Idealised numerical model of the Southern Ocean overturning, at 1/16th degree resolution.
Introduction

2010 has mostly been a year of stability for the Earth Environment Area, although two people left us: Dr K. Fitzsimmons accepted a position in Germany and Dr A. Dutton accepted a position at Florida University in USA.

2010 stood out also for our Area as we had a 70% success rate with our ARC Discovery Grant applications, although funds awarded to most of us were well below those requested, with the consequence that not all proposed targets will be achieved.

Dr T. Barrow continues his association with our group, having been successful in obtaining an ARC Discovery Grant with Prof B. Pillans, and together they conducted fieldwork in Papua New Guinea. Some equipment went to the University of Western Australia with Prof M. McCulloch (who left RSES late last year), but our collaboration with his group and access to the Triton instrument for our jointly supervised students is assured. The OSL facility and the cosmogenic preparation laboratories have been decommissioned during the year.

A new Finnigan MAT253 stable isotope mass spectrometer has been delivered in Dr M. Gagan’s area and refurbishments completed for the new facility. This will help diversify our research output and enable us to analyse much smaller samples. Dr Marc Norman has now joined the Earth Environment Area, together with Dr Bear McPhail, with groundwater investigations, especially with respect to geochemical analyses and innovative uses of isotopes in hydrogeology, forming part of the Earth Environment Area’s research interests.

Several new PhD students enrolled this year (L. Brentegani, K. James, N. Scroxton, R. Norman), while others have submitted their theses, and some have graduated (R. Berdin, J. Boyau).

A number of our postgraduates gained experience at sea in 2010 and several successfully presented at both national and international conferences. Noteworthy were the presentations made at the Australian Earth Science Convention, held in Canberra in July. It was extremely pleasing to see the great variety of topics presented by the students, and these were well received. In addition, Prof P. De Deckker gave the AESC plenary talk as a result of having been awarded the Douglas Mawson Medal by the Australian Academy of Science, for outstanding contributions to earth science in Australia.

Many members of the academic staff excelled at teaching this year and took on additional commitments over the previous year. PhD candidate Miss C. Thompson organised our bi-weekly seminar series, which was overall well attended.

We acknowledge the administrative services of Mrs S. Hutchinson, who transferred to the College Research Management Office in February, and to PRISE Administrator Mrs B. Armstrong who assisted with administration and distributed the our administrative workload among the School’s four Area Administrators. In June, we welcomed Ms R. Petch, who moved from the Earth Chemistry Area to be the on-going Earth Environment Area Administrator.

In late November, we also welcomed four Summer Research Scholars, who will gain experience in our laboratories and in the field during the summer break.

The surprise has been that little has changed since the Geochemistry and Petrology review held in 2009. Several of the review committee’s recommendations have not yet been implemented, but some of those may happen in 2011 with the advertisement of new, exciting positions at RSES.

In 2011, we look forward to the appointment of two new Super Science Fellows to work on novel dating techniques for Quaternary marine sequences, and to the arrival of Dr D. Heslop who will join Prof A. Roberts, Prof P. De Deckker and Dr M. Norman to work on magnetic properties and geochemical signals of aeolian sediments in deep-sea cores and terrestrial sequences.
Indonesian stalagmite record of abrupt Heinrich stadial changes in the Australian monsoon

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Speleothems are calcium carbonate cave deposits, such as stalagmites, which can yield high-resolution records of past climate change. In the tropics, changes in the oxygen isotopic composition (δ¹⁸O) in stalagmites are related to the composition of local rainfall and are often interpreted in terms of the amount of rainfall. The last glacial period (between 100 and 20,000 years ago) was punctuated by abrupt cool periods (the Heinrich stadials) that result from iceberg discharges into the North Atlantic. Throughout the tropics, isotopic shifts in speleothems during Heinrich stadials are interpreted as a widespread drying in the Northern Hemisphere and an increase in precipitation in the south.

In this study, we reconstruct changes in rainfall associated with the Australian monsoon system during Heinrich stadial 3 (HS3, around 30,000 years ago), using a fast growing stalagmite (LR07-E1, Fig. 2) from Flores in southern Indonesia. During HS3 cooling in the North Atlantic, wetter conditions are proposed further south in Brazil and drier conditions in the northern tropics in China. In Flores, higher stalagmite δ¹⁸O values and a hiatus in growth around HS3 (Fig. 1) indicate a decrease in precipitation at this site, showing spatial complexity in tropical responses. We suggest that Flores is highly sensitive to changes in the position of the intertropical convergence zone (ITCZ) and HS3 was characterised by a strong southward ITCZ migration. Collectively, stalagmite records from Flores also show a complexity through time in climate responses in the region during North Atlantic-driven excursions, depending on the magnitude of the event and its ability to propagate into the Southern Hemisphere tropics.

