Submission No: 22
Date Received: 29-5-08
Secretary: [signature]

Australasian Quaternary Association's submission to the "Inquiry into climate change and environmental impacts on coastal communities"

Author
Dr Craig Sloss (contact person): Secretary of the Australasian Quaternary Association
Dr Patrick Moss (President of the AQUA)
Professor Colin Murray Wallace
Adjunct Professor Henk Heijnis
(On behalf of the AQUA executive)

Organisation
Australasian Quaternary Association

Type of organisation (e.g. industry, government, not for profit, research provider)
Professional association, not for profit, voluntary.

Address
For the purpose of this submission the organisation's contact address is:
Dr Craig Sloss
Lecture in Geosciences
School of Natural Resource Sciences
Queensland University of Technology
GPO Box 2434
BRISBANE Q 4001
ph: 61 7 3138 82610
fax: 61 7 3138 1535
email: c.sloss@qut.edu.au

Declaration of Interest
Australasian Quaternary Association (AQUA) has an interest in the subject of the inquiry but does not have affiliations with the inquiry. In providing this information none of the members of AQUA stand to gain individually. The submission is made with the desire to provide the inquiry with a framework in which to assess the impact of sea level rise on coastal environments. The views given are those of members of the group, but not necessarily of all members and not the views of the organisations that employ them. I am making this submission on behalf of the AQUA executive.

Australasian Quaternary Association's submission to the "Inquiry into climate change and environmental impacts on coastal communities"

Introduction and Purpose of the Submission:

The United Nations-sponsored Intergovernmental Panel on Climate Change (IPCC – Fourth Assessment) reported there has been a temperature increase of 0.4 – 0.7°C since 1950 and that the average temperature is likely to increase by between 1.4 and 5.8°C by 2100. This climate change is likely to impact ecosystems, agriculture, and the spread of disease. The IPCC also warns that one of the most dangerous impacts of global warming is a dramatic rise in sea level and an increase in the severity and frequency of storms and coastal flooding. Over the last century global sea level has risen by approximately 10 – 20 cm and is estimated that it may rise between 9 and 88 cm by 2100. In the Australian region we have already seen a rise of 1.2 mm/yr between 1920 and 2000 (Church et al., 2004). However, the worst case scenario is that sea level may rise by as much as 6 – 12 m if global warming goes on unabated and we see a collapse of the great ice sheets (Stern, 2006; ICPP, 2007). With 80% of Australia's population living in coastal zones such rises in sea level will result in infrastructural and ecological destruction as well as significant loss of natural resources.

To truly grasp the implications that sea level rise can have on coastal environments it is fundamental to have an understating of how sea levels have changed in the past. It is important to understand that sea level is not static but that it has undergone numerous rises and falls throughout geological history. For example, there have been 30 - 40 oscillations in sea level in excess of 120 m over the Quaternary period (last 2 Million years). Such oscillations have had a significant influence on the sedimentation and geomorphic change in the coastal zone over the longer term record. Most significant is the last full interglacial/glacial cycle (last 125,000 years) where dramatic and relatively rapid fluctuations in sea level have shaped our coast as we know it today. From the geological record it is evident that there is an intrinsic link between sea level and coastal environments. However, we are now seeing a period of sea level change that could be potentially more rapid than at any time in our geological past. Understanding how coastal environments responded to sea level change (and past extreme events such as tsunami and storm surge) is fundamental for development of any adaption or mitigation programs aimed at dealing with the impact of climate change.

Also fundamental to the development of any adaption or mitigation programs aimed at dealing with the impact of climate change on coastal communities is an understanding that globally past histories of sea level change have not been the same. In fact, there are significant variations between different regions. This will also be the case for future changes in sea level. Accordingly, we cannot rely on "global estimates" and "global responses" or research conducted overseas, but must conduct our own national and regional research programs into past sea level histories, as well as regional scale adaption and mitigation strategies. It is this understanding of how and why sea level changes occur, and how such changes will affect coastal communities on a **regional scale** that is of utmost importance. With a national and regional understanding of the history of sea level change it is possible to more accurately model potential impact of future fluctuations in sea level and the relationship between sea level and extreme events.

