Foreword

The UK IODP Symposium is aimed at the UK IODP science community and is an opportunity to highlight important scientific achievements from the current IODP phase, and to solicit contributions and challenges that will take Ocean Research Drilling forward post 2013, when the existing programme ends. The UK IODP Symposium will be attended by a number of NERC Theme Leaders which will give the UK IODP community a chance to demonstrate and influence the future value and direction of the UK programme.

The two-day conference will cover a range of scientific themes:

- Geological Hazards, Seismogenic Zones and beyond
- Evolution of the Planet
- Climate, Sea-level, ice-sheets and Greenhouse/Icehouse states
- New Adventures into the Subsurface and Deep Biosphere

The conference aims to showcase post-graduate, PhD and post-doctorate research which has made use of the extensive wealth of data collected during the varied IODP Expeditions.

A session of the conference is dedicated to an open discussion on the future IODP Programme beyond 2013. During the open session conference participants will have the opportunity to present their thoughts on what IODP should focus on in the future. These thoughts will be taken circulated to the organizing committee of the IODP INVEST 2009 conference taking place from the 23rd to the 25th September 2009 at the University of Bremen, Germany. INVEST is being organized as a large, multidisciplinary, international community meeting, whose focus is to define the scientific research goals of the second phase of the IODP, expected to begin late in 2013. INVEST is open to all interested scientists and students as the principal opportunity for international science community members to help shape the future of scientific ocean drilling.

www.marum.de/en/iodp-invest.html

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Monday 18th May		
10:00-10:15	Welcome and Introduction	Alan Thorpe
10:15-10:45	KEYNOTE: Science and Society: Volcanic Hazards	Steve Sparks (Bristol)
10:45-11:00	IODP Overview and News	Sir Geoffrey Allen
Geological Hazards, Seismogenic Zones and beyond (CHAIR: Tim Henstock, NOCS)		
11:00-11:30	KEYNOTE: NanTroSEIZE: overview and initial results from the Nankai Trough Seismogenic Zone IODP drilling project	Harold Tobin (USA)
11:30-11:50	Ocean drilling on the Sumatran subduction zone margin: Understanding forearc development and the earthquake cycle	Lisa McNeill (NOCS)
11:50-12:30	**COFFEE BREAK and POSTERS**	
12:30-12:50	Rapid sedimentation, overpressure, and submarine landslides along continental margins: insights from IODP Expedition 308	Peter Flemings (USA)
12:50-13:40	**LUNCH BREAK**	
Evolution of the Planet (CHAIR: Damon Teagle, NOCS)		
13:40-14:00	Results from Superfast Spreading Crust Drilling	John MacLennan (Cambridge)
14:00-14:20	Accretion of the lower oceanic crust at fast-spreading ridges: preliminary results of a UK IODP site survey at Hess Deep	Chris MacLeod (Cardiff)
14:20-14:40	Geological and geophysical studies of the Mid-Atlantic Ridge, 12°30'N to 14°30'N: the birth and death of oceanic core complexes	Bramley Murton (NOCS)
14:40-15:00	Long-term borehole hydrologic monitoring, and observations of seismic and aseismic strain at ridge crests and subduction zones	Earl Davis (Geological Survey of Canada)
15:00-15:30	**COFFEE BREAK and POSTERS**	
Biogeochemical cycles and sea-water chemistry (CHAIR: Tim Elliott, Bristol)		
15:30-15:50	Variable Quaternary weathering budgets and ocean biogeochemical cycles	Derek Vance (Bristol)
15:50-16:10	The Lesser Antilles: interaction between volcanism and ocean chemistry	Martin Palmer (NOCS)
16:10-16:30	What fractured oceanic crust can tell us about sea-water chemistry in the past	Roz Coggon (Imperial College)
16:30-17:00	NERC Theme Leader forum: discussion and Q&A	Contribution from NERC theme leaders
17:00	**End Day 1 Nibbles, drinks and posters**	

Tuesday 19th May 2009		
Climate, Sea-level, ice-sheets and Greenhouse/Icehouse states (CHAIR: Gideon Henderson)		
09:00-09:30	KEYNOTE: A unique climate archive of the last interglacial period recovered from IODP site U1304 on the Gardar Drift	Dave Hodell (Cambridge)
09:30-09:50	The timing and form of the penultimate deglaciation: new coral constraints from IODP Expedition 310 "Tahiti Sea Level"	Alexander Thomas (Oxford)
09:50-10:10	Changes in ocean circulation and the global carbon cycle during the last interglacial-glacial transition: Marine Isotope Stage 5a to 4	Stephen Barker (Cardiff)
10:10-10:30	Records of climate and sea-level change from reef-building corals	Sandy Tudhope (Edinburgh)
10:30-11:15	**COFFEE BREAK and POSTERS**	
Climate, Sea-level, ice-sheets and Greenhouse/Icehouse states (CHAIR: Rachael James)		
11:15-11:45	First results from IODP Expedition 320: Pacific Equatorial Age Transect	Heiko Pälike (NOCS)
11:45-12:05	Results from site survey for Tanzania Paleogene drilling	Dick Kroon (Edinburgh)
12:05-12:25	Monsoons and climate	Peter Clift (Aberdeen)
12:25-13:20	**LUNCH BREAK**	
New Adventures into the Subsurface and Deep Biosphere (CHAIR: Ros Rickaby)		
13:20-13:50	KEYNOTE: Dead or alive - towards an understanding of the significance of benthic archaea in marine sediments	Kai-Uwe Hinrichs (Bremen)
13:50-14:20	KEYNOTE: Significance of bacteria, depth, temperature and pressure in the sub-seafloor biosphere	John Parkes (Cardiff)
14:20-14:40	Microbes, volcanoes, and evidence of early life on Earth: Lessons from ocean drilling	Neil Banerjee (Canada)
14:40-15:00	Energy in the dark: fuel for life in the deep ocean and beyond	Wolfgang Bach (Bremen)
15:00-15:10	**IODP Challenges and Priorities post 2013: Renewal (CHAIR: Heiko Pälike)**	
15:10-15:40	The Future of IODP: Unsolicited Contributions (5 min duration, 1 Overhead) and Panel Discussion.	
15:40-16:10	**COFFEE BREAK and POSTERS**	
16:10-16:50	The Future of IODP: Panel Discussions	
What should be IODP prioritites? New science fields? Exciting unfinished business?		
16:50-17:00	Student Poster Prize Awards	
17:00	Closing Remarks	Mike Bickle
17:05	**MEETING CLOSE**	

Abstracts for Oral Presentations

ENERGY IN THE DARK: FUEL FOR LIFE IN THE DEEP OCEAN AND BEYOND

Wolfgang Bach

University of Bremen (Germany)

Email address of corresponding author: wbach@uni-bremen.de

Chemolithoautotropy in the deep sea is supported by geochemical energy, brought to the seafloor in the form of rocks and fluids that contain reduced components. Ocean drilling provides core material that allows reconstructions of the processes that lead to the release of reduced components, which may feed microbial communities. Specifically, recent work led to new insights into the production of hydrogen, which is the primary energy source in hydrothermal systems hosted in serpentinite. Peridotite-water interactions in these systems release quantities of hydrogen that are sufficient for methanogens and sulfate reducers to thrive under a range of temperature and fluid flux conditions. In contrast, hydrogen production within basaltic aquifers is barely enough under the best of circumstances to allow for growth of methanogens and sulfate reducers. This prediction appears to be corroborated by sulfur isotope compositions of hydrothermally altered peridotites and basalts, where only the former show a distinct mode centered around light (microbial) isotopic ratios.

The specific magmatic and fluid-rock interaction processes taking place within the geological system control what metabolic reactions can support chemolithoautotrophy-based microbial ecosystems at the seafloor. Thermodynamic calculations provide a tool for assessing how much energy hot rocks can provide in different geotectonic settings to support biomass production by chemolithoautotrophic microorganisms. The dominant energy source varies greatly between hydrothermal systems in different submarine settings, from hydrogen and Fe(II) in basalt-hosted systems to dihydrogen and methane in peridotite-hosted systems to Fe and S in felsic rock systesm in island arcs. The dihydrogen fluxes related to serpentinization are at least one order of magnitude greater than those related to global magmatism, and hydrogen consumption could be one of the most important catabolic reactions in deep-sea chemolithoautotrophy.

From a global perspective, mass and energy balances coupled with thermodynamic calculations indicate that a large amount of energy in the form of chemical work (about 100 Petajoule/yr) is transported to the seafloor by hydrothermal vent fluids. A similar amount of energy is tied to the affinity of reduced components in seafloor rocks and minerals for oxidation. Chemolithoautotrophic microorganisms harness an unknown - but likely large - fraction of that energy to produce primary biomass in the deep sea. Bioenergetics estimations suggest that several teragram of carbon can by fixed annually, indicating that the total biomass maintained by geochemical energy may be considerable.

MICROBES, VOLCANOES, AND EVIDENCE OF EARLY LIFE ON EARTH: LESSONS FROM OCEAN DRILLING

Neil Banerjee

University of Western Ontario (Canada)

Over the past decade, studies of volcanic glass from modern oceanic crust recovered by ocean drilling have demonstrated the importance of endolithic microorganisms in the alteration process. Microbial alteration features are ubiquitous within the oceanic crust, having been discovered in basalts of all ages, wherever fresh glass is preserved. Several lines of evidence support the biogenicity of these structures. More recent work in ophiolites and greenstone belts has extended the evidence for microbial alteration of oceanic basalts beyond the record preserved in the modern oceans back to the Archean. Subaqueous volcanic rocks preserved in greenstone belts worldwide are a new geological setting in the search for early life on Earth. This has important implications for the exploration for life on Mars and in our solar system.

CHANGES IN OCEAN CIRCULATION AND THE GLOBAL CARBON CYCLE DURING THE LAST INTERGLACIAL-GLACIAL TRANSITION: MARINE ISOTOPE STAGE 5A TO 4

Stephen Barker, David Thornalley, Ian Hall and Gregor Knorr

The transition from Marine Isotope Stage (MIS) 5a to 4, around 75,000 years ago marked a shift from interglacial conditions (similar to today) to full glacial conditions. This transition witnessed a large build-up of continental ice sheets and a significant decrease in atmospheric CO_2. The period also saw the first appearance of the very large and abrupt climate transitions (the so-called Dansgaard-Oeschger oscillations) which characterised the last glacial period, suggesting that a critical threshold, between the relative stability of the last interglacial and the instability of glacial times, had been crossed. Within this ongoing project we are investigating changes in ocean circulation within the Atlantic basin and their role in global climate change during the MIS 5a to 4 transition. Our aim is to produce very high resolution multi-proxy paleoceanographic records from several marine locations that can be used to reconstruct the temporal evolution of oceanographic changes (both physical and chemical) during an interval of potentially significant importance for global climate evolution during the last glacial cycle.

WHAT FRACTURED OCEANIC CRUST CAN TELL US ABOUT SEA-WATER CHEMISTRY IN THE PAST

Roz Coggon[1], Damon Teagle[2], Chris Smith-Duque[2], Matthew Cooper[2] and Jeff Alt[3]

[1]Imperial College London (UK); [2]National Oceanography Centre, Southampton (UK); [3]University of Michigan (USA)

Ocean chemistry reflects the balance of exchanges between the solid Earth, hydrosphere, and atmosphere. Records of past ocean chemistry provide important constraints on variations in global biogeochemical cycles. Secular change in seawater composition throughout the Phanerozoic remains poorly documented, principally because of the paucity of the evaporite-hosted fluid inclusions and marine carbonates from which current Mg/Ca and Sr/Ca records are currently derived.

Calcium carbonate veins precipitated from low temperature (<100 °C) seawater-derived fluids are common in the upper oceanic crust. Carbonate veins from the Juan de Fuca Ridge (<3.6 Ma) record the evolution of the fluid from its initial modern seawater composition as it is heated and reacts with the basaltic basement. ^{18}O-calculated fluid temperatures correlate with the proportion of basalt-derived ^{87}Sr. The Sr/Ca and Mg/Ca of the basement fluids, calculated from carbonate trace element analyses combined with suitable partition coefficients, are also temperature dependent.

Suites of carbonate veins from older sections of ocean crust also correlate with temperature and record the chemical evolution of basement fluids away from contemporary seawater. Extrapolation of these trends back to seawater temperatures allows the determination of the Mg/Ca, Sr/Ca, ^{87}Sr/^{86}Sr (and hence age) of past seawater.

Past seawater Mg/Ca and Sr/Ca ratios recorded by carbonate veins provide independent support for low past seawater Mg/Ca (<50% modern ratio before 24 Ma) as suggested by analysis of fluid inclusions and well-preserved echinoderms, but indicate much lower Sr/Ca (~25% modern ratio before 24 Ma) compared to estimates from biogenic carbonates.

LONG-TERM BOREHOLE HYDROLOGIC MONITORING, AND OBSERVATIONS OF SEISMIC AND ASEISMIC STRAIN AT RIDGE CRESTS AND SUBDUCTION ZONES

Earl Davies

Geological Survey of Canada (Canada)

The primary goals of early ODP “CORK” hydrologic observatory efforts were to determine the natural thermal state and driving forces for fluid flow through oceanic crust and subduction-zone accretionary prisms, and to obtain pristine pore-water samples in the absence of drilling and open-hole perturbations. Some installations have been operational continuously for up to 13 years, and the long records have provided a variety of additional "fringe benefits". For example, the formation response to variable loads imposed on the seafloor by seasonal ocean circulation, tides, and storm-induced microseisms have provided constraints on elastic (matrix compressibility) and hydrologic properties (permeability, storage compressibility). Inferred properties are representative of a scale that is much greater than that sampled by standard on-site hydrologic pumping tests, and they are much less sensitive to formation heterogeneity. In young oceanic crust the diffusion scale length of diurnal signals is observed to be more than 10 km, a dimension commensurate with natural advective heat and geochemical transport.

Another originally unanticipated application of CORK hydrologic monitoring has been the use of pressure as a quantitative proxy for crustal strain. Pressure changes have been observed simultaneously at multiple sites at the times of several discrete episodes of seafloor spreading along the Juan de Fuca Ridge, and at the times of seismogenic and aseismic slip along the Nankai, Mariana, and Middle America subduction zones. With the elastic properties estimated at each site from seafloor loading response, quantitative estimates of strain have been made, and in each case, the far-field strain is significantly larger than that estimated on the basis of seismic moment. Post-slip pressure transients are also observed. In permeable sections (Juan de Fuca), these are primarily the result of hydrologic drainage, but in low-permeability sections (Nankai), they appear to reflect long-term post-seismic slip. This post-seismic strain is also greater than that estimated on the basis of the cumulative moment of aftershocks.

Various improvements to CORK hardware since the first deployments in 1991 now provide a means for accessing multiple isolated formation levels for hydrologic monitoring or fluid sampling, and for imbedding other sensors such as seismometers and strain meters. Improvements to sensors and electronics allow high resolution (e.g., 10 ppb full-scale pressure, or 0.4 Pa at 4000 m) reaching up to seismic frequencies (1 Hz). And fibre-optic cable connections (beginning this year on the Juan de Fuca Ridge and later at Nankai) will soon allow long-term observations to be made in real time with no constraints imposed by battery power or autonomous memory limits.

RAPID SEDIMENTATION, OVERPRESSURE, AND SUBMARINE LANDSLIDES ALONG CONTINENTAL MARGINS: INSIGHTS FROM IODP EXPEDITION 308

Peter B. Flemings[1] and the IODP Expedition 308 Science Party

[1]University of Texas (USA)

Email of the corresponding author: pflemings@jsg.utexas.edu.

High overpressures are present within low permeability mudstones where there have been multiple, very large, submarine landslides during the Pleistocene. IODP Expedition 308 used weighted-mud to drill, core, and take direct pressure measurements in this challenging environment. Overpressures reach 60 % of the hydrostatic effective stress in the first 200 meters below sea floor (mbsf) at Sites U1322 and U1324, respectively, in the deepwater Gulf of Mexico, offshore Louisiana. Submarine landslides are recorded by a transparent seismic facies that correlates to pronounced increases in bulk density, shear strength, and resistivity. This facies occurs as folded and homogenized mud, with rare mud clasts in cores. The average sedimentation rate from the seafloor to the top of the Blue Unit is 12 mm/year at Site U1324 and 3.6 mm/yr at Site U1322. Ursa mudstones have hydraulic diffusivities of 2 x 10-8 m2/s. We interpret that during the Pleistocene, high overpressures were generated by rapid sedimentation of low permeability material from the ancestral Mississippi River. High overpressure near the seafloor reduces slope stability and provides a mechanism for the large submarine landslides and low regional gradient (2 degrees) offshore from the Mississippi delta. The IODP has the potential to tackle a broad range of problems in geohazards through the coupling of in-situ measurements (stress, pressure, temperature) with laboratory analysis. The results will illuminate controls on the form of continental slopes, and when, where, and how submarine landslides occur.

DEAD OR ALIVE - TOWARDS AN UNDERSTANDING OF THE SIGNIFICANCE OF BENTHIC ARCHAEA IN MARINE SEDIMENTS

Kai-Uwe Hinrichs, Julius S. Lipp, Yu-Shih Lin and Xiaolei Liu

Organic Geochemistry Group, MARUM Center for Marine Environmental Sciences and Dept. of Geosciences, University of Bremen (Germany)

Email of the corresponding author: khinrichs@uni-bremen.de

Marine sub-seafloor sediments probably harbor one of Earth's largest reservoirs of microbial biomass. The study of this biosphere heavily relies on culture-independent molecular techniques – a route that is complicated by low activities and concentrations of microbial cells. In a survey of a large range of marine subsurface environments, we have recently shown that the pool of intact membrane lipids, i.e., compounds considered as proxies for live biomass, is dominated by molecules diagnostic of archaeal membranes. If these compounds are similarly unstable as their bacterial counterparts, we must conclude that so-called benthic archaea are a dominant cellular life form in the marine deep biosphere. Multiple lines of evidence suggest that these archaea are adapted to the extreme energy limitation in the subsurface and involved in the ultra-slow degradation of sedimentary organic matter. The presentation will summarize recent developments and open questions regarding a globally abundant and widespread group of microorganisms and also discuss possible impacts on the fossil record of planktonic archaea.

