The Geological Society

6-7 February 2023

Climate and Ecology

Sea Level Change in the Past, Present and Future

ABSTRACT BOOKLET

The Earth's sea level has changed substantially over the last 100s of millions of years due to factors such as tectonic activity and glaciations. The geological record contains evidence of how much sea levels have changed and what organisms dominated seawaters in the past.

This story of change can tell us how sea level might respond to changing environmental factors in the future. The rate that sea level has changed over the last 125,000 years helps inform crucial political decisions around climate targets and how we adapt the built environment.

Explore the latest research in the science of sea level change and consider how this might affect the way we make predictions about the future of our planet at 'Sea Level Change in the Past, Present and Future' with the Geological Society.

Organisers

Prof Dan Lunt (University of Bristol)
Dr Ed Gasson (University of Exeter)
Dr Douwe van der Meer (CNOOC & Utrecht University)
Dr Natasha Barlow (University of Leeds)

Invited Speakers

Prof Alessio Rovere (Ca'Foscari University of Venice)
Dr Florence Colleoni (Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS)
Dr Mike Simmons (Halliburton & Natural History Museum & University of London)
Prof Ken Miller (Rutgers University)
Dr Nicky Wright (Australia National University)
Prof Rob DeConto (University of Massachusetts)
Dr Sarah Bradley (University of Sheffield)

Further Information

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CLIMATE & ECOLOGY

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Sea level change in the past, present and future (Hybrid Event)

06 - 07 February 2023

PROGRAMME

The Geological Society

DAY ONE - Monday 6th February		
1000-1030	Registration	
1030-1045	Welcome	
1045-1115	Mike Simmons – Halliburton	Invited talk: Building a eustatic sea-level curve from the rocks up
1115-1135	Lennert Bastiaan Stap - Utrecht University	Miocene Antarctic ice sheet area responds significantly faster than volume to CO2-induced climate changes
1135-1155	Caroline Lear - Cardiff University	Playing to Proxy Strengths: Reconstructing Pliocene Sea Level Amplitudes
1155-1230	Poster flash talks	
1230-1330	Lunch	
1330-1400	In person poster session	
1400-1430	Ken Miller - Rutgers University	Invited talk: Global mean and relative- sea-level records over the past 66 Myr: Effects of ice volume and mantle dynamic topography
1430-1450	Jonathan Schueth - University of Nebraska Omaha	Paleoshorelines of the North American Western Interior Seaway: Muddying the Waters and Mistaking Absence of Evidence for Evidence of Absence
1450-1530	Discussion - updating global sea-level curves	
1530-1600	Coffee	
1600-1630	Alessio Rovere - Ca' Foscari University of Venice	Invited talk: Observing the geological past to predict a warmer future
1630-1650	Georgia Grant - GNS Science	Reduce magnitude of the onset of Northern Hemisphere glaciation during the Early Pleistocene
1650-1720	Dierdre Ryan - University of Pisa	A Pleistocene sea-level record from the archaeologically significant Balzi Rossi, north-western Mediterranean
1720-1730	Wrap up	

DAY TWO – Tuesday 7th February		
0900-0915	Registration	
0915-0920	Welcome	
0920-0950	Nicky Wright – University of Sydney	Invited talk: Long-term changes in sea level based on based on reconstructions of paleobathymetry and ocean basin volume since the Mesozoic.
0950-1010	Natasha Barlow – University of Leeds	Rates and drivers of Last Interglacial relative sea-level change in North West Europe: fingerprinting Antarctic ice sheet melt
1010-1030	Tina van de Flierdt - Imperial College London	Sensitivity of the West Antarctic Ice Sheet to +2°C (SWAIS 2C)
1030-1100	Coffee	
1100-1130	Sarah Bradley – University of Sheffield	Invited talk: Quaternary sea level, ice sheets and glacial isostatic adjustment models
1130-1230	Poster flash talks and online poster session	
1230-1330	Lunch	
1330-1400	Florence Colleoni - National Institute of Oceanography and Applied Geophysics	Invited talk: Long-term changes of Antarctic ice sheet's contribution to global sea level rise: when the past meets with the future
1400-1420	Ivan Haigh – University of Southampton	Changes in sea level and its impact on London
1420-1440	Prince Emeka Ndimele - Lagos State University	Vulnerability, Resilience and Adaptation of Lagos Coastal Communities to Flooding
1440-1500	Stephen Hencher - University of Leeds; University of Hong Kong	Reliability of sea level measurements and consequences for climate modelling into the future.
1500-1530	Coffee	
1530-1600	Rob DeConto - University of Massachusetts, Amherst	Invited talk: A paleo-perspective on the sensitivity of the Antarctic Ice Sheet to climate warming
1600-1700	Discussion (and wrap up) - palaeo sea level for the future	

Posters – *timing to be updated and dependant on whether presenting author is present in person or virtually*

Author	Poster title
In Person Day 1	
Augustus Wilson - Independent Consulting Geologist (In person)	Interaction of Eustasy and Subtle Tectonics, Evolution of Middle Late Jurassic Arabian Intrashelf Basin
Ed Gasson – University of Exeter (In person)	Constraining the amplitude of Antarctic Ice Sheet change during warm intervals of the Pliocene
Fermin Alvarez Agoues - Trinity College Dublin (In person)	Surface distribution of modern intertidal saltmarsh foraminifera in Southern Ireland: Development of a regional dataset and implications for relative sea level reconstructions
Fred Richards - Imperial College London (In person)	Can Correcting for Mantle Dynamics Reconcile Divergent Plio-Pleistocene Sea-Level Estimates?
Graham Rush - University of Leeds (In person)	Did drainage of Lake Agassiz-Ojibway drive the 8.2 ka climate event? Evidence from a sea-level reconstruction in northwest Scotland
Jim Marschalek - Imperial College London (Associate taking) Now virtual	A Large West Antarctic Ice Sheet Explains Early Neogene Sea-Level Amplitude
Jim Marschalek - Imperial College London (Associate taking) Now virtual	Pliocene Antarctic Sea Level Contribution inferred from Quantitative Sub-Ice and Marine Sediment Provenance Tracing
Joshua Solomon Avong - Ahmadu Bello University (tbc)	Early to Late Miocene Biostratigraphy in the Niger Delta by integrating foraminifera bioevents and Paleoceonographic Implications
Ray Zammit - Cardiff University (In person)	Regional hydrology changes following the Middle Miocene glacio-eustatic sea level fall (13.8 Ma)
Sophie Slater - Cardiff University (In person)	Southern Ocean Response to Antarctic Glaciation at the Eocene-Oligocene Transition
Tijn Berends - Utrecht University (In person)	Distilling sea level changes from benthic δ18O
Yang Zifei - Cardiff University (In person)	The impact of foraminiferal diagenesis on reconstructions of past sea level
Douwe van der Meer - CNOOC International & Utrecht University (In person)	Long-term Phanerozoic global mean sea level: Insights from strontium isotope variations and estimates of continental glaciation
Merula Penning - Cardiff University (In person)	Resolving disparate sea level estimates from the earliest Pleistocene
VIRTUAL Day 2	
Jamie O'Neill - University of Exeter (Virtual)	Modelling the Antarctic ice sheet under warm Pliocene climate
Jim Marschalek - Imperial College London (Associate taking) Now virtual	A Large West Antarctic Ice Sheet Explains Early Neogene Sea-Level Amplitude
Jim Marschalek - Imperial College London (Associate taking) Now virtual	Pliocene Antarctic Sea Level Contribution inferred from Quantitative Sub-Ice and Marine Sediment Provenance Tracing
Malcolm Hart - University of Plymouth (Virtual)	Indicators of sea level change in the areas bordering the Western English Channel
Martina L. G. Conti – University of York (Virtual)	Sea-level changes: molecular approaches to tell us the how and the when
Matteo Vachii – University of Pisa (Virtual)	Millennial variability of the sea-level changes along the western African coast
Yossi Mart - University of Pisa Sea (Virtual)	Level variation in historic times: Caesarea in Coastal Israel as a yardstick
Guillaume Jouve, Exail Geosciences Project (Virtual)	O'Coral Rings: Where Art Thou?

