EXTREME CLIMATES PPG (Second Report)

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MEMBERS PRESENT

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Mark Leckie, University of Massachusetts (USA)
Richard Norris, Woods Hole Oceanographic Institution (USA)
Isabella Premoli-Silva, University of Milan (Italy)
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Visitor: Paul Wilson, University of Cambridge (UK)
Visitor: Lisa Sloan, University of California (USA)
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The notes on the second extreme climate panel meeting are short and the reader is referred to the notes of the first meeting for a comprehensive strategy of the extreme climate panel. The second meeting was more of a more practical nature to discuss the progress of the proposals put forward by the panel members and the use of modeling in predicting climate change during greenhouse periods and the testing of these results by drilling. Here follows an outline of the meeting.

Short introduction to the scientific strategy of the panel:

Recent results obtained by ODP (eg. Leg 171B) suggest that the drilling of Cretaceous and Palaeogene sequences can address directly some of the most scientifically important and socially pressing issues in modern- day earth sciences, in particular:

* the effects on global climate of rapid perturbations to the geochemical carbon cycle

* the relationship between climate and biodiversity

Ironically, the best examples of rapid, wholesale extinctions linked to massive perturbations of the global carbon cycle and rapid (1ka to 1Ma timescale) and extreme changes in Earth's climate come from Palaeogene and Cretaceous sections rather than more intensively studied younger sedimentary records. We highlight three 'warm time intervals' of particular interest:

* the Late Palaeocene Thermal Maximum (LPTM)

Previous drilling by DSDP and ODP has documented a global climate system characterized by significant long- and short-term variability over the last ~ 130 myr. This variability has not always been regular in terms of magnitude or rate. On occasion, the system has drifted either gradually or rapidly toward "extremes". This includes periods of long-term warmth (e.g., Climatic Optima) such as the Early Pliocene (3.8-4.6 Ma), mid-Miocene (14-15 Ma), Early Eocene (50-52 Ma), the Cenomanian-Turonian (92-96 Ma), as well as long-term cold intervals (e.g., Glaciations) such as the Oligocene (28-34 Ma) and Pleistocene (0-3 Ma). High-resolution records have revealed shorter-term but extreme climatic states, or "transient"climates. These transient states appear to be threshold events that involve rapid shifts in the climate system in response to more gradual forcing. Geochemical feedbacks involving marine carbon reservoirs appear to amplify climatic shifts. The extreme warm transient periods include the Late Paleocene Thermal Maximum (~55 Ma). The extreme cold transient periods include the Early Oligocene (~34 Ma) and Oligocene/Miocene Boundary (23.7 Ma) Glacial Maximum. In several cases, it appears that these climatic extremes triggered major evolutionary pulses in biota.

The warm intervals, particularly the transient ones, appear to be the result of forcing by greenhouse gases. For example, the LPTM, which is characterized by 5-8^{o}C of warming, was also accompanied by a rapid world-wide negative carbon isotope excursion of -3.0^{o}/oo. Ocean carbon values recovered in less than 150 kyr, roughly the residence time of carbon in the ocean. This excursion cannot be explained from a mass-balance perspective unless an immense quantity of CO_2, greatly enriched in ^{12}C, was rapidly added to the ocean or atmosphere from a source outside the existing ocean-atmosphere/biomass reservoir at rates approaching (or exceeding) those of fossil-fuel inputs at the present-day. A plausible explanation for the excursion involves release of roughly 1100 gigatons of CH_4 gas hydrates from the continental margins. A switch in the source of intermediate to deep water, most likely after the passage of some critical threshold condition, caused significant warming of intermediate to deep ocean water during the LPTM. This warming resulted in steeper sediment geotherms on continental slopes and thermal dissociation (melting) of gas hydrate. Methane released from gas hydrate and underlying free gas zones then escaped to the ocean or atmosphere (presumably through sediment failure) where it was rapidly oxidized to CO_2. Alternatively, the excess CO_2 may have been supplied by unusually high rates of outgassing from rift and/or subduction-zone volcanism.

These and other hypotheses can be tested with deep-sea drilling. Regardless of source, such large and sudden inputs of carbon into the ocean/atmosphere system should have had profound effects on ocean carbon chemistry. In particular, geochemical models show that initially the pH would drop and the CCD would shoal, resulting in pronounced dissolution of $CaCO_3$ in deep-sea sediment deposited during these transient climate states. Ocean pH/alkalinity balance would eventually recover, within 150 kyr, via chemical weathering of silicate rocks and inorganic- and organic-carbon deposition. To accomodate the excess carbon, the CCD should initially deepen beyond the pre-excursion position before recovering. The vigor of ocean pH/alkalinity response would depend on the source of carbon. In principle, deep-sea sediments spanning a wide depth range should show evidence of systematic CCD shoaling and recovery.

