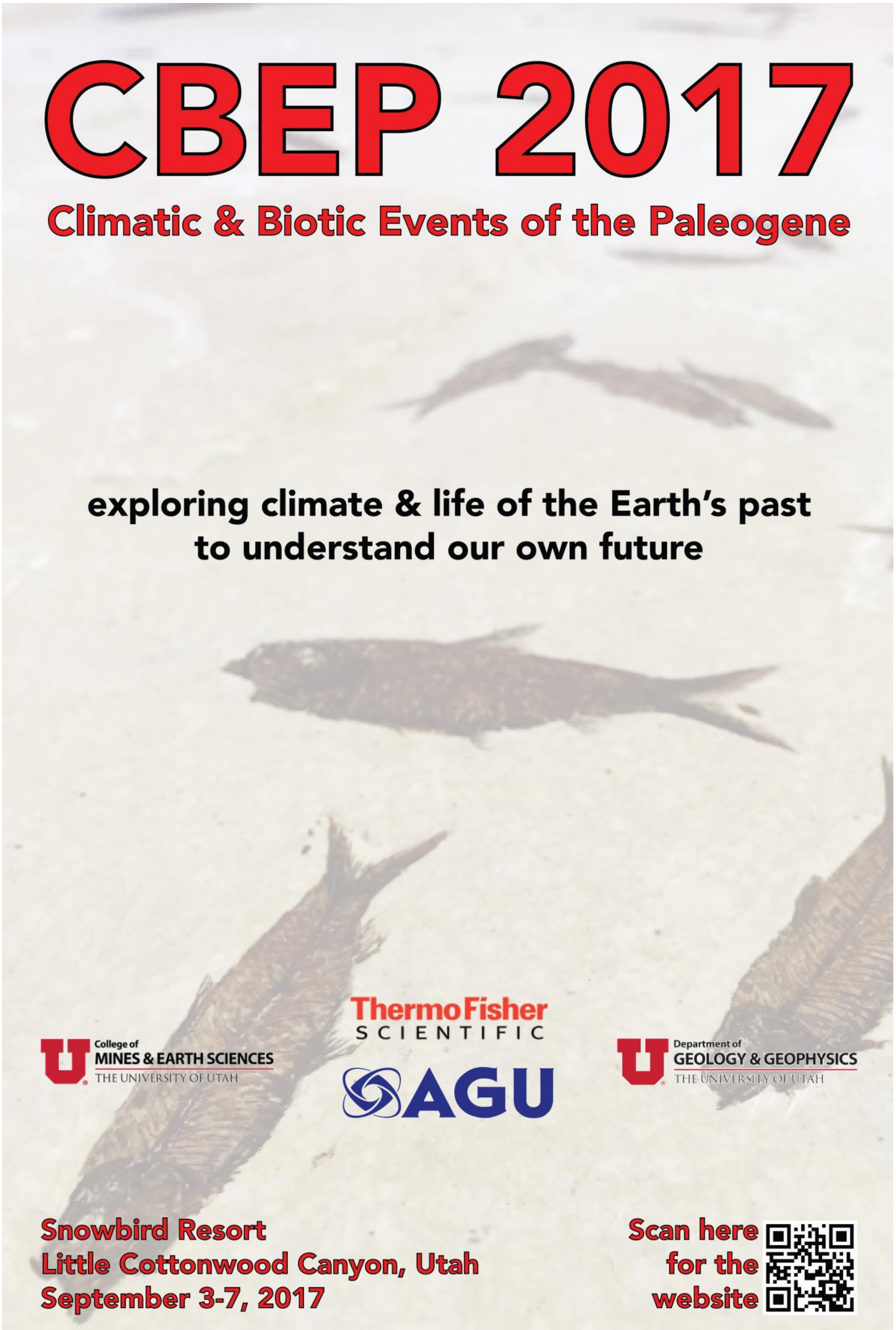


CBEP 2017

Climatic & Biotic Events of the Paleogene

**exploring climate & life of the Earth's past
to understand our own future**

ThermoFisher SCIENTIFIC

College of MINES & EARTH SCIENCES THE UNIVERSITY OF UTAH

AGU

Department of GEOLOGY & GEOPHYSICS THE UNIVERSITY OF UTAH

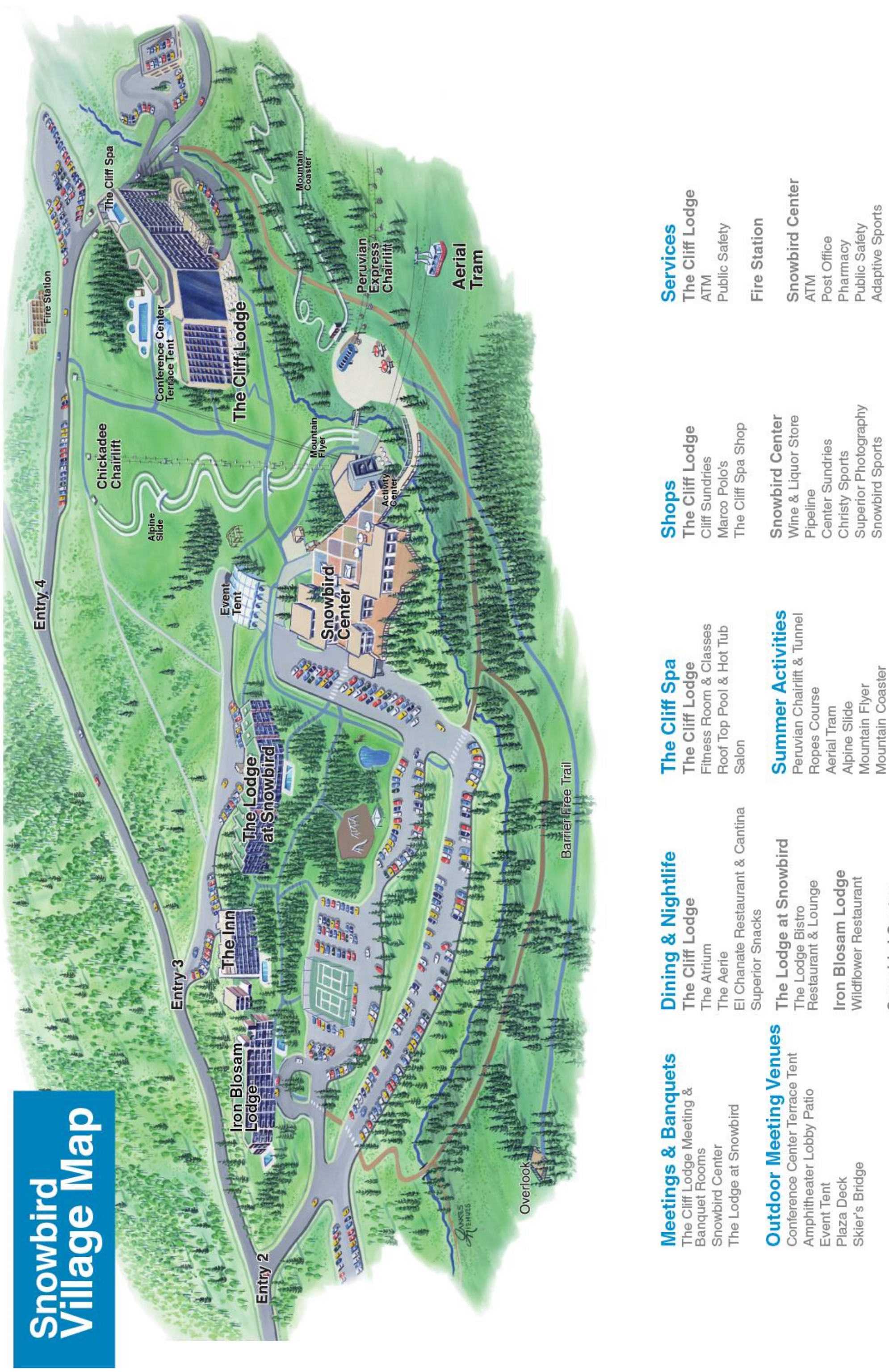
**Snowbird Resort
Little Cottonwood Canyon, Utah
September 3-7, 2017**

Scan here for the website

CONTENTS

VENUE INFORMATION

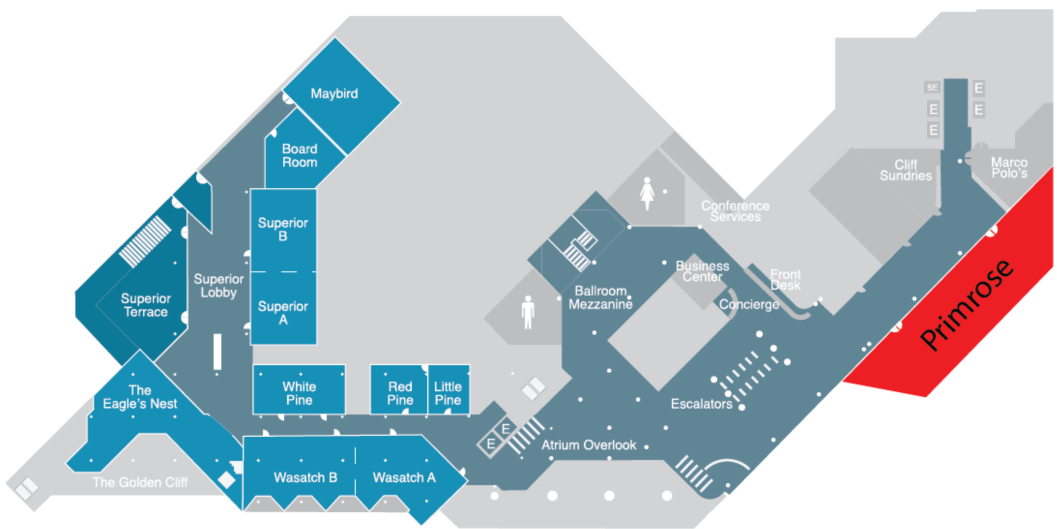
Maps



The Cliff Lodge

Level B

Level C



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Snowbird Front Desk – 1-800-232-9542

Location
The Cliff Lodge at Snowbird Resort
Registration Lobby outside The Primrose Room, Level C
Icebreaker The Primrose Room, Level C
Talks Ballroom 3, Level B
Posters The Primrose Room, Level B
Lunches The Primrose Room, Level B
Breaks The Primrose Room, Level B
Wednesday Banquet The Golden Cliff Room, Level C
Farewell Social The Primrose Room, Level B

Web Access
You should have wifi access in your rooms. In the ballrooms, you will need to login to our meeting network:

Network name: *CBEP 2017*
Password: *snowbird17*

Recreation
Your rooms at Snowbird include free access to the fitness room, pool, and hot tubs, and yoga classes. Your reservation also includes a 50% discount to access to The Cliff Spa and a 20% discount on select spa treatments (you must show your hotel registration card at Spa check-in). Visit www.snowbird.com/cliff-spa for more details.

Be sure to check out all of the summer activities available to you at the Resort during your stay (see www.snowbird.com/summer), including hiking and trail running, climbing, alpine slides, mountain biking (you can rent bikes), and tram rides.

Weather
Visit www.snowbird.com/mountain-report for updated information about weather, lift activity, and road conditions on the mountain.

Meals

Breakfast A light breakfast will be served for 45 minutes prior to the start of each morning session. This consists of breakfast sandwiches, yogurt and fruit, pastry-like items, juice, and hot drinks. If you prefer a heartier breakfast, then try one of the following options (see also www.snowbird.com/dining):

The Forklift (7:30 AM - 2:30 PM) – Snowbird Center, Plaza Deck
The Atrium (7 AM – 10:30 AM) – The Atrium, The Cliff Lodge, Level B (*i.e.*, right next to our meeting rooms)
Baked & Brewed Café (8 AM – 5 PM) – Snowbird Center, Level 2
General Gritts (8 AM – 8 PM) – Snowbird Center, Level 2

Lunch A full buffet lunch will be served in the Primrose Room each day as part of the meeting.

Dinner Organized group dinners have not been pre-arranged, except for the Oktoberfest Banquet Wednesday evening the Golden Cliff Room.

Choices on-site include (see also www.snowbird.com/dining):

The Aerie – modern American gastropub focusing on local, seasonal, and organic ingredients.
5 – 9 PM – The Cliff Lodge, Level 10
Steak Pit – prime steaks, fresh seafood, and an extensive wine list.
6 – 9 PM – Snowbird Center, Level 1
El Chanate – Snowbird's Mexican restaurant and tequila bar.
11 AM – 9 PM – The Cliff Lodge, Level A
The Lodge Bistro – French/American cuisine
5 – 9 PM, Thursday- Sunday only. The Lodge at Snowbird
Tram Car Pizza – handmade pizza and hot sandwiches
11 AM – 8 PM – Snowbird Center, Level 2
There are several off-site options within walking distance just up the road in the little town of Alta, too.

Bars/Aprés The Resort has several places to gather with an adult beverage.

The Aerie – (gastropub) 5 – 9 PM – The Cliff Lodge, Level 10
The Forklift – 7:30 AM – 2:30 PM –Snowbird Center, Plaza Deck
El Chanate – (tequila bar) – 11:30 AM – 9 PM – The Cliff Lodge, Level A
The Lodge Bistro (wine) – 5 – 9 PM, Thursday-Sunday only – The Lodge at Snowbird, Pool Level
The Tram Club (sports bar) – 11:30 AM – 11 PM – Snowbird Center, Level 1

CONFERENCE ORGANIZERS

Organizing Committee for CBEP 2017

Jon Bloch – *Florida Museum of Natural History*
Steve Bohaty – *University of Southampton*
Gabe Bowen – *University of Utah*
Will Clyde – *University of New Hampshire*
Jerry Dickens – *Rice University*
Aaron Diefendorf – *University of Cincinnati*
Guillaume Dupont-Nivet – *Potsdam University*
Majie Fan – *University of Texas, Arlington*
David Greenwood – *Brandon University*
Jorijntje Henderiks – *Uppsala University*
Chris Hollis – *GNS New Zealand*
Matthew Huber – *Purdue University*
Celli Hull – *Yale University*
Pete Lippert – *University of Utah*
Valeria Luciani – *University of Ferrara*
Francesca McInerney – *University of Adelaide*
Dick Norris – *Scripps Institute of Oceanography*
Jörg Pross – *University of Heidelberg*
Andy Ridgwell – *University of California, Riverside*
Brian Romans – *Virginia Tech*
Bridget Wade – *University College London*
Thomas Westerhold – *University of Bremen*
Scott Wing – *Smithsonian Institution*
Jim Zachos – *University of California, Santa Cruz*

Local Organizers
Gabe Bowen – *University of Utah*
Pete Lippert – *University of Utah*

Field Trip Organizers
1-Day Field Trip
Fossil lake deposits of the Green River Formation: Not all fish are preserved equally
Arvid Aase – *Fossil Butte National Monument*
Pete Lippert – *University of Utah*

2-Day Field Trip – Late Cretaceous to Eocene tectonic, climatic, and biotic change in central Utah
Lauren Birgenheier – *University of Utah*
Gabe Bowen – *University of Utah*

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Program

Sunday, Sept. 3
Registration – Primrose Room
16:00 - 20:00
Icebreaker Reception – Primrose Room
18:30 - 20:00

Monday, Sept. 4

Breakfast – Primrose Room

7:45 - 8:30

Planetary boundaries: Biological Diversity & Biotic Change 1 – Ballroom 3

8:30	Jones	The significance of nannoplankton boom-bust successions during the Cretaceous-Paleogene recovery at El Kef, Tunisia
8:50	Alvarez	The post-mass-extinction recovery of calcareous nannoplankton and the Paleogene emergence of new diversity, disparity and ecological strategies
9:10	Sepulveda	The molecular signature of the Cretaceous/Paleogene (K/Pg) mass extinction event: the El Kef Coring Program
9:30	Sibert	Fish productivity, community structure and evolution decoupled following the Cretaceous/Paleogene mass extinction
9:50	Flynn	Diverse Early Paleocene Fossil Flora from the San Juan Basin (New Mexico, USA) Documents Rapid Recovery Following the Cretaceous-Paleogene Boundary

Morning Break – Primrose Room

10:10 - 10:40

Biogeochemical consequences of ecological changes during climate events and transitions – Ballroom 3

10:40	Poster presenters	Lightning talks I
11:00	Si	Changes in 'vital' effects in photosymbiont-bearing planktonic foraminifera during the Paleocene-Eocene Thermal Maximum
11:20	Wilson	Modeling plankton community size-structure during the Paleogene: Interactions between plankton and climate.
11:40	Griffith	Export production and remineralization over Eocene hyperthermals at ODP Site 1263, Walvis Ridge, Southeast Atlantic and ODP Site 1209, Shatsky Rise, Pacific Ocean
12:00	Zill	Evaluating the Significance of Bioturbation for Constraints on Paleocene-Eocene Thermal Maximum Carbon Cycling

Lunch – Primrose Room

12:20 - 13:30

Poster Session - Earth Surface & Biogeochemistry – Primrose Room

13:30 - 15:30

Refereshments from 14:45 - 15:30

Unravelling tectonic and climatic controls on sedimentary and geochemical records – Ballroom 3

15:30	Foreman	Assessments on aliasing: Geomorphic controls on the quality of terrestrial paleoclimate proxy records
15:50	Rasmussen	Early Paleogene shifts in fluvial deposition within the Huerfano Basin, Colorado, USA: Evaluation of tectonic and climatic controls
16:10	Birgenheier	Fluvial response to Paleocene - early Eocene warming events: a complete record
16:30	Plink-Bjorklund	Fluvial and lake response to Paleocene-Eocene extreme climate, Uinta and Piceance basins, Utah and Colorado
16:50	Romans	Paleogene Deep-Sea Circulation in the North Atlantic Ocean: Evidence from Seismic-Reflection and Terrigenous Grain-Size Data, Newfoundland Ridge Contourite Drifts
17:10	Dickens, et al.	Progress and initial discoveries - IODP Leg 371 (teleconference)

Tuesday, Sept. 5	
Breakfast – Primrose Room	
7:45 - 8:30	
Planetary Boundaries: Earth Surface Change – Ballroom 3	
8:30 Hajek	Using landscape dynamics to evaluate observed responses to climate change: improving interpretations by assessing environmental noise and spatial sampling in sedimentary deposits
8:50 Fan	Global cooling and regional uplift induced diachronous aridification in the interior of western USA across the Eocene-Oligocene transition
9:10 Zachos	Early Cenozoic hyperthermals and the hydrological cycle: Theory versus observations
9:30 Acosta	Topographic controls on the Indo-Asian monsoon
9:50 Snell	Terrestrial response to past global climate and elevation changes in the western US from compiled paleotemperatures
Morning Break – Primrose Room	
10:10 - 10:40	
Biological responses to climate events and transitions – Ballroom 3	
10:40 Poster presenters	Lightning talks II
11:00 Thomas	Variability of the Benthic Foraminiferal Response to Paleogene Hyperthermal Events
11:20 Brombacher	Evolutionary response of the planktic foraminifer Orbulinoides beckmanni to climatic change during the Middle Eocene Climatic Optimum (MECO)
11:40 Sessa	The Paleocene-Eocene Thermal Maximum (PETM) mollusk fauna of the Atlantic Coastal Plain, USA
12:00 Clementz	Insight into ancient seagrass communities from examination of fossilized remains of Sirenia
Lunch – Primrose Room	
12:20 - 13:30	
Afternoon: Resort activities and informal meetings	

Wednesday, Sept. 6

Breakfast – Primrose Room

7:45 - 8:30

Planetary boundaries: Biological Diversity & Biotic Change 2 – Ballroom 3

8:30	Dunn	Forest Canopy Change During the PETM, Hanna Basin, WY
8:50	West	Polar heat: evaluating the impact of an early Eocene hyperthermal event on Arctic forests from Ellesmere Island, Nunavut, Canada
9:10	Vitek	Changes in relative molar size of the small-bodied mammal Macrocranion (Eulipotyphla, Erinaceomorpha) across the Paleocene-Eocene Thermal Maximum follow the inhibitory cascade model
9:30	Morse	Changes in Relative Abundance of Primates and Small Mammal Faunal Composition Before, During, and After the Paleocene-Eocene Thermal Maximum in the Southern Bighorn Basin, Wyoming
9:50	Bloch	Implications of immigrant arrival times during the Paleocene-Eocene Thermal Maximum for mammal habitat specificity

Morning Break – Primrose Room

10:10 - 10:40

Advances in paleo-proxies: Mechanisms, interpretations, and uncertainty – Ballroom 3

10:40	Greenwood	Palms as Paleoclimate Proxies: A new 'Palm-Line'
11:00	Fischer-Femal	Dual Isotopes of Pedogenic Carbonates Record Spatial Patterns of Climate Change over the Paleocene-Eocene Thermal Maximum (PETM)
11:20	Bhatia	Palaeoecological changes in Eocene planktonic foraminiferal species
11:40	Freimuth	Regional signal/noise in plant wax dD records: a calibration using lake sediments throughout the Adirondack Mountains, New York
12:00	Bralower	Drilling the Chicxulub impact structure: Study of large impact formation and effects on life during IODP/ICDP Expedition 364

Lunch – Primrose Room

12:20 - 13:30

Poster Session - Paleobiology & Paleoclimate – Primrose Room

13:30 - 15:30

Refreshments from 14:45 - 15:30

Tempo, interaction, and sensitivity of Earth system change across timescales – Ballroom 3

15:30	Zeebe	New astronomical solutions and orbital variations in atmospheric CO2 during the early Paleogene
15:50	Vahlenkamp	The metronome of North Atlantic deep-water circulation in the middle Eocene
16:10	Ivany	Winter temperatures drive climate cooling in the Paleogene subtropics
16:30	Judd	Late Eocene reduction in Antarctic seasonality as inferred from the isotopic composition of nearshore marine bivalves
16:50	Kirtland Turner	A probabilistic assessment of the rapidity of PETM onset
17:10	Gingerich	Temporal scaling of carbon emission rates during onset of the Paleocene-Eocene Thermal Maximum

Conference Banquet – Golden Cliff Room

19:00 - 20:30

Thursday Sept. 7

Breakfast – Primrose Room

7:45 - 8:30

Planetary boundaries: Biogeochemical flows and thresholds – Ballroom 3

8:30	Ridgwell	Paleocene-Eocene Thermal Maximum meets the North Atlantic Igneous Province: Coincidence or global environmental conspiracy?
8:50	Inglis	Global evidence for enhanced methane cycling during the Paleocene-Eocene Thermal Maximum
9:10	Papadomanolaki	Controls on marine organic carbon burial and its impact on the global carbon cycle during the Paleocene-Eocene Thermal Maximum
9:30	Reichgelt	Fossil leaves record a short-lived disruption of the carbon cycle at the Paleogene-Neogene boundary
9:50	Lyons	Destabilization of carbon on land, and coastal ocean response during the PETM: evidence from mid-Atlantic sediments

Morning Break – Primrose Room

10:10 - 10:40

General session – Ballroom 3

10:40	Pearson	Sediment creep, mixing, symbiont bleaching and diagenesis: reinterpretation of the Paleocene / Eocene boundary stable isotope records at ODP Sites 689 and 690, Maud Rise
11:00	Opdyke	Expedition 342 Descent into the Icehouse
11:20	van der Ploeg	A multiproxy sea surface temperature reconstruction of the Middle Eocene Climatic Optimum from the Newfoundland Drifts in the North Atlantic
11:40	Fiorella	Reconciling Divergent Carbon Isotope Responses in Ocean and Terrestrial Proxy Records to Constrain Causal Mechanisms for the Early Eocene Climatic Optimum
12:00	Cossey	Evidence from Eastern Mexico for a Paleocene/Eocene Drawdown of the Gulf of Mexico

Lunch – Primrose Room

12:20 - 13:30

Early Cenozoic pCO_2: Reconciling proxies and models – Ballroom 3

13:30	Naafs	A hot debate: Early Paleogene terrestrial temperatures
13:50	van Dijk	A reduced continental temperature gradient in North America during the Early Eocene
14:10	Sluijs	Eocene Tropical Temperature Evolution
14:30	Kowalczyk	Multiple proxy estimates of atmospheric CO2 from an early Paleocene rainforest
14:50	Barclay	Fossil Atmospheres: Improving Estimates of Ancient Atmospheric CO2 Levels from Ginkgo Leaves
15:10	Peppe	The relationship between terrestrial climate and CO2 through the early Paleogene and its implications for Earth-system sensitivity

Afternoon Break – Primrose Room

15:30 - 16:00

Posters, Next CBEP Planning, Wrap-up – Ballroom 3

16:00 - 17:30

Closing Reception – Primrose Room

18:00 - 19:00

Posters – Primrose Room

Earth Surface

1-1	Bralower	New core holes of the Cretaceous-Paleogene boundary near the El Kef Stratotype, northwest Tunisia
1-2	Wan	Paleogene stratigraphy and elimination of Tibet-Tethyan Sea
1-3	Beasley	Investigating Palaeogene strata from Oman and the UAE; new insights from integrated chemostratigraphy, sedimentology and biostratigraphy
1-4	McCartney	The Trans-Saharan Seaway recorded in the rocks of Mali: a key Paleogene locality for the study of global eustasy and paleotemperature in the ancient Tropics
1-5	Westerhold	Synchronizing early Eocene deep-sea and continental records: a new cyclostratigraphic age models from the Bighorn Basin Coring Project
1-6	Ma	Chronostratigraphy of the Green River Formation
1-7	Wing	PETM Stratigraphy of the Basin Substation core
1-8	Gao	Early Paleogene continental hydroclimate and surface uplift of the Uinta Mountains in southwestern Wyoming, U.S.A.
1-9	Greenberg	Reconstructing fluvial channel mobility through the Paleocene-Eocene Thermal Maximum (Willwood Formation, Bighorn Basin, Wyoming)
1-10	Dechesne	PETM response of a swampy fluvial to lacustrine system in a rapidly subsiding basin, Hanna Basin, Wyoming, USA.
1-11	Foreman	Tectonic and climatic controls on fluvial deposition during the early Paleogene in the Piceance Creek Basin, northwest Colorado, U.S.A.
1-12	Elson	A record of terrestrial hydrology in a long-lived Eocene Lake Uinta, Green River Formation, Utah
1-13	Secord	Recognition of carbon isotope excursions in the lower Paleocene terrestrial record of the San Juan Basin, New Mexico, USA
1-14	Zellman	Sedimentological evidence for increased precipitation extremes at the Paleocene-Eocene boundary in the San Juan Basin of New Mexico
1-15	Leslie	Terrestrial evidence for hyperthermals in the lower Paleocene Upper Nacimiento Formation, San Juan Basin, New Mexico
1-16	Hantsoo	Tracking the North Atlantic shelf-to-basin response to the PETM: Analysis with a high-resolution, terrain-following model

Biogeochemistry

1-17	Baczynski	Soil carbon stability during periods of global warming
1-18	Schlanser	Plant carbon isotope fractionation in the Eocene and Oligocene
1-19	Remmelzwaal	Ocean deoxygenation during the Palaeogene Hyperthermals
1-20	Witkowski	Early Eocene chert formation in the North Atlantic driven by elevated neritic diatom production
1-21	Bralower	Ocean Acidification on the Continental Shelf during the Onset of the Paleocene-Eocene Thermal Maximium
1-22	Ballaron	The magnitude of PETM carbon and oxygen isotope anomalies on the North American mid-Atlantic Shelf
1-23	Rush	Stable Isotope and %Carbonate Variations across the Paleocene-Eocene Boundary in the Howards Tract core, Maryland: Implications for Regional Sediment Fluxes and Climate Change
1-24	Kelly	Use of Single-Foraminifer Stable Isotope Analyses to Study the Response of Austral Planktic Foraminifera to the Paleocene-Eocene Thermal Maximum at ODP Site 1135

1-25	Schrader	Temperature - carbon cycle interactions during the Early Eocene Climatic Optimum (ODP Site 1263, Walvis Ridge)

Paleobiology

2-1	Arreguin Rodriguez	Faunal response to a potential hyperthermal event: benthic foraminifera at ODP Site 1262 across the Dan-C2 event
2-2	Weiss	Survivors: Ecological Selectivity of Corals Across the Paleocene-Eocene Thermal Maximum
2-3	Clyde	New Perspectives on the Correlation of South American Land Mammal Ages to Early Paleogene Climate Changes Based on Recent Chronostratigraphic Results from the San Jorge Basin, Argentina
2-4	Wagner	Environmental change in a neritic setting before, during, and after the Paleocene-Eocene Thermal Maximum: Insights from magnetofossil and microfossil assemblages.
2-5	Stassen	Shelf dynamics during the PETM along the New Jersey Coastal Plain
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2-11	Steeman	Dinocyst events across the ETM-2 hyperthermal event at the southern edge of the North Sea Basin
2-12	Hall	Ostracode Response to Eocene Thermal Maximum 2 in the Equatorial Atlantic
2-13	Kowalczyk	An assessment of climate-vegetation feedbacks under different boundary conditions using global climate model simulations
2-14	Schmidt	Effects of water availability on forest ecosystems during the Paleocene-Eocene in Wyoming
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2-16	Patrick	The early Eocene San Juan Basin flora: An investigation into the early Cenozoic history of the U.S. Mountain West
2-17	Sudermann	A palynological investigation of the Arctic late Paleocene/early Eocene Margaret formation at Stenkul Fiord, Ellesmere Island, Nunavut, Canada
2-18	Lowe	Plant community and climate dynamics at the onset of the Early Eocene Climatic Optimum, McAbee Fossil Beds, British Columbia, Canada

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2-25	Coxall	Deep-sea stable isotope stratigraphy from the late Eocene of IODP Site U1411: precession and eccentricity pacing at the close of the Eocene greenhouse
2-26	Steinthorsdottir	Significant decrease in atmospheric pCO2 prior to the Eocene-Oligocene transition
2-27	Bohaty	Timing and evolution of the Eocene-Oligocene Climate Transition: new insight from IODP Site U1411, Northwest Atlantic
2-28	Kennedy	Exploring mechanisms of change at the Eocene-Oligocene Transition
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ABSTRACTS

PLANETARY BOUNDARIES: BIOLOGICAL DIVERSITY & BIOTIC CHANGE 1

THE SIGNIFICANCE OF NANNOPLANKTON BOOM-BUST SUCCESSIONS DURING THE CRETACEOUS-PALEOGENE RECOVERY AT EL KEF, TUNISIA

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Calcareous nannoplankton were decimated at the Cretaceous-Paleogene (K/Pg) boundary, with over 93% of species and 85% of genera going extinct (Bown, 2005). However, extinction and subsequent recovery patterns were hemispherically asynchronous, with extinction rates higher and recovery slower in the Northern Hemisphere (e.g. Jiang et al. 2010, Schueth et al. 2015). In addition, Northern Hemisphere assemblages are characterized by boom-bust successions of dominant bloom taxa, which comprise over 40% of a sample. Although these assemblages have been recognized at several open-ocean and shelf sites, their paleoenvironmental and/or paleoecological significance has not yet been determined.