A UNIQUE CLIMATE ARCHIVE OF THE LAST INTERGLACIAL PERIOD RECOVERED FROM IODP SITE U1304 ON THE GARDAR DRIFT

David A. Hodell[1], Emily Kay Minth[2], Jason H. Curtis[2], James E.T. Channell[2] and Ian R. Hall[3]

[1]Godwin Laboratory for Paleoclimate Research, University of Cambridge (UK); [2]University of Florida (USA); [3]Cardiff University (UK)

The climate of the Last Interglacial (LIG) period (Marine Isotope Substage 5e) was slightly warmer than today, Arctic sea ice cover was reduced, the Greenland ice sheet was reduced in size, and sea level was several meters higher than today. Although the forcing differed (orbital versus greenhouse gases), there are many parallels between climate of the LIG period and future changes anticipated as a consequence of global warming. A major hindrance for study of the LIG is there is yet no complete, undisturbed section of the LIG recovered in Greenland ice cores. This shortcoming will hopefully be alleviated with drilling of the North Greenland Eemian ice core (NEEM). An important challenge for paleoceanographers is to identify complementary marine sections with sufficiently high sedimentation rates for comparison with the anticipated NEEM ice core. At IODP Site U1304 on the southern Gardar drift, we recovered an expanded section of the "MIS 5e plateau" (128 to 116 ka) and MIS 5d (116 to 105 ka). The sediment for this period includes the intermittent deposition of laminated diatom mats (LDM) and oozes (LDO). The high tensile strength of the mat sediment suppresses benthic activity and hinders bioturbation, thereby providing a rare opportunity to produce records of past oceanic change at ultra high temporal resolution.

Planktonic $\delta^{18}O$ of foraminifera from Gardar Drift record the nature of surface inflow to the Nordic Seas via the North Atlantic Current, whereas benthic $\delta^{13}C$ and sortable silt monitor the chemical and physical characteristics of deep water that is influenced by the outflow over the Iceland-Scotland Ridge. By comparing planktonic and benthic proxies, we examine the timing and linkages between surface water inflow and Nordic Sea overflow during the LIG. Iceland Scotland Overflow Water (ISOW) was shallower and weaker than today during the earliest part of the Last Interglacial (LIG) period (128 to 124.5 ka) when planktonic $\delta^{18}O$ indicates peak warming and/or reduced salinity. ISOW was formed during this period but was less dense than today because of high temperatures and/or lowered salinity from enhanced freshwater fluxes related to a peak in boreal summer insolation. ISOW did not penetrate to depths of 3000 m until ~124 ka and remained strong until the end of the LIG (~116 ka) when a temporary shoaling of ISOW occurred and peaked at ~113 ka. During the LIG, changes in deep-water chemical (benthic $\delta^{13}C$) and physical (sortable silt) properties were generally coincident with transitions in surface climate (planktonic $\delta^{18}O$). Results from the LIG may have relevance for how Atlantic Meridional Overturning Circulation (AMOC) might respond to a future warmer, fresher subpolar North Atlantic as a consequence of global warming.

RESULTS FROM SITE SURVEY FOR TANZANIA PALEOGENE DRILLING

Dick Kroon[1], Paul Pearson[2], Andy Purvis[3], Niamh O'Sullivan[4], Heather Birch[2], Tracey Aze[2], Thomas Ezard[3], Bridget Wade[5], Clay Bowden[5], Tjeerd van Weering[6] and Henk de Haas[6]

[1]University of Edinburgh (UK); [2]Cardiff University (UK); [3]Imperial College London (UK); [4]Trinity College Dublin (Ireland); [5]Texas A & M University (USA); [6]Royal NIOZ Texel (Netherlands)

Global warming (GLOW) is rapidly becoming a societal problem. Prediction of climate feedbacks, temperature, and the circulation state of the ocean is very difficult. Geological records give a significant framework to improve predictions in response to greenhouse warming. Past global greenhouse warming events can be regarded as analogues for the current warming event, and these past warming events can thus be used to improve prediction on the future state of the oceans. The Paleogene part of the geological record represents a climatically dynamic period in Earth history including rapid global warming events. Geological evidence for these warming events is sparse in the tropical realm, although Tanzanian onshore geological sequences contain well preserved records of these Paleogene warming events. Offshore Tanzanian geological sequences, however, have not been explored as yet for drilling. The GLOW project collected basic information on seismic sequences to understand the basic geological structures and basin infill offshore Tanzania. Sediment cores were retrieved from the sea bed in areas where older reflectors crop out, to obtain ages of the sediments. We successfully explored the Davie Ridge and in-shore areas for seismic sequences by sailing a comprehensive network of seismic lines. We identified potential drilling sites for future drilling using the new seismic network. We conclude that the GLOW deliveries provide sufficient seismic and basic stratigraphic information to support a full proposal for drilling in the area within the International Ocean Drilling program.

RESULTS FROM SUPERFAST SPREADING DRILLING

John MacLennan

University of Cambridge (UK)

An enduring aspiration of scientific ocean drilling has been the Mohole: a core providing continuous sampling of typical, intact oceanic crust and penetration into the uppermost mantle. Many of the questions that motivated the pioneers of ocean drilling remain pertinent today and secure the future appeal of the Mohole target. These questions touch upon topics as diverse as deep-earth structure, genesis of the crust, seafloor volcanism, hydrothermal activity, controls on ocean chemistry and the deep biosphere.

At a fundamental observational level a continuous section is needed to test models of the geological, geophysical and geochemical structure of the oceanic crust. The Mohole section will provide a crucial link between seismic surveys of the oceanic crust and geological study of ophiolites and create opportunities for major advances in our understanding of the mode of accretion of solid crust from mid-ocean ridge magmas. The chemical and thermal fluxes associated with hydrothermal circulation through the deep oceanic crust are also of interest, because they cool the solid crust and control seawater chemistry. Minerals precipitated by hydrothermal fluids potentially provide a record of variation in seawater chemistry.

On 13^th December 2005, drilling at Hole 1256D in the eastern Pacific penetrated gabbroic rocks of 15 Myr old oceanic crust at a depth of 1410 mbsf. The core recovered from 1256D during Leg 206 and Expeditions 309 and 312 is the first continuous core through the lavas and dykes of intact upper oceanic crust. Conditions are set fair for further deepening of 1256D into the gabbroic lower crust, where recovery and penetration rates are likely to be high. The bottom of 1256D currently sits only 4 km from the Moho, making 1256D an attractive Mohole candidate.

A number of important results have already been established from the efforts at 1256D. The boundary between seismic layers 2 and 3 of the oceanic crust does not correspond to variations in the igneous lithology, but rather to variation in porosity. The stratigraphy of the lava pile has been studied by formation microscanner in concert with lithological descriptions of the core. This stratigraphy is remarkably consistent with that expected from available mapping of seafloor volcanic facies at the active East Pacific Rise (EPR), indicating a common mode of upper crustal accretion. Similar conclusions have also been drawn from comparison of downhole variations in lava composition with across-axis spatial variations at the EPR. Geochemical observations also indicate that the 1256D core may be used to track the flow of mantle away from the Galapagos Plume. The role of hydrothermal circulation in the cooling of the 1256D crust has been highlighted not only by petrological and petrographic identification of high geothermal gradients just above the plutonic section but also by the penetrative alteration of the dikes evident from Sr-isotope studies. These observations will be used to constrain thermal and chemical models of hydrothermal circulation at mid-ocean ridges.

The plutonic rocks that have been sampled at 1256D are gabbros with a composition similar to that of trapped basaltic liquid, rather than cumulate rocks. Drilling into the cumulate rocks of the lower oceanic crust is required in order to oceanic crustal accretion models based on ophiolite stratigraphy.

ACCRETION OF THE LOWER OCEANIC CRUST AT FAST-SPREADING RIDGES: PRELIMINARY RESULTS OF A UKIODP SITE SURVEY AT HESS DEEP

Chris MacLeod, Damon Teagle, Kathy Gillis and the JC21 Scientific Party

Hess Deep (2°15'N, 101°30'W) is a rifted depression formed by the westward propagation of the Cocos-Nazca plate boundary towards the East Pacific Rise. It is one of very few places where the deeper levels of oceanic crust formed at a fast-spreading mid-ocean ridge are exposed on the seafloor and can thus be accessed directly. In January-February 2008, during RRS James Cook cruise JC21, we conducted a site survey of Hess Deep in support of proposed IODP operations there. Using the Isis remotely-operated vehicle we acquired microbathymetry and collected 145 samples from a 20 sq. km area from the nadir of the Deep (5400m water depth) up and onto the intra-rift ridge (3000m), a horst block within the broader rift valley that was drilled by ODP (sites 894 and 895) in the early 1990s. From previous investigations it was considered that a complete, continuous section through the lower crust down to the Moho transition zone existed in this region, tilted northwards as a result of extension during opening of the rift. Detachment faulting, perhaps assisted by serpentinite diapirism, had been invoked to explain uplift of the intra-rift ridge. However, our detailed mapping and dense sampling of the supposed lower crustal section yielded not only gabbros but also peridotites, dolerites and basalts, indicating a significantly more complex distribution of rock types in Hess Deep than previously supposed. We present a re-evaluation of the morphotectonics of the rift valley, discuss the ramifications for future drilling, and present some preliminary results of our investigations of the gabbro samples and their implications for magmatic accretion at fast-spreading ridges.

OCEAN DRILLING ON THE SUMATRAN SUBDUCTION ZONE MARGIN: UNDERSTANDING FOREARC DEVELOPMENT AND THE EARTHQUAKE CYCLE

[1]Lisa McNeill, [1]Tim Henstock, [2]Chris Goldfinger, [3]Sean Gulick, [3]Nathan Bangs, [3]Jamie Austin and [4]Kelin Wang

[1]University of Southampton (UK); [2]Oregon State University (USA); [3]University of Texas (USA); [4]Pacific Geoscience Centre, Sidney, British Columbia (Canada)

The second largest subduction earthquake recorded occurred off Sumatra on December 26, 2004. Advances in the understanding of seismogenic subduction margins and links to structural and sediment properties have been hindered because no great earthquakes have occurred since 1964. Subduction zone earthquakes are thought to be influenced by thermal structure, fluid pressures, fault zone composition and by stress variations, all superimposed on the larger plate force balance, however the source zones of past earthquakes have been relatively poorly constrained. Significant progress has been made in the understanding of subduction zone fault systems and earthquakes and will continue over the next few years on the Nankai and Costa Rican margins through deep ocean drilling and monitoring. But now we have an unprecedented opportunity to test new models of seismogenic rupture and plate boundary and accretionary prism dynamics using the unique seismological and geodetic datasets from the Sumatran margin. The slip distribution, temporal history, and rupture velocity of the well-recorded Sumatra event were heterogeneous, but what geologic factors controlled this complex rupture and what can margin structure and morphology tell us about future earthquake processes? We propose to use the unique capabilities of IODP to build a geologic and geophysical model of the Sumatra forearc in the 2004 rupture area that will build on ongoing geophysical surveys in the region and complement seismogenic zone investigations in Nankai and Costa Rica.

A full proposal has been submitted to IODP (anticipated as a first phase) to drill, sample and monitor elements of the Sumatran subduction zone systems, including the incoming sediment of the trench, the accretionary prism and the forearc basin. The objectives are to identify contrasts in physical properties and rheology expected from geology and implied by seismic rupture models, and to develop the temporal history of prism and forearc development. An important element of the proposed project would be to install simplified S-CORKS measuring fluid pressure to investigate strain transients in the early post-seismic phase. We anticipate a later second phase of monitoring of strain, tilt, and seismicity, and potentially incorporating riser drilling to access the deeper forearc and fault structure. Marine geophysical and geological data collection has been rapid in the last few years, producing a range of site survey data for both understanding the structural context for drilling and for selecting drill sites. Data collection has been an international effort, with UK involvement in the form of a NERC-funded consortium project focusing on the segment boundaries between earthquake ruptures. International data collected include multibeam bathymetry, multichannel seismic reflection, large scale structure from OBS deployments, sidescan sonar, gravity, magnetics, heat flow and coring. In addition, data from onshore include GPS, seismicity (combined with offshore monitoring) and paleoseismology.

GEOLOGICAL AND GEOPHYSICAL STUDIES OF THE MID-ATLANTIC RIDGE, 12°30'N TO 14°30'N: THE BIRTH AND DEATH OF OCEANIC CORE COMPLEXES

B.J. Murton[a], C.J. MacLeod[b], R.C. Searle[c], J.F. Casey[d], C. Mallows[c], S.C. Unsworth[a], K.L. Achenbach[c], M. Harris[a]

[a]National Oceanography Centre, Southampton (UK); [b]Durham University (UK); [c]Cardiff University (UK); [d]University of Houston (USA)

Oceanic core complexes are the uplifted footwalls of very-large-offset low-angle normal faults that exhume lower crust and mantle rocks onto the seafloor at slow-spreading ridges. Although it is suggested on the basis of numerical modelling that they form during periods of relatively reduced magma supply, little is known about how they initiate and become inactive, nor why only certain normal fault systems develop into core complexes. In this talk, we present results from a near-bottom sidescan sonar/bathymetric profiler survey and sampling study of the Mid-Atlantic Ridge near 13°N that identify the critical controls on oceanic core complex development and evolution. We show that core complex detachment faults initiate as high-angle (65°±10°) normal faults no different from surrounding valley-wall faults and, like them, rapidly flatten to dips of ~30° in response to flexural unloading. On certain structures, however, displacement continues rather than jumping inward to a new normal fault, resulting in locally enhanced uplift of the footwall and further flattening of the fault to the horizontal or beyond. We demonstrate that detachment faults are triggered primarily by local waning of magma supply below a critical threshold, and are greatly aided by strain localisation resulting from seawater penetration and talc formation along the fault zones. Volcanism is suppressed or absent when the core complexes are active. Detachment faults are subsequently terminated by the emplacement of renewed magma into their footwalls, here by neovolcanic ridges propagating laterally across them from magmatically robust segments along strike. Our observations demonstrate how spatial (~1–10km) and temporal (~10^5–10^6yr) variations in magma flux to the ridge axis directly control the formation, extent and duration of tectonic spreading at the Mid-Atlantic Ridge.

FIRST RESULTS FROM IODP EXPEDITION 320: PACIFIC EQUATORIAL AGE TRANSECT

Heiko Pälike on behalf of IODP Expeditions 320 and 321 Science Party

National Oceanography Centre, Southampton (UK)

We report results from a scientific research cruise following the palaeo-equator has uncovered nearly 53 million years of climate and ocean acidification history. The Integrated Ocean Drilling Program drillship JOIDES Resolution has returned to Honolulu after a two-month voyage to chart the detailed climate history of the Earth. This was the first of two voyages of the 'Pacific Equatorial Age Transect' project, and the first international scientific drilling expedition since the JOIDES Resolution underwent a multi-year, more than $100-million transformation into a 21st century floating science laboratory. The first expedition ended on 4 May after successfully coring over 3.5 km of the sediments and rocks from below the Pacific Ocean seafloor. A second expedition to the equatorial Pacific departed Honolulu, Hawaii, on 9 May and will recover sediment cores from the seafloor at two more drilling locations. The onboard studies revealed that changes in ocean acidification, linked to climatic change, have a large and global impact on marine organisms. The sediments recovered as part of the PEAT programme will allow the direct intercalibration of all major fossil groups as well as magneto-, chemo- and cyclostratigraphy from the early Eocene major sustained greenhouse until today.

THE LESSER ANTILLES: INTERACTION BETWEEN VOLCANISM AND OCEAN CHEMISTRY

Martin Palmer

University of Southampton (UK)

It has been estimated that subaerial explosive volcanism injects ~10^{15} g of tephra into the atmosphere every year. The proximity of most explosive volcanoes to the oceans means that much of this material falls into seawater, where it is joined by volcanic material delivered by dome and flank collapse events, pyroclastic flows and lahars. Our studies around the island of Montserrat show that this material is highly reactive in seawater. Recent ash fall layers in the sediments are accompanied by abundant pteropod shells that show clear signs of dissolution that likely resulted from acidification of surface waters during seawater-ash mixing. However, the most spectacular signs of ash diagenesis are seen in dissolved oxygen profiles from ash-bearing sediments, which show oxygen depleted to zero within a few millimetres of the sediment-water interface. Modelling of these profiles, in conjunction with solid phase geochemical data, suggests that the oxygen depletion is due to surface oxidation of FeII in the volcanic material. Further, the reaction rate is very rapid, such that the buried pore waters are completely stripped of oxygen within days of arrival of the material at the seafloor. The wider implications of these and other geochemical processes will be discussed.

THE TIMING AND FORM OF THE PENULTIMATE DEGLACIATION: NEW CORAL CONSTRAINTS FROM IODP EXPEDITION 310 "TAHITI SEA LEVEL"

Alexander Thomas

University of Oxford (UK)

The timing of the penultimate deglaciation – often referred to as Termination II – has been the subject of much controversy. Early estimates of the age of the deglaciation, based on orbital tuning, have been challenged by radiometric dating of cave deposits and aragonitic sediments. U/Th dating of fossil corals has also provided useful insights into this penultimate deglaciation, although most of these records are confined to the sea level highstand that followed the deglaciation and therefore only provide a constraint as to the end of the deglaciation rather than the deglaciation itself.