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ORAL ABSTRACTS
(In Programme Order)

DAY ONE

Mike Simmons – Halliburton

Building a eustatic sea-level curve from the rocks up

The isolation of the eustatic signal from the sedimentary record remains challenging, yet its nature is of interest for both academia and industry. Herein we present a simplified workflow that allows for the construction of a pragmatic, plausible short-term ("3rd order") eustatic curve. In most sedimentary sections one can observe vertical facies trends and changes in palaeobathymetry indicators. Additionally, in the subsurface and in some large-scale outcrops it can be possible to recognise sedimentary architectures indicative of changes in relative sea level. These sets of information can be interpreted using sequence stratigraphic methodologies. For a given short time interval (e.g. a stage), the examination of multiple suitable stratigraphic sections can be used to identify a commonality in the timing of major transgressive and regressive events. A prerequisite to this is detailed work on biostratigraphic calibration between different fossil groups and other chronological techniques. Having established approximate timings of age synchronous eustatic rise and fall, eustatic magnitude limits can be estimated from stratigraphic observations (e.g., measurements derived from erosional and depositional relief, fossil assemblages, facies juxtaposition), geochemical proxies (e.g., oxygen isotopic values) or from a compilation of published magnitudes. These can then be integrated with an independently calculated long-term eustasy trend, and the resultant curve analysed for plausibility. Here forward stratigraphic modelling can be powerful for assessing the impact of uncertainties in timing and magnitude on the generation of a plausible eustatic curve. A pragmatic Phanerozoic eustatic curve provides a valuable tool for not only understanding Earth systems processes through time, but also for subsurface characterisation – a major challenge of the 21st century energy transition.

Lennert Bastiaan Stap - Utrecht University

Miocene Antarctic ice sheet area responds significantly faster than volume to CO_2-induced climate changes

The strongly varying benthic δ18O levels of the early- to mid-Miocene (23 to 14 Myr ago) are primarily caused by a combination of changes in Antarctic ice sheet (AIS) volume and deep water temperatures (DWT). These factors are coupled since AIS changes affect DWT. It has recently been argued that this is due to changes in ice sheet area rather than volume. This becomes important when the AIS grows relatively faster in extent than in thickness, which needs to be tested in a transient manner. Here, we analyse simulations of Miocene AIS variability carried out using the three-dimensional ice-sheet model IMAU-ICE forced by warm (high CO_2, no ice) and cold (low CO_2, large East-AIS) climate snapshots. Performing equilibrium and quasi-orbital transient simulations with strongly varying CO_2 levels (280 to 840 ppm), we find that indeed AIS area responds significantly faster than volume to the applied forcing variability. In our transient simulations, AIS growth occurs in three distinct phases. When CO_2 is lowered, first both the AIS area and volume grow, both lagging behind the growth of the ice sheet in equilibrium with the climate. When the equilibrium ice sheet size levels off, the ice sheet extent and thickness continue to grow. The volume now increases more strongly than before, because the surface mass balance is positive over a larger area. Finally, the ice sheet extent declines after it attains equilibrium. However, because the thickness still increases in the interior, so does the total ice volume, albeit ever slower. Our simulations show limited direct effect of East-Antarctic ice sheet changes on Miocene orbital timescale benthic δ18O variability, because of the slow build-up of volume. We conclude, however, that concomitant DWT temperature changes can still be significant when they are effectuated by faster AIS area changes.

Caroline Lear - Cardiff University

Playing to Proxy Strengths: Reconstructing Pliocene Sea Level Amplitudes

During the Mid-Miocene climate transition (13.8 Ma) the Antarctic Ice Sheet expanded significantly, and the Earth System accelerated its descent towards the modern bipolar icehouse. The associated global sea level fall likely caused the final and complete disconnection between the Indian and Atlantic Oceans through the Tethys Seaway. Here we present benthic and planktic foraminiferal geochemical data from the Island of Malta (Central Mediterranean) in order to investigate the response of North African climate to these events. We measured δ18O and δ13C of Trilobatus trilobus (planktic) and Heterolepa dutemplei (benthic), foraminiferal Mg/Ca Trilobatus trilobus (planktic) and Uvigerina spp. (benthic). This allowed us to determine surface and bottom water temperatures (using Mg/Ca paleothermometers) and the δ18O of sea water. The differences between calculated bottom water and surface water δ18O allowed us to differentiate between the ice-volume signal and the precipitation/evaporation signal in the seawater δ18O records. Our results reveal a transition to a North African climate regime experiencing orbitally paced super-humid intervals, suggesting that the sea level induced closure of the Tethys Seaway may have led to a marked intensification of the West African Monsoon system. The 6th IPCC report highlights great uncertainty in predicting future precipitation and drought over the North Africa. We therefore propose that the Miocene (23 to 5.5 Ma) represents a time of great hydrological variability in this region, and can act as a natural laboratory where we can explore the interactions between climate, hydrology, carbon cycling, and depositional processes using a combined data-modelling approach. This study highlights key climate feedbacks associated with a major glacio-eustatic sea level fall.

Ken Miller - Rutgers University

Global mean and relative- sea-level records over the past 66 Myr: Effects of ice volume and mantle dynamic topography

Kenneth G. Miller, W. J. Schmelz, J.V. Browning, Department of Earth and Planetary Sciences, Rutgers University, Piscataway, NJ 08534 USA

Cenozoic (past ~66 Myr) sea-level history reflects temperature changes and cryospheric evolution of Earth from essentially ice-free conditions in the Early Eocene to bipolar ice sheets in the Quaternary. Miller et al. (2020) presented a barystatic estimate for the last 48 Myr using an astronomically calibrated Pacific benthic foraminiferal $\delta^{18}O$ splice and a 2 Myr-smoothed Pacific bottom water temperature record using benthic foraminiferal Mg/Ca data. Here, we present a new global mean sea level (GMSL) estimate using 1) new Mg/Ca data from Site 577 from 48-58 Ma, that overcome problems with previous data; and 2) a recent estimate of long-term tectonically driven sea level (Wright et al., 2020). These GMSL estimates are statistically similar to "backstripped" estimates (accounting for compaction, loading, and thermal subsidence) from continental margins (US Mid-Atlantic and Australia). However, US Mid-Atlantic margin relative sea levels were impacted by changes in mantle dynamic topography on the several Myr scale, showing 50+m higher estimates in the Eocene and regionally propagating changes in relative sea level during the Miocene. Both the barystatic and continental margin estimates have markedly higher amplitudes in the Oligocene to Early Miocene than other recently published estimates, leading us to reject those estimates (Rohling et al., 2022). Peak warmth, elevated GMSL, high CO_2, and ice-free conditions occurred during the Early Eocene (55-49 Ma). However, a new Early Eocene Mg/Ca record from Site 577 yields barystatic amplitudes of ~20-25 m, in agreement with New Jersey backstripped results, suggesting the growth and decay of significant ice sheets even during the Early Eocene. The long-held assumption of an ice-free Eocene has been clearly refuted by evidence of 1) Middle to Late Eocene barystatic sea-changes of ~25-30 m; and 2) the presence of ice sheets calving into the Antarctic coast during the Middle Eocene and possibly for the Early Eocene (Gulick et al., 2017). Continental-scale ice sheets ("Icehouse") waxed and waned beginning ~34 Ma (>50 m barystatic changes), a permanent East Antarctic ice sheet at 12.8 Ma, and full, bipolar glaciation at 2.5 Ma. The largest GMSL fall was at the Last Glacial maximum (27-20 ka; ~130 m) and was followed by a >40 mm/yr rise (19-10 ka), a slowing (10-2 ka), and a stillstand until ~1900 CE, when rates began to rise due to anthropogenic CO_2 release We conclude that glacially driven GMSL changes occurred even during the Hothouse Early Eocene and that ice sheets ~1/3 of modern grew and decayed in the purportedly ice-free world.