Figure 1. Comparison of Flores stalagmite δ¹⁸O record (blue, middle) with records from China (top, green) and Brazil (bottom, red). The timing of Heinrich stadial 3 (HS3) is shown, coinciding with higher δ¹⁸O values and a hiatus in Flores that indicate drier Heinrich conditions.

Figure 2. Photograph of stalagmite LR07-E1. Symbols show sampling locations for the uranium-series ages and the location of the ~2,300-year hiatus is also shown.
The Caribbean coral bleaching crisis


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As the temperature of the world’s oceans rise coral reefs are being threatened globally. Coral bleaching occurs when corals become stressed due to extreme environmental conditions (e.g. during periods of elevated ocean temperatures). So, what is coral bleaching? Corals host a microscopic algal symbiont (zooxanthellae) in the coral tissue. The corals require the presence of zooxanthellae in order to survive, indeed, up to 90% of a corals energy requirement comes from Zooxanthellae. Unfortunately, when stressed the corals expel their endosymbiotic algae and bleaching conditions persist this can result in partial or total coral mortality (death).

The Caribbean bleaching event of 2005 occurred between June and October. These region-wide anomalies were detected by Satellite-based sea surface temperature observations (SST) from the US National Oceanic and Atmospheric Administration (NOAA). NOAA was able to warn coral researchers about the anomalous temperatures as they developed across the region. As a result, scientists from 22 countries documented the most comprehensive basin-scale bleaching event to date. Findings for this period showed that average ocean temperatures exceeded temperatures seen at any time in the last 150 years. Surveyors continued to monitor corals beyond the bleaching event and noted that extensively bleached corals were more susceptible to disease. Findings showed that a combination of bleaching and disease outbreaks killed heat stressed colonies with continued mortality still occurring two years later in October 2007. Repeated coral bleaching events in the Caribbean since the 1980’s have been strongly linked to human induced climate change. Based on current climate change predictions coral bleaching is likely to be an even greater threat to coral reefs in the future.

Related publications:

http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0013969


http://www.sciencedirect.com/science?_ob=MImg&imgkey=B6V7H-4WK6PC-1-9&cdi=5843&user=554534&pi=501411136090000588&origin=browse&zone=rslt_list_item&coverDate=10%2F31%2F2009&sk=999319995&wchp=dGLbVzz-zSzk&md5=4304adebd18b294cd439ce12ad2f9bd&e=sdarticle.pdf
Millennial-scale changes in the Australasian monsoon during the last deglaciation

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Establishing the record of Australasian monsoon dynamics, and teleconnections to higher latitudes, is crucial for understanding the role of the tropics in global climate change. In terms of global climate, the vast Australasian monsoon system is thought to be particularly relevant because it transports moisture and heat from the Indo-Pacific Warm Pool, the warmest open-ocean water on Earth, across the equator and to higher latitudes.

In tropical settings summer monsoon rainfall is greatly depleted in $^{18}$O with respect to winter dry-season rainfall, and so the oxygen-isotope ratios ($d^{18}O$) recorded in speleothem calcite can be used as a measure of the relative amount of summer monsoon rainfall, or “summer monsoon intensity”. $d^{18}O$ signatures of speleothems from China have been found to record the dynamics of East Asian Monsoon precipitation, and the intertropical convergence zone (ITCZ) variability, since ~400 thousand years before the present (kyr BP, defined as 1950 AD) (Wang et al. 2001; Yuan et al. 2004; Cheng et al. 2006; Wang et al. 2008; Wu et al. 2009; Cheng et al. 2009). However, complementary high-quality speleothem records from the “southern half” of the Australasian monsoon system are limited to the last 12.6 kyr BP and portions of 26 to ~31 kyr BP (Griffiths et al., 2009, Lewis et al., in press). We report here on an absolute-dated speleothem $d^{18}O$ record from the island of Flores, southern Indonesia, that records millennial-scale shifts in the Australian-Indonesian monsoon (AIM) rainfall over the full course of the last deglaciation (~24 to 10 kyr BP).

Speleothem $d^{18}O$ records of monsoon intensity from Flores, Indonesia are found to be correlated to local insolation variations and the millennial-scale climate changes commonly observed in oceanic and terrestrial palaeoclimate archives during the last deglaciation.