Who we are:

The Australasian Quaternary Association (AQUA; http://www.aqua.org.au/) is an organisation comprising over 200 academics, researchers and post-graduate students that aim to promote the discussion and dissemination of information and ideas within the various disciplines and interests relating to Quaternary studies. Quaternary studies are those that relate to the Quaternary Period which is the most recent subdivision of geological time covering the last 2 million years up to the present day. This has been a period of extraordinary changes in global environment as well as the period during which much of hominid evolution and migration took place, and humans began to modify their environment. The primary emphasis of AQUA is the promotion of research and teaching activities in all areas of Quaternary studies and promotion of scientific communication within the Australasian region in relation to Quaternary studies. This is accomplished through a strong inter-disciplinary approach that provides a breadth of expertise across the disciplines of geology, geomorphology, climatology, biogeography, ecology and archaeology. Accordingly, AQUA provides workshops, conferences and field meetings that aim to develop a holistic view on Quaternary studies, including long and short-term climate change. In summary the objectives of Australasian Quaternary Association are to:

- provide a forum in Australasian region for the interchange of multi-disciplinary knowledge and skills in all fields relating to Quaternary studies;
- promote the dissemination of information and ideas relating to the Quaternary period;
- arrange or sponsor meetings, conferences and symposia on subjects consistent with the objectives of the Association;
- promote the publication of technical information in the disciplines of Quaternary Studies;
- encourage the interchange of those engaged in Quaternary Studies within Australia and overseas; and
- encourage education, training, research and development in Quaternary Studies.

As a national multi-disciplinary organisation AQUA can assist in coordinating and collating the various aspects of research that are investigating how past climate change and extreme events have impacted on coastal environments. As a national organisation we can also provide a means for the government to communicate with the scientific community and facilitate coordinated efforts for future research in to climate and sea level change.

Accordingly, it is the purpose of the submission from the Australasian Quaternary Association to provide the inquiry with:

- the fundamental background into long-term fluctuations in sea level;
- an understanding of the causes of natural variations in sea level;
- an understanding of the causes of natural hazards such as storm surge and tsunami;
- an understanding of the how the current trends in sea level change differ from those observed in the geological record;
- facilitate, coordinate and report on research that is developing an understanding of how such changes in sea level (and the impact of extreme events) effect coastal environments on national and regional scales;
- a database of researchers investigating the impact of climate change and extreme events in coastal environments; and
- a means for greater communication between the government and scientific community who are currently undertaking research into the impacts of climate change.

To whom it may concern,

Please find enclosed a signed hard copy of the AQUA submission to the "*Inquiry into climate change and environmental impacts on coastal communities*"

Thank you and please do not hesitate to contact me if you require any further information.

C. S

Dr Craig Sloss
Lecturer in Geoscience
School of Natural Resource Sciences
Queensland University of Technology
GPO Box 2434
BRISBANE Q 4001
ph: 61 7 3138 2610
fax: 61 7 3138 1535
email: c.sloss@qut.edu.au

Secretary for the Australasian Quaternary Association (AQUA)
email: Secretary@aqua.org.au

Summary: Long-term climate change

Craig R. Sloss[a] and Colin V. Murray-Wallace[b].

[a]School of Natural Resources, Queensland University of Technology, GPO Box 2434
Brisbane 4001, Queensland, Australia
[b]School of Earth and Environmental Sciences, University of Wollongong, Wollongong, NSW 2522, Australia

THE QUATERNARY

The Quaternary is the most recent subdivision of geological time (the Quaternary Period) which covers approximately the last 2 million years up to the present day. The Quaternary Period can be subdivided into two epochs; the Pleistocene (2 Ma to 10 years ago) and the Holocene (10 years ago to the present day). The Quaternary Period has been one of extraordinary changes in the global environment as well as being the period during which much of hominid evolution and migration took place. During the Quaternary there was a series of step-like, sudden, changes in climatic conditions between cool phases with expanding polar ice caps (glacials i.e. ice ages) and warm phases with a significant contraction of polar ice caps (interglacials). The alternating expansion and contraction of the great ice sheets resulted in significant fluctuations of sea level in excess of 130 m.

The glacial/interglacial cycle

During the Quaternary there were numerous rhythmic alterations from cold to warm conditions, resulting in the conventional subdivision of the Quaternary into glacial and interglacial stages, with further subdivisions into stadial and interstadial (Lowe and Walker, 1984; Mörner, 1996; Pirazzoli, 1996; Lambeck and Chappell, 2001). It is now acknowledged that there have been between 30 and 40 glacial/interglacial cycles over the past 2 million years resulting in global fluctuations of continental ice accumulation and global sea level (Imbrie *et al.*, 1984; Lowe and Walker, 1984; Peltier, 1999). These repeated changes in climate have resulted in a complex record of sedimentological, biological and geomorphological features that provides the clues and data that can be used to reconstruct past environments.

