ENVIRONMENTAL GEOCHEMISTRY AND GEOCHRONOLOGY

The Environmental Geochemistry and Geochronology Group investigates the long-term interaction between mankind and its environment. Research is directed towards two main aspects: firstly, determination of the timing and rate of change of major environmental and earth surface processes, and secondly, utilising isotopic systems to provide basic constraints on past and present environments. Our group focuses on the study of records spanning a few tens to several hundred thousand years of the Earth's recent history, which serve as a guide to the understanding of the past, present and future environments.

Research topics include the evolution and timing of the extinction of Australia's megafauna, human evolution in Africa and Australasia, as well as climate and sea level changes over the past several glacial/interglacial cycles. Our studies of the modern environment are aimed at tracing the provenance and fluxes of sediments and associated nutrients that are entering waterways and near-shore environments and quantifying how these have changed since European settlement. These environmental changes are compared with those that occurred with the arrival of Australia's first human occupants, some 60,000 years earlier. All these activities are underpinned by a unique combination of laboratory facilities consisting of thermal ionisation mass spectrometry (TIMS), laser ablation ICP-MS, optically stimulated luminescence (OSL), electron spin resonance (ESR), and gamma-ray counting equipment.

Our group is looking forward to meeting the challenges provided by the inclusion of RSES in the ARC funding schemes. In 2000, Professors Grün, McCulloch and Dr Spooner were successful in a range of collaborative international and ARC grants. Our research was vital for RSES to obtain funds from the strategic funding initiative of the Institute of Advanced Studies for environmental research. Professor Grün was the leading investigator of a successful RIEF grant application for an automated, highly sensitive ESR spectrometer. Moreover, the addition of the new Bruker Elexys 500 ESR spectrometer will put our ESR dating laboratory at the forefront of research in this area. Laboratory facilities have continued to be developed on several fronts. The new TRITON thermal ionisation mass spectrometer (TIMS) has been commissioned and performs to expectation and the NEPTUNE ICP-Multi Collector mass spectrometer will be delivered in the next months. With the opening of the new building extension it has been possible to consolidate into one facility these new instruments together with the existing MAT261 TIMS, ICP-MS, and the 61cm high sensitivity TIMS, presently being developed by Dr Esat and Professor McCulloch.

During 2000 there have been a number of personnel changes. Professor Grün was appointed group leader for two years. The success of the luminescence laboratory in raising funds in collaborative projects allowed the School to offer Mr Hill a long-term fulltime appointment, thus also securing the medium-term future of the luminescence laboratory. Marianelli, Fallon and Marshall submitted their PhD theses. Mr Marianelli's thesis involved TIMS U-series dating of the spectacular cave deposits of south-western Australia and obtained paleo-climate information based on the age/abundance distribution of cave formations. That work has resulted in an unexpected finding that the present-day interglacial climate is much wetter than during previous interglacials, probably indicating shifts in the westerly wind systems. He also undertook a re-assessment of models of oxygen isotope systematics in speleothems. Mr Fallon's thesis is centred around the development of fully quantitative elemental abundance measurements by laser ablation ICP-MS. This has involved the use of more closely matrix-matched standards with accurately known trace element abundances. In addition to high spatial resolution, laser ICP-MS has the advantage of rapid, simultaneous measurement of elements such as B, Mg, Sr, U, as well as Mn, Ba and P, the latter group being important indicators of flood plumes and nutrient fluxes that are entering the Great Barrier Reef. Mr Marshall's PhD thesis is based on the characterisation of teleconnections between the Indian and Pacific Oceans during El Nino events, using oxygen and Sr/Ca records in coral cores from the Cocos-Keeling, Christmas Islands and central Great Barrier Reef. He also examined the Holocene record of sea surface temperature changes in the Great Barrier Reef.

Studies of 300 to 400 year old coral cores have continued to be undertaken by Ms Hendy (for her PhD thesis) in collaboration with Dr Gagan and Dr Lough. This work has examined oxygen, carbon, Sr/Ca and Ba/Ca ratios in 5-year increments of these long sections of coral cores collected from the Great Barrier Reef. The aim of the work is determining the robustness and reproducibility of climate proxies in corals. Dr Esat (ARC Senior Fellow) and Professor McCulloch, in collaboration with Professor Lambeck and Ms Potter, have continued work on sea-level changes during the last interglacial and younger marine high-stands.

The newest group members are Dr W. Müller, Mr T. Wyndham and Ms. K. Ward. Dr. Müller graduated from the ETH in Zurich and will establish Th/U – Pa/U TIMS systematics. Mr Wyndham, a Hales scholar, successfully completed his Honours thesis in the Department of Chemistry. His thesis involved the study of rare earth element abundances and neodymium isotope tracing in the florescent flood bands from inshore corals in the Great Barrier Reef. Ms. Ward joined our group for her placement year from the Dept of Archaeological Sciences, Bradford University, UK, to work on the dating of South African hominid sites.

Dr C. Martin and Professor M. McCulloch have continued to apply Nd-Sr isotopic 'fingerprints' for tracing the source of suspended sediments and associated particle reactive nutrients that are entering the Great Barrier Reef, as well as inland waterways. Dr Martin has extended this approach to platinum group elements, including osmium isotopes, by examining fluxes of these elements from the Fly River of Papua New Guinea. This latter study involved collaboration with ANSTO and the Woods Hole Oceanographic Institution. Dr C. Alibert, a visiting fellow, is continuing her studies on trace element relationships between coral cores from Kavieng, Papua New Guinea, and the inshore region of the Great Barrier Reef.

A sample set from the Gotthard tunnel was investigated by ESR in a collaborative project between Professor Grün and Professor Burkhard of the University of Neuchatel to reconstruct the recent cooling history of this area. Initial results show that the ESR data reflect the relative position of the samples in the geological sequence.

A series of tooth fragments from important human fossils were dated by ESR. The results on samples from Swartkrans, South Africa, show that ESR can be used to date human fossils as old as 1.6 million years. Work on the Neanderthal Tabun C2 specimen demonstrated the particular strength of ESR dating: a recent gamma spectrometric U-series dating study had cast doubt on the antiquity of this specimen, assessing its age as somewhat less than 40,000 years. However, ESR and complimentary TIMS U-series analyses clearly agree with all earlier age assessments, namely that Tabun C2 has an age of about 120,000 years. Our work on the Mungo 3 specimen, reported in the previous RSES Annual Report, has sparked an intensive debate about the validity of the age results. The comments and replies, published in the May issue of the Journal of Human Evolution, provide interesting reading.

