British Ecological Society

The Geological Society

PAST CARBON ISOTOPIC EVENTS AND FUTURE ECOLOGIES:

PALAEOANALOGUE CIEs AND CURRENT BIOSPHERE & ECOLOGICAL CHANGE AS GUIDES TO THE 22ND CENTURY AND BEYOND

2nd and 3rd November 2010

The Geological Society, Burlington House

ABSTRACT BOOK

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Introduction - Why consider Carbon Isotope Excursions (CIEs) as palaeoanalogues for current warming

Jonathan Cowie, Concatenation Science Communication, www.science-com.concatenation.org

Geology tells us that in the past there have been episodes of abrupt, carbon-induced global warming known as 'carbon isotope excursions' (CIEs) involving carbon-12 (^{12}C). Since the Industrial Revolution, we have been processing ever-increasing amounts of ^{12}C from both the fast as well as the deep carbon cycles for food and fuel respectively. In the case of London, some of the resulting environmental impact of the former was slow to be addressed by policy-makers but was eventually by a major investment that brought substantial environmental improvement as well as major public health benefits. With regards to global climate, Svante Arrhenius first estimated the degree of likely human-induced warming.[1] Today we now confident that the disruption of both the carbon cycles is altering the atmosphere and this in turn is affecting the global climate[2]. We are now at least trying to curb greenhouse gas emissions even though there is ironically a vociferous climate sceptic movement: 'ironically' because those nations that take the opportunity to wean themselves off of fossil fuels will be in an economically better position when finite cheap fossil fuel declines, irrespective of whether or not climate change is disastrous.[3] But should we focus more on adaptation? The Intergovernmental Panel on Climate Change has warned us to be aware of 'climate surprises'.[4] Some have been concerned that CIE events may be relevant to current global warming and possible future 'climate surprises'.[5] However, while the IPCC in its latest assessment[6] has not flagged CIEs as of concern, it has, in the main body of its ~1,000page report, briefly noted that the early Eocene CIE is "a striking example of massive carbon release and related extreme climatic warming". Given this, it is arguably time to seek answers to some key questions. These might include:-

1. What causes natural CIE events?
2. What are the chances of current warming triggering a 'natural' CIE? (Negligible, small, medium, high, almost certain?)
3. Approximately what temperature change would it likely entail?
4. Would this temperature change be inclusive within, or additive to, current IPCC human-induced warming estimates?
5. Given that today our planet has ice sheets, whereas the already warmer Earth of the initial Eocene CIE did not, would there be even further possible warming from biosphere reserves of carbon in permafrost?
6. What impacts would there be on humans and the ecosystems on which we depend?
7. What signals can we look out for that might be suggestive of a forthcoming CIE?
8. What are the policy implications (hence social value) of this research?

This symposium may begin to answer some of these questions.

References

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Biography

Jonathan's career has been in science communication (promotion, publishing, policy analysis and lobbying) with learned and professional scientific bodies. This has included some 15 years with the Institute of Biology, several of which as Head of Science Policy that involved providing a forum for 69 specialist learned biological societies. He has maintained a personal interest in the human ecology and resource use following his postgraduate studies on the environmental impact of UK electricity supply policy. Among other activities, in recent years he has focussed on climate change concerns. CUP has just commissioned an expanded second edition of his 2007 book *Climate Change: Biological and Human Aspects*.

The Tempo of Climate and Carbon Cycle Variability Across the Paleocene-Eocene Boundary: Implications for the Origin of Hyperthermals

Professor James C. Zachos, Earth & Planetary Sciences Department, University of California, Santa Cruz, CA 95064, USA; jzachos@pmc.ucsc.edu

The Paleocene-Eocene Thermal Maximum (PETM; ~55 May) was caused by the relatively rapid release of thousands of petagrams of carbon as evidenced by a global carbonate dissolution horizon (i.e., ocean acidification) and a large negative carbon isotope excursion. The exact source(s) and hence trigger, however, remain a matter of debate. The possibilities for such a large and rapid flux of carbon are few and include thermal combustion of crustal carbon by intrusive volcanism, and dissociation of methane clathrates possibly triggered by orbital forcing. One key to identifying the cause of this event is to first place it within the context of longer-term background (orbital-scale) variability in the carbon cycle and climate. Previous studies have demonstrated that the PETM was followed by several smaller warming events, or hyperthermals, which might share a similar origin. A second key is to constrain the rate at which the carbon was released during the event. To date, the latter has been achieved primarily with "high-resolution", but often incomplete or condensed carbon isotope records from marine and terrestrial sequences. Some records suggest an abrupt onset ($<10^3$ y), while others suggest a more gradual onset. The disagreements are largely an artifact of sedimentary processes that either truncate or stretch records. Here, I assess the timing and scale of the PETM in the context of new high-resolution (i.e., orbital scale) carbon isotope and dissolution records, and discuss implications for a triggering mechanism of each hyperthermal.

Biography

James Zachos, Ph.D., is a Professor of Earth and Planetary Sciences at the University of California at Santa Cruz (UCSC). Dr. Zachos' research interests include the biological and chemical evolution of the oceans, and links to climate change. He received his Ph.D. in Oceanography from the University of Rhode Island in 1988, was a post-doctoral fellow at the University of Michigan, and a fellow at University of Cambridge. He has authored over 100 peer-reviewed publications on Earth's past climate, particularly the periods of abrupt and extreme greenhouse warming, as well as on the initiation of Antarctic glaciation, and past ocean acidification. He is a fellow of the American Geophysical Union, the Geological Society of America, and the Canadian Institute for Advanced Research. He has received a Presidential Young Investigator Award and an Humboldt Award for his research on past climates. Dr. Zachos also contributed to the 2007 IPCC Fourth Assessment Report.

Theories of the cause and nature of the Toarcian and other CIEs

Dr Anthony Cohen, The Open University, CEPSAR (Centre for Earth, Planetary, Space and Astronomical Research), The Open University, Milton Keynes MK7 6AA

The marine and terrestrial sedimentary records contain detailed histories of the Earth's global carbon cycle. Throughout the Phanerozoic era, as well as earlier in Earth history, a small number of unusually extreme, transient events have been associated with prominent carbon isotope excursions (CIEs) that are thought to have been caused by the rapid introduction of large amounts - thousands of gigatonnes - of isotopically 'light' carbon to the ocean-atmosphere system. The major CIEs coincided with severe global environmental perturbations and occurred against a relatively stable long-term background, or one of much more gradual environmental change. Despite major differences between the underlying conditions upon which past CIEs occurred, many of the key features with which the events were associated were broadly similar and included: Severe global warming, acidification and deoxygenation of the oceans, extinction of marine and terrestrial species, and sudden shifts in the Earth's climate and its hydrological cycle. Understanding how the Earth responded to and recovered from these events in the past represents a major challenge, which additionally is of direct relevance to many of the present-day issues surrounding anthropogenically-induced environmental change. Records of past CIEs are likely to be particularly helpful in estimating the longer-term consequences of anthropogenic environmental change over the coming centuries.