Glacials

Glacials are major cold episodes of the Earth's history characterised by the expansion of continental ice sheets and mountain glaciers accompanied by lower global sea level. Glacial conditions and the development of large continental ice sheets occur when the Northern Hemisphere receives less summer radiation favouring the persistence of snow into summer months, leading to persistence of snow cover throughout the year. Once ice sheets are growing they create a positive feedback mechanism (i.e. self perpetuating) the result of increased reflection of solar radiation and cooling air around them. This results in an increase in snow and ice cover maintaining strong latitudinal temperature gradients. During glacial phases large quantities of ocean water are locked up in the expanding ice caps resulting in a lowering of global sea levels of up to 130 m.

Stadials

These are cold phases that are shorter than glacial phases and are characterised by localised expansion of ice. During stadials temperature generaly decline at least halfway between the warmth of the climatic optimum and the maximum cold of the last glaciation. This results in fluctuations of sea level in the order of 10's of meters.

Interglacials

Interglacials are warm phases of the Earth's history where temperatures in the mid- and high latitudes were close to, or higher than, the present average temperatures. During interglacials the ice caps are significantly reduced in size liberating more water into the ocean basins resulting in a rising sea level (transgression). We currently reside in one of these warm phases.

Interstadials

Interstadials are relatively short episodes of warming within a glacial phase. During interstadials temperature rises to at least halfway between the maximum cold of the last glaciation and the maximum warmth of the climatic optimum. This also results in fluctuations of sea level in the order of 10's of meters.

Forcing mechanisms for glacial/interglacial cycles

Switching between glacial and interglacial phases (and their associated stadials and Interstadials) is, in part, related to the orbital motions of the Earth (the Milankovitch cycles named after Serbian civil engineer and mathematician Milutin Milanković). In other words, as the Earth orbits around the Sun and spins around its axis several quasi-periodic variations occur. Milankovitch studied these variations and noted that the main changes were in the Earth's *eccentricity*, *obliquity*, and *precession*. Such changes in movement and orientation change the amount and location of solar radiation reaching the Earth and have a significant influence on long-term climate change (Fig. 1).

Earth's eccentricity – 100,000 year cycle

This cycle is determined by changes in the eccentricity of the Earth's orbit around the sun due to planetary gravitational influences (primarily Jupiter and Saturn). These gravitational influences result in changes in the Earth's orbit from almost circular to mildly elliptical and back again (Fig. 2; Lowe and Walker, 1984; Williams *et al.* 1998). The more elliptical the orbit results in less insolation being received at the Earth's surface and therefore less snow and ice melt. This change in eccentricity occurs approximately every 100,000 years, and when these cycles overlap with the other orbital processes (outline below) result in climate variations corresponding in a peak in global ice and has dominated climate change for the last 700,000-800,000 years.

Tilt of the Earth's axis – 41,000 year cycle

Dominant prior to, and superimposed on, the 100,000 year cycle is a series of small surges or decreases in ice volume. This cycle matches the variations in the tilt of the Earth's axis (obliquity) with respect to the plane of the Earth's orbit which varies from 21.5° to 24.5° and back over the space of 41,000 (Fig. 2; Lowe and Walker, 1984; Williams *et al.* 1998). When the obliquity increases the annual mean insolation increases in high latitudes while lower latitudes experience a reduction in insolation. This results in cooler summers and less melting of the previous winter's ice and snow, leading to glacial periods. Presently the Earth is tilted at 23.5° from its orbital plane, roughly half way between its extreme values.

Precession – 23/19 ka cycles

Another superimposed cycle was found to occur between 23 and 19 ka due to the Earth's precession. Precession is the change in the direction of the Earth's axis of rotation relative to the Sun at the time of perihelion and aphelion. In other words it is the change in the direction of tilt but the angle of tilt remains the same. This is also known as "wobble" (Fig. 1; Lowe and Walker, 1984; Williams *et al.* 1998).