Using a new suite of drilled cores from El Kef, Tunisia; an outer shelf site and the global stratotype K/Pg section, we have used high resolution counts to compile a continuous record of nannoplankton boom-bust successions during the recovery interval. These data will be compared to a cyclostratigraphic record from the same cores to determine 1) how long boom-bust successions persisted and 2) how important shelf sites were in seeding new Paleogene nannoplankton populations. We will also correlate nannoplankton assemblage counts with stable isotopes, and abundance data for dinoflagellates, benthic foraminifera, and planktonic foraminifera. This will help constrain the paleoenvironmental and palecological signals which controlled switches between dominant bloom taxa. Because nannoplankton lie at the base of the marine food web, this study will greatly enhance our understanding of how the entire ocean ecosystem recovered following the mass extinction event.

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THE POST-MASS-EXTINCTION RECOVERY OF CALCAREOUS NANNOPLANKTON AND THE PALEOGENE EMERGENCE OF NEW DIVERSITY, DISPARITY AND ECOLOGICAL STRATEGIES

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Calcareous nannoplankton are superabundant calcifying phytoplankton and a key component of pelagic ecosystems. Their fossil record extends from the Triassic, but the ancestors of modern communities have mostly emerged since the Cretaceous/Paleogene (K/Pg) boundary, when >90% of nannoplankton species were lost. Here, we present a unique long-time-series population dataset spanning the Paleocene through lower Eocene (12 milion years) at ODP Site 1209, Shatsky Rise, Pacific Ocean. The data are sufficiently high resolution (~13 kyr intervals) to resolve assemblage dynamics on timescales of Paleogene climate and carbon cycle perturbation. These records offer a rare opportunity to track the origins of modern communities from near-zero diversity after the K/Pg event, through extended intervals of 'background-level' change, and on to the climatically turbulent Eocene hyperthermals.
Our data show a short, post-extinction interval of highly variable populations comprising successive short-lived pulses of new, small, dominant taxa that established the principle extant lineages. This is followed by the progressive emergence of more stable, diverse assemblages and new functional groups. These new groups have larger cells with heavily-calcified liths and show greater morphologic disparity and taxonomic diversity than the initial post-K/Pg assemblages. This reflects habitat partitioning, especially within oligotrophic environments, and the timing of this expansion of ecological strategies is similar but not identical to that seen in zooplanktonic foraminifera. This offset most likely reflects sensitivity contrasts comparable with those seen in the response and resilience of the different plankton groups through later Paleogene environmental change. Overall, our record demonstrates the close coupling of environment, ecologic innovation and evolutionary trends, underlining the prolonged recovery from mass extinction-level perturbation, and relative resilience to events of less profound magnitude. The evident scaling of biotic disruption across the range of Paleogene environmental change informs our understanding of future diversity and plankton function in our rapidly changing oceans.

THE MOLECULAR SIGNATURE OF THE CRETACEOUS/PALEOGENE (K/PG) MASS EXTINCTION EVENT: THE EL KEF CORING PROGRAM

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Current post-extinction models for the Cretaceous/Paleogene boundary (K/Pg; 66 million years ago) suggest that the abrupt extinction of calcareous planktonic organisms and the prolonged negative carbon isotopic excursion (CIE, 10^5-10^6 years) in bulk carbonate are explained by a collapse or reduction in primary productivity and/or carbon export. However, these models make assumptions about the effect of the mass extinction on algal groups lacking a mineralized skeleton that are seldom tested. We present biomarker results from expanded and well-preserved sedimentary sequences across the K/Pg at El Kef, Tunisia, recently obtained as part of the El Kef Coring Project. These drilling cores represent the first continuous records across the K/Pg Global Stratotype Section and Point, and offer an unprecedented opportunity to explore the interplay between environmental forcing, biological resilience, and biogeochemical cycling at unparalleled high temporal resolution.

The abundance of short-chain *n*-alkanes and total steranes indicates an overall increase in bulk algal production in the earliest Danian compared to the latest Maastrichtian. The latter was paralleled by an increase in the relative abundance of dinosteranes (dinoflagellates), a decrease and recovery in the relative contribution of C_{28} steranes (chlorophyll-c containing phytoplankton) within a very thin stratigraphic horizon, and a marked decrease in C_{30} steranes (pelagophyte) in the aftermath of the K/Pg mass extinction. These variations in planktonic ecology occurred during a time of enhanced transfer of terrestrial organic matter to the marine realm. Our results suggest that turnover in phytoplanktonic communities is evident in at least a couple of meters above the extinction horizon, where dinoflagellates and other non-calcareous phytoplankton may have played an important role in sustaining primary productivity following the decimation of the calcareous nannoplankton. We will discuss how biomarker signatures challenge existing scenarios of post-extinction productivity based on bulk stable carbon isotope records.

FISH PRODUCTIVITY, COMMUNITY STRUCTURE AND EVOLUTION DECOUPLED FOLLOWING THE CRETACEOUS/PALEOGENE MASS EXTINCTION

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The abundance and community structure of fish in modern marine ecosystems is largely a function of both abiotic factors, such as water temperature and nutrient delivery, and biotic factors, such the size structure of primary producers, and food-web interactions. The Cretaceous-Paleogene mass extinction event disrupted marine ecosystems, causing globally heterogeneous primary productivity changes, as well as extinctions in many consumer groups, allowing for a restructuring of ecosystems around the world. Here I use accumulation rate, assemblage composition, and morphological diversity of ichthyoliths, microfossil fish teeth and shark dermal scales, preserved in several deep-sea sediment cores from around the world, to investigate the dynamics the pelagic ecosystem as it recovered following the mass extinction and into the Paleogene. Following the mass extinction, the abundance of fish declined in the Atlantic Ocean but not the Pacific Ocean in agreement with estimates of export production in the two basins. However the size structure of the tooth assemblage remained constant in both basins across the extinction, and eventually shifted to more abundant larger teeth approximately 62 Ma, coincident with a pulse of radiation in tooth diversity. Furthermore, while there was a diversification event associated with the shift in tooth size and abundance at 62 Ma, increases in fish abundance are not always associated with radiations in morphological diversity: a morphological radiation occurred approximately 58 Ma, when ichthyolith abundance was at its lowest post-extinction, and is not associated with any change in tooth assemblage size structure. Fish diversity stagnated during the Early Eocene, while fish abundance, apparently co-varying with temperature, increased nearly 7-fold, and the size structure of the fish assemblage remained constant. Together these results suggest that pelagic vertebrate evolution, community structure, and productivity are decoupled, both in the post-disaster ecosystem following the mass extinction, and as the ecosystem stabilized during the early Paleogene.

DIVERSE EARLY PALEOCENE FOSSIL FLORA FROM THE SAN JUAN BASIN (NEW MEXICO, USA) DOCUMENTS RAPID RECOVERY FOLLOWING THE CRETACEOUS-PALEOGENE BOUNDARY

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Early Paleocene floras from North America are typically described as low diversity and dominated by cosmopolitan, long-ranging taxa. These low diversity, cosmopolitan floras are suggested to be a response to the Cretaceous-Paleogene (K-Pg) mass extinction followed by cooling climate through the early Paleocene. A very diverse rainforest flora from central Colorado that occurs ~1.5 myr after the K-Pg boundary runs counter to this paradigm. However, it is unclear if this flora represents an isolated response to the extinction or is part of a strong north-south diversity gradient that developed in the early Paleocene. The vast majority of early Paleocene floras are derived from the Northern Great Plains of North America inhibiting regional comparisons of floral diversity, composition, and paleoclimate. The San Juan Basin (SJB), located in northwest New Mexico, contains a nearly continuous sequence of early Paleocene terrestrial deposits making it an ideal location to study early Paleocene fossil floras from southern North America. Here we present a detailed assessment of the floral composition, diversity, and paleoclimate during the first ~2.6 myrs of the early Paleocene of the SJB.
The SJB flora is significantly more diverse than contemporaneous floras from northern North America and only slightly less diverse than the rainforest flora from the Denver Basin. Additionally, the majority of the morphotypes are endemic to the SJB, and taxa common in the Northern Great Plains are rare or absent. Paleoclimatic estimates from the SJB indicate it corresponded to a modern tropical seasonal/monsoonal forest; warmer and wetter than previously studied localities. We hypothesize that the warmer and wetter climate in the SJB led to higher rates of speciation and greater diversity there, leading to differential regional responses and the rapid establishment of a north-south diversity gradient following the K-Pg mass extinction.

BIOGEOCHEMICAL CONSEQUENCES OF ECOLOGICAL CHANGES DURING CLIMATE EVENTS AND TRANSITIONS

CHANGES IN "VITAL" EFFECTS IN PHOTOSYMBIONT-BEARING PLANKTONIC FORAMINIFERA DURING THE PALEOCENE-EOCENE THERMAL MAXIMUM

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We present evidence of large and rapid changes in "vital" effects in photosymbiont-bearing planktonic foraminifera during the Paleocene-Eocene Thermal Maximum event (ca. 56 Ma). We suggest that changes in "vital" effects indicate rapid ecologic adaptations of planktonic foraminifera in response to the abrupt global warming. First, various species experienced different changes in photosymbiotic activities, varying from significantly enhanced to suppressed. Second, isotopic ranking indicates that surface dwellers experienced changes that could be interpreted as depth migrations. Extreme temperatures (>32°C) may have exerted selective pressure that drove the biologic responses. Species with flexible depth distribution and photosymbiosis were capable of adapting to rapid warming by vertical migration in the upper ocean, while surface species restricted to tropics and subtropics would have undergone temporal expatriation during the peak warming. Equally important is that dynamic biologic adaptations of planktonic foraminifera, depending on geography and phylogeny, obscured the paleoceanographic variations when planktonic foraminifera-based paleo-proxies are used. We suggest that the patterns and magnitudes of warming and carbon isotope excursion should be interpreted with caution.

MODELING PLANKTON COMMUNITY SIZE-STRUCTURE DURING THE PALEOGENE: INTERACTIONS BETWEEN PLANKTON AND CLIMATE

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Carbon uptake in the surface ocean by phytoplankton and its export to the deep ocean and sediments, a process known as the biological pump, is a key component of the carbon cycle. In the modern ocean both the total carbon export and the efficiency of its sequestration are strongly coupled to the structure of the overlying plankton community. Different environmental conditions and ecological interactions in past climates may have led to different plankton communities and therefore differences in the way in which the carbon cycle functioned.
Here, we extend the Earth System Model of Intermediate Complexity cGENIE with a new trait-based model of plankton communities with the aim to explore interactions between plankton, ocean biogeochemistry and climate over long timescales. The ecological model explicitly resolves plankton populations with traits, such as growth and grazing rates, assigned according to organism size and functional group. We run the model with boundary conditions for the late Paleocene and Early Eocene Climatic Optimum and predict the size-structure of plankton communities. We describe a set of exploratory modeling experiments that predict a similar spatial pattern of community structure to the modern ocean but with an increase in mean size and diversity at higher latitudes and a decrease in mean size at lower latitudes compared to today. These changes in mean size are a response to differences in the fundamental niches of plankton due to warmer temperatures and the nutrient supply from the deep ocean to the surface ocean. We include a size-dependent sinking rate for particulate organic matter to explore the impact of potential biogeochemical feedbacks significantly on the results. We compare these results to observations and assess whether the model results are representative. This modeling framework presents a first step towards mechanistically representing plankton ecosystems and their interaction with climate.

EXPORT PRODUCTION AND REMINERALIZATION OVER EOCENE HYPERTHERMALS AT ODP SITE 1263, WALVIS RIDGE, SOUTHEAST ATLANTIC AND ODP SITE 1209, SHATSKY RISE, PACIFIC OCEAN

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Changes in export production and remineralization over major hyperthermal events in the lower Eocene were reconstructed using marine (pelagic) barite extracted from ODP Site 1263 (paleodepth ~1.5km) in the Southeastern Atlantic, along the Walvis Ridge, and from ODP Site 1209 (paleodepth ~2.4km) in the North Pacific. Barite data indicate export of organic matter from the photic zone and remineralization, benthic foraminiferal data reflect arrival of organic matter at the seafloor. The Paleocene – Eocene Thermal Maximum (PETM) occurred close to 55.53 Mya and was marked by the largest negative carbon isotope excursion (CIE), with nearly double the intensity of the next largest hyperthermal, Eocene Thermal Maximum 2 (ETM2, ~ 2 myr after the PETM) and ETM3 (~3.1 myr after the PETM). Understanding how export production and remineralization varied during these intervals of extreme change (including major ocean warming, which impact metabolic rates) is important in constraining the mechanisms affecting marine biota and their recovery. At both sites, the largest peaks of barite are centered at the maximum negative CIE at the PETM. At Site 1209, initial results at ETM2 show a peak in barite of roughly half the magnitude of that at the PETM. At Site 1263, barite accumulation rates peaked during each maximum CIE, and were highest during the PETM and lowest during ETM3. Interestingly, benthic foraminifera indicate a major drop in organic matter arriving at the seafloor coeval with the peaks in barite accumulation, suggesting increased remineralization in the water column: more organic matter was exported from the photic zone, but less made it to the seafloor. We do not yet know whether increased export and remineralization of organic matter was caused by increased primary productivity due to increased nutrient input or increased remineralization due to increased metabolic rates of marine bacteria, even at unchanged or declining primary productivity.

EVALUATING THE SIGNIFICANCE OF BIOTURBATION FOR CONSTRAINTS ON PALEOCENE-EOCENE THERMAL MAXIMUM CARBON CYCLING

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The Paleocene-Eocene Thermal Maximum (PETM, ~56 Ma) was an abrupt period of greenhouse warming during which thousands of gigatons of isotopically depleted carbon were added to the atmosphere over a few thousand years, leading to a global negative carbon isotope excursion (CIE) and carbonate dissolution. Deep sea sediment cores are the primary source of information for these changes in climate and global carbon cycling, but these are subject to alteration through animal activity within the sediments after deposition (bioturbation). One of the great challenges in paleoclimate research is identifying where and how the sediment record has been distorted through bioturbation or erased through dissolution. Across the PETM, differences in bioturbation intensity between ocean sites can provide unique insight into the benthic environment, and may correlate to spatial patterns in carbonate dissolution, changes in ocean oxygenation, CIE magnitude, and event recovery timescale. Here, we analyze images of the PETM interval from the South Atlantic (Ocean Drilling Program [ODP] Leg 208), Maud Rise (ODP Site 690) Shatsky Rise (ODP Leg 198), and the Caribbean (ODP Leg 199) through detailed logging of sedimentology and bioturbation on a mm-cm scale. We record differences in the intensity of bioturbation between the Pacific and Atlantic Ocean across the PETM. We next use the information derived from our analysis of core images to constrain the implementation of bioturbation in PETM simulations using the Earth system model cGENIE. We use cGENIE to generate model sediment cores for locations corresponding to the sites in our detailed logging of bioturbation intensity and compare simulated wt% $CaCO_3$ and carbon isotopes to available data from these sites in model experiments with and without bioturbation. Our analysis shows that implementation of the differential basin response in bioturbation indicated by our core image analysis improves the modeled representation of geochemical datasets across the PETM

UNRAVELLING TECTONIC AND CLIMATIC CONTROLS ON SEDIMENTARY AND GEOCHEMICAL RECORDS

ASSESSMENTS ON ALIASING: GEOMORPHIC CONTROLS ON THE QUALITY OF TERRESTRIAL PALEOCLIMATE PROXY RECORDS

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Estimates on the magnitude and frequency of past environmental change are critical for understanding the climate system and its evolution. Paleoclimate records rely on proxies hosted within sedimentary strata, and commonly produce a time series of environmental change based on linear interpolation between dated stratigraphic horizons. This assumption of linear sedimentation rates is made despite widespread recognition that short-term depositional and erosional patterns are unsteady and non-linear. Due to this geomorphic 'stochasticity' terrestrial paleoclimate records derived from proxies in river and floodplain deposits are thought to be particularly incomplete, noisy, and less resolved in comparison to those from marine strata. We evaluate these effects using fluvio-deltaic experimental basin results wherein the instantaneous topographic evolution was tracked precisely and long-term sedimentation rate known to be constant. Using experimental data we know exactly which deposition events preserve proxies in the stratigraphy and which are removed by erosional events. These preserved beds sample a synthetic time series of an oscillating climate. Subsequently, the beds are reassigned a new age based on linear interpolation, and analyzed using a REDFIT time series analysis. The results indicate that the stochastic sedimentation patterns typical of alluvial sedimentary basins can result in (1) systematic underestimates of the frequency of climate change, (2) wholesale 'shredding' of climatic variability, and (3) spurious climate events when linear sedimentation rates are assumed. However, these effects are eliminated when the timescale of climate change exceeds that of an inherent compensation timescale of the geomorphic system, wherein natural spatial disparities in deposition are accounted for. We propose a scaling formulation that postulates most alluvial systems in sedimentary basins have the capacity to faithfully preserve paleoclimatic variability in excess of 10,000 years, and illustrate its application to records of early Paleogene hyperthermals in alluvial basins of North America.

EARLY PALEOGENE SHIFTS IN FLUVIAL DEPOSITION WITHIN THE HUERFANO BASIN, COLORADO, USA: EVALUATION OF TECTONIC AND CLIMATIC CONTROLS

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There is mounting evidence linking abrupt geomorphic changes to hyperthermal events during the early Paleogene. In terrestrial basins, these geomorphic responses are observed as changes in the stacking patterns and grain size distribution of fluvial sand-bodies, as well as variations in coeval floodplain successions. In western North America, the early Paleogene was also a period of extensive tectonic activity associated with the Laramide Orogeny and resulting basin strata preserve a complex history of both allogenic forcings.

This study attempts to deconstruct these effects in the Huerfano Basin. Paleocene–Eocene alluvial deposits of the Poison Canyon and Cuchara formations are exposed along the western basin margin. The Poison Canyon–Cuchara transition is marked by an abrupt shift in fluvial deposition characterized by changes in lithofacies abundance, increased sand-body stacking patterns and channel dimensions, and coarser grain size. Fine-grained overbank facies indicate wetter Paleocene conditions shifting to direr conditions during the Eocene. Our provenance analysis using U–Pb detrital zircon geochronology and sandstone petrography indicates a uniform sediment source from the Wet Mountains for the lower Paleogene succession. A new bulk organic carbon isotope record from this section shows substantial short-term variability throughout the section, but a negative shift of ~2‰ that occurs near the Poison Canyon–Cuchara contact. Precise biostratigraphic information is lacking in this portion of the section, but grossly constrains the time period as late Paleocene to early Eocene.

These datasets show a progression similar to other Laramide basins where patterns are attributed to hydrologic changes during the Paleocene–Eocene Thermal Maximum. In the Huerfano Basin, we hypothesize that climate was a major contributor to the observed stratigraphic patterns. The carbon isotope excursion is broadly consistent with the PETM, but the signal is less distinct and is of a lesser magnitude compared to isotope records in other Laramide basins.

FLUVIAL RESPONSE TO PALEOCENE - EARLY EOCENE WARMING EVENTS: A COMPLETE RECORD

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Abrupt, transient global warming events that characterized the Paleocene to early Eocene are the best available deep time analogues to modern fossil-fuel induced warming, but ancient hyperthermal records published thus far are stratigraphically and/or geographically incomplete. Here we present a complete fluvial-lacustrine record of sedimentation style changes that were associated with dispersed organic carbon isotope ($\delta^{13}C_{org}$) excursions from the same succession in the Paleocene to Eocene fluvial-lacustrine Wasatch and Green River Formations, Uinta Basin, Utah. Negative $\delta^{13}C_{org}$ excursions from floodplain mudstone units from two widely separated localities across the Uinta Basin capture at least five warming events, including the PETM and ETM2 (H1), H2, and I1. Additional more minor $\delta^{13}C_{org}$ shifts are observed that may record five subsequent hyperthermal events and can be correlated into the stratigraphic record from other basin-wide localities. $\delta^{13}C_{org}$ excursions interpreted as hyperthermal events are concurrent with widespread, laterally correlative fluvial channel sandstone and mouthbar packages with distinct sedimentary characteristics indicative of a highly seasonal fluvial discharge regime characteristics of monsoonal climate. This is in contrast to the underlying strata that contain sedimentologic features typical of traditional fluvial facies models developed from temperate less seasonal climate regions. This study provides stratigraphically complete, basin-wide evidence of increased seasonality, fluvial expansion, and increased continental source to sink sediment delivery during abrupt Paleocene to early Eocene hyperthermal events.

FLUVIAL AND LAKE RESPONSE TO PALEOCENE-EOCENE EXTREME CLIMATE, UINTA AND PICEANCE BASINS, UTAH AND COLORADO

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The Paleocene-Eocene Wasatch and Green River formations coincide with the Paleocene-Eocene Thermal Maximum and the Early Eocene Climatic optimum. Both the fluvial and lake systems seem to respond to the strong climatic drivers. Here we explore the river and lake response to Paleogene hyperthermals.

The fluvial systems have been recognized as fluvial fans that prograde and retrograde along the southern basin margin. The fluvial fans consist of river channels that avulsed across the Uinta Basin and associated floodplain deposits. Both deposit types indicate sustained aridity with intermittent intense floods. Flood-prone variable river discharge is linked to seasonally and inter-annually variable precipitation, and collectively these fluvial strata indicate dry PETM and EECO conditions with intense and variable precipitation that resulted in short high magnitude floods that episodically transported and deposited large volumes of sediment. There are no examples of modern rivers of this size with such erratic hydrology. Thus these fluvial systems represent deposition in an extreme climate setting unlike anything present on Earth today. Based on comparison to the existing absolute ages and biostratigraphy, as well as to a stable carbon isotope record, the progradation episodes of the fluvial fans are linked to the hyperthermals.

The lake facies intertongue with the fluvial facies. After an initial fresh lake stage, the lakes become progressively more saline and alkaline during the warmest period of the Optimum, reaching mesosalinity in the Uinta basin and hypersalinity in the Piceance basin. Microbially dominated shorelines occur in both lake basins, and nahcolite deposition commences in the Piceance basin. Both lakes become highly fluctuating at the peak Optimum. Lake expansion then occurs during the Optimum cool-down. Co-varying stable isotopes are consistent with closed lake systems and the evolution from fresh to saline to fresh again.

PALEOGENE DEEP-SEA CIRCULATION IN THE NORTH ATLANTIC OCEAN: EVIDENCE FROM SEISMIC-REFLECTION AND TERRIGENOUS GRAIN-SIZE DATA, NEWFOUNDLAND RIDGE CONTOURITE DRIFTS

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Climate change in the Paleogene associated with the shift from a greenhouse to icehouse regime is the most significant global change over the past 70 Myr. However, the effect and/or response of deep-ocean circulation is poorly constrained. The timing of the shift to modern AMOC (e.g., deep-water formation in the North Atlantic) has been linked to global cooling at the Eocene-Oligocene Transition (EOT, ~34 Ma). In the North Atlantic Ocean, deep currents created a regional erosional unconformity along the U.S. continental rise that spans the late Eocene through middle Oligocene, which has been interpreted to record intensification of deep-ocean circulation at the EOT. Recent drilling during IODP Exp 342 constrains the Paleogene history of deep-sea sedimentation on the Newfoundland ridges, including two locations with preserved EOT sections. Here, we integrate seismic-stratigraphic mapping of drift distribution with terrigenous grain-size (sortable silt) data from IODP Site U1411.
Our analysis shows that Late Cretaceous through early Eocene sedimentation on the ridges was dominated by biogenic sedimentation, and then at ~47 Ma well-developed contourite drifts began to accrete, accompanied by an order-of-magnitude increase in terrigenous sediment mass accumulation rates. Our grain-size record suggests a gradual intensification of bottom currents from ~36-26 Ma within an overall seismically conformable succession of drift sediments. A significant reorganization of drift sedimentation occurred at ~25 Ma, expressed as a hiatus at IODP Site U1411 and a seismic reflection that can be mapped across the entirety of the Newfoundland ridges (~70,000 km^2). These results suggest that changes in North Atlantic circulation were not sensitive to the abrupt EOT cooling and was likely governed by longer-term processes related to the opening of tectonic gateways, such as the Greenland-Scotland Ridge and the Drake and Tasman Passages, coupled with long-term cooling trend following the Early Eocene Climatic Optimum.

PLANETARY BOUNDARIES: EARTH SURFACE CHANGE

USING LANDSCAPE DYNAMICS TO EVALUATE OBSERVED RESPONSES TO CLIMATE CHANGE: IMPROVING INTERPRETATIONS BY ASSESSING ENVIRONMENTAL NOISE AND SPATIAL SAMPLING IN SEDIMENTARY DEPOSITS

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Spatiotemporal variability is ubiquitous in sedimentary systems and challenges our ability to accurately reconstruct how terrestrial and marine environments responded to past climate changes. Internal (autogenic) sedimentary dynamics have been shown to extend over time scales that overlap with significant Paleogene climate perturbations, contributing uncertainty to interpretations of environmental response to climate change in fluvial, deltaic, and shallow marine records. Depending on the magnitude and rate of a climate event and the size of a sedimentary system, autogenic variability has the potential to dampen, overprint, or completely remove the record of landscape or seascape response to change. Furthermore, autogenic variability could produce a deposit that appears to record a climate change even in the absence of significant climate forcing – particularly when a sedimentary system is spatially under-sampled.