The Toarcian CIE and Oceanic Anoxic Event (OAE) occurred c. 183 million years ago in the Early Jurassic. The impact of the event has been documented in many marine and terrestrial records of Toarcian age from around the world. Despite their great age, some of the sections containing the Toarcian CIE are exceptionally well preserved and stratigraphically expanded, thus allowing records through the event to be established with a temporal resolution of a few centuries. Some of these records bear features that are notably similar to those of the Paleocene-Eocene Thermal Maximum and other CIEs, and suggest that the Toarcian CIE was caused by the addition of thousands of gigatonnes of isotopically 'light' carbon to the biosphere in perhaps as little as a few millennia or less. Annual rates of carbon addition may have approached those occurring today as a result of human activity. In contrast to the rapidity of its onset, records of the Toarcian CIE and of other comparable events show that the recovery of the Earth system occurred over much longer intervals of at least a few hundred thousand years. Taken together, these observations place strong constraints on the potential causes of the Toarcian and other CIEs. The observations also provide valuable information from natural geological analogues about how the Earth system responds to abrupt, large-scale carbon addition.

Biography

Anthony Cohen is a Senior Research Fellow at the Department of Earth and Environmental Sciences at The Open University. He has been involved in a wide range of advances in the development and application of radiogenic isotope geochemistry for 30 years. Over the last 15 years, he has developed novel isotopic procedures (principally centred on Os- and Mo-isotope analyses) and new techniques for obtaining ultra high-resolution C-isotope data from sedimentary successions up to 200 million years old. He uses these approaches, along with high-resolution sedimentary and biotic information, to study some of the major C-isotope events, hyperthermals and Oceanic Anoxic Events of the Phanerozoic. Having quantified some of the past responses of the Earth System to severe environmental perturbations, the overall goal is to improve our understanding of the potential longer-term consequences on the multi-decadal to centennial timescale of present-day, anthropogenically-driven global change.

The Cause and Nature of the Current and Possible Future Carbon Isotope Excursions

Professor Peter Cox, University of Exeter, School of Engineering, Mathematics and Physical Sciences, Harrison Building, Streatham Campus, University of Exeter, North Park Road, Exeter EX4 4QF

Global warming since the industrial revolution on Earth is almost certainly due to anthropogenic emissions of greenhouse gases - the underlying climate science is well-founded in the physics of the 19th and early 20th centuries. Increases in atmospheric carbon dioxide (CO_2) in the last 200 years have been associated with changes in the fraction of the heavier carbon isotopes which indicates that the rise in CO_2 has been caused primarily by the burning of fossil fuels. Recent Carbon Isotope Excursions (CIEs) are therefore one of the reasons why we are able to understand the causes of contemporary climate change.

Nevertheless there are still very significant uncertainties in how the Earth's climate will evolve in the future, and these uncertainties become very pronounced as the climate is pushed beyond its current regime of operation. The isotope records contain much evidence of abrupt changes in climate in the past. Is it possible that the Earth's climate could "runaway"or flip to a new "hothouse" stable state under scenarios of increased greenhouse gas emissions? The notion of such abrupt climate changes or "tipping points" is now a very hot topic in climate change research (excuse the rather dark pun).

One of the greatest concerns is that vast reserves of carbon, in the form of methane hydrates stored in ocean sediments and beneath permafrost, could be destabilized by global warming. An event of this type is considered to be the likely explanation for the most pronounced CIE seen in the Earth's geological record – namely the Palaeocene-Eocene Thermal Maximum (PETM). The PETM can be seen as both an analogue for 21st and 22nd century global warming, and also a warning of the possibility of very strong feedbacks that could significantly amplify human-induced global warming.

This talk will summarize the latest published work world-wide which attempts to relate the PETM Carbon Isotope Excursion to climate sensitivity and to the possibility of a future destabilization of methane hydrates.

Biography

Prof. Peter Cox is Professor of Climate System Dynamics and leader of the "Climate Change and Sustainable Futures" theme at the University of Exeter. He has previously held posts at the Met Office-Hadley Centre (1990-2004) and the Centre for Ecology and Hydrology (2004-2006) where he was Science Director for Climate Change. Prof Cox's personal research has focussed on interactions between the land-surface and climate, including the first climate projections to include vegetation and the carbon cycle as interactive elements. These simulations demonstrated the potential for the land carbon cycle to provide a significant acceleration of global warming, and also suggested that the Amazon rainforest could dieback under climate change. Prof. Cox was a lead-author on the IPCC Fourth Assessment report, was a member of the Royal Society's expert groups on "Ground-level ozone in the 21st century" and "Geoengineering the climate", and has been amongst the most highly-cited authors in climate change research during the last decade (http://sciencewatch.com/ana/fea/09novdecFea/).

Comparison of early Eocene and end-21st century climate Model forecasts

Professor Paul Valdes, University of Bristol, School of Geographical Sciences University of Bristol, University Road, Bristol BS8 1SS

The early Eocene world is characterized by high carbon dioxide concentrations, similar in value to those predicted for the end of the 21st century. It is therefore of interest to examine whether the climate models used for future climate change are able to simulate these past extremely warm climate regimes. We show results from a set of new climate model simulations using a version of the Hadley Centre Climate Model. The basics simulation is unable to simulate the warmth of the Eocene. We examine the sensitivity of the results to uncertainties in the boundary conditions of the model. The modelling shows that atmosphere, oceans and vegetation must be fully represented. Uncertainties in the continental reconstructions can also help produce small additional warmth. However the model remains too cold compared to the palaeodata, suggesting that the model is too insensitive to change. Further simulations investigate the physical parameterisations within the model. These results suggest that a much better match to data can be achieved if we change the representation of clouds and other physics within the model.