Figure 1. Oxygen-isotopes of speleothems from China (composite record from Wang et al. (2001); Yuan et al. (2004) and Wang et al. (2008), Borneo (composite record from Partin et al. (2007)) and Flores (stalagmites: LR06-C2 (green); LR06-C3 (yellow), LR06-C5 (orange); LR06-C6 (red) this study and stalagmites LR06-B1 (light blue), LR06-B3 (dark blue) (Griffiths et al. (2009) and LR07-E1 (Lewis et al. (in press)). U-Th ages with 2s error bars are also shown for the stalagmites of this study. Portions of LR06-C5 (dashed) were found to be mixtures of magnesian calcite and aragonite and have been corrected to magnesian calcite–equivalent $d^{18}$O values on the basis of X-ray diffraction analysis.
throughout the world, Fig.s 1 and 2. Past monsoon intensity is governed by the positioning of the ITCZ which is, in turn, determined by changes of interhemispheric thermal gradients. We speculate that 23 to 20 kyr BP, when local insolation was at a maximum and monsoon intensity peaked in our speleothem record, that heat and moisture was transported to higher latitudes via ocean/atmosphere teleconnections. This resulted in melting of Northern Hemisphere (NH) ice and partial re-establishment of the Atlantic thermohaline circulation producing the melt water pulse at ~19kyr BP. These events, together with the subsequent increases in NH insolation, ultimately culminated in the termination of the last ice age.

References:
Australian landscapes

A new book on Australian geomorphology

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Australian Landscapes (Bishop & Pillans 2010) is the third major volume in a trilogy of edited books on Australian geomorphology that have been published in the last 50 years, the previous two volumes being Landform Studies from Australia and New Guinea (Jennings & Mabbutt 1967) and Landform Evolution in Australasia (Davies & Williams 1978). There is a strong thread running between these three volumes, not only through the enduring theme of the antiquity of Australian landscapes, but also through the people themselves. Joe Jennings, who was Professor of Geomorphology at ANU from 1953 to 1978 and considered by many to be the father of modern Australian geomorphology, was an editor of the first volume. The second volume marked the retirement of Joe Jennings, and one of Joe’s former PhD students, Martin Williams, was an editor of that volume, while Paul Bishop, an editor of the third volume, was a PhD student of Martin Williams.

Australian Landscapes was born out of discussions at the 13th biennial conference of the Australian & New Zealand Geomorphology Group (ANZCGG), held in Queenstown in Tasmania in February 2008, and provides an up-to-date statement on the geomorphology of Australia. A wide range of environments and topics are covered, including karst, coasts, glaciation, tectonics, biogeomorphology and deserts, showcasing the latest geochronological techniques and remote sensing methods.

Further details about the book may be accessed online through the Lyell Collection of the Geological Society: http://sp.lyellcollection.org/content/vol346/issue1/

References:
The chronology of the WLH 50 human remains, Willandra Lakes World Heritage Area, Australia

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Ever since its discovery in 1980, the Willandra Lakes Human 50 (WLH 50) has played an enigmatic role in our understanding of recent human evolution. There is general agreement, that WLH 50 is a modern human. However, some see strong resemblances between WLH 50 and the Ngandong specimens, whilst others attribute its robusticity to a pathological source. Considering the importance of the WLH 50 individual, it is timely to report previously unpublished as well as the most recent dating results.

Dating was carried out at different times, partly due to the development and availability of dating methods. Initially, two samples were collected for radiocarbon dating. ANU-2921 consisted of freshwater shells collected at the surface of Unit 3; ANU-3124 was a carbonate sample, which encrusted the human bone. In 1997, gamma spectrometry was carried out on the WHL 50 cranium (Figure 1), and thermal ionisation mass spectrometric (TIMS) U-series analysis on a small postcranial bone fragment. Around the same time, two OSL samples were collected to bracket the age of WLH50. ANUOD-1146 was collected from Unit 3, from which WLH 50 may have been eroded and ANU OD-1145 from the underlying sediments. While the association of the former sample is perhaps ambiguous, the latter should give a firm maximum age for this human specimen. For the spatial and stratigraphic relationships of the sample, see Figure 2, below.

Radiocarbon analyses were carried out in 1981 and 1982. The following information was retrieved from the archive of the ANU radiocarbon laboratory. We cannot find any evidence that this information has been published elsewhere. The radiocarbon age estimates were hand-written on the data sheets (by H. Polach) without any further analytical detail. The carbonate encrusting human bone (ANU-3124) yielded a result of 9050±310 BP (calibrated to 9.5 - 11.1 ka, 2-σ error) and a fresh water shell (ANU-2921) 14380±240 BP (calibrated to 16.5 to 18.0 ka). The TIMS U-series results formed an isochron, indicating a single stage rapid U-uptake at 12.2±1.8 ka. The gamma spectrometric measurements resulted in Th/U ages of 13.1±2.7 ka and Pa/U of 13.5±1.2 ka. The optical dates were calculated to 32.8±4.6 ka (ANUOD1145) and 25.8±3.6 ka (ANUOD1146).

