Early Mesozoic Biodiversity and Climate Change (EMBiCC) Final Summary Report

Project overview and rationale

The Early Mesozoic (from the Permian/Triassic boundary to the Middle Jurassic) is a critical, yet understudied, interval in the history of life. Three major extinction events (the Late Permian, Late Triassic and Early Toarcian events) occur within this interval of time. All of these biotic crises triggered major reorganization of marine ecosystems (McGhee et al., 2004), and taken together were largely responsible for the present structure and composition of marine ecosystems. They were also all intimately associated with evidence for dramatic global warming and increase in the atmospheric concentrations of CO_2 (e.g. Kidder and Worsley, 2004). The global rise in temperature between the latest Permian and the earliest Triassic, for example, is estimated as some 5-6°C (Magaritz and Holser, 1991), which is within the upper range of estimates for temperature rise in the next century (e.g. Cox *et al*., 2000). This resulted in ocean stratification and expansion of the oxygen minimum zone (e.g. Wignall and Twitchett 1996; Hotinski et al., 2000) and the most profound biotic crisis in Earth history (e.g. Erwin, 1994; Benton and Twitchett, 2003).

There is a wide consensus that changes in atmospheric CO_2 is a major driver of global temperature and climate change; a view that is supported by the GEOCARB III model (Berner & Kothavala, 2001) and geological archives of ancient pCO_2 data such as fossil leaves and fossil soils (McElwain *et al*., 1999; Montanez *et al*., 2007). However, estimates of past temperatures, from isotopic analyses of calcitic fossils such as brachiopods and belemnites, show limited correlation with the estimates of past pCO_2 (Veizer *et al*., 2000; Shaviv and Veizer, 2003). This apparent mismatch is particularly striking in the Early Mesozoic, where the GEOCARB III data indicate rising CO_2 levels, but $\delta^{18}O$ analyses of fossil shells indicate falling temperatures (i.e. global cooling). Shaviv and Veizer (2003, and refs therein) have used this apparent negative relationship to infer that global temperatures are controlled by extraterrestrial factors, such as cosmic ray flux, rather than pCO_2, with obvious implications for our understanding of past, present and future climate change.

Hence, despite the importance of the Early Mesozoic as a critical interval in Earth history, there are still some fundamental questions that need addressing and have relevance for the present-day.

Project Aims

The major aims of our project were to address the following two key questions:
1. What drives global temperature and climate in the Early Mesozoic?
2. What are the biotic responses associated with changes in temperature?

Research Methodology

In order to determine how temperature changed during the Early Mesozoic we undertook isotopic analyses of some 400 well-dated fossil brachiopod shells. This is a standard and routine method of reconstructing past temperatures (e.g. Korte *et al*., 2005). The sediment matrix surrounding the fossils was removed mechanically and the shell surface cleaned with de-ionized water in an ultrasonic bath. The primary layer, which is considered to be secreted out of isotopic equilibrium with oceanic water in modern species was carefully removed with a dental scraper under a binocular microscope or avoided during micro-drilling. Structures (mainly contained in the posterior part of the shell) and the uppermost part of secondary shell were also avoided as they may display isotopic values out of the expected equilibrium with environmental water in modern brachiopod species. Only the innermost part of the fibrous secondary layer of the anterior shell was sampled for isotopic measurements. Each brachiopod shell was also sub-sampled for trace element analysis. Some 20-50mg of shell was reacted with 20% nitric acid and the resulting solution analysed on a Varian 725-ES ICP-OES for the proportions of major elements present. Cathodoluminescence analyses were performed on polished longitudinal sections of brachiopod shells to allow the identification of the best preserved parts of the shells and the rejection of entirely altered specimens. The polished shells were further screened by scanning electron microscopy (SEM), in order to analyse the preservation of the shell microstructures and to ensure the quality of sampling. Oxygen isotope compositions of brachiopod shells were determined using a GV Instruments Isoprime mass spectrometer with a Gilson Multiflow carbonate autosampler at the University of Plymouth and the results calibrated against Peedee Belemnite (PDB) using the international standard NBS-19. The isotopic data were then converted to palaeotemperatures using standard equations and assumptions.

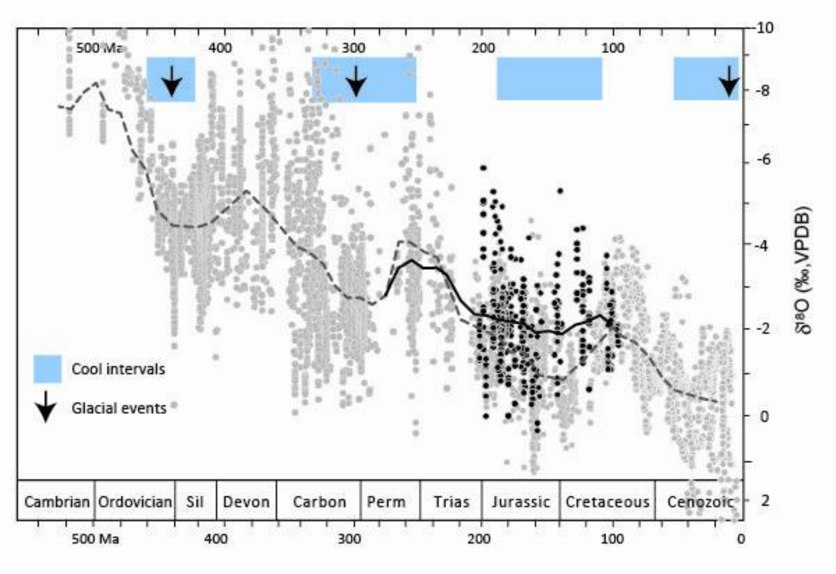

Figure 1: The Phanerozoic oxygen isotope curve with inferred cool intervals based on data from Veizer *et al*. (2000) and Shaviv and Veizer (2003)(grey circles, dashed line), and our new isotope data generated in this study (black circles; solid line).

Results

Our isotopic analyses of articulate brachiopods have provided the first detailed brachiopod-based oxygen-isotope/palaeotemperature curve for the Early Mesozoic. These data differ significantly from the isotopic data described by Shaviv and Veizer (2003) for the study interval. Our new Early Mesozoic isotopic values are significantly more negative than those of Veizer *et al.* (2000) and Shaviv and Veizer (2003), which means that ocean temperatures must have been warmer than previous estimates (Fig. 1). In particular, our data do not support the presence of a Jurassic cool interval identified by Shaviv and Veizer (2003). Our new palaeotemperature curve will also be correlated with detailed palaeoecological analysis of the fossil assemblages of the Early Mesozoic in order to provide the first detailed model of how ancient marine ecosystems respond to global warming events that is based on empirical data.

The apparent decoupling of temperature and CO_2 described by Shaviv and Veizer (2003), that has been used as a central argument of those sceptical of current global warming and CO_2 issues (e.g. a key claim in the 2007 Channel 4 documentary "*The Great Global Warming Swindle*" that argues that global warming is not due to the observed increase in anthropogenic greenhouse gas concentrations) is not supported by our new study. One reason is that the Mesozoic data compiled by Shaviv and Veizer (2003) is based on analyses of molluscan taxa such as belemnites, which are highly mobile, whereas the Palaeozoic data is derived from brachiopods, which are immobile shallow water organisms. By utilising brachiopods to produce a Mesozoic dataset we have eliminated potential problems inherent in using different, unrelated, taxa as palaeotemperature proxies through different eras of the Phanerozoic.

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