Biography

Prof. Paul Valdes is Professor of Physical Geography and Head of the School of Geographical Sciences. He is an internationally recognized researcher on modelling Earth system change. He has published more than 120 peer-reviewed papers on various aspects of past, present, and future climate change. A few highlights of his research include: (a) the first ever high resolution model integration for the Last Glacial Maximum, (b) Calculation of the global climate response to Amazonian Deforestation, and (c) Documentation of the ability of climate models in simulating storm tracks in present and past climates. He led the team that developed the GENIE model, and leads several large national projects and consortia on climate change.

He is also non-executive director of Greenstone Carbon Management. In 2007, he won a Royal Society Wolfson Merit Award for his work on climate change.

Cretaceous carbon-isotope excursions and their significance for global change

Dr Hugh C. Jenkyns, Oxford University, St Edmund Hall, Oxford OX1 4AR

The Cretaceous Period was one of the most significant intervals in Earth history for the formation of petroleum source rocks, with ~60% of all known oil formed during this time. This Period is conventionally viewed as representing the 'greenhouse state' of the planet, with equatorial sea-surface temperatures >30˚C and polar sea-surface temperatures >15˚C. Through the medium of fossil carbon, in organic-rich black shales, oil and carbon dioxide, heat is effectively being transmitted along a geological time-line from the past to the present: energy is being conserved. The isotopic signature of this process, as registered over the last two centuries, is a 1‰ negative carbon-isotope excursion registered in skeletal carbonates, ice cores and organic matter (wood).

A number of negative carbon-isotope excursions, similarly recording the addition of isotopically light carbon into the ocean–atmosphere system, punctuate the Cretaceous record. Many of these excursions are accompanied by falls in the oxygen-isotope ratio of carbonate minerals or increases in the value of the organic geochemical proxy, TEX_{86}, implying abrupt (millennial scale or less) warming of the surface ocean by several degrees. There is some evidence that the signal of increased temperature propagated from the atmosphere to the ocean, in accord with the notion that gases such as carbon dioxide and/or methane were directly involved.

The Cretaceous greenhouse was also characterized by broader, longer period positive carbon-isotope excursions registered in carbonate and marine and terrestrial organic matter. These phenomena were apparently forced by atmospheric warming that resulted in increased continental weathering and fluvial nutrient flux, enhanced plankton productivity, regional deoxygenation, accelerated carbon flux to the seafloor and greater sequestration of organic matter in marine and lacustrine sediments. Burial of photosynthetically produced carbon, with its discrimination against the heavier stable isotope, ^{13}C, led to relative increase of this component in the ocean–atmosphere system. The relatively high temperatures characteristic of these phenomena, some of which have been termed Oceanic Anoxic Events, appear to have been tempered somewhat by drawdown of carbon dioxide due to globally increased burial of marine organic matter and weathering of continental rocks.

In some parts of the Cretaceous record the abrupt negative carbon-isotope excursions interrupt these broader positive excursions, suggesting complex interactions in different components of the carbon cycle during intervals of global warming.

Biography

Hugh C. Jenkyns has more than 40 years research experience focused on the palaeoceanography and palaeoclimatology of Jurassic and Cretaceous marine sediments, particularly pelagic and shallow-water carbonates of the Alpine-mediterranean region. He has undertaken research at the Universities of Leicester, Basel, Cambridge and Oxford. His fields of expertise range across geochemistry (C, Fe, S, N, O isotopes), sedimentology and stratigraphy. He has published extensively on the causes and consequences of 'oceanic anoxic events', and the application of chemostratigraphy (particularly carbon-isotope stratigraphy and strontium-isotope stratigraphy) to understanding Mesozoic palaeoenvironmental change. He has considerable experience of DSDP and ODP science, both shore-based and at sea, largely centred in the Pacific Ocean (Legs 33, 61, 143), and has published the first palaeotemperature data from the Cretaceous of the Arctic Ocean.

Climate change and mammalian evolution across the PETM/IETM in the continental record of North America (mid-latitude)

Ross Secord[1,2], Jonathan I. Bloch[2], Stephen G. B. Chester[3], Douglas M. Boyer[4], Scott L. Wing[5], and John Krigbaum[6]

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2. Florida Museum of Natural History, University of Florida, Gainesville, FL 32611-7800, USA.
3. Department of Anthropology, Yale University, New Haven, CT, 06520, USA.
4. Department of Anthropology and Archaeology, Brooklyn College, City University of New York, NY 11210, USA.
5. Department of Paleobiology, Smithsonian Museum of Natural History, Washington, DC 20560, USA.
6. Department of Anthropology, University of Florida, Gainesville, FL 32611-7800, USA.

Dramatic climate change during the Paleocene-Eocene thermal maximum (PETM) has been documented in both the marine and continental records. Global temperatures increased by ~5-9 °C at mid- to high-latitudes. The warming of high-latitude land bridges (Koch, 1992) allowed mammals to disperse among the northern continents resulting in a profound, and permanent reorganization of mammalian faunas (Gingerich, 1989). The earliest perissodactyls (odd-toed ungulates), artiodactyls (even-toed ungulates), and euprimates ("true" primates) first appeared in North America, Europe, and possibly Asia during the PETM. Transient "dwarfing" occurred in several mammalian groups during the PETM, whereby individuals in presumed evolutionary lineages become markedly smaller (Gingerich, 2006).

The most detailed records of continental climate and faunal change through the PETM come from the Bighorn Basin (BHB), Wyoming, USA. In the northern BHB the PETM is recognized by a decrease in $\delta^{13}C$ values in soil carbonates of ~5.5‰ (Bowen, 2001), marking the onset of the associated carbon isotope excursion (CIE). From this area, stable oxygen isotopes in *Phenacodus* (an archaic ungulate) tooth enamel ($\delta^{18}O_E$) and other evidence suggests a pulse of warming directly below the CIE, followed by additional warming in the CIE (Secord et al., 2010). A similar pattern is seen in some marine sections (Sluijs et al., 2007).

