Earth Environment Introduction 2007

The Earth Environment group undertakes research on environmental and climate change with particular emphasis on the interactions between humans and the environment. The group specialises in the development of diagnostic environmental proxies within an absolute chronologic framework that spans a few tens to several hundred thousand years of Earth history. These records are used as a basis for understanding past, present and potentially future environmental and climate changes. Emphasis is placed on the reconstruction of high-resolution environmental records of both human impacts and global climate change using geochemical proxies preserved in the growth banding of foraminifere, marine sponges, fossil and modern corals, speleothems (cave deposits), layered sedimentary deposits and materials preserved in anthropologic sites of special significance.

Dr Mike Ellwood, Dr Steve Eggins, Dr Stewart Fallon, Professor Malcolm McCulloch together with Dr Martin Wille a new Post Doctoral Fellow at RSES are undertaking studies of biogenic skeletons from both modern and ancient marine sequences to determine recent as well as longer-term changes in the chemistry of the Southern Oceans. This research is being conducted in close cooperation with Professor Patrick De Deckker from the Department of Earth and Marine Sciences and is part of ANU’s new marine science initiative. One of the important processes being examined is changes in the oceans 'biologic pump' which acts as a mechanism to draw-down CO$_2$ and hence provides an important feedback in modulating climate change. Carbonate as well as silicate secreting organisms (e.g. foraminifer, deep-sea corals and sponges) are being used as archives of ocean temperatures, acidity, nutrient fluxes and ventilation rates. The research is being undertaken using state of the art laser ablation ICPMS (including multi-collector) techniques, high precision U-series dating, accelerator mass spectrometer $^{14}$C dating, combined with boron isotopic analyses to determine changes in seawater pH. The latter is a relatively new approach pioneered at RSES with the potential to provide constraints on the extent of acidification of the oceans from uptake of anthropogenic CO$_2$.

Human impacts on the environment are being examined at several timescales. On modern timescales we are quantifying the extent of direct human impacts on modern coral reefs from degradation of river catchments, mangrove estuarine habitats and near shore coastal zones being conducted under the auspices of the ARC Coral Reef Centre of Excellence. Work undertaken by Dr Stacy Jupiter, Dr Guy Marion (University of Queensland) and Professor McCulloch have shown that the most severe impacts on coral reefs are due to agricultural practices such as cattle grazing, intensive sugar cane plantations and associated practices such as land clearing. Geochemical records (e.g. Ba/Ca, N isotopes) preserved in the long-lived coral skeletons, show that land-use changes in river catchments has increased sediment and nutrient supplies to many inshore reefs by up to an order of magnitude relative to pre-European 'natural' values. Work is also ongoing quantifying the extent of acidification of corals in the Great Barrier Reef due to increasing CO$_2$.

On Longer timescales Professor Grün's Linkage proposal on the Willandra Lakes World Heritage Area ranks is especially important for documenting Australia's unique cultural and environmental history.

This project is being undertaken jointly in a strategic alliance between the custodians and managers of the area and to build a picture of the continent's human and environmental history before this evidence is irretrievably lost. Professor Grün, Dr Maxime Aubert and PhD student Mr Renaud Joannes-Bayau have been developing and applying least destructive methods such as electron spin resonance and together with Dr Eggins using in-situ laser ablation ICPMS methods to directly date human samples of fossil teeth. This work is showing
that modern humans colonised Australia well before sites in Europe. High resolution isotopic analyses of human teeth and associated soils is also being employed by PhD student Ms Tegan Kelly to trace diets and hunting ranges as well as patterns of migration. Dr Mike Gagan and Dr Linda Ayliffe are also continuing their major research program in Indonesia examining closely the links between human evolution and climate. This involves the application of both stable isotope proxies as well as precise U-series dating to corals and speleothems and is being undertaken in collaboration via ARC projects at the Universities of Queensland and Wollongong.

Research on landscape evolution is being conducted by Professor Brad Pillans and Dr Kat. Fitzsimmons using dating methods such as paleomagnetism and optically stimulated luminescence together with Dr Tim Barrows (Dept of Nuclear Physics) who is undertaking studies using cosmogenic nuclides. This work is showing that Australia has some of the world’s oldest regolith and landforms as well as providing quantitative measurements of the rates of weathering and denudation that are proving to be exceedingly slow reflecting the tectonic stability and extreme aridity of our continent.
Speleothems from Flores, Indonesia: tropical archives of climate change

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Very few precisely-dated paleorecords of climate from the tropics currently exist, despite the fact the tropics play a critical role in driving the Earth’s large-scale atmospheric circulation by the export of heat and moisture to higher latitudes. Here we present some initial d18O results for the past 25ka from tropical speleothems from the island of Flores, Indonesia, which is a focal point for our ARC Discovery research (Gagan et al. 2006). The island of Flores, located at the southern-most extent of the Intertropical Convergence Zone (ITCZ) in the Austral summer and just within the current southern boundary of the Western Pacific Warm Pool (Sturman and Tapper 1996), is sensitive to past climate change. Tropical speleothems are ideal archives of changes in past rainfall as they can be dated precisely with the U-Th technique and their d18O values can be interpreted in terms of rainfall intensity as tropical rainfall d18O values are inversely proportional to rainfall amount (Dansgaard, 1964).

Two stalagmites from Liang Luar Cave (8°32'S, 120°27'E) were collected in July 2006 –500m from the cave entrance. The d18O results of these two specimens are shown in Figure 1 together with other climate proxy records covering the past 30ka. When compared to the speleothem d18O records from nearby Borneo (4°N, 114°E) the Flores speleothems display a somewhat different response in rainfall d18O during the past 25ka, Figures 1 and 2. This is perhaps not surprising given the present day differences in climatology between the two sites. Borneo lies under the ITCZ year-round and exhibits little seasonality in rainfall (Cobb et al. 2007), while Flores has a distinct wet and dry season determined by the annual migration of the ITCZ.

Last Glacial Maximum (LGM) (19-23ka) d18O values of the Borneo speleothems are 1.3±0.3‰ greater than modern values (Partin et al. 2007) while Flores speleothems are only 0.9±0.3‰ greater than modern values during the LGM. The modern–LGM d18O differences of the Flores speleothems are less than what would be anticipated from global ice volume changes (+1‰) and ~2–3.5°C lower regional temperatures (+0.4‰ to +0.7‰). This suggests that rainfall d18O values were lower during the LGM at the Flores site in contrast to the neighboring Borneo site. Changes in eustatic sea levels during the LGM would have increased the continentality of Flores which probably resulted in decreased rainfall d18O values (Rozanski et al. 1993) at this time.

Local differences in proximity to exposed continental shelves between Flores and Borneo may explain why LGM rainfall d18O at Borneo was not affected to the same extent as Flores by lowered sea levels.

The response of the Flores and Borneo speleothem d18O records appear anticorrelated during the deglacial (17-10ka), Fig. 2. Peaks(troughs) in the Borneo record correspond with troughs(peaks) in the Flores speleothem record within error of the chronological errors (Partin et al. 2007). Furthermore most of these features appear to be synchronous with known
climate excursions during this time interval, namely that of: Heinrich Event 1 (H1); Antarctic Cold Reversal (ACR) and the Younger Dryas (YD), seen in ice core and Chinese speleothem records Fig. 1,2. Modeling results of Zhou and Delworth (2005) predict that the ITCZ migrated south in the Pacific ocean, the Walker circulation moved eastward and that the east Asian monsoon intensity weakened during H1. Negative rainfall anomalies in parts of the S/W Pacific, including Borneo, were predicted outcomes of these coupled model simulations.