As we cannot think of any naturally occurring process that would allow WLH50 to be older than the underlying unit, its OSL age of 32.8±4.6 ka provides the older age limit for the WLH50 specimen. In the most likely scenario, where WLH 50 weathered out from Unit 3, the best age estimate for WLH 50 is that of ANUOD1146: 25.8±3.6 ka with the younger age bracket of 16.5 – 18.0 ka cal BP provided by the shell ANU-2921. If WLH 50 was deposited from younger units, it could be as young as 12.2±1.8 ka, the younger age bracket established by the U-series isochron age on the WLH50 bone fragment.

For more detailed information about the exact stratigraphy, interpretation of the age results and their significance, check the website of the Journal of Human Evolution for our forthcoming paper. We thank the custodians of the Willandra Lakes Area, the 3 Traditional Tribal Groups, for their active support of this study and the permission to submit this publication.
Figure 2. Stratigraphy of the WLH50 burial site.
Coral records of calcification and reef water chemistry from the southern Great Barrier Reef

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The accumulation of anthropogenic carbon dioxide (CO2) in the atmosphere and ocean over the last ~100 years is causing global warming and ocean acidification, with potential effects on the secretion of calcium carbonate by marine biota. To-date concern has mainly focused on the fate of tropical corals and reefs with less attention being given to calcification in subtropical environment, where corals develop under more limiting conditions of reduced solar radiation and lower ocean pH. Thus, it is of critical importance to investigate how subtropical corals are responding to environmental changes. To constrain the matter, we have measured geochemical proxies (δ11B, δ13C, δ18O, Sr/Ca, Mg/Ca, and calcification rates) in ~100 year old Porites at annual resolution and bimonthly for the recent 5 years (2000-2005).

From coral boron isotopic systematics shows the obvious impact of enhanced uptake of anthropogenic CO2 on the ocean chemistry, resulting in a trend of decreasing seawater pH and decreasing δ13C compositions due to fossil fuel burning (Suess effect). Ocean warming is also observed in the coral skeleton Sr/Ca record, whereas calcification rate is almost constant from 1907 to 2005. This lack of response of calcification is consistent with modeled calcification rate using calculated aragonite saturation state and in-situ temperature records, suggesting an increase in coral calcification by increasing sea surface temperature may buffer a decline of calcification by reduced carbonate ion concentration in this region. Investigating the influence of the natural variability in these records also carried out by removing the long-term linear trends from each of coral proxies. The detrended coral records are strongly correlated with the Interdecadal Pacific Oscillation (IPO), which is best explained by the redistribution of Pacific water masses and entering alkaline, warmer, and saltier tropical surface water to this study area during negative IPO. Moreover, the physiological process of coral calcification affects both δ13C compositions and reef water pH, showing that δ13C of coral skeleton decreases with increasing the calcification rate. Therefore, this study suggests that the modulation of the reef water chemistry in this region is best explained by three main mechanisms; (1) the anthropogenic driven increasing levels of CO2 in the atmosphere, causing ocean warming and ocean acidification, (2) the natural variability of ocean and atmospheric anomalies in the Pacific, and (3) decrease in local reef water pH by build-up CO2 as a result of coral calcification.
High-pressure experiments on anhydrous carbonated eclogite at 9-20 GPa

Implications for the recycling of carbonate into the mantle

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It is generally agreed that large amounts of carbonates together with oceanic basalts can be subducted deep into the mantle. However, little experimental work has been done on the fate of carbonated eclogites deeper than about 300 km (>10 GPa). In this study we present the phase relations and solidus temperatures of carbonated eclogite at pressures ranging from 9-20 GPa.

Multianvil experiments were conducted using the 3000-ton press at Tohoku University, Sendai. The experiments were conducted under the range of pressures and temperatures of: 9, 13, 17, and 20 GPa at 1200-1800°C. The experimental compositions were two synthetic mixtures, which are GA1 and Volga \cite{1} with an addition of 10% of calcite (10%cc). All the experiments were conducted in the Au\textsubscript{25}-Pd\textsubscript{75} capsules with 12-72 hours run durations.

The mineral assemblage in the runs differed depending on the pressure, however garnet is the most abundant phase in all the experimental runs. At 9 and 13 GPa, the major phases were garnet, clinopyroxene, carbonate (both calcitic and magnesitic), high-pressure modified form of rutile (only at 9 GPa) and minor stishovite. No K-rich phase was detected and presumably K partitions mainly in clinopyroxene. At 17 GPa clinopyroxene was no longer stable; the mineral assemblage consisted of Na-rich majoritic garnet, carbonate (both calcitic and magnesitic) and K-hollandite, which contained most of the K. Stishovite was observed in most of the runs at 17-20 GPa. With the increase of pressure up to 20 GPa, CAS (in GA1+10%cc) and Ca-perovskite (in Volga+10%cc) appeared in addition to garnet and calcitic carbonate, but not in all experiments. K-hollandite was also detected at low temperatures.

