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Discussions

Interactive comment on "Phanerozoic black shales and the Wilson Cycle" *by* J. Trabucho-Alexandre et al.

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Dear Dr Wignall,

Thank you for the useful review and feedback.

After reading your comments and those by Dr Jímenez-Berrocoso, we realise that our manuscript may convey the unintended message that black shale deposition would be only or largely defined by basin evolution. Indeed, this is not the case; climate, ocean circulation and the availability of nutrients are important as well, and whereas these are partly related to the Wilson Cycle, we discuss environments in which black shales may be preferentially formed in that context. A slight change of title and rephrasing of the abstract and parts of the manuscript may improve the perceived message.

The stage of an ocean basin within the Wilson Cycle defines the size of the basin which in turn determines to which extent wind and tides affect vertical mixing. The orientation of the basin with respect to the dominant wind patterns affects the chance that estuarine circulation causes an enrichment in nutrients thus making (parts of) the basin more prone to black shale deposition. An increased volume of ocean ridges and LIPs, related to rift activity, together lead to a rise of sea level and to an increase of CO2 in the atmosphere resulting in climate warming. At the same time increased ridge volume and LIP activity lead to an enrichment of nutrients in ocean waters. We argue that for the young North Atlantic these features together culminated around the Cenomanian–Turonian boundary. The increased volume of ocean ridges and LIP activity led to a high sea level, high atmospheric CO2 values and to high nutrient levels, thus promoting the stratigraphic clustering of black shales. Nutrients and CO2 were fixed in black shales in the relatively small southern North Atlantic as in this basin the conditions for high productivity and burial of organic matter were more favourable than elsewhere.

The Cenomanian–Turonian boundary interval is remarkably organic matter-rich. We infer that this is related to LIP activity (perhaps the Caribbean Plateau amongst others) and to the highest sea level in the Phanerozoic, which occurred just then. At some localities in the North Atlantic the full Aptian–Santonian interval is organic matter-rich (SW North Atlantic) and at others only certain intervals are characterised by black shale deposition or none at all. It is remarkable that most known mid-Cretaceous black shales were deposited in this basin and on surrounding shelves. We argue that this was due to the favourable basin configuration in combination with the other features mentioned above. Moreover, we describe how in a basin which is prone to black shale deposition, different subenvironments in the basin can become enriched in organic matter by different processes, e.g. pelagic settling under upwelling zones, settling of wind-blown terrigenous organic matter, turbidity current deposition due to slope instability, etc.

Whilst global forcing mechanisms, such as climate, nutrient availability and basin evolution, are important, black shale deposition occurs where local conditions are most favourable. It is thus defined by local processes acting in the context of global forcing. Even during OAEs, there are more coeval organic matter-lean marine deposits (e.g. in mature ocean basins) than black shales.

We argue that it is important to clearly define the depositional setting of a black shale succession in order to successfully understand the processes that have led to black shale formation at any given location. From this knowledge, it follows that coeval black shale successions may be or may not be correlated in terms of processes.

Black shale deposition in the mature Panthalassa is poorly understood. If the Cretaceous and Cenozoic distribution of organic matter-rich sediments in the Pacific is an analogue, then Panthalassa black shales in the Triassic and Early Jurassic were not deposited on the abyssal seafloor, but rather locally on pericontinental shelves, in marginal basins and on the meso-pelagic seafloor of seamounts.

With respect to the Toarcian, we would argue that the zenith of Pangaean accretion occurred earlier sometime during the Permo-Triassic. The Neotethys is a clear example of a flooded continental shelf, associated with rifting, where the conditions were favourable for black shale deposition thus capturing (part of) the excess nutrients provided by the coeval Karoo-Ferrar LIP.

Black shales may be deposited in different environments. Correlating them just because they are coeval may lead to unjustified conclusions with regards to the spread of anoxia in the oceans. At any given moment in Earth's history basins at different stages of their Wilson Cycle coexist. Each has a number of typical environments where black shale deposition is favoured, and each environment is characterised by conditions and processes that may result (or not) in black shale deposition. Global phenomena as LIP activity and an increased ridge volume may affect nutrient availability and sea level, thus favouring black shale deposition in sensitive systems.

We disagree that black shale deposition may be widespread in mature ocean basins, e.g. in the mature Panthalassan Ocean in the early Triassic and early Jurassic,

whereas in an open ocean basin vertical mixing, largely driven by wind and tides prevents oxygen exhaustion in deeper waters (cf. Trabucho et al. 2010, de Boer & Trabucho 2011).

Yours sincerely, João

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