Recent work suggests that the CCD shoaling was noticeably greater than predicted by modeling: strong dissolution occurred at paleodepths from 1600 to 3400m on Walvis Ridge (Thomas and Shackleton, 1996), and sites with relatively shallow paleodepths (<2000 meters) in the Caribbean exhibit pronounced clay layers(Thomas et al., in press). There are several possible explanations for this model/data mismatch. For one, the amount of carbon added to the ocean may have been significantly greater than the 1200 Gt assumed in the model. Alternatively, the Caribbean sites may have been proximal to the point source of methane release. Two vertical transects of cores are therefore needed to test these ideas. One should be located in the Atlantic, the second in the Pacific.

The climatic extremes are of interest to a broad segment of the earth sciences community including paleoclimatologists, paleoceanographers, biogeochemists, and paleobiologists. The periods of exceptional warmth, particularly those of a transient nature, provide natural experiments for testing our current understanding of how climate and biogeochemical systems and the biosphere respond to and operate under extreme greenhouse conditions. They also test fundamental theories on mechanisms of climate change, particularly theories on the role of greenhouse gas forcing.

Some Key Scientific Issues:

1) To what extent were changes in greenhouse gases responsible for the transient (<0.5 my) episodes of global warmth in the Cenozoic and Cretaceous?

2) Are the short-term climate forcing mechanisms similar to the long-term (>1 my) forcing mechanisms?

3) Was there a mechanistic link between the long-term warming trends and transient climatic states?

4) How did the ocean-atmosphere system operate during intervals of exceptional global warmth?

5) Were ice-sheets and/or sea-ice present during any of the extreme greenhouse intervals?

6) What was the sensitivity of Earth's biosphere to extreme climates?

7) What was the biogeochemical response to episodes of rapid global warming?

* the Cenomanian/Turonian oceanic anoxic event (OAE 2: Bonarelli Event)

New stable-isotope data (fig. 1) reveal that maximum temperatures in the Cretaceous were established in the middle Turonian and around the Cenomanian/Turonian boundary. The initiation of the Cenomanian-Turonian boundary oceanic anoxic event appears to be broadly coincident with a paleotemperature maximum. Cooling, immediately post-dating the event, was initiated by an inverse greenhouse effect due to sequestration of atmospheric CO_2 as sedimentary organic carbon (Arthur et al., 1988; Jenkyns et al., 1994). A positive carbon-isotope excursion broadly corresponds in time to the period of excess carbon burial that defines the anoxic event. It is apparent that the Cenomanian-Turonian OAE had a major influence on the world's climate and needs to be studied in detail. High-resolution sections through the sedimentary record of this event need to be drilled in various settings from low to high latitudes and in different depths in the oceans. Stable-isotope records obtained from planktonic foraminifera from Blake Nose (low-latitude Atlantic) confirm a temperature optimum prior to the Cenomanian/Turonian event, which shows that sections can be found with diagenetically unaltered tests of planktonic foraminifera.

* the Aptian oceanic anoxic event (OAE 1a: Selli Event)

Recent drilling at Resolution Guyot (north Pacific) has shown the impact of OAE 1a (early Aptian Selli Event) even in shallow-water peritidal sediments: both black shales and the accompanying carbon-isotope excursion are recorded. As with the Cenomanian-Turonian event, there is coincidence in time with a palaeotemperature maximum, followed by global palaeotemperature decline, leading to the formation of glendonites (pseudomorphs after the low-temperature form of calcium carbonate, ikaite) in Arctic and Australian Basins during the late Aptian. New stable-isotope records confirm the perturbations in the carbon cycle associated with this event (fig. 2), but the exact relationship between the OAE (relatively brief) and the positive carbon-isotope excursion (relatively long) remains obscure. The PPG recommends that the sedimentary record of this event be drilled at other sites across a range of latitudes in high-resolution sections to elucidate the trends observed at Resolution Guyot. This procedure would establish the global extent, or otherwise, of the perturbations in the carbon-cycle and compare results to OAE2 (Bonarelli Event). The ultimate aim is to understand the mechanisms that changed the planet's climate during the Cretaceous.

Scientific Strategy

Until recently, palaeoceanographic studies of warm intervals in the Palaeogene and Cretaceous carried the label 'low resolution'. While this description derived partly from typically low-density sampling strategies, it also reflected the view that warmer worlds were inherently less climatically variable than the late Neogene 'icehouse'.

* Increased sampling resolution brought to light extreme excursions in the oceanic record that challenge this 'warm is stable' paradigm and future work requires the same approach.

* Recent recognition of semi-periodic features in sedimentation and/or biotic composition that show statistical patterns and periods characteristic of variations in Earth's orbital elements (eccentricity, obliquity, and precession) opens up the possibility of studying our target warm intervals of Palaeogene and Cretaceous time at temporal resolutions achieved in the Pleistocene. Modeling of the climate system is an important tool to target certain time intervals. The PPG discussed this at length. Dr. Lisa Sloan as an invited member showed the importance of modeling to predict climate features at certain Milankovitch periodicities and under certain boundary conditions. The modeling highlights features such as the location of upwelling sites in the world's ocean (fig. 3). A good example is the Site of Blake Nose in the low-latitude Atlantic Ocean where intense upwelling is predicted by the models in the Eocene period. Importantly, the recently produced stable isotope curve confirms large temperature variations at Milankovitch periodicities.