In the southern BHB (Cabin Fork drainage) new carbon isotope measurements of mammalian tooth enamel ($\delta^{13}C_E$) provide a detailed record of the CIE. Mammalian herbivores reflect the $\delta^{13}C$ values of vegetation they consume, which in turn tracks atmospheric $\delta^{13}C$ with influences from environmental factors. Phenacodontid mammals (*Ectocion* & *Copecion*) record a negative shift of ~4.5‰ at the onset of the CIE, which is similar to the shift seen in leaf waxes from Cabin Fork (Smith et al., 2007). A paleoclimate record can be inferred using $\delta^{18}O_E$ values from *Coryphodon*, an archaic ungulate. *Coryphodon* was probably semiaquatic or closely tied to water (Clementz et al., 2008; Secord et al., 2008) and was the largest mammal in the PETM fauna. For these reasons it should be the best suited taxon for tracking meteoric water $\delta^{18}O$ values. *Coryphodon* $\delta^{18}O_E$ values exhibit an increasing trend within the CIE, which is consistent with increasing temperature based on the modern meteoric water $\delta^{18}O$-temperature relationship. This is followed by a rapid decrease in *Coryphodon* $\delta^{18}O_E$ values at the end of the CIE. Remarkably, temperature changes inferred from $\delta^{18}O_E$ mirror trends in body size in the earliest horses (Equidae), as inferred from first molar area. The earliest known equid, *Sifrhippus* (formerly *Hyracotherium*), first occurs ~3 m above the onset of the CIE, and is the most common genus in the PETM fauna. Over an interval of ~30 m within the CIE, *Sifrhippus* shows a ~30% reduction in body size from an average of ~7 kg to ~5 kg. This is followed by a rapid increase in body size of ~70% from ~5 kg to ~8.5 kg at the end of the CIE. The covariation of temperature and *Sifrhippus* body size through the CIE is significant ($p \leq 0.05$), but warming may not directly drive decreasing body size. We propose that smaller body size was favored by reduced resources as plant productivity diminished under greater water stress caused by higher temperature and more seasonal precipitation.

Biography

Professional Preparation

The University of Nevada, Reno	Geology	B.S., 1993
The University of Wyoming, Laramie	Geology	M.S, 1996
The University of Michigan, Ann Arbor	Geology	Ph.D., 2004
Smithsonian Institution	Paleobiology	Postdoc, 2004-2005
Florida Museum of Natural History	Vert Paleontology	Postdoc, 2007-2008

Current Appointment

Assistant Professor/Curator, Earth & Atmospheric Sciences, University of Nebraska, Lincoln (2008-current).

Postdoctoral Associate, FLMNH, University of Florida (2007-2008).

Recent Relevant Publications:

Secord, R., Gingerich, P.D., and Lohmann, K.C., MacLeod, K.G., *in press,* Continental warming preceding the Paleocene-Eocene boundary: Nature.

Chester, S.G.B., Bloch, J.I., **Secord, R.**, and Boyer, D.M., *in press*, A new, small species of *Palaeonictis* (Creodonta, Oxyaenidae) from the Paleocene-Eocene Thermal Maximum: Journal of Mammalian Evolution.

Secord, R., Wing, S.L., and Chew, A., 2008, Stable isotopes in early Eocene mammals as indicators of forest canopy structure and resource partitioning: Paleobiology, no. 2, v. 34, p. 282-300.

Mid to high latitude land ecosystem changes across the Paleocene-Eocene Thermal Maximum in northwest Europe

Professor Margaret Collinson[1], Jerry Hooker[2], Rich Pancost[3] & Johan Weijers[4]

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2) Department of Palaeontology, Natural History Museum, Cromwell Road, London, SW7 5BD
3) Organic Geochemistry Unit, School of Chemistry, University of Bristol, Cantocks Close,Bristol, BS8 1TS.
4) Department of Earth Sciences – Geochemistry, Utrecht University, P.O. Box 80-021, 3508 TA Utrecht, The Netherlands.

Understanding the effects of Carbon Isotope Excursions (CIEs) on Earth's biomes requires data from both marine and continental realms and from various parts of the globe. In the case of the CIE marking the PETM there are three main areas where continental biotic response can be examined, namely North America, northwest Europe and Asia. Here we focus on northwest Europe where the CIE has been documented in the Cobham Lignite and the Reading Formation in the UK, the Tienen Formation in Belgium and the Soissonnais and Vaugirard Formations in France.

A number of UK and Belgian sites can be independently cross-correlated and include a few sites that contain co-occurring plant and mammalian fossils. A considerable amount of new data is also now available for early Paleogene mammalian faunas in the UK. To assess shifts in mammalian ecology we will compare ecological diversity spectra and dietary/locomotor adaptation biplots for the latest Paleocene, PETM and post-PETM pre-EECO faunas. In the light of new information on latest Paleocene mammalian species the level of extinctions in mammals will be re-assessed.

The PETM fruit and seed floras in the UK contain several unique taxa that do not occur in pre- or post-PETM floras but these do not signal any distinctive character for within PETM vegetation. However, high resolution palynological and plant mesofossil data across the CIE onset at Cobham document a major vegetation change. A pre-PETM low diversity, fire-prone, herbaceous fern and woody angiosperm community is replaced in the earliest PETM. Ferns are lost, fires cease, wetland plants increase (including swamp conifers and water ferns like *Azolla* and *Salvinia*) and a wider variety of flowering plants, including palms, occur. The PETM marks the first occurrence of *Salvinia* in the UK Paleogene. Also of note are a number of very rare but distinctive pollen within the PETM.

The Cobham Lignite has also provided unique organic geochemical data from high-resolution sampling. In addition to the negative CIE in bulk organic matter there is a striking negative CIE in hopanes. This indicates an increase in the methanotroph population and suggests a positive feedback where PETM warming led to increased methane release from the terrestrial biosphere, namely peat-forming areas. Ongoing research is using soil bacterial GDGTs (glycerol dialkyl tetraethers) to further understand environmental changes across the onset of the CIE at Cobham.

Biography

Margaret Collinson obtained her BSc in Botany with Marine Botany at UCNW Bangor and her PhD in Palaeobotany in the University of London. She held a Royal Society University Research Fellowship (1983-1993) initially at King's College London, relocating to Royal Holloway University of London where she was subsequently appointed Lecturer. She is now Professor of Plant Palaeobiology at Royal Holloway and her research focuses on the characterisation and evolution of continental ecosystems and their response to global environmental changes, in particular across the K/T boundary and Paleogene climate shifts (various hyperthermals and the Greenhouse/Icehouse transition). She is an Honorary Research Fellow at the Natural History Museum and an elected Foreign Member of the Royal Netherlands Academy of Arts and Sciences.

Current signs of terrestrial ecosystem change

Professor Tim Sparks, Poznań University of Life Sciences, Technische Universität München, Institute for Advanced Study, Lichtenbergstraße 2 a, 85748 Garching

Temperatures can fluctuate greatly from year to year but have risen sharply since the 1980s. However, the change already experienced is likely to be modest relative to warming predicted for the 21st century. Examining contemporary and historic data on native species in relation to climate provides evidence for the impacts of recent climate change, allows cautious prediction of changes in the coming decades, and provides parameters for modelling future impacts.