IODP Expedition 310 has provided corals from earlier in the deglaciation that constrain the timing lower sea levels. These corals show that the timing of the penultimate deglaciation is in agreement with other radiometrically determined estimates and therefore is inconsistent with the traditional orbital forcing hypothesis. The timing of sea level rise also not out of phase with CO_2 rise, which suggests that sea level may play a role in determining atmospheric CO_2 during a deglaciation. The fall of atmospheric $\delta^{18}O$ is shown to significantly lag sea level rise, therefore implying a variable Dole Effect that compensates for the changing $\delta^{18}O$ of the ocean across the deglaciation.

The dynamicity of ice sheets is of fundamental importance to our ability to forecast future sea level change. Records of paleo sea level have shown that in the past ice sheets must have behaved more dynamically than we have become accustomed, during the Holocene. In particular it has been suggested that a rapid millennial scale rise and fall of sea level punctuated the penultimate deglaciation. The corals recovered during Expedition 310 support this scenario, by recording a deepening and shallowing of paleo water depth with a single drill hole.

NANTROSEIZE: OVERVIEW AND INITIAL RESULTS FROM THE NANKAI TROUGH SEISMOGENIC ZONE IODP DRILLING PROJECT

Harold Tobin

University of Wisconsin-Madison (USA)

IODP Expeditions 314-316 took place over five months of continuous drilling operations in the off-Kumano region of the Nankai Trough subduction zone (September, 2007 – February, 2008). This effort was both the maiden scientific voyage of the new drilling vessel Chikyu and the first stage in the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), a multi-year effort designed to investigate fault mechanics and seismogenesis along a subduction megathrust through direct sampling, in situ measurements, and long-term monitoring. The principal elements of the project include (a) the 2006 3D seismic survey of the intended transect, (b) four planned stages of IODP drilling, sampling, and downhole measurements, and (c) long-term real-time monitoring of the plate interface in cabled borehole observatories. The three Stage 1 expeditions accomplished drilling, logging, and sampling of 8 sites as deep as 1400 meters below the sea floor. These first expeditions in NanTroSEIZE set the stage for coming deep drilling efforts to reach the plate interface at seismogenic depths. The first Chikyu riser drilling at Nankai Trough for IODP will commence on Expedition 319, which will be underway during the UK IODP conference.

RECORDS OF CLIMATE AND SEA-LEVEL CHANGE FROM REEF-BUILDING CORALS

Sandy Tudhope

University of Edinburgh (UK)

Email of the corresponding author: sandy.tudhope@ed.ac.uk

There are three MSP IODP initiatives that target submerged coral reefs. These are Tahiti (Expedition 310, 2005), Australia's Great Barrier Reef (Expedition 325, planned drilling late 2009) and Hawaii (proposal in advanced stage). Two of the main objectives of these missions are to better constrain the magnitude, timing and rates of regional and global sea-level changes during periods of rapid de-glaciation and to improve our understanding of changes in tropical climate and their role in driving or moderating global climate on seasonal to glacial-interglacial timescales.

Sea-level studies: The Tahiti drilling successfully sampled reefs that grew through a substantial proportion of the last deglaciation as well as parts of the last glacial and the previous deglaciation. These samples are providing new constraints on the timing and rapidity of sea-level changes during deglaciation (e.g., see Thomas et al in this meeting). However, it appears that last glacial maximum reefs were not sampled. Site Survey results from Australia's Great Barrier Reef (scheduled for drilling later this year) have revealed distinctive submerged reef targets including a terrace at about 130 m below present sea level raising hopes that a more complete glacial-to-de-glacial sequence may be recovered. Preliminary dating of dredge samples confirms the presence of shallow water de-glacial coral material (dated in the range 10-13 ka BP) at the seabed at ~-90m water depth. Submerged reefs off Hawaii are the focus of a third proposed drilling expedition. The rapidly subsiding setting of these Hawaiian reefs offers exciting opportunities to sample reefs that grew during periods of global sea level fall (i.e., ice build-up); periods that are normally poorly represented in more stable or uplifting tectonic settings.

Palaeoclimate potential: The annually-banded skeletons of massive reef-building corals are capable of yielding records of changes in temperature and water composition with ~monthly resolution over the lifespan of the colony (up to several hundred years). Analysis and radiometric dating of 'fossil' colonies allows this approach to be extended to address changes through the late Quaternary. Arguably the greatest contribution of these studies to date has been in helping determine the nature and likely drivers of changes in ENSO and other forms of interannual-decadal climate variability that originate in the tropics. However, the likelihood of IODP drill cores perfectly intersecting large massive corals to yield ~ century-long continuous records is slim and, therefore, the potential to quantify changes in the strength and frequency of interannual and decadal-interdecadal climate variability depends to a significant degree on good fortune. However, many smaller coral heads are sampled by the drilling, yielding 'windows' into past conditions of a few years to a few decades in length. These samples can yield important information on changes in mean conditions, and in the nature and amplitude of seasonality. This potential to quantify changes in seasonality in both temperature and rainfall (or more correctly inferred changes in the precipitation-evaporation balance) offers exciting possibilities to investigate changes in the spatial and temporal patterns of atmospheric and ocean circulation that are critical to understanding the true nature and mechanisms of regional and global climate change. These records can also put into context lower-resolution records from deep sea sediment cores where climate and surface ocean conditions are often reconstructed from proxies that may have a significant seasonal dependence or bias.

VARIABLE QUATERNARY WEATHERING BUDGETS AND OCEAN BIOGEOCHEMICAL CYCLES

Derek Vance

University of Bristol (UK)

Rivers are the dominant source of many elements and isotopes to the ocean. But this input from the continents is not balanced by the loss of the elements and isotopes through hydrothermal and sedimentary exchange with the oceanic crust, or by temporal changes in the marine inventory for elements that are demonstrably not in steady state. In order to resolve the problem of the observed imbalance in marine geochemical budgets, attention has been focused on uncertainties in the hydrothermal and sedimentary fluxes. In recent Earth history, temporally dynamic chemical weathering fluxes from the continents are an inevitable consequence of periodic glaciations. Chemical weathering rates on modern Earth are likely to remain far from equilibrium owing to the physical production of finely ground material at glacial terminations that acts as a fertile substrate for chemical weathering. Here we explore the implications of temporal changes in the riverine chemical weathering flux for oceanic geochemical budgets. We contend that the riverine flux obtained from observations of modern rivers is broadly accurate, but not representative of timescales appropriate for elements with oceanic residence longer than Quaternary glacial–interglacial cycles. We suggest that the pulse of rapid chemical weathering initiated at the last deglaciation has not yet decayed away and that weathering rates remain about two to three times the average for an entire late Quaternary glacial cycle. Taking into account the effect of the suggested non-steady-state process on the silicate weathering flux helps to reconcile the modelled marine strontium isotope budget with available data. Overall, we conclude that consideration of the temporal variability in riverine fluxes largely ameliorates long-standing problems with chemical and isotopic mass balances in the ocean.

Abstracts for Poster Presentations

TESTING MODELS OF MANTLE UPWELLING AND TECTONIC EXHUMATION: THE PETROSTRUCTURAL RECORD OF THE ODP LEG 209 PERIDOTITES (15°39'N, MID-ATLANTIC RIDGE)

Kay L. Achenbach[1], Michael J. Cheadle[2], Ulrich Faul[3], Susan Swapp[2], Peter Kelemen[4]

[1]Durham University (UK); [2]University of Wyoming (USA); [3]Boston University (USA); [4]Lamont-Doherty Earth Observatory, Columbia University (USA)

We present results of a microstructural and crystal lattice-preferred orientation (LPO) analysis of peridotites drilled from at 15°39'N on the Mid-Atlantic Ridge.

ODP Leg 209 Hole 1274A penetrated to a depth of ~156m with ~22% recovery. Our study includes eleven harzburgites and one dunite from Hole 1274A. Microstructures suggest that the peridotites experienced high-temperature (~1200°C) deformation (textures are coarse granular or "asthenospheric") followed by pervasive post-deformation melt-rock interaction. A weak olivine foliation was identified in the rocks; orthopyroxene foliation is very weak or absent. Electron backscatter diffraction (EBSD) analysis reveals LPOs consistent with olivine (010)[100] slip and orthopyroxene (100)[001] slip, indicative of dry high-temperature, low-stress deformation. Olivine [100] axes, preserving the interpreted flow direction in the mantle, were subhorizontal and oriented at low angle to the ridge axis at the time of the onset of serpentinization as recorded by paleomagnetic data. These observations require some three-dimensionality during the uplift of mantle rocks at the Mid-Atlantic Ridge, either during asthenospheric upwelling or during tectonic exhumation to the seafloor.

HEAVY MINERAL ANALYSIS OF THE INDUS FAN

Orji Akaa[1], Peter Clift[1], Liviu Giosan[2] and Tim Henstock[3]

[1]University of Aberdeen (UK); [2]Woods Hole Oceanographic Institution (USA); [3]National Oceanography Centre, Southampton (UK)

Although the Indus Fan is the world's second largest sediment body, substantial parts of the inner continental shelf remained undocumented. To address this, between December 10, 2008 and January 7, 2009, cruise 64PE300 of the RV Pelagia deployed a cocktail of survey and coring techniques, in the Arabian Sea, in order to chart sediment delivery to the submarine fan through time, and by so doing understand the interaction between climatic forcing and delta evolution.

The study aims to process recovered core samples, from across the inner fan, for heavy-minerals to gather information on mineralogical assemblages. Additionally, major and trace elements, and U-Pb zircon analyses will be undertaking to facilitate provenance and climatic fingerprinting.

Overall, this study will promote better understanding of sediment movement from the river mouth to the canyon and how this has evolved through time, perhaps, in response to climate change.

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HOLOCENE EVOLUTION OF THE INDUS RIVER AND TRIBUTARIES: THE EFFECT OF CLIMATE AND DRAINAGE REORGANIZATION ON THE HARAPPAN

Anwar Alizai[1], Peter D. Clift[1], Sam Vanlaningham[1], Geoff Duller[2], Julie Durcan[2], Andrew Carter[3] and Steve Hillier[4]

[1]University of Aberdeen (UK); [2]Abersystwyth University (UK); [3]University of London (UK); [4]Macaulay Land Use Research Institute, Aberdeen (UK)

The Indus in SW Asia is one of the world's largest and longest rivers. It is the third largest river in terms of annual flow from the Indian Sub-Continent and carries as much as 300 million tons of sediments per year to the delta. The sediments of the delta also represent a potentially important source of information on the tectonic and the geological history of the Himalayas. Rapid transport from areas of high relief and negligible chemical weathering in arid climates results in detrital signatures in the resultant river sands that accurately reflect the geology of the source terrains. Because of this, the Indus River represents a superb region in which to study the relationships between active orogenic processes, erosion, and sediment composition. In particular, we seek to quantify transport times and the amount of buffering and sediment storage between the sources and the deep oceanic fan since the Last Glacial Maximum. Our results have implications for the interpretation of the deep sea turbidite record that is proposed for drilling to IODP. We also wish to understand the links between drainage evolution and the development of early human societies in the region, especially the Harappan (Indus Valley) Civilization.

Seismic reflection profiles from the Indus Fan suggest high mass accumulation rates during the Pliocene epoch, partly driven by increased drainage to the Indus River after five million year ago and partly by faster erosion linked to a stronger monsoon over the past four million years. Nd isotope data from the Indus Fan provides strong evidence for a significant change in the geometry of western Himalayan river systems in the geologic past.

We use modern river samples and sediments sampled from pits and shallow boreholes in the alluvial plans of the Indus and the now inactive Ghaggar-Hakra River to study the provenance evolution of sediment in the flood plain. We use these data to reconstruct the Holocene evolution of these drainages in the Indus Basin. Age control is established using ^{14}C by Accelerator Mass Spectrometer (AMS) and Optical Stimulated Luminescence (OSL) methods. OSL dating is used to determine sediment depositional age where no appropriate organic material is available for ^{14}C. Initial results suggest active aggradation of the flood plain in the Early Holocene up to around 4–5 ka.

Provenance will be established using heavy mineral analysis, U-Pb dating of zircon grains, XRD (bulk) and Ar-Ar dating of mica. U-Pb ages show major differences between the trunk main Indus stream and the Himalaya tributaries. Mid Holocene sands along the path of the Ghaggar-Hakra River indicate that if this river reached the Himalaya then it was strongly diluted by reworking of dune sands from the Thar Desert, at least prior to around 4 ka.

PLANKTONIC FORAMINIFERA: EVOLUTION AND SIZE CHANGE

Tracy Aze

Cardiff University (UK)

Using a stratophenetic approach, a phylogeny of the macroperforate planktonic foraminifera group has been constructed for the past 65 million years. This phylogeny forms part of a wider study macroevolutionary study and will be used to address key questions about speciation, extinction and character change and how these processes interrelate. A more detailed investigation will focus upon the processes underlying Cope's Rule (the trend towards larger organism body size over time), this will entail detailed size analysis of 50 randomly sampled planktonic foraminifera lineages from the phylogeny, principally using material from deep sea cores.

PLANKTONIC FORAMINIFERA ECOLOGY AND PELAGIC ECOSYSTEM RECOVERY AFTER THE K/PG BOUNDARY MASS EXTINCTION

Heather Birch[1], Dr Helen Coxall[1], Dr Carrie Lear[1] and Dr Daniella Schmidt[2]

[1]Cardiff University (UK); [2] University of Bristol (UK)

The Cretaceous/Paleogene (K/Pg) mass extinction, seriously affected the marine ecosystem with a 90% loss of Cretaceous planktonic foraminifera species. Surface to deep-ocean foraminiferal $\delta^{13}C$ gradients and carbonate accumulation records show that this extinction coincided with a crash in organic matter flux to the sea floor and a long (3Myr) delay in recovery. This delay has been attributed to major disruption of the pelagic ecosystem due to extinctions of larger pelagic life that facilitate export of organic matter to the sea floor through faecal material, and the long timescales required for rebuilding complex food webs. This hypothesis, coined the 'living ocean' model has potential problems. Firstly, benthic foraminifera, which utilise food from surface waters don't show parallel patterns of extinction. Secondly, the 'final stage' of carbon system recovery, coincides with major changes in planktonic foraminifera isotopic signatures as Photosymbiotic ecologies diversified in several clades.

Here we present new planktonic foraminifera multispecies carbon and oxygen isotopic data from the lower Paleocene of Walvis Ridge ODP Site 1262, that reveal ecological evolution of the potentially important geochemical proxy species through the critical 'final stage' of carbon system recovery. These time slices provide a picture of depth-controlled thermal stratification of the upper water column compared to conditions at the sea floor and a relative indication of the depth at which organic recycling was occurring in the water column. This fully astronomically tuned section has huge potential for resolving the detailed timing and palaeoecology of planktonic foraminifera after the K/Pg.

A GLOBAL DEEP-SEA DISSOLUTION EVENT DURING THE EOCENE-OLIGOCENE TRANSITION

Bohaty, S.M.[1], Pälike, H.[1], Ridgwell, A.[2], Zachos, J.C.[3], and Lear, C.H.[4]

[1]University of Southampton (UK); [2]University of Bristol (UK); [3]University of California (USA); [4]Cardiff University (UK)

In deep-sea records spanning the Eocene-Oligocene (E-O) boundary, a two-stage positive shift in marine carbonate $\delta^{18}O$ values has been shown to occur in tandem with a two-step global deepening (by ≥1 km) of the calcite compensation depth (CCD). The oxygen isotope shift and interpreted de-acidification of the deep waters are intricately linked to major global cooling and expansion of polar ice sheets, representing the most significant step towards 'icehouse' climates of the Paleogene time interval. The initial or precursor phase of major global climate changes at the E-O boundary, however, has previously received little attention. Compilation of multiple foraminiferal stable isotope and carbonate concentration records indicates that the initiation interval (at ~34.0 Ma) is characterized by both a negative carbon isotope excursion and a strong carbonate dissolution horizon at several deep-sea sites around the globe. Correlation of carbonate concentration records reveals reduced or no carbonate accumulation within this interval at sites situated below ~3200 m paleo-water depth, inclusive of sites in the equatorial Pacific (ODP Site 1218), equatorial Indian (ODP Site 711), mid-latitude South Atlantic (DSDP Site 523), and Southern Ocean (ODP Sites 699 and 1090). We hypothesize that this dissolution event reflects a rapid, but brief, shoaling of the CCD due to a decrease in carbonate ion saturation (acidification) of deep waters. This shoaling episode occurs immediately prior to the well-documented CCD deepening and indicates that CCD changes through the E-O transition are more complex than previously thought. On-going study of this event is aimed at acquiring constraints that can be used to evaluate possible mechanisms causing the CCD variation. Ultimately, we hope to gain a better understanding of the complex series of events and changes in carbon cycling that led to the major shift in global climate across the E-O transition.