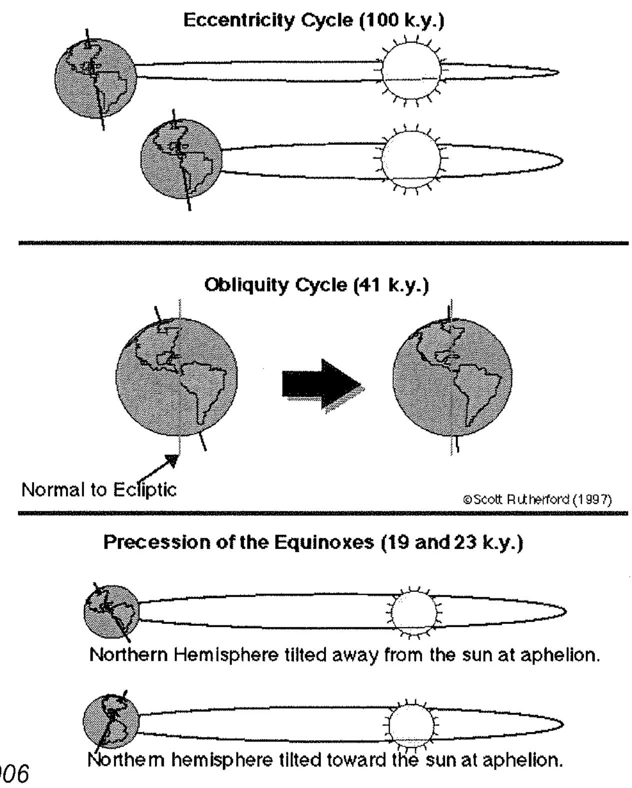

Figure 1: Orbital forcing on climate change adapted from Scott Rutherford and Terri King, School of Oceanography, URI, Narragansett, 2006

Marine isotope record and Quaternary climate change

As many marine organisms secrete carbonate shells and abstract oxygen from saltwater in the process, the oxygen isotope ratio preserved in the fossil carbonate reflects the ratio of oxygen in the saltwater at the time of secretion. There is now considerable evidence to show that $\delta^{18}O$ (ratio between $H_2{}^{16}O$ and $H_2{}^{18}O$) in ocean waters varies between glacial and interglacial cycles. The variations of $\delta^{18}O$ found in deep sea foraminifera is a result of natural fractionation of oxygen isotopes during evaporation of water from the sea surface and lighter $H_2{}^{16}O$ molecules are preferentially drawn into the atmosphere compared to the heavier $H_2{}^{18}O$. Accordingly, during glacial phases with expanding ice sheets and glaciers, large quantities of $H_2{}^{16}O$ were trapped in the accumulating ice masses, leaving the oceans enriched in $H_2{}^{18}O$ (isotopically positive). In contrast, during interglacial and interstadials periods large volumes of enriched $H_2{}^{16}O$ are liberated back into the oceans as the ice sheets melt, resulting in lighter $\delta^{18}O$ ratios (isotopically negative).

Analyses of the $\delta^{18}O$ record, preserved by deep-sea foraminifera collected from deep-ocean core from different parts of the world's oceans has verified the presence of these orbital-forcing influences on long-term climate change and the glacio-eustatic sea-level signal (Emiliani, 1955; Shackleton and Opdyke, 1973; Imbrie *et al.*, 1984; Chappell and Shackleton, 1986). This indicates that the oceans as a whole have been responding to a common climatic forcing mechanism (i.e. the Milankovitch cycles). Accordingly, changes in the $\delta^{18}O$ isotopic record form the basis for stratigraphic division of individual profiles and the correlation of late Quaternary sea-level and climate change on a global scale (Fig. 3; Imbrie *et al.*, 1984; Chappell and Shackleton, 1986). The peaks of the $\delta^{18}O$ isotope record are given odd numbers and correspond with interglacial and interstadial sea-level highstands (warm phases with lighter $\delta^{18}O$ values). In contrast the troughs observed in the isotopic record are given even numbers and correspond with glacial and stadial sea-level lowstands (Cold phases with heavier $\delta^{18}O$ values; Fig. 2; Shackleton and Opdyke, 1973; Chappell and Shackleton, 1986; Lambeck and Chappell, 2001).

THE LAST GLACIAL-GLACIAL CYCLE

The last glacial cycle encompasses 130,000 – 17,000 years ago (Fig. 2). This period of time has been extensively studied with a diverse array of palaeo-environmental records including the oxygen isotope records from deep sea sediments, high-resolution pollen records, and lake sediments, gas profiles from ice cores as well as evidence from geomorphological and stratigraphic data. This period of Earth's history also saw a dramatic fluctuation in environmental conditions from the warm interglacial with higher than present temperatures and sea levels to the Last Glacial Maximum (LGM) with colder than present temperatures and lower than present sea levels. However, most significant in this time period (from a human perspective) is that this is the period that modern humans (anatomically and genetically) evolved. Accordingly, due to the wealth of proxy environmental data, various dating methods appropriate to this time period and the significance to the study of human evolution the last interglacial – glacial cycle has attracted multi-disciplined research including geology and geomorphology, ecology, archaeology and anthropology.