New approaches for identifying scales of autogenic variability in ancient deposits provide an avenue for constraining the maximum range of internal sedimentary dynamics from outcrop and subsurface datasets. This scaling can provide an estimate of the background environmental variability in a particular setting and can be used as a baseline for comparing observed changes and identifying unequivocal regional responses from what would be expected from local stochastic variability. Here we show examples of how this insight can be applied to terrestrial and shallow marine successions that span Eocene hyperthermal events. Measured scales of ancient landscape variability can be used to evaluate and compare spatial sampling in different settings. This is especially useful for gauging the degree to which datasets may be directly correlatable and whether nearby records that appear to show different trends may actually be responding to the same event coherently at a landscape scale. We show examples of how field data, models, and statistical tests can be combined to enhance interpretations and help define uncertainties on otherwise qualitative interpretations.

GLOBAL COOLING AND REGIONAL UPLIFT INDUCED DIACHRONOUS ARIDIFICATION IN THE INTERIOR OF WESTERN USA ACROSS THE EOCENE-OLIGOCENE TRANSITION

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Transitions to eolian deposition in continental interiors indicate aridification and changes in continental hydroclimate. Middle Cenozoic aridification of central Asia is a well-documented example, with cause variably attributed to global cooling at the Eocene-Oligocene transition (EOT), land-sea redistribution, or Asian tectonism. Evidence of continental aridification beyond central Asia holds the key to evaluate hydroclimate changes induced by global climate or regional tectonism across the EOT. Here we document that eolian deposition and associated continental aridification, over an area greater than ~600,000 km^2, occurred in the continental interior of the western USA during the middle Cenozoic. In the central Rocky Mountains and its adjacent central Great Plains, stratified, poorly sorted, fluvial sedimentary rocks changed to massive, better-sorted, eolian siltstones and fine-grained sandstones. The eolian sedimentary rocks are characterized by bimodal grain size distributions, quartz surface textures typical to eolian transport, and enhanced rock magnetic properties, suggesting transport of material by upper level airflow and a volume percent increase in finer grained magnetite and maghemite. The eolian deposition initiated during the latest Eocene, persisted across the EOT global cooling, and expanded progressively eastward. This transition of depositional environment is also synchronous to the renewed uplift of the North American Cordillera. By testing the independent and combined influence of surface uplift and global cooling on regional climate using the ECHAM5 model, we find that early Cenozoic uplift of the Cordillera initiated drying in the Cordilleran hinterland and immediate foreland, but moistening farther east. Global cooling at the EOT finally drove the observed eastward expansion of continental aridification.

EARLY CENOZOIC HYPERTHERMALS AND THE HYDROLOGICAL CYCLE: THEORY VERSUS OBSERVATIONS

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TOPOGRAPHIC CONTROLS ON THE INDO-ASIAN MONSOON

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The relationship between the Indo-Asian Monsoon and regional tectonic uplift is a leading example of the interaction between geological and climate processes on long time scales. We present results from a high-resolution global climate model, developed by NCAR (CAM4), at 28 km resolution. Counter to the previous notion on what controls the Indo-Asian Monsoon, we provide evidence that the monsoon onshore flow is maintained without the Himalayan Mountains, nor the Tibetan Plateau. Instead, the flow is influenced by the Western Ghats and Mizoram mountains. However, rainfall across the northern Indo-Asian monsoon sector only occurs when the Himalayan Mountains or the Tibetan Plateau is present. Results from our study demonstrate that the Indo-Asian monsoon should have existed during the early Paleogene, prior to any regional tectonic uplift.

TERRESTRIAL RESPONSE TO PAST GLOBAL CLIMATE AND ELEVATION CHANGES IN THE WESTERN US FROM COMPILED PALEOTEMPERATURES

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New paleotemperature proxies have yielded a wealth of temperature estimates for terrestrial regions. However, results from these new proxies highlight the complexities inherent in terrestrial paleotemperature reconstruction. Here we present a compilation of new and existing paleotemperature records in the western US to 1) determine whether the variability of terrestrial temperatures precludes regional trends from following global trends and 2) how this framework may improve reconstructions of paleoelevation from paleoclimate data.

1) The compiled paleotemperatures in the western US show similar long term trends to the marine benthic foraminiferal $d^{18}O$ record (e.g. Zachos et al., 2008). In addition, high-resolution records within this compilation show strong responses in the western US to rapid global warming events (e.g. early Eocene hyperthermals). These data show that new and existing terrestrial paleotemperature proxies are capturing short and long-term climate trends. Thus, efforts to generate and compile regional paleotemperature datasets such as this in other regions will likely yield critical terrestrial constraints at scales useful for comparison with climate model output.

2) Records from regions within the current interior of the western Cordillera are on average cooler with more negative water isotope values (when available) than from the high plains and midwest region that has been, and currently is, at lower relative elevation. These temperatures and water isotope values are consistent with the idea that much of the Cordillera has been elevated throughout most of the Cenozoic, and back into the Cretaceous in the Sevier hinterland region. Development of a spatial and temporal framework of paleotemperature provides critical context needed to generate more robust climate averages with which to estimate ancient elevation. Future paleoaltimetry studies will require higher resolution and greater sampling density to produce sufficiently accurate climate averages.

Zachos, J.C., Dickens, G.R., and Zeebe, R.E., 2008: Nature, v. 451, no. 7176, p. 279–283.

BIOLOGICAL RESPONSES TO CLIMATE EVENTS AND TRANSITIONS

VARIABILITY OF THE BENTHIC FORAMINIFERAL RESPONSE TO PALEOGENE HYPERTHERMAL EVENTS

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The early Paleogene warm climate was interrupted by geologically short periods of extreme global warming (hyperthermals), used as analogs for modern-future climate change. Hyperthermals are recognized in the sedimentary record by negative carbon isotope excursions (CIEs), reflecting emission of thousands of gigatons of isotopically light carbon into the ocean-atmosphere, associated with geochemical and biotic proxy-evidence of global warming, regionally variable evidence for deoxygenation, and evidence for ocean acidification in surface waters and the deep ocean. The most extreme event, the Paleocene Eocene Thermal Maximum (PETM), has been best documented, but for lesser hyperthermals the biotic response has been documented at few locations. The response of biota to hyperthermals of varying intensity can be used to evaluate whether there is a correlation between the amplitude of the environmental disturbance and that of the response of biota, whether such a correlation exists only once a threshold value is crossed, and whether the initial status of the populations and the rate of change are important (e.g., Gibbs et al., 2012). Benthic foraminiferal assemblage data across a mid-Paleocene event, the PETM, and Eocene Thermal Maxima-2 and -3 at two sites at different depths along Walvis Ridge (SE Atlantic; paleodepths ~3500-~1500m) show that only the largest event, the PETM, led to significant extinction, with no clear between-site difference. The mid Paleocene event, predating the extinction, had a transient effect on species richness and assemblage composition. ETM2 and -3 similarly showed somewhat more pronounced transient effects on species richness and assemblage composition, and more severe at the shallower site. Biotic effects of lesser hyperthermals thus varied by depth, even in a restricted geographic region, so that extrapolations of the effects of environmental change on biota from a few locations to a global scale cannot easily be made.

Gibbs, S. J., et al., 2012. Biogeosciences, 9, 4679-4688.

EVOLUTIONARY RESPONSE OF THE PLANKTIC FORAMINIFER ORBULINOIDES BECKMANNI TO CLIMATIC CHANGE DURING THE MIDDLE EOCENE CLIMATIC OPTIMUM (MECO)

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Evolution is most likely driven not by any single environmental variable, but by the whole climate system. Analogously, selection on one organismal trait often generates a response in others. Thus, to quantify biotic responses to abiotic drivers it is crucial to study the effects of multivariate climate change on multiple morphological traits. Planktonic foraminifera are particularly well suited to this because their fossil record is extraordinarily complete, well-dated and yields a diverse suite of environmental parameters from geochemical analysis.

Here, we present the first study of a species' evolutionary response to climate change through its entire duration from origination to extinction, using the Eocene planktonic foraminifera *Orbulinoides beckmanni*. This species' short range (40.5 Ma to 40.0 Ma) defines planktonic foraminiferal Zone E12 and includes the transient global warming event, the Middle Eocene Climatic Optimum (MECO). We have generated a suite of new high-resolution (~25 kyrs) biometric data including test size, test shape, final chamber size and shape, and the number and size of sutural and areal apertures for *O. beckmanni* and its immediate ancestor *Globigerinatheka euganea.* Cluster analysis of all measured traits is subsequently used to determine the exact timing of the origination of *O. beckmanni* (and morphological criteria for defining this key species), and so the base of Zone E12.

To quantify evolutionary response of ancestor and descendant species to multivariate environmental change before, during and after the MECO, all traits are compared to existing regional environmental reconstructions. The results will provide new insights in a species' response to multivariate climate change from origination to extinction, and in particular to transient climate change during the MECO as compared to 'background' Eocene environmental variability.

THE PALEOCENE-EOCENE THERMAL MAXIMUM (PETM) MOLLUSK FAUNA OF THE ATLANTIC COASTAL PLAIN, USA

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The response of many organisms to climatic and environmental changes during the Paleocene-Eocene Thermal Maximum (PETM; ~56 Ma) has been well documented, except for that of marine mollusks. We describe a diverse PETM assemblage of pteropods (holoplanktic gastropods) recovered from the Marlboro Clay of the US Atlantic Coastal Plain (ACP), which contains some of the most complete records of shallow marine PETM deposition. Specimens are preserved as pyritized internal molds, except for two specimens where shell remains. The assemblage consists of six species representing three genera (*Altaspiratella, Heliconoides* and *Limacina*). Four species (one new) could be identified to species level. Only *Heliconoides* was previously known from pre-Eocene and early Eocene sediments, with a single Campanian specimen and one latest Paleocene species.

The Marlboro Clay sediments were deposited at inner through middle-outer shelf depths, presently too shallow for pteropods, which may have been transported from more open ocean areas. At Bass River, the pH of surface waters (as recorded in B/Ca measured on planktic foraminifera) may have declined by 0.3-0.4 units during the PETM (Babila et al., 2016). Apparently, the drop in surface water pH was insufficient to dissolve living or dead pteropods before they reached the seafloor, likely because of rapid buffering in coastal waters. Pteropods have thin, not easily fossilized shells, and their appearance within the PETM could therefore reflect better preservation: the underlying sandy, glauconitic Paleocene Vincentown Fm. (NJ) or Aquia Fm (MD) has poor preservation of calcareous microfossils. In contrast, during the PETM, increased sediment supply from high rainfall may have rapidly buried the pteropods. However, potentially existing ancestors have not been found anywhere else, and so we argue that the rapid environmental changes during the PETM may have triggered pteropod diversification.

Babila, T. et al. 2016. *Geology*, 44:75-278.

INSIGHT INTO ANCIENT SEAGRASS COMMUNITIES FROM EXAMINATION OF FOSSILIZED REMAINS OF SIRENIA

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Seagrasses are important primary producers in coastal areas, providing food and shelter for consumers in shallow, oligotrophic waters. Knowledge of their contribution to coastal areas in the past is limited because of their poor fossil record, a problem that has been addressed by inferring their presence from the occurrence of fossil remains from organisms typically found in seagrass beds today. As an example, sirenians (manatees, dugongs, sea cows) are primary consumers of seagrasses today, and their fossils are commonly used as proxies for ancient seagrass meadows. Prior stable isotopic and sedimentological evidence support a close association between sirenians and seagrasses since the early Eocene. Here, we apply this proxy to examine how seagrass communities may have been impacted by major climatic events of the Paleogene.

Today, geographic ranges for extant sirenian species are restricted to subtropical waters where sea surface temperatures do not fall below 20°C. In the Paleogene, sea surface temperatures were much warmer than today and the latitudinal range of sirenians was significantly expanded. Relative to fossil occurrences for other marine mammals (i.e., cetaceans), sirenian fossils are abundant through most of the Eocene but show a significant decline in the late Paleogene that corresponds with major changes in ocean temperatures. Interestingly, this event is associated with the first appearance of the subfamily Dugonginae, a clade that showed morphological specialization for digging and consuming rhizomes within seagrass meadows. The timing of this specialization may reflect an increase in belowground biomass of seagrasses as temperatures dropped and seasonality increased in coastal environments in the late Paleogene. Future study of these fossils, as well as those of other organisms associated with seagrasses communities, may yield additional insight into how these communities have evolved during the Cenozoic.

PLANETARY BOUNDARIES: BIOLOGICAL DIVERSITY & BIOTIC CHANGE 2

FOREST CANOPY CHANGE DURING THE PETM, HANNA BASIN, WY

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At the current rate of greenhouse gas emissions, atmospheric carbon dioxide (pCO_2) levels will increase to values not known on Earth in the last 50 million years. How will vegetation, more specifically, primary productivity respond to this exponential increase in pCO_2 and the associated climate changes? Much of our present knowledge about the effects of pCO_2 on plant growth comes from modeling studies and small-scale experimental work. How whole ecosystems will be affected on longer temporal scales remains largely unknown.
This study tests how increased pCO_2 during the Paleocene-Eocene Thermal Maximum (PETM ~ 56 million years ago) affected forest ecosystems in the Hanna Basin of south-central Wyoming, USA. We demonstrate that canopy density, quantified as Leaf Area Index (LAI – foliar area/area of ground) can be reconstructed using light-dependent cellular morphology of leaf epidermis in modern environments. We then present a reconstructed LAI record from fossilized dispersed leaf cuticles from middle Paleocene–early Eocene strata using the newly developed proxy method. Our preliminary results show consistently dense forest habitats throughout most of the Paleocene with an abrupt increase in LAI early in the PETM. These results suggest that increased pCO_2 had a fertilizing effect on forest ecosystems in the Hanna Basin where wet, swampy conditions prevailed for much of the Paleocene and Eocene and where thick coal beds accumulated. Like other basins (e.g. the Piceance Creek Basin), the PETM in the Hanna Basin corresponds with sedimentological evidence for increased fluvial discharge and sediment flux. However our result of increased LAI suggests mechanisms other than decreased plant cover were responsible for altered hydrological and sedimentological signals during the climate event. We look to expand this work to other localities that preserve terrestrial PETM sequences to better understand the nature of the carbon cycle perturbation and recovery following the event.

POLAR HEAT: EVALUATING THE IMPACT OF AN EARLY EOCENE HYPERTHERMAL EVENT ON ARCTIC FORESTS FROM ELLESMERE ISLAND, NUNAVUT, CANADA

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During the early Eocene, global temperatures were much higher than modern values and the climate was punctuated by several short-lived hyperthermal events (e.g. the Paleocene-Eocene Thermal Maximum (PETM) ca. 56 Ma, and the Eocene Thermal Maximum 2 (ETM2) ca. 53.7 Ma), intense episodes of global warming that represent the warmest intervals of the Cenozoic. The polar regions during the early Eocene experienced far greater impact than lower latitudes as a result of polar amplification; however, the role climate change had on these terrestrial polar ecosystems is poorly understood. Fossil-rich sediments of the late Paleocene-early Eocene Margaret Formation at Stenkul Fiord, 77°N on Ellesmere Island, preserve evidence of lush Arctic ecosystems rich in mesothermal forest and swamp genera (e.g., *Metasequoia, Fagus*, *Acer*, *Alnus*, and *Betula*) growing under warm equable temperatures (i.e., MAT ~12-15°C). U-Pb dating of Zircon crystals from Stenkul Fiord indicate an age of 53.7 ± 0.6 Ma; analyses of carbon isotopes have been used to identify the location of the ETM2 event within the local stratigraphy. Census collections of fossil leaves collected as part of the CASE (Circum-Arctic Structural Events) project of the BGR and GSC, sampled stratigraphically near the ETM2 event, will make it possible to assess changes in environment and climate, as well as variations in forest composition, in a context of rapidly changing climate. Integration of macrofossil data with quantitative analyses of fossil pollen and spores will contribute to reconstruction of terrestrial vegetation, as well as provide biostratigraphic constraint. Fossil remains of lush Arctic early Paleogene forests from Ellesmere Island represent some of the best deep-time analogs for a warm Earth.

CHANGES IN RELATIVE MOLAR SIZE OF THE SMALL-BODIED MAMMAL MACROCRANION (EULIPOTYPHLA, ERINACEOMORPHA) ACROSS THE PALEOCENE-EOCENE THERMAL MAXIMUM FOLLOW THE INHIBITORY CASCADE MODEL

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The Paleocene-Eocene Thermal Maximum (PETM) is marked by the rapid onset of a negative carbon isotope excursion ~56 Ma that lasted ~175 ky with an associated shift towards warmer global mean annual temperatures (MAT) by ~5-8 °C, followed by a recovery to pre-excursion MAT. First lower molar (M_1) areas change significantly across the PETM in at least 40% of measured mammalian genera. However, change in a single tooth position may not correspond to change in other tooth positions. Differences in climate, diet, and nutritional stress are linked to metameric variation in relative molar crown area (RCA) within modern species.

To test the possibility of environmentally-linked change in RCA, we asked whether (a) different molar positions change in crown area (CA) similarly through the PETM, and (b) if they do not, whether changes in RCA through the PETM follow the expectations of the developmental inhibitory cascade model (ICM). The ICM predicts that clades have developmental trajectories along which they are most likely to change RCA. Our dataset consists of CA measurements of isolated $M_{1\text{-}3}$ of the small-bodied (~24 g) lineage *Macrocranion junnei*-*Macrocranion nitens* (N = 128).

CA of $M_{1\text{-}2}$ does not change significantly through the PETM, but M_3 CA significantly decreases during the PETM-recovery and post-PETM time bins (p = 0.02). Although these patterns result in significant differences in RCA among time bins (Wa-0.3 vs. Wa-0.1, p = 0.01; Wa.1 vs. Wa-0.1, p = 0.004), all mean molar ratios follow a common developmental trajectory with complete molar rows of later-occurring *M. nitens*. Variation in RCA within PETM *Macrocranion* is of similar magnitude to previously published between-population differences in RCA, consistent with predictions of the ICM and the hypothesis that developmental pathways shape responses to dietary and nutritional changes associated with climatic change.

CHANGES IN RELATIVE ABUNDANCE OF PRIMATES AND SMALL MAMMAL FAUNAL COMPOSITION BEFORE, DURING, AND AFTER THE PALEOCENE-EOCENE THERMAL MAXIMUM IN THE SOUTHERN BIGHORN BASIN, WYOMING

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The Paleocene-Eocene Thermal Maximum (PETM) was a period of transient global warming, when temperature increased rapidly by ~5-8° C, was sustained for ~100 kyrs, then gradually returned to background. The PETM altered terrestrial ecology through changes in aridity, seasonality, and floral community composition. Among mammals, the PETM is associated with decreased body size and a notable increase in first appearances and species richness. These trends have only been investigated at the resolution of mammalian biozones—treating the PETM as a single interval of time—and it remains unknown how faunal composition and relative abundances, particularly among small-bodied taxa such as the first euprimates, changed within the PETM. To address this, we intensively sampled PETM terrestrial faunas by screenwashing productive localities from a high resolution stratigraphic section spanning the PETM and correlated to the carbon isotope excursion. Based on rarefaction analyses, we analyzed nine localities with >100 specimens (total *N*=9,706): one late Paleocene site prior to the PETM, five during the PETM, and three following it. The late Paleocene was characterized by relatively low mammalian generic richness and evenness, and high abundance of the multituberculate *Ectypodus*. Richness and evenness increased thereafter, with community composition varying across changing environments during and after the PETM. Faunal composition during the PETM was dominated by eulipotyphlan insectivores and the endemic uintasoricine primate *Niptomomys*, but post-PETM localities were dominated by the macroscelidean *Haplomylus* and the immigrant euprimate *Cantius*. In contrast to *Niptomomys* and *Cantius*, the immigrant euprimate *Teilhardina* maintained stable abundance (3-5%) through the PETM, declining slightly (2-4%) thereafter. Remarkably, the earliest PETM locality to preserve euprimates also preserved a relatively high abundance of rodents and low abundance of eulipotyphlans and *Niptomomys*. This distinctive shift in faunal composition may reflect an immigration event that perturbed small mammal communities that had been largely dominated by endemic taxa.

IMPLICATIONS OF IMMIGRANT ARRIVAL TIMES DURING THE PALEOCENE-EOCENE THERMAL MAXIMUM FOR MAMMAL HABITAT SPECIFICITY

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Fieldwork in sections spanning the Paleocene-Eocene boundary in the southern Bighorn Basin, Wyoming, has yielded 21,584 vertebrate fossils from 1,100 localities tied into a high-resolution stratigraphic framework. Three distinct phases of the Paleocene-Eocene Thermal Maximum (PETM) are recorded by paleosols, fossil plants and isotopes: a sudden 'onset' with prominent negative carbon isotope excursion associated with warmer, drier climate; a sustained 'body' of hot, seasonally dry climate lasting ~100 kyrs; and a more gradual 'recovery' when climate shifted back to cooler, wetter conditions.

The PETM onset includes the first appearances of perissodactyls and artiodactyls and a poorly preserved flora dominated by palms. The body is characterized by dry-tolerant plants that extend their ranges northward from the Gulf Coast Plain and southern Rockies, and the staggered first appearances of euprimates, amphilemurid insectivores, miacid carnivores, and hyaenodontid creodonts. These immigrants from Eurasia comprise ~20% of North American PETM mammalian diversity. The recovery period records the first appearances of plants known from the Paleocene of Eurasia, but no new intercontinental mammalian immigrants.

If the immigrant mammals were tracking specific habitats, their intercontinental dispersal would imply continuity of biomes across Holarctica and intercontinental mammal and plant immigrants should appear concurrently. Instead, mammalian immigrants that cross through high latitude belts of warm temperate forest appear in the Bighorn Basin during peak PETM conditions, when plant fossils suggest a dry tropical forest. Warm temperate Eurasian plants don't appear until the recovery phase, but the return of temperate forest does not coincide with a decline of mammals that occupied PETM forests. The arrival of intercontinental mammalian immigrants ahead of the floras implies the ability to take advantage of a broad range of habitats with different resources and seasonal cycles, and that PETM mammalian biogeographic patterns are not simply the result of expanded habitat previously restricted to lower latitudes.

ADVANCES IN PALEO-PROXIES: MECHANISMS, INTERPRETATIONS, AND UNCERTAINTY

PALMS AS PALEOCLIMATE PROXIES: A NEW 'PALM-LINE'

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Fossil palms (Arecaceae) are used as evidence of past climates that were tropical or 'frost-free', owing to palm richness in the modern tropics and low diversity under temperate climates, and absence from areas with sustained freezing. Palm temperature limitations are due to their growth form – a single apical bud – and the lack of anatomical features that allow dormancy or freezing tolerance. The freeze intolerance of palms varies across different organs and life stages, with seedlings in particular shown experimentally to be less tolerant of sub-zero temperatures than adult plants, limiting successful establishment of populations while permitting adult palms to survive in cultivation outside their natural ranges. Numerous authors have used modern limits of palms as proxies for temperature minima in the Paleocene and Eocene, with Wing and Greenwood defining a 'palm line' where MAT_{min} 10°C and $CMMT_{min}$ 5°C. Experimental data suggests that $CMMT_{min}$ 3–5°C was higher under Paleogene hyperthermal pCO_2 levels (= 800ppm). These data have accentuated model-proxy mismatches for high latitudes during Paleogene hyperthermals such as the PETM when palms expanded poleward in both hemispheres, implying $CMMT_{min}$ = 5°C or ~ 8°C. Analyses of a global dataset (*n* = 21322) of palm distribution and their climates across major palm clades refines understanding of the climate controls of modern palm distribution and diversity, reinforcing recognition that palms are primarily tropical, despite evolution of temperate climate adaptation by coryphoid palms since the Miocene or older; <1% of palms occur where MAT <10°C and winter-MT <5°C. Members of the subfamily Coryphoideae, Tribe Trachycarpeae can grow in temperate climates where $CMMT_{min}$~2 °C (*n* = 4614), however with winter-MT < 5°C for < 1% of all records, and MAT_{min} ~10°C (MAT_{min} < 10 °C < 1%). Lower winter-MT is associated with high seasonal temperature range, with implications for hyperthermal temperature estimates.

DUAL ISOTOPES OF PEDOGENIC CARBONATES RECORD SPATIAL PATTERNS OF CLIMATE CHANGE OVER THE PALEOCENE-EOCENE THERMAL MAXIMUM (PETM)

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The PETM was a rapid warming event ~56 Ma characterized by a carbon isotope excursion (CIE) that reflects a large injection of carbon into the ocean/atmosphere system. Marine and terrestrial records indicate that climate seasonality changed over the PETM, but details of the spatial patterns of these changes are poorly understood. Here we show that pedogenic carbonates record carbon and oxygen isotope excursions of varying magnitudes in four northern mid-latitude sites, with strong coupling between the magnitudes for carbon and oxygen. This oxygen-carbon isotope excursion coupling could indicate that similar, spatially heterogeneous, climatic drivers influenced these values for both isotopic systems over the PETM. Pedogenic carbonates usually precipitate in association with soil drying; therefore, their carbon and oxygen isotope values can reflect the influence of both annual and seasonal environmental conditions. Assessing the major controls on carbon and oxygen isotopic values of pedogenic carbonate reveals that they share a common set of seasonal and annual climatic drivers. We developed a mechanistic model of the dual isotope system in pedogenic carbonates. This model was applied to the coupled paleosol carbonate oxygen and carbon isotopic records over the PETM using a Bayesian inverse technique, with a comprehensive assessment of uncertainty. Model results suggest that site-specific changes in seasonality of temperature could drive the variability and coupling of carbon and oxygen isotopic excursions in these continental sites over the PETM.

PALEOECOLOGICAL CHANGES IN EOCENE PLANKTONIC FORAMINIFERAL SPECIES

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Planktonic foraminifera are commonly utilised for palaeoclimatic and palaeoceanographic reconstructions (e.g. Wade *et al.* 2012, Hollis *et al.* 2015). Carbon and oxygen isotope signatures in planktonic foraminifera have also previously been shown to reflect their palaeobiology i.e. depth habitats and photosymbiotic partnerships (Douglas & Savin 1978, Norris 1996, Ezard *et al.* 2015). However, since planktonic foraminifera are also known to change their palaeoecologies through time (e.g. Wade & Pearson 2008, Edgar *et al.* 2013), it is important to understand when and/or if this occurs so valid palaeoclimatic and palaeoceanographic reconstructions are made.

The palaeoecologies of various Eocene planktonic foraminifera have not been resolved. Carbon and oxygen isotope and laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) derived trace element data obtained for various size fractions of multiple species of well preserved Eocene age planktonic foraminifera (including acarininids, globigerinathekids and subbotinids) from ODP Site 763, Bass River (ODP 174AX), Hampden Beach and Tanzania will be presented, and their palaeobiological and palaeoclimatic implications discussed. Trace element/Ca and isotope data collected thus far suggest inter-species offsets in both surface and thermocline dwelling species, and between different size fractions.

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REGIONAL SIGNAL/NOISE IN PLANT WAX DD RECORDS: A CALIBRATION USING LAKE SEDIMENTS THROUGHOUT THE ADIRONDACK MOUNTAINS, NEW YORK

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The hydrogen isotopic composition of sedimentary plant waxes (dD_{wax}) is an important proxy for the dD of past precipitation (dD_p) and paleohydrologic change. Such investigations rely on estimates of apparent fractionation (e_{app}) between dD_p and the resulting dD_{wax}. Numerous studies have observed a large range of biological 'noise' in e_{app} values among modern plants, even within the same catchment. However, relatively few studies have assessed the e_{app} 'signal' ultimately preserved in lake sediments. Developing datasets for e_{app} at the sediment level is critical both for calibrating more accurate e_{app} values to apply downcore, and for amplifying the signal (in sediments) to noise (in plants) ratio associated with this proxy.