AN EOCENE/OLIGOCENE BOUNDARY GEOCHEMICAL PROXY RECORD FROM OCEAN DRILLING PROGRAM SITE 1211 ON THE SHATSKY RISE, PACIFIC OCEAN

T. Broadbent, L.J. Clarke, and M Leng

University of Wales, Bangor (UK)

Evidence for significant global oceanographic and climatic change at the Eocene/Oligocene Boundary (EOB) is well documented, but records from the Pacific Ocean are limited to a single location, Site 1218 (Lear et al., 2004; Coxall et al., 2005). This study presents a new Pacific dataset from ODP Site 1211 for the EOB. Recovered during ODP Leg 198 from the Southern High of the Shatsky Rise, Site 1211 (palaeodepth 2000-3000m) contained a seemingly complete calcareous nannofossil ooze midldle Eocene to late Oligocene section, suggesting deposition above the carbonate compensation depth (CCD) for the duration of the period. Deposition above the CCD should mean that changes in carbonate ion saturation, a possible control on foraminiferal Mg/Ca ratios, will be reduced in comparison to existing records from Site 1218 (palaeodepth ~3800 m; Lear et al., 2004). Benthonic and planktonic foraminiferal stable-isotope and element/Ca ratios were determined for Site 1211 across the EOB are presented along with proxies relating to carbonate saturation.

GAS HYDRATE QUANTIFICATION FROM SEISMIC DATA ALONG THE CONTINENTAL MARGIN OF WESTERN SVALBARD.

Anne Chabert[1], Tim A. Minshull[1], Graham K. Westbrook[2], Christian Berndt[3]

[1]National Oceanography Centre Southampton (UK); [2]University of Birmingham (UK); [3]IFM-Geomar (Germany)

The stability of shallow gas hydrate in the Arctic region is expected to be affected by the warming of the bottom-water in the next decades. It is, therefore, important to evaluate how the gas hydrate systems will react to future increases in bottom-water temperature and the impact on climate of the spatial and temporal variability of the release of methane from these reservoirs.

As part of the International Polar Year initiative, a multidisciplinary marine expedition was carried out in September 2008 along the continental margin west of Svalbard in the Arctic. One of the objectives was to investigate the extent the gas hydrate stability zone (GHSZ) of the continental slope and the quantity of methane present from the geophysical properties of methane hydrate- and gas-bearing sediments, which occur in and beneath the GHSZ.

Three seismic experiments employing ocean-bottom seismometers (OBS) were carried out across and along the continental margin as part of the project. Seismic data from 13 arrays of closely spaced OBS were acquired from 5 representative sites off west Svalbard, above and below the upper limit of the GHSZ. 2 to 4 OBSs were deployed at each site, with a spacing of 200 m. The high frequency airguns were fired at 5-s intervals,concurrently with the acquisition of multi-channel seismic reflection profiles. The OBSs were equipped with a 3-component 4.5 Hz geophone package and a broadband hydrophone; the data-loggers were operated at 1 kHz sample rate.The OBS experiments were designed to recover P- and S-wave velocities to depths of a few hundreds metres below the seabed in order to estimate the amount of hydrate in the region, hydrate increasing both the P- and S-wave velocities of the sediments in which it is present. The data show clearly recorded P reflections at short offsets, as well as refracted arrivals at larger offsets, from depths of 1 to 2 kilometres below the seabed. S waves, generated by P-S conversion on reflection, are identified as strong low-frequency reflections on the geophone components from depths down to a few hundred metres below the seabed.Modelling of the P- and S-wave velocities will allow a better understanding of the sub-seabed distribution of the seismic properties from which the amount of hydrate present in sediment can be estimated and features indicative of its presence recognised.

A PROPOSAL TO OBTAIN CONTINUOUS, HIGH-RESOLUTION RECORDS FROM SEDIMENT DRIFTS OFF THE ANTARCTIC PENINSULA AND WEST ANTARCTICA (PROPOSAL 732-FULL2)

J.E.T. Channell[1], R.D. Larter[2], C.-D. Hillenbrand[2], M. Vautravers[2], D.A. Hodell[3], F.J. Hernández-Molina[4], K.Gohl[5] & M. Rebesco[6]
[1]University of Florida (USA); [2]British Antarctic Survey (UK); [3]University of Cambridge (UK); [4]Universidad de Vigo (Spain); [5]Alfred Wegener Institute for Polar and Marine Research (Germany); [6]Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) (Italy)

Ice sheet histories and palaeocenographic interpretations based on sediment cores from high southerly latitudes have been stymied by imprecise chronological control, due in large part to lack of foraminiferal carbonate for isotopic analyses. The chronological problem can now be partially offset by using relative geomagnetic palaeointensity records.

Previous coring on ODP Leg 178 demonstrated that sediment drifts off the Antarctic Peninsula carry a continuous, high-resolution Miocene to Recent archive of palaeoceanographic conditions and history of the Antarctic Peninsula Ice Sheet. However, the potential of existing ODP cores is compromised by two factors: (1) incomplete composite sections and (2) lack of precise chronological control.

We propose to drill a series of new sites on these sediment drifts, and on ones further to the southwest that contain records of West Antarctic Ice Sheet fluctuations. Six proposed sites target expanded Pliocene-Quaternary sequences, with two sites targeting the pre-Pliocene record at locations characterized by relatively thin younger sequences.

There are few targets in the circum-Antarctic region that rival the potential offered by these sediment drifts. Recovery of these sediment cores and integration of data from them with polar ice cores will contribute significantly to our understanding of the role of West Antarctica and the adjacent Southern Ocean in global atmospheric and oceanographic processes.

PALEOREDOX ACROSS THE PALEOCENE-EOCENE THERMAL MAXIMUM

Cecily O. J. Chun[1*], Margaret L. Delaney[1], and James C. Zachos[2]

[1]University of California (USA); [*]Now at National Oceanography Centre, Southampton (USA)

Email of the corresponding author: Cecily.Chun@noc.soton.ac.uk

A massive benthic extinction event during the Paleocene-Eocene thermal maximum (PETM) has been attributed to several factors, including a global reduction in dissolved oxygen. Changes in bottom water oxygen have yet to be quantified for this period. To this end, we have measured manganese (Mn) and uranium (U) enrichment in Atlantic and Pacific deep-sea cores to constrain paleoredox changes across the PETM. We use bulk sediment Mn and U enrichment factors (EF) to infer bottom-water oxygen concentrations during this abrupt warming event. The comparison of Mn EF before and after a reductive cleaning procedure allows us to determine the presence of Mn-oxides or Mn-carbonates. Mn EF representing Mn oxides and no U EF suggest oxygenated bottom-waters. Mn-carbonates and U EF suggest reducing conditions and an early diagenetic phase. Mn EF range from 1-9 in Atlantic sites, 1-35 Southern Ocean sites, and 5-400 in Pacific sites. U EF range from 1-5 in Atlantic sites, 1-90 in Southern Ocean sites, and are at crustal averages EF = 1 in Pacific sites. Our results indicate reducing conditions prior, during, and in the recovery of the PETM at intermediate depth sites in the Atlantic and Southern Ocean while the Pacific sites remain oxygenated. Reducing bottom-water conditions in the Atlantic and Southern Ocean may have contributed to the benthic foraminifera extinction event. Release of methane in the oceans oxidizes to carbon dioxide, depleting bottom-water oxygen concentrations. Because our sites in the Atlantic have the most reducing bottom-waters, we suggest the Atlantic Ocean could have been the source for isotopically light carbon release during the PETM.

DEEP WATER PRODUCTION IN THE GIN SEAS: THE ND RECORD FROM FENI DRIFT

Kirsty Crocket[1a], Marcus Gutjahr[2a], Gavin L. Foster[2a], David A. Richards[1a], Derek Vance[2a], Martyn Tranter[1b]

[1]School of Geographical Sciences, University of Bristol (UK); [2]Department of Earth Sciences, University of Bristol (UK); [a]Bristol Isotope Group; [b]Bristol Glaciology Centre

Email of the corresponding author: k.crocket@imperial.ac.uk

The Greenland, Iceland, Norwegian (GIN) Seas are a key area of modern deep water production. At the last glacial maximum, deep water production is proposed to have shifted from the GIN Seas to the subpolar North Atlantic[1-3], although increasing evidence is being presented of significant contributions to glacial deep water from the GIN Seas via Greenland-Scotland Ridge overflow[4-6]. So far attempts to reconstruct GIN Seas surface conditions have resulted in contradictory interpretations, thus impeding efforts to determine the role and response of deep water production to specific climate events of the glaciations and deglaciation. To gauge variations in the intensity of GIN Seas deep water production during the last glaciations, we present a Nd isotope record ($^{143}Nd/^{144}Nd$ expressed in ε_{Nd} notation) from the Rockall Trough, which captures exchanges between the overflow of GIN Seas water and incursion of southern sourced waters (SSW), both identifiable by their distinct range of ε_{Nd}. Our record shows rapid radiogenic excursions of up to +2.8 ε_{Nd} units toward a more radiogenic end member coeval with Heinrich events and at 20 ka. These shifts most likely reflect incursion of radiogenic SSW in the Rockall Trough when deep water production in the GIN Seas ceased or was dramatically reduced in response to surface ocean freshening, implying a concomitant reduction of Glacial North Atlantic Intermediate Water in the North Atlantic. The return to less radiogenic ε_{Nd} between excursions suggests intermittent deep water production was present in the GIN Seas during the last glaciations.

PALEOCEANOGRAPHIC RECORDS FROM THE TROPICAL PACIFIC: EVIDENCE FOR GLACIO-EUSTASY DURING THE MIDDLE EOCENE

Caroline F. Dawber and Aradhna K. Tripati

University of Cambridge (UK)

The onset of glacial conditions during the Cenozoic marks a fundamental change in Earth's climate. Although the widely held view is that the 'greenhouse-icehouse' transition began ~34 million years ago (Ma)[1], recent work suggests that it may have commenced earlier[2,3,4,5,6,7,]. The sequence stratigraphic record supports the occurrence of high-frequency sea-level change of tens of meters in the Middle and Late Eocene[2], and calcite and seawater $\delta^{18}O$ excursions of ~0.5-1.0‰ have been reported in foraminifera from open ocean sediments[3,4]. Also, there is evidence for sea and glacier ice in the northern hemisphere as early as ~47[5] and 45[6,7] Ma respectively. As a result, the Middle Eocene is often considered the intermediary 'doubthouse' interval. However the extent of continental ice storage during this interval is controversial, with estimates of glacioeustatic sea level fall ranging from 30 to 125[2,3,4] meters.

We present a new seawater $\delta^{18}O$ reconstruction for Ocean Drilling Project (ODP) Site 1209 in the tropical Pacific Ocean. It is a high-resolution record (~1 sample per 14 kyrs) for an open-ocean site that should not be directly influenced by changes in the carbonate compensation depth. Our record shows increases of 0.8 ± 0.3 (1 s.e)‰, 1.1 ± 0.3‰ and 0.8 ± 0.3‰ at ~44-45, ~42-41 Ma and ~39-40 Ma, respectively, and decreases of 0.8 ± 0.3‰ and 1.3 ± 0.3‰ at ~42.8 Ma and ~40.4 Ma respectively. These variations in seawater $\delta^{18}O$ are consistent with the presence of a dynamic cryosphere during the Middle Eocene, driving glacioeustatic sea level variations of ~90 m. Modelling studies have shown that fully glaciating Antarctica during the Eocene should drive a change in seawater $\delta^{18}O$ of 0.45‰, and lower sea level by ~55 m[8]. Our results would therefore support significant ice storage in both the Northern and Southern Hemisphere during the Middle Eocene 'doubthouse'.

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TESTING THE EOCENE BIPOLAR GLACIATION HYPOTHESIS

Kirsty M. Edgar[1], Paul A. Wilson[1], Philip F. Sexton[1,2] and Yusuke Suganuma[3].

[1]National Oceanography Centre, Southampton (UK); [2]Now at Scripps Institution of Oceanography, University of California (USA) and Cardiff University (UK); [3]University of Tokyo (Japan)

Email addresses of the corresponding authors: kme@noc.soton.ac.uk or paw1@noc.soton.ac.uk

The first large permanent ice sheets were established on Antarctica approximately 34 million years ago (Miller *et al*., 1991). It is generally thought that it wasn't until much later that significant ice sheets developed in the Northern Hemisphere (11 to 5 million years ago) (e.g. Zachos *et al*., 2001). But recently several new studies (Tripati *et al*., 2005; Moran *et al*., 2006; Eldrett *et al*., 2007) have called this view into question and suggested that Northern Hemisphere glaciation may have been initiated as early as the Middle Eocene. Here we present high-resolution stable isotope records in foraminiferal calcite from the equatorial Atlantic Ocean, Ocean Drilling Program Leg 207, Demerara Rise to test this early Cenozoic bipolar glaciation hypothesis.

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IODP MISSION SPECIFIC PLATFORM EXPEDITIONS

Dan Evans

ECORD Science Operator

To date ESO, the ECORD Science Operator, has conducted, is conducting, or has definite plans for 4 IODP expeditions:

The Arctic Coring Expedition (ACEX, #302) was managed by ESO (in cooperation with the Swedish Polar Research Secretariat) from August to September 2004. The drillsites were located on the Lomonosov Ridge, at a point only 250 km from the North Pole. ACEX was a huge logistical challenge because the drillship had to hold its position while surrounded by the moving ice sheets of the Arctic Ocean. This required two icebreakers, the *Oden* and *Sovetskiy Soyuz* to clear a channel through the ice to allow a third icebreaker, *Vidar Viking*, specially converted for the task, to undertake the drilling.

Expedition 310 Tahiti Sea Level sought to establish the course and effects of the last deglaciation on the subsiding volcanic island of Tahiti at a considerable distance from former ice sheets. ESO contracted Seacore to carry out the drilling and used the *DP Hunter* as the drilling vessel.

The objective of the #313 New Jersey Shallow Shelf IODP expedition, also supported by ICDP, is to obtain continuous cores and downhole logging measurements of siliciclastic sequences on this modern continental margin within crucial paleo-inner-shelf facies at three sites that represent the most sensitive and accessible locations for deciphering amplitudes and testing facies models. The expedition is taking place in May–July 2009, the drilling contractor is DOSECC and the platform is the lift boat *Kayd.*

The #325 Great Barrier Reef Environmental Changes Expedition is scheduled for October-December 2009 and will begin and end in Townsville, Queensland. It is proposed to drill 5 transects along the Great Barrier Reef to reconstruct the deglaciation curve since the Last Glacial Maximum, to establish sea surface temperature variation, and to identify and establish patterns of short-term paleoclimatic changes. A contract has been signed with Bluestone Offshore Pte of Singapore to carry out the drilling using the *Bluestone Topaz*.

AN ALGORITHMIC, QUANTITATIVE FRAMEWORK: SPECIES DELIMITATION AND THE DYNAMICS OF DISPARITY

Thomas H.G. Ezard

Imperial College London (UK)

Since the 1950s, taxonomists have speculated on the development of the planktonic foraminiferan genus Turborotalia. Turborotalia originated around 47 million years ago with relatively globular forms, metamorphosed and ended keeled and compressed, with speciation and extinction events also postulated. Whilst DNA barcoding has provoked rapid development of genetic clustering techniques, algorithmic developments for morphological traits have been hampered by theoretical limitations. Here, we refine novel clustering techniques in a hypothesis-driven approach that generates statistics describing sample homogeneity and employ it to resolve the arguments on Turborotalia's evolutionary history. Using 12 morphometric traits on 200 individuals at each of 51 time intervals over ~13 million years, each sample was delimited statistically. On a macro-evolutionary scale, inferred species were statistically well-separated in four intervals. On a micro-evolutionary scale, a homogeneous sample tends to become more disparate in the subsequent interval, and vice versa, but there appeared no gradual increase in heterogeneity prior to speciation. The unified methodology elucidates patterns in evolutionary change that might otherwise remain cryptic.

EVIDENCE FOR ICEBERG ARMADAS FROM EAST ANTARCTICA IN THE SOUTHERN OCEAN DURING THE LATE MIOCENE AND EARLY PLIOCENE

T. van de Flierdt[1,2], T. Williams[2], E. Chung[2, 3], M. Roy[2,4], S.R. Hemming[2], and S.L. Goldstein[2]

[1]Imperial College London (UK); [2]Lamont-Doherty Earth Observatory (USA); [3]University of Maryland (USA); [4]Université de Quebec a Montreal (Canada)

Email of the corresponding author: tina.vandeflierdt@imperial.ac.uk

Sediments from Ocean Drilling Program Site 1165 in the Indian Ocean sector of the Southern Ocean (off Prydz Bay) contain a series of layers that are rich in ice-rafted debris (IRD). Here we present evidence that IRD-rich layers at Site 1165 at 7, 4.8, and 3.5 Ma record short-lived, massive discharges of icebergs from source areas more than 1500 kilometers to the west of the depositional site (Wilkes Land and Adélie Land). This distant source of the icebergs is clearly defined by the presence or IRD hornblende grains with ages of 1200-1100 Ma or 1550-1500 Ma, ages that can not be found on the East Antarctic continent in locations more proximal to Site 1165. This observation requires enormous amounts of detritus-carrying drifting ice, most likely in form of large icebergs. These events probably reflect destabilization, surge, and rapid retreat of ice streams on the Wilkes Land and Adélie coast margins of the East Antarctic ice sheet under warming conditions, which however do not seem to happen simultaneously but rather as discrete events. The data presented here constitute the first evidence of far-traveled icebergs from specific source areas around the East Antarctic perimeter. Launch of these icebergs may have happened during quite dramatic events, perhaps analogous to “Heinrich Events” in the North Atlantic.

PLIO-PLEISTOCENE PCO2 – A MULTIPROXY APPROACH USING ALKENONE AND BORON BASED CARBONATE SYSTEM PROXIES

Gavin L. Foster[1], Osamu Seki[2+3], Daniela N. Schmidt[4], Andreas Mackensen[5], Kimitaka Kawamura[3], Richard Pancost[2]

[1]Bristol Isotope Group, University of Bristol (UK); [2]Organic Geochemistry Unit, University of Bristol (UK); [3]Hokkaido University (Japan); [4]Department of Earth Sciences, University of Bristol (UK); [5]Alfred Wegener Institute for Polar and Marine Research (Germany).