Last Interglacial (MIS 5e)

The start of the last interglacial is marked by an abrupt shift from the heavy isotopic values that characterised Marine Isotope Stage 6 (MIS 6) to lighter isotopic values that reflect glacial melting. This abrupt shift (a.k.a. Termination II) occurred approximately 130,000 years ago and provides a marker horizon defining the lower boundary of the last interglacial (Figure 3). The last interglacial has been divided into 5 oxygen Isotope sub-stages (MIS 5a – MIS 5e; *sensus lato*). However, only MIS 5e is now regarded as the true interglacial i.e. *sensus strict* (Fig. 2). Globally the MIS5e is characterised by temperatures up to 5°C warmer and sea surface temperatures as high as 4°C warmer than present temperatures. Globally Sea levels during the thermal maximum of MIS 5e have been estimated to have been up to +6 m higher than present. A comprehensive review of Last Interglacial shorelines and chronologies in the Australian region obtained using various dating methods on *in situ* mollusc shells from widespread MIS 5e marine strata has been presented by Murray-Wallace and Belperio (1991) and Murray-Wallace (1995). Results from these reviews indicated that sea-level during the Last Interglacial ranged from -2 m around the Great Barrier Reef to +32 m in northeast Tasmania and, apart from regions influenced by tectonic uplift, the most consistent datum for MIS 5e maximum sea-level was +2 m.

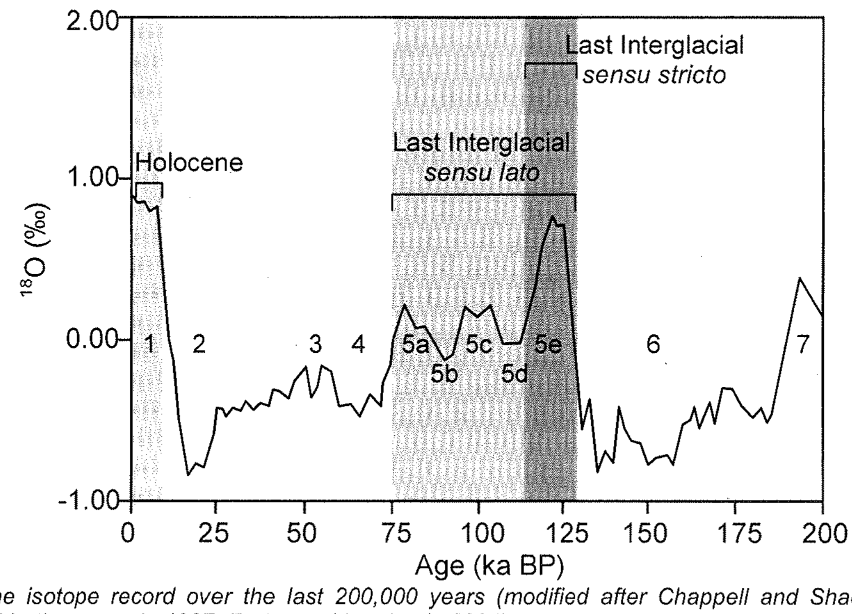

Figure 3: Marine isotope record over the last 200,000 years (modified after Chappell and Shackleton, 1986; Stearns, 1984; Martinson et al., 1987; Potter and Lambeck, 2004).

Summary of climate and sea levels following the last interglacial.

The period from the close of the last interglacial (*sensus stricto*) to the early part of the Last Glacial Maximum (LGM) was characterised by oscillating climate conditions with the positive oscillation (interstadials) and the intervening negative oscillation (stadials) corresponding to the growth of continental icesheets and fluctuations in sea-level that concentrated in a depth range of 70 to 20 m below present mean sea level. However these fluctuations are superimposed on a general decline in sea-level leading into the LGM (Fig. 2; Lambeck and Chappell, 2001; Yokoyama *et al.*, 2001; Lambeck *et al.*, 2000, 2002).

