealand and New Caledonia - after long-lived subduction along the East Gondwana margin, what drove the cessation of subduction and subsequent widespread continental extension that ultimately rifted Zealandia from Australia? Why is the eastern margin of Australia so narrow, compared to the wide rifting of the LHR? And what sequence of events then set the scene for initiation of the Tonga-Kermadec subduction zone east of the LHR in the early Cenozoic? These questions are central to our understanding of fundamental processes such as the mechanisms of continental extension and breakup, and subduction initiation. Further, they underscore attempts to assess the petroleum systems potential of some of Australia’s largest frontier basins, which will be the sites of extensive geophysical surveying and scientific drilling in the coming years. This project will combine insights from geophysical data sets with state of the art numerical modelling of lithospheric extension, using the Underworld software, to explore the geodynamic evolution of eastern Australia and the Lord Howe Rise. The project would also involve participation in a research cruise on the Japanese research vessel Kairei (http://www.jamstec.go.jp/e/about/equipment/ships/kairei.html)

Planned geophysical survey along a profile across the central Lord Howe Rise.
Evolution of the Australian climate and landscape over the last 100 Myr

Supervisors: Tristan Salles, Nicolas Flament, Dietmar Müller

It has long been identified that continents tilt as they drift over the convecting mantle. Australia is an ideal continent to study this process because it has undergone little tectonic deformation since the Jurassic. The aim of this project is to model the evolution of the Australian landscape over the last 100 Myr from a history of varying climate, sea level and mantle-driven topography.

The focus of the project is two-fold:

Data focus:
• you will investigate the evolution of dynamic topography deduced from river profiles dataset,
• you will compile from paleo-climate datasets a series of Australian regional and continental climatic evolution (precipitation) scenarios for the last 100 Myr,
• you will generate a set of paleo-topography for Australian landscape based on the sedimentary record of basins, and paleo-environment datasets.

Numerical focus:
• you will couple the dynamic topography predictions with a continental-scale surface process model to simulate 100 Myr of landscape evolution from the compiled history of varying climate, sea level and mantle flow,
• you will compare simulated erosion and drainage patterns to paleo-drainage from paleogeography, denudation rates from thermochronology,
• you will validate model results against sedimentary record in key Australian basins.

Tools: you will use the state-of-the-art computational tools Badlands, GPlates and CitcomS.
Unravelling the causes of Cretaceous oceanic anoxic events in the South Atlantic

Supervisors: Adriana Dutkiewicz and Dietmar Müller

Sedimentary deposits of the South Atlantic contain a record of seven Cretaceous (~ 145 – 65 Ma) oceanic anoxic events (OAEs) during which organic-rich black shales were deposited under greenhouse conditions (Jenkyns, 2010). OAEs record profound changes in the climatic and paleoceanographic state of the planet and represent major disturbances in the global carbon cycle, but their exact timing and origin are not well understood. Potential causes include limited ocean circulation (ocean stagnation), fluctuations in primary productivity, sea-level fluctuations, increases in seafloor spreading rates causing an increase in atmospheric CO2 and global warming, and continental weathering. Regional circulation in ocean sub-basins may be restricted through the stepwise evolution of ocean gateways and/or intraoceanic sills (microcontinents/igneous ridges) such as the Rio Grande Rise and Walvis Ridge, but at most only a subset of South Atlantic OAEs can be explained this way. Volcanism has also been proposed as a potential trigger mechanism, but only for OAE2 at 93.5 Ma (Turgeon and Creaser, 2008). The ICORDS project at EGI (Univ. of Utah) has compiled and biostratigraphically recalibrated key DSDP/ODP data in the South Atlantic and provides a new opportunity to re-evaluate the potential causes of Cretaceous OAEs. This project will be based on the analysis of these sedimentological and geochemical data in a plate tectonic context, making use of a new set of paleobathymetry maps for the South Atlantic (Seton et al., in prep) paired with a revised model for the opening of the South Atlantic (Heine et al., 2013).

Skills involved in the project include Arc GIS, GPlates and OSXBackstrip software for drill site subsidence analysis. The project may involve a visit to EGI at the Univ. of Utah in Salt Lake City starting around 25 May 2016.

References:

Global distribution of deep-sea sediments in the Miocene

Supervisors: Adriana Dutkiewicz and Dietmar Müller

The Earth has experienced major changes in global ocean circulation throughout the Cenozoic, during the transition from a hothouse to an icehouse climate. Our understanding of these major changes has mainly been derived from analyses of individual or small groups of ocean drill sites. However, a distinction of regional vs global effects in ocean circulation, and associated climate change, will only be possible by evaluating the sediment deposition history of all ocean basins in a global tectonic context. The ICORDS DSDP/ODP/IODP data compilation and re-evaluation now opens the opportunity to map global patterns of sediment accumulation rates and lithology distribution in the world’s ocean basins for the first time. At the same time, the GPlates software, which is in the process of being adapted to handle ICORDS data, provides the opportunity to put all these data into a plate tectonic and paleobathymetric context. These two combined approaches potentially enable major breakthroughs in understanding how changes in ocean basin paleophysiography, the opening and closing of major gateways, and changes in continental topography (based on as yet unpublished continental paleotopography maps within the EarthByte Group) have affected the patterns of deep-sea sedimentation through time. For this project, we will focus on the time around the Mid-Miocene Climate Optimum. The Miocene was a key stage in the global ocean basins’ tectonic and oceanographic evolution. Associated changes in meridional overturning circulation are thought to have affected climate during this time, including the expansion of Antarctic ice sheets at ~14 Ma. A recent Atlantic ocean-wide synthesis of Miocene benthic foraminifer δ13C data, underpinned by new high-resolution climate simulations (Herold et al., in review), reveals several key changes in ocean ventilation, including a cool phase (~21-17 Ma) leading up to the Miocene Climatic Optimum (MCO, 17-14.5 Ma) and the subsequent Middle Miocene Climate Transition (MMCT, 14.2-13.8 Ma) to warmer climates. How these changes in the Atlantic circulation are reflected in changes in global ocean circulation and sediment accumulation patterns is currently unknown. We plan to adapt the recently developed method by Dutkiewicz et al. (2015) to grid the global seafloor lithology from reconstructed drill sites through key stages in the Miocene to generate the first sets of digital paleo-seafloor lithology maps for this time period. We also plan on gridding the accumulation rates of key sediment components, particularly carbonate ooze, siliceous ooze, total organic carbon and clay components. This long-term project will require access to the global ICORDS dataset of relevant geological and geochemical measurements.

Skills developed in the project include using Arc GIS, GPlates, Generic Mapping Tools (GMT) and OSXBackstrip software for drill site subsidence analysis. The project may involve a visit to EGI at the Univ. of Utah in Salt Lake City starting around 25 May 2016.

References:
Dutkiewicz, A., Müller, R. D., O’Callaghan, S., and Jónasson, H., 2015, Census of seafloor sediments in the world’s ocean: Geology, v. 43, no. 9, p. 795-798.
Influence of dynamic topography on Cretaceous global sea level change

Supervisor: Nicolas Flament and Simon Williams

The chronology of past sea level changes is marked by high sea levels during the Late Cretaceous, with consequences for the composition of the oceans and atmosphere, life, and the formation of hydrocarbon-rich basins (Haq et al., 1987). Rapid seafloor spreading during the Late Cretaceous has long been known to be a controlling factor to this sea level high (Hays and Pitman, 1973), amplified by a hotter climate. Since this early work, the chronology of Cretaceous sea level changes has been revisited (Haq, 2014) based on updated geological time scales, and the role of mantle convection on individual passive margins has been recognised (Müller et al., 2008; Flament et al., 2013).

The aim of this project is to identify the contribution of mantle flow on Cretaceous sea level change by 1/ investigating the vertical motions of key sedimentary basins (Haq et al., 2014) predicted by time-dependent global mantle flow models (Figure) and 2/ comparing the Cretaceous marine flooding predicted by global mantle flow models to reconstructed paleoenvironments (e.g. Smith et al., 2004). The effect of mantle flow on sea level change will then be compared to that of changes in ocean volume caused by continental deformation, eruption of subaqueous large igneous provinces and oceanic sedimentation.

Example of the dynamic topography and dynamic topography rate of change predicted for the late Cretaceous by time-dependent mantle flow models.

This project will be the opportunity to further develop your analytical skills, your basic scripting skills (in shell, python or other) and your software skills (including GPlates and the Generic Mapping Tools - GMT).

References:
Plate tectonic history and basin evolution around Myanmar

Supervisors: Sabin Zahirovic, Simon Williams, Khin Zaw (Univ. of Tasmania), Kara Matthews (Univ. Oxford)

Myanmar, previously Burma, is located within a complex tectonic zone extending from the northern continuation of the Sunda-Andaman volcanic arc into the eastern Himalayan Mountain Range, where India collided with a southwest-facing arc system on the margin of Asia in the Eocene. Both onshore and offshore Myanmar contains a large number of onshore and offshore resource-rich basins and mineral deposits, whose history in their associated complex tectonic setting is not well understood. This project aims at reconstructing the Late Jurassic-Cenozoic tectonic history of the Myanmar region based on recently compiled data, data available in the published literature as well as the recently published high-resolution global gravity grid (Sandwell et al., Science, 2014). The types of data to be used to constrain the new tectonic model include ophiolites, types and ages of intrusives such as granites, types and ages of volcanic arc rocks, ore deposits, paleobiogeography, the stratigraphy in key sedimentary basins, thermo- and geo-chronology data and gridded gravity and magnetic data. We will use GPlates (plate tectonic reconstruction software developed by the EarthByte group and international collaborators) to test and generate quantitative models that match a regionally consistent plate model. The project will also involve the use of ArcGIS for data synthesis and Generic Mapping Tools (GMT) for visualization and data processing, which are both widely-used government and industry standard software packages.

EarthByte - www.earthbyte.org, GPlates - www.gplates.org,

GMT - gmt.soest.hawaii.edu
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.
Feedbacks between lithospheric extension, surface processes, and climatic forcing

Supervisors: Patrice Rey, Tristan Salles, Luke Mondy

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.