Jonathan Schueth - University of Nebraska Omaha

Paleoshorelines of the North American Western Interior Seaway: Muddying the Waters and Mistaking Absence of Evidence for Evidence of Absence

The Late Jurassic through Paleocene North American Western Interior Seaway (WIS) stretched from the Arctic Ocean to the Gulf of Mexico and had a complex history of transgression and regression due to tectonism and eustatic sea level variation. Paleogeographic reconstructions and depositional models of the WIS have historically oversimplified the transition from marine to continental environments and underestimated the amount of marine connectivity and influence. In many cases paleoshorelines were placed geographically based on an absence of data. However, there are significant gaps in the record surrounding the placement of the western shoreline. Here, we utilize sedimentological, proxy, and paleontological data from field observations, subsurface well logs, and literature reviews to review and refine shoreline maps for key intervals. The Early Cretaceous Mowry Seaway is often shown as discontinuous with the Gulf of Mexico (GOM) to the south. However, the presence of Tethyan fauna in the Mowry Shale and correlative marine sediments in Oklahoma and Kansas suggest an open connection with the GOM. Widespread, subaqueous erosional features in the Niobrara and Mancos Formations are commonly mischaracterized as subaerial unconformities, leading to depictions of land in areas that were not exposed. Shoreline maps of the Late Cretaceous Mesaverde Group and Lance Formation in Wyoming, USA historically depict a consistent, eastward retreat but analysis of outcrops and subsurface well logs suggest that local Laramide uplifts shed sediment in multiple directions into the seaway. Paleogene deposits in southern Wyoming were universally interpreted as continental based on the abundance of coal, channelform sandstone bodies, and absence of marine body fossils. The recognition of tidalites and marine ichnofossils necessitates at least two marine flooding events. These examples emphasize that the key to greater fidelity in paleoshoreline reconstructions is to focus on evidence for absence of marine influence rather than the absence of evidence.

Alessio Rovere - Ca' Foscari University of Venice

Observing the geological past to predict a warmer future

The assumption that “the present is key to the past”, first formalised by James Hutton and Charles Lyell, has driven the discipline of geology for nearly two centuries. Starting in the mid-1970s, concerns about a changing climate have motivated geoscientists to apply our knowledge of past and present processes to predict the behaviour of the Earth’s system under warmer global temperatures, working under the assumption that “the past is key to the future”. Past interglacials are central to understanding thresholds, the potential for rapid changes, and the intensity of processes under different climate forcings. The Last Interglacial (Marine Isotopic Stage 5e) is the last time the Earth was warmer than the pre-industrial due to different orbital forcing. Geological imprints of the Last Interglacial have been left (among others) on glacial deposits, soils, and coastal sections. Among the latter, thousands of sites globally have preserved relic beaches or lagoonal deposits, coral reefs, and erosional features. Geologists use these features to answer pressing questions about the recent geological past of our coasts: how much higher than pre-industrial was sea level, and why was it higher? Were there periods of abrupt sea-level change triggered by rapid ice-sheet collapse? Did more powerful swells characterise oceans, and if so, where? The answers to these questions are often elusive, as geologists have to deal with uncertainty in analytical methods, preservation bias, and challenging interpretation of stratigraphic units. However, geological observations of coastal proxies in the Last Interglacial are the next best thing to a time machine, as they provide benchmarks to models predicting the intensity of processes that the Earth’s coastlines will face in a warmer future.

Georgia Grant - GNS Science

Reduce magnitude of the onset of Northern Hemisphere glaciation during the Early Pleistocene

Intensification of the Northern Hemisphere glaciation to continental scale began about 2.7 million years ago (Ma), indicated by the geographic distribution of ice-berg rafted debris in deep ocean sediment cores and increasing amplitude of cyclicity in the benthic oxygen isotope (δ18O) proxy global ice volume record, beyond what Antarctica could reasonably contribute. However, the location, extent, and thickness of these ice sheets is poorly constrained by proximal geologic evidence, and the interpretation of ice volume from proxy δ18O is uncertain due to the additional influence of bottom-water temperature on δ18O composition. A new direct and continuous sea-level record (PlioSeaNZ) has been recently developed from Pliocene shallow-marine sedimentary deposits in Whanganui Basin, New Zealand, using the relationships between sediment transport, water depth, and grain size on a wave-graded continental shelf. Here we present an extension of the PlioSeaNZ sea-level record using the early Pleistocene sedimentary sequences from Whanganui Basin, and reconstruct the amplitude and frequency of glacial-interglacial, global sea-level fluctuations between 3.3-1.7 Ma. Early Pleistocene (~2.6-1.7 Ma) fluctuations in global mean sea-level were between 5-45 m, with an average of 20 m, significantly lower amplitude than those reconstructed from benthic δ18O records (17-60 m) during the intensification of the Northern Hemisphere Ice Sheets (NHIS). We suggest that while NHIS reached an extent whereby they were calving ice bergs at the coast by 2.7 Ma, their volume is overestimated in reconstructions based on the benthic δ18O proxy. This has significant implications for the wide use of δ18O as an ice volume proxy, the assumptions of NHIS distribution, and the relative contribution of Antarctic and NHIS to global sea-level at this time.

Dierdre Ryan - University of Pisa

A Pleistocene sea-level record from the archaeologically significant Balzi Rossi, north-western Mediterranean

The caves complex of Balzi Rossi (Ventimiglia, adjacent to the Italian-French border) is recognized as an important site for the study of Palaeolithic settlements within the Mediterranean and Europe. As such, it has been subject to archaeological investigation for over a century but with little regard for the associated coastal and marine deposits. Archaeological documentation has suggested possibly four Pleistocene interglacial periods, with three coastlines located at distinct altimetric altitudes. However, former archaeological excavations have removed much of the coastal/marine deposits previously documented in the cave and open-air sites at Balzi Rossi and many of the deposits are preserved only as fragmented remnants at museums and other repositories. A primary objective of the SPHeritage Project is to precisely identify, describe, and geochronologically constrain the palaeo-coastlines.

This will be a presentation of the ongoing work within the SPHeritage Project, the challenges we have encountered, and our successes so far. This includes last interglacial sea-level indicators between 7 and 13 m above present sea level, an ancient sea level record at approximately 105 m, and intervening traces suggesting a highstand record around 23 m above present. These results are supported by new sedimentological analyses of archaeological samples and age constraint using a comprehensive suite of geochronological methods.

DAY TWO

Nicky Wright – University of Sydney

Long-term changes in sea level based on based on reconstructions of paleobathymetry and ocean basin volume since the Mesozoic.

Long-term changes in eustatic sea level in an ice-free world, i.e., most of the Mesozoic and Cenozoic, are largely driven by changes in the volume of ocean basins. Reconstructions of paleobathymetry tied to a plate tectonic model can be used to explore variations in ocean basin volume, which is primarily dependent on the volume of the global ridge system, and to a lesser extent, marine sediment accumulation, seafloor volcanism, and dynamic topography. Previous studies have determined ocean basin volume changes from plate tectonic reconstructions since the Mesozoic; however, these studies have not considered a number of important elements that contribute to ocean basin volume, such as regional differences in sedimentation, or uncertainties within the plate tectonic model itself, such as spreading asymmetries and the incomplete representation of back-arc basins in the Mesozoic. Additionally, studies on long-term changes in sea level related to the extension and rifting of passive margins have not been performed on a global-scale and likely significantly underestimated the influence of this process.

In order to improve reconstructions of sea level on geologic time scales and assess the uncertainty in deriving the volume of ocean basins based on a global plate kinematic model, we create new paleobathymetry reconstructions and investigate the influence of back-arc basins, spreading asymmetry, large igneous provinces (LIPs), sediment thickness, and passive margins on ocean basin volume since the Jurassic. We find that less-constrained plate tectonic elements, such as the presence of back-arc basins or spreading asymmetry, may contribute up to ~120 m or ~150 m to sea level respectively. Changes in the sea level related to sedimentation and LIPs are respectively ~75–165 m and ~45 m. Changes in sea level associated with passive margin formation are almost negligible at present day, though were much larger in the Cretaceous, and the assumed sedimentation style strongly influences the rate and magnitude of sea-level change. We incorporate predictions for these components during times where ocean basins are predominantly synthetic reconstructions and find that sea level driven by fluctuating ocean basin volume has changed by ~200 m since the Jurassic, which is comparable to previous estimates. Our revised estimates will need to be combined with other processes driving long-term sea-level change, including mantle convection-driven dynamic topography and glacio-eustasy for constructing a complete eustatic sea-level curve. Understanding and quantifying the uncertainties in the volume of ocean basins has implications for modelling subduction flux, the oceanic carbon cycle, and heatflow, and is important for exploring Earth's evolutionary cycles, especially during times in the geologic past where much of the ocean basin history has been lost.