The last glacial phase (MIS 2)

Early in MIS 2 sea-level fell rapidly to between 120 and 130 m below PMSL between 20,000-22,000 years ago (Fleming *et al.*, 1998; Peliter, 2002; Lambeck *et al.*, 2000, 2002). Although there appears to be a generalised global sea-level lowstand of approximately -120 m, minor regional variations have been noted due to the shape and/or volume of oceans, redistribution of ocean waters in ocean basins, and vertical movements of coastal areas (Fleming *et al.*, 1998; Potter and Lambeck, 2004).

HOLOCENE SEA LEVEL CHANGE

The termination of the last glacial phase resulted in a global rise in sea level approximately 11,000 years ago (Martinson *et al.*, 1987). However, no single history of sea level rise can be applied in detail across regions, let alone globally. In fact, the apparent Holocene sea level records from sites around the world show great diversity in the maximum height relative to present sea level, and in the timing that these maximum levels represent. The causes for these regional variations in timing, and maximum levels reached, is a complex interaction of geomorphic and geological controls. For example, tectonism or volcanic processes, climate, sediment discharge and/or compaction, tidal changes, local geoid perturbations and isostatic warping. Regionally and even locally these factors can create vertical changes in the elevation of the ground, thus offsetting or enhancing changes in sea level. These local characteristics then need to be considered in relation to predicting variations in melting histories from the continental ice loads that existed during the Last Glacial Maximum (Pirazzoli, 1996). The combination of global and local geological, geomorphological and climatic controls creates a complex and varied sea level history which makes it impossible to create one accurate global sea level curve.

Regardless of the problems associated with creating a global sea level curve, a generalised account of the most recent post-glacial marine transgression can be reconstructed that does indicates a relatively simultaneous pattern of global sea level rise following the commencement of deglacialistion at some time after 17,000 years ago (Williams *et al.* 1998). This general rise in sea level occurred rapidly, with present sea level being reached between 8,000 and 4,000 years ago.

This near simultaneous sea level rise experienced during the Holocene can be inferred from the initiation of most Holocene deltas, and in the development of Holocene coral reefs (Pirazzoli, 1996). For example, most deltaic sequences that we see today began to accumulate systematically only when the rate of river sediment input overtook the declining rate of sea level rise (Pirazzoli, 1996). Stanley and Warne (1994) reviewing 36 worldwide deltas with clearly definable basal, or near basal units, from tropical, temperate and higher latitude deltas have developed a generalised sea level history from the initiation of Holocene delta evolution. They have shown that Holocene deltaic evolution on a worldwide basis reveals that sea level rose rapidly between 18,000 and 10,000 years ago, then decelerating and approaching present levels between 6,000 and 5,000 years ago (Stanley and Warne, 1994).

Another palaeo-indicator of a generalised PMT is evident in the development of present day coral reefs that started almost everywhere during the Holocene, when the rate of sea level rise decreased. For example, at various depths offshore at sites from Barbados, the tectonically uplifted Huon Peninsula and numerous other locations from the Caribbean to the Great Barrier Reef, indicated that the initiation of coral reefs began between 10,000 and 7,000 years ago as sea level rise decelerated (Pirazzoli, 1996). Thus, Pirazzoli (1996) concluded that by 6,000 years ago most of the present deltas and coral reefs systems were in place.

However, as noted earlier there is significant regional variability due to geological, geomorphological and climatic variations. In Australia sea level stabilised about 7,000 years ago whereas in parts of the northern hemisphere sea level stabilised 3,000 – 4,000 years ago and in some areas the level has never ceased rising, albeit much more slowly. Nevertheless, rising sea level during the post-glacial marine transgression was responsible for the formation of deltaic systems, coral reefs and the flooding of river and glacial valleys to form estuaries and fiords, respectively. The most comprehensive palaeo-sea level reconstruction in the Australasin region comes from the southeast coast of Australia (Sloss *et al.*, 2007). Results from that research show that rising sea level during the most recent post-glacial marine transgression attained an elevation of -10 m by 10,000 years ago and continued to rise to -5 m by 8,500 years ago. Between 8,300 and 8,000 years ago sea-level had risen to at least 3 m below present mean sea level and inundated shallow incised valleys.

Sea-level attained its present level by 7,700 years ago and continued to rise to between 1 and 1.5 m above present levels by 7,400 years ago.

This was followed by a sea-level highstand that lasted to sometime between 3,000 and 2,000 years ago and eventually a relatively slow and smooth regression of sea-level from +1.5 m to the present level. A series of minor negative and positive oscillations in relative sea-level associated with variations in ocean topography and/or climate change during the mid- to late-Holocene appear to be superimposed over the Holocene sea-level highstand and subsequent smooth sea-level regression. These oscillations in sea-level most likely represent intertidal species adjustment to variations in coastal exposure and/or variable wave and climate conditions during the Holocene.