Although predictions for changes in rainfall are less certain for eastern Indonesia (incl. Flores) during H1, slight increases in rainfall are suggested at the less than 95% level of confidence by Zhou and Delworth (2005). If the ITCZ did move south during H1 to be located more directly over eastern Indonesia throughout the year, then this could explain the negative d\(^{18}\)O excursion seen in the Flores record (indicating higher rainfall) at the same time that Borneo was experiencing rainfall diminishment. The antiphase response in the Flores and Borneo records during the ACR (Flores: dryer, Borneo: wetter), YD (Flores: wetter, Borneo: dryer) and at \(\sim 11.4\)–11.8ka (Flores: dryer, Borneo: wetter) might also be accounted for by similar oscillations in the mean position of the ITCZ.

The last major difference between the Flores and Borneo speleothem records is observed at \(\sim 5\)ka when the Borneo record displays a decrease in rainfall d\(^{18}\)O values (increased rainfall) while the Flores \(^{18}\)O record shows no change, Fig. 1. Partin et al. (2007) attribute this \(^{18}\)O decrease to either enhanced warm pool convection from an insolation-driven increased tropical Pacific zonal SST gradient, or changes in the position of the ITCZ. The fact that the Flores speleothem record does not show the same \(^{18}\)O increase as the Borneo record at this time suggests that intensification of the Walker circulation is unlikely to be the principal cause, as if it were the case, similar increases in Flores rainfall d\(^{18}\)O might also be expected at 5ka.

Traditionally global climate models have struggled to robustly predict past climate changes in the tropics. It is hoped that additional palaeo-rainfall d\(^{18}\)O records, such as those presented here, will contribute significantly to improving the skill of future generations of GCM’s.
Figure 1. Speleothem d\textsuperscript{18}O records from Flores (8°32’S, 120°27’E) (LR06-B3 (blue) & LR06-C6 (red)) compared with speleothem d\textsuperscript{18}O records from Borneo (4°N, 114°E) and S/E China (Dongge: 25° 17’N, 108° 5’E, Hulu: 32° 30’N, 119° 10’E) and ice core d\textsuperscript{18}O records from The North Greenland Ice core Project (NGRIP) and the European Project for Ice Coring in Antarctica (EPICA).
Figure 2. Speleothem $\delta^{18}O$ record from Flores (LR06-C6 (red)) and Borneo (blue).

High resolution elemental and isotopic distribution in fossil teeth: Implications for diet and migration

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New developments in laser ablation ICPMS permit the measurement of high resolution elemental and isotopic distributions in fossil teeth. For the reconstruction of diets and migrations, Sr and Ca elemental and Sr isotopic distributions were measured on sectioned teeth of a sample set from the site of Payre (Ardèche, France), which included herbivores, omnivores, carnivores and Neanderthals. In order to investigate diagenetic strontium uptake, Sr concentration and isotopic ratios were mapped in a Neanderthal tooth. The Neanderthal tooth showed by far the lowest Sr/Ca ratio of all teeth analysed followed by the carnivores and the herbivores. These observations tend to confirm earlier results based on nitrogen isotopes that had implied that Neanderthals were “super-carnivores” (Bocherens et al., 1999; Richards et al., 2000). On the other hand, post-depositional Sr uptake seems to play a significant role in Sr isotope distribution through the dentine and enamel. Research continues to evaluate whether a two component mixing model can be used to eliminate post mortem Sr contamination. The maps clearly demonstrate that original, perhaps variable Sr isotopic compositions of Neanderthal teeth cannot be obtained by bulk analysis whether or not associated with any leaching protocols.


In situ oxygen isotope analysis of fossil human teeth using a secondary ion micro-probe: a new tool for palaeoecology and archaeology

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The oxygen isotopic composition (δ¹⁸O) in tooth enamel of freely drinking animals is closely associated to the isotopic composition of the drinking water at the time of tooth formation. While the isotopic composition of surface waters may depend on a large number of factors, in moderate climates, a strong seasonal change is observed, mainly driven by changes in temperature. As a result, compositional changes in the oxygen isotope signature in teeth give powerful insights into seasonal variability over time.

Traditionally, samples are obtained through micro-drilling. While this is adequate for the analysis of fast growing faunal teeth, any seasonal signatures in human teeth are averaged out. Following major modifications to the RSES SHRIMP II ion microprobe, it is now possible to analyse oxygen isotopic compositions on polished sections of tooth enamel on a scale of about 30 μm, allowing the detailed analysis of human teeth with a weekly resolution. A 10 kV beam of caesium ions is focused onto the tooth, thereby sputtering oxygen ions from the enamel for real time isotopic analysis by a high resolution multiple collector mass spectrometer. Each analysis only consumes about 2 ng of enamel, with a precision of about 0.2 ‰ (s.d.).

A series of experiments is currently under way to optimize measurement parameters, with a particular emphasis on the analysis of Neanderthal molars. Herbivore teeth recovered from the Neanderthal fossil sites have shown large seasonal signatures, indicating that the original oxygen isotopic compositions were relatively well preserved. So far, the apparent seasonality in a Neanderthal molar was much smaller. This may reflect a much more restricted range of diet, a much more uniform sources of drinking water during tooth formation, namely in the first five years of a Neanderthal child's life or diagenetic alteration.
Discovery of Late Pleistocene rock art in Egypt

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Intensive surveying of the Nubian sandstone cliffs immediately east of the modern village of Qurta, along the northern edge of the Kom Ombo Plain, Egypt in February–March 2007 led to the discovery of three rock art sites, designated Qurta I, II and III. These sites show petroglyphs executed in a vigorous naturalistic, ‘Franco-Cantabrian, Lascaux-like’ style (Fig. 1). The Qurta rock art is quite unlike any rock art known elsewhere in Egypt. It is substantially different from the ubiquitous ‘classical’ Predynastic rock art of the fourth millennium BC, known from hundreds of sites throughout the Nile Valley and the adjacent Eastern and Western deserts. On the basis of style, patination and weathering, these petroglyphs are definitely extremely old. Direct ages for this rock art are not yet available, but analyses are under way to explore its potential for AMS ¹⁴C dating of organics in the varnish rind and/or U-series dating.

Figure 1. Detail of a bovid at Qurta II (QII.5.1)
Holocene mega-droughts and the seasonal structure of El Niño events in the Philippines

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The Holocene climatic evolution of the Southeast Asian monsoon domain was largely controlled by opposing trends in the summer monsoon (weaker towards the present) and El Niño-Southern Oscillation (stronger towards the present). These trends have been attributed to orbitally driven changes in the seasonal cycle of insolation, which enhanced Asian monsoon rainfall and suppressed El Niños during the middle Holocene (Clement et al. 2000, Liu et al. 2000). However, new coral-based palaeoclimate reconstructions from the Philippines provide surprising evidence for abrupt shifts in climate and mega-droughts superimposed on this somewhat benign climatic picture (Gagan et al. 2006).