In collating evidence for climate impacts on natural systems, the Intergovernmental Panel on Climate Change (IPCC) concluded that the bulk of change was in the direction expected under a warming climate. This evidence includes examples of distributional shifts and changed population sizes, but the bulk of evidence comes in the form of phenological (timing) changes. This bias partly reflects available data, but also that phenology is simple and cheap to record and that it can be remarkably responsive to temperature.

Complications do arise in predicting future changes. Responses to climate are unlikely to be linear. There may be tipping points, step changes or inertia (delayed) effects that all need to be considered. Furthermore, species are not immune to changes happening to prey, predators and competitors, from land use change, from exploitation, and from environmental pollution.

In this talk I will present some examples illustrating the impacts of climate on terrestrial species and discuss the difficulties associated with prediction of future change.

Biography

Tim Sparks worked in agricultural research for a decade before joining the Institute of Terrestrial Ecology at Monks Wood in 1991. He developed a research programme in climate impacts, particularly phenology, and was responsible for establishing the new UK Phenology Network in 1998. He worked at Monks Wood until its closure in 2009. Subsequently he is experiencing a “portfolio career” which includes a visiting professorship at the Poznań University of Life Sciences in Poland, and a visiting senior fellowship at the Technische Universität München in Germany.

Evolution and Extinction in Marine Environments during the Paleocene-Eocene Thermal Maximum (PETM)

Professor Ellen Thomas, Department of Geology and Geophysics, Yale University, 210 Whitney Avenue, P. O. Box 208109, New Haven, CT 06520-8109, USA; ellen.thomas@yale.edu

The Paleocene-Eocene Thermal Maximum and other (less severe) hyperthermals were short (10^4-10^5 years) episodes of very warm climate, linked to emission of isotopically depleted carbon into the ocean-atmosphere system (early Eocene, ~55-50 Ma). They are marked by deep-sea acidification as seen in severe carbonate dissolution on the seafloor, but evidence for surface ocean acidification (deformation of calcifying phytoplankton) is not universally accepted. Sedimentological, ichnofossil, microfossil and geochemical evidence indicates widespread low oxygen conditions during the PETM and possibly other hyoerthermals in coastal regions and epicontinental basins (New Jersey, New Zealand, North Sea, parts of Tethys), but also at mid-depths in the Southeastern Atlantic, where the Oxygen Minimum Zone expanded. The geographic and bathyal extent of hypoxia is not well defined. Eutrophication may have increased in marginal and epicontinental basins, whereas oligotrophy increased in open ocean environments, possibly linked to increasing ocean stratification.

The overall effects of the PETM on oceanic biota and ecosystems is poorly understood, and the roles of various environmental drivers of evolutionary turnover (e.g., high temperature, deoxygenation, acidification) are not clear. Most oceanic pelagic autotroph and heterotroph fossilizing unicellular eukaryotes (calcium-carbonate, siliceous, organic walled) did not suffer major extinction. Thermophilic taxa migrated to higher latitudes, and there was considerable evolutionary turnover, with rapid evolution of short-lived ‘excursion taxa’. Possibly, high rates of environmental change affected relatively rare species.

Benthic organisms reacted differently. The rising temperatures may have led to a stepwise demise of Paleocene coralgal reefs, starting in the tropics, followed by a main PETM phase of extinction in tropics and mid-latitudes, possibly due to a combination of warming, eutrophic conditions on the shelves, and acidification. Aragonitic coralgal taxa were replaced by calcitic larger foraminifera, which dominated Tethyan early Eocene shallow-water platforms. Turnover patterns are not well established for neritic smaller benthic foraminifera, but deep-sea benthic foraminifera suffered serious extinction: 30-50% of taxa suffered extinction, including cosmopolitan, common, long-lived species (e.g., *Stensioeina beccariiformis*). Post-extinction assemblages of $CaCO_3$-secreting taxa have a low diversity, high dominance, and abundant small and thin-walled taxa, similar to assemblages during later hyperthermals. Both calcareous and agglutinated taxa were affected during the PETM, however, and at depths below the Calciumcarbonate Compensation Depth (CCD) throughout Paleocene and Eocene, earliest Eocene agglutinated assemblages are in the ‘*Glomospira*-biofacies’, seen as indicative of oligotrophic, well oxygenated conditions. Deep-sea ostracodes (Crustacea, metazoans) appear not to have been as severely affected as benthic foraminifera in the same samples.

We do not yet have a convincing explanation for the unusual extinction of cosmopolitan, abundant deep-sea benthic foraminifera, which were not able to find refugia in the global deep-sea, the largest habitat on Earth. There is presently no convincing evidence for global anoxia or globally severe acidification or global eutrophication or the reverse. Possibly, global anoxia did exist, but for such a short period that we do not see it reflected in the sedimentary record. Alternatively, the high temperatures themselves were one of the main contributing causes of extinction, through their influence on metabolic processes.

Biography

Ellen Thomas is a micropaleontologist and paleoceanographer studies the impact environmental and climate change on marine biota, at time scales from millions of years to decades, in environments from the deep sea to supra-tidal salt marshes, but benthic foraminifera (unicellular eukaryotes) are always involved. She studied at the University of Utrecht (Netherlands; 1971: BSc; 1975: MSc; 1979: PhD, title *The development of Uvigerina in the Cretan Mio-Pliocene*), moved to Arizona State University (USA) as a postdoctoral scholar, then became a staff scientist with the Deep-Drilling Project (Scripps Institution of Oceanography, San Diego; Lamont-Doherty Earth Observatory, Palisades NY). She has been a lecturer in Micropalaeontology at the University of Cambridge (UK), a research professor at Wesleyan University (Middletown, CT, USA), and is now senior research scientist at Yale University (New Haven, CT, USA).

Biological consequences of present and future acidification of the ocean

Professor John A Raven, Division of Plant Sciences, University of Dundee at SCRI, Scottish Crop Research Institute, Invergowrie, Dundee DD2 5DA

The increase in atmospheric CO_2 since 1800 has increased the surface ocean CO_2 concentration and caused a re-equilibration of dissolved CO_2 - H_2CO_3-HCO_3^--CO_3^{2-}-H^+-OH^- system. In addition to increased CO_2 (and the minor component H_2CO_3) there is a smaller relative increase in HCO_3^- and a decrease in CO_3^{2-}; H^+ increases and OH^- decreases This re-equilibration of the surface ocean inorganic carbon system of the inorganic resulting from the increased dissolved CO_2 . Surface ocean pH has already fallen by 0.1 units, with a further 0.4 pH unit decrease projected for 2100; the decreasing CO_3^{2-} will make first aragonite, and then calcite, under-saturated with respect to CO_3^{2-} and Ca^{2+} concentrations in the surface ocean well before 2100.