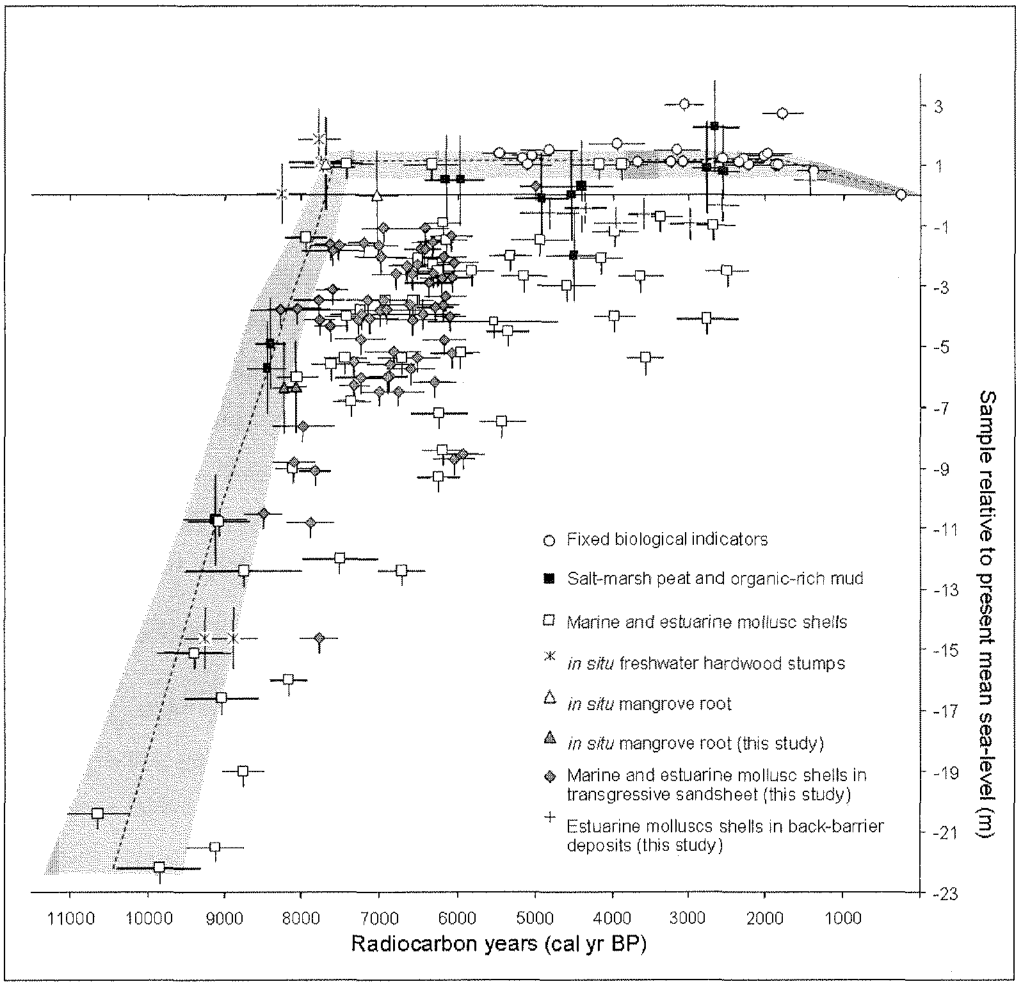

Figure 4: Revised Holocene sea-level curve for the southeast coast of Australia. The shaded area representing the envelope of relative Holocene sea-level rise based on the a synthesis of previously published data and new data obtained for this study (from Sloss et al., 2007)

Conclusion:

The climate induced sea level fluctuations during the Quaternary have had a significant influence on the sedimentation and geomorphic change in the coastal zone over the long and short term. Most significant is the last full interglacial cycle where dramatic and relatively rapid fluctuations in sea level have shaped our coast as we know it today. From the geological record it is evident that there is an intrinsic link between sea level and coastal environments. It is also evident that although the reasons that sea level change may be similar there is significant regional variability in sea level histories. We are also now seeing a period of sea level change that will be more rapid than those documented in our recent geological past, which will also be subject to significant regional variability. Accordingly, it is vital that an understanding of how coastal environments responded to sea level (and past extreme events) on national and regional scales is fundamental when dealing with any adaption or mitigation programs. Without this historic framework it is impossible to predict how future changes in sea level and extreme events will influence our coasts environments.