Dr Spooner carried out research in the luminescence laboratory on single-grain analysis applied to projects as diverse as source-bordering dune formation in the Murrumbidgee floodplain, karst geomorphology in the Jenolan caves, megafaunal extinction in Fiji, and beach deposits in the Antarctic. Pioneering research involved the modelling of single quartz grain optical dates in conjunction with cosmogenic isotope data. The palaeohydrology of the Lake Lewis basin has been investigated in collaboration with Ms P English and Professor J Chappell. Work with Dr R. Ogden focussed on the dating changes in the hydrologic regime of the Murray-Darling basin since the late Pleistocene. Collaborative work with Dr J. Magee and Professor G. Miller included extensive fieldwork at key megafaunal sites relating to the timing of extinction events, stratigraphic results from a transect across the Lake Eyre basin and commencement of a study of age-depth profiles in a continental dune field. A series of optical dates of archaeological and megafaunal remains and the key stratigraphic units at the controversial Lake Mungo site has been finalized and optical dating of the lunettes and beach ridges of the megalakes, notably Lake Eyre, Lake George, Lake Mungo and Lake Lewis has continued. Work on the photon-counting imaging system has progressed with the involvement of Mr I. McCulloch. Research continued in collaboration with Ms D. Questiaux and Professor

A. Franklin (University of Maryland) on the stability of recently discovered luminescence signals to ascertain their potential for dating.

None of these scientific endeavours could have been carried out without the active involvement of our excellent support staff: Mr N. Hill (luminescence), Mr L. Kinsley (mass spectrometry instrumentation), Ms M. Lukatela (secretary), Dr G. Mortimer (chemistry and mass spectrometry), Mr S. Robertson (IT, ESR), Mrs L. Taylor (ICP-MS, U-series chemistry), and Mrs G. Watson (chemistry). We are particularly pleased to welcome back Dr Mortimer after a serious illness.

Dating control of coral records using fluorescent banding

E J. Hendy, M.K. Gagan, M.T. McCulloch, and J. Lough[1]

To demonstrate that different corals accurately record common climate signals over several centuries requires consistent age assignment between the coral cores. Two independent annual markers, density and fluorescence, have been used to assign dates in eight *Porites* coral cores spanning the last 120 to 420 years. These coral cores come from seven reefs in the central Great Barrier Reef (between 17.78-18.51°S, 146.13-147.06°E) and were selected from the Australian Institute of Marine Science's collection. Following methods developed in tree-ring studies, skeleton-plots of fluorescent banding were produced for each core. Thus it was possible to establish a continuous, precise chronology across gaps between core sections and patches of ambiguous growth orientation. Parallel records were then combined into a master fluorescence chronology for the period 1985-1610, against which future cores can be cross-dated.

The strong correlation of fluorescent lines, in strength and pattern, with records of the Burdekin River run-off to the central Great Barrier Reef has been recognised for some time. In this study, by comparing fluorescent banding between coral colonies from inshore and mid-shelf reefs, it was discovered that less distinct but still identifiable fluorescent lines also occurred in the mid-shelf corals. If river-borne humic acids are responsible for coral fluorescence, as has been proposed, then the mid-shelf coral fluorescent bands are evidence that low salinity river flood plumes regularly reach the main reef tract. The master fluorescent chronology identifies 93 drought or dry years (observed by a marked absence of fluorescence), out of a total of 377 years. These years frequently coincide with historical ENSO (El Niño Southern Oscillation) events and drought records from the western Pacific. The Federation (1895-1903) and Centennial (1888-1889) droughts in particular are prominent in the master fluorescent record and can be identified in almost all of the coral cores.

Two incidents of coral tissue death and subsequent regrowth were discovered in the cores from Pandora Reef and Brook Island, dated to 1817 and 1782-85, respectively. Contemporary historical and proxy records indicate that both die-offs occurred during El Niños. Strong fluorescence in the surviving corals suggest that a large freshwater flood contributed to the 1817 event, providing an environmental situation analogous to conditions leading up to the severe 1998 bleaching event at the same reef. Elevated sea surface temperatures, calm doldrum-like seas, and reduced cloud levels, combined with a low salinity river plume, are known to cause coral bleaching and mortality even in a resilient genus like *Porites*. The 1782-85 die-off occurred during a very strong ENSO identified in historical records from South America, India and Africa. The local severity of drought conditions during 1782-85 are seen in the absence of fluorescence in surviving corals and strong negative rainfall anomalies recorded in a Javanese tree-ring record.

[1] Australian Institute of Marine Science

Response of porites coral to the 1998 mass-bleaching event

M. McCulloch, S. Fallon, J. Marshall, C. Alibert and B. Roark[2]

In February-March 1998, as part of a global phenomenon, the Great Barrier Reef experienced an episode of large-scale mass coral bleaching that was probably the most intense and widespread yet recorded. More than two thirds of the inshore reefs exhibited severe bleaching with a quarter being subject to extreme (irreversible?) bleaching. To better quantify the response of *Porites* coral to bleaching, we report here high-resolution laser ablation and mass spectrometric trace element and isotopic analyses (^{18}O and ^{13}C) of *Porites* coral affected by bleaching to varying degrees. Trace element proxies for sea surface temperature (Sr/Ca and U/Ca) were determined in corals collected eight months after the mass bleaching episode from the inshore reefs at Frankland Islands and Pandora Reef. All the corals clearly record the high-temperature bleaching event, indicating that calcification continued despite sea surface temperatures being in the range of 30-31^{o}C. For 2-4 weeks following the bleaching episode, some growth (extension) of the coral polyps continued, although at a much lower density, indicating a major decrease in the overall rate of calcification, presumably due to the expulsion of symbiotic algae. This latter phase is recorded as a rapid increase in Sr/Ca ratios (Figure 1). During the bleaching event, corals also show anomalously light (more negative) ^{13}C isotopic compositions due to metabolic stress, another possible fingerprint for bleaching. The longer-term response to the bleaching is variable. One coral shows relatively minor effects, corresponding to about a month-long hiatus in calcification. Another coral still containing tissue, remains dormant after eight months, showing no signs of renewed calcification. Finally, there are many dead *Porites* where macro-algae has resorbed parts of the former coral tissue. Studies are continuing using these diagnostic skeletal fingerprints of coral bleaching to ascertain whether bleaching has occurred in the past, or whether this is a recent phenomenon due to global warming.

