Abstract

Large Scale Climate Teleconnections Driving Marine Black Shale Formation in the Mesozoic Ocean: Conceptual Ideas from Jurassic-Cretaceous Case Studies

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Expanded successions of marine black shale provide direct climate proxy records to test climatic teleconnections across palaeo-latitudes. The causal and generic relationships controlling the timing, composition and internal variability of these marine OC-rich shale over large distances and during variable global climate states are, however, still far from understood. Despite detailed documentation of the processes operating in individual ocean basins and under specific climatic conditions it remains a challenge to present a unifying concept that explains the generic far field interconnections between climate zones and ocean basins at multiple temporal and spatial scales. Progress towards such a unifying model would be an important step forward to simulate the location and internal heterogeneity of black shale formation more reliably, especially for areas where limited field data exist due to harsh or remote conditions, such as the Arctic.

Initially established for the Cretaceous subtropical-tropical Atlantic basins, we introduce a conceptual framework that identifies the generic processes linking the processes that connect orbital forcing with carbon burial across low latitude ocean basins (Wagner et al, 2013). Selected sedimentological, geochemical, biotic marine records are presented along with advanced biogeochemical and global climate modelling to show how the relationships between continental runoff and wind-driven upwelling determine the spatial distribution and internal heterogeneities of black shales in different sectors of the ocean basins, and how these patterns changed with global scale levels in atmospheric pCO_2 (e.g. between mid-Cretaceous super greenhouse vs. early Cretaceous temperate climate). We argue that the identified processes, although targeted in low latitude sediments, are generic and thus relevant for polar (Arctic) regions.

The Hadley Cell model proposes that internal, small-scale heterogeneities in Cretaceous black shales were generically related under the ascending (tropical) and descending (subtropical) limbs of the palaeo-Hadley Cells, the main atmospheric circulation cell driving humidity and wind fields in the low latitudes, with fluctuations at variable time (seasonal, orbital, geological) and spatial (shelf, margin, deep basin) scales. These dynamic variations low latitude atmospheric circulation with the Intertropical Convergence Zone (ITCZ) separating the two Hadley Cells on the northern and southern hemispheres, translate into characteristic patterns of OM quantity and quality and sediment composition in both Atlantic basins, best preserved near the continents, where the forcing effects are strongest. Using a comprehensive compilation of bulk organic geochemical data - total organic carbon concentration (TOC), hydrogen index (HI), oxygen index (OI), and kerogen type – study explains how basic geochemical patterns identify the underlying generic processes and how this knowledge can potentially be used to develop a predictive tool for black shale formation.

AAPG Datapages/Search and Discovery Article #120178 © 2015 AAPG Hedberg Research Conference, Latitudinal Controls on Stratigraphic Models and Sedimentary Concepts, September 28-October 1, 2014 – Banff, AB, Canada

Global climate simulations of this Cretaceous setting identify a previously unrecognized link between higher latitude climate dynamics and tropical African climate (Floegel and Wagner, 2006), the latter leading to exceptionally high burial of organic carbon in the deep tropical Atlantic (Beckmann et al. 2005). By varying one of Earth's orbital parameters, the precession of the equinoxes, the model provides new insights to the dynamics of global climate during the mid-Cretaceous. Accordingly, strongest variations in atmospheric pressure occurred within the South Atlantic mid-southern latitude region between 25–55°S. The establishment of such an atmospheric tele-connection between the South Atlantic and tropical Africa, however, has been shown to be limited to one specific orbital configuration, which lasted for only about 5 thousand years, causing strongest climate contrasts in a seasonal cycle. These new observations are insofar relevant as they challenge common notions on role of the tropics as main driver of climate. The modelling results rather support the conclusion that tropical climate is ultimately triggered by climate change at mid-southern latitudes, with precipitation and river discharge being the transport mechanisms, at least for Cretaceous peak greenhouse conditions. The broader implications of this study indicate substantial interaction between the water cycle and atmospheric circulation on regional and hemispheric scales during times of global warmth, supported by large scale modelling of zonal hydrological and climatic patters at increasing levels of atmospheric pCO_2 (Floegel et al., 2011).

We test and further develop the implications from the Cretaceous model by investigating new, detailed geochemical and sedimentological records from the Jurassic boreal ocean, where widespread deposition of the Jurassic Blue Lias and Kimmeridge Clay Formation occurred. Strong similarities in geochemical patters of reference sections from the UK Dorset and Cleveland Basins with those from the Cretaceous Atlantic basins suggest similarities in the depositional controls on carbon production and burial. We suggest that the Jurassic boreal sector may also have been driven by Hadley Cell dynamics, however, significantly modulated by variable surface water currents from either the Tethys ocean in the south or the Arctic ocean in the north. Building on this new evidence a preliminary model is presented, providing a first step to test possible feedbacks between polar and low latitude ocean basins and their effects on black shale deposition.

Our first observations from the Jurassic boreal ocean are still preliminary but they are encouraging towards a more integrated model, in particular when short (orbital) time scale processes are considered. We expand on these fundamental challenges by identifying potential drivers and feedbacks that may have interconnected polar and low latitude regions. Amongst others, we discuss the role of super-continent breakup and the associated development of ocean gateways, providing new connections across latitudes, as drivers of the global climate-carbon system. Aspects that will be discussed include (1) role of warm surface waters in mid and southern ocean basins as moisture sources for large scale, long term ice build-up in polar (Antarctic) regions, resulting in global scale sea level fall and, through feedbacks of the global carbon cycle, changes in atmospheric $CO_{2;}$ (2) Extreme hydrological cycling in the polar (Artic) ocean during periods of extreme warmth (role of hyperthermals on Artic carbon burial); (3) Understanding the relative importance of low versus high latitude solar insolation as drivers of the Earth's climate.

We argue that our study, despite focussing on two distinct time periods of the Mesozoic and the mid to low latitude ocean, provides clues to identify generic processes that influenced biogeochemical processes and carbon burial in the polar ocean.

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