Name: Mark Pagani

Affiliation: Yale University

Country: USA

Title of presentation: Creating a Cenozoic record of atmospheric CO_2

Name: Gretta Bartoli

Affiliation: ETH Zürich, Geological Institute

Country: Switzerland

Title of presentation: Atmospheric CO2 decline during the Pliocene intensification of Northern Hemisphere Glaciations

Abstract of presentation:

Several hypotheses have been put forward to explain the onset of intensive glaciations on Greenland, Scandinavia and Northern America during the Pliocene Epoch between 3.6-3.0 million years ago (Ma). A decrease in atmospheric CO_2 is may have played a role during the onset of glaciations but other tectonic and oceanic events occurring at the same time may have played a part as well. Looking at high-resolution atmospheric CO_2 records may be a way to disentangle between these various forcings through time. Here we present detailed atmospheric CO_2 estimates from boron isotopes in planktic foraminifer shells spanning 2.0-4.6 Ma. Our data confirm earlier estimates of elevated Pliocene atmospheric CO_2 compared to the Pleistocene but the greater data density allows us to determine CO_2 decreases across each step of the glaciation progress, as well as resolution of glacial and interglacial features. In particular, around 2.73 Ma, a 60-µatm drop in atmospheric CO_2 concentrations occurred coincident with the establishment of large-scale ice-sheets on the Northern Hemisphere and coeval with the increased ocean stratification in the North Pacific and the Southern Ocean. After the intensification of glaciations at 2.5 Ma atmospheric CO_2 concentrations stayed below 300 µatm until the 1940s.

Name: Aradhna Tripati

Affiliation: University of Cambridge

Country: UK

Title of presentation: B/Ca ratios in planktonic foraminifera from Sites 806 and 588: Systematics, climate implications, and questions

Co-authors: Robert Eagle, Christopher Roberts, Gaojun Li

Abstract of presentation:

We use new and published data to discuss the systematics of interpreting planktic foraminiferal B/Ca ratios. If the incorporation of boron into foraminiferal tests can be empirically described by (1) the apparent partition coefficient, $K_D = \frac{B/Ca_{CaCO_3}}{[B(OH)_4^-]/[HCO_3^-]_{seawater}}$ (Hemming and Hanson, 1992) and (2) a species-specific relationship between K_D and temperature(Yu et al., 2007), then shell B/Ca ratios can be used to accurately reproduce the ice core record of pCO_2. Although these two relationships may be robust, there is reason to suspect they may mask the true controls on boron incorporation into foraminifera. The observed correlation between temperature and K_D represents an empirical fit at best for several reasons. First, the correlation between temperature and K_D may be an artifact of the covariance of temperature and other hydrographic variables in the ocean, including carbonate system parameters. Second, there is evidence that K_D may be affected by solution $[HCO_3^-]/[CO_3^{2-}]$ ratios (i.e., pH), or by $[CO_3^{2-}]$. Finally, the theoretical basis for the definition of K_D and for a temperature control on K_D is of debate. These relationships do, however, allow us to reasonably approximate past pCO_2 over relatively short geological timescales, as indicated by comparison with the ice core record of pCO_2 for the past 800 ka. We apply this framework for interpreting B/Ca data to explore possible implications of a downcore record for the history of pCO_2 in the Neogene. Over the last 20 Ma, changes in foraminiferal B/Ca ratios and in reconstructed pCO_2 apparently were synchronous with major episodes of glacial expansion and contraction on East Antarctica, West Antarctica, and Greenland. B/Ca-based estimates of pCO_2 are similar to values inferred from foraminiferal boron isotopes for the past 10 Ma(Pearson and Palmer, 2000; Hönisch et al., 2009) and from plant stomatal density from ~20-12 Ma(Kürschner et al., 2008).

Name: Gavin Foster

Affiliation: University of Southampton

Country: UK

Title of presentation: Miocene to Pleistocene pCO_2 change - a comparison between Boron isotope and alkenone based pCO_2 records

Name: Bärbel Hönisch
Affiliation: Lamont-Doherty Earth Observatory
Country: USA
Title of presentation: Comparison of surface ocean carbonate chemistry proxies
Abstract of presentation: Over the last two decades alkenones, and planktic foraminiferal boron isotopes and B/Ca have been developed to estimate past atmospheric CO_2 variations. Continued proxy validation and improved temporal resolution have refined earlier estimates and a clearer picture of the interplay between climate and atmospheric CO_2 is emerging. However, many estimates are still based on unconfirmed assumptions, and not all estimates match up. I will present a comparison of CO_2 estimates from various time intervals of the Cenozoic, from different proxies and methods, and study similarities and differences. Such comparisons should help us to identify the underlying problems and thus to move forward to refined tests and improved reconstructions.

Name: **Peter K. Bijl**

Affiliation: **Biomarine Sciences, Institute of Environmental Biology, Faculty of Sciences, Utrecht University**

Country: **The Netherlands**

Title of presentation: **The Middle Eocene Climatic Optimum and pCO2: warming the doubthouse.**

Abstract of presentation:

The warmth of the Eocene "greenhouse world" (56-35 Ma) is generally considered to be related to generally elevated atmospheric carbon dioxide concentrations (pCO_2). Evaluation of this relationship is however hampered by the absence of high-resolution pCO_2-records. Here we present a reconstruction of pCO_2 and sea surface temperature (SST) over an episode of global warming, the Middle Eocene Climatic Optimum (MECO, ~40 Ma). Molecular paleothermometry (TEX_{86}, $U^{k'}_{37}$) reveals an increase in Southwest Pacific Ocean SST by 5-6°C. Warming is furthermore manifested by the incursion of low-latitude dinoflagellate cysts at the expense of high-latitude taxa. These results confirm a major SST perturbation associated with theMECO.We augmented the alkenone pCO_2 proxy with biotic information derived from microfossil assemblages in order toconstrain soluble phosphate concentrations, a critical parameter for application of this proxy. The marked consistency between SST and pCO_2 during the MECO leads us to suggest that pCO_2 is not only a driver for long-term Paleogene climate trends, but also for transient anomalies like the MECO. The combined SST and pCO_2-data contribute towards constraining high latitude climate sensitivity in the Paleogene "greenhouse world".