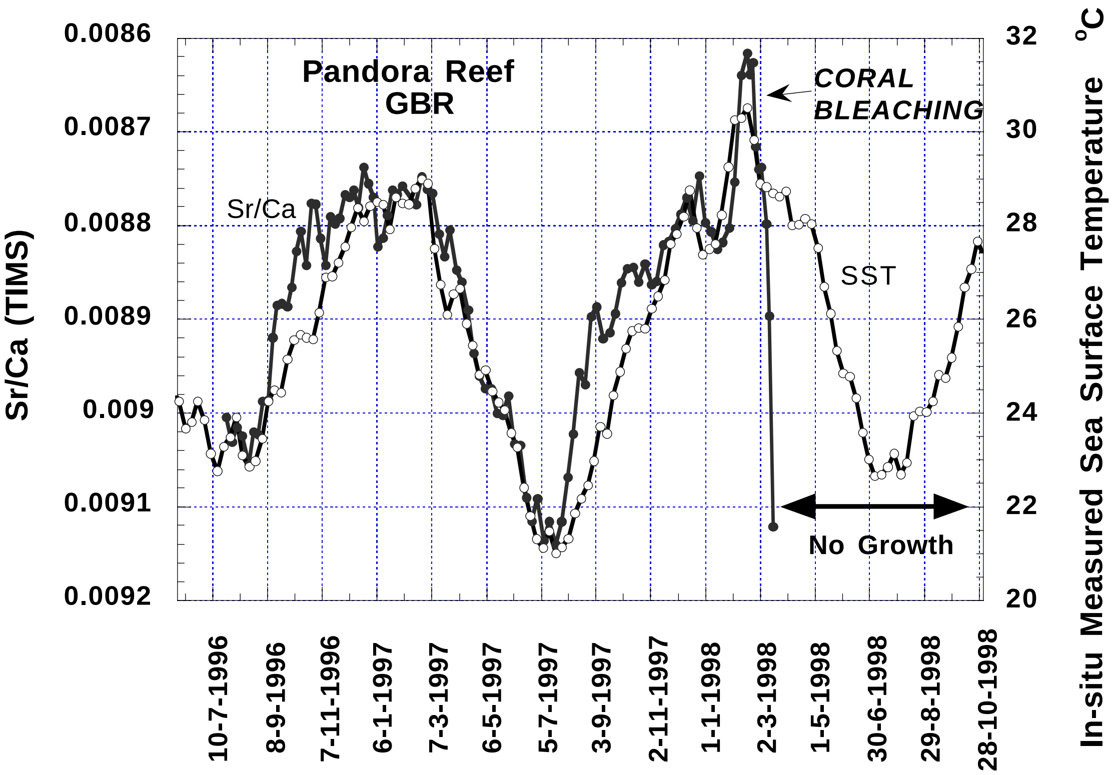

Figure 1: Plot of Sr/Ca ratios measured in Porites coral versus the in-situ measured sea surface temperature (SST). Coral bleaching occurred when temperatures exceeded 30 ^{o}C and is then marked by a rapid increase in Sr/Ca ratios.

[2] Geography Department, University of California, Berkeley, USA

Ba/Ca in corals of the inner Great Barrier Reef as a proxy for river discharge, regional rainfall and sediment load

C. Alibert, M.T. McCulloch, S.J. Fallon, E. Hendy and L. Kinsley

A 10 year Ba/Ca record has been obtained by laser ablation ICP-MS for a *Porites* coral from Pandora Reef, that has been growing under the influence of freshwater plumes. During the floods of the Burdekin River, the freshwater plume stretches several hundreds of kilometres northward, being carried by the alongshore current. The Burdekin River has a "dry" catchment of ~129,600 km^2 which extends between the latitudes 24°S and 18°S. Floods occur in summer in the wake of tropical depressions associated with the monsoon and/or tropical cyclones. This short coral record shows the double potential of Ba/Ca for reconstructing the discharge history of the Burdekin River as well as monitoring changes in the suspended sediment load following European settlement and development of agricultural and pastoral industries.

Ba is incorporated in the coral skeleton in proportion to its ratio to Ca in seawater (D $\approx$ 1.2) as shown in Figure 2 (top) by a "background" Ba/Ca ~4x10^{-6} mol/mol. The terrestrial Ba input is recorded in the coral skeleton as transient Ba/Ca peaks, a week or two after the maximum flood discharge. The enrichment in Ba of the plume waters, relative to seawater, reflects desorption from suspended sediments along the salinity gradient near the river mouth, in addition to leaching of soils and sediments in the upper catchment region (river Ba soluble pool).