Here, we evaluate sedimentary leaf waxes from 12 Adirondack lakes that have similar dD_p but a range of vegetation structure, basin size, catchment erosion and fluvial inputs. We report dD_{wax} and e_{app} values from *n*-alkanes and *n*-alkanoic acids in coretop sediments from each lake, along with sedimentation rate, grain size distribution and C:N ratios. We compare e_{app} values among lakes and investigate potential relationships with basin morphology and transport processes specific to each site.

Preliminary data reveal low 'noise' in sedimentary e_{app} values based on *n*-C_{29} alkane (-134 ± 3‰, n = 7) for a subset of sites ranging from five fluvial inputs to none. This suggests insensitivity of this proxy to a range of basin-specific factors that may affect plant wax sourcing and transport within each catchment. Comparison with prior studies of lake coretop e_{app} values in similar and contrasting biomes suggests that low regional 'noise' in sedimentary e_{app} may be specific to forested catchments, which may therefore be particularly suited to application of this proxy deeper in the geologic record.

DRILLING THE CHICXULUB IMPACT STRUCTURE: STUDY OF LARGE IMPACT FORMATION AND EFFECTS ON LIFE DURING IODP/ICDP EXPEDITION 364

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TEMPO, INTERACTION, AND SENSITIVITY OF EARTH SYSTEM CHANGE ACROSS TIMESCALES

NEW ASTRONOMICAL SOLUTIONS AND ORBITAL VARIATIONS IN ATMOSPHERIC CO_2 DURING THE EARLY PALEOGENE

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Geologic records across the globe show prominent variations on orbital time scales across various epochs. The origin of these cycles are variations in orbital parameters of the bodies of the Solar System. On long time scales, the orbital variations cannot be computed analytically because of the chaotic nature of the Solar System. Thus, numerical solutions are used to estimate changes in, e.g., Earth's orbital parameters in the past. The orbital solutions represent the backbone of cyclostratigraphy and astrochronology, now widely used in geology and paleoclimatology. Hitherto only two sets of solutions for Earth's eccentricity appear to be used in paleoclimate studies, provided by two different groups that integrated the full Solar System equations over the past >100 Myr. In this presentation, I will touch on the basic physics behind, and present new results of, accurate Solar System integrations for Earth's eccentricity over the past hundred million years. I will discuss various limitations within the framework of the present simulations and compare the results to existing solutions. Furthermore, I will present new results from practical applications of such orbital solutions, including effects of orbital forcing on coupled climate- and carbon cycle variations. For example, I will describe a mechanism for a large lag between changes in carbon isotope ratios and eccentricity at the 400-kyr period, which has been observed in Paleocene, Oligocene, and Miocene sections. Finally, I will present the first estimates of orbital-scale variations in atmospheric CO_2 during the early Paleogene.

THE METRONOME OF NORTH ATLANTIC DEEP-WATER CIRCULATION IN THE MIDDLE EOCENE

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Modern ocean overturning is dominated by deep water formation in the North Atlantic and the Southern Ocean. A major knowledge gap in paleoceanography is when this bipolar circulation regime arose. Despite this crucial role in today's climate system, vigorous debate remains as to when NADW formation may have been initiated. Here, we present results obtained from Newfoundland Drift sediments drilled during Integrated Ocean Drilling Program Expedition 342. These middle Eocene sediments present a unique carbonate-rich archive of paleoceanographic change, allowing for the characterization of orbital-scale ocean circulation changes in the North Atlantic in a climate system that transitioned from the extreme warmth of the early Eocene into the progressive climatic cooling through the middle Eocene. Well-defined cycles in different proxy records depict these lithologic couplets, occurring at a ~41 kyr beat. Given this dominant periodicity in all proxy records, we interpret obliquity to be the main driver of middle Eocene North Atlantic overturning circulation variability. Benthic foraminifer oxygen and carbon isotope data (~2 kyr resolution) indicate that obliquity minima are characterized by cold, nutrient-depleted Western Atlantic deep waters. At the same time, deep waters are relatively well oxygenated, implying that the deep western boundary current was strengthened. We thus link stronger NADW formation with obliquity minima. These results excellently agree with simulations from a fully coupled Earth system model for the middle Eocene, underscoring that decreased (increased) latitudinal temperature gradients and cool (warm) temperatures in the North Atlantic were the primary causes of intensification (reduction) of Atlantic Meridional Overturning Circulation during obliquity minima (maxima).

WINTER TEMPERATURES DRIVE CLIMATE COOLING IN THE PALEOGENE SUBTROPICS

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We present a paleotemperature record for the middle Paleocene through early Oligocene for the subtropics (~30°N paleolatitude) that derives from oxygen isotope analysis of accretionary biogenic carbonates on the US Gulf Coastal Plain (GCP) shelf. The dataset is comprised of more than 7000 $d^{18}O$ analyses from 350 mollusk shells and fish otoliths compiled from new and published data. Most individuals are sampled at intra-annual temporal resolution, allowing for reconstructions of summer and winter temperatures in addition to mean annual temperature (MAT). This level of resolution not only facilitates comparison with published records of MAT across latitudes, but also enables assessment of how changes in mean temperature are brought about in this region. Clumped isotope analysis of select shells and TEX_{86} analysis of sediment samples from key stratigraphic intervals, including the early Eocene climatic optimum window, which is largely devoid of skeletal carbonate in the GCP, provide additional constraints. Oxygen isotope values through time generally follow the benthic $d^{18}O$ stack and are depleted by about 3 ‰. Calculated $d^{18}O$-derived mean paleotemperatures range from an early Eocene peak around 27°C to a minimum in the low 20s in the early Oligocene. TEX_{86} data suggest temperatures just over 30°C during the EECO. Even in comparison with recently revised cooler temperature estimates from the SW Pacific, our data suggest an exceptionally low meridional temperature gradient in the early and middle Eocene at least. Seasonally resolved temperatures reveal an increase in seasonal range through time from roughly 3°C to 10°C. Cooling MAT through time is driven by a statistically significant decline in winter temperatures; summer temperatures are largely unchanged throughout the section. This pattern is the opposite of that seen in the polar, Antarctic section (see presentation by Judd et al.), pointing to latitudinal differences in the means by which climate change is brought about.

LATE EOCENE REDUCTION IN ANTARCTIC SEASONALITY AS INFERRED FROM THE ISOTOPIC COMPOSITION OF NEARSHORE MARINE BIVALVES

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The Eocene Epoch was a time of large-scale global climate change, experiencing both the warmest temperatures of the Cenozoic and the onset of southern hemisphere glaciation. While the temporal record of average global temperatures is reasonably well constrained throughout this transition, considerably less is known about the accompanying changes in seasonality, particularly in polar regions. Here, we assess seasonal variations in the temperature of shallow nearshore Antarctic waters during the Eocene, inferred from high-resolution oxygen isotope profiles from accretionary bivalves.

Specimens come from the La Meseta Formation, Seymour Island, Antarctica. As age control within the formation is uncertain, we subdivide the formation into two relative time intervals, representing the middle Eocene and late Eocene. We utilize exceptionally preserved, bivalves from the genera *Cucullaea* and *Eurhomalaea*. For each specimen, we milled 40 – 100 discrete sample paths, which were analyzed for oxygen isotope values. Isotope profiles were transformed from the distance domain into time space, and data from all years within each time interval were pooled.

The late Eocene dataset exhibits a strongly attenuated seasonal amplitude, with a more enriched mean value, when compared with data from the middle Eocene. These results indicate that the late Eocene was cooler and dramatically less seasonal than the middle Eocene, suggesting that high latitude Eocene cooling was achieved primarily through preferential decreases in summertime temperatures. Recent studies, however, have identified monsoonal precipitation regimes near the poles during the early-middle Eocene. It is conceivable that summer precipitation and runoff could create a brackish, isotopically depleted lens in shallow nearshore environments, increasing calculated summer temperatures, and thereby inflating the inferred mean and range of temperatures in the middle Eocene. The addition of seasonally resolved clumped isotopes should deconvolve the extent to which the isotope profiles reflect pure changes in temperature versus seasonally variable seawater composition.

A PROBABILISTIC ASSESSMENT OF THE RAPIDITY OF PETM ONSET

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Knowledge of the onset duration of the Paleocene-Eocene Thermal Maximum — the largest known greenhouse gas-driven global warming event of the Cenozoic — is central to our ability to draw appropriate inferences for future climate change. Single-foraminifera records of the associated carbon isotope excursion from Maud Rise in the South Atlantic Ocean (Ocean Drilling Program Site 690) have proved controversial, as the absence of intermediate isotope values during the onset seems to indicate a geologically instantaneous carbon release and an anomalously long ~10 kyr time-scale of mixing into the ocean interior. Here we present a fundamental reinterpretation of this record and extract critical information regarding the likely onset duration. We start by employing an Earth system model to illustrate how the response of ocean circulation to warming does not support the interpretation of the observed signal as implying an instantaneous carbon release. Instead, to resolve the observed conundrum, we use a novel sediment-mixing model that tracks individual particles and show how changes in the relative population sizes of the calcareous plankton used to track surface to deep ocean conditions, combined with sediment mixing, can explain the observations. Furthermore, for any plausible PETM onset duration and sampling methodology, our model allows us to place a probability on not sampling an intermediate, syn-excursion isotopic value. Assuming that mixed-layer carbonate production continued through the onset period at Maud Rise, we deduce the PETM onset was likely less than 5 kyr.

TEMPORAL SCALING OF CARBON EMISSION RATES DURING ONSET OF THE PALEOCENE-EOCENE THERMAL MAXIMUM

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Rates are ratios, sensitive to both their numerators and denominators. Contrary to common belief, dividing a numerator by a denominator does not remove the denominator's effect. How fast we run is not simply how quickly we move, but how far we run in a specified time or how rapidly we cover a specified distance. To make running rates comparable, they must be indexed by their distance or time.

This problem also appears in carbon emission rates, where it is common to claim that current rates, on a time scale of years, are unprecedented in earth history where time can rarely be resolved at less than a thousand years. Rates of anthropogenic carbon emission today are about 10 petagrams of carbon [PgC] per year (Le Quéré et al. 2015). In contrast, during onset of the PETM Cui et al. (2011) found a carbon emission rate of 0.3–1.7 PgC per year for an onset (denominator) estimated at ca. 8,000 years. Kirtland Turner and Ridgwell (2016) found a rate of 2.275 PgC per year for an onset estimated to be less than 3,000 years. Zeebe et al. (2016) found a rate of 1.1 PgC per year for an onset estimated to be greater than 4,000 years.

How do we compare rates on a timescale of years with rates on timescales ranging from 3,000 to 8,000 years? We can use anthropogenic rates on a range of shorter time scales to estimate what we expect on longer time scales, or rates on a range of longer time scales to estimate what we expect on shorter time scales (or both): we have to bring anthropogenic and PETM emission rates to some common time scale. We know anthropogenic emission rates on time scales ranging from 1 to 56 years, and by temporal scaling—comparing how the rates change as their time intervals or denominators change—we can calculate what to expect on the time scale of the PETM onset.

What we find is surprising: the anthropogenic rates for 1959–2014 fall on a log-rate log-interval [LRI] plot with slope of zero indicative of a directional process with little random or stationary influence. The LRI intercept of 0.758 indicates a median one-year rate of $10^{0.758}$ = 5.73 PgC. Rates for a time series with a random component decline with a slope approaching −0.5 on an LRI plot. Without testing for this, we might assume that anthropogenic emissions also decline with a slope approaching −0.5. This would lead us to expect anthropogenic emissions to have a lower rate than those estimated for PETM emissions when compared on the same time scale. This is manifestly not what we find. Anthropogenic carbon is being emitted at rates greater than PETM emission rates for the full range of current estimates of PETM onset intervals. Forcing PETM rates to exceed those for anthropogenic emissions would require a PETM onset interval or release time shorter than about 1,000 years.

PLANETARY BOUNDARIES: BIOGEOCHEMICAL FLOWS AND THRESHOLDS

PALEOCENE-EOCENE THERMAL MAXIMUM MEETS THE NORTH ATLANTIC IGNEOUS PROVINCE: COINCIDENCE OR GLOBAL ENVIRONMENTAL CONSPIRACY?

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The Palaeocene-Eocene Thermal Maximum (PETM, ~56 Ma), with its multiple lines of attendant evidence for massive greenhouse gas release and global-scale warming, is regarded as a highly plausible future analogue. However, because the onset of the PETM likely took place at a rate at least one, if not two, orders of magnitude slower than current century-scale anthropogenic warming, it is uncertain what we can learn e.g. re. biotic sensitivities, except perhaps to place a lower limit on potential future disruption. Instead, focus has often been on what the PETM might reveal regarding the sensitivity of surficial, reduced carbon stores (e.g. vegetation and soil carbon, permafrost, marine hydrates) to warming, and hence the strength of positive feedbacks between atmospheric CO_2 and climate change. Indeed, almost all explanations to date for the PETM have relied either solely, or dominantly, on one or more of these carbon sources. Yet one of the largest igneous provides (the North Atlantic Igneous Province, NAIP) recorded in the geological record was being emplaced exactly at this time and its role to date, almost entirely, overlooked.

Here present a revised view of the PETM as one predominantly the product of massive volcanism, making it rather unexpectedly more like the end Permian in character. Feedbacks with climate and involving reservoirs of reduced organic carbon likely only play a more minor role, reducing the event’s future relevance. We come to these conclusions on the basis of new paired records of boron and carbon isotope changes, assimilating these data in an Earth system model to reconstruct the unfolding carbon cycle dynamics across the event. Model results indicate >10,000 PgC with an average isotopically heavier than -17‰ is required to account for the observations, leading us to identify volcanism associated with the NAIP as the main driver of the PETM.

GLOBAL EVIDENCE FOR ENHANCED METHANE CYCLING DURING THE PALEOCENE-EOCENE THERMAL MAXIMUM

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Terrestrially-sourced methane (CH_4) may have been an important warming mechanism during past greenhouse climates (Beerling et al., 2011). However, there are no proxy methods to reconstruct ancient CH_4 cycling beyond the Pleistocene. Previous studies suggest that the carbon isotopic composition ($\delta^{13}C$) of bacterial geohopanoids can be used to infer relative changes in the terrestrial CH_4 cycle. For example, a decrease in the $d^{13}C$ value of hopanes (up to –70 ‰) during the onset of the Paleocene-Eocene Thermal Maximum (PETM; ~56 million years ago) within the Cobham (UK) lignite indicates enhanced consumption of isotopically light CH_4 by aerobic methanotrophs (Pancost et al., 2007).
However, it is unknown how observed hopane $\delta^{13}C$ values in the Cobham lignite compare to those found in modern wetlands and whether the Cobham lignite reflects a global signal. We therefore analyzed hopanoid $\delta^{13}C$ values in modern wetlands from around the world. We find that the lowest hopane $\delta^{13}C$ value in modern wetlands is –35‰, significantly more enriched compared to that observed in the Cobham lignite. To assess lipid biomarker evidence for enhanced methane cycling during the PETM we examined the $\delta^{13}C$ value of hopanes in other lignites, from Otaio River Gorge (New Zealand) and Recito Mache (Venezuela). Both exhibit a 10 to 30‰ decrease in hopane $\delta^{13}C$ values during the PETM, consistent with that observed in the Cobham lignite. These results indicate that: 1) the PETM was characterized by a globally enhanced terrestrial methane cycle and 2) the environmental conditions that occurred in PETM wetlands are exceptional and unlike anything encountered in modern-day wetlands.

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CONTROLS ON MARINE ORGANIC CARBON BURIAL AND ITS IMPACT ON THE GLOBAL CARBON CYCLE DURING THE PALEOCENE-EOCENE THERMAL MAXIMUM

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Feedbacks within the carbon cycle affect the lifetime of CO_2 in the ocean-atmosphere system and will determine the fate of anthropogenic carbon emissions on time scales of millennia or longer. The Paleocene-Eocene Thermal Maximum (PETM; ~56Ma), an interval of rapid carbon injection and subsequent global warming, provides an excellent opportunity for the study of these feedback processes. Here we assess the impact of enhanced marine organic carbon burial on atmospheric pCO_2 during the PETM by combining geochemical sediment records with carbon cycle model simulations. Total organic carbon records from a wide range of sites, including the North American and European shelf, the open Indian Ocean and the enclosed Arctic Ocean, are used to estimate the amount of organic carbon sequestered in marine sediments during the PETM. The role of water column anoxia in promoting organic matter burial is assessed using records of various redox proxies, including trace metals. Our model results provide further constraints on the amount of organic carbon burial needed to reduce atmospheric CO_2 during the PETM and the potential role of redox-driven changes in nutrient recycling and preservation of organic matter. Finally, we discuss the importance of organic carbon sequestration relative to weathering during the termination of the PETM, as the mechanisms that ended the event are still a matter of debate.

FOSSIL LEAVES RECORD A SHORT-LIVED DISRUPTION OF THE CARBON CYCLE AT THE PALEOGENE-NEOGENE BOUNDARY

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The Mi-1 transient glaciation event spans the Paleogene-Neogene boundary (~23.0 Ma) and represents a major source of uncertainty in Cenozoic climate history. During this event, the Antarctic ice-sheet grew to ~125% its modern size, and subsequently decayed to 50% its modern size. Thus far, the reason for this mass-wasting is poorly understood. To investigate the role of the carbon and hydrological cycles at the termination of the Mi-1, we examined a continuous record of exquisitely preserved subfossil leaves from southern New Zealand spanning the interval 23.03–22.93 Ma. This interval represents the initial deglaciation phase of Mi-1. Leaf gas-exchange reconstructions and leaf-derived $d^{13}C$ and dD suggest a major perturbation of both the carbon and hydrological cycles during this interval. Background levels of ~400–500 ppm atmospheric CO_2were punctuated by a ~20 kyr period during which CO_2 may have been 1.5–3× higher. At the same time, leaf wax-derived carbon and hydrogen isotopes suggest a major increase in regional precipitation. The 20 kyr period of carbon and hydrological cycle disturbance coincides with the onset of Antarctic deglaciation. Our data therefore suggest atmospheric CO_2 changes were an important factor in the Mi-1 deglaciation . A key observation is that, although our record indicates that atmospheric CO_2 fell back to baseline levels after ~20 kyr, the Antarctic ice-sheet deglaciation continued for another 100 kyr, suggesting an important role for internal feedback mechanisms. Our record provides evidence for the existence of relatively brief carbon cycle fluctuations, with far-reaching climatic effects. It also emphasizes the importance of terrestrial records of climate variability, because of the near instant response of the terrestrial biosphere to changes in the Earth's atmosphere.

DESTABILIZATION OF CARBON ON LAND, AND COASTAL OCEAN RESPONSE DURING THE PETM: EVIDENCE FROM MID-ATLANTIC SEDIMENTS

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During the PETM, global warming, CO_2 rise, and an altered hydrologic cycle shifted the patterns of organic matter production and preservation on land and in the sea. Globally, terrestrial PETM records demonstrate a 10% decrease in organic matter content, and clay content in ocean sediments suggest heightened weathering across continental landscapes. Conversely, organic matter accumulation increased 2-3 fold in marine records, and is accompanied by molecular and isotopic evidence for anoxia, carbon source change, and enhanced productivity. The opposite responses from terrestrial and marine environments suggest a potential link between their carbon cycles. Decreased landscape stability and enhanced weathering during the PETM suggest the delivery of organics and nutrients from terrestrial deposits and soils to coastal oceans, enhancing coastal productivity and organic matter preservation. Prior studies have lacked direct evidence for a terrestrial driver for the altered marine carbon cycle.

Coastal records integrate terrestrial and marine signals, providing needed datasets to understand the nearshore marine response to terrestrial destabilization. We investigated changes in primary productivity, redox, and organic matter provenance in coastal marine cores from the paleo-Atlantic shelf (MD) in order to evaluate organic carbon dynamics across the land-sea interface. Here, we present organic carbon isotope and lipid biomarker data for sediments across a pro-delta to inner shelf transect. Molecular records of the PETM detail a major shift in organic matter provenance, from contemporaneous marine to transported terrestrial and fossil carbon. Additionally, a ~6 permil enrichment in the carbon isotopes reverses the usual PETM excursion, and implies an altered carbon cycle. Transported organic matter input, increased productivity, and a change in primary producers will be evaluated as the cause of the enrichment using compound specific isotope analyses. This assessment of coastal organic matter source, production, and preservation changes during the PETM can elucidate Earth's mechanistic responses to rapid CO_2 increases.

GENERAL SESSION

SEDIMENT CREEP, MIXING, SYMBIONT BLEACHING AND DIAGENESIS: REINTERPRETATION OF THE PALEOCENE / EOCENE BOUNDARY STABLE ISOTOPE RECORDS AT ODP SITES 689 AND 690, MAUD RISE

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The Paleocene / Eocene Thermal Maximum (PETM) and its associated Carbon Isotope Excursion (CIE) were first discovered at Ocean Drilling Program Site 690 (Maud Rise, Southern Ocean) which continues to be one of the most important and widely discussed PETM sections worldwide. Innovative single-specimen foraminifer isotope analyses published by Thomas et al. (2002) and Zachos et al. (2007) at Site 690 and neighbouring Site 689 suggested that the CIE occurred initially in surface mixed layer-dwelling *Acarinina* and only later in thermocline-dwelling *Subbotina*, and that the CIE was about twice as large in the former than the latter. This was used as evidence for top-down propagation and attenuation of the CIE through the water column, suggesting that the marine CIE, as now recorded in many places, may be a muted response to a large and abrupt atmospheric perturbation. This idea gains added significance following more recent arguments for a catastrophic PETM event associated with a comet impact. However an alternative interpretation for the isotope data is presented here involving 1) a major change in the foraminifer assemblage at the CIE, 2) initial loss and subsequent recovery of photosymbionts in *Acarinina,* 3) down-slope sediment creep during the PETM, forming a 10-15 cm thick mixed bed at both Site 689 and 690 which has a distinctive sedimentological expression, 4) some additional displacement of shells by reworking and burrowing, and 5) major overprinting and partial homogenisation of the inter-shell isotope values during diagenetic recrystallization. According to this interpretation, the original CIE was ~ -4 per mil throughout the whole water column and the surface ocean warmed much more than previously thought. There is no reason to infer that the onset of the CIE at Maud Rise was instant.

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EXPEDITION 342 DESCENT INTO THE ICEHOUSE

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We will present a stable isotope record Benthic Foraminifera from 39 to 37 million years ago. In this post-MECO world, planetary temperatures are cooling toward the E-O boundary (e.g. Bohaty et al. 2009). The exceptionally well preserved foraminifera (glassy tests) from the clay rich sediments recovered by Expedition 342 have given us the unique opportunity to produce isotope records of Quaternary quality in the Late Eocene. Stable isotopes of oxygen and carbon were run on *Nuttallides truempyi and Cibicidoides eocaenus.* Sample resolution is at a millennial time scale and several cooling 'events' that temporarily move the stable isotope ratios by 0.5 per mil in a positive direction can be identified. The planktonic foraminfers *Pseudohastigerina micra and Acrinina mcgowrani (Wade and Pearson, 2008) were also run for their stable isotopes of oxygen and carbon at selected intervals. Additionally, trace metals were run on these samples using laser-ablation inductively coupled mass-spectrometry (LA-ICPMS) focusing on Mg/Ca, largely to look at sea surface temperature variability during excursions in the benthic foraminiferal stable isotope record.*

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A MULTIPROXY SEA SURFACE TEMPERATURE RECONSTRUCTION OF THE MIDDLE EOCENE CLIMATIC OPTIMUM FROM THE NEWFOUNDLAND DRIFTS IN THE NORTH ATLANTIC

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The Middle Eocene Climatic Optimum (MECO) represents a ~ 500 kyr episode of global ocean and atmosphere warming that occurred ~ 40 Myr ago, superimposed on the long-term Eocene cooling trend. The MECO is generally associated with a rise in atmospheric CO_2 concentrations and carbonate dissolution in the deep oceans, but its cause remains enigmatic. While an increasing number of ocean temperature and chemistry records have been generated for the event over the past years, many of these reconstructions are compromised by the limited temporal resolution and/or relatively poor preservation state of deep-sea sediments. In contrast, the recently acquired sedimentary records from the Newfoundland Drifts in the North Atlantic (IODP Expedition 342) accumulated at high sedimentation rates and contain exceptionally well-preserved foraminifera, which allows for new climate reconstructions at an unprecedented detail. Here, we present the first results of a multiproxy sea surface temperature record of the MECO from the Newfoundland Drifts at IODP Site U1408, based on stable oxygen and carbon isotope ratios, Mg/Ca ratios and clumped isotope ratios of planktonic foraminifera, as well as TEX_{86} paleothermometry. By integrating high-resolution records of these four independent temperature proxies, we aim to fully unravel the amplitude and character of sea surface warming and cooling during the MECO in the North Atlantic.

RECONCILING DIVERGENT CARBON ISOTOPE RESPONSES IN OCEAN AND TERRESTRIAL PROXY RECORDS TO CONSTRAIN CAUSAL MECHANISMS FOR THE EARLY EOCENE CLIMATIC OPTIMUM

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The early Eocene climatic optimum (EECO, ~53-50 Ma) is a period of extended warmth and marks the apex of a long-term early Paleogene warming trend. Distinct and divergent carbon cycle responses are observed in marine and terrestrial proxy records, suggesting a complex period of carbon cycle change with different timescales and magnitudes of warming for the land and oceans during the EECO. Marine proxy records indicate a persistent negative carbon isotope excursion (~0.5 ‰ $d^{13}C$ planktic; ~1.0‰ $d^{13}C$ benthic), which may be consistent persistent addition of an isotopically-light carbon source such as biogenic methane. In contrast, terrestrial records of soil organic carbon and pedogenic carbonate from four mid-latitude sites from both the Northern and Southern Hemisphere indicate a more abrupt positive $d^{13}C$ excursion during the EECO of ~4‰ and peak warming of ~6°C lasting only ~1 Myr. Therefore, a causal mechanism explaining the onset, maintenance, and termination of the EECO should account for the differences in carbon isotope excursion sign as well as the temporal decoupling between terrestrial and marine realms.

To investigate the viability of different causal mechanisms for the EECO, we explore a series of carbon cycle change scenarios to explain these observations using the Long-term Ocean-atmosphere-Sediment CArbon cycle Reservoir box model (LOSCAR). LOSCAR provides an efficient framework to test the impacts of redistributing carbon between the ocean, marine sediments, and the atmosphere or adding an exogenic pulse of carbon. We test four potential causes of the EECO: (a) increased volcanism, (b) increased methane flux, (c) increased carbonate weathering flux, and (d) increased ocean ventilation. None of these single-factor mechanisms are able to explain the proxy observations. As a result, we suggest that the EECO resulted from the complex interaction of multiple carbon cycle changes.

EVIDENCE FROM EASTERN MEXICO FOR A PALEOCENE/EOCENE DRAWDOWN OF THE GULF OF MEXICO

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Outcrops of the Paleocene/Eocene Chicontepec Formation in eastern Mexico provide a unique opportunity to study exposed time equivalent sections of the deepwater Gulf of Mexico's Wilcox Formation. A 2012 study established a stratigraphic framework in the Tampico-Misantla Basin (TMB) and identified sequence boundaries that could not be correlated globally. Fieldwork in 2008 had also established a network of paleo-canyons in the basin associated with a particular sequence boundary near the Paleocene/Eocene boundary. The Paleocene turbidite basin was fed from the northwest and then incised by a collection of NE-facing erosional canyons that coalesced laterally into the main SE-trending Chicontepec paleo-canyon; this canyon network was then filled in the Early Eocene. Using the 2012 study chronostratigraphic scheme, recent micropaleontological studies were performed on a unique outcrop containing a bitumen bed within one of these paleo-canyons, the Acatepec Canyon, and on its fill sequence. The paleo-canyons in the TMB were eroded by fluvial systems feeding directly into the central Gulf basin, probably a land-locked sea. The results suggest that the basin's water level fell rapidly by at least 200 m, starting after 55.8 Ma and leading to subaerial exposure of the bathyal beds, prior to canyon refill. Evidence of rooting (limonite tubes) occurs in the bathyal turbidites below the bitumen bed and possible paleo-karsting appears in bathyal sediments within the canyon-fill, indicating subaerial exposure may have occurred more than once. The interpreted large and rapid fall and rise of water level around the P/E boundary supports the "Gulf of Mexico drawdown hypothesis", i.e., that the GOM may have been isolated from the world's oceans due to the closure of the Florida Straits as the Cuban arc collided with the Bahamas and northeast Yucatán. The Paleocene-Eocene Thermal Maximum (PETM) appears to be missing in the hiatus found in two of the detailed sections.