Natasha Barlow – University of Leeds

Rates and drivers of Last Interglacial relative sea-level change in North West Europe: fingerprinting Antarctic ice sheet melt

We present results of analysis and modelling of Last Interglacial sea-level change in the North West Europe. This region offers a unique opportunity to fingerprint the rate of Antarctic ice sheet melt at a time when polar temperatures were at a level similar to those predicted for the coming centuries. We develop a novel approach to establish the timing and nature of the transgression of the Last Interglacial North Sea, from a series of sediment cores and mapping of geophysical wind farm data. Isolating the signal of Antarctic ice sheet melt from our records requires understanding of the solid Earth response to the large Eurasian ice sheet that covered much of north Europe. We combine innovative modelling of the deglaciation of the MIS 6 Eurasian ice sheet, within a glacial isostatic adjustment model, to infer the spatial sensitivity across the northwest European region to our Earth and ice sheet inputs. Our initial results indicate high rates of relative sea-level rise during the peak warmth of the Last Interglacial, and suggest a notable contribution from Antarctica to Last Interglacial sea level.

Tina van de Flierdt - Imperial College London

Sensitivity of the West Antarctic Ice Sheet to +2°C (SWAIS 2C)

The West Antarctic Ice Sheet (WAIS) presently holds enough ice to raise global sea level by 4.3m if completely melted. Despite efforts through previous land and ship-based drilling on and along the Antarctic margin, unequivocal evidence of major WAIS retreat or collapse in times of past warmth has remained elusive. Yet such data are vital to inform numerical models aimed at quantifying predictions of future sea level rise. The International Continental Scientific Drilling Program (ICDP) project 'Sensitivity of the West Antarctic Ice Sheet to a Warming of 2°C (SWAIS 2C)' will constrain past and current drivers and thresholds of WAIS dynamics to improve projections of the rate and size of ice sheet changes under a range of elevated greenhouse gas levels in the atmosphere as well as the associated average global temperature scenarios to and beyond the +2°C target of the Paris Climate Agreement. Researchers, engineers, and logistics providers representing Australia, Germany, Italy, Japan, New Zealand, Republic of Korea, United Kingdom, and United States have established an international partnership comprised of geologists, glaciologists, oceanographers, geophysicists, microbiologists, climate and ice sheet modelers, and engineers to tackle the specific research objectives and logistical challenges associated with the recovery of Neogene and Quaternary geological records from the West Antarctic interior adjacent to the Kamb Ice Stream and at Crary Ice Rise. New geophysical surveys at these locations have identified drilling targets in which new drilling technologies will allow for the recovery of up to 200m of sediments beneath the ice sheet. The scientific and technological advances developed through this program will enable us to test whether WAIS collapsed during past intervals of warmth and determine its sensitivity to a +2°C global warming threshold.

Sarah Bradley – University of Sheffield

Quaternary sea level, ice sheets and glacial isostatic adjustment models

Florence Colleoni - National Institute of Oceanography and Applied Geophysics

Long-term changes of Antarctic ice sheet's contribution to global sea level rise: when the past meets with the future

Early to Middle Miocene sea-level oscillations of approximately 40-60 m estimated from far-field records are interpreted to reflect the loss of virtually all East Antarctic ice during peak warmth. This contrasts with ice-sheet model experiments suggesting most terrestrial ice in East Antarctica was retained even during the warmest intervals of the Middle Miocene. Data and model outputs can be reconciled if a large West Antarctic Ice Sheet (WAIS) existed and expanded across most of the outer continental shelf during the Early Miocene, accounting for maximum ice-sheet volumes. Here, we provide the earliest geological evidence proving large WAIS expansions occurred during the Early Miocene (~17.72-17.40 Ma). Geochemical and petrographic data show glacimarine sediments recovered at International Ocean Discovery Program (IODP) Site U1521 in the central Ross Sea derive from West Antarctica, requiring the presence of a WAIS covering most of the Ross Sea continental shelf. Seismic, lithological and palynological data reveal the intermittent proximity of grounded ice to Site U1521. The erosion rate calculated from this sediment package greatly exceeds the long-term mean, implying rapid erosion of West Antarctica. This interval therefore captures a key step in the genesis of a marine-based WAIS and a tipping point in Antarctic ice-sheet evolution.

Ivan Haigh – University of Southampton

Changes in sea level and its impact on London

Understanding changes in mean sea-level is of the utmost importance, as it is a key indicator of climate change and it affects the livelihoods of hundreds of millions of people living in the world's coastal regions. Rising mean sea levels threaten low-lying coastal areas in many ways, including increasing extreme sea-levels which can give rise to serious coastal flooding and erosion. Coastal cities are where the largest increase in losses from extreme sea level events can be expected. London, located on the Thames Estuary in the UK, is one of the world's most important coastal cities, and the largest city in northern Europe. It has been estimated that up to 1.42 million people and £321 billion worth of residential property in London, Kent and Essex would currently be exposed to a 0.5% annual probability of tidal flooding without the Thames Barrier and many hundreds of kilometres of associated defences6. Furthermore, within the Thames tidal flood zone there are also 496 education facilities, 711 healthcare facilities, 4 world heritage sites, and designated habitat sites, as well as critical energy, transport and water infrastructure. This includes the Port of Tilbury and London Gateway Port, the Blackwall Tunnel and Dartford Crossing, 167 km of rail routes, 116 train or tube stations, over 2400 km of paved roads, and 9 power stations. Recently, we have digitised historical hand-written tabulated ledgers of sea level from the Port of London Authority (PLA). In this presentation, I will describe this new dataset and the insights we have obtained as to how sea level has changed in the Thames over the last 150 years. I will put the results in the context of the Thames Estuary 2100 Plan that provides strategic direction for the continued management of flood risk in the Thames Estuary through to the end of the 21st century and beyond.

Prince Emeka Ndimele - Lagos State University

Vulnerability, Resilience and Adaptation of Lagos Coastal Communities to Flooding

Lagos has been identified as one of the 50 cities most vulnerable to extreme sea levels. The state also ranked 30th among 136 port cities in terms of population exposure to flooding under past climate scenario (2005) and 15th under a future climate scenario (2070s). The state faces significant environmental strains as a result of its geographic location and economic importance. Some of the problems are loss of wetlands, pollution, population pressure, restricted access to drinkable water and flooding. All these factors have contributed to the instability of Lagos ecosystems but the impacts of flooding is particularly significant because Lagos State is surrounded by aquatic ecosystems and its low elevation and topography increases its susceptibility to flooding. Flooding is one of the key factors that has prevented Africa's growing urban population from escaping poverty, and it also impedes the achievement of some Sustainable Development Goals like: SDG-1 (No poverty), SDG-2 (Zero hunger), SDG-3 (Good health and well-being), SDG-6 (Clean water and sanitation), SDG-11 (Sustainable cities and communities) and SDG-13 (Climate action). This is due to the fact that many African cities lack the resources and infrastructures needed to withstand extreme weather conditions. Surviving in flood-prone cities like Lagos is a daunting task because flood affects livelihood, human health and can even cause death. Specifically, 2020 flood incidence in Nigeria affected about 40% of the local government areas, 97% of the states, displacing over 120,000 persons and killed 68 persons aside from the properties and farmlands destroyed. This catastrophe may have been exacerbated by COVID-19 pandemic. The 2022 flood in Nigeria could surpass the previous episodes going by the mortality figure, which currently stands at about 600. Therefore, this study examined the vulnerability and resilience of Lagos coastal communities to flooding and measures that can be taken to ameliorate its impacts