In this study, we examined the evolution of El Niños from 7,600 years ago to the present using annually resolved records of $^{18}$O/$^{16}$O in a suite of fossil *Porites* corals from eastern Samar, Philippines. At Samar, coral $^{18}$O/$^{16}$O reflects the combined effect of rainfall and sea surface temperature (SST) and pronounced positive $^{18}$O/$^{16}$O anomalies relate to droughts and cooler SSTs during El Niños (Fig. 1a). The coral $^{18}$O/$^{16}$O records show that long droughts (>3 years duration) were more prevalent in the middle Holocene, the longest of which lasted 14 years. These protracted droughts appear to be linked to multi-decadal climate fluctuations. The extraordinary duration of the mid-Holocene droughts may help explain why agricultural societies were not firmly established in the Philippines until after ~4,000 years ago.

To investigate the seasonal structure of the droughts in detail, we performed bi-weekly analysis of coral $^{18}$O/$^{16}$O throughout the most prominent events (Fig. 1b). We compared coral $^{18}$O/$^{16}$O anomalies at the start, peak and end of the four most recent El Niño events (1986/7, 1990-95, 1997/98 and 2002/03) with events recorded at 7.2 ka and 2.3 ka. Composite analysis of the droughts reveals significant changes in the onset and magnitude of the $^{18}$O/$^{16}$O anomalies. Droughts associated with El Niño events in the modern coral record typically peak towards the end of the calendar year. In contrast, droughts at 7.2 ka and 2.3 ka commenced about 3-6 months earlier and ended in the middle of the calendar year within two months of the termination-time for present-day events.

In summary, the coral records show that the longest droughts occurred in the middle Holocene, yet peak anomalies on seasonal time-scales were largest in the late Holocene (at ~2.3 ka). This finding is consistent with a climate model (Clement et al. 2000) and palaeo-ENSO records (Moy et al. 2002) showing large amplitude and more frequent events in the late Holocene. Our results indicate that the magnitude, duration and seasonal structure of El Niño events have evolved substantially through the Holocene.
Figure 1. Holocene mega-droughts and the seasonal structure of El Niño events in the Philippines. (A) Evolution of El Niño events from 7,600 years ago (7.6 ka) to the present based on annually resolved 40Ar/39Ar anomalies in fossil corals from eastern Samar, Philippines. (B) Composite analysis of bi-weekly coral 18O/16O anomalies to reveal the seasonal structure of El Niño events at 7.2 ka, 2.3 ka, and the present.


Speleothem records of palaeomonsoon dynamics from Flores, Indonesia

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Speleothems are cave deposits which potentially yield high resolution, independently dated proxy records of climate. At tropical sites, speleothem oxygen isotope (¹⁸O) variations are primarily dominated by rainfall amount. Fluctuations in carbon isotopes (¹³C) are related to the response of local vegetation and soil to climate variations. As part of an Australian Research Council Discovery grant, fieldwork was carried out in 2006 and 2007 within caves in Flores, Indonesia to collect speleothem material for the generation of palaeoclimate records. Collaborators from RSES, Indonesian Institute of Sciences, University of Queensland and University of Newcastle collected speleothems spanning various time periods in order to document millennial to seasonal extremes of regional monsoonal rainfall.

Preliminary uranium-series dating of the speleothem calcite indicates that the samples span a broad temporal range. Stalagmite samples collected during the 2006 field season provide records of rainfall variability from 23.5 kyr to the late Holocene. Flowstone material collected at the same time covers an overlapping period to 30 kyr and additionally from 99 kyr to 109 kyr. High resolution stable isotope and trace element analysis of this material is currently being conducted. In 2007, our team specifically targeted for collection stalagmite samples that span up to 50 kyr and flowstone material that ideally covers the past 150 kyr.

This study forms part of the stream of ARC research program Monsoon extremes, environmental shifts and catastrophic volcanic eruptions: quantifying impacts on the early human history of southern Australasia, which aims to reconstruct a continuous history of monsoon rainfall variability within the Australasian region over the last 50 kyr. Ideally, this study will clarify the connection between the Northern and Southern Hemisphere climates on millennial timescales, and the nature and source of recorded variability. Specifically, we aim to determine whether short-term, abrupt climatic changes documented in Northern Hemisphere records, such as Dansgaard-Oeschger cycles and Heinrich events, are identifiable in tropical Southern Hemisphere records. By addressing these research questions, we expect to elucidate the role of the tropics in the global climate system over the last 50 kyr.
Figure 1. Coring a flowstone in Liang Luar cave, Flores, Indonesia during 2007 (G. Smith).

Figure 2. Stalagmite LR06-C6 from Liang Luar Cave, Flores, Indonesia, providing monsoon rainfall proxy data from 7.35-23.5 kyr (L. Ayliffe).

Boron in biogenic silica: insights into pH and pCO$_2$ of the Southern Ocean

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The boron isotope composition of biogenic carbonate (e.g. foraminifera, coral) has been used as a proxy for measuring seawater pH. Boron has two isotopes, $^{10}$B and $^{11}$B, and their partitioning into the two species of boron that exist in seawater, boric acid (B(OH)$_3$) and borate (B(OH)$_4$) strongly correlates with seawater pH. This relationship can be exploited to determine the pH of seawater at the time of carbonate precipitation.

This research looks to extend this proxy by using the boron composition of biogenic silica to measure the palaeo-pH of the Southern Ocean. The Southern Ocean is thought to play an important role in controlling atmospheric pCO$_2$; however the mechanism by which the ocean exerts this influence is poorly understood. An understanding of the pH, and hence the carbonate chemistry, of the Southern Ocean will provide important insights into this relationship. Using biogenic silica, namely diatoms and siliceous sponges, a palaeo-pH profile of the Southern Ocean that covers glacial-interglacial climate transitions will be used to investigate changes in Southern Ocean chemistry during these fluctuations in atmospheric pCO$_2$.

Work so far has focussed on developing the techniques required to measure the boron isotope composition of biogenic silica. These techniques will be used on live-collected and cultured samples in order to constrain the boron isotope pH proxy, and then applied to sediment core samples taken from the Southern Ocean.
Silica banding in the deep-sea lithistid sponge Corallistes undulatus: Investigating the potential influence of diet and environment on growth

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It is becoming increasingly clear that food supply and diet strongly influence the structure of deep-ocean communities and the nature of growth in the constituent organisms. We know that the export of labile phytodetritus to the ocean's interior is episodic and is influenced by climate. However, characterizing these export events and their influence on deep ocean organisms can be problematic. The use of proxy records is one way of reconstructing changes in surface ocean export and its influence on the deep-ocean community. A major hurdle is the availability of marine invertebrates that have long life spans and skeletons that archive the history of the animal's growth and diet. Marine sponges offer a unique approach to this problem as their silica spicules incorporate trace elements and carbon thus providing a potential archive of food supply related to surface ocean export.

To realize this potential, we made detailed records of trace metals and carbon isotopes to understand siliceous spicule (Figure 1) formation in the deep-sea lithistid sponge Corallistes undulatus Levi and Levi, 1983 (Demospongiae: Corallistidae). X-ray analysis of two longitudinal sections removed from this cup-shaped sponge revealed ~140 light and dark density band-pairs within the siliceous skeleton. In addition, four portions of silica were removed for silicon-32 (³²Si) dating in order to constrain the overall extension rate of the sponge. Although there was some variability in the ³²Si data, the overall age established using these data indicated that the sponge was between 135 and 160 yr old. This agreed well with the counts of density band-pairs, indicating that these band-pairs appear to represent an annual deposition of layers of silica in the sponge skeleton.