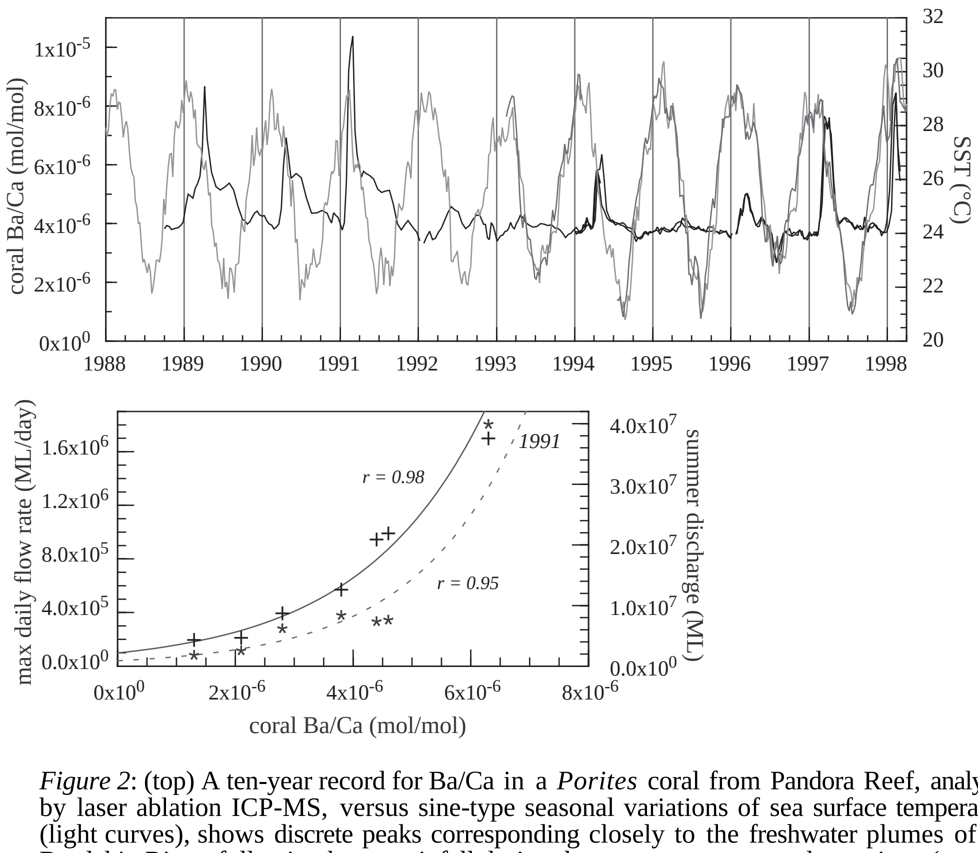

Figure 2: (top) A ten-year record for Ba/Ca in a *Porites* coral from Pandora Reef, analysed by laser ablation ICP-MS, versus sine-type seasonal variations of sea surface temperature (light curves), shows discrete peaks corresponding closely to the freshwater plumes of the Burdekin River, following heavy rainfall during the summer monsoon depressions (e.g., in Feb 1991) and/or tropical cyclones (e.g., TC Aivu in Apr 1989 or TC Justin in Mar 1997). (bottom) The best transfer function between the Burdekin River discharge, either as maximum daily flow rate at the time of the flood (crosses) or as cumulative summer discharge (stars), and coral Ba/Ca is exponential (least-square fit). This reflects the "saturation" in sediment load of the river water during the heaviest rainfall events.

The transfer function between coral Ba/Ca and river discharge is inferred to bear some similarities with the sediment load/discharge relationship. Figure 2 (bottom), based only on seven flood events, suggests that an exponential function provides the best fit between measured coral Ba/Ca and river discharge. Due to its extensive catchment, the Burdekin River discharge is also well correlated with rainfall (r = 0.76 with inland precipitation between 17.5°S and 25°S, r = 0.69 with Townsville rainfall, both significant above the 99.9% confidence level). It is therefore anticipated that the instrumental precipitation record, available back to 1913, could be extended back into the seventeenth century, using a collection of long cores collected by the Australian Institute of Marine Science .

Environmental signals from rare earth element abundances in coastal corals from the Great Barrier Reef

T.D. Wyndham and M.T. McCulloch

Corals incorporate rare earth elements (REEs) into their calcium carbonate skeleton in proportions that closely reflect the composition of the surrounding seawater. Long-lived *Porites* corals therefore provide a continuous proxy record of REEs seawater chemistry for the past 200-300 years. Using laser ablation ICP-MS, we have analysed REEs in cores from two Great Barrier Reef coastal corals from Pandora and Havannah Reefs. Two chemical signals appear to show sensitivity to geochemical processes: the ratio of the actual Ce concentration to that estimated by interpolation between the adjacent elements in the REE pattern (Ce anomaly), and mass dependent REE fractionation (the slope of the REE pattern). These signals were reproduced at both sample sites and show consistent behaviour over time. Neither of the signals are observed at mid-shelf Davies Reef, indicating that they result from coastal processes.

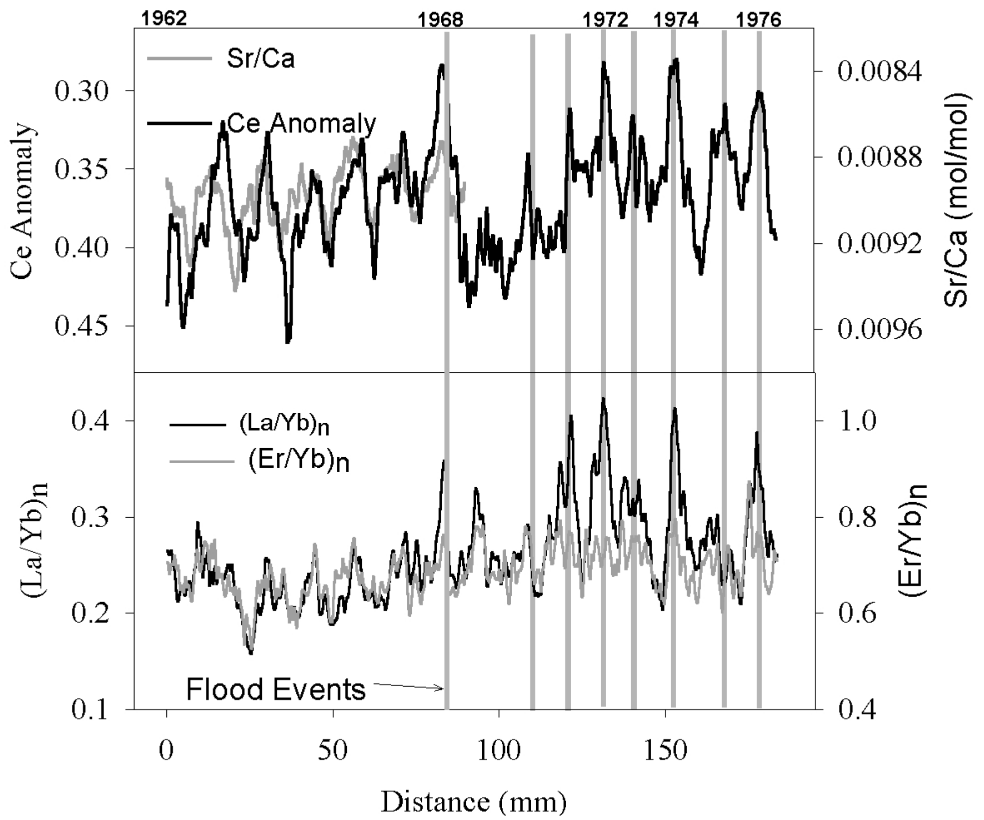

Figure 3: The Ce anomaly, $(La/Yb)_n$ and $(Er/Yb)_n$ ratios recorded in a *Porites* coral from Havannah Reef. The period of growth represented in this sample is from 1962 to 1977 and incorporates a period of prolonged drought from 1962 to 1968 (0 to 80mm) and a period of more frequent flooding from 1968 to 1977 (80 to 185mm).

Figure 3 shows the Ce anomaly recorded at Havannah Reef for the section of skeleton corresponding to growth between 1962 and 1977. The section from 0 to 80 mm is a period prolonged dry conditions. Unperturbed by flood events, the Ce anomaly approximates the seasonal cycle indicated by the Sr/Ca ratio. The section from 80 to 185 mm is affected by numerous significant flood events as indicated. Where the coral is affected by flood events, the Ce anomaly displays more negative peaks (<0.32). The normal seasonal cycle is attributed to the increased abundance of Ce oxidising bacteria in summer compared to winter. The peaks during flood events are attributed to increased abundance of Ce oxidising bacteria within the nutrient rich, biologically active flood plume. The increased abundance of Ce oxidising bacteria results in an increase in the rate of removal of soluble Ce(III) by oxidation to insoluble Ce(IV) and thus produces an enhanced negative Ce anomaly.