Name: Paul Pearson

Affiliation: School of Earth & Ocean Sciences, Cardiff University

Country: UK

Title of presentation: Boron isotope pCO_2 reconstructions from the Eocene / Oligocene transition of Tanzania

Paul Pearson (Cardiff), Gavin Foster (Southampton) and Bridget Wade (Leeds)

Abstract of presentation:

We recently published a set of boron isotope measurements on well preserved planktonic forminifera across the Eocene / Oligocene boundary of Tanzania which we used to make estimates of atmospheric pCO_2 (Pearson, Foster & Wade, 2009, Nature v. 661 p. 1110-3). Here we describe the challenge involved in obtaining the data and interpreting the results. We highlight the uncertainties involved in obtaining quantitatively reliable pCO_2 estimates. We discuss the implications of our estimates of pCO_2 change though this major climate transition and highlight the potential of future work in the Cretaceous and Paleogene sediments of Tanzania.

Name: James Zachos

Affiliation: University of California, Santa Cruz

Country: USA

Title of presentation: Cyclical and Transient pCO_2 change during the Paleocene and Eocene as inferred from coupled sediment geochemical records.

Name: Eric Wolff

Affiliation: British Antarctic Survey

Country: UK

Title of presentation: CO2 from ice cores – what we know and what we can hope for

Abstract of presentation:

Ice cores provide by far the most direct way to determine past atmospheric CO2 mixing ratios. The bubbles trapped in the ice enclose a sample of ancient air that, with careful treatment, provides a direct measure. The record extends 800 ka into the past, and shows the remarkable similarities between the changes in CO_2 mixing ratio and Antarctic climate over this period, as well as the unusual nature and rate of the recent increase. The next few years should see an improvement in our ability to state the phasing between temperature and CO2 changes, and a greatly increased volume of $^{13}CO_2$ data, giving clues to the causes of change. However, there is a huge appetite to go further back in time, especially across the mid-Pleistocene Transition, and into the era of 40 ka climate cycles. The international ice core community has formulated an “oldest ice” project and believes that a 1.5 Ma ice core ought to be achievable. However the likely location for such a core is not yet established and there are big scientific, logistical and financial challenges to overcome if such a record is to be obtained.

Name: Rob DeConto

Affiliation: University of Massachusetts

Country: USA

Title of presentation: What is the impact of CO2 on the Earth System?"

Name: Malte Heinemann

Affiliation: Max Planck Institute for Meteorology

Country: Germany

Title of presentation: High climate sensitivity to pCO2 during the Paleocene-Eocene

Abstract of presentation:

We investigate the sensitivity of the Paleocene-Eocene (PE) climate to a variation of atmospheric carbon dioxide concentrations (pCO2) using the coupled atmosphere-ocean-sea ice general circulation model ECHAM5/MPI-OM. Applying a moderate CO2 concentration of 560ppm yields a warm and ice-free model solution which resembles the climate before the onset of the Paleocene-Eocene Thermal Maximum (PETM). Decreasing pCO2 from 560 to 280ppm leads to a cooling at the surface by 4.7K, and to regrowing sea ice; the resulting climate is too cold to be a good PE surrogate. Increasing pCO2 from 560 to 840ppm yields a surface warming of 3.7K.

Fitting the model results to a one-dimensional energy balance model shows that about 65% of the warming are caused by decreased longwave emissivity of the clear sky atmosphere, about 35% of the warming are due to a decreased shortwave cloud radiative effect. These results suggest that the PE climate was very sensitive to a variation of pCO2 because of 1) a strong water vapour feedback especially in the tropics, and 2) a positive shortwave cloud feedback in the subtropics.

The simulated warming in response to the pCO2 increase from 560ppm to 840ppm is comparable to the reconstructed surface warming during the PETM. This suggests that a relatively small input of carbon -- possibly from methane hydrates -- could have caused the PETM.

Gilles Ramstein

Inferring thresholds in evolution of Carbon dioxyde during Cenozoic using climate models

An authors list

G. Ramstein, C. Dumas, N. Hamon, R. Waldman, S. Bonelli, P. Sepulchre, Y. Donnadieu

Abstract

The aim of this abstract is not yet related to fully coupled climate-carbon model simulations but on the use of climate models (EMICS or GCM) to infer plausible atmospheric CO2 values at different periods of the Cenozoic. The Cenozoic is a period of global CO2 decrease but this trend is not linear. Nevertheless it is during this period that ice sheets appeared. Using a climate model coupled with an ice sheet model (CLIMBER/GRISLI/GREMLINS) and using real insolation (Laskar) we depict the relative impact of CO2 decrease and Drake passage opeening 34 Ma ago, as well as the threshold in CO2 necessary, in our model, to trigger the Greenland inception. Both
thresholds for Antarctica and Greeenland are in agreement with data.
On the other side, we also investigated using FOAM GCM and snapshot simulations, the climate of Mid Miocene Climate Optimum (15 Ma) and, in agreement with other studies, we show that high CO2 values (2 PAL° are necessary to produce temperatures consistent with temperature reconstructions.

Name: Paul Valdes

Affiliation: University of Bristol

Country: UK

Title of presentation: Climate response to CO2 - the role of model parameters

Name: Maureen Raymo

Affiliation: Boston University

Country: USA

Title of presentation: What are the ultimate drivers of past greenhouse gas change

Name: **Professor Damon A.H. Teagle**

Affiliation: **School of Ocean and Earth Science, National Oceanography Centre, Southampton, University of Southampton, SO14-3ZH**

Country: **UK**

Title of presentation: **Does seafloor weathering play an important role in the global carbon cycle?**

Authorship:

Damon A.H. Teagle, Rosalind M. Coggon, Heiko Pälike, Jeffrey c. Alt and Christopher E. Smith-Duque

Abstract of presentation:

Whether the formation of new crust at oceanic spreading centres and its hydrothermal alteration at the ridges and across the vast ridge flanks is a source or sink of carbon to the oceans is an important parameter in understanding the Earth system. Changes in spreading rates (e.g., [1]) and the age-area distribution of the ocean crust (e.g., [2]) may impact the global carbon cycle if the uptake of carbon during ridge flank circulation is a persistent processes. The amount of carbon taken up by the ocean crust remains poorly quantified due to under sampling [3] but carbonate veins are much more abundant in Mesozoic ocean crust compared to Tertiary crust.