We also investigated the links between silica deposition and growth (food supply) were established using the radiocarbon and stable carbon isotope signatures of organic material trapped with the spicule matrix and the zinc content of the silica. A carbon budget based on these results indicated that the amount of fresh, labile surface export organic carbon reaching C. undulatus was not sufficient to support its growth. The radiocarbon results for organic carbon trapped in the silica spicules, deposited after the 1960s, supports this assertion; only a small atmospheric nuclear weapons ‘bomb’ spike was observed in the data. Taken together, the stable and radio-carbon data, and trace-metal results all indicate that the organic carbon source to C. undulatus is likely to be a mixture of fresh, labile, surface-derived material and older, perhaps sediment-derived material, with the latter being dominant.
Figure 1. SEM image of the silica skeleton of the sponge *Corallistes undulatus* Levi and Levi, 1983
Determning Age and Growth Rate of Marine Sponges by Radiocarbon Dating of Carbon trapped in Silica Spicules

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Radiocarbon (¹⁴C), the radioactive isotope carbon can be used to determine the age of material that was once part of the biosphere. On land this is simple with the carbon-14 sourced from the atmosphere by the cosmic irradiation of Nitrogen-14. This carbon-14 is quickly oxidised to $^{14}$CO₂ and mixes into the biosphere in its proportion to $^{12}$CO₂ and $^{13}$CO₂. In the ocean there are slightly more complicating factors, the ocean takes ~10 years to come into equilibrium with the atmosphere and the residence time for a parcel of water in the deep ocean is long enough for radioactive decay. This results in the surface ocean having an apparent age of ~400 years, this is termed the reservoir age. This adds a small complication to estimating the age of a marine organism but it is correctable.

Marine sponges are filter-feeder organisms; they are ubiquitous in the world’s seas. They obtain their carbon from the food they eat. Sponges are made up of an organic matrix and silica spicules. It is thought that as a sponge grows spicules are formed and a small amount of organic carbon is trapped. If we sample spicules from different areas and determine the age of the carbon in the spicules we should be able to obtain age and growth rate information. A marine sponge was collected from the Ross Sea, Antarctica. We determined that the spicules were very low in carbon content ~0.05% and that it is necessary to thoroughly clean the spicules to remove contaminant carbon. Our preliminary results suggest that as one samples further back in time along the sponge the radiocarbon age increases (Figure 1). The outer most edge of the sponge has an apparent age of 1075 years, even though it was alive when it was collected in 2005. The reason for this is that upwelling occurs in the Ross Sea, this brings water with an older age to the surface, the average radiocarbon age of surface water in Antarctica is ~950 yrs. The innermost sample (oldest) dates to ~1350 years ago, suggesting this sponge lived for ~270 years. This gives an average growth rate of 0.8 mm per year. Although the graph suggests that the growth rate may change as the sponge get older.
The history of aridity in central Australia over the last glacial cycle: Evidence from desert dunefields

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Australia is the driest inhabited continent on Earth. Aridity on the continent has intensified during the glacial cycles of the last few million years, creating stony deserts, dry salt lakes, and the extensive dunefields which preserve evidence of episodes of aridity during the more recent glacial intervals. Aridification has not been limited to Australia; drier conditions have remobilised desert dunes worldwide. Alarmingly, models of future desert dune activity suggest that human-induced climate change in the twenty-first century may enhance aeolian activity still further, resulting in even more widespread landscape instability (Thomas et al., 2005). Our work focuses on the timing of aeolian episodes in the past and their relationship to palaeoenvironmental conditions, in order to better understand mechanisms for future change.

Linear dunes occupy more than one third of the Australian continent, but the timing of their formation and their reliability as proxies for arid conditions is poorly understood. Our work has focused on the late Quaternary history of aridity of the Strzelecki and Tirari Desert dunefields, a region in the driest part of Australia. We collected 82 samples from 26 sites across the Strzelecki and Tirari Deserts in the driest part of central Australia to provide an optically stimulated luminescence (OSL) chronology for these dunefields (Fitzsimmons et al., in press). The dunes preserve up to four stratigraphic horizons, bounded by palaeosols, which represent evidence for multiple periods of reactivation punctuated by episodes of increased environmental stability. Dune activity took place in episodes around 73–66 ka, 35–32 ka, 22–18 ka and 14–10 ka. Intermittent partial mobilisation persisted at other times throughout the last 75 ka and dune activity appears to have intensified during the late Holocene.

Dune construction occurred when sediment was available for aeolian transport; in the Strzelecki and Tirari Deserts, this coincided with cold, arid conditions during marine isotope stage (MIS) 4, late MIS 3 and MIS 2, and the warm, dry climates of the late Pleistocene–Holocene transition period and late Holocene. Localised influxes of sediment on active floodplains and lake floors during the relatively more humid periods of MIS 5 also resulted in dune formation. The timing of widespread dune reactivation coincided with glaciation in southeastern Australia, along with cooler temperatures in the adjacent oceans and Antarctica. We are now also able to compare three different proxies for aridity in the Australian arid zone, using dune, salt lake and emu eggshell oxygen isotope records, in order to more precisely reconstruct past environmental conditions and mechanisms for dune reactivation.
Figure 1. Comparing the Australian dune record from this study (A) with other palaeoclimatic records; (B) Aeolian concentration of dust in Tasman Sea sediments (Hesse, 1994); (C) Dust concentration in the Dronning Maud Land (EDML) and Dome C (EDC) ice cores in Antarctica (EPICA, 2006); (D) $\delta^{18}$O (corrected) ice volume record from the EDML ice core (EPICA, 2006), and (E) Stacked sea-surface temperature record from the Australasian region (Barrows et al., 2007). Age groupings for dune activity are highlighted in orange.

Coral chemo-geodesy: long-term perspectives for improved prediction of 
great submarine earthquakes

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The nature of catastrophic earthquakes and tsunamis, such as those generated by the 2004 
and 2005 earthquakes in Sumatra, is poorly understood, largely because the recurrence 
interval of great submarine earthquakes remains unknown. Fossil coral reefs preserved along 
the Sumatran subduction zone mark vertical motions during great earthquakes back to 
~7,000 years ago.

Our ARC Discovery grant team has discovered that carbon-isotope ratios (¹³C/¹²C) in the 
skeletons of well-preserved massive Porites corals record vertical crustal deformation during 
submarine earthquakes (Gagan et al. 2006). The initial finding was based on analysis of a 
Porites microatoll from the Mentawai Islands, southwest Sumatra, that revealed a spectacular 
increase in coral ¹³C/¹²C in response to 0.7 m uplift during the magnitude ~8.4 earthquake in 
1797 AD. Water column light intensity, coral symbiont photosynthesis, and skeletal ¹³C/¹²C are 
inextricably linked. This record showed, for the first time, that ¹³C/¹²C in coral skeletons is 
sensitive to the increase in light intensity when corals rise to shallower water during co-
seismic uplift.

Given this encouraging result, we are developing the coral “chemo-geodesy” technique for 
massive (vertically growing) Porites corals, which are abundant in tectonically active tropical 
arc settings. We now have a continuous, high-resolution time-series of coral ¹³C/¹²C 
showing crustal deformation before, during, and after the 1907 AD (M ~7.8) and 1935 AD (M 
~7.7) earthquakes in Sumatra. In both cases, crustal rupture is preceded by an increase in 
seafloor submergence (lower light intensity recorded by coral) for a few years before the 
quakes. This apparent acceleration in crustal deformation prior to rupture is interesting 
because it may be a precursor to large earthquakes.