The combination of climate modeling and paleoceanographic data can help to define and understand the climate system. We can gauge our understanding of these past warm climate systems by predicting aspects of the paleoceanographic sytem with models, and then testing the ypotheses with strategic scientific drilling. For example, modeling results can be used to predict oceanic regions with high sensitivity to particular (or tectonic) forcing, for boundary conditions of a given time period. Drilling of sediments in these regions can support or refute such hypotheses, and analyses of sediments from these regions may provide more valuable information than sediments from other, less climatically sensitive, ocean regions.

Certainly important as highlighted by the modeling are the implications of the low-high latitudinal temperature gradient as a function of CO_2 on the climate system (fig. 4). Drilling is essential to define the latitudinal gradients in the Paleogene and Cretaceous. Attempts have been made in the past, but these results are sporadic and highly expanded sections with well-preserved foraminifera are needed to document the gradients. Particularly the need to find high-resolution sites becomes obvious.

Drilling Strategy

Many issues relevant to understanding extreme climates in general and the LPTM and OAEs in particular can be addressed by the application of the same drilling strategies that are currently and successfully employed for tackling Neogene paleoceanographic objectives.

* Drilling transects should be conducted at multiple locations where chosen drill sites have: (i) good preservation of primary carbonate sediments, (ii) high sedimentation rates across time intervals of interest and, where possible, (iii) a wide range of paleowater depths.

* Issues of rate and magnitude during the LPTM and OAEs require continuous stratigraphic records. Such records can only be reconstructed by complete core recovery through chosen intervals by taking multiple cores and logging holes.

* In Palaeogene and Cretaceous sediments, lithological variations (eg. chert bands) present challenges to the above objectives. We therefore highlight the need to develop the technology that would allow us to revert from rotary coring to hydraulic piston and/or extended barrel coring techniques, once resistant lithologies are known to have been penetrated, in second or third holes at any site.

* In Palaeogene and Cretaceous drilling, results from earlier DSDP and ODP legs have provided vital reconnaissance information to guide our selection of new sites for scientifically focused dedicated transect drilling. However, these reconnaissance sites are a limited resource. We have discussed a number of potentially exciting target areas for transect drilling where we have no well control. Our discussion highlights the need to give increased priority to drilling 'sites of opportunity' in such areas.

Leg Proposals

* Existing: We support the following pre-existing proposals with Palaeogene and/or Cretaceous objectives: (i) Weddell Sea (proposal 503), (ii) Scott Plateau (proposal 513), (iii) Shatsky Rise (proposal 534).

* New: We have submitted the following new proposals designed to meet our Palaeogene objectives: (i) Walvis Ridge, (ii) J-Anomaly Ridge, Newfoundland Margin.

* Planned: We have begun work to evaluate, in detail, two sites that have significant potential to meet some of our Cretaceous objectives: (I) Demerara Rise, Surinam margin, (ii) Western Australian margin. Demarara Rise is a promising site and PPG members have started to evaluate its potential in terms of its mid-Cretaceous record. Seismic lines have been obtained from Shell.

*Next PPG meeting is planned prior to the AGU meeting in San Francisco 1999. Here, we will further evaluate the response from ESSEP on the Walvis Ridge and J-Anomaly Ridge proposals and work on the progression of the Demarara Rise proposal. Another important point that needs to be discussed is the use of proxies in paleoceanography. Exciting new results have been obtained in using chemical proxies (elemental ratios) that are definitely needed to evaluate paleotemperatures.

References

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Figure captions.

Figure 1. Composite Southern Hemisphere $\delta^{18}O$ records compiled using data from Exmouth Plateau Ocean Drilling. A: Measured values; B: $\delta^{18}O$data corrected for burial-related diagenetic alteration; C: 5-point moving average through corrected $\delta^{18}O$ data.

Figure 2. Stable carbon isotope profiles (squares: $\delta^{13}C$ organic matter-circles: $\delta^{13}C$ carbonate) from Resolution Guyot illustrating the large climatic swings associated with the early Aptian oceanic anoxic event.

Figure 3. North Atlantic wind-driven upwelling calculated from Genesis (v.2) climate model results. Diagonally-hatched regions are areas of upwelling, with darker shades denoting relatively stronger upwelling. each model case contained early Eocene boundary conditions; the difference between the two cases is the orbitally-influenced solar insolation distribution.

Figure 4. Mean annual sea surface gradients produced with the Genesis (v.2) climate model. Each model case contained Early Eocene boundary conditions. Critical boundary conditions noted in figure.