References

Chappell, J. and Shackleton, N.J., 1986. Oxygen isotope and sea level. *Nature,* 324: 137-140.

Church, J.A., White, N.J., Coleman, R., Lambeck, K. and Mitrovica, J.X., 2004. Estimates of the regional distribution of sea level rise over the 1950-2000 period. *Journal of Climate*, 17, 2609-2625.

Cutler, K.B., Edwards, R.L., Taylor, F.W., Cheng, H., Adkins, J., Gallup, C.D., Cutler, P.M., Burr, G.S. and Bloom, A.L., 2003. Rapid sea-level fall and deep-ocean temperature change since the last interglacial period. *Earth and Planetary Science Letters*, 206, 253-271.

Emiliani, C., 1955. Pleistocene temperatures. *Journal of Geology*, 63, 538-575.

Fleming, K., Johnston, P., Zwartz, D., Yokoyama, Y., Lambeck, K. and Chappell, J., 1998. Refining the eustatic sea-level curve since the Last Glacial Maxiumu using far- and intermediate-field sites. *Earth and Planetary Science Letters*, 163, 327-342.

Imbrie, J., Hays, J.D., Martinson, D.G., 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine 18O record. *In*: Berger, A.L., Imbrie, J., Hays, J., Kukla, G. and Saltzman, B (Eds.). Milankovitch and Climate: Understanding the Response to Astronomical Forcing. Reidel, Dordrecht, pp. 269-305.

Lambeck, K. and Chappell, J., 2001. Sea level change through the last glacial cycle. *Science*, 292, 679-686.

Lambeck, K.,Yokoyama, Y., Johnston, P. and Purcell, T., 2000. Global ice volumes at the Last Glacial Maximum. *Earth and Planetary Science Letters*, 181, 513-527.

Lambeck, K.,Yokoyama, Y., Johnston, P. and Purcell, T., 2002. Into and out of the Last Glacial Maximum: sea-level change during Oxygen Isotope Stages 3 and 2. *Quaternary Science Reviews*, 21, 343-360.

Lowe, J.J. and Walker, M.J.C., 1984. Reconstructing Quaternary Environments. 2nd Edition, Longman, London, pp. 446.

Martinson, D.G., Pisias, N.G., Hays, J.D., Imbrie, J., Moore, T.C. and Shackleton, N.J., 1987. Age dating and the orbital theory of the ice ages: Development of a high-resolution 0 to 300,000-year chronostratigraphy. *Quaternary Research*, 27, 1-29.

Mörner, N., 1996. Rapid changes in coastal sea-level. *Journal of Coastal Research*, 12, 797-800.

Murray-Wallace, C.V., 1995. Aminostratigraphy of Quaternary coastal sequences in southern Australia - an overview. *Quaternary International*, 26, 69-86.

Murray-Wallace, C.V. and Belperio, A.P., 1991. Last Interglacial Shoreline in Australia- A Review. *Quaternary Science Reviews*, 10, 441-461.

Peltier, W.R., 1999. Global sea level rise and glacial isostatic adjustment. *Global and Planetary Change*, 20, 93-123.

Pirazzoli, P.A., 1996. Sea-level changes: the last 20,000 years. John Wiley and Sons, England.

Potter, E. and Lambeck, K., 2004. Reconciliation of sea-level observations in the Western North Atlantic during the last glacial cycle. *Earth and Planetary Science Letters*, 217, 171-181.

Shackleton, N.J. and Opdyke, N.D., 1973. Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volume on a 105 and 106 year scale. *Quaternary Research,* 3, 39-55.

Sloss, C. R., Murray-Wallace, C. V., and Jones, B. G., (2007) Holocene sea-level change on the southeast coast of Australia: a review. *The Holocene*, 17, 999-1014.

Stanley, D. J. and Warne, A. G., 1994. World wide initiation of Holocene marine deltas by deceleration of sea-level rise. *Science*, 265, 228-231.

Williams, M., Dunkerley, D., DeDeckker, P., Kershaw, P. And Chappell, J., 1998. Quaternary Environments. 2nd Edition, Arnold, London, pp. 329.

Yokoyama, Y., Purcell, A., Lambeck, K. and Johnston, P., 2001. Shore-line reconstruction around Australia during the Last Glacial Maximum and late Glacial Stage. *Quaternary International*. 83-85, 9-18.