Stephen Hencher - University of Leeds; University of Hong Kong

Reliability of sea level measurements and consequences for climate modelling into the future

Measuring current sea level is extremely difficult, because it is a constantly changing parameter, with waves and tides causing variation. The surface of the oceans has an instantaneous roughness with a relief of up to 200 m (Pirazzoli, 1996). Nevertheless, he confirmed that the most realistic range of recent global sea-level rise is 0.9 ±0.3 mm a-1. Similarly, measurements in the UK at 31 locations from 1859 to the present show that the rate of sea level change is approximately ~1 mm per year (Woodworth, 2018). Geological measurements are rather easier and Figure 1 shows sea level changes over the last 20,000 years (Miller et al., 2005 & 2011). Most of the data were obtained from drill core and analysis of the ratio of O16 to O18 in foraminifera. A very similar trend is shown in Pugh (1987) based on carbon14 data. Global temperatures over the last 20,000 years from the European Project for Ice Coring in Antarctica ("EPICA") data set and by Jouzel, et al (2007) tie in nicely. It can be measured that sea level was rising quickly at about 12 mm a-1 up to about 9,000 years ago, since when it has been rising at approximately 1.8 mm a-1 which agrees with the estimates of Pirazzoli and measurements of Woodworth. Greenland and Arctic ice melt are essential parts of the ice age cycle in that, prior to a cooling episode, the north pole needs to be free of ice, to allow evaporation from the sea surface and precipitation of snow at lower latitudes so that next ice age can develop (Holmes, 1965). Following the last Ice Age, it took about 10,000 years for ice to retreat from Bristol to the Lake District, and another 10,000 before it finally left Scotland this year.

Rob DeConto - University of Massachusetts, Amherst

A paleo-perspective on the sensitivity of the Antarctic Ice Sheet to climate warming

Despite a major effort to constrain peak sea level during the mid-Pliocene warm period, uncertainties remain large. This interval is of interest because of the analogous CO2 concentration to present day and because of the potential retreat of a large portion of the Antarctic Ice Sheet. The usefulness of this period to constrain ice sheet model physics is limited by these large uncertainties on peak sea level. Here we discuss efforts to produce a new record of the amplitude of sea level change from interglacial to glacial periods during the early and mid-Pliocene, which have lower uncertainties than peak sea level. We combine this effort with new climate and ice sheet model simulations of the glacial to interglacial cycle for ice sheets in both hemispheres. We discuss how this work will constrain the magnitude of Antarctic Ice Sheet retreat during warm intervals of the mid-Pliocene and how we use these constraints to discriminate between different ice sheet model physics.

POSTER ABSTRACTS

Augustus Wilson - Independent Consulting Geologist

Interaction of Eustasy and Subtle Tectonics, Evolution of Middle Late Jurassic Arabian Intrashelf Basin

The interaction of several factors, sea level change, subtle tectonics, palaeolatitude and palaeowind combined to form and fill the Jurassic Arabian Intrashelf Basin in the eastern Arabian Peninsula. With subtle subsidence and a middle Callovian rise in sea level, Tuwaiq Mountain Formation carbonates formed a shallow rim around the basin. An end-Callovian-early Oxfordian lowstand exposed the rim, stopped progradation and restricted the basin, in which a cyanobacterial-rich laminite was deposited. A significant climate change from greenhouse to a cooling phase has been hypothesized for the sea level fall and a change favouring cyanobacterial deposition in restricted basins. A slow sea level rise returned more normal marine conditions, beginning progradation of Hanifa Formation carbonates, which filled ~2/3 of the basin. Another significant lowstand terminated Hanifa progradation. With sea level rise , the last intrashelf basin phase, the Jubaila-Arab-D carbonates largely infilled the basin, ending with grainstone shoals and remnant lagoonal mudstones. Deposition shifted to a blanketing Arab-Hith carbonate-evaporite (gypsum-anhydrite) platform. Alternation between evaporite and carbonate deposition was controlled by interaction of sea level rise with development of a Tethyan shelf uplift and a westward structural tilt. All of this of course formed the hydrocarbon system for the major Jurassic oil in the area of the intrashelf basin. Several factors with global implications will be illustrated and discussed.These include: Estimation of magnitude of eustatic fluctuation partly depends on degree of syndepositional isostatic subsidence of the thick, heavily loaded carbonate rim facies vs subsidence in the thinner equivalent intervals within the basin. The evolution of the basin spans a minimum in the global 87Sr/86Sr curve, with Callovian-Oxfordian in the low.

Diversity of species and genera may have decreased late Callovian-early Oxfordian. (This presentation is extracted and expanded from interpretations in Wilson, 2020, Geological Society of London Memoir 53.)

Douwe van der Meer – CNOOC

Long-Term Phanerozoic Global Mean Sea Level: Insights from Strontium Isotope Variations and Estimates of Continental Glaciation

Global mean sea level is a key component within the fields of climate and oceanographic modelling in the Anthropocene. Hence, an improved understanding of eustatic sea level in deep time aids in our understanding of Earth's paleoclimate and may help predict future climatological and sea level changes. However, long-term eustatic sea level reconstructions are hampered because of ambiguity in stratigraphic interpretations of the rock record and limitations in plate tectonic modelling. Hence the amplitude and timescales of Phanerozoic eustasy remains poorly constrained. A novel, independent method from stratigraphic or plate modelling methods, based on estimating the effect of plate tectonics (i.e., mid-ocean ridge spreading) from the 87Sr/86Sr record led to a long-term eustatic sea level curve, but did not include glacio-eustatic drivers. Here, we incorporate changes in sea level resulting from variations in seawater volume from continental glaciations at time steps of 1 Myr. Based on a recent compilation of global average paleotemperature derived from δ18O data, paleo-Köppen zones and paleogeographic reconstructions, we estimate ice distribution on land and continental shelf margins. Ice thickness is calibrated with a recent paleoclimate model for the late Cenozoic icehouse, yielding an average ~1.4km thickness for land ice, ultimately providing global ice volume estimates. Eustatic amplitudes (isostatically corrected) are ~200m for tectonics, and ~90m for glaciations (at timescales > 1 Myr), resulting in an overall ~250m range throughout the Phanerozoic. A comparison with other sea level curves is also made, and we discuss key differences and their implication with an example of seismo-stratigraphy of an Atlantic passive margin. In summary, the published Tectono-Glacio-Eustatic curve provides novel viewpoint on global climatological processes during the Phanerozoic and provides a useful background for understanding and interpretation of stratigraphy of passive margins.

Ed Gasson – University of Exeter

Constraining the amplitude of Antarctic Ice Sheet change during warm intervals of the Pliocene

Despite a major effort to constrain peak sea level during the mid-Pliocene warm period, uncertainties remain large. This interval is of interest because of the analogous CO2 concentration to present day and because of the potential retreat of a large portion of the Antarctic Ice Sheet. The usefulness of this period to constrain ice sheet model physics is limited by these large uncertainties on peak sea level. Here we discuss efforts to produce a new record of the amplitude of sea level change from interglacial to glacial periods during the early and mid-Pliocene, which have lower uncertainties than peak sea level. We combine this effort with new climate and ice sheet model simulations of the glacial to interglacial cycle for ice sheets in both hemispheres. We discuss how this work will constrain the magnitude of Antarctic Ice Sheet retreat during warm intervals of the mid-Pliocene and how we use these constraints to discriminate between different ice sheet model physics.