Two values that can be used to describe REE fractionation are the shale normalised $(La/Yb)_n$ and the $(Er/Yb)_n$ ratios. The $(La/Yb)_n$ and $(Er/Yb)_n$ ratios (Figure 3) correlate strongly in the section from 0 to 80 mm where the effects of flood events are not present. During this period, the changes in these values approximate a seasonal signal and also correlate strongly with Mn concentration. The section from 80 to 185 mm shows that the $(La/Yb)_n$ ratio is sensitive to flood events, and displays significantly different behaviour compared to $(Er/Yb)_n$ during these events. The differences in the behaviour of $(La/Yb)_n$ and $(Er/Yb)_n$ suggests two mechanisms of REE fractionation. We propose that light REE enrichment observed during flood events is caused by desorption from light REE enriched sediments carried by the flood plume. The seasonal cycle on the other hand is attributed to light enriched REE, sourced from the photoreductive dissolution of Mn oxides, which increases in summer with increased solar radiation. This investigation suggests that REE in corals are sensitive to a number of geochemical signals in seawater and have significant potential as environmental indicators.

Reconstructing seawater temperatures from the Great Barrier Reef using Coralline Sponges

S.J. Fallon and M.T. McCulloch

Coralline sponges have been proposed as a new source of tropical paleoclimatic information. Profiles of $\delta^{13}C$ in coralline sponges have documented (better and more accurately than in corals) the atmospheric increase of ^{12}C associated with increased fossil fuel consumption. Due to their very slow growth rates (~0.2 mm per year) sponges are better suited to recording and providing long-term environmental information rather than annual information. These sponges appear to smooth the record stored in their skeleton by adding secondary aragonite near the base of the living tissue layer. This smoothing limits their use as annual environmental recorders but still enables their use for decadal or longer environmental fluctuations. Smoothed records of Sr/Ca from three sponges collected from the Great Barrier Reef suggest that these sponges are able to capture five year, and longer seawater temperature anomalies over the past 50-200 years (Figure 4). This interdecadal response is very important to climate models and shows up in various coral and other climate proxy data.

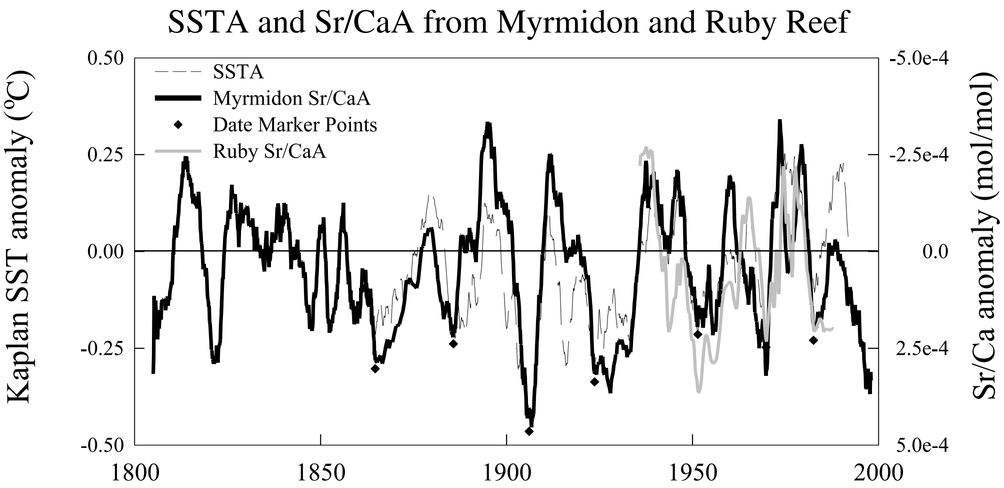

Figure 4: Kaplan sea surface temperature anomaly (SSTA) and Sr/Ca anomaly from Myrmidon and Ruby Reef sponge samples. Myrmidon reef has a correlation coefficient of –0.67, Ruby Reef sample has a correlation of –0.65.

The data in Figure 4 suggest that the Sr/Ca ratio in sponges varies by ~0.7-0.9 mmol/mol per ºC. This is 7-12 times larger than coral Sr/Ca, which is ~0.07 mmol/mol ΔSr/Ca per ºC. If this relationship holds up, then less precise methods (e.g. laser ablation-ICP-MS) and not necessarily TIMS could be used for the reconstruction of sea surface temperature from sponges with a resolution in the order of 0.05ºC. However, care is still needed in interpreting Sr/Ca data as sponges correlate best with temperature anomalies rather than absolute temperatures.

Evidence of mid-Holocene cooling of the tropical Western Pacific from Sr/Ca ratios of corals from the central Great Barrier Reef.

J.F. Marshall, D.P. Burrows[3] and M.T. McCulloch.

A number of small cores of *Porites* sp., recovered from two holes drilled on Myrmidon and Stanley Reefs in the central Great Barrier Reef have been analysed for Sr/Ca. Corals from Myrmidon Reef give TIMS U-series ages of 7,600-8,000 years, while two corals from Stanley Reef give ages of 6,200-6,350 years. Sea surface temperatures (SSTs) for these corals were derived from their Sr/Ca ratios by using the calibrations determined for the modern corals from both reefs. Sr/Ca derived SSTs for the top core at Myrmidon Reef show that each summer maximum is greater than 30ºC over the entire 9 years of measurement (Figure 5). They exceed the threshold temperature for bleaching for modern corals from the region. Another coral shows SSTs that are several degrees cooler than present (Figure 5). In the latter example the summer maxima are considerably lower than the modern instrumental SST. Two of the four cores show SSTs that are much the same as modern values. The two cores from Stanley Reef also show differences between each other. While both cores show similar maximum SSTs, which are about 2ºC cooler than the modern record, the average winter minimum for one is 19.4ºC, while for the other it is 21.6ºC. Unusually, the Myrmidon Reef cores show fluorescent bands; these are not present in modern corals from that reef as it is some 150 km from the nearest river. Stable isotope results verify that the fluorescence is not a result of increased river discharge to the outer shelf during the early Holocene. However, increased levels of barium in the Holocene corals suggest that upwelling, which does produce fluorescence, was more frequent and intense along the edge of the continental shelf in this region at this time.

[3] Maunsell and Partners, Adelaide, South Australia

There may be several possible explanations for the apparent variability in SSTs at Myrmidon and Stanley Reefs. While the data indicates rapidly changing environmental conditions at the end of the deglaciation, it is unlikely that they would occur over the small time span represented by the corals. For example, the warm temperatures recorded by the top core from Myrmidon appear to be too high. The differences could be attributed to the use of calibrations which were derived from modern corals.