The melts produced in our experiments are highly carbonatitic with the increasing of the amount of alkali elements (Na and K) with pressure.

In most GA1+10%cc and few of Volga+10%cc runs crystallization of diamonds were observed (Fig 1). The possible explanation to that is a pressure-induced increase of the Fe\textsuperscript{3+} content in garnet. Accordingly, this oxidation process can cause partial reduction of carbonates to diamond. However, we did not measure Fe\textsuperscript{3+} in garnet and this question requires further investigation.

A striking feature of the new data is the relatively flat solidus located between 1200 and 1300°C for all the analyzed pressures. This may be the result of the relative incompatibility of Na\textsubscript{2}O and K\textsubscript{2}O with increasing pressure. In the lower pressure runs, Na behaves compatibly due to the relative stability of the jadeite component in clinopyroxene. With increasing pressure progressive dissolution of clinopyroxene into majoritic garnet may lead to Na becoming incompatible and it may flux melting at a sodic carbonate solidus. Although being located at lower temperatures relative to other (K-free) carbonated eclogite studies \cite{2} it remains at higher temperatures than the hottest estimated subduction geotherm (e.g. \cite{3}), in a good agreement with previous, lower pressure studies \cite{4,5,6}. Thus, subducting carbonates in eclogite may reach the deep convecting mantle, where they may partially melt to produce carbonate-rich liquids which could have a role in fertilizing the surrounding peridotite mantle and producing enriched magmas.

References

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IODP Expedition 325 to the Great Barrier Reef

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In February-April 2010, Integrated Ocean Drilling Program (IODP) Expedition 325 drilled 33 boreholes into submerged reef structures preserved along the outer margin of the Great Barrier Reef. The objectives of Expedition 325 are to establish the course of sea level change, define sea-surface temperature variations, and analyze the impact of these environmental changes on reef growth over the course of the last deglaciation (Expedition 325 Scientists, 2010).

Co-Chief Scientists Jody Webster and Yusuke Yokoyama, and Expedition 325 scientists Mike Gagan and Tezer Esat, examined the 225 m of drill-core during the Onshore Science Party at the IODP Bremen Core Repository (Germany) in July 2010 (Fig. 1). Remarkably, the cores intersected >200 individual massive fossil coral colonies that will provide unique archives of climate change in the Great Barrier Reef, as revealed by isotope and trace element signatures preserved in their aragonitic skeletons. 60 U-series and radiocarbon dates confirm that the corals range in age from >30 to 9 cal. y BP (Fig. 2), an outstanding outcome for the Expedition.

Given these exciting findings, the stage is now set for the Australian team members to play key roles in producing the exacting U-series (Esat, Dutton) and radiocarbon (Yokoyama, Fallon) chronologies required to establish the course of postglacial sea level rise (Webster) and climatic change (Gagan, McGregor) in the Great Barrier Reef. All going well, the records will allow us to see how the reef responds to a broad range of past climatic regimes, and thus improve our understanding of how the reef might change as the world warms.

Reference

New archaeological finds below Liang Bua: a split-level home for the Hobbit?

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We report new archaeological finds for a cave-chamber hidden below Liang Bua on the island of Flores in eastern Indonesia, where the dwarf hominin Homo floresiensis (“the Hobbit”) was recovered from Late Pleistocene sediment. In search of speleothems, we abseiled into the lower chamber where, to our surprise, the surface-sediment contained abundant, well-preserved bone material and stone tools that allow us to describe the archaeological potential of this archive for the first time.

At the rear of Liang Bua, a narrow 23 m-long passage inclined at 60° leads to the impressive lower chamber measuring 23 m x 24 m x 5.4 m high (Fig. 1). The floor area is ~430 m² (about half the size of Liang Bua) and covered with firm, sticky, reddish-brown mud. Bones and stone tools were clearly evident in the surface sediment at the base of the passage and around the perimeter of a ~5 m-high mud-mound filling the northwest sector of the chamber.

Preliminary analysis of the faunal remains yielded specimens belonging to Stegodon (tibia fragment, metapodia), giant endemic rats, endemic pigs, primates, small murid rodents, and introduced species. The bones are exquisitely preserved in the anoxic mud and clear butchering marks (sharp cuts and percussion dents) are common (Fig. 2). Stone tools made from chert and volcanics include bifacial flakes, points, perforators, scrapers, and hammer-stones.