Fermin Alvarez Agoues - Trinity College Dublin

Surface distribution of modern intertidal saltmarsh foraminifera in Southern Ireland: Development of a regional dataset and implications for relative sea level reconstructions

The reliable reconstruction of past relative sea-level (RSL) from foraminifera buried in high-saltmarsh sediment requires accurate species-height relationships to be developed from appropriate modern analogues. However, the species distribution from a saltmarsh is the product of numerous, complex interactions among the organisms and their environment where the specific composition and elevational range of foraminifera assemblages varies in time and space responding to the influence of different secondary variables. Whilst it is important to compile a modern training set representative of the study area where RSL will be reconstructed, the choice of whether these data are collected from a single site (local) or multiple sites (regional) is open to discussion. Understanding the variability of saltmarsh foraminiferal assemblages in the study area is a prerequisite for making informed choices about training set construction, but such data are currently lacking from the Irish coast. We present the first regional training set of modern intertidal saltmarsh foraminifera from Southern Ireland, with the aims of: 1) determining whether saltmarsh foraminifera in this region are vertically zoned: 2) assessing whether these vertical distributions are consistent among sites. We demonstrate that foraminifera are vertically zoned at the twelve surface transects examined making them useful sea-level indicators. However, the number and composition of assemblages zones varies with location with implications for the reliability and precision of RSL reconstructions generated from site-specific transfer functions. We examine the potential role that differences in tidal range, precipitation, exposure, marsh physiography and human modification may play in influencing the strength of species-elevation relationships in Irish saltmarshes. We conclude that tidal range appears to be the principal factor influencing inter-site assemblage variability, and that reconstructions based on a regional training set can be improved by careful screening of samples associated with saltmarsh cliffs, high energy regimes and areas of human modification

Fred Richards - Imperial College London

Can Correcting for Mantle Dynamics Reconcile Divergent Plio-Pleistocene Sea-Level Estimates?

Estimates of global mean sea level (GMSL) during past warm periods provide a key constraint on ice-sheet sensitivity to future climate change and inform projections of long-term sea-level rise. Measurements from the most recent periods of enhanced warmth are especially valuable since these intervals represent the closest climatic analogues to near-future conditions. Considerable focus has therefore been placed on reconstructing sea-level during the Mid-Pliocene Warm Period (MPWP; 3.3–3.0 Ma) and the Last Interglacial (~129–116 ka), periods characterised by mean temperatures 2¬–3 °C and ~1 °C above preindustrial levels, respectively. Many GMSL estimates have been obtained from palaeoshoreline deposits since these geomorphic proxies provide a more direct and potentially more precise constraint on past sea-level than stable isotope records. However, estimates from different sites often differ by several metres due to spatially variable vertical crustal motions caused by geodynamic processes, including glacial isostatic adjustment and mantle dynamic topography. To tackle this issue, we integrate a suite of Australian sea-level markers and geodynamic simulations into a probabilistic inverse framework to quantify and remove the effect of vertical crustal motions at a continental scale. We find mantle dynamic topography accounts for most of the observed MPWP sea-level marker deflection and is also significant for the LIG. After correcting for this process and glacial isostatic adjustment, we obtain a revised MPWP GMSL estimate of +16.0/10.4–21.5 m (50th/16th–84th percentiles). Similarly, we find that post-LIG dynamic topography may account for several metres of relative displacement across the Great Barrier Reef and between Western Australia and the Seychelles, potentially reconciling discrepant GMSL estimates from these sites. Recalibration of sea-level projections with these revised estimates suggests a more stable Antarctic Ice Sheet under future warming scenarios, appearing to rule out recent high-end forecasts.

Graham Rush - University of Leeds

Did drainage of Lake Agassiz-Ojibway drive the 8.2 ka climate event? Evidence from a sea-level reconstruction in northwest Scotland

Guillaume Jouve, Exail Geosciences Project

O'Coral Rings: Where Art Thou?

About ten years ago, coral rings 25 km off of Cape Corsica have been discovered. There are hundreds of them laying on the seafloor at about 115m below sea level. These 25 m in diameter coralligenous rings are composed of a central core and a crown that seem to be of plant origin and attract numerous animals. They exist in a unique place in the world: an area of 4 km² between 110 and 120 m deep in the Natural Marine Park of Cape Corse and Agriate, in the French Mediterranean. These mysterious circular shapes were the subject of the scientific expedition « Gombessa 6 » led by par Laurent Ballesta during summer 2021. In this presentation, we will first focus on unique subaquatic photographs of the corals and life around them. Then, we will discuss about the origin of these rings, throughout a coral core that has been recovered during the scuba diving mission in 2021. Radiocarbon datings will be critical to best constrain the environmental & climatic context, and the associated sea level context during which these structures have been created. Are there post-glacial submerged structures first created in very shallow water environments? Preliminary results from a seismic reflexion survey acquired with Exail Echoes 3500 T1 onboard of the Unmanned Surface Vehicule DriX will also be presented. Finally, we will present the next mission in summer 2023, during which a Triton underwater robotics will be mobilized to "visit" these structures, together with a ROTV implemented with an Echoes 5000 to best acquire high-resolution seismic reflexion data on individual coral rings.

Jamie O'Neill - University of Exeter

Modelling the Antarctic ice sheet under warm Pliocene climate

The warm Pliocene was a period of comparable atmospheric carbon dioxide concentrations to modern, but with sea level up to tens of metres higher. The high end this reconstructed range suggests collapse of the West Antarctic ice sheet, and mass loss from East Antarctic subglacial basins. Previous work has suggested that East Antarctic retreat was facilitated by catastrophic collapse of the ice sheet through the process of marine ice cliff instability. We used an ice sheet model to explore the Antarctic ice sheet under warm Pliocene climate, simulating grounding line and ice stream dynamics at relatively high resolution without marine ice cliff instability. To quantify uncertainties in basal sliding, surface mass balance processes, bedrock-ice sheet interactions and ice shelf basal melt sensitivity to ocean forcing, we ran a 120-member Latin Hypercube perturbed parameter ensemble. We explored the role of climate model choice in simulated Antarctic configuration, using four different climate models evenly divided across our ensemble. Additional experiments explored parametric uncertainty under a modern climate, and initial condition uncertainty. We simulated an Antarctic sea level contribution range of -16 to 28 m for our main ensemble, wider than the reconstructed Pliocene sea level range. We show that our modelling framework can simulate magnitude and location of Pliocene Antarctic mass loss consistent with proxy-based reconstructions under some modelling choices. However, simulated sea level contribution was highly sensitive to a perturbed basal sliding parameter. We show that using a reduced volume Pliocene initial ice sheet increases mean sea level contribution by 11 m, whilst subtracting a control ensemble increases mean sea level contribution by 8 m. This work demonstrates that combined margin retreat and sea level contribution constraints can reduce uncertainty in our model ensemble. It highlights the importance of uncertain basal processes in determining Antarctic sea level contribution on millennium time-scales.

Jim Marschalek - Imperial College London

A Large West Antarctic Ice Sheet Explains Early Neogene Sea-Level Amplitude

Early to Middle Miocene sea-level oscillations of approximately 40-60 m estimated from far-field records are interpreted to reflect the loss of virtually all East Antarctic ice during peak warmth. This contrasts with ice-sheet model experiments suggesting most terrestrial ice in East Antarctica was retained even during the warmest intervals of the Middle Miocene. Data and model outputs can be reconciled if a large West Antarctic Ice Sheet (WAIS) existed and expanded across most of the outer continental shelf during the Early Miocene, accounting for maximum ice-sheet volumes. Here, we provide the earliest geological evidence proving large WAIS expansions occurred during the Early Miocene (~17.72-17.40 Ma). Geochemical and petrographic data show glacimarine sediments recovered at International Ocean Discovery Program (IODP) Site U1521 in the central Ross Sea derive from West Antarctica, requiring the presence of a WAIS covering most of the Ross Sea continental shelf. Seismic, lithological and palynological data reveal the intermittent proximity of grounded ice to Site U1521. The erosion rate calculated from this sediment package greatly exceeds the long-term mean, implying rapid erosion of West Antarctica. This interval therefore captures a key step in the genesis of a marine-based WAIS and a tipping point in Antarctic ice-sheet evolution.