With these limitations in mind, estimates of Holocene Sr/Ca derived SSTs from this study have been combined with previous Sr/Ca derived estimates from the region. The combined data from the southwest Pacific and eastern Indian Oceans shows a consistent pattern of rising SSTs with values of -6ºC lower than present from about 10,000 calendar years to about modern values by about 8,000 years (Figure 5). However, by 7,200 years the temperature had fallen once again to between 2 to 4ºC below modern temperatures. The results from Stanley Reef, Huon Peninsula and Ningaloo Reef suggest that average temperatures remained cooler than present until about 5,000 years, after which they rose sharply to modern values by 4000 years. The previous SST estimate from Orpheus Reef of +1ºC has been lowered to -1.8ºC on the basis of revised Sr/Ca vs SST calibrations for that reef and others from the same area.

There is evidence of a relationship between the mid-Holocene cooling in the western Pacific and the change in frequency of El Niño around about 5,000 years ago. While the mid-Holocene was a time of generally warmer or milder conditions, in the western Pacific it was slightly cooler than today because of a more equal distribution of heat across the equatorial Pacific Ocean due too relaxation of the trade winds and lower frequency of El Niño events.

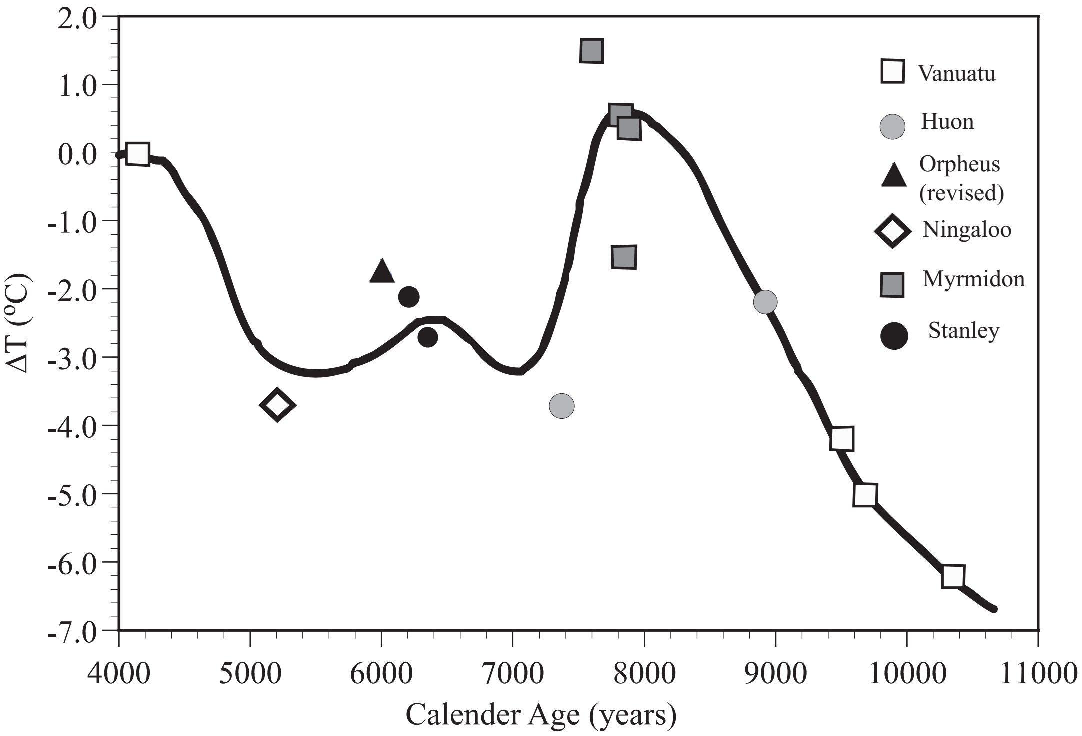

Figure 5. Estimated palaeo sea surface temperatures for the early to mid-Holocene for the tropical western Pacific Ocean.

Terrestrial Palaeotemperature estimates over the last 125,000 years from Australian and New Zealand speleothem records

P.C. Marianelli and T.T. Barrows

Stable oxygen isotopic variations in speleothem calcite have been extensively investigated for proxy palaeoclimatic data, largely because they can be reliably dated beyond the limit of radiocarbon (^{14}C) dating, using the $^{230}Th/^{234}U$ method. They can be sampled at high resolution and are common in mid to low latitudes, where well-dated, continuous terrestrial records are rare. In the Australian region, fluctuations in stable oxygen isotopic composition of their calcite have been interpreted as reflecting changes in temperature, water balance, and regional atmospheric circulation. These types of records are essential for resolving such questions as the magnitude of cooling at the land surface during the last glacial maximum, the apparent discrepancy between temperature reconstructions for the oceans, and the much larger cooling inferred for the continents.

While speleothems can potentially provide well-dated, continuous terrestrial temperature records for mid latitudes, the derivation of quantitative temperature estimates has proven to be problematic because their isotopic composition is partly dependent on the isotopic composition of meteoric waters at the time of formation. The most common approach, based on the formulation of palaeotemperature equations by incorporation of a simplified model for temporal changes in the isotopic composition of meteoric waters into the calcite-water fractionation equation, has so far met with limited success.

We used the modern isotopic composition of precipitation data from the Australian region to evaluate the assumptions on which such formulations are based. Using the modern relationships, we formulated an expression which was evaluated at sites of known modern calcite composition before being applied to speleothem records of Australia and New Zealand spanning the last 125,000 years. We show that once long term changes in sea surface temperatures of the inferred moisture source region are taken into account, a relative temperature record can be obtained from mid-latitude speleothem $\delta^{18}O$ records in the Australian region. The records appear to represent a regional rather than local signal, controlled by regionally averaged parameters. Both the pattern and the amplitude of calculated temperature variations are consistent with the available independent regional records from the Southern Hemisphere.

Sources and delivery of suspended sediment and phosphorus to Australian rivers

C.E. Martin, C. Wilson,[4] P. Wallbrink,[5] R. Oliver[6] and D. Sinclair[7]

Sedimentation in streams and rivers draining agricultural land has resulted in severe environmental degradation of Australian river systems. Eutrophication is a major associated issue, and the persistent occurrence of algal blooms has been linked with excess available phosporus. The total amount of phosporus in these systems has been shown to be dominated by the sediment bound load derived from erosion of diffuse sources, although fertiliser phosporus has also been implicated. The major diffuse sources of sediment include surface erosion from cultivated, pasture and steep forested land as well as subsoil erosion from the significant number of channels and gullies present within these systems.

