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Consequences of moderate ~25,000 yr lasting emission of light CO_2 into the mid-Cretaceous ocean

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Abstract

Future warming is predicted to shift the Earth system into a mode with progressive increase and vigour of extreme climate events possibly stimulating other mechanisms that invigorate global warming. This study provides new data and modelling investigating climatic consequences and biogeochemical feedbacks that happened in a warmer world ~112 Myr ago. Our study focuses on the Cretaceous Oceanic Anoxic Event (OAE) 1b and explores how the Earth system responded to a moderate ~25,000 yr lasting climate perturbation that is modelled to be less than 1 °C in global average temperature. Using a new chronological model for OAE 1b we present high-resolution elemental and bulk carbon isotope records from DSDP Site 545 from Mazagan Plateau off NW Africa and combine this information with a coupled atmosphere–land–ocean model. The simulations suggest that a perturbation at the onset of OAE 1b caused almost instantaneous warming of the atmosphere on the order of 0.3 °C followed by a longer (~45,000 yr) period of ~0.8 °C cooling. The marine records from DSDP Site 545 support that these moderate swings in global climate had immediate consequences for African continental supply of mineral matter and nutrients (phosphorous), subsequent oxygen availability, and organic carbon burial in the eastern subtropical Atlantic, however, without turning the ocean anoxic. The match between modelling results and stratigraphic isotopic data support previous studies [summarized in Jenkyns, H.C., 2003. Evidence for rapid climate change in the Mesozoic–Palaeogene greenhouse world. The Royal Society, 361: 1885–1916.] in that methane emission from marine hydrates, albeit moderate in dimension, may have been the trigger for OAE 1b, though we can not finally rule out alternative mechanisms. Following the hydrate mechanism a total of 1.15×10^{18} g methane carbon ($\delta^{13}C=-60$ ‰), equivalent to about 10% to the total modern gas hydrate inventory, generated the $\delta^{13}C_{carb}$ profile recorded in the section. Modelling suggests a combination of moderate-scale methane pulses supplemented by continuous methane emission at elevated levels over ~25,000 yr. The proposed mechanism, though difficult to finally confirm in

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the geological past, is arguably more likely to occur in a warmer world and apparently perturbs global climate and ocean chemistry almost instantaneously. This study shows that, once set-off, this mechanism can maintain Earth's climate in a perturbed mode over geological time leading to pronounced changes in regional climate.

Keywords: Cretaceous greenhouse; oceanic anoxic events; marine black shale; Mazagan Plateau; biogeochemical modelling; nutrient cycle

1. Introduction

Atmospheric CO_2 concentrations in the early Albian about 112 Myr ago are reconstructed to have ranged from 500–3000 ppm depending on the proxy parameter considered (Royer et al., 2004). For future climate the consensus view of climate scientists is that doubling or even higher increase of modern levels of atmospheric CO_2 will occur by 2100 (IPPC, 2001), placing future levels of atmospheric CO_2 well within the range of early Albian greenhouse conditions. Climate sensitivity for a doubling of pre-industrial CO_2 concentrations is in the range of 1.5–4.5 °C and a global sea level rise up to 88 cm (IPCC, 2001) likely causing serious harm to terrestrial and shallow marine ecosystems and global human infrastructure. Recent estimates of climate sensitivity based on modelling (Pittock, 2006) suggest an even higher range in average global temperature, around 2–6 °C, casting doubts on the low end of the IPCC 2001 range at the same time increasing demand for immediate, concern action. The probability of even earlier and possibly more serious impacts on future climate is attributed to a series of processes that are not fully constrained at present time including global dimming, permafrost melting, biomass feedbacks, Arctic sea ice retreat, circulation changes in mid to high latitudes, and tropical cyclones (for forum discussion see Pittock, 2006).

This study seeks insights into climatic consequences and biogeochemical feedbacks that are more likely to happen in a warmer and climatically more extreme world. By studying one relatively short climate perturbation in the geological past we aim to understand one climate scenario in detail being aware that there are many other possible scenarios we do not address. This investigation investigates early Albian marine sediments of DSDP Site 545 at Mazagan Plateau in the eastern subtropical Atlantic and combines this information with modelling. The Mazagan Plateau is located about 200 km SW of Casablanca in the Atlantic Ocean at 33°39.86′ N 09°21.88′ W. Site 545 was drilled during Leg 79 in 1981 at the foot of the Mazagan Plateau, in a water depth of 3142 m (Shipboard Scientific Party, 1984) (Table 1). DSDP Site 545 (Fig. 1) covers a well preserved section of the early Albian oceanic anoxic event (OAE) 1b (Leckie, 1984; Herrle et al., 2004). OAE 1b was accompanied by a phase of elevated carbon burial similar to other OAEs in the Cretaceous (Erbacher et al., 2001; Herrle et al., 2004; Leckie et al., 2002; Tsikos et al., 2004) although the amplitude of carbon burial was moderate in comparison.

To develop earlier studies on OAE1b and importantly provide approximations of GHG volumes and climate response we here present a new age model for OAE1b at the Mazagan site including high-resolution accumulation records of organic carbon burial, terrigenous matter and nutrient (phosphorous, P) supply, bottom water redox conditions (inferred from vanadium over aluminium ratios), ^{13}C from bulk carbonate and organic matter, and combine this stratigraphic information with global geochemical modelling. The results, particularly from modelling, show the atmosphere–land–ocean relationships of the late Albian subtropical Atlantic and help identifying the succession of processes leading through one of the shortest OAEs in the Palaeogene–Cretaceous greenhouse.

2. Material and methods

2.1. Sample material

Sample material for this study was obtained from the lower part of the *Hedbergella planispira* foraminiferal zone at one-cm resolution from DSDP 545 Sections 1–4 of core 42 (388.5–394.5 mbsf). Inspection of the cores and dm-scale digital core photographs, specifically from the transition intervals to the black shale, do not provide evidence for hard grounds, interruptions and/or

Table 1

Site information

Leg/Site	DSDP 79/545	Section	42/1/65–42/3/110 (Top–Bottom)
Modern latitude	33.6° N	Water depth	3142 m
Cretaceous latitude	~15° N	Water depth	~2000 m