A new approach to estimate past seawater chemistry [4] from suites of carbonate veins formed within the ocean crust during ridge flank circulation, provides additional information on the timing and duration of carbonate vein forming events. This data shows that carbonate veins form in discrete events (<10 Myr.s) in relatively young crust although the time elapsed between crustal accretion and vein precipitation is variable. This suggests that carbonate vein formation is not a persistent process and that greater carbonate uptake by the oceanic crust during the Mesozoic reflects past oceanic conditions (e.g., pCO2, T). As calcium carbonate is one of the latest phases to form during ridge flank hydrothermal circulation, the timing of carbonate vein formation also gives a measure of the duration of effective chemical exchange between the oceans and ocean crust at a particular site.

[1] Muller, et al., *Science* **319**, 1357 (2008); [2] Seton et al., *Geology* **37**, 687 (2009); [3] Alt, J. C., D. A. H. Teagle, *Geochim. Cosmochim. Acta* **63**, 1527 (1999). [4] Coggon et al., Science, 327:1114-111710.1126/science. 1182252. 4th Feb,2010.

Name: Toby Tyrrell

Affiliation: National Oceanography Centre, Southampton

Country: UK

Title of presentation: Could the Rise in Coccolithophores have Lead to Global Cooling via Loss of Calcium from the Oceans?

Abstract of presentation:

Coccolithophores first became abundant in the Jurassic, then spread into the open ocean during the Cretaceous, producing thick beds of chalk in the Late Cretaceous. The slow climatic cooling from the Late Cretaceous greenhouse to the present icehouse has been accompanied by a decline in calcium ion concentrations in seawater. I will tentatively put forward a speculative hypothesis that these long-term changes to both [Ca^{2+}] and atmospheric CO_2 (climate) have been driven by the rise to abundance of pelagic coccolithophores. A possible mechanism for these linkages will be outlined, and evidence both for and against presented.

Name: Dr Albert Galy
Affiliation: University of Cambridge
Country: UK

Title of presentation: Erosion, climate and atmospheric CO_2: insight from the Taiwan orogen

Abstract of presentation:

Erosion, climate and atmospheric CO_2: insight from the Taiwan orogen

A. GALY1, D. CALMELS1, R.H. HILTON2, R.B. SPARKES1, N. HOVIUS1, A.J. WEST3 AND M.J. BICKLE1
1Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK (*correspondence: nhovius@esc.cam.ac.uk) 2Laboratoire de Géochimie et Cosmochimie, IPGP, 4 Place Jusieu, 75252 Paris, France. 3Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, UK

Systematic monitoring of river loads helps refine and extend the map of internal dynamics and external feedbacks in Earth's surface and near-surface system. Our focus is on Taiwan where erosion is driven by earthquakes and cyclonic storms. This gives rise to patterns of erosion that cannot be understood in terms of bulk characteristics of climate, such as average annual precipitation. Instead, these patterns reflect the distribution and history of extreme precipitation. Crucially, these events do not only mobilize large quantities of clastic sediment, but they also harvest particulate organic carbon (POC) from rock mass, soils and the biosphere. Most non-fossil POC is carried in hyperpycnal storm floods and its export is positively correlated with rainfall. Recent analysis of sediments deposited after the Typhoon Morakot in August 2009 - a typhoon with enhanced precipitation due to a monsoonal feed moisture level in the atmosphere - indicate the rapid burial and near complete preservation of POC in turbidites, representing a draw down of CO2 from the atmosphere that is potentially larger than that by silicate weathering in the same domain. Oxidation of fossil POC during exhumation and surface transport could offset this effect, but in Taiwan the rate of preservation of fossil POC is extremely high, due to rapid erosion and short fluvial transfer paths. Moreover, the silicate-weathering rate has been quantified in some catchment. Our 6-yrs survey displays a power-law relation relationship with discharge that allowed us to estimate chemical weathering rate with the 37-yr record of daily-discharge. We calculated that the total flux of cations (Na, Ca, Mg and K) released by silicate weathering is one of highest measured so far in the world. However, the detailed analysis of chemistry-discharge relationship implies the contribution of at least three components. One of these components has been identified as deep circulation and that deep chemical weathering of silicate accounts for 38% of the riverine silicate flux. The relative contribution of deep groundwater to the riverine solute load could thus be an important parameter in the control of chemical weathering fluxes worldwide. Its links with climatic parameter has yet to be established.

Name: Helen Coxall
Affiliation: Cardiff University
Country: UK
Title of presentation:
CCD deepening, ocean fertilization and CO_2 during the E-O climatic transition
Helen Coxall and Paul Wilson
Abstract of presentation:
Antarctic glacial inception at the Eocene-Oligocene (E-O) climate transition is characterized by a large ~1.0 ‰ ™$_{13}$C excursion lasting ~1 million years and a semi-permanent deepening of the global calcite compensation depth (CCD) that indicate a major perturbation to the carbon cycle. Gradually decreasing pCO_2 past a threshold is thought to be the underlying cause of the fundamental switch in climate mode but the carbon system force or feedback roles represented by the proxy signals, including 'overshoots' in ™$_{13}$C and carbonate accumulation, and their relationship with pCO_2 during the transition, remains poorly understood. We focus on this problem by presenting new and revised climate proxy records of glaciation and productivity change across the E-O transition from ODP Site 1218 in the eastern equatorial Pacific (EEP). The records constrain the timing of early Oligocene glaciation and suggest a 2-3 fold increase in EEP organic production and burial that correlates closely with records of opal accumulation from the Southern Ocean. The new data support the view of a major global increase in biomass production and burial in the early Oligocene for several hundred thousand years, likely driven by changes in ocean circulation, resulting in upwelling that fertilized surface waters. The similarity of Southern Ocean and equatorial records suggests the development, or strengthening of, an association between high and low latitude ocean circulation in the basal Oligocene. The inferred increase in biological carbon pumping, as well as contemporaneous CCD deepening, would be expected to have temporarily helped drawdown pCO_2, stabilizing early Oligocene ice-sheets. Recent proxy data however, suggest a temporary CO_2 rise associated with glacial inception. But do we fully understand the proxies or ocean-atmosphere carbon system interactions?