Jim Marschalek - Imperial College London

Pliocene Antarctic Sea Level Contribution inferred from Quantitative Sub-Ice and Marine Sediment Provenance Tracing

Tracing the provenance of Antarctic sediments yields unique insights into the form and flow of past ice sheets. However, sediment provenance studies are typically limited to qualitative interpretations by uncertainties regarding subglacial geology, glacial erosion, and transport of sediment both subglacially and in the ocean. To quantitatively determine what ice sheet state may produce a given provenance signature offshore, we here use the results of an ice sheet model and simple approximations of marine detrital particle transport processes to predict neodymium (Nd) isotope compositions in marine sediments. For the modern ice sheet, the algorithm's prediction closely agrees with seafloor surface sediments. Calibrating parameters to the modern setting permits application of the algorithm to potential Pliocene ice sheet configurations. Preliminary Pliocene results show significant changes to sediment provenance signatures around the Antarctic margin; these are of a similar magnitude to the changes observed in marine sediment cores. Comparison between the predictions of the algorithm and the measured Nd isotope compositions of Integrated Ocean Drilling Program (IODP) Site U1361 sediments constrains ice sheet retreat in the Wilkes Subglacial Basin, thus Antarctic sea-level contribution, during the Pliocene.

Joshua Solomon Avong - Ahmadu Bello University

Early to Late Miocene Biostratigraphy in the Niger Delta by integrating foraminifera bioevents and Paleoceonographic Implications

The Niger Delta is formed as result of the break up of Africa from South America continent in the Santonian and led to subsequent accumulation of Tertiary deltaic sediments leading to the deposition of the three formations(Akata,Agbada and Benin), caused by various sedimentation cycles due to ;tectonic processes, sea-level change and climatic influences. In this study, an integration of sedimentology, micropaleontology palaeobathymetry and sequence stratigraphic analysis was carried out. Foraminifera and nannofossil diversity were used for defining the age of candidate surfaces. Three foraminifera planktonic zones were proposed and correlated to the Neogene (N) 6 to N17 zone. Two calcareous nannoplankton zones were proposed, which spanned the Neogene Nannofossil (NN) 3 to NN11 zone. In this study interval, three third-order sea-level rises and falls occurred during the Early to Late Miocene; namely Cycle 10, 9 and 7 of the eleven (11) discrete Niger Delta Cycles recognized from the Global sea level chart. Regionally, Cycle 10 marked below by the 9.5 Ma Marker Shale, Cycle 9 was marked at the top by the 11.5 Ma Marker Shale and Cycle 10 marked below by the 15.9 Ma Marker Shale which suggested that these depositional cycles were produced by global eustatic movements, local delta tectonics and allocyclic and autocyclic sedimentation processes.These were shown by the Chiloguembelina-3 Shale (16.0 Ma), Dodo Shale (11.6 Ma) and the Uvigerina-8 Shale (9.2 Ma),which were associated with transgression.The study interval is said to have penetrated sediments of the parallic Early to Late Miocene Agbada formation.

Malcolm Hart - University of Plymouth

Indicators of sea level change in the areas bordering the Western English Channel

In areas bordering the Western English Channel (South Devon, South Cornwall, Channel Islands) there is abundant evidence of sea level changes throughout the Late Pleistocene and Holocene, such as infilled buried channels in estuaries (e.g., Plymouth Sound), submarine sea cliffs (Berry Head, Tor Bay), raised beaches and submerged 'fossil' forests. Many of these features have been investigated using microfossils (especially foraminifera). Offshore Jersey, in submarine cores, a peat has been recorded with a radiocarbon date of 8860±30 b.p., overlain by a succession that includes a typical benthic assemblage of foraminifera (e.g., Trochammina inflata, Jadammina macrescens) that are probably indicative of a saltmarsh environment. The overlying estuarine-like sediments are characterised by an assemblage dominated by Elphidium spp. and Ammonia spp., overlying which are marine clays and silts, including horizons rich in 'maerl' (calcareous algae) and abundant marine macrofauna. The dating of this Holocene peat and the overlying marine sediments provides an accurate chronology of sea level rise around Jersey, although a crustal subsidence rate of -4 mm/year must be used to increase the impact of the sea level rise and development of the present tidal regime. In the Torbay and Plymouth areas there are important terrestrial caves with a distinct megafauna as well as hominin remains and stone tools. Many of these have been dated and can be compared to marine caves (Berry Head caves) in which foraminifera have been washed in during interglacials when the caves were open to the sea, and glacial times when sediment access was impossible. South Devon is, therefore, one of the only areas in the UK where both a marine and a terrestrial record is present in caves within a restricted area. Some of the foraminifera washed into the Berry Head caves appear to be derived from the nearby sea grass meadows.

Martina L. G. Conti – University of York

Sea-level changes: molecular approaches to tell us the how and the when

The study of past sea-level changes is important to understand and predict future scenarios. Two key questions are: how was the paleoenvironment affected by sea-level changes, and when did the sea-level change occur? Sedimentological analyses and dating are key and in this work we explore geochemical ways of answering these questions. Targeted analysis of palaeontological evidence in sediment (e.g. pollen, foraminifera, microfossils) can help reconstruct the paleoenvironment, helping to provide data for rates of sea-level change. However, in some sequences microfossils are present only in low amounts, or are poorly preserved in the sediment, precluding detailed paleoenvironmental interpretation. In these cases, the molecular fossils trapped in the sediment matrix can help in the interpretation; these molecules tend to be well-preserved in sediments and can be biomarkers of specific groups of organisms that can be linked to palaeoenvironmental conditions via knowledge of their habitats. Using lipids and chlorophyll pigments, a more sensitive and accurate record of relative sea-level transgressions and their impact on palaeoclimate was recorded in Holocene and Mid-Pleistocene sediments. Alongside the identification of transgressive and regressive phases, dating is essential to contextualise the sea-level fluctuations. Where fossils are preserved, their intra-crystalline molecules have the potential to provide age information through amino acid geochronology (AAG). Previous studies on the marine gastropods Littorina and Nucella and foraminifera Ammonia and Neogloboquadrina pachyderma have provided relative dating spanning the Pleistocene period. In this work, we extend the aminostratigraphy to bivalves (Arctica islandica, Ostrea edulis and Cerastoderma edule), which have a more complicated shell microstructure. These case studies demonstrate the power of molecular approaches to reveal insights into past sea-level change.

Matteo Vachii – University of Pisa

Millennial variability of the sea-level changes along the western African coast

Merula Penning - Cardiff University

Resolving disparate sea level estimates from the earliest Pleistocene

There are significant discrepancies between different sea-level records from the earliest Pleistocene (2.3Ma – 2.6Ma) (Rohling et al. 2014; Jakob et al. 2020), with estimates of glacial-interglacial sea-level amplitudes differing by more than 60m, the approximate equivalent of the modern Antarctic Ice Sheet. The highest amplitude glacial-interglacial sea level changes are derived using benthic Mg/Ca temperatures at IODP Site U1313, and may be an artefact of changing bottom water chemistry (Rohling et al., 2022). This Site is a reoccupation of DSDP Site 607, known to have a strong bottom water mass signal on glacial-interglacial timescales later in the Pleistocene (Lear et al., 2016). However, an unusually large Laurentide ice sheet has been proposed for a glacial interval around 2.4Ma, where the ice limit reached a latitude (39˚N) more typical of the late Pleistocene (Balco and Rovey, 2010). Understanding glacial response to atmospheric CO2 concentrations (ρCO2) is key to understanding future sea level, so it is important to understand the reasons behind these disparate sea level estimates. We tackle this question using paired Mg/Ca and oxygen isotope records from IODP Site U1476 at the northern ridge of the Mozambique Channel. We chose this site because it bears a remarkable similarity to the LR04 oxygen isotope stack, perhaps reflecting near global average bottom water conditions. We focus on the 2.4-2.6Ma interval and use four key benthic foraminiferal species (Cibicidoides wuellerstorfi, Oridorsalis umbonatus, Uvigerina peregrina, and Melonis pompilioides), which have infaunal and epifaunal habitats. We analyse samples for oxygen and carbon isotope, and trace metal composition (Mg/Ca, B/Ca, Cd/Ca, U/Ca), to disentangle the temperature, carbonate saturation state, and the ice volume effects on the geochemical proxies. Our preliminary results will be discussed in terms of our understanding of these geochemical proxies, and the sensitivity of early Pleistocene ice sheets to changing ρCO2.