We have determined the relative contributions of both sediment and sediment bound phosporus from these different landuses and erosion sources in two contrasting catchments: the

[4] Los Alamos National Laboratory, Los Alamos, USA
[5] Environmental Hydrology, CSIRO Land and Water, Canberra
[6] Murray-Darling Freshwater Research Centre, Albury, New South Wales
[7] Environment Division, ANSTO, Menai, New South Wales

Bundella Creek catchment (8,700 ha) in the Liverpool Plains of New South Wales and the Berner Creek catchment (1069 ha) in tropical Queensland. Overall there are important similarities and differences in the delivery of sediment and phosporus from the temperate and tropical systems. Subsoil was found to dominate sediment and phosporus delivery (~60%) at the catchment scale in temperate Bundella creek. However, due to high phosporus concentrations in surface soils, there is a significant contribution of surface derived phosporus from catchment surfaces at the land use/farm scale. On the other hand, surface soil erosion dominated the catchment scale flux of phosporus in the tropics (~70%). This situation was very much influenced by the high yield and phosporus concentrations in runoff from cultivated areas. For both geographic regions, the relative yields per unit area of sediment and phosporus from cultivated lands was many times higher than from uncultivated lands. However, the overall sediment and phosporus flux from cultivated lands was exceeded by that from forested areas in the temperate case because of its larger surface area and higher concentrations of phosporus. There was little overall contribution of sediment or phosporus from surface erosion of pastureland areas in either region.

A variety of geochemical methods are used to show that fertiliser phosporus is transported off land surfaces with sediments in both regions and can then impact on offsite phosporus concentrations. For example, some 50% of the phosporus in sediments outflowing from cultivated regions in the tropical Berner Creek was found to be of fertiliser origin and was a significant factor in the overall contribution of P(~42%) at the catchment scale. In contrast, fertiliser phosporus only contributed some 3% to total phosporus in runoff from cultivated lands in temperate Bundella Creek. The difference between the two was attributed to the method by which the fertiliser was applied. In the tropics, it is applied to the surface, from where it is easily removed by surface erosion with particulates, whereas in Bundella Creek, it is applied below the surface at about 10 cm depth. The overall contribution of fertiliser phosporus at the catchment scale was less important (~10%) but found to be highly variable.

The contribution of fertiliser phosporus to soluble reactive phosporus was considerable (~70%) in runoff from cultivated lands in Bundella Creek and less important from pastoral areas (~19%). This is important at the land use scale. Fertiliser phosporus was found to contribute ~10% to the total soluble reactive phosporus in waters at the catchment scale. However, there was no formal gauging of the event size, duration or timing of the flows from which these data were obtained and so we have no formal knowledge of total event or annual loads. Thus, we attribute some of the variability in the fertiliser phosporus and total soluble reactive phosporus concentrations within and between land uses to timing and volume of rainfall events within the catchment.

We created a topographic model to independently predict the contributions of sediment and phosporus from these different sources. The strength of the model was its ability to characterize not only fluxes of material from surface erosion, but also that from subsoil channel and gully erosion processes. We found that the model predictions of fluxes of sediment and phosporus from both these systems were consistent with those from the tracers within uncertainties.

The ability of these tracers to determine the source of bioavailable phosporus was investigated in a pilot project. The trace elements are strongly taken up into *Anabena* ("blue-green" algae) as determined in a laboratory culturing study. For urban Lake Kialla in Shepparton, Victoria, the relations between biota and the dissolved and particulate load support the suggestion that these tracers can be used to monitor the source of the bioavailable fraction in the lake.

Revised open system U-series/ESR age calculations for teeth from Stratum C at the Hoxnian-Interglacial type locality

Rainer Grün and Henry P. Schwarcz[8]

The interglacial lake sediments at Hoxne represent the British type locality for the Hoxnian Interglaciation. Sedimentological and palynological considerations lead to the conclusion that the deposition of the Hoxnian interglacial lake sediments immediately followed Anglian glacio-lacustrine sediments. Shackleton, thus, associated the Hoxnian with oxygen isotope stage (OIS) 11, because the Anglian, being the major glaciation of the Pleistocene, could only be correlated with OIS 12. Independent stratigraphical, palynological and other dating evidence supports this age assignment. Earlier ESR age estimates on teeth from Stratum C, however, corresponded to OIS 9. Samples were measured in 1986. At the time no appropriate methods for error calculation had been implemented. However there have since been numerous other improvements in the ESR dating method.

For age re-assessment we have used only samples 145 and 293, because these were analysed by both Electron Spin Resonance (ESR) and U-series methods. Apart from the combined U-series/ESR (US-ESR) uptake modelling, we have also used an alternative model, (closed system U-series)-ESR (CSUS-ESR). The differences between these U-uptake models are shown in Figure 6A. It is important to know in this context that the CSUS-ESR model provides the oldest possible ages that can be modelled from ESR and U-series analyses. The best age estimate for Stratum C can be derived from the weighted means of samples 145 and 293: 404^{+33}_{-42} (US-ESR) and 437±38 ka (CSUS-ESR).

The closely similar U-series isotopic ratios in the constituents of the two teeth indicate that the uranium uptake history of these components is more or less the same. Rather than continuous U-uptake since burial, as used for the US-ESR open system model, it is more likely that a relatively recent environmental event (< 200 ka) led to ground water mobilisation and associated U-uptake. As such, the correct ages for samples 145 and 293 may be somewhat older than calculated by the US-ESR model. Considering that the extreme CSUS-ESR model yields a mean age that is only 8% older than the corresponding US-ESR result, the correct open system age for Stratum C should be within the error envelope provided by the US-ESR age estimate.

The mean CSUS-ESR age indicates a possible overlap with OIS 13 (Figure 6B). However, since there seems to be consensus that the Anglian Tills, which underlie the Hoxnian lake deposits, can clearly be correlated with OIS 12, together with the fact that the CSUS-ESR model presents the extreme end for modelling, a correlation with OIS 13 or 12 can be ruled out. If Stratum C indicates the climatic transition from a late interglacial to an early glacial climate, the re-calculated US-ESR age estimates would clearly relate this to the transition of OIS 11 to OIS 10 at around 390 ka. The re-calculated data do not support the earlier proposition that Stratum C may represent sediments from a subsequent interglaciation.