Exploratory uranium-series dates for flowstone layers and stalagmites capping the ~5 m-high mud-mound range in age from 12,000 to 3,000 years before the present, thus the sediment itself could be Late Pleistocene in age. It is possible, therefore, that the lower chamber could house a unique archive of late Pleistocene faunal evolution and, potentially, remains of the Hobbit. The floor of the upper occupation chamber of Liang Bua was at least 10 m lower in the Late Pleistocene and in close proximity to the lower chamber, thus they may have been connected in the past. Whether the lower chamber acted as a convenient refuse tip for the Hobbit, or a split-level home, is yet to be determined.
The 8.2 ka event in southern Australasia: a different response between the ocean and atmosphere?

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Corals and speleothems have the potential to resolve outstanding questions about changes in the Australasian monsoon during the 8.2 ka “cold event”. We present an analysis of Sr/Ca and $\delta^{18}$O in massive \textit{Porites} corals from Alor (southern Indonesia) with U-series ages of 8.5 to 7.9 ka (thousand years ago). The Alor corals are well suited for reconstructing tropical ocean-atmosphere systems at seasonal to interannual timescales. In contrast, $\delta^{18}$O and $\delta^{13}$C in tropical speleothems from the nearby island of Flores provide information on Indonesian monsoon dynamics and surface air temperature at millennial to centennial timescales. Together, these records have allowed us to explore how the ocean and atmosphere of southern Indonesia responded to the 8.2 ka event.

We measured Sr/Ca and $\delta^{18}$O in the corals at 5-year resolution across the 8.2 ka event to detect any changes in the mean climate state. Whereas the $\delta^{18}$O record shows two sharp increases reaching maxima at 8.3 and 8.0 ka, ICP-AES measurements of coral Sr/Ca show a gradual cooling of sea-surface temperature (SST) starting at $\sim$8.3 ka and finishing with an abrupt $\sim$1.5-2°C cooling at $\sim$8.0 ka. The coral $\delta^{18}$O record is consistent with the $\delta^{18}$O analyzed at 5-year resolution in the speleothem from Flores. The coral and speleothem records from southern Indonesia show that the atmosphere responded rapidly (over decades) to the 8.2 ka event, whereas the SSTs appear to have responded more slowly (over centuries).

The result is unanticipated, given that recent studies of the Younger Dryas in southern Indonesia and the 8.2 ka event in South America indicate an antiphased response to northern hemisphere cooling. In order to investigate the rainfall response in Alor/Flores during the 8.2 ka event, we analysed the annual cycle of $\delta^{18}$O in the Alor corals, the amplitude of which primarily reflects the intensity of summer monsoon rainfall. The results indicate that Indonesian summer monsoon rainfall was generally weaker during the early Holocene, compared to today, and did not change significantly during the 8.2 ka event. We propose that the flooding of the Indonesian maritime continent and cooler SSTs around Alor/Flores during the 8.2 ka event reduced Australian monsoon rainfall to suppress the antiphased response (stronger SH monsoon) to high-latitude northern hemisphere cooling. To confirm this result, we are in the process of analyzing the annual cycle of Sr/Ca in the same Alor corals.
Sea Level variation and the Zonation of Stromatolites in Hamelin Pool, Shark Bay

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The zonation of stromatolites of Hamelin Pool, Shark Bay, Western Australia (see Fig. 1), has, since their discovery in 1954, been related to tidal variations of sea-level. Initially these stromatolites were considered to be entirely intertidal ecosystems (Logan 1961), though they were later recognised also in shallow subtidal waters (Logan et al 1974). Data from various sources were drawn together into a notional cartoon by Playford (1980) that summarised his understanding of the tidal zonation of stromatolite types in Hamelin Pool. This cartoon has been frequently cited since to account for stromatolite zonation in Hamelin Pool. Detailed surveys of stromatolite types by John Bauld (pers. comm) confirm the conclusion of Burne and James (1986) that Hamelin Pool stromatolite principally grow in shallow subtidal environments where they are colonised by colloform microbial mats, with some being later exposed by falling sea levels. The intermittently exposed stromatolites are re-colonised by smooth or pustular microbial mats.

The application of modern methods of time-series analysis to a record of sea-level variation at Flint Cliff, Hamelin Pool between October 1983 and April 1985 has shown that tidal variation accounts for only a minor component of sea level variation in Hamelin Pool (Fig. 2). We have identified five key components of the variation of sea level in Hamelin Pool; a seasonal oceanic cycle; a short term irregular cycle; the complex tidal system in the Pool; isolated major events; and less marked variations, still able to defeat the tide in the short term, probably by wind stress. Clearly it is not valid to conceptualize the zonation of stromatolite types in terms of tidal variation alone. The dominance of a seasonal cycle is the fundamental determinant of the timing of immersion and exposure. We conclude that the zonation of microbial communities in Hamelin Pool (Fig. 1) is controlled by duration of periods of inundation and exposure in the littoral zone, but that tidal variation is not the major cause of this variation. The stromatolite forming colloform mat is virtually never exposed. The exposed stromatolites have been stranded by relative fall of sea level, and are colonised by intermittently submerged microbial communities capable of modifying but not creating the club-shaped stromatolites characteristic of this locality.

