Cenozoic evolution of the Indonesian Throughflow and the origins of Indo-Pacific marine biodiversity: Mapping the biotic response to environmental change

Final Report Summary - THROUGHFLOW (Cenozoic evolution of the Indonesian Throughflow and the origins of Indo-Pacific marine biodiversity: Mapping the biotic response to environmental change)

Cenozoic evolution of the Indonesian Throughflow and the origins of Indo-Pacific marine biodiversity: Mapping the biotic response to environmental change (http://ipaeg.org/throughflow)

The coral reefs and other shallow tropical marine ecosystems of Southeast Asia are the most diverse in the world and have been for at least the past 25 million years. Biologists have been working for two centuries to understand the origins and maintenance of this biodiversity maximum by studying the distribution and evolutionary history of extant taxa. But fossils can provide direct evidence of past diversity and, for coral reefs, a significant portion of the biota is preserved in the fossil record. To date this valuable
resource remains underexploited. Southeast Asia contains the modern-day Indonesian Throughflow (ITF), the last remaining equatorial oceanic gateway and a major control on global climate. The long-term history of the ITF is controlled by the complex plate tectonic history of the region that had a strong impact on regional ecosystems by causing environmental changes that helped to shape the modern-day diversity. However the environmental and biotic history of the region remains obscure. In this project we examined the Miocene history preserved in the sediments of East Kalimantan (Indonesia) to understand how biota responded to past intervals of global and regional environmental change. The Miocene represents an ideal test case as it includes the middle Miocene Climatic Optimum, one of the warmest intervals in the past 50 million years. We think that this warm interval might be a useful analogue for future conditions resulting from accelerating anthropogenic climate change. When combined with increasing knowledge of other warm intervals in each of the three Cenozoic coral-reef provinces, new data from the SE Asian biodiversity maximum will allow a better understanding of the potential modes of change on extant coral reefs. Analysis of these long-term data from multiple regions with differing biotic and environmental histories are required to predict the “new normal” for modern tropical shallow marine ecosystems.

The THROUGHFLOW team includes earth systems modellers, geochemists, geologists, palaeoceanographers, palaeontologists, sedimentologists, and stratigraphers, each working on different aspects of the same rocks. The project focused on fossil-bearing units in the Kutei Basin and Mangkalihat Peninsula in Indonesian Borneo. In 2010 and 2011, we deployed two field parties, totalling 1117 researcher-days, to study the Miocene shallow marine facies of East Kalimantan, Indonesia. Over 160 exposures were studied, and eight tonnes of samples were collected for study as part of 11 ESR projects within five research areas.

Stratigraphy - All outcrops are placed in a consistent stratigraphical framework that provides the chronology of events during the evolution of shallow marine ecosystems in the biodiversity hotspot. In addition, these new data are an independent control of the timing of the extinction of the lepidocyclinids - a major regional biostratigraphic event in the Miocene. Palaeomagnetic tools combined with planktonic foraminiferal biostratigraphy proved that this extinction was almost a million year after the Middle Miocene sea-level drop to which it was previously correlated. This is significant as this extinction is one of the most important events used for correlation in the oil and gas industry.

Environments - We have studied the sedimentary context of the development of Early to Late Miocene reefs in East Kalimantan. An interesting result is that the reefs developed in mesophotic to euphotic conditions under varying siliciclastic influx in temporarily sheltered shallow prodelta to delta front habitats. Changes in turbidity driven by river discharge controlled the development of individual reefs. On the flanks of some reefs and on the surrounding sea floor microbial mats, presumably fertilized by run-off, induced the precipitation of microbial carbonates. Formation of microbialites was previously unknown in such turbid, shallow marine environments. Continuous palaeo-proxy records from Tridacna shells provide detailed insight into Miocene tropical SST variability that is a key parameter for climate models and therefore allow better assessment of the dynamics of the Miocene tropics.

Palaeoceanography - We have new high-resolution records of Late Pleistocene climate variability from both the ITF inflow and outflow, using various palaeoclimate proxies including foraminiferal stable isotopes and Mg/Ca ratios, XRF core scanning, and Uk’37 alkenone analysis. These data show that Late Pleistocene precipitation variability in the inflow is driven by precessionally-forced changes in both the position of the Intertropical Convergence Zone (ITCZ) and strength of the Walker circulation. In addition, we completed new calibrations of foraminiferal Mg/Ca chemistry to sea-surface temperature in along the ITF pathway. These records suggest existing isotopic records of precipitation in the West Pacific may be driven to a large extent by atmospheric transport mechanisms, a result that agrees with land-based runoff...
Driven to a large extent by atmospheric transport mechanisms, a result that agrees with land-based runoff records. Moreover, a benthic Mg/Ca temperature calibration proves that the relationship between Mg/Ca ratios and bottom water temperature is robust against potential bias owing to low carbonate saturation levels. Finally, we provide a ITF reconstruction from the lower thermocline (500 m) to surface spanning the last glacial cycle.

Biodiversity - Study of several benthic marine groups confirm high diversity in shallow marine habitats during early Miocene. We greatly expanded the known fossil record of Bryozoa, calcareous algae, and reef corals including the diverse extant genus Acropora. These data provide important new calibration points for molecular phylogenies of calcareous algae and corals. Biodiversity in particular habitats was explored through integrated studies that suggest a regional shift in habitats from low-relief coral reefs in the Early Miocene towards coral carpets in the Middle-Late Miocene to more modern-looking high relief coral buildups in the Late Miocene. This habitat shift coincided with a major taxonomic turnover in benthic foraminifera but not in other benthic groups - although community structure of corals was strongly altered. We discovered ancient highly diverse seagrass habitats and developed new protocols for identifying seagrass habitats from the fossil record.

A primary contribution of this project is the large new collections of fossils, sediments, imagery, and other data that are now accessioned into European natural history collections. These valuable new resources, are now part of the European research infrastructure, and will be available for future researchers working to understand the diverse marine ecosystems of Southeast Asia. Oceanographic results are likely to have significance for global climate studies including new insights on the past variability of climate and the ITF and its interconnection with large scale climatic features such as the Indian Ocean Monsoon systems, El Nino Southern Oscillation and the Indian Ocean Dipole. Species and region-specific calibrations of palaeoclimate proxies allow improved accuracy of future climate reconstructions from the ITF region. New palaeoclimate data will help improve models of future climates, especially monsoonal evolution in the densely populated East Asian region. We have discovered an apparent Late Miocene regional shift in coral reef ecosystems from turbid shallow mesophotic habitats to modern-style reefs living in the clear-water euphotic zone. This shift post-dates the origins of high biodiversity, showing that extant diversity originated in these so-called marginal settings. The future of corals reefs may well include a shift back into these dark, deep or turbid settings as biological communities in such settings are thought by some researchers to be more resilient and thus more likely to persist in the face of ongoing anthropogenic change. The future of corals reefs in Southeast Asia might require a step back into the past. We hope that our project will inspire future integrated studies of biodiversity, habitat and age and allow increased understanding of the origins and maintenance of biodiversity in shallow marine ecosystems.

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