Name: Ros Rickaby

Affiliation: University of Oxford

Country: UK

Title of presentation: Unbalancing the carbonate system during glaciation.

Abstract of presentation: Ocean pH is one of the dominant controls on the partitioning of CO_2 between the atmosphere and ocean. The whole ocean CO_3^{2-}, a reflection of ocean pH, acts as a chemical mediator between the input of alkalinity to the ocean from continental weathering and the burial of alkalinity into carbonate sediments. Whole ocean CO_3^{2-} shifts to maintain a balance between the input and output fluxes via carbonate compensation. Any increase in CO_3^{2-}, and pH reflects an excess of weathering supply over burial and acts to draw-down atmospheric CO_2 into the ocean. Such an increase reflects a greater relative ratio of CO_3^{2-} to HCO_3^- ions in the ocean, effectively transforming the atmospheric exchangeable aqueous CO_2 into ionic species which exist only in the ocean. Cenozoic cooling and pCO_2 decrease must be associated with an imbalance between the rate of CO_2 supply to the ocean and atmosphere and the sink in the form of continental silicate weathering. We will use B/Ca records to explore the mechanism by which ocean pH feedbacks may alter the gearing of the pCO_2 response to silicate weathering during ice sheet growth and sealevel drop.

Name: **Philip Sexton**

Affiliation: **Cardiff University**

Country: **UK**

Title of presentation: **Late Pliocene atmospheric CO_2 drawdown from a stronger low latitude biological pump**

Abstract of presentation: **Although the precise cause of the late Pliocene Intensification of Northern Hemisphere Glaciation (INHG) has remained elusive, recent hypotheses have centred on oceanographic processes at high latitudes, particularly those reducing oceanic CO_2 outgassing. Here we propose that, while the ultimate trigger may have lain with high latitude oceans, a major proximal cause of the INHG was drawdown of atmospheric carbon dioxide levels at ~2.9 Ma caused by a long-term increase in sedimentary organic carbon burial at low and mid-latitudes. From 2.9 to 1.9 Ma, organic carbon burial rates across lower latitudes are, on average, 2.5 times those of the prior early Pliocene and the succeeding Pleistocene, and were likely driven by a coeval increase in diatom accumulation rates at lower latitudes. A contemporaneous late Pliocene collapse in diatom accumulation in the Southern Ocean suggests a global reorganisation of silicic acid cycling, whereby the modern confinement of surface ocean silicic acid (essential for diatoms) to the Southern Ocean (only 17% of total surface ocean area), was relaxed during the late Pliocene. In a macro-scale analogy to that hypothesised for the last glacial, greater silicic acid leakage into low and mid-latitudes from 2.9 to 1.9 Ma greatly expanded the available habitat range of diatoms and, consequently, their ability to draw down CO_2. Our findings indicate a greater role for the low latitudes in controlling atmospheric CO_2 levels than has been appreciated in recent decades, via wholesale ocean biogeochemical reorganisation strengthening the low and mid-latitude biological pump sufficiently to permanently sequester organic carbon into the sedimentary reservoir.**

Name: Richard E. Zeebe

Affiliation: School of Ocean and Earth Science and Technology, Department of Oceanography, University of Hawaii

Country: USA

Title of presentation: Long-term carbon cycle controls on atmospheric CO2 over the Cenozoic: The fine mass balance and the role of organic carbon.

Abstract of presentation: Feedbacks controlling long-term fluxes in the carbon cycle and atmospheric CO2 are fundamental to stabilizing Earth's climate over the Cenozoic. Based on available data, a strong case is made that atmospheric CO2 concentrations over millions of years are controlled by a CO2-driven weathering feedback that maintains a mass balance between the CO2 input to the atmosphere from volcanism, metamorphism and net organic matter oxidation, and its removal by silicate rock weathering and subsequent carbonate mineral burial. The present contribution will focus on the fine mass balance of long-term carbon fluxes that can be derived from reconstructions of atmospheric CO2 and ocean chemistry records. In addition, the potential role of organic carbon in driving greenhouse gas changes over the Cenozoic will be discussed.

Name: Cecily Chun

Affiliation: University of Southampton

Country: UK

Title of presentation: PETM climate sensitivity: Reconciling the relative roles of CO_2 and CH_4

Abstract of presentation: The predictions of recent carbon cycle models of the atmospheric

CO_2 change that occurred during the Paleocene-Eocene Thermal Maximum create difficulties in reconciling the reconstructed warming across the event with what we think we know about climate sensitivity. While the nature of climate sensitivity across geological events may be qualitatively different from values calculated using ocean-atmosphere models and on a century time-scale, the warming is still rather greater than commensurate with estimated CO_2 rise. Appreciating the possible role of changes in atmospheric CH_4 concentrations can help. In particular, results from a methane-enabled Earth system model suggest that initial PETM carbon release to the atmosphere in the form of CH_4 rather than CO_2 could enhance the warming during the interval of release by an average of ~50%, reducing the effective warming that CO_2 changes must explain.