Email of the corresponding author: g.l.foster@bristol.ac.uk

The recent rapid rise in atmospheric CO_2 is unprecedented in Earths history, and the current level (~385 ppm) is higher than previously experienced for at least the last ~800 kyr. Therefore in order to better understand the link between climate and CO_2 it is desirable to examine times in the past that experienced similar or higher levels of CO_2 compared to today. The Pliocene (2.6 to 5.3 Ma) is the most recent warm period and hence offers such an opportunity. Detailed reconstructions show that global temperatures were 2-3 ºC higher ([1], ~6 ºC at high latitudes) and the polar ice sheets were considerably smaller (sea level was 15-20 m higher; [2]) yet other boundary conditions, such as continental configuration, were similar at this time. Earlier studies, typically with low temporal resolution, have shown that at ~3 Ma during the Mid-Pliocene pCO_2 concentrations were in the range 300-400 ppm. A common assumption is that pCO_2 dropped from this high value to pre-industrial values at a time coincident with the intensification of northern hemisphere glaciation (NHG) that occurred at around 2.7 Ma, although this has yet to be demonstrated. Here we present a continuous pCO_2 record recovered from ocean sediments using a multiproxy approach based on the boron [3] and alkenone [4] carbonate system proxies. This new data allows both a determination of the magnitude of Pliocene pCO_2 and for the first time the Plio-Pleistocene evolution of pCO_2 that accompanied the intensification of NHG.

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MILLENNIAL-SCALE FLUCTUATIONS IN NORTH ATLANTIC SURFACE-WATER TEMPERATURES DURING MIS 100

Oliver Friedrich, Clara T. Bolton, Paul Wilson and Ralf Schiebel

National Oceanography Centre Southampton (UK)

Email of the corresponding author: of2w07@noc.soton.ac.uk

Given its proximity to the large dynamic ice-sheets of the northern hemisphere and the role in deep-water formation the North Atlantic represents on of the climatically sensitive regions on Earth. Hence, data sets in key areas like the North Atlantic are extremely useful in order to e.g. quantify and reconstruct the paleoceanographic dynamics of the Pliocene. The broad objective of this study is to quantify, at millennial time-scales, paleoclimatic and paleoceanographic changes during the Late Pliocene (MIS 99 to 101). These objectives will be met by the integration of the Mg/Ca paleotemperature method and its use to allow a differentiation between changes in global ice-volume and SST.

The recently drilled Integrated Ocean Drilling Program Site 1313 from the central North Atlantic (50°N) provides an ideal opportunity to tackle these questions. A demonstrably complete Mid to Late Pliocene section for Site 1313 was recovered, consisting mainly out of nannofossil ooze and nannofossil silt. A very high sedimentation rate and the abundant and well-preserved microfossils provide the requirements for high-resolution studies on planktic foraminifera and optimal reconstruction of the phasing of SST records and their relationship to salinity and ice-sheet changes on a high temporal resolution.

For this study 145 samples in 2-cm spacing (resulting in a ~400 years resolution) of isotope stages MIS 99 to 101 were prepared for parallel Mg/Ca and stable isotope analyses. Per sample 60 tests of *G. ruber* were picked from the 212 to 250 μm size interval and subsequently split in half for Mg/Ca and stable isotope analyses. Mg/Ca ratios of the samples were measured by inductively coupled plasma-optical emission spectrometry.

SUBMARINE GEOMORPHOLOGY OFFSHORE IONIAN SEA, ITALY

Rajasmita Goswami[1], N. C. Mitchell[1], S.H. Brocklehurst[1] and A. Argnani[2]

[2]University of Manchester (UK); [2]CNR, Bologna (Italy)

Submarine continental slopes are landscapes characterized by large variety of relief from rills and gullies to large canyon net systems, but how these features develop is still not well understood. Marine-geoscientists suspect that sediments delivered from the adjacent land might be the ultimate “driver” for these landscapes, for example, by supplying erosive sedimentary flows. However, it is difficult to prove an intimate cause for submarine system formation as along most coasts the shelf is too wide to allow us to assign individual canyons to rivers and we have poor idea of the sediment supply. The coasts of NE Sicily and SW Calabria have narrow shelves and their uplift rates are well quantified. As the Sicilian coast landscape in particular is mature, the long term sediment flux can be assessed from the uplift rates and their drainage catchment areas. The marine geophysical dataset, used for the present study, reaches to within 100m water depth around the coast. As, according to estimates, local relative sea level was depressed by 120m, the data represents areas that were exposed during the Last Glacial Maximum. This allows an assessment of sediment transport paths during glacial times. Spectacular underwater landscape is observed from the data with developing rills, gullies and deeply incised canyons. Different types of erosional and mass-wasting landforms are also observed. The nearest IODP site to this area is the Site 964, in the Ionian Basin, where the sediments show turbidites as the most obvious features. The terrigenous detrital material in this site also reflects fluvial input from the northern borderlands. Our findings suggest that the erosion offshore is limited by the onshore erosion and these turbidites seems to be originated from upstream.

CHANGES IN NORTH ATLANTIC DEEP WATER STRENGTH AND BOTTOM WATER MASSES DURING MARINE ISOTOPE STAGE 3 (45 TO 35 KA BP)

Marcus Gutjahr[1,2], Babette A. A. Hoogakker[3], Martin Frank[1,4] and Ian N. McCave[3]

[1]ETH Zürich (Switzerland); [2]Bristol Isotope Group (UK); [3]University of Cambridge (UK); [4]now at: IfM-GEOMAR, Leibniz Institute for Marine Sciences at the University of Kiel (Germany)

Many studies used benthic carbon isotopes ($\delta^{13}C$) to infer major hydrographic changes in the deep Atlantic during glacial-interglacial cycles as well as intervals characterized by rapid climatic reorganisations, including Heinrich drift ice events. While this proxy is of great value, it is important to corroborate deep water mass changes through the use of other paleoceanographic proxies that are not affected by other effects such as productivity changes. Here we present high-resolution authigenic Fe-Mn oxyhydroxide-derived Nd isotope compositions from drift sediments along the Blake Ridge in the deep western North Atlantic (ODP Leg 172, Site 1060, 3481 m water depth) covering the interval from 45 to 35 ka BP in order to sample water mass changes over the course of major Heinrich event 4 (~40-39 ka BP), an interval which includes the Laschamp magnetic excursion.

The Nd isotope record suggests that NADW was not present over the deeper part of Blake Outer Ridge at any time between 45 to 35 ka BP, which is fundamentally different from the hydrographic situation during the Holocene. The authigenic deepwater ε_{Nd} recorded in Blake Ridge sediments was least radiogenic during Dansgaard/Oeschger (D/O) Interstadial (IS) 8 (ε_{Nd} = -11.3) and most radiogenic preceding IS 9 (ε_{Nd} = -9.8). More radiogenic compositions were also recorded during Heinrich iceberg discharge event 4 (H4) ($-10.2 \leq \varepsilon_{Nd} \leq -9.9$). Strikingly, and analogous to a sortable silt record published earlier from this Site (Hoogakker *et al.* 2007), the authigenic Nd isotope compositions recorded during MIS 3 in the deep western North Atlantic do not follow the Northern Hemisphere D/O climatic cycles. Our data suggest reduced mixing with northern source water starting in stadial 12 and lasting until after H4 in stadial 9, followed by a rapid resumption thereafter. The change in Nd isotope compositions predates the iceberg discharge event Heinrich 4 by more than 3 kyr, indicating a shallowing of the vertical water mass boundary between Glacial North Atlantic Intermediate Water and Southern Source Water at that time. This early rise in the vertical water mass boundary likely suggests hydrographic changes in the deep North Atlantic were not directly related to Heinrich event 4.

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AMINOPENTOL, A POSSIBLE NOVEL BIOMARKER TRACER FOR METHANE HYDRATE STABILITY IN SEDIMENTARY RECORDS

Luke Handley, Helen M. Talbot, Martin P. Cooke and Thomas Wagner
Newcastle University (UK)

Email of the corresponding author: luke.handley@ncl.ac.uk

The Congo Fan is a region of important methane (CH_4) storage and seepage: large gas hydrate reservoirs, at and just below the sediment surface, occur alongside deeply-buried reservoirs of thermogenic methane linked with hydrocarbon source rocks. Methane release from both reservoirs has the potential to drive or respond to changes in local and global climate, thus causing changes in ocean chemical properties and biotic responses. Understanding these mechanisms of methane emission and reconstructing the history of past emissions in the Congo Fan (ODP Site 1075) is the main focus of this study.

Bacteriohopanepolyols (BHPs) are lipid membrane constituents of bacteria and occur with a wide range of structural and functional variability. Amino-BHPs are produced by methane-oxidising bacteria and the 35-aminobacteriohopane-30,31,32,33,34-pentol (aminopentol) is a highly specific biomarker for aerobic methane oxidation. Aminopentol is present throughout and its sedimentary concentration varies significantly throughout the studied section, with a suspected precession-driven cyclical variability superimposed on longer-term eccentricity cycles. Other amino-BHPs are also present, with variability that mirrors that observed in the aminopentol record. Compound-specific stable carbon isotope analyses confirm that the amino-BHPs are of methanotrophic origin. Adenosylhopane, a soil derived BHP, is also present in most sediments, although there is a general diagenetic decrease in concentration downsection, and increases and decreases in concentration relative to total BHPs mirror changes in the BIT index, a proxy for soil derived organic matter input, revealing discreet episodes of lower terrigenous input over the last 1 Myr.

The aerobic oxidation of methane is thought to be intrinsically linked with methane gas hydrate dissolution. Thus, the variability in amino-BHP abundance could provide an indicator for past methane emission events, directly linking key aspects of structural geology with gas hydrate stability, deep ocean processes, and methane cycling.

FLUID FLOW IN UPPER OCEANIC CRUST: STRONTIUM AND OXYGEN ISOTOPIC PROFILES THROUGH IN SITU OCEANIC CRUST AT ODP HOLE 1256D, EASTERN EQUATORIAL PACIFIC

Michelle Harris[1], Damon A.H. Teagle[1], Christopher E. Smith-Duque[1], Neil R. Banerjee[2], Matthew J. Cooper[1] and Rosalind M. Coggon[1]

[1]National Oceanography Centre, University of Southampton (UK); [2]University of Western Ontario (Canada)

The circulation of hydrothermal fluids through oceanic crust affects the chemical composition of the oceans as well as the ocean crust. However the magnitude and distribution of hydrothermal fluids remains poorly constrained despite studies of ophiolites and drilling of modern ocean crust.

Strontium and oxygen isotopes provide useful tracers of fluid-rock interaction in ocean crust because the end-member compositions are well characterised. In this study whole-rock strontium and oxygen isotope ratios have been measured to determine the nature and magnitude of hydrothermal circulation through the first intact sampling of modern upper ocean crust at ODP Hole 1256D.

All samples have $^{87}Sr/^{86}Sr$ ratios elevated from fresh EPR MORB and the average $^{87}Sr/^{86}Sr$ of Hole 1256D is 0.70346. The lavas display a limited range in $^{87}Sr/^{86}Sr$ whilst the sheeted dikes have a broad range up to hydrothermal fluid values (0.7029 - 0.7053). The $^{87}Sr/^{86}Sr$ profile indicates horizons of focussed fluid flow within the upper crust and at the dike-gabbro boundary. The $\delta^{18}O$ profile has a sharp cross-over from enriched values (relative to fresh MORB) to depleted values at the transition zone. This study shows that fluid flow is variable with depth and is unlike that seen in other sections of oceanic crust.

TECTONIC-CLIMATE INTERACTION IN SE ASIA: RECONSTRUCTED FROM SEDIMENT RECORDS OF THE SHONG HONG-YINGGEHAI AND QIONGDONGAN BASINS AND ODP SITE 1148, SOUTH CHINA SEA

Long Van Hoang,[1] Peter D. Clift,[1] Anne Schwab,[2] Mads Husse,[3] Fu-Yuan Wu,[4] Sun Zhen [5]

[1]University of Aberdeen (UK); [2]Marathon International Petroleum (G.B.) Limited; [3]University of Manchester (UK); [4]Institute of Geology and Geophysics, Chinese Academy of Sciences (China); [5]South China Sea Institute of Oceanography, Chinese Academy of Sciences (China)

Email of the corresponding author: l.v.hoang@abdn.ac.uk

The Song Hong-Yinggehai (SH-Y) and Qiongdongnan (Qi) Basins together form one of the largest Cenozoic sedimentary basins in SE Asia. Here we present new sedimentary records from erosion of these two basins. We compare these records to geochemical data derived from cores of the ODP Site 1148 offshore northern South China Sea (SCS) to derive proxies for continental weathering and thus monsoon intensity. Furthermore, we will evaluate the evolution of the Red River System based on in-situ U-Pb Dating and Hf isotope analysis of zircons.

The SH-Y Basin is a pull-apart basin which started opening during the Late Paleocene-Eocene (~50 Ma). Two basin inversion phases are recognised: the first event likely occurred at ~34 Ma while the later uplift took place at ~15 Ma. The Qi Basin developed on the northern rifted margin of SCS. A large canyon developed in the Qi Basin oriented in a NE-SW direction, widening and deepening towards the SW

Geochemical data show that chemical weathering has gradually decreased in SE Asia after ~25 Ma, while physical erosion became stronger, especially after ~15 Ma. Clastic sediment flux increased sharply after 4 Ma. Clay mineralogy indicates more physical erosion together with high sedimentation rates from ~15–10 Ma suggesting a period of strong summer monsoon in the Mid-Miocene. Nonetheless, the monsoon appears to have intensified since at least ~23 Ma.

The U-Pb age and Hf isotope data show that the Yangtze Craton and the Songpan Garze block are the most important sources for sediment into the Red River, although this material is usually reworked via Triassic Indosinian sedimentary rocks in the upper reaches. Analysis of the age spectra suggests that the palaeo-Red River ran through the Lo River Basin (NE of the Day Nui Con Voi), not through the Lao Cai Basin in the Middle and Late Miocene. The Red River appears to have been largely stable in its provenance since at least the Late Miocene.

EXPEDITION 307 – DRILLING CHALLENGER MOUND: UNRAVELLING SEDIMENT DYNAMICS AND CLIMATE SIGNALS IN A COLD-WATER CORAL CARBONATE MOUND

Huvenne[1], V.A.I., Thierens[2], M., Van Rooij[3], D., O'Donnell[2], R., De Mol[4], B., Foubert[5], A. & the IODP Exp.307 Scientific Party

[1]National Oceanography Centre, Southampton (UK); [2]University College Cork (Ireland); [3]Ghent University (Belgium); [4]Universitat de Barcelona (Spain); [5]K.U.Leuven (Belgium)

Email of the corresponding author: vaih@noc.soton.ac.uk

IODP Expedition 307 targeted the 160 m high Challenger cold-water coral carbonate mound and its surroundings in the Porcupine Seabight. More than 1000 such mounds are found in the area, all rooted on a common unconformity ('RD1'; Van Rooij et al., 2003) and embedded in drift sediments. Their initial trigger and formation mechanisms are still not clear: they have been linked to a potential hydrocarbon seep-based food supply, while other authors suggest dependence on environmental conditions.

During the short Exp307 (a mini-leg of 18 days), a 3-site downslope transect was drilled, including one on-mound site, one off-mound site, and one background site. The main aims were to clarify the mound's origin, formation history and potential paleoceanographic records, by obtaining the first complete section through a modern cold-water coral carbonate mound. The standard IODP procedures were altered in this unusual environment: coral-bearing sections were frozen before being split, while entire 1 to 1.5 m sections were taken out of the core flow for microbiological analysis, immediately afer arriving on deck.

This poster presents some of the main results obtained from the Exp307 records, in addition to a more specific study of the core interval that overlies the RD1 unconformity. The grainsize and planktonic foraminifera assemblage records overlying this sharp boundary at the three drill sites give insights in the initial stages of Challenger Mound, and in the sedimentary regimes that both supported the first, explosive mound development and the subsequent partial mound burial. Sedimentation within the initial mound was characterised by a 2-mode system, with the observed cyclicities related to glacial/interglacial stages. However, the conditions were less extreme than observed in the recent-most glacial/interglacial cycles, allowing continuous cold-water coral growth. This sustained presence of coral framework was the key factor for fast mound build-up, baffling sediments at periods of slack currents, and protecting them from renewed erosion during high-current events. The off-mound and background sedimentation mainly consisted of a succession of contourite beds, ranging from sandy contourites in the initial stages to muddy contourites higher up in the sequence. The latter illustrate the increasing importance and dominance of glacial conditions after the Mid-Pleistocene Revolution.

The overall findings are summarised in a new descriptive mound development model.

Van Rooij et al. (2003). *Mar. Geol.*, 195, 31-53.