The most obvious biological effect will be in organisms calcified with $CaCO_3$, where calcification will become more costly in energetic terms if it can occur at all, and calcified structures outside cells will dissolve. |However, experiments in which calcification of marine organisms has been measured under future CO_2 conditions have yielded variable results: while the majority show a decreased calcification rate other work shows no effect or even an increase. Loss of $CaCO_3$ from calcified structures can be decreased by an organic coating. While chemically very different, it is of interest that the surface ocean has been undersaturated with silicic acid with respect to silica biominerals since at least the radiation of marine diatoms started 120 Ma ago. However, extant diatoms, radiolarians and sponges in the surface ocean can still silicify as a result of intracellular accumulation of silicic acid to above the concentration need to precipitate opal. Furthermore, extracellular silicified structures have an organic coating which decreases the rate of silica loss to the undersaturated medium by an order of magnitude. These possibilities notwithstanding, and the fact that the experiments were conducted on naïve organisms not given an opportunity to show genetic adaptation to increased surface ocean CO_2, there is likely to be significant extinctions of calcified marine organisms.

There will also be effects of increased surface ocean CO_2 on organisms not dependent on $CaCO_3$ structures. An obvious possibility is a stimulation of photosynthesis and hence of primary productivity as the carboxylase used in photosynthesis, ribulose biosphosphate carboxylase oxygenase, gets closer to saturation with CO_2. However, the majority of marine photosynthetic organisms have CO_2 concentrating mechanisms rather than relying on CO_2 entry by diffusion, and growth (cell division) rates often show only a small, or no, increase with increasing CO_2, although there is often more organic carbon production. These direct effects of ocean acidification on photosynthetic productivity must be viewed in the context of the predicted shoaling of the thermocline with ocean warming, and model predictions with no direct account take on CO_2 effects on photosynthesis predict a decrease in global marine primary productivity as the surface ocean warms.

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Biography

John A Raven FRS FRSE is Emeritus Professor of Biology at the University of Dundee. He has published over 330 peer-reviewed papers over 50 book chapters, has authored one book (J A Raven 1984 *Energetics and Transport in Aquatic Plants*, A R Liss, New York USA) and co-authored another (P G Falkowski and J A Raven 1997 *Aquatic Photosynthesis*, Blackwell Science, Maldon USA) which is now in a second edition (2007 Princeton University Press, Princeton USA), and was chair of the panel that produced the Royal Society of London report on *Ocean Acidification due to increasing Carbon Dioxide* in 2005. John has been publishing on how aquatic photosynthetic organisms acquire inorganic carbon, and their response to altered carbon dioxide and pH, since 1968. His current research ranges from cell level studies of how aquatic photosynthetic organisms acquire inorganic carbon, through the colonization of the land by photosynthetic organisms in the Palaeozoic, to photosynthetic aspects of astrobiology.

Global biodiversity and global climate the deep time perspective

*Dr Peter Mayhew, University of York, Department of Biology (Area 18), University of York
Heslington, York YO10 5DD*

Over the Phanerozoic (the last 540 millions years, in which animal fossils are abundant) the fossil record of taxonomic richness, extinction and origination is associated with change in numerous other variables; these include the rock record itself (e.g. the richness, origination and extinction of rock packages), numerous isotopic proxies of environmental change (such as carbon, strontium and oxygen), and estimates of abiotic variables such as tropical sea surface temperatures, global sea level, and atmospheric carbon dioxide levels. The patterns of causation amongst these variables are largely unknown, and the subject of active research. Global climate has shifted between warm, greenhouse modes (in which evidence for glaciation is absent) and cool icehouse modes seven times over the Phanerozoic, and this long term change is associated with higher turnover (extinction and origination) during greenhouse modes than in icehouse modes; turnover that includes many of the largest mass extinctions. There is also an association between taxonomic richness and temperature, although the direction of this association varies between datasets.

Biography

Peter Mayhew is an evolutionary ecologist working in the Department of Biology at the University of York. His background is in life history evolution and entomology (insects), including comparative analyses and phylogenetics. From this stemmed an interest in the macroevolutionary effects of life history evolution. His recent work combines phylogenetic and fossil information to infer the macroevolutionary history of insects, and the environmental drivers of evolutionary change.

Terrestrial environmental and ecological (IPCC) **B-a-U consequences**

Dr Pam Berry, Environmental Change Institute, School of Geography and the Environment, South Parks Road, Oxford, OX1 3QY

Climate change is already projected to have a major impact on species, with on average 15% to 37% of species committed to extinction by 2050 and between 1% and 43% of endemic species by 2100. Significant changes are also projected for the end of the century for some ecosystems and the services they provide. This paper will explore some of the more extreme scenarios and possible thresholds in order to project what might happen in the 22nd century under a BAU scenario and briefly consider the implications for biodiversity and for human development.

Biography Dr. Pam Berry is a Senior Research Fellow of the ECI and Deputy Leader of the Terrestrial Ecology Group at the University of Oxford. She has been involved in projects on modelling climate change impacts on species, habitats and landscapes and their implications for conservation and biodiversity policy. Also, she has used the model outputs to examine the impacts of climate change on species, including their vulnerability and adaptation potential. More recently she has been researching aspects of the inter-relationship between adaptation and mitigation measures in a range of sectors and biodiversity and also ecosystem services. She has been a consultant on biodiversity and climate change issues for a range of organisations including the UNFCCC and the Council of Europe.

The marine environment and the ecological consequences of a business-as-usual scenario

Dr Manuel Barange, Plymouth Marine Laboratory, Prospect Place, Plymouth
M.barange@pml.ac.uk

The large majority of the warming associated with climate change is accumulating in the global ocean. Such warming and its associated changes are already affecting marine ecosystems and the services they provide. However, our ability to predict the ecological consequences of climate change in marine ecosystems is limited by three significant reasons:

- Model shortcomings – The geographical scale of Global Climate Models does not capture well processes in the shelf and coastal regions, where most of the resources are exploited, and so new ecosystem models capable of capturing biological processes at the right scale and resolution are needed.
- Ecological uncertainty – There is significant uncertainty associated with predictions of climate change impacts on future global aquatic net primary production. Furthermore, the transfer of this production through the food chain is complex and uncertain.
- Multiple impacts – It is difficult to separate the multiple additional stressors affecting marine ecosystems production, including differential geographical and temporal patterns and policies regarding use of ecological goods and services.