EARLY CENOZOIC PCO_2: RECONCILING PROXIES AND MODELS

A HOT DEBATE: EARLY PALEOGENE TERRESTRIAL TEMPERATURES

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The early Paleogene is characterized by a long-term maximum in pCO_2 levels and can provide valuable information about the operation of the Earth system in an equilibrium high pCO_2 world. Existing estimates of terrestrial temperatures for this period indicate higher temperatures than modern, but are significantly lower than sea surface temperature (SST) estimates. This difference is difficult to reconcile given the current understanding of the climate system. In addition, the majority of climate model simulations fail to reproduce the high-latitude warming suggested by SST proxies. Within this context there is a need to obtain new and independent early Paleogene terrestrial temperature estimates. Such estimates are also critical because terrestrial temperatures govern diverse components and potential feedback mechanisms of the Earth system and have a large impact on biogeochemical processes. We therefore developed peat-specific organic geochemical temperature proxies based on the distribution of both bacterial and archaeal membrane lipids in a global database of peat samples (n=470).

The results highlight that the degree of methylation of bacterial brGDGTs is linearly correlated with mean annual air temperature, as shown previously for mineral soils. We then applied this organic geochemical proxy to early Paleogene lignites (fossilized peat) to provide novel and independent terrestrial temperature estimates. We demonstrate that terrestrial temperatures during the early Paleogene were higher than previously thought with values in the mid/high latitudes above 22 °C. The identification of a range of unusual archaeal biomarkers at all locations, heretofore observed only in thermophiles and hyperthermophilic settings, further support these high temperature estimates. Our results demonstrate that terrestrial temperatures were not only much higher than present at mid/high latitudes but were likely tropical, in-line with SST-estimates. These novel terrestrial temperature estimates have important climatic and biogeochemical implications and can now be used to constrain the next generation of climate models.

A REDUCED CONTINENTAL TEMPERATURE GRADIENT IN NORTH AMERICA DURING THE EARLY EOCENE

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The Early Eocene (56 Ma) is the youngest period of Earth's history when atmospheric CO_2 concentrations rose to levels close to those predicted for future emission scenarios (600-1500 ppm). Marine proxies record a significant reduction in the equator-to-pole meridional sea surface temperature gradient during the Early Eocene, while on land, a limited and relatively uncertain data-set prevents a thorough examination of the gradient. Here, we present clumped and stable oxygen isotope measurements of nine siderite samples collected along a north-south transect on the Americas. These siderites formed in kaolinitic soils that developed broadly under the extremely wet and warm conditions of the Early Eocene. They provide a record of both soil temperature and the $\delta^{18}O$ of meteoric water ($\delta^{18}O_{mw}$), which are independent proxies of climate. Both parameters were estimated using an in-house calibration constructed with synthetic siderite precipitated in the presence or absence of iron reducing bacteria at ambient temperatures. Seven preliminary clumped-based soil temperatures are indistinguishable from Texas (30 °N) to southern Alaska (56 °N) recording temperatures of approx. 25 °C. Even so, preliminary estimates of $\delta^{18}O_{mw}$ suggest that the Rayleigh distillation along this transect was significantly reduced compared to the present. By expanding our data-set even further with two new sites in Colombia and northern Alaska, we provide strong evidence for a reduced continental temperature gradient from 0 to 70 °N.

EOCENE TROPICAL TEMPERATURE EVOLUTION

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The long-term trend of polar and deep ocean cooling from the Early Eocene Climatic Optimum (EECO) toward the Eocene-Oligocene Transition is well established[1,2]. Yet a global picture is lacking because tropical paleoclimate proxy records have been too sparse to constrain the timing, magnitude, or global extent of temperature trends or to distinguish between the two hypothesized cooling causes—changing greenhouse gas concentrations[3,4] or altered ocean circulation[5,6]. Here we show, based on lipid biomarker paleothermometry applied at Ocean Drilling Program Site 959, that sea surface temperatures in the equatorial Atlantic Ocean exhibit a ~8°C long-term Eocene cooling trend synchronous with polar and deep sea temperature evolution. Embedded in this cooling trend is the Middle Eocene Climatic Optimum (MECO) (~40 Ma), a ~500,000-year warming previously evidenced only in deep sea[7,8] and Southern Ocean[3] records. Our new equatorial record shows substantial tropical warming of 4°C during the MECO, proving that the MECO was a global climate event. Based on a compilation of our new temperature record with the few existing data and a set of fully-coupled climate model simulations, we demonstrate parallel trends in tropical and deep ocean records in both long-term climate trends and superimposed events. This strongly implicates that changes in greenhouse gas forcing, rather than changes in ocean circulation, were the main cause of Eocene climate variability.

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MULTIPLE PROXY ESTIMATES OF ATMOSPHERIC CO2 FROM AN EARLY PALEOCENE RAINFOREST

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Proxy estimates of atmospheric CO_2 are necessary to reconstruct Earth's climate history. Confidence in paleo-CO_2 estimates can be increased by comparing results from multiple proxies at a single site, but so far this strategy has been implemented only for marine-based techniques. Here I present CO_2 estimates derived using plant fossils from the well-studied and unusually diverse early Paleocene (64.5 Ma) Castle Rock site via four proxy methods: the traditional stomatal index, two newer models based on gas-exchange in C_3 plants, and a model based on liverwort photosynthesis. Median estimates range from 447 to 812 ppm, demonstrating fair correspondence. I also present sensitivity analyses for the multi-parameter proxy methods, providing a helpful guide to model users by highlighting parameters that contribute most to uncertainty in estimated CO_2.

A synthesis of the Castle Rock CO_2 estimates yields a median of 636 ppm (349 – 1103 ppm at 95% confidence), considerably higher than previous early Paleocene CO_2 estimates (~300 ppm). When this result is placed into the broader context of other Cenozoic CO_2 estimates from plant-gas-exchange approaches and coeval estimates of global mean surface temperature, the pattern emerges of an Earth system sensitivity around 3 °C per CO_2 doubling during the Paleocene and Eocene, a time with little land ice, then steepening to ~7 °C after the Eocene once land ice was present on Antarctica.

FOSSIL ATMOSPHERES: IMPROVING ESTIMATES OF ANCIENT ATMOSPHERIC CO2 LEVELS FROM GINKGO LEAVES

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During the Mesozoic and early Cenozoic Earth's climate was much warmer than today, often punctuated by geologically rapid hyperthermal events. The background warmth and hyperthermals are often attributed to increased pCO_2, yet paleo-pCO_2 proxy estimates for this interval often disagree widely, and few paired records of temperature and pCO_2 have been produced. Consequently, we have an inadequate understanding of what generated past warm climates, and of the magnitude of pCO_2 change associated with hyperthermals. We aim to develop a more reliable stomatal proxy for paleo-pCO_2 by quantifying the effect of pCO_2 and other environmental variables on stomatal properties of living and historic *Ginkgo biloba* trees. The stomatal proxy for paleo-pCo_2 using *Ginkgo* has been widely applied (Royer, 2003), but has been hindered because anatomical changes in *Ginkgo biloba* stomata under pCO_2 above 400 ppm have been poorly constrained (Barclay and Wing, 2016). To rectify this problem, we are conducting an elevated CO2 experiment that will quantify the response of *Ginkgo* to elevated pCO_2, growing 15 *Ginkgo biloba* trees in open-topped chambers under atmospheres with ambient (400), 600, 800, and 1,000 ppm of CO_2 (Figure 1). Each tree is regularly monitored for changes in stomatal frequency, and rates of photosynthesis and transpiration to constrain parameters used in gas exchange models of paleo-pCO_2 (Figure 2). We are also conducting a survey of geographical variability in the stomatal features of *Ginkgo* trees from sites with known temperature, precipitation, and light environment from across the USA, to quantify the effect of factors other than pCO_2 on stomatal features. Our results can then be used to infer paleo-pCO_2 from stomatal features of Late Cretaceous-Paleogene fossils of the nearly identical species, *Ginkgo wyomingensis,* allowing for paleo-pCO_2 estimates from these terrestrial fossils to be compared with temperature and paleo-pCO_2 records derived from the marine realm.

THE RELATIONSHIP BETWEEN TERRESTRIAL CLIMATE AND CO_2 THROUGH THE EARLY PALEOGENE AND ITS IMPLICATIONS FOR EARTH-SYSTEM SENSITIVITY

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The early Paleogene represents the warmest time in the Cenozoic when global temperatures were significantly higher than today. Numerous proxy-based studies suggest that this interval of Earth history was characterized by a low latitudinal temperature gradient and relatively high CO_2. However, climate models generally have difficulty reproducing low temperature gradients without using CO_2 values significantly higher than proxy reconstructions. This discrepancy could be because latitudinal temperature gradients are generated by time-averaging reconstructions of climate, possibly masking variability in the gradient through time. Alternatively, climate models could be missing key feedback mechanisms. Here we present a long-term record of early Paleogene terrestrial climate from North America based on temperature estimates from fossil leaves and compare it to global records of CO_2 to assess latitudinal temperature gradients and regional Earth-system sensitivity.

Our results suggest that terrestrial climate underwent long-term cooling from the late Cretaceous to the middle Paleocene, followed by a long-term, but variable, warming trend during the late Paleocene to early Eocene. An assessment of the mid-continental latitudinal temperature gradient indicates that it varied through the early Paleogene. During the Paleocene it was similar to modern, which is steeper than previous reconstructions; while during the early Eocene the gradient was flatter, similar to other proxy reconstructions. This suggests that some aspects of the Earth's climate system, such as the degree of polar amplification and equatorial buffering of climate were different during the Paleocene and the Eocene. A comparison of terrestrial temperatures and CO_2 suggests regional temperatures varied more than CO_2. This suggests that regional Earth-system sensitivity varied through the early Paleogene. Taken together, these results indicate that regional climate and Earth-system feedbacks were dynamic through the early Paleogene and this variability must be taken into account in modeling of the early Paleogene and when modeling future climate.

POSTERS: EARTH SURFACE

1-1 **NEW CORE HOLES OF THE CRETACEOUS-PALEOGENE BOUNDARY NEAR THE EL KEF STRATOTYPE, NORTHWEST TUNISIA**

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We drilled six cores near the Global Boundary Stratotype Section of the Cretaceous-Paleogene (K/Pg) boundary at El Kef in northwestern Tunisia. The first hole is 65 m in length and extends well into the Maastrichtian. The other five holes are between 25 and 35 meters and extend into the very uppermost Maastrichtian. The main goals of the project are to develop a holistic understanding of the recovery from the K/Pg boundary based on the combination of biotas (nannoplankton, planktonic foraminifera and dinoflagellates) and lipid biomarkers (algae and bacteria) representing different trophic levels, in addition to sedimentary properties and bulk stable isotope geochemistry.

Magnetic susceptibility was measured on the unsplit cores on a Geotek track at MARUM, University of Bremen. The cores were then split, described, line-scanned, and analyzed for color reflectance data at the IODP Bremen Core Repository and MARUM. Core surfaces were then analyzed with an X-ray Fluorescence (XRF) Core Scanner. Preliminary nannofossil biostratigraphy has been conducted on a sample every 30 cm in each core. Finally, TOC contents (bulk sediment) and stable carbon isotopes have been analyzed on the bulk organic carbon fraction in four of the cores, and carbon and oxygen isotopes of bulk carbonate have been analyzed in two of the cores.

Core sites were offset by between 25 and 50 meters. Preliminary stratigraphy suggests that two of the cores did not cross the K/Pg boundary even though they were drilled to the same depth as the other cores. This suggests that there are minor faults between some of the sites on the same slope as the El Kef GSSP for the K/Pg boundary. In addition, the upper 3-5 meters of the cores is heavily weathered. The combination of biostratigraphy, color and XRF scanning, and stable isotope data suggests that the combination of these cores (i.e., the splice) represents the first continuous and expanded sequence of the upper Maastrichtian and the K/Pg boundary through the lower part of nannofossil Zone NP2 in the GSSP of El Kef.

The cores contain morphologically well-preserved microfossils that will enable detailed studies of the recovery of planktic and benthic ecosystems. In addition, excellent biomarker preservation will allow for the reconstruction of microbial and algal communities in the immediate aftermath of the mass extinction.

1-2 **PALEOGENE STRATIGRAPHY AND ELIMINATION OF TIBET-TETHYAN SEA**

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Paleogene marine sediments are well exposed in the Tethyan Himalaya. The Cenozoic pre-collision related Tethys Himalayan Sequence varies between locations. The initial timing of the Indian-Eurasian collision and the elimination of the Tethyan Ocean are directly constrained by the cessation of the marine sedimentation on Indian margin. The Tethyan Ocean that once covered parts of southern Tibet was eliminated when the Indian and Eurasian continents collided along the Yarlung Tsangpo suture zone. The timing of the last marine sedimentary rocks thus places a constraint on this first-order tectonic event. Although several sedimentary successions have been reported from southern Tibet their documentation is commonly incomplete or important questions remain regarding stratigraphic continuity and/or the reliability of fossil identifications.

The existing data are critically assessed in order to correlate and compare between sections in three zones: one to the north of the suture on the Asian margin and two to the south on the northern margin of India. We examine the planktonic foraminiferal and nannofossil biostratatigraphy of the youngest sections, which occur in the Tibetan Himalayan succession and lie around 100 km south of the suture. This also includes a previously unreported section 70 km east of Gamba. We also consider the ages of radiolarians from cherts in mélange zones immediately south of the suture zone in Ladakh, NW India and Tibet. We discuss the implications of our results for understanding the timing of continent-continent collision. In doing this we take into account the effects of crustal loading, eustatic sea level variation, orogenesis associated with the on-going convergence between India and Asia together with the likely migration rate of any fore-deep in front of a colliding continental mass. This research demonstrates that a marine seaway remained in existence south of the Yarlung Tsangpo suture zone until at late Priabonian time. However, the Paleogene basins in southern Tibet are not oceanic, but foreland basins, with the characteristics of epicontinental basins. Early collision causes basin formation through tectonic loading. It is implied that during the Paleocene and Eocene, marine shelf deposition was widespread in the Himalayan region, indicating the existance of a Tethys seaway along strike the Indus-Yalung Tsangbo Suture Zone, extending from Kohat, Zanskar and Simla to southern Tibetan and as far as the eastern syntaxis area. According to the foraminiferal assemblages within these final marine sediments, we suggest the faunas were similar and probably shared the same habitat in the foreland basins. The shallow marine deposition might have been connected with the Bengal basin and extended as far as to the Indus-Burman suture zone. Shallow marine conditions did not change until the end of Lutetian in most parts of Himalaya region. As subduction continued, the Indian and Eurasian plates finally collided completely and the foreland basins disappeared resulting from the syn-collisional uplift. According to our results from investigation of the last marine deposit in the Gamba-Tingri region, the Tethys seaway still existed in the Priabonian indicating that continental collision did not happen until at least that time.

1-3 **INVESTIGATING PALEOGENE STRATA FROM OMAN AND THE UAE; NEW INSIGHTS FROM INTEGRATED CHEMOSTRATIGRAPHY, SEDIMENTOLOGY AND BIOSTRATIGRAPHY**

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There is a scarcity of detailed palaeoenvironmental and biostratigraphic data from low-latitude areas, such as the Middle East, spanning the early Palaeogene at a suitable resolution to discern orbital-scale variability. While data is available from key Tethyan sections in Egypt and Israel (Speijer & Schmitz, 1998; Speijer & Wagner, 2002), comparable data further south from the United Arab Emirates (UAE) and Oman is of limited temporal and spatial resolution. Through the use of fully-cored borehole sediments from onshore Abu Dhabi, UAE and extensive, well-exposed outcrop, this PhD project will focus on gaining new insights into a low-latitude, shallow water, carbonate-dominated setting through the application of multi-proxy geochemical, sedimentological, and palaeontological techniques. High-resolution carbon and oxygen bulk stable isotope records will be generated as a chemostratigraphic tool, which will be paired with new larger benthic foraminifera (LBF) and smaller foraminifera biostratigraphic data. Detailed hand-held XRF data, supported with ICP-OES data, will be used to establish fluctuations in the trace-element record; paired with comprehensive study of lithological changes, this data will be used to track regional sea level variation. The changing LBF biodiversity from the late Cretaceous through the early Palaeogene will also be investigated, as little is known about the recovery periods following extinction events such as the K-Pg boundary and the Palaeocene Eocene Thermal Maximum (PETM). The palaeoceanographic drivers behind this region being a major LBF diversity hotspot in the lower to middle Eocene will also be investigated (Renema *et al.*, 2008).

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1-4 THE TRANS-SAHARAN SEAWAY RECORDED IN THE ROCKS OF MALI: A KEY PALEOGENE LOCALITY FOR THE STUDY OF GLOBAL EUSTASY AND PALEOTEMPERATURE IN THE ANCIENT TROPICS

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The epeiric Trans-Saharan Seaway extended episodically from the Tethys Ocean into the continental interior of West Africa from the Cretaceous to the middle Eocene. Through periods of transgression and regression, this sea ultimately left extensive near shore marine sedimentary structures and fossiliferous deposits whose stratigraphy and paleobiology we have described. It remains controversial whether the temperature of the tropics in the Paleogene was elevated well above what occurs today, or whether equatorial heat dissipated globally. The fauna of Mali included many species often considered to be shallow marine such as dyrosaurid crocodyliforms, pycnodontiform and amiid fishes, and sea snakes. Many of these species were among the largest members of their clades.

Recent research has shown how extinct species might be used as biological climate proxies. For example, the extinct Paleocene species *Titanoboa*, an enormous boid snake, was estimated to have been 13 m long, a size that may have required that temperatures in the tropics were distinctly more elevated than those of the Recent. Temperatures may even have been high enough to have been lethal to certain other species. Malian rocks also contain remains of gigantic early Paleogene snakes - palaeophiids - whose estimated total size of more than 9 m means that they were also among the longest snakes known. By the same climate proxy methods, palaeophiids would also have required mean temperatures meeting or exceeding the maximum recorded in the tropics today. Thus, the ancient population of palaeophiids in Mali constitutes a second biological proxy data point for high Paleogene tropical temperatures. Complicating the use of any of these ancient snakes as temperature proxies is the fact that they may have been aquatic or even marine, rather than terrestrial.

1-5 **SYNCHRONIZING EARLY EOCENE DEEP-SEA AND CONTINENTAL RECORDS – NEW CYCLOSTRATIGRAPHIC AGE MODELS FROM THE BIGHORN BASIN CORING PROJECT**

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To understand the effects of major climate perturbations of the geological past on both marine and terrestrial ecosystems a consistent stratigraphic framework is an important prerequisite. Transient global warming events in the early Eocene, 54-56 Ma ago, show the impact of large scale input of carbon into the ocean-atmosphere system. Here we provide the first high-resolution time scale synchronization of continental and marine deposits spanning the Paleocene-Eocene Thermal Maximum (PETM) and the interval just prior to the Eocene Thermal Maximum 2 (ETM-2). XRF core scanning data from drill cores of the Bighorn Basin Drilling Project (BBCP, Wyoming, USA) and from deep-sea sediments retrieved by the Ocean Drilling Program (ODP) both cover these intervals in unprecedented resolution and quality. The cyclicity in both settings is dominated by eccentricity modulated precession which is utilized to compose a common cyclostratigraphy. The integration of age models results in a revised astrochronology for the PETM in deep-sea records that is generally consistent with ^{3}He-derived age models. According to these results the carbon isotope excursion (CIE) of the PETM lasted ~200 kyr with ~120 kyr for the pelagic clay layer. The common terrestrial and marine age model also shows concurrent changes in marine and terrestrial biotas about 200 kyr before ETM-2. In the Bighorn Basin, the change is referred to as Biohorizon B and it represents a period of significant mammalian turnover and immigration, separating the upper *Haplomylus-Ectocion* Range Zone from the *Bunophorus* Interval Zone and approximating the Wa-4–Wa-5 land mammal zone boundary. In sediments from ODP Site 1262 (Walvis Ridge), major changes in the biota at this time are documented by the radiation of a “2nd generation” of apical spine-bearing sphenoliths species (e.g., *S. radians* and *S. editus*), the emergence of *T. orthostylus*, and the marked decline of *D. multiradiatus*.

1-6 **CHRONOSTRATIGRAPHY OF THE GREEN RIVER FORMATION**

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The lacustrine deposit of Green River Formation (GRF) offers super archive for the study of paleoclimate and evolution of life in early Eocene Climatic Optimum (~50 Ma), and formation of oil & gas and minerals. Understanding the mechanism behind this archive needs high resolution geochronology and comparison of deposits in different areas. This study summarizes geochronology especially the astrochronology of Green River Formation in Utah, Colorado and Wyoming, aiming to construct a comprehensive stratigraphic map in both time and space, and understand the interaction between orbital forcing, pleoclimate and lacustrine deposits.

1-7 **PETM STRATIGRAPHY OF THE BASIN SUBSTATION CORE**

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The Bighorn Basin Coring Project (BBCP) drilled cores through Paleocene-Eocene interval near the easternmost extent of Willwood Fm. outcrop NW of Basin, Wyoming (Clyde et al., 2013). The site was chosen because exposures with abundant carbonaceous beds and few red paleosols, suggested good organic preservation. Palynomorphs, biomarkers and dispersed organic matter were recovered from the lower and upper parts of both cores, but so little organic matter was preserved in the middle section of the cores that the negative carbon isotopic shift characteristic of the Paleocene-Eocene Thermal Maximum (PETM) was not detected. Here we use palynological markers and surface features projected into the core to define the position of the PETM.

Uppermost Fort Union and lowermost Willwood Fm. strata immediately to the east of the coring site (BSN11) dip ~30° down to the SW with a strike of 156°, but dip shallows rapidly into the basin and is ~16° at the coring sites. Marker beds visible in outcrop are also seen in core. The Wa0 (=PETM) index mammal *Sifrhippus sandrae* occurs about 300 m SE of the coring sites at or below the base of the bed marked 'Red 1' (K.D. Rose, pers. comm.). The base of Red 1 is thus the highest possible level for the beginning of the PETM. Red 1 occurs in BSN11B from 82.10–80.04 meters below surface (mbs). Palynological study of BSN11B reveals typical Paleocene floras with abundant *Caryapollenites* and taxodiaceous pollen from the bottom of the core to sample 3102022 at 82.40 mbs. Preservation is poor in this sample (only 50 grains counted), however, the paleosols near 82 mbs are distinctive. Below the pollen sample pyrite crystal aggregates are visible in the core face at 82.76 and 82.82 mbs, suggesting the soils were originally dysoxic. Weak purple mottles and small $CaCO_3$ nodules (2-3 mm), are present above the pollen sample, from 82.31-82.40 mbs, suggesting intermittently drained, but still wet, oxic paleosols. This rapid transition, with the highest Paleocene palynoflora preserved above a swampy paleosol and below a better-drained one, may well represent rapid warming and increased seasonality of soil moisture at the onset of the PETM. Furthermore, a similar organic-rich paleosol with small $CaCO_3$ nodules ("strange gray") is present in the southeastern Bighorn Basin, where it coincides with the onset of the CIE (Wing et al. 2009, Baczynski et al. 2013). The most likely position for the onset of the CIE in BSN11B is thus ~82.4 mbs, though poor pollen preservation in the 10 m between the base of Red 1 and the top of 'Carbshale 3' means that the onset could be lower.

The lowest appearance of an Eocene index palynomorph in BSN11B is a single specimen of *Intratriporopollenites instructus* in sample 3101686 at 61.74 m, though the taxon becomes more abundant where preservation improves above 40.29 m. The lowest occurrence of *I. instructus* in the southeastern Bighorn Basin is in the recovery phase of the CIE, which occurs low in a sequence of thick, laterally extensive purple paleosols ('Big Red Sequence' of Wing et al. 2009). In BSN11B there is a thick purple paleosol ('Red 2' - 58.94–55.51 mbs) three meters above the lowest *I. instructus*. This purple paleosol (separated into two distinct paleosols by a non-pedogenic interval in core and in outcrop to the south) could be laterally equivalent, in part, to the middle and upper part of the Big Red Sequence in the southeastern Basin. Biostratigraphy and lithostratigraphy suggest that the body of the CIE in BSN11B most likely extends from ~82.40 to 61.74 mbs (20.36 m). Although the Basin Substation PETM section is similar in thickness to those in the southeastern Bighorn Basin, there are many fewer paleosols. Weak development of soils along the eastern flank of the basin may reflect poorly drained conditions caused by uplift of Torchlight Dome, a basin margin anticline that developed to the east along the Rio Thrust during the late Paleocene and early Eocene.

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1-8 EARLY PALEOGENE CONTINENTAL HYDROCLIMATE AND SURFACE UPLIFT OF THE UINTA MOUNTAINS IN SOUTHWESTERN WYOMING, U.S.A.

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The Laramide deformation in the central Rocky Mountains lasted until the early Paleogene, a period when global climate experienced punctuated warming in a greenhouse world. Although oxygen isotope paleoaltimetry can be used to document surface uplift of the Laramide ranges, the interpretation may be influenced by the extreme climate changes. We studied $d^{18}O$ values of authigenic carbonate cements and paleosol carbonates, bulk organic matter $d^{13}C$ values ($d^{13}C_{org}$), paleosol morphology, and CIA-K of the Paleocene and early Eocene sedimentary rocks in the southern Greater Green River Basin, Wyoming, in order to reconstruct continental hydroclimate and paleotopography of the basin catchment. The $d^{13}C_{org}$ values show a negative excursion of ~4 ‰ at the Paleocene-Eocene boundary, and another excursion of lower magnitude during the early Eocene, representing the PETM and ETM-2. Our reconstructed mean annual precipitation (MAP) based on CIA-K ranges from 400 to 1600 mm with low values of 400-800 mm during the hyperthermals, indicating that the early Paleogene climate was generally humid, and transient drying occurred during the hyperthermals. The carbonate cements $d^{18}O$ values were stable during the early Paleocene, but decreased gradually from -10 ‰ (VPDB) during the late Paleocene to -18 ‰ during the earliest Eocene. This decrease is neither related to the reconstructed MAP, nor influenced by isotope fractionation caused by temperature change, suggesting that climate change was not the cause of this trend. The decrease suggests highland precipitation arrived the basin during the late Paleocene-earliest Eocene. Northward paleoflow directions and abundant feldspars in the lower Eocene rocks suggest that surface uplift of the Uinta Mountains supplied the highland precipitation into the study site. Our reconstructed paleoelevation of the Uinta Mountains was at least 3.5 km, and the paleorelief between the basin and the Uinta Mountains was ~4 km during the earliest Eocene.

1-9 **RECONSTRUCTING FLUVIAL CHANNEL MOBILITY THROUGH THE PALEOCENE-EOCENE THERMAL MAXIMUM (WILLWOOD FORMATION, BIGHORN BASIN, WYOMING)**

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Reconstructing river dynamics from ancient fluvial deposits is important for understanding how terrestrial landscapes respond to climate change. Several field studies have suggested that river systems in North American interior basins changed in response to the Paleocene-Eocene Thermal Maximum (PETM). For example, the Eocene Willwood Formation (Bighorn Basin, WY, USA) exhibits large-scale changes in channel-body architecture during the PETM; however, the degree to which these changes were driven by changes in discharge, sediment supply, or land cover through PETM remains unclear. In order to constrain what factors controlled Willwood Formation river dynamics before, during and after the PETM, we used field observations to reconstruct the relative paleomobility of Willwood channels. In particular, we focused on measurements useful for differentiating avulsion behavior from intra-channel-belt mobility (such as river meandering and migration) in order to understand how sediment supply, water supply, and bank stability influenced Willwood channel dynamics. In the northern Bighorn Basin (Sand Coulee area) we mapped avulsion-generated channel-belt deposits across the PETM and evaluated the scale, stacking, lateral continuity and preservation of bar deposits within each channel belt. Results indicate that individual channel-belt deposits have similar scales and show low lateral and vertical preservation of bar-stories throughout the PETM onset, body, and recovery. Where observable, bar deposits show relatively long migration distances, suggesting that Willwood channels had a high degree of lateral mobility before, during, and after the PETM. Qualitatively, avulsion reoccupation appears to be more common during the peak of the PETM; however, statistically there is likely no difference in the occurrence of avulsion reoccupation throughout the event. These results suggest that Willwood rivers were relatively insensitive to discharge, sediment supply, and land-cover changes during the PETM.