References


Figure 2. The first pass of the time series analysis identified the varying amplitude characteristic of tidal activity, the seasonal cycle of sea level, and an irregular 11 day cycle.
Studying the Earth by oceanic scientific drilling

Integrated Ocean Drilling Program (IODP)

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Integrated Ocean Drilling Program (IODP) cores through sediments and rocks beneath the world’s oceans contain a remarkable story of how the Earth has worked in the past, and may work in the future. IODP’s main research fields are broad - environmental change, processes and effects; solid earth cycles and geodynamics; and the deep biosphere and ocean floor. ANU, through RSES, hosts the Australian IODP Office. The Australian and New Zealand IODP Consortium (ANZIC) has access to all IODP activities (www.iodp.org.au). A review of Australia’s involvement in IODP and its predecessors was published in mid-2010: see link.

In 2010, eight Australians participated in IODP science parties, but only early scientific results are known. The University of Queensland’s Kevin Welsh took part in palaeoclimate expedition 318 (January-March) to the Wilkes Land region off Antarctica. The cores collected document the onset of cooling at around 33.5 million years ago, leading to the first Antarctic glaciers. The growth and retreat of Antarctica’s ice sheets impact upon global sea level, and oceanographic and biotic evolution, and keep the planet cool by reflecting heat from the sun. It is vital that we understand what drives these ice sheets so that we can make predictions about what will happen in the future.

Expedition 325 to the Great Barrier Reef (February-April) investigated the history of the 120 m sea level rise in the Great Barrier Reef since the last glacial maximum about 18,000 years ago, and the associated changes in the coral reefs and their water properties as they migrated landward. Australian participants were Jody Webster from Sydney University, Michael Gagan from ANU and Tezer Esat from ANU/ANSTO. Understanding what has happened to the reef as the ocean warmed and sea level rose can surely help us better understand what might happen to the reef in a future warming world.

Recent published review of IODP and Australian research within it: http://www.iodp.org.au/IODP%20AJMOA%20article%20only.pdf
Rhodoliths: archives of environmental change.

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Rhodoliths are free-living forms of calcareous, coralline red algae that can be found worldwide, from low to high latitudes, in relatively shallow (0->250m) waters. They can live up to hundreds of years and form a high-Mg calcite skeleton that presents periodical growth bands.

Recent geochemical studies on coralline algae have focused on sea-surface temperature (SST) secular changes and have shown a strong relationship with the variations of the Mg/Ca ratio in the algal skeleton at a monthly or bi-weekly resolution. By analysing a Sporolithon durum rhodolith species from the tropical Pacific (New Caledonia) presenting a high growth rate (~0.7-0.8 mm/yr), we are able to characterise that Mg/Ca_SST relationship on a couple-of-days to a daily basis.

Improvements on the method of the Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA ICPMS) technique enable us to reach a spatial resolution <5µm along the rhodoliths’ axis of main growth. Chronology is established with the support of Single Stage Accelerator Mass Spectrometer (SSAMS) radiocarbon dates and geochemical data can, then, be correlated to daily local SST measurement over a period of over 45 years.

Although the Mg/Ca_SST relationship is strong at different timescales (r>0.75), it appears that some of the Mg/Ca variations cannot be strictly explained by the local temperature variations. Therefore, other factors (environmental and/or biological) are to be investigated. For example, Electron Probe Micro Analysis (EPMA) intensity maps, associated with LA ICPMS data at the micrometre scale, suggest that S. durum displays well-defined, sub-monthly Mg/Ca cycles that seem to be primarily biologically-driven and correspond to lunar cycles.

Further research will be directed towards the understanding of the other factors potentially contributing to the variations of the Mg/Ca ratio in coralline algae and the quantification of their effect on the reliability of the proxy as a palaeo-temperature recorder.

Other aspects are focused on the use of trace elements and stable isotopes to reconstruct different environmental parameters such as salinity and river discharge.
Figure 2. *Sporolithon durum* LA ICPMS high resolution Mg/Ca variations compared against local, daily Sea Surface Temperature (SST) data for Ricaudy Reef (New Caledonia) over the mid-2005 to end-2008 period.