ASTRONOMICALLY-FORCED CLIMATE CHANGES DURING THE LATE OLIGOCENE AND EARLY MIOCENE; TUNED MAGNETIC SUSCEPTIBILITY AND STABLE ISOTOPE RECORDS FROM THE WALVIS RIDGE (SOUTH-EAST ATLANTIC OCEAN)

Diederik Liebrand, Lucas. J. Lourens, David A. Hodell, B. David A. Naafs

Magnetic susceptibility (MS) records from Site 1265 and Site 1264 (Walvis Ridge, South East Atlantic Ocean) were orbitally tuned. Magnetostratigraphy from Site 1265 was correlated to the Site 1264 through MS and Green/Red-data pattern matching. The astronomical tuned age model resulted in revised ages for the GPTS chron boundaries C6Cn.3n (o) through C5En (o). Tuning of Walvis Ridge MS records yielded an Oligocene-Miocene (Paleogene-Neogene) boundary age of 23.12 Ma; ~90 Kyr older than the ATNTS2004 age. High resolution (< 3 kyr) oxygen and carbon stable isotope records from ODP Site 1264 (2505 m) were constructed, spanning the late Oligocene and early Miocene. These records show generally good agreement with other Atlantic high-resolution records [Billups, et al., 2002; Pälike, et al., 2006a], although carbon values are heavier, indicating a vertical gradient or a different water mass at this site. Oxygen isotopes contain a much cleaner imprint of the 100 kyr eccentricity periodicity during the Mi-1 glacial period (nomenclature after [Miller, et al., 1987; Miller, et al., 1991]). Spectral analysis of the isotope and magnetic susceptibility records contain dominant control of the climate system on Milankovitch timescales by the 400 kyr and 100 kyr eccentricity periodicities. This implies that controlling mechanisms on these timescales must have been the same during this interval in time as during the preceding Oligocene [Pälike, et al., 2006b].

NEW CORES FROM THE INDUS SHELF, PAKISTAN

David Limmer[1], Peter Clift[1] and Tim Henstock[2]

[1]University of Aberdeen (UK); [2]University of Southampton (UK)

Email of the corresponding author: d.r.limmer@abdn.ac.uk

Preliminary work on cores collected from the Indus continental shelf during Winter 2008/09 is presented. They form part of a greater project to ascertain the response of the subaqueous delta to the Holocene sea level rise, the Asian monsoon record and possible anthropogenic impacts on sedimentation. The understanding of these processes has already begun with work on the terrestrial delta. The cores in this study showed a marked contrast between sedimentation in the eastern and western parts of the shelf, most notably the appearance of unconformities at the northern edge of the western shelf, and greater numbers of turbidites. Provenance work and radio carbon dating, combined with grain size analyses will be conducted along with scanning of physical and geochemical properties of the cores in order to complete the original objectives of the project

HIGH SEA-SURFACE TEMPERATURES IN THE EARLY CRETACEOUS

Kate Littler[1], Stuart Robinson[1], Paul Bown[1], Alexandra Nederbragt[1] and Richard Pancost[2]

[1]University College London (UK); [2]Bristol Biogeochemistry Research Centre, University of Bristol (UK)

Email of the corresponding author: kate.littler@ucl.ac.uk

The Early Cretaceous (~140 to 125 Ma) is widely thought to have been a period of elevated atmospheric CO_2 yet, conversely, some geological evidence seems to suggest the existence of relatively colder conditions and even transient glaciations. Previous geochemical studies of Early Cretaceous palaeotemperatures have relied upon oxygen-isotopes and Mg/Ca ratios of belemnites, foraminifera and fish-tooth phosphate. However, species-specific responses and uncertainty relating to the original isotopic and elemental-ratio composition of Cretaceous seawater remain problematic. In this study, we apply the TEX_{86} organic palaeothermometer to Early Cretaceous marine sediments from DSDP/ODP sites, thereby producing sea-surface temperature estimates which are independent of the original seawater chemistry. This study extends the range of application of this technique to the earliest part of the Cretaceous record. Our results show high average annual sea-surface temperatures in the sub-tropical Proto-North Atlantic of ~32˚C; considerably warmer than modern values of ~25˚C at the equivalent present-day latitude. The temperature record in this region is also remarkably stable over a time period greater than 10Myr, which is interesting in light of the large positive carbon-isotope excursion which occurred in the late Valanginian (~137Ma). In addition, we present results from a higher latitude site (~52˚S palaeolatitude) that yield an average temperature of ~26˚C; far in excess of modern values of ~8C at this latitude. Our results imply a flatter pole-to-equator temperature gradient during the Early Cretaceous than at present, but steeper than suggested by some previous oxygen isotope studies.

SEABED ROCK DRILLING: PREVIOUS SCIENTIFIC RESULTS AND FUTURE APPLICATIONS

C.J. MacLeod[1], T. Freudenthal[2], D. McInroy[3] and D.J. Smith[3]

[1]Cardiff University (UK); [2]MARUM Center for Marine Environmental Sciences, University of Bremen (Germany); [3]British Geological Survey (UK)

A number of portable remotely-operated seabed rock drills have been developed that allow short cores to be drilled in hard seafloor substrates, using a conventional research vessel rather than a specialist drill ship. Such tools offer an alternative mode of ocean drilling which complements that conducted using *JOIDES Resolution* and *Chikyu*, and offer enormous potential scientific opportunities if employed as mission-specific platform operations under the IODP/post-IODP umbrella. Seabed drills have the potential to penetrate 1-100m below seafloor and have previously been operated in water depths in excess of 5000m. They are ideal for exploring horizontal variability (in the *x-y* dimension) and perfectly complement deep drilling platforms, which optimally investigate the *z* dimension. Oriented coring is possible with some tools, opening many additional opportunities for innovative science. In this poster we document the abilities of the available seabed drill rigs, and outline their potential scientific application by showing brief results from previous seabed drilling expeditions.

PLATE SEPARATION MECHANISMS AND LITHOSPHERIC ACCRETION IN AREAS OF REDUCED MAGMATISM: THE MID-ATLANTIC RIDGE AT 13°N

C.Mallows and R.C. Searle

Durham University (UK)

In areas of reduced magmatism, plate separation along mid-ocean ridges (MORs) is largely accommodated by tectonic processes. Long-lived detachment faulting exhumes lower crustal rocks and mantle peridotites to the sea-floor, forming oceanic core complexes (OCCs). Little is known about the exact nature in which these OCCs initiate, evolve and subsequently terminate. We present here a combination of deep-towed sidescan sonar and magnetic data with shipboard gravity data collected across an area of seafloor where OCCs are actively accommodating plate separation. Sidescan sonar data have been mapped to produce a geological interpretation of the region which highlights the close relationship between magmatism and tectonism. Gravity and magnetic anomalies are highly asymmetric (both along and across axis), indicating a complex tectonic history. Forward modelling of datasets is ongoing in order to quantify: 1) OCC composition (i.e. density and thickness variations - gravity), 2) the relationship between OCC formation and along-axis spreading rate asymmetry (i.e. magnetic) and 3) the precise regional variation in tectono-magmatic ratio (to be calculated from surface area of faults identified with sidescan sonar).

ROLE OF OCEANIC DETACHMENT FAULTS IN CONTROLLING THE CHEMISTRY OF HYDROTHERMAL SYSTEMS

Andrew McCaig* and Teddy Castelain, University of Leeds (UK)

*IODP Expedition 304/305 Scientific Party, JR63 Scientific Party

Recent studies in the Atlantic have emphasised the links between major off-axis high temperature vent fields and oceanic detachment faults. In particular, the TAG field has been shown to be underlain by a dipping zone of seismicity which steepens downwards to root at about 7 km below the seafloor (deMartin et al., 2007); oceanic detachment faults have been shown to be the locus of high temperature (300-400°C) fluid flow at high fluxes (McCaig et al., 2007; Boschi et al., 2006); and detachment faulting has been shown to be an important mode of spreading accounting for about 30% of the Atlantic ocean floor (Smith et al., 2008).

In this poster, evidence from inactive detachment faults at 30°N and 15°45'N is used to speculate on the geological evolution and fluid flow patterns in and around the detachment fault beneath the TAG field.

TROPICAL AND HIGH-LATITUDE SURFACE OCEAN CIRCULATION ACROSS THE MID-PLEISTOCENE TRANSITION: TELECONNECTIONS AND IMPACTS FOR ICE-SHEET GROWTH AND ENVIRONMENTAL CHANGE ONSHORE

E.L. McClymont [1] and A. Rosell-Melé [2]

[1]Newcastle University (UK); [2]Institut de Ciencia i Tecnologia Ambientals (ICTA) Universitat Autonoma de Barcelona (UAB) (Spain)

Email of the corresponding author: erin.mcclymont@ncl.ac.uk antoni.rosell@uab.es

The early to middle Pleistocene was marked by a series of climatic, environmental and faunal changes that resulted in a major transition for the global climate system and the evolution of many modern biotic assemblages. A shift toward a cooler climate and the development of larger Northern Hemisphere ice sheets ~0.9 Ma was accompanied by an increase in the duration and intensity of the glacial cycles from 41 ka to 100 ka by 0.6 Ma: the "mid-Pleistocene climate transition"or MPT. The MPT cannot be explained by external forcing mechanisms alone, and is significant in demonstrating an change in the global climate system response to external insolation forcing. Existing hypotheses link the MPT to falling atmospheric CO_2 concentrations, cooler deep-water temperatures, changing sea-ice distribution, and the basal conditions of the northern hemisphere ice-sheets.

We present alkenone-derived records of sea-surface temperature from Ocean Drilling Programme (ODP) sites in the tropical Pacific and the south-east Atlantic spanning 1.5-0.5 Ma, coupled with evidence of arctic/polar water mass distributions in the high northern latitudes of the Atlantic and Pacific Oceans. At all sites we find evidence for cooling beginning from ~1.2 Ma, supporting the hypotheses invoking cooling of both the atmosphere and deep-waters as a driver of the MPT. We identify an early intensification of Walker Circulation in the tropical Pacific that modern teleconnections suggest may have been conducive to northern hemisphere ice-sheet growth. However, we propose that the temporary equatorward migrations of arctic and subarctic water masses from 1.2 Ma may have been critical in delaying the ice-sheet growth until after 1.0 Ma *via* negative feedbacks on moisture transport to the ice-sheet source regions. Ocean and atmospheric circulation changes that pre-date the northern hemisphere ice-sheet growth are also found in the SE Atlantic, both in the Benguela upwelling system and in the heat-salt exchange between the Indian and Atlantic Oceans (via the Agulhas retroflection). Significantly, we find that the MPT was not simply a high-latitude or ice-sheet phenomenon, but was accompanied by (and perhaps driven by) significant changes to ocean and atmosphere circulation from 1.2 Ma. Furthermore, the changing climate conditions that we identify can be linked to the development of cooler and more arid environments onshore and the associated evolutionary events, including hominid evolution and migration and the massive faunal turnover described by the end-Villafranchian event in Europe.

CONSTRAINING EROSION DURING ARC-ARC COLLISION FROM TURBIDITE SANDS IN THE NANKAI TROUGH

Uisdean Nicholson[1*], Peter Clift[1] and Expedition 316 sedimentologists

[1]University of Aberdeen (UK)

Email of the corresponding author: u.nicholson@abdn.ac.uk

Arc-arc collision is a fundamental process in the growth and evolution of continental crust. Such an event is currently taking place in southeast Japan where the Izu-Bonin arc is colliding with Honshu (Figure 1). Sediment derived from the collision zone is accumulating in the Nankai Trough and has been drilled as part of the NanTroSEIZE. We aim to determine the timing of arc-collision and quantify the influence of collision on exhumation by carrying out fission track analyses of zircon and apatite grains and U/Pb dating of zircons from turbidite sand samples obtained during IODP Expedition 316.

Data derived from Pliocene-Recent turbidite sands will be compared to modern river samples draining the Kii peninsula and the collision zone and published data from these regions. This will allow the exhumation record to be extended back to the Pliocene, and to observe the effect collision had on exhumation rates in Honshu. It will also constrain the relative flux of sediment to the trench from these potential areas throughout this time.

Pliocene-Pleistocene turbidite sands at site C0004 and C0008 are predominantly arc-derived, based on heavy mineral assemblages, which are consistent throughout the drilled sequences. Therefore it may be necessary to use the extended stratigraphic database from ODP and DSDP expeditions to determine the timing of collision and fully understand the impact on exhumation rates.

COMBINED REFRACTION/REFLECTION TOMOGRAPHY OF AN ACTIVE VOLCANO, MONTSERRAT, LESSER ANTILLES

M. Paulatto[1], T. A. Minshull[1], B. Baptie[2], S. Dean[1], J. O. S. Hammond[3], T. Henstock[1], C. L. Kenedi[4], E. Kiddle[3], P. Malin[4], C. Peirce[5], G. Ryan[4,6], E. Shalev[4], R. S. J. Sparks[3] and B. Voight[7]

[1]University of Southampton (UK); [2]British Geological Survey (UK); [3]University of Bristol (UK); [4]University of Auckland (NZ); [5]Penn State University (USA); [6]Montserrat Volcano Observatory, (Montserrat); [7]Durham University (UK)

Email of the corresponding author: m.paulatto@noc.soton.ac.uk

To better understand the volcanic phenomena acting on Montserrat, the SEA-CALIPSO seismic experiment was conducted in December 2007 with the aim of imaging the upper crust and the magmatic system feeding the active Soufriére Hills Volcano. The 3D survey covered an area of about 50 x 40 km and involved the deployment of 247 land stations and ocean-bottom seismometers (OBSs). A subset of the data, recorded by four OBSs and four land stations on a south-east to north-west line, has been analysed, and travel times have been inverted to obtain a 2D seismic velocity model through the island. Inverted phases include crustal and sediment P-waves and wide-angle reflections. The resulting velocity model reveals the presence of a high velocity body (3.5 - 5.5 km/s) beneath the island, with highest velocities beneath the Soufriére and Centre Hills, corresponding primarily to the cores of these volcanic edifices, built of a pile of andesite lava domes and subsequent intrusions. In the offshore region, velocities in the surficial sediment layer vary from 1.5 to 3.0 km/s, consistent with a mainly calcareous and volcaniclastic composition. A basement reflector is observed at a depth of about 1200 m below the seabed, and appears to deepen beneath the island. The upper crust beneath this reflector has velocities of 4.0 - 6.0 km/s and is inferred to correspond to plutonic and hypabyssal rocks and sedimentary material of the old arc. The high velocity region beneath the island, extends into the crust to a depth of at least 5 km, and is believed to be caused by an intrusive complex, possibly of intermediate composition. A low velocity anomaly, as would be expected to be associated with an active magma chamber, was not observed perhaps due to the limited resolution below 5.0 km depth. Our results so far provide the first wide-angle seismic constraints on the upper crustal structure of the island to a depth of 10 km, and will help understanding the processes that drive volcanism at Montserrat and other island arc volcanoes.

CORE REORIENTATION USING FORMATION MICROSCANNER IMAGES: APPLICATION TO THE PALAEOMAGNETIC STUDY OF ATLANTIS MASSIF

Nicola Pressling[1], Antony Morris[1], Jeff Gee[2], Barbara John[3] and Chris MacLeod[4]

[1]University of Plymouth (UK); [2]Scripps Institution of Oceanography (USA); [3]University of Wyoming (USA); [4]Cardiff University (UK)

Email of the corresponding author: nicola.presling@plymouth.ac.uk

The inherent lack of azimuthal control on core material associated with the Integrated Ocean Drilling Program (IODP) is an ongoing problem. The dip of brittle features, such as veins or open fractures, can be measured directly on the core, but the strike of these features with respect to geographic north is not known. However, wireline logging data can provide a near-continuous record of the physical properties of the borehole wall. The Formation MicroScanner (FMS) tool images resistivity contrasts, and distinct inclined planar features can be identified by their sinusoidal shape on unwrapped images. Importantly, these structural features can be accurately oriented in the geographic co-ordinate system due to the inclusion of a magnetometer on the FMS toolstring. Therefore, features seen on the core can be correlated with features seen on the borehole wall, enabling full re-orientation.

This core re-orientation technique is applied to data from IODP Expedition 304/305, which sampled exhumed lower oceanic crust at Atlantis Massif, an oceanic core complex located on the western flank of the Mid Atlantic Ridge at 30°N. Hole U1309D reached a total depth of 1415 metres below sea floor (mbsf), had a high average core recovery of 74% and good quality FMS images. By re-orienting structural features seen on core pieces that have also been sampled for palaeomagnetic analyses, the resulting magnetic remanence directions are re-oriented into geographic co-ordinates. Consequently, we can perform a robust, fully quantitative analysis of the amount and axis of tectonic rotation during the development of the oceanic core complex. Results demonstrate a 46°± 6° counterclockwise rotation of the Atlantis Massif footwall around a Mid-Atlantic ridge-parallel horizontal axis trending 011°± 6°, consistent with rolling-hinge models for the development of oceanic core complexes.

$\delta^{11}B$ AND B/CA IN BENTHIC FORAMINIFERA: UNLOCKING THE OCEAN'S CARBON CYCLE

J.W.B. Rae*, G.L. Foster, D.N. Schmidt, T. Elliott

Bristol Isotope Group, University of Bristol (UK)

Email of the corresponding author: james.rae@bristol.ac.uk

Changes in deep ocean carbon storage are invoked in nearly all IODP climate studies, but direct proxies for the ocean's carbonate system have been scarce. Boron isotopes in benthic foraminifera should record deep ocean pH. The chemical theory behind this proxy is well understood, but its reliability has been questioned, due to uncertainties in the isotopic fractionation factor, models of boron incorporation in carbonate, and analytical difficulties associated with NTIMS measurements. B/Ca ratios in benthic forams have been shown empirically to correlate with carbonate saturation state (ΔCO_3^{2-}) [1].

We have developed a technique for measuring boron isotopes by MC-ICPMS [2]. This methodology overcomes several problems encountered with NTIMS measurements [3, 4], and has been refined to allow accurate measurements of the small numbers of benthic foraminifera typically found in deep ocean sediments. As few as 5 benthic tests (~5 ng boron) may now be measured with an external reproducibility of < 0.3 ‰ (95% confidence), equivalent to < 0.03 pH units. B/Ca and other trace element ratios are measured on the same samples.