1-10 **PETM RESPONSE OF A SWAMPY FLUVIAL TO LACUSTRINE SYSTEM IN A RAPIDLY SUBSIDING BASIN, HANNA BASIN, WYOMING, USA.**

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Outcrops of the Hanna Formation exposed in the Hanna Basin in southeastern Wyoming, USA, show a series of cyclic successions of sandy, fluvial channels punctuating intervals dominated by lignites and coals that span the Paleocene – Eocene boundary (PETM). A multi-dimensional pattern allows analysis of strata from different directions and gives insight in paleogeography through time. Although transitions between fluvial and lacustrine sediments are mostly gradual, the system is more lacustrine in nature on the east side, while the west side of the basin was dominated by low-gradient, avulsive rivers and swamps. Over the entire Hanna succession, the water table deepened, and the swampy fluvial system graded to a more lacustrine system. This corroborates reportedly high subsidence rates for the Hanna and surrounding basins during the Laramide orogeny, where overall sediment influx can barely keep up with accommodation. However, from both sides of the basin, a distinct pulse of coarse-grained, amalgamated fluvial channels disrupts this trend at the PETM, identified here by leaf macrofossils, palynology, and preliminary $\delta^{13}C$ bulk carbon isotopes. This increased sediment flux during the PETM is also observed in other Laramide basins and appears to be a regionally universal response to a climatic event. However, the paleoenvironment appears to be much wetter here than described in other basins and the change in sedimentation less pronounced. In contrast to the sedimentary response to climate, tectonic influence appears mostly expressed by overall basin subsidence and local angular unconformities at the margins at the base of the section. This study integrates information from plant fossils and sediments to come to an integrated picture of the changes in paleoenvironment during the PETM climatic event in a relatively wet and tectonically active basin.

1-11 **TECTONIC AND CLIMATIC CONTROLS ON FLUVIAL DEPOSITION DURING THE EARLY PALEOGENE IN THE PICEANCE CREEK BASIN, NORTHWEST COLORADO, U.S.A.**

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There is an increasing amount of evidence for significant geomorphic responses to hyperthermal events in the early Paleogene. This includes indirect evidence for increased runoff from continents in marine strata and direct evidence from changes in soil development and fluvial deposition in terrestrial basins. While geomorphic responses may be expected from large perturbations associated with events such as the Paleocene-Eocene Thermal Maximum (PETM), it is important to assess two additional factors; (1) potential tectonic forcings and (2) autogenic variability that may occur on overlapping timescales with climatic forcings. We present a geologic history of the Wasatch Formation in the Piceance Creek Basin that includes multi-proxy assessments of these factors. This includes a detailed provenance analysis from new fluvial sandstone petrographic and U-Pb detrital zircon geochronologic data sets as well as a revised subsidence history for the basin. These data suggest early Paleogene sediment was predominantly derived from the Sawatch Range and Uncompahgre Uplift until the early Eocene when the White River Uplift became a sediment source. The Wasatch Formation is composed mostly of recycled Upper Cretaceous fluviodeltaic and marine shales. Major shifts in fluvial deposition in the form of changes in lithofacies abundance, flow depths, and sand-body dimensions occurs coincident with the negative carbon isotope excursion of the PETM, and the large size of our dataset (n > 100 typically) allows characterization of the inherent autogenic variability in the alluvial systems. Increases in upper flow regime structures, crevasse splay prevalence, channel flow depths, and both the thickness and width of fluvial sand-bodies are likely driven by an increase hydrologic variability during the PETM. This inference is consistent with new soil morphologic and geochemical results from coeval floodplain deposits. Based on polycyclic aromatic hydrocarbon abundances landscape-clearing events related to fire frequency do not appear to be a driving geomorphic factor.

1-12 **A RECORD OF TERRESTRIAL HYDROLOGY IN A LONG-LIVED EOCENE LAKE UINTA, GREEN RIVER FORMATION, UTAH**

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Understanding how past rapid warming has affected global precipitation patterns in warm worlds is essential to enhancing our forecasting ability of the impacts of future climate change. The Early Eocene (~55-52 Ma) represents an interval of peak warmth during the past 65 million years, with global temperatures ~5-10°C warmer than present. Lakes particularly closed-basin systems, are sensitive to global change and tend to record dramatic responses to changes in the catchment. The Eocene Green River Formation is comprised of giant lakes deposited from ~53.5 and 48.5 million years, spanning much of the Early Eocene Climatic Optimum. White River Shale project drill cores from through the Parachute Creek Member, in the Uinta Basin, Utah offer an unprecedented opportunity to explore a high-resolution terrestrial record, where this long-term warming trend has rarely been reported. A tentative astronomically tuned time scale pinned in time by radioisotopic dates from 21 intercalated tuff beds, allows correlation to the well-studied marine sequences.

In this study, we report the isotopic expression of mid-latitude hydrological change during rapid warming through the Early Eocene Climatic Optimum by comparison of compound-specific hydrogen isotopes of *n*-alkanes (*n*-27, *n*-29 and *n*-31), steranes and hopanes recorded in the Uinta Basin, Utah. These units reveal different orbitally-modulated cyclicity from these parameters.

1-13 **RECOGNITION OF CARBON ISOTOPE EXCURSIONS IN THE LOWER PALEOCENE TERRESTRIAL RECORD OF THE SAN JUAN BASIN, NEW MEXICO, USA**

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Numerous short-lived, negative carbon isotope excursions (CIEs), putatively associated with warming climate, have been documented in the early Paleogene. The Paleocene-Eocene Thermal Maximum (PETM) is the largest of these "hyperthermals" and is characterized by dramatic faunal and floral change linked to rapid warming, including mammalian immigration and dwarfing. Biotic responses to other hyperthermals are poorly known and several have yet to be confidently recognized in the continental record. Here we report two, large (3-4‰) CIEs in the upper Nacimiento Formation based on carbon isotopes in dispersed bulk organics. Both occur in the late Torrejonian land-mammal age. The lower excursion occurs in the upper part of polarity zone C27r, and has not been recognized in the marine record. The upper excursion occurs at the top of C27n and is correlated to the Latest Danian Event (LDE), previously known with confidence only from the marine record. Results suggest that the lower excursion is associated with marked faunal turnover between the *P. cavirictum-M. pungens* (Tj5) and overlying *M. pungens* (Tj6) biozones. The excursion occurs at the top of Tj5, which has eleven last occurrences followed by thirteen first occurrences in Tj6. No mammal fossils occur above the LDE, precluding turnover analysis. We document a 13% decrease in body size in or near the LDE in the "condylarth" *Tetraclaenodon puercensis*, the only mammal abundant enough to analyze, based on m1 area. However, some teeth may be from below the LDE and better stratigraphic control is needed to fully test the dwarfing hypothesis. Recognition of these excursions in the continental record holds promise for a better understanding of how continental biota responded to repeated, transient warming events of the Paleogene.

1-14 **SEDIMENTOLOGICAL EVIDENCE FOR INCREASED PRECIPITATION EXTREMES AT THE PALEOCENE-EOCENE BOUNDARY IN THE SAN JUAN BASIN OF NEW MEXICO**

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The San Juan Basin (SJB) in New Mexico preserves the southwestern-most sedimentary record of the Paleocene-Eocene (P-E) boundary in North America, and thus represents a critical point for comparison with boundary sections preserved in Colorado and Wyoming. Nevertheless, rocks of the SJB, which include the upper Nacimiento Formation and the lower San Jose Formation, have not been studied extensively. The purpose of this research is to (1) characterize the P-E boundary section in more detail, and to (2) determine whether records of hyperthermal events are preserved in the SJB.

Current biostratigraphic data suggest a late-Paleocene age for the upper Nacimiento and an early-Eocene age for lower San Jose. The transition from uppermost Naciemento and lowermost San Jose is characterized by a lithologic change from isolated fluvial channel deposits bounded by drab mudstones in the Nacimiento to laterally-continuous, amalgamated fluvial channel complexes in the San Jose. Changes in channel deposits are consistent with an increase in deposition and discharge rates into the Eocene, while associated changes in mudstone floodplain deposits from drab to increasingly variegated are consistent with improved soil drainage. These changes in fluvial deposits are similar to those associated with the P-E boundary further to the north that have been interpreted as having been deposited under highly seasonal precipitation regimes. At present, it is not clear whether a record of the PETM hyperthermal is preserved. Carbon isotope data from organic matter record a ~4‰ decrease at the base of the San Jose, but isotopic variations of similar magnitude are also observed higher in the section. Therefore, carbon isotope variability may be inherent to the basin, or records of multiple post-PETM hyperthermals may be preserved. Continued data collection will help clarify our understanding of the P-E boundary in the SJB, and how it compares to other North American records.

1-15 **TERRESTRIAL EVIDENCE FOR HYPERTHERMALS IN THE LOWER PALEOCENE UPPER NACIMIENTO FORMATION, SAN JUAN BASIN, NEW MEXICO**

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The upper Nacimiento Formation of the San Juan Basin, New Mexico, contains extensive outcrops of alluvial deposits recording lower Paleocene mammalian evolution. Through the Nacimiento, there are intervals of high faunal turnover, one of which occurs in the Tj5 and Tj6 local biozones (~late To2 and To3 biochrons) of the Torrejonian (To) North American Land Mammal “age” (NALMA). We present a detailed paleoclimatic and paleoenvironmental record for this interval at four locations across the basin (Torreon East, Torreon West, Escavada Wash, and Kutz Canyon) utilizing sedimentology, paleosol macromorphology, and bulk geochemical proxies to investigate the role of climate and/or environmental change driving the Tj5-Tj6 mammalian turnover.

Detailed analyses of the sedimentology and paleosols through the Tj5-Tj6 interval indicate considerable variability in environments of deposition across the basin. The Torreon West section contains interstratified crevasse splay and overbank deposits indicating a channel proximal-transitional landscape position. The Kutz Canyon, Torreon East, and Escavada Wash sections have amalgamated sandstones suggesting close proximity to channel complexes. Analyses of bulk organics in fine-grained strata document two 3-4‰ negative shifts in $d^{13}C$ values, and temperature reconstructions using paleosol geochemical proxies indicate intervals of rapid 3-4°C warming immediately following the peak of each isotopic excursion, suggesting these represent early Paleocene hyperthermal events. The first hyperthermal occurs in the Tj5 biozone and the second in the Tj6 biozone at the end of chron C27n, strongly suggesting that it corresponds to the Latest Danian Event (LDE). The timing of LDE warming relative to the duration of the carbon excursion in the marine record suggests that the bulk organic record is truncated in the Nacimiento Formation. These findings suggest that the Tj5-Tj6 faunal turnover was driven by rapid, short-term warming and that the LDE was a global event.

1-16 **TRACKING THE NORTH ATLANTIC SHELF-TO-BASIN RESPONSE TO THE PETM: ANALYSIS WITH A HIGH-RESOLUTION, TERRAIN-FOLLOWING MODEL**

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The Paleocene-Eocene Thermal Maximum (PETM), a transient greenhouse interval spurred by a large release of carbon to the ocean-atmosphere system, provides a geological analog for anthropogenic carbon emission. However, while geochemical proxies and fossil assemblages have yielded insights into the continental shelf response to the PETM, existing ocean-atmosphere models of the PETM do not resolve shelf and slope bathymetry. Model-proxy comparisons are of particular interest along continental margins, which are ecologically and biogeochemically critical environments that supply many of the available proxy records of the PETM.

We present a high-resolution model of the pre- and syn-PETM North Atlantic basin that includes a resolved continental shelf along the eastern margin of North America. We use the Regional Ocean Modeling System (ROMS), whose terrain-following coordinate system permits a new level of detail along continental margins while also capturing open ocean processes. Our model's boundary conditions are drawn from existing CCSM-3 and GENIE models of the PETM. Under a forcing of approximately 0.6 Pg C per year for 15 kyr, the calcite saturation horizon reaches a depth of 500 to 600 m throughout the North Atlantic basin. Calcite saturation (O_{cal}) along the continental shelf of eastern North America ranges from 2.5 to 3 at 50 m depth, to 1.5 at 150 m. Planned tests for the model basin include forcing the coastal ocean of eastern North America with riverine salinity, nutrient and alkalinity fluxes to test their effects on calcite saturation and oxygenation. Ongoing whole-basin spin ups will also yield further data on shelf oxygenation during the PETM's onset, and the model can easily incorporate new combinations of alkalinity, dissolved inorganic carbon, and atmospheric pCO_2 for future simulations.

POSTERS: BIOGEOCHEMISTRY

1-17 **SOIL CARBON STABILITY DURING PERIODS OF GLOBAL WARMING**

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Soils contain three times as much carbon as either the atmosphere or terrestrial vegetation, making soil organic carbon (SOC) a potentially large feedback if destabilized due to anthropogenic climate change. The long-term stabilization of SOC is not well understood and represents a major source of uncertainty in climate change projections. Modern soil experiments can provide critical insight into the effects of increasing mean annual temperature and perturbations to the hydrologic cycle[1]. However, these experiments can only reveal change over annual to decadal timescales whereas ancient soils preserved in the rock record can provide insight into how SOC responded to climate perturbations on geologic timescales. Previous studies of paleosols spanning the Paleocene-Eocene Thermal Maximum (PETM) in the Bighorn Basin, WY inferred that microbial degradation rates doubled and fossil carbon input increased ~28-63% in response to hydrologic and carbon cycle perturbations[2]. These calculations are based on the hypothesis that fossil carbon is inherently recalcitrant and conforms to Arrhenius kinetics[2]. Within the last decade, however, new data have emerged that challenge the long-held hypothesis that molecular recalcitrance governs the persistence of SOC and instead argue for environmental and biological controls, such as organic-mineral interactions[3]. To more fully explore this, we will conduct laboratory experiments to study how SOC and biomarkers such as *n*-alkanes interact with different minerals in modern soils. After ground-truthing in the modern, we will examine the persistence of soil organic matter as a function of mineralogical and sedimentological change across the PETM in the Basin Substation core drilled by the Bighorn Basin Coring Project. By examining SOC preservation during the PETM, we hope to better understand the vulnerability of SOC to future climate change.

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1-18 **PLANT CARBON ISOTOPE FRACTIONATION IN THE EOCENE AND OLIGOCENE**

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Recent studies have proposed using leaf carbon fractionation ($_{leaf}$) as a paleo proxy for pCO$_2$. Decades of studies on plant carbon isotopes have shown $_{leaf}$ is affected by water availability, light intensity, photosynthetic pathway, growth strategy, and physiological differences among species as the primary controls. However, recent growth chamber studies on C_3 plants have found that $_{leaf}$ is impacted by changes in pCO$_2$ over a plant's lifespan. Conversely, field studies conducted on longer times scales (years to decades) and those that use the geologic record (millions of years), indicate that $_{leaf}$ is not sensitive to pCO$_2$ change. This suggests that plants evolve with respect to pCO$_2$ on geologic timescales, possibly by modifying leaf gas exchange properties and, therefore, calibrations based on short-term pCO$_2$ changes might not be directly applicable to the geologic past. In order for $_{leaf}$ to be used as a paleo proxy for pCO$_2$, the response of $_{leaf}$ to variable pCO$_2$ through geologic time must be tested. Here, we measured carbon isotope (δ^{13}C) values of n-C_{29} alkanes from localities across the western US and Canada that capture a range of pCO$_2$ levels from ~ 300 ppmV to over 1000 ppmV during the Eocene and Oligocene. Sample age, atmospheric pCO$_2$, paleovegetation, mean annual temperature (MAT) estimates, and mean annual precipitation (MAP) estimates are reasonably constrained for these sites. Preliminary results find that Paleogene $_{leaf}$ is not correlated with pCO$_2$. Paleogene $_{leaf}$ values are instead very similar to those that would be expected based on the paleoprecipitation. These preliminary results suggest that pCO$_2$ does not appear to influence $_{leaf}$ on geologic time scales.

1-19 **OCEAN DEOXYGENATION DURING THE PALAEOGENE HYPERTHERMALS**

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In the past half century oxygen minimum zones have been growing rapidly due to the rising seawater temperatures caused by global warming. Ocean deoxygenation has significant implications for marine biodiversity and therefore it is crucial to assess the extent and intensity of deoxygenation during past climate events. The climate events most similar to anthropogenic warming are the short-lived Palaeogene hyperthermals. These include the Palaeocene-Eocene Thermal Maximum (PETM) and the Eocene Thermal Maximum 2 (ETM2). We applied two redox proxies, $d^{53}Cr$ and Ce/Ce* in planktonic foraminifera to assess redox changes during the aforementioned events. Both $d^{53}Cr$ and chromium concentrations respond markedly during the PETM in shallow and open ocean settings indicative of a wide-spread reduction in dissolved oxygen concentrations. Open ocean sites 1210 and 1263 suggest deoxygenation during the PETM caused by changes in ocean ventilation. A strong correlation between $d^{53}Cr$ and benthic $d^{18}O$ as well as dissolved climate simulations using the climate model cGENIE suggest temperatures to be a strong driver of deoxygenation during the PETM. In contrast, the absence of a correlation with $d^{13}C$ indicates a limited increase in nutrient transport to the open ocean with most nutrients trapped by high productivity on continental shelves.

1-20 **EARLY EOCENE CHERT FORMATION IN THE NORTH ATLANTIC DRIVEN BY ELEVATED NERITIC DIATOM PRODUCTION**

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Early DSDP operations in the Atlantic both targeted and were greatly hindered by ubiquitous indurated siliceous sediments of early Paleogene age. It has been well documented that many of the strong seismic reflectors in the North Atlantic correspond to Eocene cherts and porcellanites, but these horizons continue to present a paleoceanographic puzzle. Although various biogenic and abiogenic processes have been invoked to explain their formation (including elevated rates of biosiliceous sedimentation, volcanism, and clay mineral-mediated precipitation), the source of silica required to produce such volumes of cristobalite/tridymite and quartz in early Eocene sediments in the Atlantic, has remained elusive. To this end, we have generated biogenic silica records from ODP Sites 1050, 1051 and 1053 on the Blake Nose spanning the early Paleocene-to-late Eocene interval (~62 to 37 Ma), supplemented by bulk carbonate stable carbon isotope records and a characterization of siliceous microfossil assemblages from multiple sites in the North Atlantic Ocean. Building on an early hypothesis by Weaver and Wise (1974), we propose prolonged elevated rates of shallow-water diatom production on the North American margin during the early Paleogene, combined with an intense lateral transport into the pelagic zone of the North Atlantic, as the source of silica for the formation of widespread diagenetically altered siliceous sediments in deeper waters. Neritic diatom production constitutes an overlooked link between elevated terrestrial silicate weathering rates associated with the early Paleogene greenhouse climates and deep-sea silica burial and subsequent diagenesis. The scenario proposed here is simpler than previous hypotheses on chert/porcellanite occurrences in the early Paleogene, but also supported by a range of micropaleontological evidence and consistent with modeling results.

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1-21 **OCEAN ACIDIFICATION ON THE CONTINENTAL SHELF DURING THE ONSET OF THE PALEOCENE-EOCENE THERMAL MAXIMIUM**

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Paleoshelf cores from Maryland and New Jersey contain a ~0.19 m to 2.7 m thick interval with reduced percentages of carbonate during the onset of the Paleocene-Eocene Thermal Maximum (PETM). This carbonate-barren interval likely represents significant dissolution coincident with the introduction of carbon to the ocean globally and deposition of a mobile mud belt regionally. We attribute dissolution to one or more of the following potential causes. The mud-rich shelf sediments contain abundant framboidal pyrite as well as zones rich in siderite, indicative of early diagenesis of a reactive-iron-rich anoxic sediment. Comparison of the abundance and preservation of pyrite and total organic carbon content indicates that limited dissolution possibly occurred as a result of the oxidation of organic matter during early burial, or following core recovery with the oxidation of pyrite. However, we doubt that this is the primary cause of the carbonate barren zone, and instead contend that significant dissolution occurred in the water column or on the seafloor after deposition. A compilation of %$CaCO_3$ data from global sections spanning bathyal to shelf depths (~ 100-300 m) shows a similar carbonate-free interval during the onset of the PETM on other continental margins, suggesting that low-carbonate interval was more than a regional phenomenon. Moreover, rare and heavily etched nannofossils from within the dissolution interval are similar in preservation to those at Walvis Ridge deposited at lysoclinal depths. Thus the global dataset is consistent with shoaling of the lysocline onto the paleoshelf. Specimens of *Discoaster* from the claystone are fragile and often malformed, possibly as a consequence of surface ocean acidification, as has been proposed previously. B isotope data indicate a minimum pH decrease of 0.35 during the core of the PETM, but it is possible that the decline was more extreme during the onset, and not captured in proxies.

1-22 THE MAGNITUDE OF PETM CARBON AND OXYGEN ISOTOPE ANOMALIES ON THE NORTH AMERICAN MID-ATLANTIC SHELF

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The Paleocene-Eocene Thermal Maximum (PETM) is characterized by a rapid and large negative carbon isotope excursion (CIE), extreme global warming, and intensification of the hydrologic cycle. The latter significantly impacted coastal environments by increasing freshwater runoff and the transport of sediments to coastal environments. This study focuses on a suite of recently recovered continental shelf cores spanning the PETM that include Cambridge-Dorchester (CamDor), South Dover Bridge (SDB) and Howards Tract 1 and 2 (HT) located on the mid-Atlantic coast in Maryland. These sites are of special significance due to their high sedimentation rates and clay content, which yield expanded sections of the CIE onset. We correlate between these sites to reconstruct spatial and temporal $d^{13}C$ trends along the continental margin, and to better constrain the local environmental changes during the PETM. Bulk carbonate stable isotopic records show two distinct $d^{13}C$ anomalies: a negative 1-2 ‰ pre-onset excursion (POE) as well as a negative 5‰ CIE, perhaps indicating two pulses of isotopically light carbon. Preliminary planktonic foraminiferal $d^{13}C$ data for CamDor track complementary bulk carbonate data, but with a smaller magnitude excursion. Both surface dwelling (*Morozovella* and *Acarinina*) and thermocline dwelling (*Subbotina*) foraminifera show a negative 3-4‰ CIE. Comparison with SDB and HT shows a marked similarity in bulk carbonate excursion magnitudes with the exception of the Howards Tract core, which shows a significantly depleted CIE with a minimum $d^{13}C$ of -13‰. These unusually depleted values are possibly the result of local diagenetic effects. Foram records from further north, New Jersey sites (e.g., Wilson Lake, Ancora and Bass River) also show a ~4‰ CIE, with larger excursions recorded in bulk; however, no POE is recorded from sites outside the Salisbury Embayment, Maryland along the Atlantic coast.

1-23 STABLE ISOTOPE AND %CARBONATE VARIATIONS ACROSS THE PALEOCENE-EOCENE BOUNDARY IN THE HOWARDS TRACT CORE, MARYLAND: IMPLICATIONS FOR REGIONAL SEDIMENT FLUXES AND CLIMATE CHANGE

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The Paleocene-Eocene Thermal Maximum is a globally recorded event marked by a massive carbon release and a significant rise in global temperatures. Owing to the complex nature of climate systems, the regional to local scale responses to this warming often varied dramatically. In the case of the Mid-Atlantic Coastal Plain of North America, prior work suggests there were significant changes in seawater carbon chemistry and siliciclastic sediment flux, possibly related to changes in regional precipitation. This study seeks to assess the local climatic and environmental response by means of stable isotope analysis of $\delta^{18}O$ and $\delta^{13}C$ obtained from bulk sediments and well-preserved foraminifera, building upon the existing records in the region with the addition of new data obtained from the Howards Tract core, a site located on the Eastern Shore, Maryland. The lithology is dominated by siliciclastic silts and muds consistent with deposition in a nearshore marine setting. Initial results show a marked reduction in the carbonate content as well as a negative shift in carbon isotopes, though marked by extremely low values of $\delta^{13}C$. The lowest values are associated with the lowest carbonate concentrations and are likely reflecting the contribution of authigenic carbonate (e.g. siderite) phases formed during early diagenesis, though unusually low $\delta^{18}O$ in some samples are indicative of meteoric diagenesis. The high variability in bulk $\delta^{18}O$ along with the presence of well-preserved foraminifera tests suggest that meteoric diagenesis is confined to discrete, more permeable beds. The results obtained from the study site will be compared to other Mid-Atlantic sites in order to expand the climate record of the region as well as providing additional insight into secondary diagenetic processes. The results will eventually be compared to paleoclimate models of the region with the goal of being able to place further constraints on their parameterization.

1-24 USE OF SINGLE-FORAMINIFER STABLE ISOTOPE ANALYSES TO STUDY THE RESPONSE OF AUSTRAL PLANKTIC FORAMINIFERA TO THE PALEOCENE-EOCENE THERMAL MAXIMUM AT ODP SITE 1135

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Core 25 of ODP hole 1135A from the southern Indian Ocean features a stratigraphic section spanning the Paleocene-Eocene Thermal Maximum (PETM), a transient global warming event that occurred ~56 Ma. A hallmark of the PETM is a negative carbon isotope excursion (CIE) signaling the rapid release of isotopically light carbon into the ocean-atmosphere system. Throughout the circum-Antarctic region, the CIE onset is closely associated with the first appearance (FA) of warm-water taxa ascribed to the planktic foraminifer genus *Morozovella*. Resolving the relative timing of the morozovellid FA to the CIE onset may corroborate the view that climatic warming preceded carbon input. Unfortunately, determining the relative timing of these two events is hampered by incomplete core recovery and drilling disturbance caused by a chert nodule that appears to have been displaced down-hole into the top of underlying Core 26. To overcome these stratigraphic shortcomings, we are using stable isotope signatures ($\delta^{13}C$, $\delta^{18}O$) of individual morozovellid shells to determine if any specimens register pre-CIE $\delta^{13}C$ values. To date, only one of the ~65 morozovellids analyzed from the Core 25 PETM section has yielded a pre-CIE $\delta^{13}C$ value. However, examination of samples from the upper 50 cm of underlying Core 26 revealed that morozovellids are present above and below the chert nodule. This raises the possibility that the earliest stages of the PETM may have been recovered within highly disturbed uppermost part of Core 26. Alternatively, it may simply indicate that the morozovellids were displaced down-hole along with the chert nodule. Work is currently underway to resolve this problem through the use of single-shell stable isotope analyses to determine if any of the morozovellids from Core 26 return pre-CIE $\delta^{13}C$ values. If these morozovellids register pre-CIE $\delta^{13}C$ values then it would confirm warming before the CIE onset as proposed by others.

1-25 **TEMPERATURE - CARBON CYCLE INTERACTIONS DURING THE EARLY EOCENE CLIMATIC OPTIMUM (ODP SITE 1263, WALVIS RIDGE)**

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The Late Paleocene to Early Eocene warming trend is characterized by a gradual temperature rise culminating in the Early Eocene Climatic Optimum "EECO". This warming trend was punctuated by several hyperthermals, which were geologically brief (<200kyr) episodes of extreme warmth. Recently, Lauretano et al. (2016) published a new high-resolution benthic foraminiferal stable isotope record of ODP Site 1263, which encompasses the EECO. This record confirms the presence of hyperthermals during and at the termination of the EECO as was previously found for ODP Site 1258 (Kirtland-Turner et al., 2014). Also, the record reveals a highly significant linear relationship between ^{18}O and ^{13}C for these events, similar to the PETM and ETM2. This indicates a strong coupling between global warming and the release of isotopically light carbon into the ocean-atmosphere system during these events. However, whilst the coupling between temperature changes and perturbations in the exogenic carbon pool remain stable on short-term time scales, they do not for the long-term trend. At ~52 Ma a rapid ^{13}C enrichment in carbon data occurs that is not accompanied by changes in the oxygen record. It was hypothesized that enhanced carbonate and organic carbon burial rates might be responsible for this shift in average isotopic values during a temporary reduced efficiency of the biological pump. To test this hypothesis, additional records over various water depths are necessary to create a depth-transect. We will present our new stable isotopic results of two planktic foraminiferal species derived from the same samples as Lauretano et al. (2016), which portray changes in surface (*Acarinina ssp*.) and thermocline (*Subbotina ssp*.) waters. Since high-resolution planktic foraminiferal records covering the EECO are still scarce, these records will also help confirm the presence of the "new" hyperthermals during the peak and termination of the EECO, as one would expect for global events.