MODERN ACIDIFICATION OF BENTHIC FORAMINIFERA: UNDERSTANDING EVENTS AT THE PETM

Malcolm B. Hart, University of Plymouth, U.K., **Bruna B. Dias**, Universidad Federal de Santa Catarina, Florianopólis, Brazil, **Christopher W. Smart**, University of Plymouth, U.K. and **Jason M. Hall-Spencer**, University of Plymouth, U.K. (e-mail: mhart@plymouth.ac.uk)

The seas around the island of Ischia (Italy) have a variable and, on average, lowered pH as a result of volcanic gas vents that emit carbon dioxide from the sea floor at ambient seawater temperatures. These areas of acidified seawater provide natural laboratories in which to study the long-term biological response to rising CO_2 levels. Benthic foraminifera are routinely used to interpret the effects of climate change as they have short life histories, are environmentally sensitive and have an excellent fossil record. Here, we examined changes in foraminiferal assemblages along gradients in pH at CO_2 vents on the coast of Ischia as they may provide a useful model on which to base future predictions of the consequences of ocean acidification. We show that foraminiferal abundance, diversity and ability to calcify decreased markedly in living and dead assemblages as pH decreases, the result of CO_2 percolating through the seawater. These results are in accord with the responses recorded by coralline algae, corals, molluscs, barnacles and echinoderms at the same sites.

Samples from the normal (pH8.17) environments around Ischia contain a diverse fauna dominated by miliolid foraminifera (e.g., *Peneroplis planatus*, *P. pertusus*, *Quinqueloculina* spp.) while those from areas with reduced pH (7.8 to 7.6) have faunas that are progressively less diverse and composed of <100% agglutinated taxa (e.g., *Ammoglobigerina globigeriniformis*, *Miliammina fusca*, *Trochammina inflata*, *Textularia* sp. cf. *T. bocki*). The changes in the benthic foraminifera are quite dramatic for only a slight reduction in pH and confirm the possibility that events, such as the PETM, could quite easily record a widespread loss of diversity or extinction as a result of ocean acidification.

Work on Ischia is on-going and there is a parallel example under investigation on the south-east coast of the island of Vulcano (Mediterranean Sea).

Name: Hayley Manners
Affiliation: University of Plymouth
Country: England

Title of presentation: Understanding the Sensitivity of the Earth's Climate to CO_2 forcing: Comparative Organic Geochemistry of Hyperthermal Events

Abstract of presentation:

The Paleocene/Eocene Thermal Maximum (PETM) occurred approximately 55 Ma, lasting for 100 – 200 Kyr, initiating a period of global warming, biotic extinction and migration, and fundamental changes in the carbon and hydrological cycles [1]. During the PETM it is estimated that 4500 Gt of carbon was released into the environment, causing global temperature rises of up to 9°C [1], comparable to that released if the entire fossil fuel resource base was burned [2], thus understanding this event is of significant topical importance. The most widely accepted theory as to how the event occurred remains the release of methane hydrates, which were subsequently oxidised to carbon dioxide. Marine and terrestrial sediments record the event, however discrepancy between the carbon isotope excursion (CIE) measured in the two realms has been observed ($\delta^{13}C$ marine 2.5 - 4 ‰, $\delta^{13}C$ terrestrial 6 - 8 ‰). Two hypotheses have recently been proposed for this discrepancy – the "marine modification" and the "plant community change" hypothesis [2]. The plant community change hypothesis states that the true magnitude of the CIE is overestimated in the terrestrial realm owing to major changes in floral composition during the PETM from gymnosperms (conifers) to angiosperms (flowering plants) [2, 3]. This hypothesis will be tested as angiosperms in the present day are known to be ca. 2.5 – 6 ‰ more depleted in ^{13}C than conifers; if the same discrimination occurred in Paleocene-Eocene vegetation then the records would be in agreement. To date, the plant community change hypothesis has been tested in North America and the Arctic. I will test the hypothesis across a terrestrial to marine transect in Northern Spain. A series of *n*-alkanes will be extracted and analysed to measure the average chain length and $\delta^{13}C$, also biomarkers characteristic of the different types of flora during the event will be measured to determine whether a change in the dominant flora occurred.

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1. Bowen G. J., Bralower T. J., Delaney M. L., Dickens G. R., Kelly D. C., Koch P. L., Kump L. R., Meng J., Sloan L. C., Thomas E., Wing S. L. and Zachos J. C. (2006) Eocene hyperthermal event offers insight into greenhouse warming. *Eos: Transactions of the American Geophysical Union*. **87**, 165 - 169.

2. Smith F.A., Wing S.L., Freeman K.H. (2007) Magnitude of the carbon isotope excursion at the Paleocene–Eocene thermal maximum: The role of plant community change. *Earth Plan. Sci. Lett.* **262**, 50-65

3. Schouten S., Woltering M., Rijpstra W.I.C., Sluijs A., Brinkhuis H. and Sinninghe Damsté J.S. (2007) The Paleocene-Eocene carbon isotope excursion in higher plant organic matter: Differential stable carbon isotopic fractionation of angiosperms and conifers on the Arctic continent. *Earth Plan. Sci. Lett.* **258**, 581-592.

Luke Handley

"Pronounced surface water warming in the Cretaceous subtropical North Atlantic across Oceanic Anoxic Event 1a"

Abstract:
A new TEX86 based sea surface temperature (SST) record from the Galicia Margin (ODP Site 641C) reveals significant and sustained warming of subtropical North Atlantic surface waters during Oceanic Anoxic Event 1a (OAE 1a, ca. 120 Ma) in the early Aptian. Off the Galicia Margin, SSTs progressively rose by more than 5°C to well above 30°C over the course of the OAE and elevated temperatures are sustained over several 100 kyr before decreasing by the same order of magnitude as the initial rise. The onset of the warming pulse is synchronous with a negative carbon isotope excursion, adding support to the proposed deterioration of marine gas hydrates as one possible trigger for the event. The main phase of surface water warming, however, is correlated to the initiation of a long-lasting volcanic episode in the Pacific Ontong Java area, suggesting that the prolonged emission of volcanic greenhouse gases was the principal driver for the prolonged warming during OAE 1a. Intermittent increases and decreases in SST of 1 to 4°C are superimposed on the overall warming trend of the Galicia Margin record, suggesting a causal link with similar, but more pronounced, cooling episodes reported from the central Pacific region. The exact nature and timing of these intervals and their direct relation to volcanic activity remains to be elucidated, but we suggest that global fluctuations in pCO2, possibly in response to variations in volcanic activity, may have been responsible for the observed fluctuations in SST in both oceanic basins.