We have tested our understanding of the $\delta^{11}B$-pH proxy with a thorough core-top study of a range of benthic species, spanning ambient living conditions from pH 7.4 - 8.2, and 1 - 20 °C. All $\delta^{11}B$ values for epifaunal species show a close match to predicted $\delta^{11}B$ of $B(OH)_4^-$ in seawater [5], and infaunal species show offsets to lower values indicative of calcification from more acidic pore-waters. Despite differences in absolute values and trends of B/Ca ratios between species, we find no evidence for a vital effect on boron isotopes, nor for any incorporation of $B(OH)_3$, nor a significant temperature effect on the isotopic fractionation factor. We also see no change in $\delta^{11}B$ with sample size or apparent dissolution.

The ability of MC-ICPMS $\delta^{11}B$ measurements on small numbers of benthic forams, potentially of different species, to accurately record changes in the ocean's carbonate system makes them a powerful tool for IODP studies of past climate change.

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THE MARINE GEOLOGICAL RECORD OF INDUSTRIALIZATION

Andy Ridgwell

Bristol Research Initiative for the Dynamic Global Environment (BRIDGE), University of Bristol (UK)

In the far distant future, what traces of our industrialized civilization could a hypothetical alien visitor to the Earth identify our ever having existed by? Popular perception is of landfills being excavated and species extinctions identified. However, localized terrestrial deposits and loss of only a relatively small proportion of species would be fickle candidates for reliable preservation in the geological record. Rather, the imprint of our current civilization will be seen in a global-scale dissolution-preservation event of carbonate in deep-sea sediments, coupled to a pronounced negative carbon isotopic excursion. This is the geological fingerprint of massive carbon release to the oceans and atmosphere with subsequent recovery via enhanced rock weathering. Just such a phenomenon is, of course, already known from the marine sedimentary record, particularly associated with the 'poster child' of global warming events – the Paleocene-Eocene Thermal Maximum. Here I present model simulations of what might be expected to be recorded in the marine geological record as a means of better interpreting the paleoceanographic record.

SURFACE TEMPERATURE GRADIENTS IN THE PALEOGENE: RESOLVING THE MISMATCH BETWEEN SEDIMENTARY DATA AND CLIMATE MODELS

Chris D. Roberts[1], Allegra N. LeGrande[2] and Aradhna K. Tripati[1]

[1]University of Cambridge (UK); [2]NASA Goddard Institute of Space Studies, New York (USA)

A long-standing challenge for the paleoclimate community has been to resolve the impact of changing greenhouse gas levels on pole-to-equator temperature gradients. During the early Paleogene (65 to 45 million years ago), levels of greenhouse gases are estimated to have been significantly higher than pre-industrial levels. Proxy records generated from ocean sediment cores taken by the Integrated Ocean Drilling Program and its predecessors (DSDP and ODP) indicate that pole-to-equator temperature gradients may have been much lower than they are today, with polar sea surface temperatures (SST) ranging from 15-25°C and tropical SST similar to or slightly warmer than modern values. Currently, no climate model can reproduce such low meridional temperature gradients, even when forced with incredibly high (~2000 ppm) levels of CO_2.

We will present modelled SST and $\delta^{18}O_{calcite}$ results from a fully-coupled, water isotope enabled, general circulation model (GISS Model-ER). Model-ER was configured with realistic Paleogene boundary conditions including bathymetry/topography, elevated greenhouse gases (4 x preindustrial CO_2, 7xCH_4), and estimated vegetation types. These simulations will be compared to a compilation of proxy estimates for SST and also with foraminifera $\delta^{18}O_{calcite}$ for several different time slices during the Paleogene. In addition, we will discuss some of the potential uncertainties in model/data comparisons. Future efforts will be focused on identifying novel processes that might 1) preferentially warm the high latitudes and impede freezing during the polar night and/or 2) reduce tropical climate sensitivity to greenhouse gases.

OCEAN ACIDIFICATION AT THE PETM

D.N. Schmidt[1] , A.J. Ridgwell[2], S.A. Kasemann[3] , E.Thomas[4]

[1]Department of Earth Science, University of Bristol (UK); [2]School of Geographical Sciences, University of Bristol (UK); [3]University of Edinburgh (UK); [4]Yale University (USA)

Email of the corresponding authors**:** d.schmidt@bristol.ac.uk andy@seao2.org simone.kasemann@ed.ac.uk ellen.thomas@yale.edu

The ocean will absorb increasing amounts of fossil fuel CO_2 in the future, with the *p*H of surface waters decreasing by up to 0.5-0.6 *p*H [*Caldeira and Wickett*, 2003]. The Palaeocene-Eocene Thermal Maximum (PETM) has been suggested as a close palaeo-analogue for future climate change and ocean acidification [*Zachos, et al.*, 2005] as the carbon release is thought to be comparable to that possible over the coming centuries. However, a prerequisite for the use of evaluated ecological response during the PETM as a constraint on future impacts on ecosystems of acidification due to fossil fuel burning is knowing how the paleo-*p*H changed at this time.

We measured boron isotopes and the boron/calcium ratio of benthic foraminifers across the PETM at deep-sea ODP Leg 113, Site 690B (Maud Rise) and shelf at Bass River, Leg 174AX. Mg/Ca indicates a two-step temperature increase from 12.7°C to 18.5°C at Maude Rise. Since the boron isotope composition of Paleocene seawater is unknown, we applied the *p*H estimated by an Earth system model as a starting value. The reconstructed *p*H record across the PETM shows a large, two-step reduction coeval with temperature rise, with a recovery period to pre-event values significantly more drawn out than that of the isotopic composition of the ocean. The *p*H change provides additional constraints on the amount of carbon input, the rate of change and hence our understanding of this past acidification event.

BIRTH AND DEATH OF OCEANIC CORE COMPLEXES

R.C. Searle[1], C.J. MacLeod[2], B.J. Murton[3] and RRS James Cook JC007 Scientific Party (J.F. Casey[4], C. Mallows[1], S.C. Unsworth[3], K.L. Achenbach[1,5] & M.Harris[3])

[1]Durham University (UK); [2]Cardiff University (UK); [3]National Oceanography Centre, Southampton, (UK); [4]University of Houston (USA); [5]formerly at University of Wyoming (USA)

Oceanic core complexes are the uplifted footwalls of very-large-offset low-angle normal faults that exhume lower crust and mantle rocks onto the seafloor at slow-spreading ridges. Although it has been suggested on the basis of numerical modelling that they form during periods of relatively reduced magma supply, little is known about how they initiate and become inactive, nor why only certain normal fault systems develop into core complexes. Here we present results from a near-bottom sidescan sonar/bathymetric profiler survey and sampling study of the Mid-Atlantic Ridge near 13°N that identify the critical controls on oceanic core complex development and evolution. We show that core complex detachment faults initiate as high-angle (65°±10°) normal faults no different from surrounding valley-wall faults and, like them, rapidly flatten to dips of ~30° in response to flexural unloading. On certain structures, however, displacement continues rather than jumping inward to a new normal fault, resulting in locally enhanced uplift of the footwall and further flattening of the fault to the horizontal or beyond. We demonstrate that detachment faults are triggered primarily by local waning of magma supply below a critical threshold, and are greatly aided by strain localisation resulting from seawater penetration and talc formation along the fault zones. Volcanism is suppressed or absent when the core complexes are active. Detachment faults are subsequently terminated by the emplacement of renewed magma into their footwalls, here by neovolcanic ridges propagating laterally across them from magmatically robust segments along strike. Our observations demonstrate how spatial (~1–10km) and temporal (~10^5–10^6yr) variations in magma flux to the ridge axis directly control the formation, extent and duration of tectonic spreading at the Mid-Atlantic Ridge.

MULTIPLE EOCENE 'HYPERTHERMAL' EVENTS DRIVEN BY OCEAN VENTILATION

Philip Sexton

Cardiff University (UK)

'Hyperthermals' are intervals of rapid, pronounced global warming known from six episodes within the Palaeocene and Eocene Epochs (~65 to 34 million years (Myr) ago) – the most extreme of which was the ~170 thousand year (kyr) interval of 5 to 7 °C global warming during the Palaeocene-Eocene Thermal Maximum (PETM, 55 Myr ago). The PETM is widely attributed to massive release of greenhouse gases from buried sedimentary carbon reservoirs and other, less extreme hyperthermals have also been linked to the release of sedimentary carbon. Here we show, using new 2.4 million year-long Eocene deep ocean records, that the less extreme hyperthermals are much more numerous than previously documented, paced by orbital eccentricity and have shorter durations (~40 kyr) and more rapid recovery phases than the PETM. These findings reveal the operation of fundamentally different forcing and feedback mechanisms than for the PETM, involving redistribution of carbon among Earth's readily exchangeable surface reservoirs rather than carbon exhumation from, and subsequent burial back into, the sedimentary reservoir. Specifically, we interpret our records to indicate repeated, large-scale releases of carbon (at least 1600 gigatonnes) from the ocean by ventilation. Our findings suggest that these pronounced climatic warming events were driven not by repeated releases of carbon from buried sedimentary sources, but, rather, by patterns of surficial carbon redistribution familiar from younger intervals of Earth history.

CONSTRAINTS ON FLUID EVOLUTION DURING MID-OCEAN RIDGE HYDROTHERMAL CIRCULATION FROM ANHYDRITE SAMPLED BY ODP HOLE 1256D

Smith-Duque, C.E. [1], Teagle, D.A.H. [1], Alt, J.C. [2] and Cooper, M.J.C[1]

[1]University of Southampton (UK); [2]University of Michigan (USA)

Email of the corresponding authors**:** csd2@noc.soton.ac.uk, dat@noc.soton.ac.uk, jalt@umich.edu, mjc@noc.soton.ac.uk

Anhydrite is a potentially useful mineral for recording the evolution of seawater-derived fluids during mid-ocean ridge hydrothermal circulation because it exhibits retrograde solubility, and hence may precipitate due to the heating of seawater or the sub-surface mixing of seawater with black smoker-like fluids. Here we provide new insights into the chemical and thermal evolution of seawater during hydrothermal circulation through analyses of anhydrite recovered from ODP Hole 1256D, the first complete penetration of intact upper oceanic crust down to gabbros. Previously anhydrite as only been recovered from Hole 504B. Measurements of $^{87}Sr/^{87}Sr$, major element ratios, Rare Earth Elements and $\delta^{18}O$ in anhydrite constrain the changing composition of fluids as they chemically interact with basalt.

Anhydrite fills veins and pore-space in the lower lava sequences from ~530 to ~1000 meters sub-basement (msb), but is concentrated in the lava-dike transition (754 to 811 msb) and uppermost sheeted dikes. Although present in greater quantities than in Hole 504B, the amount of anhydrite recovered from the Site 1256 crust is low compared to that predicted by models of hydrothermal circulation (e.g., Sleep, 1991).

Two distinct populations of anhydrite are suggested by measurements of $^{87}Sr/^{87}Sr$ suggesting different fluid evolution paths within Site 1256. One group of anhydrites with $^{87}Sr/^{87}Sr$ of 0.7070 to 0.7085, close to that of 15 Ma seawater (0.70878), suggests that some fluids penetrate through the lavas and into the sheeted dikes with only minimal Sr exchange with the host basalts. A second group, with low $^{87}Sr/^{87}Sr$ between 0.7048 and 0.7052, indicates precipitation from a fluid that had undergone far greater interaction with basalt. This range is close to that estimated from Sr-isotopic analyses for the Hole 1256D hydrothermal fluids ($^{87}Sr/^{87}Sr$ 0.705).

$\delta^{18}O$ measurements indicate an irregular trend with depth from +17$\permil$ in the lower volcanics to +10 ‰ in the sheeted dikes suggesting an increase in precipitation temperatures from 105 to 211^{o}C. One sample, from a chalcopyrite-mineralized dike margin has a very light $ $\delta^{18}O$ of +2.2 ‰ suggesting a temperature of 408^{o}C. It is likely that fluid here was superheated following direct contact with the hot intrusive body. This sample also records low $^{87}Sr/^{87}Sr$ and high total REE. Sr/Ca and $^{87}Sr/^{87}Sr$ indicate a similar relationship to that seen at ODP Hole 504B suggesting that Sr/Ca ratios reduced during recharge before there was significant Sr exchange with the host basalts.

THE MIDDLE EOCENE ARCTIC OCEAN: ENVIRONMENTAL CHANGES AND ORBITAL FORCING

David Spofforth and Heiko Pälike

National Oceanography Centre, Southampton (UK)

We present a high resolution X-ray fluorescence (XRF) core scanner record for the expanded middle Eocene section from Integrated Ocean Drilling Program (IODP) Expedition 302 (ACEX) drilled on the Lomonosov Ridge, central Arctic Ocean. XRF elemental intensities were calibrated using sediment geochemistry to produce a near continuous record of major element (Al, Ti, K, Si, Fe and Mn) concentrations and used to investigate paleoenvironmental conditions over the middle Eocene interval from ~ 48.6 – 44.4 Ma (~ 198.7 – 302.5 metres composite depth [mcd]). These records, coupled with physical property measurements of the bulk sediment divide the middle Eocene was into two parts (subunit 1/6 and unit 2) and show a strong orbital cyclicity. Initially the sediments are rich in biogenic silica (unit 2), but there is a pronounced shift towards terrigenous dominated sediment accumulation in subunit 1/6. However, throughout both units the Arctic Ocean remained predominately euxinic, although periodic oxygenation must have occurred during Unit 2.

The strong cycles observed within this geochemical record initiated a high resolution multiproxy study including organic geochemical, sedimentological and biological parameters on one core (M0002A-55X, ~ 236 – 241 mcd) to investigate the environmental response to orbital forcing. The environmental signal derived from this integrated multiproxy approach suggests that in an enclosed Arctic Ocean at time of ice (sea ice and glacial ice) initiation the biological proxies responded more strongly to growing season length / darkness (obliquity), whereas the terrigenous components, directly driven by sea ice and/or glacial ice formation and extent, responded more directly to seasonal insolation (precession).

TOWARDS QUANTIFYING METHANE RELEASE FROM GAS HYDRATE ON THE WESTERN SVALBARD CONTINENTAL MARGIN

Kate Thatcher and Graham Westbrook

University of Birmingham (UK)

The release of methane from gas hydrate at continental margins has been proposed as a positive feedback mechanism in past climate warming. Improving understanding of how hydrate systems have responded to warming and sea level change since the last glacial maximum will help predictions of their behaviour in the future.

Predictions of the changing hydrate stability field on the continental shelf of west Svalbard since 20ka are presented. The behaviour of the system has been controlled by local sea level change, and variable flow of Atlantic waters, changing the temperature profile within the water column. The West Spitsbergen Current (WSC) flows northwards along the Svalbard margin, transporting heat to the Arctic, and making this area particularly sensitive to changes in ocean circulation.

To estimate the amount of methane released, a better understanding of the distribution of hydrate within the hydrate stability zone is required. Current evidence of free gas from seismic data and hydrate found in cores indicates that hydrate is likely to be widespread, but does not provide quantitative information. Drilling and downhole logging within the hydrate stability zone would provide the quantitative information on hydrate distribution needed to estimate methane gas volumes released in climate warming events.

PETROPHYSICAL FACIES OF THE NANKAI TROUGH ACCRETIONARY PRISM: NANTROSEIZE, IODP EXPEDITION 314

Joanne Tudge, M. A. Lovell, S. J. Davies, S. Saito and P. K. Harvey

University of Leicester (UK)

Email of the corresponding author: jt58@leicester.ac.uk

Characterizing the physical properties and identifying boundaries within active accretionary prisms is necessary in understanding their behaviour and recent movement. In such unstable conditions core recovery is not always reliable, especially around fault zones. IODP Expedition 314 was the first stage of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), and used logging while drilling (LWD) technology to record continuous physical property data. Our approach has been to apply a variety of techniques to the LWD data to assess the quality and variability of the data across the various sites, and to identify gross changes in responses with depth. Building on this initial approach, we have used statistical analysis, specifically iterative non-hierarchical cluster analysis (INCA) to quantitatively define the characteristics of the slope sediments and sediments within the accretionary prism at sites C0001 and C0004.

A new and detailed log-based lithostratigraphy is developed, and positions of major boundaries, defined by 3-D seismic profiles and initial interpretation of individual log responses, are refined. The results produce clusters that clearly distinguish the slope sediments and characterize formations within the accretionary prism. Boundaries which correlate to the seismic-defined unconformity between the slope sediments and the accretionary prism, and a boundary within the accretionary prism that corresponds to a mega-splay fault previously unresolved by individual log analysis and borehole images, are identified. Our study demonstrates INCA analysis of LWD data can accurately define boundaries and characterize sediments in environments where core recovery may be incomplete.

CLASSIFICATION AND ANALYSIS OF THE EROSIONAL SHAPES OF SUBMARINE DISTRIBUTARY SYSTEMS

D. Vachtman and N.C. Mitchell

University of Manchester (UK)

Email of the corresponding author: dina.vachtman@manchester.ac.uk

Canyons and gullies are an integral part of slope morphology on most continental margins. The submarine channel systems can extend for up to a thousand kilometres or more from the continental margins, forming branched networks whose origin is not well understood. The gradual accumulation of world-wide bathymetric and seismic data on continental margins provides a basis for the classification of slope morphology and consequent erosional and depositional processes which contribute to the formation of the shapes of these networks. Discussion and development of models for analysis of shapes of submarine networks along continental margins has been confusing and controversial. Since canyon systems may cross both shelf and slope, limiting discussion to parts of the system can be problematic. Turbidity currents are generally credited with the excavation of submarine canyons and with transporting sediment down the canyon to the base of the continental slopes to the marine basin. However, studies indicate that turbidity currents are not necessarily the initial cause of the valley formation and, similar to subaerial river valleys, submarine systems are formed by various processes. The valleys of the sea floor appear to have had several origins, producing distinctive types, where submarine features may include numerous tributaries entering from both sides, and relief comparable to major land canyons.