To further ground-truth the chemo-geodesy technique, we have collected coral cores from 
Sumatran reefs surrounded by a global positioning system (GPS) array that fortuitously 
measured crustal deformation during the 2004 and 2005 earthquakes. We drilled corals in 
areas of strong uplift (+1.5–2.8 m), and also specimens that experienced vertical displacements 
separated by ~3 months during the 2004/2005 “compound earthquake”.

If this test is successful, we will embark on a program to produce a precisely dated, semi-
continuous reconstruction of the recurrence intervals of giant submarine earthquakes along 
the Sumatran subduction zone over the past ~7,000 years.

In principle, such histories could be produced for any tropical island arc setting to improve our 
knowledge of great-earthquake cycles and tsunamis in Asia-Pacific region.
Figure 1. Coral chemo-geodesy along the Sumatran subduction zone. (A) Chain-saw slicing a giant Porites microatoll in the Mentawai Islands, Sumatra. (B) Profile of skeletal $^{14}$C/$^{12}$C in a Porites microatoll showing abrupt increase in $^{14}$C/$^{12}$C marking ~0.7 m co-seismic uplift during the M 8.4 earthquake in February 1797 AD. (C) Emergence (+2.8 m) of massive Porites corals on the island of Nias during the M 8.7 March 2005 earthquake. (D) Profile of skeletal $^{14}$C/$^{12}$C in a massive Porites coral showing crustal deformation before (submergence), during (abrupt emergence), and after (crustal rebound) the 1907 AD (M 7.8) and 1935 AD (M 7.7) earthquakes in Sumatra.

High resolution analysis of uranium and thorium concentration as well as U-series isotope distributions in a Neanderthal tooth from Payre using laser ablation ICP-MS

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A Neanderthal tooth from the site of Payre was selected to evaluate and advance in situ analyses, including U-series, Sr, Ca and O isotopes. First results on SHRIMP oxygen isotope analysis (with spot sizes of 35 _m diameter, 2 _m deep, allowing weekly to bi-weekly resolutions in human molars) and Sr elemental distributions on this tooth using laser ablation were reported by Grün et al. (2006), maps of Sr isotopes by Aubert et al. (2007). Here, we present the first high resolution U and Th concentration and U-series isotope maps of a human fossil.

In a first exploration of the U-distribution, 21 parallel laser scans were measured, covering a cross section of occlusal and lingual enamel and the adjacent dentine (Area 1, Figure 1). The tracks had a width of 85 _m, with a spacing of 100 _m and consisted of 1100 individual measurements. Figure 2 shows maps of the U and Th elemental distributions. In the enamel Th is predominantly enriched right at the surface (Figure 2C) where it is associated with detrital coatings (Figure 1). In the 3-D presentation, this thin veneer occurs as separate isolated cones, which is the result of rastering caused by the track width and interpolation strategies of the software. Uranium diffusion into the enamel did not follow a simple D-A model (Pike et al 2002), which would have produced _-shaped U distributions. The lowest concentrations are found near the occlusal surface where U-concentrations drop to less than 10 ppb, indicating little or no U-uptake. Elsewhere uranium has migrated into the enamel in a variety of modes. Firstly, U is concentrated along visible cracks, one is clearly visible starting from the cusp of the dentine reaching to the surface (just above “I” in Figures 2A and B).

At least three different lineaments with enriched U-concentration are visible, all running at shallow angles to the surface and dentine/enamel boundary. The most obvious feature in the enamel is a relatively large domain of greatly increased U-concentrations of up to 1500 ppb (around Cycle 500 in Tracks 9 to 14, Figure 2B). Uranium migrated from the dentine into the enamel along two pathways (perhaps tubules that pass from the dentine through into the enamel) leading to a U-enrichment in an area, which reaches about 600 _m into the enamel and has a width of about 800 _m. A series of smaller linear diffusion paths lead further into the enamel. This domain of high U can clearly not be explained by monotonic diffusion into a homogeneous layer, but more likely is due to a mineralogical change in this area. The uranium concentrations in dentine ranged from about 25,000 ppb to 45,000 ppb. There is a general gradient from the centre of the dentine (Cycles 500-800, Tracks 1 to 5) towards the enamel. It is obvious that U-mapping is essential to understanding the mode of U-migration.

Figure 3A shows an SEM photograph of the approximate dentine region of Area 2. Figure 3B shows the Th distribution in Area 2. Th was adsorbed at the outside of the dentine and shows no sign of diffusion into the dental tissue. Inside the dentine, U/Th ratios were well above 10,000. U-series ratios and age estimates were calculated from the U maxima at the surfaces of the dentine (Figures 3C to E). At the outside surface, elemental U/Th concentrations ratios were as low as 350, at the inside surface well in excess of 1000 implying that none of the U-series age calculations were affected by the presence of detrital ^230Th, particularly those of Track 6.
The $^{234}\text{U}/^{238}\text{U}$ ratios (Figure 3D) varied within a small band width, the average value being $1.202\pm0.023$. In contrast, $^{230}\text{Th}/^{234}\text{U}$ ratios (Figure 3E) varied greatly along and between the tracks. The same applies, of course, to the calculated apparent U-series age estimates (Figure 3F). Depending on the relationships between U-concentration and apparent U-series ages, we can distinguish four regions (I–IV, Figure 3C). In Region I, at and near the inner surface of the dentine, the highest U-concentrations are associated with the higher apparent U-series ages. This is generally expected from the predictions of the D-A model.

The oldest ages occur at the inner surface (Cycles 240 to 260) and are steadily increasing from Track 1 to Track 6. Region II shows some distinct U maxima and minima, and these are inversely associated with U-series ages. In the central Region III, the U-concentrations are lowest, but the apparent U-series ages are significantly higher than in the surrounding Regions II and IV. Region IV shows a similar pattern as Region II. The apparent U-series ages near the outer surface (Cycles 40 to 80, Region IV) are significantly lower than on the opposite side (Region I). On the SEM image (Figure 3A), Region I closely correlates to the darker rim around the pulp cavity (see Figure 1), which consists of secondary dentine and/or weathered primary dentine. Region II seems to be dominated by tubules, while Regions III and IV are undistinguishable in the SEM characteristics with non-directional patterns, perhaps caused by an overprint of secondary dentine or other secondary minerals.

Near the inner surface, there is no sign of U-leaching, so that the apparent U-series ages in Region I, around 200 ka, can be regarded as minimum age estimates for the tooth. This is in good agreement with independent age estimates for this tooth of 175 to 230 ka.

![Figure 1. Photos of the Neanderthal tooth from Payre. Area 1 was scanned for U and Th elemental concentrations, Area 2 for U and Th elemental concentrations and U-series isotopes. The arrows indicate the directions of the laser tracks.](image)
Figure 2. 3A: SEM image of Area 1; B: U-distribution. The solid lines indicate the enamel boundaries and lineaments of increased U-concentration. C: Th-distribution. The dotted line limits and area of higher Th concentration, which is unrelated to the enamel/dentine boundary.
Figure 3. Elemental, isotopic and age distributions in Area 2. A: SEM of the dentine in Area 1, but about 50 m below in depth. The large red square is for orientation, subdivided into 50 cycle sections. Black lines indicate the boundaries of Regions I to IV (see Figure C). B: Th distribution. C: U distribution, Regions I to IV indicate areas of different relationships between U-concentrations and U-series age calculations. D: $^{238}$U/$^{234}$U ratios. E: $^{230}$Th/$^{234}$U ratios. F: U-series age estimates.
Direct dating of fossil human remains

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Renaud Joannes-Boyau is an international PhD student at RSES from France. He started is PhD “direct dating of fossil human remains” in October 2006, under the supervision of Professor Rainer Grün. His research focuses at the moment on decomposing the ESR spectra observe in fragments of tooth enamel crystal from the CO₃⁻ defect. Studies on tooth enamel fragments have shown that the ESR spectra are significantly more complex than previously assumed (Figure 1, Grün et al. in press). The ESR signal of the CO₃⁻ radical in hydroxyapatite has been used for the assessment of the past radiation dose, which in turn is converted into numerical age estimates, once the dose rate parameters are assessed. ESR dating studies are conventionally carried out on powdered samples, and it has repeatedly been demonstrated that the ESR spectra recorded from fossil samples are qualitatively similar to those generated by laboratory irradiation.