POSTERS: PALEOBIOLOGY

2-1 **FAUNAL RESPONSE TO A POTENTIAL HYPERTHERMAL EVENT: BENTHIC FORAMINIFERA AT ODP SITE 1262 ACROSS THE DAN-C2 EVENT**

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Paleogene hyperthermals are global perturbations of the carbon cycle, characterized by negative carbon isotope excursions, global warming, and ocean acidification. One of the earliest Cenozoic perturbations of the carbon cycle (250 kyr after the Cretaceous/Paleogene [K/Pg] boundary) is known as Dan-C2, and considered non-typical because the CIE is not globally present in benthic foraminifera, and there is no evidence of bottom water warming.
Benthic foraminifera were affected by environmental perturbations associated with hyperthermals in different ways, possibly depending on the magnitude of the event and local effects, and their response ranges from extinction and appearance of species to decreased diversity, or reduction in foraminiferal test size. However, the response to the Dan-C2 has not been studied in detail so far. Here we analyze the benthic foraminiferal turnover across the Dan-C2 at Southeast Atlantic ODP Site 1262.
Benthic assemblages suggest meso-oligotrophic conditions throughout the studied interval. Gradual changes observed before the Dan-C2 (decrease in diversity and in relative abundance of *Nuttallides truempyi*, increased abundance of *Stensioeina beccariiformis*) imply environmental instability prior to the event. This instability might have been an indirect, long-term effect of the K/Pg impact, which caused changes in the type and/or amount of food supply linked to fluctuations in the post-extinction recovery of primary producers. A marked increase in abundance of *Spiroplectammina spectabilis* during the Dan-C2 points to elevated input of organic matter and higher siliciclastic flux (relative to carbonate flux) to the seafloor. The peak abundance of opportunistic species (*Bulimina kugleri*, *Seabrookia cretacea*) after Dan-C2 suggests that the previous, unstable trophic conditions returned. Contrary to typical hyperthermals, there was no major turnover in benthic foraminifera across Dan-C2 at Site 1262, possibly due to the lack of bottom water warming, but they adapted to variability in food supply because planktic organisms were not fully recovered from their extinction.

2-2 **SURVIVORS: ECOLOGICAL SELECTIVITY OF CORALS ACROSS THE PALEOCENE-EOCENE THERMAL MAXIMUM**

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The Paleocene-Eocene Thermal Maximum (PETM) is a well-known carbon cycle perturbation associated with a rise in atmospheric pCO_2 and temperature, as well as increases in turbidity and anoxia in the ocean. Coral reefs are particularly sensitive to these disturbances, and there is a lack of coral reefs in the fossil record during the late Paleocene and early Eocene. Nevertheless, in spite of this loss of habitat, corals do not experience extinction during this period; in fact their generic diversity increases. Analysis of coral survival during this time provides unique insight into how these keystone organisms respond to environmental stress over long periods of time. The aim of this study is to identify whether ecologic selection based on physiology, behavior, habitat, and other factors plays a role in the survival of corals during the PETM.

Coral taxa vary from one another in many areas of their ecology: coloniality, feeding and reproductive strategies, habitat preference and behavioral flexibility (among others). Statistical analysis is used to identify common traits among corals that are able to survive and/or diversify during the PETM and to identify possible geographic trends in coral distributions across the Paleocene-Eocene boundary. A database with coral taxa occurrence and ecological information from the Paleoeene and Eocene was built from data compiled in the Paleobiology Database and the Paleoreefs Database. Many of the coral genera and species from this time are extant, allowing confident paleobiological assessments of their ecology from modern coral relatives. Multivariate analysis is used to highlight whether there are correlations between these ecological traits and coral taxa extinction or survival. Geospatial analysis is used to find geographic trends in coral distribution. This analysis will test the hypothesis that certain traits (e.g. flexibility in diet, spawning rather than brooding reproduction) allow corals to survive periods of increased environmental stress.

2-3 NEW PERSPECTIVES ON THE CORRELATION OF SOUTH AMERICAN LAND MAMMAL AGES TO EARLY PALEOGENE CLIMATE CHANGES BASED ON RECENT CHRONOSTRATIGRAPHIC RESULTS FROM THE SAN JORGE BASIN, ARGENTINA

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Early Paleogene land mammal age frameworks from Holarctic continents (e.g. North America Land Mammal Ages [NALMAs], Asian Land Mammal Ages [ALMAs]) are relatively well correlated to the global geological timescale compared to those from southern hemisphere continents like South America. Such correlations allow for detailed comparison between the timing of continental faunal turnover and global climate changes. For example, the PETM, ETM2, and EECO have all been linked to mammalian evolutionary and/or paleoecological changes in one or more Holarctic continents but their relationship to South American Land Mammal Ages (SALMAs) is less clear. Many of the most important fossil mammal localities that help define the early Paleogene SALMAs are from the San Jorge Basin in the Patagonian region of Argentina. Renewed paleomagnetic and geochronological field work over the last 7 years in the San Jorge Basin has led to many new age constraints for key sedimentary units and their associated faunal assemblages. We will review these results and present new findings from our 2017 fieldwork in stratigraphic sections from coastal sites where many of the original fossil assemblages were described. Some conclusions of this work so far include (1) the Peligran SALMA is interpreted to be considerably older than previously acknowledged, correlating to the early Torrejonian NALMA/Shanghuan ALMA (~63.5 Ma) and thus is pre-PETM, (2) the Las Flores fauna (referred to the Itaboraian SALMA) is constrained to be between ~56-51.4 Ma, correlative with the Wasatchian NALMA/Bumbanian ALMA, and thus potentially encompasses ETM2, and (3) the *Ernestokokenia* faunal zone (=Riochican SALMA) is interpreted to be between 46.7-42.2 Ma and thus post EECO, however this awaits further confirmation based on results from our 2017 sampling campaign.

2-4 **ENVIRONMENTAL CHANGE IN A NERITIC SETTING BEFORE, DURING, AND AFTER THE PALEOCENE-EOCENE THERMAL MAXIMUM: INSIGHTS FROM MAGNETOFOSSIL AND MICROFOSSIL ASSEMBLAGES.**

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Magnetotactic bacteria (MTB) are prokaryotic biomarkers for oxic-anoxic transition zone environments. MTB biomineralize morphologically distinct, iron-rich particles called magnetosomes that can be preserved in the geological record as magnetofossils. Continental shelf sediments along the NE margin of North America contain a near-pristine magnetofossil-rich interval that is coincident with the Paleocene-Eocene Thermal Maximum (PETM), an abrupt global warming event that occurred ~56 Ma. Here we present component-specific room-temperature and cryogenic magnetic measurements of samples from the Wilson Lake-A core from New Jersey. We use these data— which can discriminate the distribution of sizes, shapes, and compositions of iron-rich particles in bulk sediments— to assess the relative contribution of biotic *vs.* abiotic magnetite and to estimate changes in MTB abundance and (potentially) biodiversity during the PETM. High-resolution first-order reversal curves with distinct central ridges confirm published magnetic coercivity and electron microscopy data that suggested an abundance of conventional magnetofossils at the onset of and throughout the PETM. Low temperature saturation isothermal remanent magnetization measurements of the same samples, however, indicate that one or more previously unrecognized magnetic contributions partially or completely mask another hallmark of magnetofossils: the lower component of the double Verwey transition. We present additional magnetic grain size and composition calculations to test whether this masking is caused by diagenesis or additional primary magnetic components in these coastal sediments. Finally, we perform principal component and canonical correlation analyses of these magnetic data combined with published microfossil assemblages and geochemical data from the same core to test what biogeochemical factors associated with rapid warming modulate MTB and microfossil diversity in this neritic environment.

2-5 SHELF DYNAMICS DURING THE PETM ALONG THE NEW JERSEY COASTAL PLAIN

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The early Paleogene is recognized as a climatically dynamic period with relatively short intervals of rapid global warming (superimposed on a warm background climate), of which the Paleocene-Eocene thermal maximum (PETM) is the best documented and most extreme. Records from continental margins with high sediment accumulation rates and well-preserved microfossils are ideal to evaluate the temporal and spatial responses of biota and environments to this warming event. Detailed isotope data and biotic studies on sedimentary sequences of the New Jersey Coastal Plain provide evidence to unravel the progression of environmental changes during peak warming and recovery phase. In this region, PETM warming was reflected in a 5 to 8°C increase in surface water temperatures, which resulted in broad hydrographic adjustment of the water column structure. An intensification of the hydrologic cycle due to the warming initiated fluvial discharge and widespread dispersal of mud across the shelf.

We present monospecific stable isotope ($\delta^{13}C$ and $\delta^{18}O$) records of benthic foraminiferal species within the expanded PETM interval at Wilson Lake, and link their different isotope signatures and variability to corresponding paleoecological interpretations. During the peak warming phase, intraspecific isotope trends reveal distinct changes in the water column (and pore water gradient) structure, with niche instability (changes in microhabitat zone), as indicated by reduced isotope gradients between stress-tolerant taxa with supposedly infaunal and epifaunal lifestyles. Persistent ocean warming probably created more homogenous annually averaged bottom water conditions during the initial stages of the PETM, marked by an expansion of the thermocline, and increased hypoxia and eutrophication at the sea floor. Isotope values diverge during the upper stages of the PETM, indicating the (re)occupation of preferred ‘optimal’ niches in the benthic foraminiferal ecosystem. Correlations with other sites enable us to further constrain the evolution of depositional and environmental conditions across this siliciclastic shelf.

2-6 **DIFFERING FORAMINIFERAL SIGNATURES OF THE PALEOCENE-EOCENE THERMAL MAXIMUM ONSET IN SHALLOW MARINE SEDIMENTS**

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The Paleocene-Eocene Thermal Maximum (PETM) is recognized in marine sediments across the globe by a carbonate dissolution zone, the turnover of benthic foraminifer taxa, and a radiation of planktic foraminifera. The environmental and ecological changes centered on the PETM onset may provide an analog for the Earth under projected increases in atmospheric carbon dioxide and associated ocean acidification. We present foraminiferal evidence from two sites in southern Maryland that detail very different responses to the same climate forcings. South Dover Bridge (SDB) and Mattawoman Creek-Billingsley Road (MCBR) cores are located in the central Salisbury Embayment, an area of marine overlap during most of the Tertiary. Foraminifera describe changes in the water column at SDB. Benthic taxa define the transition from oxic, oligotrophic bottom waters to more eutrophic conditions during the latest Paleocene followed by decreased oxygenation in the earliest Eocene. Planktic taxa relate similar ecological changes as surface productivity increased in the latest Paleocene, followed by a deepening of the thermocline in the earliest Eocene. Benthic assemblages relate a rise in sea level of 10-20 m in the earliest Eocene. At MCBR, foraminifera describe changes in sedimentation regime. Benthic faunas indicate a seasonally variable trophic state across the PETM onset. The movement toward a nearly mono-specific assemblage in the earliest Eocene is likely related to increasing dysoxia, and the coincident progression through increasingly stress-tolerant taxa indicates an increasing and perhaps highly variable sedimentation rate. An apparent drop in relative sea level at MCBR is a spatially-restricted event that we interpret as delta progradation. These differing responses of shallow marine ecosystems to the PETM onset reflect specific manifestations of global increases in temperature and sea level, regional effects of the enhanced hydrological cycle and localized changes in coastal geomorphology.

2-7 **VERY (VERY) PRELIMINARY CHRONOSTRATIGRAPHIC FRAMEWORK OF AN EXPANDED AND STRUCTURALLY CONTROLLED EARLY EOCENE SECTION FROM THE KNAPPS NARROWS CORE, SALISBURY EMBAYMENT, USA**

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The 2015 USGS Knapps Narrows core, Maryland, obtained a thick sequence (~36.3 m) of early Eocene marine glauconite-rich quartz sands of the Nanjemoy Formation. Sediments contain unusually high amounts of very coarse to granular quartz, with occasional pebbles, mixed with ~50 percent glauconite. The Nanjemoy unconformably overlies the Aquia Formation, and the absence of the intervening Marlboro Clay and corresponding Paleocene-Eocene Thermal Maximum is coupled with an unusually thick sequence of coarse sediments and evidence of nearby faulting, such as abrupt changes in the distribution and thickness of stratigraphic units. This suggests that the early Eocene sediments at Knapps Narrows are representative of basin infilling following structural uplift coupled with paleocurrent activity. Preliminary paleomagnetic and calcareous nannofossil biostratigraphic analysis of the core suggests a relatively complete early Eocene section. The base of the Nanjemoy is at 102.9 m and contains specimens of *Rhomboaster* spp., but lacks excursion taxa *Discoaster salisburgensis anartios* and *Discoaster salisburgensis araneus*, placing it in upper, but not uppermost, Zone NP10; paleomagnetics place it in Chron C24r. By 92.0 m, *Rhomboaster* spp. has disappeared and *Tribrachiatus orthostylus* has appeared, placing this sample in Zone NP11. Zone NP11 spans the C24r/C24n boundary, at ~91.1 m. The first occurrence of *Discoaster lodoensis* at 79.4 m, which marks the base of NP12, occurs within Chron C23r (78.3-85.0 m), and suggests that the base of Zone NP12 is missing. Zone NP12 continues to ~71.6 m, and incorporates all of Chron C23n (from 71.5-78.3 m). The last occurrence of *T. orthostylus* at 71.4 m marks the base of Zone NP13, which is associated with the Chron C23n/C22r boundary. This successful preliminary work is encouraging and suggests the possibility of a complete chronostratgraphic composite of early Eocene hyperthermals that can be used as a standard reference section for future work in the Embayment.

2-8 **AN INITIAL LOOK AT PETM FORAMINIFERAL ASSEMBLAGES FROM HOWARDS TRACT 2, A NEW USGS CORE FROM THE SALISBURY EMBAYMENT**

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Two new USGS cores, Howards Tract 1 and 2, provide shallow shelf sediments of the Paleocene-Eocene Thermal Maximum (PETM) from the Atlantic Coastal Plain and complete a transect along the flexural low axis in the Salisbury Embayment between the South Jersey High and the Norfolk Arch. In June 2016, the Howards Tract cores were drilled to ~213 m depth in the Blackwater Wildlife Refuge, Dorchester County, Maryland, USA, between the existing downdip South Dover Bridge (SDB) and updip Mattawoman Creek-Billingsley Road (MCBR) cores. Unique from other cores along this transect, Howards Tract exhibits centimeter-scale climbing ripples indicative of high sediment supply in the lower 1.2 m of earliest Eocene sediments. We conducted an initial low-resolution analysis of 25 samples from one of the Howards Tract cores (HT2) spanning ~20 m of the late Paleocene Aquia Formation and the early Eocene Marlboro Clay and Nanjemoy Formations, to preview the changes in foraminiferal assemblages over the PETM onset and main body. Two zones of decreased foraminifer abundance in the upper Aquia Formation and in the lowermost Marlboro Clay could indicate dissolution zones associated with the latest Paleocene pre-onset excursion and the early Eocene PETM carbon isotope excursion onset, respectively. They are similar to what has been recorded at SDB. The presence of the benthic foraminifera marsh species Trochammina within ripple beds in the lowermost Marlboro Clay, however, argues for an ecologic or sedimentologic driver of the decrease in foraminifera. We examine the species assemblages, density per gram, and preservation state of Howards Tract foraminifera to determine whether ecological changes related to coastal zone processes, paleodepth, and/or ocean acidification is responsible for the individual zones of decreased foraminifer abundance.

2-9 **ANALYZING EARLY EOCENE DEEP-SEA BENTHIC FORAMINIFERA**

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Several hyperthermal events occurred during the early Paleogene, reflecting intermittent perturbations of the global carbon cycle, the most extreme of which was the Paleocene-Eocene Thermal Maximum (PETM). This event represents a critical interval for deep-sea benthic foraminifera, since they suffered their largest extinction of the Cenozoic and the replacement of the globally recognized “Velasco fauna”, which survived the Cretaceous/Paleogene impact event, by the “Paleogene fauna”. In spite of numerous studies of benthic foraminifera across the PETM, early Eocene faunas have not been well documented, and there is no consensus or definition of the most relevant assemblages of this time.

Here, we analyse middle bathyal to lower abyssal benthic foraminiferal assemblages from the Atlantic, Pacific and Indian Oceans in order to define the typical deep-sea faunas immediately after the PETM and higher up into the Ypresian (early Eocene), across several less intense hyperthermals. Our results show variations in the assemblages at the studied sites, possibly related to differences in paleobathymetry and/or paleogeography. However, in general the typical early Eocene fauna seems to be represented by taxa that are most resistant to regularly perturbed environments.

We contribute to the current knowledge of early Eocene benthic foraminiferal assemblages, by making it possible to compare assemblages from distinct sites and sections as described by different authors. Such comparison and global compilation is necessary to determine the severity of the extinction during the PETM, which is complicated due to the use of different taxonomical concepts, and to evaluate faunas living in a warm period with several superimposed hyperthermals. Therefore, this analysis is expected to contribute data to climate, earth system and ecosystem models.

2-10 **PLANKTIC FORAMINIFERAL RESPONSE TO THE EARLY EOCENE CARBON CYCLE PERTURBATIONS**

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We present quantitative planktic foraminiferal assemblages variations from multiple sites to explore their relationship with early Eocene climate variability and carbon cycle perturbations. A prominent switch in abundance between the genera *Morozovella* and *Acarinina*, occurred close to the carbon isotope excursion referred to as the J event (~53 Ma), which marks the beginning of the Early Eocene Climatic Optimum (EECO; ~53–49Ma). The relative abundance of *Morozovella* permanently declined along with a progressive decrease in diversity. Concomitantly, the genus *Acarinina* almost doubled its abundance and diversified within the EECO. Size restricted carbon isotope analyses demonstrates that morozovellids reduced their algal-symbiont relationships at the beginning of the EECO but the recorded bleaching was a transitory effect, excluding the permanent loss of photosymbionts as the main cause of the morozovellid decline. At South Atlantic Site 1263 the morozovellid abundance decrease is delayed by ~165 kyr with respect to low-latitudes, suggesting a temporary migration of the warm-water morozovellids southwards at the initiation of the EECO, but suffering consequently to the unfavourable environmental conditions triggered by the persistent EECO perturbation. We also document the virtual disappearance within the EECO of the biserial chiloguembelinids, commonly considered as inhabiting the oxygen minimum zone, and a reduction in abundance of the thermocline-dweller subbotinids. We interpret these critical changes as a signal of upper water-column destratification and associated contraction of ecological niches, possibly related to subsurface water warming. Our data highlight that the *Acarinina* over *Morozovella* turnover was global and hypothesize that competition in the mixed-layer may have played a significant role as implied by their anti-phase variations in abundances as recorded at the early Paleogene hyperthermals and within the EECO in different settings. We record shifts in the coiling of *Morozovella* during the extreme warming intervals of the early Eocene, stimulating renewed thought on ecological responses.

2-11 **DINOCYST EVENTS ACROSS THE ETM-2 HYPERTHERMAL EVENT AT THE SOUTHERN EDGE OF THE NORTH SEA BASIN**

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The extensive and almost complete record of the Ypresian, regionally known as the Ypresian Clays, in the Belgian Kallo core makes this a key site to unravel the environmental dynamics across early Eocene global warming events in the North Sea Basin. The existence of multiple carbon isotope excursions was recently revealed during an update of the regional stratigraphic framework. This renewed framework not only provides a clear link with the early Eocene climate evolution, but is also an excellent building stone to re-evaluate the existing dinocyst record recovered from the Ypresian Clays as well as to add some much-needed data on the biotic response to the Eocene global warming events in shelf areas.
Several distinct dinocyst events were previously recognized in the Ypresian Clays (De Coninck, 1996), however, a major re-evaluation of the dinocyst record is essential considering the wealth of newly published research on the early Eocene global climate. Here we present the initial results of the updated dinocyst record across the Eocene thermal maximum 2 (ETM-2), which shows a complex interplay between regional changes in relative sea level, productivity, and salinity. This allows for a better understanding of the stratigraphic importance of these ecological dinocyst events in the southern shallow water settings of the North Sea Basin, as well as any links with ecological events in other paleocommunities inhabiting this shelf. Relative sea-level change for instance, seems to have been the primary factor influencing the initial appearance of dinocyst taxa in the run-up to ETM-2. Initial results further indicate no significant peaks of *Apectodinium* taxa prior to and during ETM-2. The updated dinocyst record also provides valuable additional insights into the paleogeographic evolution of the North Sea Basin during the Eocene.

2-12 **OSTRACODE RESPONSE TO EOCENE THERMAL MAXIMUM 2 IN THE EQUATORIAL ATLANTIC**

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Hyperthermal events in the late Paleocene and early Eocene, characterized by relatively rapid increasing temperatures and corresponding negative carbon isotope excursions, represent some of the best ways for us to study the effects of a sudden input of carbon into Earth's climate system. The Paleocene-Eocene Thermal Maximum (PETM, ~56 Ma) is the largest and most well-known of these hyperthermal events, but several smaller hyperthermals followed in the early Eocene. The Eocene Thermal Maximum 2 (ETM2, ~54.1 Ma) is the first in a series of hyperthermal events that follow the PETM, and has been identified globally in marine and terrestrial records. While previous studies have evaluated the response of unicellular marine organisms to environmental change during ETM2 (e.g. Foster et al. 2013; Jennions et al., 2015), relatively few studies have focused on impacts on multicellular groups. Here we investigate patterns of ostracode abundance across ETM2 at ODP Site 1258, north of Suriname. At this site, Eocene hyperthermal events, including ETM2, have been previously identified using bulk carbonate carbon and oxygen isotopes(Kirtland Turner et al., 2014). Preliminary results indicate that ostracodes persisted throughout ETM2 at this site in varying levels of abundance. We further evaluate the relationship between ostracode accumulation rate, temperature, and carbon cycle indicators (wt% $CaCO_3$ and carbon isotopes) across this interval in order to assess the response of multicellular animal life to environmental changes associated with increased input of carbon to the atmosphere and ocean.

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2-13 **AN ASSESSMENT OF CLIMATE-VEGETATION FEEDBACKS UNDER DIFFERENT BOUNDARY CONDITIONS USING GLOBAL CLIMATE MODEL SIMULATIONS**

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While many global climate models predict drying for northern continental interiors under anthropogenic climate change, fossil evidence suggests warmer, wetter periods in the past. Here I explore if climate-vegetation feedbacks, such as CO_2 fertilization, transpiration, and albedo, can help us to understand this dichotomy. Using the NCAR Community Earth System Model (CESM), I compare changes to climate and vegetation for three different CO_2 scenarios: (1) with atmospheric CO_2 in the atmosphere and land model components set to the preindustrial value (PI; 280 ppmv), (2) with atmosphere and land CO_2 set to 4 × PI, and (3) with atmospheric CO_2 set to 4 × PI in the atmosphere component but fixed at PI in the land component. The third configuration represents a warmer climate without CO_2 fertilization and allows us to distinguish the effect of increased atmospheric moisture and rainfall on vegetation versus that of CO_2 fertilization. All model runs are conducted with carbon-nitrogen cycling and dynamic vegetation using 15 plant functional cycles. Additionally, I conduct these runs with two different orbital configurations, December and June perihelion, as Earth's precession affects seasonal length and temperature, particularly at greater ellipticity. I find that for both orbital configurations, CO_2 fertilization leads to increased mean annual temperature at high latitudes due to the increase in vegetation. The CO_2fertilization effect is relatively more important for northern high latitude continental interiors in the June perihelion case than in the December perihelion case, perhaps due to the shorter northern hemisphere growing season under June perihelion. While precipitation increases in all high CO_2cases due to the increase in atmospheric saturation vapor pressure, the cases with CO_2 fertilization are drier than those without. Thus, our model simulations with CO_2 fertilization show not a warmer, wetter world but rather a warmer, greener one.

2-14 **EFFECTS OF WATER AVAILABILITY ON FOREST ECOSYSTEMS DURING THE PALEOCENE-EOCENE IN WYOMING**

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The geologic record of the Early Paleogene allows for better understanding of the water cycle's response to rising temperatures, which is imperative. Water availability is a critical driver of terrestrial ecosystem structure and function, and by documenting the dynamic relationship between changes in water, the abiotic environment, and living communities, we can isolate and quantify its effects on the non- microbial ecosystem. Previous research has focused predominantly on biotic responses to Early Paleogene temperature fluctuations, and yet water availability is likely to be a more important factor controlling plant growth and forest diversity. We therefore propose to document climate change, focusing on moisture regime, during the Paleocene-Eocene in the Hanna Basin, southeastern Wyoming, and study its effects on forest communities. We expect that the physiological demand for CO_2 and water were alleviated within this microclimate, allowing diverse and even plant communities to thrive, which in turn supported diverse and abundant insect herbivore populations.

In summer, 2017, we will sample plant macrofossils from 3 stratigraphic levels in the Hanna Formation. At each stratigraphic level we will: 1) morphotype the fossil flora, 2) analyze plant diversity and evenness, 3) estimate paleoclimate using paleobotanical proxies for mean annual precipitation and mean annual temperature, 4) reconstruct the paleoecology of the canopy using proxies such as leaf epidermal cell undulation index, and 5) quantify insect herbivore damage on fossil leaves. After analyzing variance within the Hanna Basin, results will be compared to those from the Bighorn Basin, northwestern WY, whose abundant Eocene red-beds suggest lower water availability than the coal-rich Hanna Basin. Future research will analyze fossil cuticle $d^{13}C$ and dD to reconstruct leaf fractionation of carbon ($d^{13}C$) and relative humidity (dD).

2-15 **INSECT HERBIVORY IN THE HOTHOUSE EARLY EOCENE WIND RIVER FORMATION FLORAS, CENTRAL WYOMING, USA**

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Knowledge of the organization and host specificities of plant–herbivore food webs is of considerable importance for understanding historical biodiversity patterns and the processes of their maintenance. Of particular interest to today's steadily warming world is how biodiversity is distributed and maintained during hothouse earth conditions, and the Early Paleogene is the ideal study interval for these questions. We analyzed plant community structure and insect herbivory in early Eocene floras from the Wind River Formation of the Wind River Basin, central Wyoming, USA. We compared leaf compressions collected from the edge (4 sublocalities, 910 specimens) and the interior (8 sublocalities, 1755 specimens) of the basin to examine how differences in plant community influence herbivory distribution.

Our analyses show that the basin edge and interior represent different environments with distinct vegetation; just 9.8% of the leaf morphotypes are shared. Plant diversity within a sublocality is higher in the edge than in the interior, but there is little difference in diversity when we analyze the bulk floras. Evidence of insect-plant and fungal-plant interactions was present in only 10.76% of leaf specimens in the edge flora, versus 45.41% in the interior flora. Rarefaction analysis showed that interior area has more specialized damage types (as mines and galls) in comparison with the edge area. The fact that the higher frequency and diversity of herbivory, and more specialized types of damages, are associated with the less diverse flora was unexpected. Possible factors influencing this pattern include differences in paleoelevation, and depositional environment. To further explore the influence of these factors, we plan to add contemporaneous data from interior sites collected from the Bighorn Basin to the north, which is separated from the Wind River Basin by the Owl Creek Mountains.