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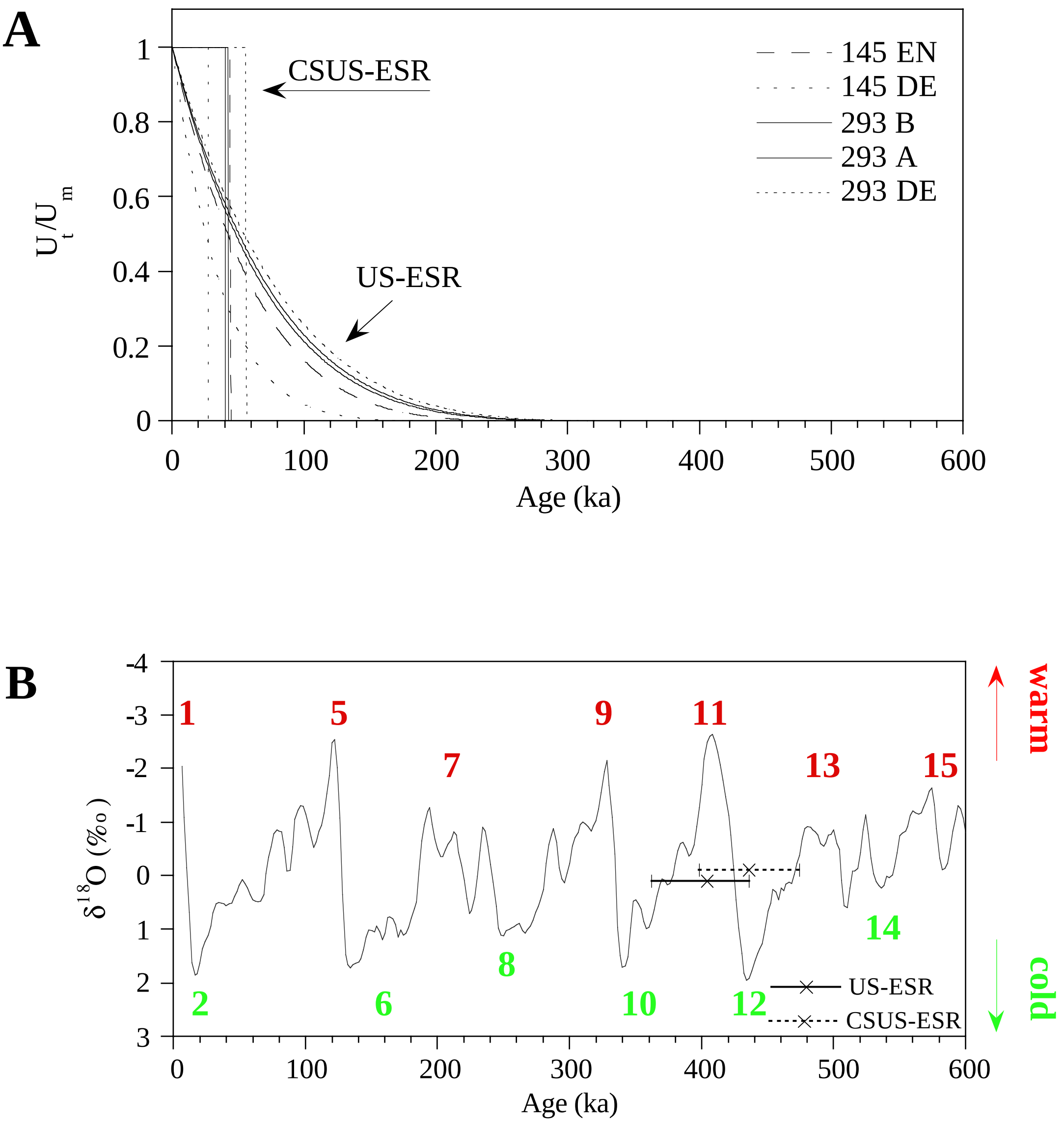

Figure 6:(A) U-uptake models used for age calculation. U_t = uranium concentration at the given age t; U_m = measured, present day U-concentration. The US-ESR model assumes a continuous U-uptake since the sample was buried. The CSUS-ESR model assumes a short-time U-uptake event at the apparent U-series age. The latter model is an extreme that provides the maximum open system age. For comparison with Figure 6B, the U_t/U_m ratios are shown here as a function of age rather than time.

(B) Weighted mean ages for Stratum C, compared to the generalised oxygen isotope curve. The fact that the underlying Anglian Tills were firmly correlated with OIS 12, allow only correlation with OIS 11. If Stratum C indicates the climatic transition from a late interglacial to an early glacial climate, the re-calculated US-ESR age estimates would clearly relate this to the transition of OIS 11 to OIS 10 at around 390,000 years ago.

Optical dating of river terrace sediments from Kanto plains, Japan

N.A. Spooner, D.G. Questiaux, K. Tanaka [9], R. Hataya [9], Y. Saito [10] and T. Hashimoto [11]

A pilot study in collaboration with the Central Research Institute of the Electric Power Industry has successfully tested optical dating as a means for age determination of river terrace formation in Japan over the last 100,000 years. Project motivation was the eventual production of an uplift distribution map for the future (next 100,000 years) uplift/subsidence of the inland areas of the Japanese Islands, to assist in the selection of the safe site for a deep underground nuclear waste storage facility for high-level radioactive waste generated in nuclear power plants in Japan. The tectonic instability (uplift/subsidence) of the Japanese Islands demands special care in the selection of the site for the waste disposal facility, with uplift being of great concern as it can result in exposure of the waste to erosive processes near or at the surface.

The facility is to be established inland. However, all reliable uplift data are coastal, based on marine terrace isotope dates. In this study we applied optical dating to a series of sediment samples collected from inland river terraces in the Kyowa and Kuji areas of the Kanto Plain, to test the feasibility of extending uplift data to inland areas. The study sites were chosen as having chronological control from ^{14}C, stratigraphy and tephrachronology. Quartz grains were separated from the sediment samples for analysis by the multiple-grain “Australian-slide” method in the first instance.

Optically stimulated luminescence results from the Kuji area Yamagata and Iwaibashi sites agreed well with the age of the Nakadaicha tephra (55,000-60,000 years) at the former location, and with the ^{14}C age of 1720 ± 800 years at the latter. At the Kyowa area site, a gravel pit, optical ages in the range of 50,000-80,000 years were obtained from the lower units of the sequence, in good accord with the alternative evidence. However, four samples in the upper section showed excessively “scattered” optically stimulated luminescence growth curves and gave age inversions, believed to result from bioturbation and substantial mixing by farming activities. The single aliquot regenerative method (SAR) was then applied to individual 350-435 micron quartz grains from these samples and confirmed that a range of grain ages were present. The age of the youngest populations from each sample were in accord both with expectation and with the optical ages measured for the underlying units.

It is concluded that optical dating is suitable for determining uplift and subsidence rates of inland river terrace sediments, and that the method can identify and correctly date mixed age sediments resulting from human activities such as ploughing, or bioturbation.

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