Olga Pepple - Rivers State University

Changes in Global sea level and mitigating factors

Factors that affect sea level changes and ways of mitigation

Ray Zammit - Cardiff University

Regional hydrology changes following the Middle Miocene glacio-eustatic sea level fall (13.8 Ma)

During the Mid-Miocene climate transition (13.8 Ma) the Antarctic Ice Sheet expanded significantly, and the Earth System accelerated its descent towards the modern bipolar icehouse. The associated global sea level fall likely caused the final and complete disconnection between the Indian and Atlantic Oceans through the Tethys Seaway. Here we present benthic and planktic foraminiferal geochemical data from the Island of Malta (Central Mediterranean) in order to investigate the response of North African climate to these events. We measured δ18O and δ13C of Trilobatus trilobus (planktic) and Heterolepa dutemplei (benthic), foraminiferal Mg/Ca Trilobatus trilobus (planktic) and Uvigerina spp. (benthic). This allowed us to determine surface and bottom water temperatures (using Mg/Ca paleothermometers) and the δ18O of sea water. The differences between calculated bottom water and surface water δ18O allowed us to differentiate between the ice-volume signal and the precipitation/evaporation signal in the seawater δ18O records. Our results reveal a transition to a North African climate regime experiencing orbitally paced super-humid intervals, suggesting that the sea level induced closure of the Tethys Seaway may have led to a marked intensification of the West African Monsoon system. The 6th IPCC report highlights great uncertainty in predicting future precipitation and drought over the North Africa. We therefore propose that the Miocene (23 to 5.5 Ma) represents a time of great hydrological variability in this region, and can act as a natural laboratory where we can explore the interactions between climate, hydrology, carbon cycling, and depositional processes using a combined data-modelling approach. This study highlights key climate feedbacks associated with a major glacio-eustatic sea level fall.

Robert John Morley - Palynova Ltd

Sea- and lake-level changes driven by glacio-eustacy provide a pulsebeat of transgressive-regressive cycles that enables precise stratigraphic correlation within Southeast Asian continental margin and lacustrine sediments.

Obtaining confident age interpretations using a traditional biostratigraphic approach fail in many of the continental margin successions across Southeast Asia since most of the microfossil extinction datums are diachronous due to a combination of facies and carbonate dissolution issues, whereas evolutionary appearances are affected by both facies and caving when cuttings samples are used, and so there is invariable subjectivity in placement of such datums. In continental margin successions there is a sedimentation ‘pulsebeat’ across Southeast Asia, independent of local and regional tectonics, driven by patterns of global sea level change. For the Oligocene and Miocene, Antarctic glaciation is the key driver, whereas the Pliocene cycles are mainly driven by the expansion and contraction of Northern Hemisphere glaciers. In marine-influenced successions this pulsebeat provides the basis for a detailed stratigraphy for the whole region. The cycles are captured as ‘SEA’ transgressive-regressive cycles, by integrating foraminiferal and palynological signals based on the systematic analysis of cuttings samples from petroleum exploration wells. The late Eocene to Pliocene is divided into 46 such divisions which are ‘fingerprinted’ in distal facies using age-restricted foraminifera, nannofossils and palynomorphs. In Oligocene and late Eocene non-marine basins, cyclicity patterns are also present, but away from a marine connection these are driven by 406 ka eccentricity-driven cycles. These can be calibrated to the absolute timescale using well-dated evolutionary appearances and extinctions of palynomorphs. Cyclicity patterns can be used to date both marine-influenced and non-marine successions and permit accurate correlation of marine and non-marine basins for the first time. The paper will discuss the approach of sequence biostratigraphy to stratigraphic interpretation using examples from Malaysia, Indonesia and Vietnam.

Sophie Slater - Cardiff University

Southern Ocean Response to Antarctic Glaciation at the Eocene-Oligocene Transition

The establishment of the Antarctic ice sheet at the Eocene-Oligocene Transition (EOT) caused a sea level fall of several tens of metres, and is recorded by a two-step change to the global ocean oxygen isotope record (e.g. Coxall and Wilson, 2011; Langton et al., 2016). Interpretation of this record in terms of ice volume / sea level change requires an independent paleothermometer (e.g. foraminiferal Mg/Ca or clumped isotopes), and an understanding of additional complicating factors on both proxies, including diagenesis, carbonate saturation state, and regional salinity variations. These have precluded quantitative analysis of the oxygen isotope record at some sites. Here we revisit the classic EOT section at Site 1218 (Equatorial Pacific), using new analytical techniques (Electron Probe Micro Analysis and Laser Ablation ICP-MS) to interrogate the existing Mg/Ca record, which at face value fails to record a cooling through the glaciation event. We discuss the implications of our results for sea level change through this greenhouse-icehouse transition. We also present paired planktic foraminiferal Mg/Ca, oxygen, and carbon isotope records from the EOT at ODP Site 1138 (Central Kerguelen Plateau), alongside intratest EPMA maps of Mg/Ca from selected samples. EPMA maps can show the presence of high-Mg banding within the test wall, which suggests whether the Mg/Ca record can be robustly interpreted in terms of temperature change (Staudigel et al., 2022). We reconstruct a two-step cooling and freshening across the EOT at ODP Site 1138, despite evidence that the second step in $\delta^{18}O$ is dominated globally by the ice volume signal with little cooling (e.g. Lear et al, 2008). We suggest that ODP Site 1138 recorded a local shift in surface water mass properties, likely reflecting a northward shift of the polar front as the ice sheet blanketed the continent.

Tijn Berends - Utrecht University

Distilling sea level changes from benthic δ18O

Benthic oxygen isotope concentrations (δ18O), recorded in oceanic sediments, are often assumed to reflect changes in global ice volume and deep-ocean temperature. Disentangling these two contributions is not straightforward, as they are not always in phase, so that the signal can at times be dominated by either process. However, because changes in both global ice volume and deep-ocean temperature are ultimately driven by changes in climate, they are still strongly related. Different approaches now exist to solve the inverse problem: “how should the global climate have changed in the past in order to produce the observed benthic oxygen isotope record?”. We use an ice-sheet model with an elaborate global paleoclimate component to produce self-consistent simulations of CO2, global climate, ice-sheet configuration, sea level, and benthic oxygen δ18O, throughout the Late Pliocene and Pleistocene. Our results agree well with available proxy data during colder-than-present climate periods, but show generally larger discrepancies during warmer periods. We expose crucial roles for feedbacks between ice geometry and regional climate, as well as for ice-dynamical instabilities, in the past evolution of Earth’s ice sheets and climate, marking the potential for future non-linear sea level rise.

Yang Zifei - Cardiff University

The impact of foraminiferal diagenesis on reconstructions of past sea level

Oxygen isotope and Mg/Ca ratios of foraminiferal tests are important geochemical proxies for reconstructing palaeo-ocean temperature, global ice volume and past sea level (Lear et al., 2000; Wara et al., 2005). Once buried in deep sea sediment, foraminiferal calcite tests may experience various diagenetic processes which can introduce bias into sea-level reconstructions (Raymo et al., 2018). These include partial dissolution, authigenic coatings such as calcite cement, and recrystallisation of the test calcite, during which biogenic crystallites are transformed into blocky calcite crystals typically 1-2 microns in diameter. The impact of recrystallisation on test geochemistry is the least well understood of these diagenetic processes, with recent modelling suggesting that it may impact oxygen isotopes before Mg/Ca (Staudigel et al., 2022). In this study, we generate a suite of geochemical and textural data from planktonic and benthic Oligocene foraminifera from a single time-slice (early Oligocene), from three ocean sites with different burial histories and preservation states. SEM images are used to show the microstructural alteration of foraminifera during diagenesis, and EPMA maps are used to evaluate the preservation of primary high Mg/Ca bands within the foraminiferal tests. We relate these textural and intra-test geochemical changes with the whole test element composition and oxygen isotope values. We present recommendations for reducing uncertainties in sea level reconstructions due to diagenetic processes.

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