In this presentation we will use results from the QUEST_Fish (NERC-funded) project and other associated initiatives to investigate the impacts of a business-as-usual climate change scenario on marine ecosystems, with particular emphasis in marine resources. We will use coupled high resolution physical-biological models to investigate the differential changes in primary productivity across regions, and will use static and dynamic algorithms to explore the consequences of these changes on marine resources in different parts of the globe.

There is an additional uncertainty limiting our ability to predict: human behaviour. In recent years there has been an increasing recognition that the impacts of climate on marine ecosystems and their resources interact with human responses to influence the outcome. In other words, humans are not just recipients of the impacts but part of the process leading to change. We will conclude the lecture by exploring the role that humans will play in accelerating or slowing down ecosystem change, and how this role may change the way we model ecological systems in coming years.

Biography

Dr Manuel Barange is Director of Science at the Plymouth Marine Laboratory, in Plymouth, UK. He is also Chair of the Scientific Committee of the International Council for the Exploration of the Sea (ICES), and until recently he was Director of the International Project Office of the IOC-SCOR-IGBP core project GLOBEC (Global Ocean Ecosystem Dynamics). Dr Barange is a marine ecologist working on climate and anthropogenic impacts on marine ecosystems, and on exploitation and sustainability of marine resources. He heads the NERC QUEST_Fish consortium and is a workpackage leader in the EC MEECE (Marine Ecosystem Evolution in a Changing Environment) integrated project. He recently chaired the FAO-ICES-PICES international symposium on climate change effects on fish and fisheries in Sendai, Japan (May 2010). Dr Barange was recently awarded the UNESCO-IOC 2010 Roger Revelle medal for contributions to marine science. He has published over 70 peer-reviewed papers, sits on a number of national and international advisory boards, and is a founding member of the Global Partnership for Climate, Fisheries and Aquaculture (PaCFA).

Recent papers:

- **Barange, M., W. Cheung, G. Merino and R. I. Perry 2010.** Modelling the potential impacts of climate change and human activities on the sustainability of marine resources Current Opinion in Environmental Sustainability 2(6): in press.
- **Merino, G., M. Barange and C. Mullon 2010**. Impacts of aquaculture expansion and environmental change on marine ecosystems. Global Environmental Change. DOI information: 10.1016/j.gloenvcha.2010.07.008 (in press).
- **Barange, M., I. Allen, E. Allison, M.-C. Badjeck, J. Blanchard, B. Drakeford, N.K. Dulvy, J.Harle, R, Holmes, J, Holt, S.Jennings, J. Lowe, G. Merino, C. Mullon, G.Pilling, E. Tompkins, F. Werner 2010**. Predicting the impacts and socio-economic consequences of climate change on global marine ecosystems and fisheries: the QUEST_Fish framework. In: Ommer, R. et al., Coping with climate change in marine socio-ecological systems. Blackwell FAR Series (in press).
- **Barange, M. and R.I. Perry 2009.** Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In K. Cochrane, C. De young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. *FAO Fisheries and Aquaculture Technical Paper.* No. 530. Rome, FAO. pp. 7-106
- **Allison, E.H., M. Barange and N.K. Dulvy 2009.** Sustaining fish supplies for food security in a changing climate. Climate Sense: a publication for the World Climate Conference -3. Climate Prediction and information for decision making. Tudor House, UK. pp. 59-62.

Probabilities, possibilities and uncertainties: Early warning of future tipping points

Professor Tim Lenton, University of East Anglia, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ

Paleo-science shows us that the Earth system has undergone abrupt and non-linear transitions in the past, and gives us valuable clues as to where to look for future vulnerabilities. In existing work, we have defined and identified a suite of ‘tipping elements’ in the climate system that may pass a tipping point under human-induced climate change. Recent climate changes add to the collective concern that these pose a real threat to societies. By their very nature, tipping point changes involve a mixture of deterministic and stochastic drivers, so their timing cannot be precisely predicted. Still the situation is not hopeless. I will address how potential future tipping points can be detected, and whether any useful early warnings can be provided before a tipping point is reached. I will review the methods that have been proposed, and are being actively developed. These are quite general and can equally apply to tipping points in other systems (notably, ecological ones). Analysis of past abrupt climate changes show that some did carry early warning signals in the form of ‘critical slowing down’, whereas others were purely ‘noise induced’ (i.e. triggered by large natural variability) with no early warning. Our analysis of recent climate data suggests that a new climate state is already beginning to emerge.

Biography

Tim Lenton is Professor of Earth System Science at the University of East Anglia. His Bachelors degree is in Natural Sciences from the University of Cambridge (1994) and his PhD in Environmental Sciences from the University of East Anglia (1998). His PhD research examined what regulates the nutrient balance of the ocean and the oxygen content of the atmosphere. Subsequently, he has sought to develop James Lovelock’s Gaia theory. He worked for 6 years as an Earth system modeller at the Centre for Ecology and Hydrology in Edinburgh before returning in 2004 to the University of East Anglia. He has led the GENIE Earth system modelling project and produced some of the first projections of climate and carbon cycle change on the millennial timescale. His research on the potential tipping points in the Earth’s climate system won the Times Higher Education Award for Research Project of the Year 2008. He has also been awarded a Philip Leverhulme Prize in 2004, a European Geosciences Union Outstanding Young Scientist Award 2006, the BA Charles Lyell Award Lecture 2006, and the Geological Society William Smith Fund 2008. His book with Andy Watson on the ‘Revolutions that made the Earth’ is published in 2011.