Name: Diederik Liebrand

Affiliation: National Oceanography Centre Southampton

Country: United Kingdom (Dutch nationality)

Title of presentation: Early Miocene episodes of enhanced climate instability paced by multiples of long-term (400 kyr) eccentricity cycles

Abstract of presentation: The Oligocene and Miocene (33.9 to 5.3 Ma) represent epochs in Earth's history that comprise large ice-sheet fluctuations on Antarctica (Coxall et al., 2005; DeConto and Pollard, 2003; Lear et al., 2000). Maximum ice-sheet expansions are clearly depicted in deep-sea oxygen isotope records as the quasi-periodic Oi and Mi episodes (Miller et al., 1991; Wright and Miller, 1992). High-resolution stable isotope records for this time interval are sparse, which limits a thorough evaluation of the orbital pacing theory of these episodes (Billups et al., 2002; Billups et al., 2004; Pälike et al., 2006a; Pälike et al., 2006b; Paul et al., 2000; Zachos et al., 1997; Zachos et al., 2001b). Here we present new oxygen and carbon stable isotope records from the Walvis Ridge in the southeastern Atlantic Ocean, which resolves early Miocene at less than 3 kyr resolution. Our results indicate that the oxygen and carbon stable isotope variability is primarily determined by the long-term (406 kyr) eccentricity cycle, supporting a close link between deep-sea temperature, Antarctic ice volume and changes in the carbon cycle. The Mi-episodes stand out in the oxygen isotope record as periods of amplified climate instability paced by the short-term eccentricity (~100 kyr) cycle and occur four (or two) long-term eccentricity cycles apart from each other

Name: Sindia Sosdian

Affiliation: Cardiff University

Country: Wales

Title of presentation: North Atlantic Climate Evolution across Plio-Pleistocene Climate transitions

Author list: Lawrence, K.T., **Sosdian, S**., Rosenthal, Y. and H.E. White

Abstract of presentation:During the Plio-Pleistocene, the Earth witnessed the growth of large northern hemisphere ice sheets and profound changes in both North Atlantic and global climate. Here, we present a 3.2 Myr long, orbitally-resolved alkenone surface sea surface temperature (SST) record from Deep Sea Drilling Project (DSDP) Site 607 (41ºN, 33ºW, water depth 3427 m) in the North Atlantic Ocean. We employ a multi-proxy approach comparing these new observations with existing bottom water temperature (BWT) and stable isotope time series from the same site and sea surface temperature (SST) time series from other sites, shedding new light on Plio-Pleistocene climate change. The remarkable consistency in trend and structure of these records suggests a strong common influence of northern hemisphere high latitude processes. All North Atlantic temperature records show a long-term cooling with two major steps occurring during the late Pliocene (3.1 to 2.4 Ma) and the mid-Pleistocene (1.4 to 0.6 Ma), coincident with intervals of major change in northern hemisphere ice sheets. Existing evidence suggests that late Pliocene transition may have been caused by a threshold response to secular changes in atmospheric CO_2. In contrast, while an explanation for the MPT may also involve glacial-interglacial changes in atmospheric CO_2, it seems to also require changes in the behavior of the ice sheets themselves. While both surface and deep ocean temperature records at site 607 exhibit the classic shift in dominant periodicity from 41k to 100k in association with the intensification of NH ice ages around 0.9 Myr ago, their phasing relative to the benthic oxygen isotope record (d18Ob) changes markedly across this transition. The similarity observed in phase behavior of SST and BWT records during the 41k world is consistent with a strong common NH high latitude imprint both on the surface and deep sea temperatures. The lead of BWT on SST after the climate transition suggests, however, a shift from strongly northern to southern hemisphere influence on N. Atlantic bottom water temperatures. The evolution of these proxy phase relationships speaks to a complex control on and history of ice sheet, deep ocean circulation, and water column temperature changes across Plio-Pleistocene climate transitions.

Name: Catherine Bradshaw

Affiliation: BRIDGE

Country: UK

Title of presentation: Constraining paleo-CO2 estimates for the Late Miocene through the use of model-data comparisons

Abstract of presentation:

The period following the Mid-Miocene Climatic Optimum experienced a continued downward trend in the $\delta^{18}O$ record - this record is generally believed to a proxy indicator of both ice volume and temperature (Zachos et al., 2001). Given the link between atmospheric CO_2 and temperature (IPCC, 2007), it could be thought that the timeline throughout the Late Miocene would show a general decline in CO_2 in accordance with the $\delta^{18}O$ record. Examination of the palaeo-CO_2 record, however, shows a relatively flat profile across this time, or perhaps even a slight increase, but there is a wide variation in the palaeo-CO_2 estimate for the differing approximation methods.

We use the fully coupled atmosphere-ocean-vegetation model HadCM3L (Hadley Centre Coupled Model, Version 3 - low resolution ocean) with TRIFFID (Top-down Representation of Interactive Foliage and Flora Including Dynamics: Cox, 2001) to generate CO_2 sensitivity scenarios for the Late Miocene: 180ppmv, 280ppmv and 400ppmv, as well as a preindustrial control simulation: 280 ppmv. We also run the BIOME4 model offline to produce predicted biome distributions for each of our scenarios. We compare both marine and terrestrial modelled temperatures, and the predicted vegetation distributions for these scenarios against available palaeodata

As we simulate with a coupled dynamic ocean model, we use planktonic and benthic foraminiferal-based proxy palaeotemperature estimates to compare to the modelled marine temperatures at the depths consistent with the reconstructed palaeoecology of the foraminifera. We compare our modelled terrestrial temperatures to vegetation-based proxy palaeotemperatures, and we use a newly compiled vegetation reconstruction for the Late Miocene to compare to our modelled vegetation distributions. The new Late Miocene vegetation reconstruction is based on a 200+ point database of palaeobotanical sites. Each location is classified into a biome consistent with the BIOME4 model, to allow for easy data – model comparison.