However, when attempting non-destructive ESR analysis, which is essential when working on fossil human remains, measurements are carried out repeatedly on tooth enamel fragments. Because of the anisotropic nature of hydroxyapatite, the ESR spectra show strong angular dependencies. In contrast to powders, the ESR spectra of fossil samples are significantly different to those generated by laboratory irradiation. Because of unstable components, it was initially suspected that all ESR age estimations could be underestimated (Joannes-Boyau et al. 2007).

At the present point, the study focuses on the enamel structure to understand where the different components are located within the crystal. The enamel structure is exceptionally complex. Our studies have so far revealed a composite organisation of crystal clusters, in prismatic and inter-prismatic configurations, both having different ESR responses. At the same time, research has been performed to understand the incorporation of uranium into the different tissues of the tooth. To clarify the assimilation of uranium in the teeth, especially in enamel, a cross section of an entire tooth has been analysed using laser ablation ICP-MS (for details see annual report of Grün et al.).
Figure 1: The main difference between powder and fragments while working on tooth enamel is the strong angular dependency of the CO$_2$-radicals. The BHL configuration corresponds to a rotation around the occlusal surface of the tooth. The irradiated spectra (laboratory) and natural spectra present some significant differences.

Linkages between coral assemblages and coral-based proxies of terrestrial exposure along a cross-shelf gradient of the Great Barrier Reef

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Field studies from recent decades suggest that coral assemblages from sites within proximity to land are shifting in response to both local and diffuse sources of terrestrial pollution. While coastal and nearshore communities have been identified to be at high risk from agricultural runoff in the Mackay section of the Great Barrier Reef, few baseline studies have been performed in this region to assess current coral assemblages and how they may be affected by terrestrial exposure.

We scored transects for benthic cover composition at seven reef locations along a gradient of distance offshore from the Pioneer River mouth. We categorized community structure into major benthic cover types (live hard coral, soft coral, fleshy macroalgae, substratum), dominant coral families, and growth morphology Acroporid corals, the most abundant group. Multivariate analysis of transect data showed that the nearshore reef assemblages at Keswick and St. Bees Islands (~33 km offshore) were categorically different from the other nearshore and midshelf sites due to the high cover of fleshy macroalgae overgrowing dead reef matrix.

Multiple tracers (luminescence intensity, _¹⁵N, barium to calcium ratios) measured from coral core records collected from long-lived _Porites colonies showed a gradient of disturbance from terrestrial runoff across the inner-shelf sites. While values of Ba/Ca and _¹⁵N were strongly correlated with terrestrial runoff at Keswick and St. Bees, there was no significant influence of river discharge at the next island offshore (Scawfell at ~50 km). The enriched _¹⁵N during major flood years in Keswick Island corals suggest that coral reef communities are receiving pulses of anthropogenic nutrients (mostly fertiliser-derived nitrogen) sourced from the Pioneer catchment. We therefore suggest that the current community composition at reef sites within 35 km of the Mackay coast is likely to be strongly influenced by repeated influx of sediments and nutrients delivered from flood plumes, which likely affect coral recovery and enable the persistence of late-successional algal stands.
Figure 1. (a) Coral luminescence intensity from Round Top (RT), Keswick (KI) and Scawfell (SC) fringing reefs, with major cyclones marked through the period. (b) Annual coral skeletal $\delta^{15}N$ from a 3-core composite at RT and single cores from KI and SC. Data courtesy of G. Marion. (c-e) Representative habitat conditions at RT (c), KI (d) and SC (e).
Strontium isotope tracing in animal teeth at the Neanderthal site of Les Pradelles, Charante, France.

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Strontium isotope ratios (⁸⁷Sr/⁸⁶Sr) can be utilised in reconstructing the migration and mobility of ancient animal and human populations. The Sr isotope ratios of geological materials are a function of the age and composition of the material (Capo et al. 1998) and therefore vary across rock units. The bio-available Sr isotopes in rocks and soils are passed on to local plants and into the food chain (Beard & Johnson 2000). Sr isotopes in tooth enamel reflect the isotopes consumed by an animal during the period of tooth formation (Bentley 2006). In most animals, this period is early childhood, though rodents, with ever-growing incisors, are an exception (Rinaldi & Cole 2004). Strontium isotopes in fossil tooth enamel can be compared to a geological, bio-available strontium isotope map, to determine whether teeth are from local or migrant individuals.

This study was carried out on the Upper Pleistocene site of Les Pradelles (Marillac-le-Franc, Charente, France), which has yielded numerous faunal remains including an important collection of Neanderthal pieces (Homo neanderthalensis) (Beauval et al. 2002). The surrounding area consists of two main rock regions, the limestones of the Dordogne and the metamorphic and granitoid rocks of the Massif Central, which yield differing average strontium isotope ratios (see below).

Soil and plant samples were collected from 40 locations across both rock regions. Soil samples were sieved and leached to ensure only biologically available strontium would be measured. Plant samples were dried, ashed and dissolved. All samples had total Sr concentration measured via solution ICP-MS before Sr separation was undertaken via ion exchange chromatography. ⁸⁷Sr/⁸⁶Sr ratios were measured via ICP-MS analysis. The fossil faunal samples from the site consisted of 23 teeth from seven species including both herbivores and carnivores. Sr isotopes in the tooth enamel were measured via laser ablation ICP-MS, resulting in high resolution records along the growth axis of the enamel.

Despite some variation in ⁸⁷Sr/⁸⁶Sr within each rock region, the two main regions can be successfully differentiated on the basis of bio-available Sr isotopes of soils and plants and a Sr isotope map of the area is produced (fig 1). The Sr isotope ratios in animal teeth do not vary significantly along the growth of the tooth enamel (fig 2), potentially indicating a lack of migration across the rock provinces while the teeth were forming. However, the lack of seasonality may alternatively be explained by reservoir effects and complexities in tooth mineralisation. Animals with small feeding ranges, such as marmots, are successfully linked to particular rock regions according to Sr isotope ratio, whereas intermediate ⁸⁷Sr/⁸⁶Sr values in migrating animals, such as reindeer, suggest an averaging of values from both units (fig 3). The wolf sample provides a high ratio, tracing it to the granitoid region, although it would have eaten migratory animals. This suggests the animal migrated to this region in later life, spending its childhood in an area away from the influence of the limestone values.
Hence, although seasonal migration was not detectable in the tooth enamel Sr isotope ratios, lifetime migration may be determined. This study forms the basis for an ongoing study into Neanderthal migration.
Coral Reefs and Global Change