Ecosystem (service) vulnerability in the event of a PETM / IETM analogue

Jonathan Cowie, Concatenation Science Communication, www.science-com.concatenation.org

Glacial-interglacial climate transitions of about 5°C in average global temperature saw marked biome change across the planet. These biological changes have been well documented and reviewed elsewhere (*cf*.[1, 2]). Ecosystems furnish us with both economic goods and services not generally accounted for by economists. Since the UN Millennium Ecosystem Assessment formalised the definition of 'ecosystems services'[3] there has been increasing interest by policy makers to capture all ecosystem benefits from 'ecosystem services', as demonstrated last month in the UK.[4,5] Models suggest that should the planet be subject to a (theoretical) 3°C or 4°C warming from present day temperatures we would see major biome change broadly comparable in degree of spatial dislocation to that of glacial-interglacial transitions. They also suggest critical change to those biomes in areas[6,7] that currently provide us with traditional economic benefits, such as food, as well as trap carbon.[8] Consequently, both the direct (normally accounted), as well as the less-visible, economic costs of the climate-induced disruption to ecosystem services globally would be profound. This lends urgency into nailing the question as to whether or not current warming is likely to trigger an event analogous to carbon isotope excursion (CIE) events of the past? *If* there is a meaningful risk and hazard – and depending on the likely timescales involved – then societies, in addition to attempting to curb greenhouse emissions, may want to pay more attention to climate adaptation policies.

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Avoiding catastrophic climate change: Towards a sustainable future?

Professor Robert M May, Oxford University, Zoology Department, Oxford University, Oxford OX1 3PS

Against the long history of past “Carbon Isotopic Histories” surveyed over this 2-day meeting, I will outline the UK Climate Change Committee’s recommended path to 2050, set such that – if implemented – the UK would have played its “fair share” in the necessary reduction of its per capita carbon footprint (namely a reduction such that we have a 50% chance of holding average global temperature rise below 2°C were all countries to achieve this per capita footprint). I will indicate the current and unsustainable global ecological footprint of humanity, and the wide variations among countries in footprint per person, and in total. Threats posed if we fail to implement such an ambitious target will be sketched, and the current state-of-play outlined. This will not be an upbeat presentation!

Biography

Robert McCredie May, Lord May of Oxford, OM AC Kt FRS, holds a Professorship jointly at Oxford University and Imperial College, London and is a Fellow of Merton College, Oxford. He was President of The Royal Society (2000-2005), and before that Chief Scientific Adviser to the UK Government and Head of the UK Office of Science and Technology (1995-2000). His career includes a Personal Chair in Physics at Sydney University aged 33, Class of 1877 Professor of Zoology at Princeton, and in 1988 a move to Britain as Royal Society Research Professor. Particular interests include how dynamical systems are structured and respond to change, particularly with respect to infectious diseases and biodiversity. Honours include: the Royal Swedish Academy’s Crafoord Prize, the Swiss-Italian Balzan Prize, the Japanese Blue Planet Prize, and the Royal Society’s Copley Medal, its oldest (1731) and most prestigious award.

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Exit at front of theatre (by screen) onto Courtyard or via side door out to Piccadilly entrance or via the doors that link to the Lower Library and to the staff entrance.
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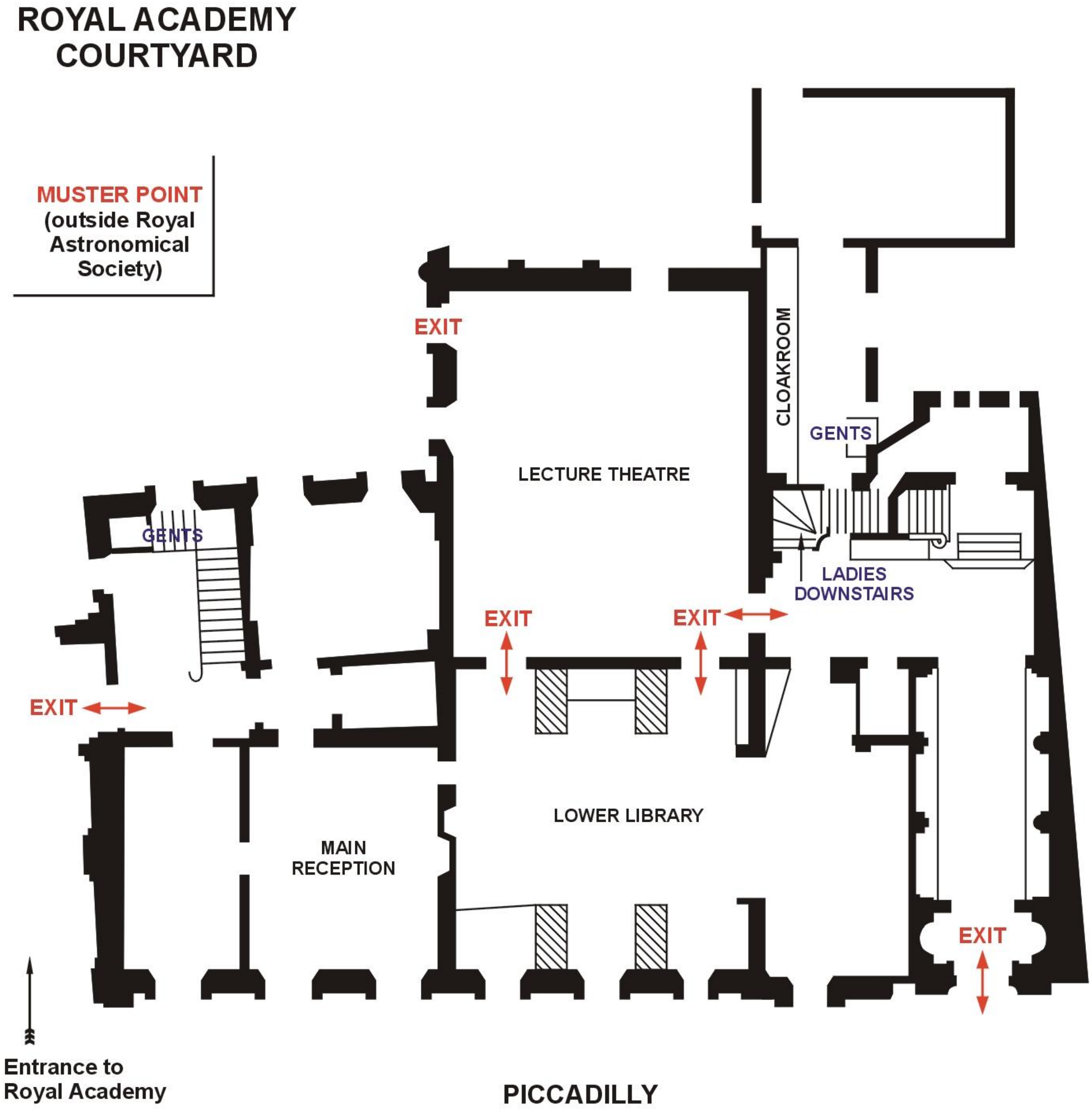
Ground Floor Plan of the Geological Society, Burlington House, Piccadilly



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