We use all these data - model comparisons to constrain the best-fit scenario and the overall most likely Late Miocene CO_2 estimate according to the model simulations.

Name: Martin Butzin

Affiliation: University of Bremen, MARUM-Center for Marine Environmental Sciences

Country: Bremen, Germany

Title of presentation: Marine carbon cycle changes according to Miocene climate simulations, by M. Butzin, G. Knorr, T. Bickert, and G. Lohmann

Abstract of presentation: Carbon dioxide reconstructions point to an enigmatic decoupling between atmospheric CO_2 levels and climate during the Miocene. Here, we present first results of a modelling sensitivity study in which we investigate the response of the marine carbon cycle to environmental changes typical for the Miocene. We employ the results of fully coupled climate simulations to run an offline model of the marine carbon cycle which is also able to diagnose atmospheric CO_2 concentrations.

Name: Kujau, Ariane

Affiliation: Ruhr-University Bochum

Country: Germany

Title of presentation: Organic-geochemical characterization of sediments deposited during a time of severe carbon cycle perturbations during the lower Cretaceous (SE France). (Preference for poster presentation)

Abstract of presentation:

The Valanginian (136.8-133.9 Ma) is characterized by a significant Carbon Isotope Excursion (CIE) of ~2.5 permil, lasting for more than 2.0 Ma, which represents the first of a number of prominent carbon cycle perturbations during the Cretaceous. Here, this event is investigated for the first time on a high resolution with a combined stable-isotope and biomarker approach (incl. compound-specific analyses). Sample material was collected from three sites located in SE France (Vocontian Basin), with all sites being deposited in a hemipelagic setting. According to existing scenarios, the Valanginian CIE was accompanied by increased volcanic activity leading to enhanced pCO_2 and widespread biocalcification crisis, followed by a distinct cooling phase. The occurrence of oceanic anoxia associated with the CIE is still a controversial issue. Biomarker data including *n*-alkane ratios, dinosterane (indicative of dinoflagellates), 2α-methyl-hopane (indicative of cyanobacteria) and 3β-methyl-hopane (indicative of methanotrophic bacteria) show no distinct changes at the onset of the CIE. Abundances for these compounds are quite low during the initial phase of the CIE, whereas enhanced concentrations (except for cyanobacteria markers) are observed during the recovery phase. The comparison of $\delta^{13}C_{org}$ and $\delta^{13}C_{carb}$ curves shows a similar evolution during the onset of the CIE. However, this trend is decoupled in the upper part, with $\delta^{13}C_{org}$ values remaining comparatively heavy, while $\delta^{13}C_{carb}$ values are declining towards pre-excursion values. This lack of synchronicity in the two different substrates may indicate that severe pCO_2 variations took place during the Early Cretaceous.

Name: Edward Gasson

Affiliation: University of Bristol

Country: UK

Title of presentation (poster):

Exploring uncertainties in the relationship between temperature and sea level over the past 50 million years.

Abstract of presentation:

Given projected 21st century warming, determining the rate and form of the relationship between temperature and sea level is critical to understanding future equilibrium sea level. This relationship is investigated using proxy sea level and temperature records from the past 50 million years. This period is chosen as it provides a full spectrum of sea levels higher than present. As the proxy records on this timescale contain large uncertainties a full exploration of errors is undertaken. It is shown that a nonlinear function provides a physically plausible fit to the data. Fitting is undertaken using total least squares to account for errors in both variables. The data suggests that there are rapid transitions between multiple quasi-stable states, consistent with ice-sheet modelling studies.

Name: Michael Henehan (POSTER)

Affiliation: National Oceanography Centre, Southampton

Country: UK

Title of presentation: Ground-truthing the Boron Isotope Proxy

Abstract of presentation:

Anthropogenic ocean acidification, often referred to as "the other CO_2 problem", is garnering an increasing amount of scientific attention. Surface waters have experienced a post-industrial drop in pH of 0.1, and may well see a further 0.3-0.4 pH decrease by 2100, with some oceans becoming undersaturated with regards to aragonite as a result. Consequences for the global biota and ocean-climate system remain largely uncertain, despite a profusion of culturing and modelling work. One prospective aid for the forecasting of future changes, defining 'tipping points' and informing mitigation strategies is the study of the effects of past ocean acidification events. Unfortunately, such research has been impeded by a dearth of reliable proxies for the oceanic carbonate system.

The Boron isotope-pH proxy has huge potential to document past carbonate system conditions. Yet, while its theoretical foundations are sound, its applicability until recently remained questionable, due mainly to uncertainty over the magnitude of isotope exchange between boron species in seawater ($^{11-10}K_B$), and to poor reproducibility and accuracy of published $\partial^{11}B$ measurements. Recent years however have seen significant advances in the field including a new empirically-derived value for $^{11-10}K_{B,}$ and the advancement of MC-ICPMS measurements (offering precision of ~0.25‰ from as little as 10 ng of boron). Consequently, researchers are now close to realising the proxy's rich potential.

Building on these recent advances, this project aims to further 'ground-truth' the boron isotope proxy via a combination of foraminiferal species calibrations (culture-, tow- and core-top-based). Such an approach will shed light on not only foraminiferal calcification processes and the often-implicated 'vital effects' but also ultimately provides a solid foundation for the successful application of the proxy to the geological record.

Name: George Swann

Affiliation: NERC Isotope Geosciences Laboratory

Country: UK

Poster presentation

Title of presentation: **Carbon dynamics in the Subarctic North Pacific Ocean during the intensification of major Northern Hemisphere Glaciation**

Abstract of presentation:

The development of large ice-sheets across the Northern Hemisphere during the late Pliocene and the emergence of the glacial-interglacial cycles which punctuate the Quaternary geological record marks a significant threshold in the Earth's climate history. Whilst a number of different mechanisms have been proposed to initiate the global cooling and glacial advances associated with these transitions, uncertainty remains over the extent to which a lowering of atmospheric greenhouse gases may have contributed towards these changes. Records of diatom $\delta^{13}C$, $\delta^{30}Si$ and C/N ratios are employed here to suggest that reduced deep water upwelling and nutrient availability in the photic zone in the North West Pacific Ocean from 2.78 Ma to 2.73 Ma led to a lowering of surface water pCO_2. Such changes may have decreased rates of oceanic CO2 ventilation to the atmosphere and provided a key support mechanism in lowering global temperature from 2.78 Ma onwards. In combination with other oceanic/atmospheric changes, these events would have aided the progressive advancement of ice-sheets across the Northern Hemisphere, culminating in the development of a halocline stratification in the North West Pacific at c. 2.73 Ma which further lowered atmospheric *p*CO2 and the intensified the onset of major Northern Hemisphere Glaciation.