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Although coral reefs inhabit only about one percent of the world’s continental shelf area, they represent a disproportionately important and essential marine resource as well as being of immense ecological value. Coral reefs are however sensitive to the threats from global climate change as well as direct human impacts from degradation of their local marine environment, both of which are now occurring at unprecedented rates. Higher levels of atmospheric CO2 from fossil fuel burning, is not only causing global warming, but also increasing the acidity of the world’s oceans. The effects of increased ocean acidity on marine ecosystems are however still only very poorly understood as previous episodes of global warming, such as occurred during the Last Interglacial ~125,000 years ago, were accompanied by lower (~300 ppm) rather than the significantly higher levels of CO2 predicted for the near future (i.e. ~400 to 500 ppm by 2100). Increasing acidity of the world’s oceans and the resultant decrease in the carbonate saturation state of seawater thus has the potential to cause substantial and still largely uncertain impacts on coral reef and marine ecosystems generally. Recent changes in seawater pH due to CO2 uptake by seawater are now being investigated at RSES using boron isotopic variations in coral skeletons. These provides a long-term record of changes in seawater pH since industrialising and are demonstrating significant shifts in seawater pH of >0.2 pH units especially during the last several decades.

In order to better understand how corals have adapted to past episodes of global warming we are continuing our studies of Last Interglacial reefs such as those that are preserved along the Western Australian coastline. These reefs which grew when ocean temperatures where several degrees warmer than today, similar to those predicted for our Greenhouse Earth by 2100, and show that in the absence of mankind’s footprint, corals given time, can adapt to the effects of warming. This is evident from the prolific coral growth observed in high latitude reefs of the southern-most portion of south-west Western Australia. The timescales for adaptation under Last Interglacial (normal) pH conditions are however still poorly constrained and maybe of the order of hundreds to thousands of years. Whether corals can adapt or acclimatis to the combined effects of global warming and lower seawater pH however remains at best highly problematic and ultimately depends on the future level that atmospheric pCO2 stabilises. The most immediate and severe impacts on coral reefs are still nevertheless those that arise from direct human activities. Locally, landuse changes in river catchments, wetlands and estuaries is leading to increased supplies of sediment and nutrients to many inshore coral reefs. In some cases these, together with pressures from other activities such as trawling and overfishing are now resulting in an evolutionary trajectory that may ultimately result in an abrupt phase shift from a coral to macro-algae dominated ecosystem. It is thus clear that the long-term sustainability of coral reefs is not only dependent on the still poorly understood effects of global climate change and increased ocean acidity, but also on maintaining the health and hence the resilience of reef systems by minimising direct/local human impacts.
Long-term landscape evolution of the Yilgarn Craton, Western Australia

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The antiquity of Australian landscapes has long been postulated. Almost 100 years ago Jutson (1914, p. 92) observed that “the land surface of Western Australia is one of the oldest land surfaces on the globe, and that it has not been below the sea for many geological ages”. In doing so, Jutson cited the complete lack of younger marine strata overlying the Precambrian shield (Yilgarn and Pilbara Cratons), other than in coastal areas, as “strong negative evidence” for his conclusion. Jutson’s reasoning was that if the sea had covered a significant proportion of the shield, then it was highly improbable that some remnants of marine strata were not preserved at inland locations. Indeed, Jutson’s broad conclusion is entirely consistent with modern paleogeographical reconstructions (e.g. BMR Palaeogeographic Group 1990) indicating that parts of the Australian continent, including the Yilgarn Craton, have been subaerially exposed for hundreds of millions of years.

Recent advances in dating regolith on the Yilgarn Craton provide ample evidence of ancient regolith and landforms, some with paleomagnetic weathering ages extending back to the late Carboniferous (e.g. at Meekatharra and Laverton - Pillans 2007). However, long-term denudation rate estimates for the Yilgarn Craton based on cosmogenic nuclides are in the range 1-3 m/Ma on 10^5-10^6 year timescales (Chappell 2003), while denudation rates on 10^7-10^8 year timescales, based on sediment budgets (Killick 1998) and apatite fission-track thermochronology (Kohn et al. 2002; Weber et al. 2005), are generally higher. Therefore the persistence of pre-Tertiary regolith and landforms at or near the surface is unlikely, and their survival is more likely as the result of burial and exhumation. On the other hand, relic Tertiary regolith and landforms are widespread surface and near-surface features across the Yilgarn Craton.

Based on apatite fission-track thermochronology, Weber et al. (2005) derived a model for the denudation history of the northern Yilgarn Craton. The essential elements of their model are surface exposure and weathering during the Late Carboniferous, followed by rapid burial by a ~3 km cover of Permian sediments, and then slow exhumation until re-exposure in the Late Cretaceous. Such a model is consistent with the preservation of Permo-Carboniferous regolith and landforms. The thick Permian cover also explains the lack of Archean-age detrital zircons in Late Paleozoic and younger sediments of the adjacent Perth Basin (Sircombe and Freeman 1999).
Figure 1. Paleomagnetic dating of deeply oxidised regolith at Meekatharra has yielded Late Carboniferous weathering ages.

Two distinct processes of U-series isotopic diagenesis in a single fossil
Porites coral and model correction age

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We made multiple measurements of U-series isotopes in skeletal sub-samples within a single Porites coral to explore the diagenetic history of U-series isotopes in fossil corals from the raised reefs of Sumba, Indonesia (Gagan et al. 2006). Detailed analysis of two recognizable diagenetic stages and corresponding changes in U-series isotopic composition has revealed two distinct processes of U-series isotope diagenesis in this single coral. Both styles of diagenesis are different from those suggested before (e.g.: Gallup et al., 1994; Scholz et al., 2004; Thompson et al., 2003; Villemant and Feuillet, 2003).

The earlier-stage process demonstrates the addition of allochthonous dissolved $^{234}\text{U}$ and $^{238}\text{U}$ together with detrital non-radiogenic $^{230}\text{Th}$, while the later-stage shows that loss of $^{234}\text{U}$ and $^{238}\text{U}$ occurred along with the introduction of detrital $^{230}\text{Th}$. Locally, radiogenic $^{230}\text{Th}$ appears to have played an important role in maintaining a constant $^{234}\text{U}/^{238}\text{U}$ as allochthonous U was added, while detrital $^{230}\text{Th}$ was critical to maintain a fixed $^{234}\text{U}/^{230}\text{U}$ when percolating meteoric water dissolved coral skeletal U. The results strongly suggest that a mechanism like diffusion or osmosis controls the addition or loss of dissolved U and detrital Th into or out of the coral by way of a solute concentration gradient. Model correction ages could be determined for both diagenetic processes and they yield essentially the same age of 133.6 ka.

![Figure 1. Diagenetic alteration of U-series isotopes in fossil coral MV03-A-2 from the island of Sumba, Indonesia. Analysis of two groups of sub-samples (red and blue) from different cores through the coral demonstrate that two distinct diagenetic processes have altered the $^{234}\text{U}/^{238}\text{U}$ and $^{230}\text{Th}/^{238}\text{U}$ activities.](image-url)
The red line is the linear regression for 3 sub-samples from core "c" while the blue line is the regression for all 4 sub-samples from core "a". The different slopes for the two data sets ($S = 3.6S_e$) are indicative of two distinct diagenetic pathways. Independent "isochron" ages were determined by intersecting the regression lines with the seawater evolution curve. The results show that both sample groups yield essentially the same model age of 133-134 ka. Error bars for individual data points are 2s.