This study aims to establish to what extent the same or similar origin can be invoked for the hundreds of canyons found around various coasts of the world along *convergent*, *divergent* and *transform* continental margins. In detail, we interpret evidence for submarine erosion from bathymetric data that correspond to different slope curvatures and display unique canyon branching morphologies. The methodology for quantitative classification of canyon systems is based on the bathymetric data and involves 2-D depiction of tributary-like channel networks and the establishment of their spacing, paths of tributaries and channel patterns.

Additionally, we examine main channel and tributary cross-sections with emphasis on the position of the river channel thalwegs, along with the 3-D analysis of shapes of various morphological elements and bedforms. These are performed so that differences in canyon morphology can be related statistically to the properties of downslope progression of slope profile, slope shape and curvature, as well as the competence of the transport mechanism with increasing distance from sediment source. This is in analogy to both subaerial fluvial systems and erosional processes at the shelf break. Quantitative methodologies based on computational geometry used in this study have the potential to construct deductive spatial models of sequences of topological structures, spatial relationships of “non-connected” objects, and integration of objects and space, which might open ways of re-thinking traditional parameter-based approaches for classification of the erosional shapes and processes of submarine canyon systems.

DENSE, SEDIMENT-LADEN UNDERFLOWS RAPIDLY EXIT THE BERING SEA DURING GLACIAL TIMES TO FORM MEIJI SEDIMENT DRIFT

Sam VanLaningham[1]*, Nicklas Pisias[2], Robert Duncan[2], Peter Clift[1]

[1]University of Aberdeen (UK); [2]Oregon State University (USA); *Now at University of Alaska Fairbanks (USA)

A large sediment deposit in the northwestern Pacific Ocean known as the Meiji Drift is thought to have formed from deep water exiting the Bering Sea, although no notable deep water forms there presently. We determine the terrigenous sources to the drift to reconstruct paleo-circulation patterns since 140 ka using bulk sediment 40Ar-39Ar and Nd isotopic analyses on the silt-sized fraction from Ocean Drilling Program (ODP) Site 884. There are large changes in both isotopic tracers, varying on glacial-interglacial cycles. During glacials, bulk sediment 40Ar-39Ar ages range between 40–80 Ma, while Nd isotopic values range from εNd = -1 to +2. During interglacials, sediments are derived from much younger and more radiogenic source rocks, with bulk sediment ages falling to 2–15 Ma and Nd isotopic values between εNd = +5 to +9. These data and quantitative comparison to potential source rocks indicate that the young Kamchatkan and Aleutian Arcs, lying NW and NE of the Meiji Drift, contribute the majority of sediment during interglacials. Conversely, older source rocks, such as those drained by the Yukon River and northeast Russia are the dominant origin of sediments during glacials. A possible mechanism that could bring the Yukon-derived material so far from its source during glacial times is development of dense, sediment-laden underflows at the Bering Shelf-slope interface. The shelf edge (i.e., the LGM shoreline) is thought to be the sea ice margin during the LGM and is also where the Yukon River would have dumped huge volumes of sediment into the Bering Sea. These two processes could have combined to create dense sediment-water flows capable of moving rapidly downslope out of the Bering Sea to the North Pacific.

PAST ACHIEVEMENTS AT LEG 172 SITE 1060: PALEOCEANOGRAPHY IN THE GULF STREAM AREA.

M.J. Vautravers

British Antarctic Survey (UK)

My poster lists previous paleoceanographic and paleoclimatic studies based on the high-resolution records reconstructed from the drift Site 1060 (Subtropical Western Atlantic) on which I have been involved in the past years.

These studies focused mainly on the last glacial and the previous interglacial in order to gain a greater understanding the Earth system at millennial-scale resolution.

The achievements for this site clearly highlight both the importance of drift sites drilled by ODP-IODP for paleoceanography and the value of well-focused multi-proxies reconstructions on such high-quality sediments.

It has been a great privilege to work on this site. I am in debt to my collaborators and colleagues in the UK the EU and the USA. Over the years they have turn these studies into successes. I am grateful to ODP for the recovery of such great sediments. This above all made my contribution possible.

List of Attendees

Dr	Kay	Achenbach	Durham University
Mr	Orji	Akaa	University of Aberdeen
Mr	Anwar	Alizai	Aberdeen University
Prof Sir	Geoffrey	Allen	Outgoing UK IODP Chairman
Dr	Morten	Andersen	Bristol Isotope Group
Miss	Tracy	Aze	Cardiff University
Prof	Wolfgang	Bach	University of Bremen
Prof	Neil	Banerjee	University of Western Ontario
Dr	Stephen	Barker	Cardiff University
Dr	Sara	Benetti	University of Ulster
Dr	Juan-Carlos	Berrio	University of Leicester
Prof	Mike	Bickle	University of Cambridge
Miss	Heather	Birch	Cardiff University
Dr	Steven	Bohaty	University of Southampton
Mr	Tom	Broadbent	Bangor University
Prof	Jonathan	Bull	National Oceanography Centre, Southampton
Dr	Andrew	Carter	Birkbeck
Mr	Teddy	Castelain	University of Leeds
Dr	Cristian	Cavozzi	University of Parma
Dr	Anne	Chabert	National Oceanography Centre, Southampton
Dr	Cecily	Chun	National Oceanography Centre, Southampton
Dr	Leon	Clarke	Bangor University
Dr	Josephine	Clegg	University of Cambridge
Prof	Peter	Clift	University of Aberdeen
Prof	Mike	Coffin	National Oceanography Centre, Southampton
Dr	Rosalind	Coggon	Imperial College London
Dr	Jenny	Collier	Imperial College London
Dr	Matthew	Cooper	University of Southampton
Prof	Elisabetta	Costa	University of Parma
Ms	Kirsty	Crocket	University of Bristol
Prof	David	Cronan	Imperial College
Dr	Earl	Davies	Geological Survey of Canada
Dr	Sarah	Davies	University of Leicester

Miss	Caroline	Dawber	University of Cambridge
Dr	Tom	Dunkley Jones	University College London
Dr	Graeme	Eagles	Royal Holloway University of London
Dr	Kirsty	Edgar	National Oceanography Centre, Southampton
Prof	Harry	Elderfield	University of Cambridge
Dr	Tim	Elliott	University of Bristol
Dr	Mike	Ellis	British Geological Survey
Dr	Dan	Evans	British Geological Survey
Dr	Thomas	Ezard	Imperial College London
Mr	Peter	Fitch	University of Leicester
Prof	Peter	Flemings	University of Texas
Dr	Gavin	Foster	University of Bristol
Dr	Laura	Foster	University of Bristol
Dr	Chris	Franklin	UKIODP Programme Manager
Dr	Oliver	Friedrich	National Oceanography Centre, Southampton
Ms	Alessia	Gadaleta	University of Parma
Dr	Samantha	Gibbs	National Oceanography Centre, Southampton
MSc	Natalia	Gonzalez	University of Leicester
Miss	Rajasmita	Goswami	University of Manchester
Dr	Mervyn	Greaves	University of Cambridge
Dr	Marcus	Gutjahr	Bristol Isotope Group
Dr	Ross	Haacke	Royal Holloway University of London
Mr	Luke	Handley	Newcastle University
Miss	Michelle	Harris	National Oceanography Centre, Southampton
Prof	Gideon	Henderson	University of Oxford
Dr	Tim	Henstock	National Oceanography Centre, Southampton
Prof	Stephen	Hesselbo	University of Oxford
Prof	Kai-Uwe	Hinrichs	University of Bremen
Mr	Long	Hoang	University of Aberdeen
Prof	Dave	Hodell	University of Cambridge
Dr	Veerle	Huvenne	National Oceanography Centre, Southampton
Dr	Rachael	James	National Oceanography Centre, Southampton
Dr	Hugh	Jenkyns	Oxford University
Prof	Tim	Jickells	University of East Anglia

Dr	Cedric	John	Imperial College London
Dr	Pamela	Kempton	NERC
Dr	Sev	Kender	British Geological Survey
Prof	Dick	Kroon	University of Edinburgh
Prof	Nick	Kusznir	University of Liverpool
Dr	Rob	Larter	British Antarctic Survey
Dr	Carrie	Lear	Cardiff University
Miss	Sasha	Leigh	UKIODP Programme Manager
Prof	Ally	Lewis	University of York
MSc	Diederik	Liebrand	National Oceanography Centre, Southampton
Mr	David	Limmer	University of Aberdeen
Miss	Kate	Littler	University College London
Dr	Lidia	Lonergan	Imperial College London
Prof	Mike	Lovell	University of Leicester
Dr	John	Ludden	British Geological Survey
Dr	John	MacLennan	University of Cambridge
Dr	Chris	MacLeod	University of Cardiff
Mr	Christopher	Mallows	Durham University
Miss	Elaine	Mawbey	Cardiff University
Prof	Nick	McCave	Cambridge University
Dr	Erin	McClymont	Newcastle University
Dr	Lisa	McNeill	National Oceanography Centre, Southampton
Prof	Tim	Minshull	University of Southampton
Dr	Neil	Mitchell	The University of Manchester
Dr	Joanna	Morgan	Imperial College London
Dr	Antony	Morris	University of Plymouth
Dr	Bramley	Murton	National Oceanography Centre, Southampton
Doctor	Yago	Nestola	University of Parma
Mr	Uisdean	Nicholson	University of Aberdeen
Dr	Euan	Nisbet	Royal Holloway, Univ. of London
Miss	Taryn	Noble	University of Cambridge
Dr	Heiko	Palike	National Oceanography Centre, Southampton
Dr	Martin	Palmer	University of Southampton
Prof	John	Parkes	University of Cardiff

Mr	Michele	Paulatto	University of Southampton
Dr	Laura	Pea	University of Parma
Prof	Paul	Pearson	Cardiff University
Dr	Vicky	Peck	British Antarctic Survey
Prof	Kevin	Pickering	University College London
Dr	Alex	Piotrowski	University of Cambridge
Dr	Nicola	Pressling	University of Plymouth
Prof	David	Prior	University of Liverpool
Prof	Andy	Purvis	Imperial College London
Mr	James	Rae	University of Bristol
Prof	John	Rees	British Geological Survey
Dr	David	Richards	University of Bristol
Dr	Ros	Rickaby	University of Oxford
Dr	Andy	Ridgwell	University of Bristol
Mr	Chris	Roberts	University of Cambridge
Miss	Natalie	Roberts	University of Cambridge
Dr	Stuart	Robinson	University College London
Mr	Sudipta	Sarkar	National Oceanography Centre, Southampton
Dr	Daniela	Schmidt	University of Bristol
Prof	Roger	Searle	Durham University
Dr	Phil	Sexton	Cardiff University
Dr	Amelia	Shevenell	University College London
Mr	Christopher	Smith-Duque	University of Southampton
Prof	Steve	Sparks	University of Bristol
Mr	David	Spofforth	National Oceanography Centre
Ms	Heather	Stewart	UKIODP Science Coordinator
Prof	Damon	Teagle	University of Southampton
Dr	Kate	Thatcher	University of Birmingham
Dr	Alexander	Thomas	University of Oxford
Dr	David	Thornalley	Cardiff University
Prof	Alan	Thorpe	NERC
Mr	Alemayehu	Tilahun	EHNRI
Prof	Harold	Tobin	University of Wisconsin-Madison
Miss	Joanne	Tudge	University of Leicester

Dr	Sandy	Tudhope	University of Edinburgh
Dr	Alexandra	Turchyn	University of Cambridge
Dr	Elspeth	Urquhart	Petra Associates
Dr	Dina	Vachtman	University of Manchester
Dr	Tina	van de Flierdt	Imperial College London
Dr	Derek	Vance	University of Bristol
Dr	Sam	VanLaningham	University of Aberdeen
Dr	Maryline	Vautravers	British Antarctic Survey
Prof	Giuliana	Villa	University of Parma
Miss	Katie	Waiters	UKIODP Programme Administrator
Mr	David	Wilson	University of Cambridge

Glossary

www.iodp.org/acronyms/

ACEX	Arctic Coring Expedition
BCR	Bremen Core Repository
BoG	Board of Governors
CDEX	Center for Deep Earth Exploration
CDP	Complex Drilling Projects
DSDP	Deep Sea Drilling Project
ECORD	European Consortium for Ocean Drilling Research
EDP	Engineering Development Panel
EMA	ECORD Management Agency
EPC	European Petrophysical Consortium
EPSP	Environmental Protection and Safety Panel
ESO	ECORD Science Operator
ESSAC	ECORD Science Support and Advisory Committee
ETF	Engineering Task Force
GCR	Gulf Coast Repository
ICDP	International Continental Scientific Drilling Program
IIS-PPG	Industry-IODP Science Program Planning Group
ILP	Industry Liaison Panel
IO(s)	Implementing Organization(s)
IODP	Integrated Ocean Drilling Program
IODP-MI	Integrated Ocean Drilling Program – Management International
ISP	Initial Science Plan
J-DESC	Japan Drilling Earth Science Consortium
JOI	Joint Oceanographic Institutions, Inc.
KCC	Kochi Core Center Repository
LUBR	Leicester University Borehole Group
MEXT	Ministry of Education, Culture, Sports, Science, and Technology (Japan)
MOST	Ministry of Science and Technology (People's Rep. of China)
MSP	Mission Specific Platform
NanTroSEIZE	Nankai Trough Seismogenic Zone Experiment
NERC	Natural Environment Research Council
NSF	National Science Foundation (USA)
ODP	Ocean Drilling Program
OTF	Operations Task Force
PI	Primary Investigator
POC	Platform Operations Costs

SAS	Science Advisory Structure
SASEC	Science Advisory Executive Committee
SOC	Science Operating Costs
SPC	Science Planning Committee
SSEP	Science Steering and Evaluation Panel
SSP	Site Survey Panel
STP	Scientific Technology Panel
TAP	Technology Advice Panel
USAC	United States Advisory Committee for Scientific Ocean Drilling
USIO	United States Implementing Organization
USSAC	United States Science Advisory Committee
USSSP	United States Science Support Program

Useful Websites

Integrated Ocean Drilling Programme (UK)

www.ukiodp.bgs.ac.uk

www.nerc.ac.uk/research/programmes/ukiodp/

ECORD Sites

European Consortium for Ocean Research Drilling (ECORD) - www.ecord.org

ECORD Science Support Advisory Committee – www.essac.ecord.org

IODP Central Sites

IODP Management International Inc. - www.iodp.org

Initial Science Plan for IODP - www.iodp.org/isp

JAMSTEC - www.jamstec.go.jp/chikyu/eng/index.html

IODP Science Advisory Structure - www.iodp.org/sas

IODP Implementing Organisations

Centre for Deep Earth Exploration (CDEX) –

www.jamstec.go.jp/chikyu/eng/index.html

ECORD Science Operator - www.eso.ecord.org

JOI-Alliance US Implementing Organisation - www.iodp-usio.org

IODP National Offices

Finland - http://iodpfinland.oulu.fi/

France - www.iodp-france.org/

Germany - www.iodp.de/

Italy - www2.ogs.trieste.it/iodp/

Netherlands - www.iodp.nl/

Portugal - http://e-geo.ineti.pt/ecord/

Spain - http://carpe.usal.es/~iodp/

Switzerland - www.swissiodp.ethz.ch

IODP China – www.iodp-china.org/chs/

IODP Korea - www.kodp.re.kr

ODP Australia - www.odp.usyd.edu.au

IODP Related Sites

European Science Foundation (ESF) - www.esf.org

Japan Drilling Earth Consortium (J-DESC) – www.j-desc.org/

International Continental Scientific Drilling Program (ICDP) –

www.icdp-online.org/contenido/icdp/front_content.php

Lamont Doherty Earth Observatory - www.ldeo.columbia.edu

MEXT Ministry of Education, Culture, Sports, Science and Technology - www.mext.go.jp/english/

National Science Foundation - www.nsf.gov

Natural Environment Research Council - www.nerc.ac.uk

USSSP U.S. Science Support Program - www.usssp-iodp.org

ODP Legacy Sites

Joint Oceanographic Institutions for Deep Earth Sampling - www.ifm-geomar.de

Consortium for Ocean Leadershio - www.oceanleadership.org/

ODP Wireline Logging Services - www.ldeo.columbia.edu/BRG/ODP/

Science Operator Texas A&M University (TAMU) - www-odp.tamu.edu/index.html

Mid-Ocean Ridge Links

InterRidge Office - www.interridge.org
NOAA Vents Programme - www.pmel.noaa.gov/vents

DeRIDGE - www.deridge.de

Margins Links

HERMES (hotspot ecosystem research on the margins of European seas) - www.eu-hermes.net/

US Margins Programme - www.nsf-margins.org/

NERC Marine Programmes

Joint Climate Research Programme - www.nerc.ac.uk/research/programmes/jointclimate/

Oceans 2025 - www.nerc.ac.uk/research/programmes/oceans2025/

RAPID - www.nerc.ac.uk/research/programmes/rapid/

Technology Proof of Concept - www.nerc.ac.uk/research/programmes/technologypoc/

Completed NERC Marine Programmes

Autosub Under Ice (AUI) Programme - www.nerc.ac.uk/research/programmes/autosubunderice/

COAPEC (Coupled Ocean-Atmosphere Processes and European Climate) - www.nerc.ac.uk/research/programmes/coapec/

Ocean Margins LINK Programme - www.nerc.ac.uk/research/programmes/oceanmargins/

Surface-Ocean/Lower-Atmosphere Study (SOLAS) - www.nerc.ac.uk/research/programmes/solas/