2-16 **THE EARLY EOCENE SAN JUAN BASIN FLORA: AN INVESTIGATION INTO THE EARLY CENOZOIC HISTORY OF THE U.S. MOUNTAIN WEST**

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Studies from the early Cenozoic of Wyoming and Colorado have greatly contributed to our understanding of the Paleocene-Eocene Thermal Maximum (PETM) and the effect it had on terrestrial flora. Here we seek to expand the geographic range of this information by studying a basin of roughly equal longitude to those previously explored, but at a much lower latitude. The goal of this study is to assess the paleoclimate and paleoecology of the San Juan Basin, New Mexico by collecting and analyzing fossil flora found in the Cuba Mesa Member of the San Jose Formation. Samples were collected from two separate sites, the latest Paleocene "Clear as Mud" locality and the early Eocene "Twin Pines" locality. In between the two sites is the PETM– a geologically abrupt global warming event caused by a major perturbation to the carbon cycle. The Paleocene site consists of five separate fossiliferous mud clasts found in the face of a Cuba Mesa sandstone cliff. These mud clasts contained cm scale layers of alternating light and dark gray siltstones. The leaf-bearing layer of our Eocene site is a fine-grained carbonaceous shale lens bounded by massive Cuba Mesa sandstones. A full examination of our Eocene site has revealed a swamp flora dominated over 50% by *Averhoites affinis*, with palms, conifers, monocots, the aquatic fern Salvinia, seeds, and beetle wings also preserved. The presence of thermophilic species *Aleurites glandulosa* and a *Rhus sp.* have important biogeographic implications, as representatives of both genera occur during warm intervals in the Bighorn Basin, Wyoming. *Averhoittes affinis* is also found at our Paleocene site along with several morphotypes much larger than those from the Eocene site. Early results of this study suggest a distinct early Eocene temperature gradient between northwestern New Mexico and other well collected Eocene basins of Colorado and Wyoming.

2-17 A PALYNOLOGICAL INVESTIGATION OF THE ARCTIC LATE PALEOCENE/ EARLY EOCENE MARGARET FORMATION AT STENKUL FIORD, ELLESMERE ISLAND, NUNAVUT, CANADA

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High latitudes responded profoundly to early Paleogene warming events, but much of the data for these changes are from the marine record. Stenkul Fiord on Ellesmere Island offers a nearly continuous lithostratigraphic section of high-latitude fossil-rich late Paleocene–early Eocene aged rocks of the Margaret Formation. These sediments were deposited during a period of major climate warming in the early Paleogene and likely capture the early hyperthermal events (i.e., the Paleocene-Eocene Thermal Maximum and the Eocene Thermal Maximum 2). These rocks have been dated from Zircon crystals recovered from ash layers, and have produced a UPb age result of 53.7 ± 0.6 Ma. Prior megafloral studies reconstructed rich forest ecosystems and a warm wet paleoclimate for early Eocene Ellesmere Island, but lacked fine stratigraphic resolution. Hitherto, pollen reconstructions of Arctic Eocene terrestrial vegetation in the Ellesmere region have been restricted to either marine cores east of Greenland, or from the Lomonosov Ridge. Previous palynological analysis at Stenkul Fiord presented very coarse resolution of the floristic components and did not consider the role played by the early hyperthermal events. Using higher resolution sampling methods, coupled with detailed quantitative analyses of fossil pollen and spores, the terrestrial vegetation at Stenkul Fiord will be reconstructed for multiple beds throughout the section. Different facies, such as coals and mudstone, may be representative of different plant communities within the Eocene landscape. These data will be integrated into parallel analyses of megaflora from the section and provide much needed biostratigraphic context for analyses of the chronology of the Eurekan deformation as part of the CASE (Circum-Arctic Structural Events) project of the BGR and GSC. This study will seek to determine how floral communities have shifted over time in response to intervals of major climatic change. Presented here are initial observations from the July 2017 field season.

2-18 **PLANT COMMUNITY AND CLIMATE DYNAMICS AT THE ONSET OF THE EARLY EOCENE CLIMATIC OPTIMUM, MCABEE FOSSIL BEDS, BRITISH COLUMBIA, CANADA**

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The early Eocene McAbee Fossil Beds, in southern British Columbia, hosts a diverse megafloral assemblage including fossil leaves, flowers, and seeds of predominately warm-temperate vegetation, within finely-laminated lacustrine shales. An interbedded ash has been previously dated at 52.9 ± 0.83 Ma, coinciding with recent estimates of the onset of the Early Eocene Climatic Optimum (EECO). Previous work at McAbee has amalgamated fossil collections from several stratigraphically unconstrained exposures, producing a ~10^3 - 10^5 year time-averaged perspective on the local plant community composition and climate. While this perspective is useful in assessing regional spatio-temporal patterns, paleoecological information is available through high-resolution, stratigraphically-constrained, and un-biased census collecting. This study is applying census techniques to assess the para-taxonomic composition and leaf physiognomy of three stratigraphically-separated, purpose-made megaflora collections. A stratigraphic framework for McAbee is being developed by constructing and correlating high-resolution stratigraphic columns for several fossiliferous exposures, to which the stratigraphic distribution of census collections from individual beds are being determined. Preliminary results from 2015-2016 census collections show high abundance and diversity of plant fossils from two individual beds (i.e., 31 & 36 morphotypes) and differences in relative abundance of taxa between beds. Preliminary rarefaction analysis demonstrates dicotyledonous diversity comparable to the hyperdiverse early-middle Eocene sites of Falkland, Laguna del Hunco, and Río Pichileufú. CLAMP estimates of climate from the 2015 collection are largely consistent with previous work and suggest a warm (MAT = 9.7 ± 2.1 °C), mesic (GSP ˜ 93 cm/yr), and seasonally-mild (CMMT = -2 ± 3.4 °C) climate and will be updated incorporating new specimens and additional physiognomic proxies (e.g., DiLP, LMA). Using trends and relationships in climate estimates and plant community reconstructions through section, we will assess the response of these local systems over millennial time-scales to the onset of the EECO at moderately-high paleoelevations (~600-800 m a.sl.).

POSTERS: PALEOCLIMATE

2-19 **REVISED ESTIMATES OF ATMOSPHERIC CO2 ACROSS THE CRETACEOUS-PALEOGENE (K-PG) BOUNDARY**

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The Cretaceous-Paleogene (K-Pg) boundary marks a critical extinction event in Earth's history that is associated with a major perturbation in the global carbon cycle. However, we presently lack robust CO_2 estimates directly following the K-Pg boundary that can provide context to the extinction and the biological response. Currently, only the study of Beerling et al.[1]provides proxy-based constraints. Beerling et al.[1] concluded that CO_2 at the K-Pg boundary exceeded 2300 ppm based on stomatal index (SI) values for the fossil aff. *Stenochlaena*, collected from strata in the Raton Basin within 10 kyr of the boundary, which were lower than any SI from their modern calibration set. An important caveat to these results is that they are unbounded because the SI proxy loses sensitivity at elevated CO_2 levels (>500-1000 ppm).
Here we reconstruct CO_2 across the K-Pg boundary using the fossil material of Beerling et al.[1] and fossils collected from the San Juan Basin, New Mexico using a stomatal-based proxy for paleo-CO_2 reconstruction based on basic plant gas-exchange principles[2]. In contrast to the SI proxy, the gas-exchange method[2] produces well-bounded CO_2 estimates, even at high CO_2. We reconstruct CO_2 directly at the K-Pg boundary to be between 550 and 1500 ppm (95% confidence), considerably lower than previous estimates[1]. Analyses of early Paleocene floral from the San Juan Basin are ongoing. Importantly, these estimates are the first fully-bounded CO_2 estimates for the K-Pg boundary and earliest Paleocene, which provide critical insights into the global carbon cycle perturbation at the boundary and the climatic conditions of the early Paleocene.

Beerling, D. J., Lomax, B. H., Royer, D. L., Upchurch, G. R. & Kump, L. R. *Proceedings of the National Academy of Sciences of the United States of America* **99**, 7836-7840 (2002).

Franks, P. J. *et al. Geophysical Research Letters* **41**, 4685-4694 (2014).

2-20 **MULTIPROXY RECORDS OF PALEOCENE TO EOCENE CLIMATES AND ENVIRONMENTS, BIG BEND NATIONAL PARK**

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Fluvial and floodplain deposits of the Tornillo Group preserve a long record of low-latitude climatic and environmental change in Big Bend National Park, West Texas, USA. Through several decades of stratigraphic, paleotological, and geochemical study, a composite section with good chronostratigraphic control spanning the earliest Paleocene through the Early Eocene has been developed. Here we report new geochemical data, including major elemental analysis of pedogenically modified mudstones and clumped isotope analysis of pedogenic and diagenetic carbonates, which document regional climatic conditions. Average soil temperature estimates are ~25° C throughout the Paleocene, with a slight cooling during the latter half of the Paleocene and warming to ~29° C in the Early Eocene. These values are ~2-10° cooler than coeval clumped isotope paleosol carbonate temperatures that have been interpreted to reflect summer-biased soil temperature at a higher-latitude site in Wyoming's Bighorn Basin. They are ~10° warmer than leaf margin mean annual temperatures from Wyoming, approximately equaling the modern MAT difference between the sites. This suggests that Big Bend data may be less influenced by seasonality and more closely record MAT than the Wyoming data, and is consistent with an Early Paleogene meridional temperature gradient similar to or lower than today. Mean annual precipitation estimates from the Big Bend paleosols average ~1200 mm/year and vary slightly throughout the section, with drier conditions in the mid-Paleocene and wetter conditions in the Early Eocene. These values are similar to those reconstructed for Paleocene-Eocene conditions in Wyoming, with estimates from both sites exceeding modern values by ~2.5 times (Big Bend) to ~5 times (Wyoming). Reconstructed soil water isotope ratios were also nearly identical at the two sites, suggesting either 1) limited rainout-induced meridional gradients in rainwater isotope ratios across the Texas-to-Wyoming transect or, more likely, 2) enhanced soil water isotope enrichment due to evaporation during the formation of pedogenic carbonate at the Wyoming site.

2-21 **SITE-SPECIFIC TRENDS IN D13C AND D18O ACROSS THE LATE PALEOCENE TO EARLY-MIDDLE EOCENE**

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Benthic foraminiferal oxygen isotope records indicate that from the late Paleocene to early-middle Eocene, Earth's climate experienced dramatic long term variations. Beginning in the late Paleocene (~57 Ma) and culminating in the Early Eocene Climate Optimum (EECO, ~51-53 Ma), a 1‰ decrease in $\delta^{18}O$ indicates warming of ~4 to 5 °C, followed by the onset of long-term cooling at the early-middle Eocene boundary (~48 Ma). At the same time, benthic foraminifera record major changes in carbon isotopes, with a decline in $\delta^{13}C$ of ~2 to 2.5‰, indicating that the temperature changes coincided with profound changes in the carbon cycle. Combined, these trends are consistent with a long-term increase in atmospheric CO_2, perhaps caused by increased volcanic outgassing or decreased net organic carbon burial. However, a temporal offset exists between $\delta^{13}C$ and $\delta^{18}O$, with the long-term minimum in $\delta^{13}C$ significantly preceding peak global temperatures indicated by the long-term minimum in $\delta^{18}O$. This offset may suggest changes in carbon fluxes across this interval of long-term global warming. To constrain possible causes of the offset between $\delta^{13}C$ and $\delta^{18}O$ across the late Paleocene to early Eocene, we analyze the timing of $\delta^{18}O$ and $\delta^{13}C$ signals from each individual site within the Cramer et al. 2009 benthic foraminiferal composite [*Paleoceanography* 24.4 (2009)]. Our analysis shows that trends in $\delta^{13}C$ consistently lead trends in $\delta^{18}O$ at each site, consistent with varying carbon sources across this interval. However, the duration of the offset between the long-term minima in $\delta^{13}C$ and $\delta^{18}O$ varies significantly between sites. We find that the duration of this offset is greatest at high latitude sites, potentially indicating that changing patterns of deep water formation contribute to the apparent decoupling between $\delta^{13}C$ and $\delta^{18}O$ trends.

2-22 NEW EOCENE BENTHIC STABLE ISOTOPE RECORD FOR THE PACIFIC: COMPLETING A 22 MA HIGH-RESOLUTION SINGLE SITE PALEOGENE SECTION FROM SHATSKY RISE

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We present a new high-resolution, benthic stable isotope record (*Nuttallides truempyi*, *Oridorsalis umbonatus*) for ODP Site 1209 spanning 44 to 56 Ma at 5 kyr resolution. Site 1209 is located on the southern high of Shatsky Rise (at 2387 m water depth) in the west-equatorial Pacific and encompasses an expanded Paleogene section. These new data, by extending an existing record at the same site, creates a 22 million year long record, the longest such benthic isotope record for the Pacific Ocean. Multiple carbon stable isotope excursions during the Ypresian and Lutetian correspond in timing and magnitude to previously described hyperthermal layers. These events are characterized by maxima in XRF core scanning Fe intensities and pronounced minima in the wt% coarse fraction indicating carbonate dissolution throughout the 1209 record. The new astronomically calibrated stable oxygen isotope record helps define the true extent of the Early Eocene Climate Optimum (EECO, 49.1 to 52.1 Ma) and the beginning and termination of global cooling after the EECO (45.5 - 49.1 Ma). The cooling trend is interrupted by two major warming episodes at 47.2 and 46.7 Ma. A major shift in the benthic carbon isotope record in magnetochron C23n coincides with the global reorganization of the plate-mantle system suggesting a causal relationship. Benthic carbon isotope records from Atlantic and Pacific converge from 52 to 47.5 Ma pointing to a closer connection of deep-water convection initiating well in advance of the final connection ~40 Ma ago.

2-23 **EARLY EOCENE CLIMATE VARIABILITY IN THE NORTH SEA BASIN: A BELGIAN PERSPECTIVE**

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Abrupt climate change, involving threshold crossing towards different climate states, frequently occurred in the past such as during early Eocene greenhouse warming events. The environmental impact of these so-called hyperthermals has been primarily studied in deep-sea sites, while their impact on shallow-marine ecosystems is relatively unexplored, specifically for the less prominent hyperthermals that occur after the Paleocene-Eocene Thermal Maximum (PETM). We present the lithologic, biotic and geochemical expression of these hyperthermals in shallow marine silty-clay sequences in the type region of the Ypresian in the southern parts of the North Sea Basin (Belgium, Kallo reference site). Our stable isotope records reveal a succession of small carbon isotope excursions, correlatable to the high-resolution records of ODP Site 550 (North Atlantic - Goban Spur) and IODP Site 1263 (South Atlantic - Walvis Ridge). In this shallow marine setting, the CIE's correspond to distinct facies changes and regional biotic events. The biotic expression includes basin-wide blooms of characteristic foraminiferal taxa and compositional changes in nannoplankton assemblages. The onset of the Early Eocene Climatic Optimum (EECO) coincides with the deposition of more fine-grained sediments and marks the constitution of a renewed foraminiferal shelf fauna. Although early Eocene hyperthermals in shallow-water sequences still need to be fully characterized relative to background conditions, our results indicate that also the less extreme post-PETM hyperthermal events triggered distinct perturbations of marine ecosystems at the southern edge of the North Sea Basin. Yet, the overall evolutionary impact of this sequence of global warming events seems to be limited. Our data also emphasize the potential application of stable isotope stratigraphy within a holostratigraphic framework, enabling correlation over a wide range of marine settings in the North Sea Basin and North Atlantic shelf areas.

2-24 **HOW HOT IS HOT? PALAEOTEMPERATURES IN THE EOCENE INDO-PACIFIC WARM POOL**

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One of the motivations for studying sea surface temperatures (SST) from past warm climates such as the Early Eocene (~55–52 Ma) is the enhanced understanding this brings of possible future greenhouse conditions. The Indo-Pacific Warm Pool (IPWP) is the warmest body of open-ocean water, and together with the tropical regions plays a fundamental role in the redistribution of heat around the globe. Thus, obtaining SST estimates from such areas during past intervals of global warmth can provide deeper insights into the complex atmosphere-ocean coupled system and associated climate feedbacks under a greenhouse world. Despite the fact that significant advances are being made in palaeoclimate model performance with a broader range of climate feedbacks being considered, SST constraints and model-data mismatches still present a challenge for models, urging greater data collection. The study aims to produce empirical data in order to reconstruct SSTs from around the IPWP of the Eocene. This is achieved by using different geochemical proxies associated with planktonic foraminiferal calcite shells (Mg/Ca, $d^{18}O$). Very often, infilled tests are found in the record, and the possibility to turn these archives into useful information is currently being explored by trying to separate the original part of the test from the infilled one. The resulting pilot data presented here were derived from different Eocene foraminiferal species from the Moogli Mudstones of Papua New Guinea, and show SST estimates from the IPWP area of the Early Eocene, as well as species-specific water depth habitats. The results could significantly enhance our understanding of the different processes underpinning greenhouse climates and the ability of models to represent the Earth system.

2-25 **DEEP-SEA STABLE ISOTOPE STRATIGRAPHY FROM THE LATE EOCENE OF IODP SITE U1411: PRECESSION AND ECCENTRICITY PACING AT THE CLOSE OF THE EOCENE GREENHOUSE**

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IODP Expedition 342 drilled sediment drifts on the Newfoundland margin to recover high-resolution records of North Atlantic ocean-climate history through the Late Cretaceous and Early Cenozoic. A major achievement was recovery of an expanded sequence through the Eocene-Oligocene climate transition (EOT). Here we showcase the exceptional orbital cyclicity imprinted in high-resolution (2.5-3 cm/kyr), well preserved (glassy) deep sea benthic foraminifera and bulk sediment $\delta^{18}O$ and $\delta^{13}C$ from Site U1411 and U1406 during the last ~1.4 million years of the Eocene. Initial results show that $\delta^{13}C$ in the older part of this interval (Site U1406 cores) is on average 0.75‰ higher than the upper part. This alludes to major decrease in benthic $\delta^{13}C$ between 35.75 and 35.2 Ma on the western Atlantic margin, although the exact timing is currently uncertain due to a sampling gap. Spectral analysis on the U1411 sequence reveals strong precession (~20kyrs) signals in $\delta^{18}O$ and $\delta^{13}C$ in both bulk and benthic records, with a persistent modulation at the 100kyr and 400 kyr eccentricity bands, especially for $\delta^{13}C$. In contrast, obliquity is surprisingly weak compared to records from other regions. A provisional tuning to the stable 400 kyr eccentricity cycle helps refine the Site U1411 age model. The detailed time framework and nature of the $\delta^{13}C$ shift will have implications for interpreting the role of orbital forcing and changes in Atlantic circulation in priming the Earth system for the shift into the icehouse.

2-26 **SIGNIFICANT DECREASE IN ATMOSPHERIC PCO2 PRIOR TO THE EOCENE-OLIGOCENE TRANSITION**

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A unique collection of fossil leaves belonging to species *Eotrigonobalanus furcinervis* (extinct trees of the beech family, Fagaceae) from a stratigraphic sequence in central Germany was utilised to derive an atmospheric pCO_2 record with the stomatal proxy method. The record comprises multiple data points spanning the late middle to latest Eocene, two sampling levels which may be earliest Oligocene, and two samples from later in the Oligocene. The new record indicates that pCO_2 decreased continuously by ca. 40% in the late middle to late Eocene, from ca. 630 ppm to ca. 410 ppm at the Eocene-Oligocene boundary. Based on the subsequent records, pCO_2 in later parts of the Oligocene was similar to latest Eocene values. A significant drop in pCO_2 at the Eocene-Oligogene boundary is not observed, in contrast to marine oxygen isotope records. These results may suggest that: 1) decrease in pCO_2 preceded the large shift in temperatures and/or ice sheet expansion that characterizes the Eocene-Oliogocene boundary, probably when a certain threshold of pCO_2 was crossed; and 2) that pCO_2 levels – and thus this climate change threshhold – were lower than previously assumed, suggesting important implications for estimations of climate sensitivity.

Results published in: Steinthorsdottir et al. (2016). Climate of the Past 12, 439-454.

2-27 **TIMING AND EVOLUTION OF THE EOCENE-OLIGOCENE CLIMATE TRANSITION: NEW INSIGHT FROM IODP SITE U1411, NORTHWEST ATLANTIC**

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One of the most expanded deep-sea sections spanning the Eocene-Oligocene Transition (EOT) known to date was recovered at IODP Site U1411 on the Southeast Newfoundland Ridge. The combination of high sedimentation rates and excellent preservation of carbonate microfossils and organic biomarkers at this site allow development of new climate and paleoceanographic records for the northwestern North Atlantic – providing much needed insight for a region where very few EOT records currently exist. We have assembled a composite splice of high-resolution X-ray fluorescence core scanning, coulometric %CaCO3, magnetostratigraphic, biostratigraphic, and bulk carbonate stable isotope records spanning the EOT interval of Site U1411. Regular cyclicity is observed in most of the XRF elemental records, with particularly prominent cycles in calcium, zirconium, and barium. Bundles of precessionally paced cycles are identified in the XRF data, which we use as a basis for astronomical tuning. Bulk carbon isotope ($d^{13}C$) stratigraphy provides a means of precisely correlating Site U1411 to the Eocene-Oligocene boundary stratotype at Massignano, Italy, and key pelagic sections across the Atlantic basin. Integration of these multi-site records reveals that a series of brief, negative $d^{13}C$ excursions and pulsed carbonate compensation depth (CCD) shoaling events preceded the first benthic $d^{18}O$ step at the onset of the EOT. Moreover, application of our new astronomical age model for Site U1411 indicates that a prolonged, but stable, intermediate climate state existed prior to major ice-sheet expansion and CCD deepening at the second benthic $d^{18}O$ step (Oi-1). These results have important implications for our understanding of interaction between the carbon cycle and ice-sheet growth across the EOT and shed new light on the chain of climate events during the EOT.

2-28 **EXPLORING MECHANISMS OF CHANGE AT THE EOCENE-OLIGOCENE TRANSITION**

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The growth of the Antarctic ice sheet at the Eocene-Oligocene Transition (EOT) marks one of the biggest changes in the Paleogene Earth system, however the mechanisms behind this transition are still not fully understood. Modelling studies have shown that declining atmospheric pCO2 was likely the dominant driver of the global cooling, but changes in palaeogeography can also have significant regional impacts on climate. Questions remain as to why such a major transition occurred at this point in time: was it the manifestation of multiple feedback processes or was the Earth more sensitive to pCO2 change around the time of the EOT? This research addresses these questions using results from a large ensemble of >40 fully coupled GCM (HadCM3L) simulations. This ensemble is used to assess the relative contributions of pCO2 reduction, ice sheet growth and palaeogeographic change (both in terms of the direct effect on climate and on climate sensitivity) on Antarctic and global climate at the EOT and in the Paleogene more broadly. In agreement with earlier research, pCO2 is consistently found to be the likely dominant driver of global climate at the EOT. The effect of Antarctic ice sheet growth is more regional and the direct effect of palaeogeographic change is more simulation specific. Climate sensitivity to a doubling of pCO2 varies subtly between simulations, but the palaeogeography around the time of the EOT is not statistically more sensitive to pCO2 change than earlier (e.g. Upper Cretaceous) palaeogeographies. However, the cooling invoked by pCO2 decline in these model simulations is not sufficient to result in major Antarctic glaciation, suggesting other important feedback processes are missing from the model setup. The magnitude and possible causes of the drop in pCO2 at the EOT remain open questions.

2-29 MAGNETOFOSSIL AND OCEANOGRAPHIC CHANGE ACROSS THE EOCENE-OLIGOCENE TRANSITION IN A NORTHWEST ATLANTIC SEDIMENT DRIFT

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The Eocene-Oligocene Transition (EOT, ~34 Ma) marks a step change in the Earth climate system. How marine productivity and benthic ecosystems transitioned to the presence of permanent ice on Antarctica and changes in ocean and atmospheric circulation is informed primarily by observations from equatorial and high southerly latitudes. Few of these studies have examined how magnetotactic bacteria (MTB) communities— prokaryotic biomarkers for suboxia and, potentially, marine productivity, nutrient availability, and C_{org} supply— responded to the EOT. To fill this gap, IODP Expedition 342 (Newfoundland Sediment Drifts) Site U1411 recovered an exceptional record of the EOT from the northwest Atlantic Ocean. Here, we present a shore-based magnetostratigraphy for the E-O boundary interval. At Site U1411, the EOT, which is nearly coeval with the C13n/C13r chron boundary, is magnetically characterized by a 2-order of magnitude decrease in the intensity of the natural remanent magnetization and anhysteretic remanent magnetization from the Eocene to the lower Oligocene that is not accompanied by a change in the lithostratigraphy. Distinct central ridges in high-resolution FORC diagrams and double Verwey transitions in low-temperature remanence measurements demonstrate the biogenic origin of abundant single-domain magnetite in upper Eocene sediments and their absence in lower Oligocene sediments. The diversity and preservation of the MTB assemblage is interpreted within the context of continuous 2cm resolution $CaCO_3$, Mn, S, and Fe X-ray fluorescence records. Our results hint at dramatic changes in sediment redox conditions in the North Atlantic during the lead up to, onset of, and acme of Oi-1 that controlled the diversity and preservation of MTB during the transition from a greenhouse to icehouse.

2-30 **NORTH ATLANTIC OLIGOCENE SEA SURFACE TEMPERATURE CHANGE AT IODP SITES U1406 AND U1411 (NEWFOUNDLAND MARGIN)**

Gwen Owen Jones, Matthew Carmichael, David Naafs, Richard Pancost, Zhonghui Liu, Paul Wilson, Steve Bohaty

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The Oligocene epoch (~34 – 23 Ma) marks the early phase of the modern 'Icehouse' climate system, following the onset of rapid high-latitude cooling and establishment of permanent Antarctic ice sheets at the Eocene-Oligocene transition (EOT, ~34 Ma). The Oligocene is often overlooked in Paleogene climate studies, but deep-sea proxy records suggest that it was characterised by highly dynamic behaviour of the East Antarctic ice sheets and higher-than-present atmospheric carbon dioxide levels. Our understanding of this critical time interval is currently limited by the scarcity of continuous high-resolution records from mid-to-high latitude regions of the Northern Hemisphere. Thick hemipelagic drift sections recovered at IODP Expedition 342 Sites U1406 and U1411 on the J-Anomaly and Southeast Newfoundland ridges provide an opportunity to fill this knowledge gap, due to high sedimentation rates (~3 cm/kyr) and excellent preservation of carbonate microfossils and organic biomarkers. Here we present an initial organic geochemical proxy record of sea surface temperature using the alkenone unsaturation index (Uk'37) for the Northwest Atlantic (Sites U1406 and U1411) that spans the mid-to-late Oligocene, exhibiting apparent strong variability. These results will be directly integrated with high-resolution benthic foraminiferal stable isotope records, which will be used to document orbital-scale environmental changes on the Newfoundland margin.

2-31 **ASTRONOMICAL FORCING OF EOCENE ASIAN MONSOONS**

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Monsoons are the major source of moisture for central Asia but their dynamics remain poorly understood. To provide insight in their driving forces we focus on early monsoonal records during the transition from a greenhouse to an icehouse world, as a part of the ERC "MAGIC" project.

The continental mudrocks of the Xining Basin in central China provide a unique opportunity to study early monsoons because of their relatively continuous deposits from 40 to 15 Ma yielding reliable records of Earth's magnetic reversals and observed astronomically-forced alternations of monsoonal moisture. This study specifically aims to extend the stratigraphy further back in time to examine cyclicity in the Early to Middle Eocene.

Magnetostratigraphic analysis of three parallel sections near Xining shows three chrons that are correlated to C20, C21 and C22. The correlation is supported by U/Pb radiometric dating of zircons in a tuff (50.0 ± 0.4 Ma). The lithostratigraphy shows dry mudrocks alternating with wetter fluvio-lacustrine intervals in regular 10-12 meter cycles. These cycles are paced by the 405 kyr eccentricity cycles according to the age model, with lacustrine facies occurring in eccentricity maxima. This indicates astronomically-forced monsoons at this time. Towards the Late Eocene the lacustrine intervals become increasingly gypsiferous and the cyclicity disappears. This is linked to the 4th Paratethys sea incursion by supplying moisture via the westerlies.

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