Uncertainties in seawater thermometry deriving from intra- and inter-test Mg/Ca variability in *Globigerinoides rubber*

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Laser ablation ICPMS microanalysis of fossil and live *Globigerinoides ruber* from the eastern Indian Ocean reveals large variations of Mg/Ca composition both within and between individual tests from core-top or plankton pump samples. Although the extent of inter- and intra-test compositional variability exceeds that attributable to calcification temperature, the pooled mean Mg/Ca molar values obtained for core-top samples between the equator and >30°S form a strong exponential correlation with mean annual sea-surface temperature (Mg/Ca mmol/mol = 0.52*exp(0.076*SST°C; r²=0.99) (fig.1). The inter-test Mg/Ca variability within these deep-sea core-top samples is a source of significant uncertainty in Mg/Ca seawater temperature estimates, and is notable for being site specific. Our results indicate that widely assumed uncertainties in Mg/Ca thermometry may be underestimated. We show that statistical power analysis can be used to evaluate the number of tests needed to achieve a target level of uncertainty on a sample by sample case (fig.2). A varying bias also arises from the presence and varying mix two morphotypes (*G. ruber ruber* and *G. ruber pyramidalis*) which have different mean Mg/Ca values. Estimated calcification temperature differences between these morphotypes range up to 3°C and are notable for correlating with the seasonal range in seawater temperature at different sites. (Article accepted, Journal of Paleoceanography, 2007)

Fig. 1 Plots of annual SST at each core-top site versus the measured Mg/Ca composition of individual tests (black diamonds) and the sample mean Mg/Ca composition for each core top (grey circles – core-tops younger than 3 kyr; grey triangles older than 3 kyr.). The standard errors of the sample mean Mg/Ca and the SST values for each core-top sample are represented by the height and width of the boxes. Error bars indicate the 95% confidence interval for each sample mean Mg/Ca composition, and the thin dotted line outlines the envelope of predicted Mg/Ca values based on the seasonal SST range at each site (taken from World Ocean Atlas 2001 [Conkright et al., 2002]).

Fig.2 Calculated sample size (number of tests) required to achieve a target temperature uncertainty using Mg/Ca thermometry of *G. ruber* based on power analysis. The figure shows results for SST = 18°C based on the typical intra- and inter-test Mg/Ca sample variance. Calculations have been performed for four different target levels of SST uncertainty (0.5°C, 1°C, 1.5°C and 2°C).
Ge-Si ratio in siliceous organisms: A proxy for oceanic circulation?

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This research project will utilise both the Si isotope signature and the germanium (Ge) to Si concentration ratio (Ge/Si) of diatom frustules and sponge spicules to reconstruct historical Si concentrations in surface and deep ocean waters, thereby allowing concentration depth profiles to be recreated. In addition, a radically new model for interpreting isotope and elemental fractionation within siliceous organisms will be utilised. Further, new Si isotope and Ge/Si records will be generated to link changes in the Si cycle to the biological pump and the extent to which carbon is sequestered away from the atmosphere-equilibrated surface waters to the ocean’s interior.

This research aims to lay the groundwork to understand the oceanic cycling of Si during the past, with a particular focus on the Southern Ocean, using a multi-proxy and multi-organism approach. The main objectives of this research are to: (1) examine Si isotope and Ge/Si fractionation of diatoms and sponges grown under controlled conditions to understand processes that lead to fractionation; (2) relate culture results for isotope and elemental fractionation within diatoms and sponges to the Si isotope and Ge/Si distribution patterns in the modern ocean; (3) measure the Si isotope and Ge/Si signatures of fossil organisms, with the aim of reconstructing the distribution of Si in the ocean during the last ice age.

Method development and construction of experimental culture facilities for this project began earlier this year. The main objectives of this research are currently being investigated with a particular emphasis on the development of sponge culture. A few experimental sponge culture studies (figure 1) have been successful and chemical analysis of the experiments is currently underway.

A research cruise is planned from Hobart to Antarctica on the Aurora Australis (Figure 2) at the end of 2007. On this cruise biological and water samples from the Southern Ocean will be collected and analysed for distribution patterns germanium and Si isotopes in the Southern ocean.
Figure 1. Experimental sponge culture experiment.

Figure 2. Aurora Australis
Decoding past rainfall trends from southwest Australian speleothems

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Southwest Western Australia experienced a reduction in rainfall of around 10-20% that has persisted since about 1970. This rainfall reduction has had significant consequences for dam levels and water-dependent ecosystems in the region. Dr Treble is the chief investigator on a project to reconstruct the frequency, duration and intensity of past multi-decadal dry periods in the southwest Western Australian speleothem record for the past 1000 years. Research during 2007 in Earth Environment by Dr Treble focused on constraining the climatic controls on cave drip water chemistry in the southwest of Western Australia. Understanding the relationship between surface climate and cave hydrology/geochemistry are fundamental for unraveling past climatic information preserved in cave speleothems.

A key process in understanding the relationship between surface climate and the stalagmite geochemical trends is monitoring the real-time encoding of inter and intra-annual climate variations in the cave environment. This was done by monitoring changes in the drip water hydrology and geochemistry, as well as soil moisture and rainfall events. Interpretation of a 2.5 year long dataset has revealed that speleothem growth takes place primarily during the winter seasons driven by the partial pressure of cave CO₂ which in turn is related to the hydrology of the overlying rock. Distinct annual cycles in cave drip water Mg/Ca and Sr/Ca are directly related to the amount and duration of winter rainfall entering the cave each year. The existence of these annual cycles provides an important chronological tool as well as valuable seasonal information. Importantly, this research demonstrated that the cave drip water chemistry responded to the winter rainfall deficit in 2005 which was the driest year on record for this region.

This research was partly aided by an Exchange Fellowship granted to Dr Treble by the British Council. Dr Treble travelled to the University of Birmingham in the UK to collaborate with Prof Ian Fairchild on this research topic. Journal articles reporting the results of this study are currently in preparation.
Deep water upwelling and its implication for the Precambrian Cambrian boundary. Evidences from Molybdenum isotopes in black shales

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The environmental circumstances which have caused a decline in abundance and diversity of the soft-bodied Ediacara fauna at the end of the Precambrian followed by the "Cambrian explosion", is still a question of debate. It has been proposed that an increase in atmospheric oxygen concentration during the late Neoproterozoic period, and a subsequent change in ocean redox conditions could have played a key role in the evolution of eukaryotic organisms. The molybdenum isotope record is a good tool to investigate global paleoredox conditions and redox changes of the ocean.

We present Mo isotope signatures in black shales from two sample sets (Ara Group, Oman, and Yangtze Platform, China) which were deposited at and shortly after the Precambrian-Cambrian (PC-C) boundary. At first view, the overall Mo isotopic signature of the early Cambrian black shales from Oman and China is similar to that found in mid-Proterozoic sediments [1] and might support the idea of a stratified ocean with anoxic bottom water through most of the Proterozoic.

On closer inspection, however, a transient Mo signal following immediately after the PC-C boundary in both sample sets indicates a short global non-steady state situation. Combined with extreme Mo enrichment, found in the Chinese sulfide marker bed at the PC-C boundary, which cannot be explained by Mo scavenging mechanisms known from the modern oceans, upwelling of euxinic bottom water masses provides a reasonable explanation for this Mo signal. This scenario not only explains the Mo isotopic signal, it can also be responsible for the sudden extinction of the Ediacaran fauna.