Figure 3. Left: Back Scattered Electron (BSE) image of a part of a rhodolith branch showing the high porosity of the sample. Right: EPMA intensity map showing variations of Mg/Ca at the micrometre scale in correspondence to the BSE image. High frequency variations can be determined (30-50µm) and are thought to be associated with lunar cycles. A portion of a lower frequency cycle (annual cycle) can also be observed that is to extend beyond the area covered by the map (>500µm period).
Air-breathing adaptation in a marine Devonian lungfish

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Our research shows that as far back as 380 million years ago, \textit{Rhinodipterus}, a marine lungfish possessed skeletal specialisations required for air-breathing. Lungfishes were most likely driven to breathe air, not from venturing into lower oxygen, freshwater habitats (as was previously thought), but directly from pressures arising from lower global oxygen levels, which were down to 12\% at this time (current levels are about 21\%). This also drove other marine fishes in the same environment to simultaneously develop air-breathing adaptations.

Thus air-breathing arose twice in this early time in vertebrate evolution; once in lungfishes, and once in the line leading to tetrapods (or land animals), and ultimately to us.

See our Biology Letters paper online http://rsbl.royalsocietypublishing.org/content/firstcite
Figure 3. An x-ray CT scan of the Rhinodipterus skull, visualised in ANU software Drishti, courtesy of Dr. Tim Senden (ANU).
Groundtruthing coral chemo-geodesy

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Catastrophic earthquakes, such as the 2004 Sumatran earthquake and subsequent tsunami, are poorly understood due to the limited understanding of the recurrence interval of great submarine earthquakes. Characterization of past earthquakes is necessary to predict future earthquakes and mitigate disasters in the Indonesian region. Large corals inhabit fringing reefs in the tectonically-active islands offshore of the Sumatran mainland. During an earthquake, coral reefs experience co-seismic uplift (or submergence), and it has been shown that carbon isotope ratios (d\textsubscript{13}C) in coral skeletons respond to changes in water column properties (i.e. light intensity, turbidity; Gagan et al. in prep) brought about by crustal deformation. Here we present geochemical evidence from massive Porites corals that ground-truths the use of d\textsubscript{13}C and elemental ratios in coral skeletons (coral chemo-geodesy) to reconstruct past earthquakes. To test the proxy we drilled corals from reefs surrounding the island of Nias, west Sumatra, that experienced a 8.7 magnitude earthquake in March 2005. Fortuitously, a GPS array in place during the earthquake recorded the magnitude of uplift and submergence associated with the event. Corals were collected from four study sites that experienced 2.5 m, 1.8 m, and 0.5 m of uplift, and 0.5 m of submergence. Our preliminary findings suggest that changes in d\textsubscript{13}C are sensitive to vertical motion during an earthquake, but only in simplistic environments such as fringing reefs. Supplementary data from Mn and rare earth elements record dramatic shifts in environmental conditions related to the earthquake. Together, the d\textsubscript{13}C and trace elements provide a unique geochemical signal for paleoseismic events. With further development, the coral chemo-geodesy technique potentially could provide an archive of pre-historical earthquakes and shed light on the recurrence interval and precursors of great earthquakes.
Figure 2. Carbon isotope and Y/Ca (yttrium-to-calcium ratios) data from a coral collected from a 1.8 meter uplift site off the island of Nias. Note the dramatic shift in both tracers associated with the 2005 earthquake.
Characterising the macro and micro-nutrient status of the North Tasman Sea

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The Tasman Sea is one of the most sensitive oceanic regions to climate change and iron supply. Current predictions are for this region to warm by 2 degrees by 2060 potentially resulting in a floristic shift in the plankton community toward nitrogen fixers, which have a high iron requirement. However, it remains uncertain to what extent an increase aerosol iron supply would aid this floristic shift and its associated impact on the marine food-web. Three research voyages were conducted in 2005, 2006 and 2010 to examine the degree of nitrogen limitation and the role of macro- and micro-nutrients in stimulating the phytoplankton community in the water north of the Tasman Front. Water column measurements confirmed that these waters are oligotrophic with surface nitrate and phosphate concentrations less than 10 nmol/L and 60 nmol/L, respectively, and dissolved iron concentrations varying between 0.05 and 0.7 nmol/L depending on dust inputs. Deck-board perturbation experiments involving the addition of macro- (NH₄ & PO₄) and micro- (Fe, Co, Cu & Zn) nutrients confirm nitrogen availability to be the primary control on phytoplankton production, with phosphate and iron availability playing minor secondary roles even though the concentration of these elements are close to bio-limiting. Within these experiments, the addition of nitrogen was found to stimulate eukaryote, prokaryote and bacterial production and inhibited nitrogen fixation. Current work from our 2010 voyage is centred on further elucidating the role of redox active trace elements play in regulating the nitrogen cycle in this region.