Name: Erin McClymont

Affiliation: Newcastle University

Country: U.K.

Title of presentation: Glacial-interglacial $\delta^{13}C_{alkenone}$ results across the mid-Pleistocene transition: preliminary results from the SE Atlantic (POSTER)

Abstract of presentation:

Key transitions in climate over the Pliocene and Pleistocene have been linked to falling atmospheric CO_2 concentrations, but data to confirm these hypotheses are limited for periods earlier than those of the ice-core records. Here, we present preliminary data from the analysis of $\delta^{13}C$ in alkenones, $\delta^{13}C$ in planktonic and benthic foraminifera, and potential assessments of nutrient contents and/or primary productivity. We have selected samples from the 41-kyr world (pre-1.2 Ma) and across the transition to the 100-kyr world (after 0.9 Ma). Our focus is on the SE Atlantic, outside of the main upwelling cells. The preliminary data show that strong correlations exist between ε_p and the sea-surface temperatures quantified using the alkenone U^K_{37}' index. A more complex relationship to alkenone and pigment fluxes and $\delta^{13}C$ in foraminiferal calcite is explored.

Name: JOE STEWART

Affiliation: University of Southampton, NOCS

Country: UK

Poster title:

Lithium isotope proxy for silicate weathering rates across the Oligocene-Miocene boundary (POSTER)

Abstract:

On geological time scales (10^5-10^7yrs) the level of atmospheric CO_2 is primarily controlled by the balance between inputs from metamorphism and mantle degassing and the output through weathering of silicate rocks[1]. Records showing changes in silicate weathering rates in the past are vital to our understanding of the long-term processes that precondition the climate system, perhaps triggering threshold shifts in global climate. One proposed proxy record for silicate weathering is the measurement of lithium concentration and isotopic composition in planktonic foraminifera[2].

One of the major sources of Li in seawater is riverine input derived from chemically weathered silicate rocks. Changes in the silicate weathering rates therefore affect the riverine flux of Li and the total Li concentration of the oceans.

During transit to the ocean, Li can be removed by the formation of secondary clay minerals in rivers. The process of secondary mineral formation causes isotopic fractionation of Li to occur due to the clay mineral affinity for the lighter ^{6}Li isotope (up to 20‰ in the modern Amazon basin[3]). The lithium isotopic composition of seawater can therefore give insight into the amount of Li removed from the system before reaching the oceans.

The Mi-1 glaciation at the Oligocene-Miocene boundary (23Ma) was a transient yet substantial perturbation in Cenozoic climate[4]. We are in the process of generating lithium isotope (δ^7Li) and Li/Ca ratios in planktonic foraminifera across the O-M boundary (21.5 - 24.5Ma) from ODP site 925A & 926B (Ceara Rise) in order to assess silicate weathering during this interval. It is hypothesised that a high temporal resolution Li/Ca record will yield a proxy for the changes in net flux of Li from silicate weathering sources. In conjunction, δ^7Li measurements will allow the degree of Li removal into secondary minerals to be evaluated hence giving a gross flux of silicate weathering-derived Li.

Careful species selection and understanding of the chemical variation due to vital effects are fundamental to this study. We present detailed trace-element/Ca and stable oxygen and carbon isotope measurements of various planktonic foraminifera species, in particular *G.venezuelana*, to be used in conjunction with previous studies of Oligocene-Miocene taxa[5, 6]. This preliminary work allows us to assess any temporal changes in vital effects to ensure that Li analyses are representative of past seawater Li concentrations.

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6. Pearson, P.N. and B.S. Wade, *Taxonomy and stable isotope paleoecology of well-preserved planktonic foraminifera from the uppermost Oligocene of Trinidad.* Journal of Foraminiferal Research, 2009. **39**(3): p. 191-217.

Name: James Rae

Co-authors: Gavin Foster, Daniela Schmidt, Tim Elliott

Affiliation: Bristol Isotope Group, Department of Earth Sciences, University of Bristol

Country: UK

Title of presentation:

Boron isotopes in benthic foraminifera and palaeo-CO_2 in the deep ocean

Abstract of presentation:

The cause of glacial-interglacial CO_2 changes has been described as the “holy grail” of palaeoclimatology. All models currently proposed invoke changes in deep ocean carbon storage, but the mechanisms by which this took place remain unclear. Boron isotopes in benthic foraminifera have long held the potential to track deep-ocean pH and thus CO_2 storage, but their reliability has been questioned. We have measured boron isotopes by MC-ICPMS in modern samples, which show a good match to ocean pH and are entirely consistent with our theoretical model of the boron-isotope – pH proxy. We have applied this proxy over the last 25 kyr in the deep Southern Ocean. Our data show a deglacial pH changes consistent with deep ocean carbon storage and carbonate compensation in this region.

Name: Tim Elliott

Affiliation: UoB

Country: UK

Title of presentation: Li isotope variations in seawater over the last 60Ma; speculations on changing weathering intensity of CO_2 drawdown

Abstract of presentation: We have developed a method to make high precision (0.3‰) analyses of the Li isotopic composition of foraminifera on small sample sizes (~1ng). This has allowed us to investigate changing d^7Li in mono-specific foraminferal tests over the last 60Ma. Although there are additional issues that need to be considered (minor core top variability in the modern species and the need to use several species to produce a 60Ma year record), there is a strong first order increase in d7Li over the last 60Ma that at face value seems explicable as an increase in the intensity of continental weathering.