



## **Methane seepage in a Cretaceous greenhouse world as evidenced by a peculiar carbonate deposit in the Tarfaya Basin, Morocco**

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The Cretaceous was characterized by major episodes of oceanic anoxic conditions and the large scale deposition of marine black shales rich in organic carbon. Several oceanic anoxic events (OAEs) have been documented during the Cretaceous including the Cenomanian to Turonian OAE 2, which is among the best studied examples to date. This study reports on a large limestone body that occurs within a black shale succession exposed in a coastal section of the Tarfaya Basin, Morocco. The black shales were deposited in the aftermath of OAE 2 in a shallow continental sea. To decipher the mode and causes of carbonate growth in black shales, we use a combination of element geochemistry, palaeontology, thin section petrography, stable isotope geochemistry and lipid biomarker patterns.  $^{13}\text{C}$ -depleted biphytanic diacids reveal that the carbonate deposit resulted, at least in part, from microbially-mediated anaerobic oxidation of methane in the shallow seafloor at a hydrocarbon seep. The lowest obtained  $\delta^{13}\text{C}$  carbonate values of  $-23.5\text{‰}$  are not low enough to exclude other carbon sources than methane apart from admixed marine carbonate, indicating a potential contribution from in situ remineralization of organic matter contained in the black shales. Nannofossil and trace metal inventories of the black shales and the macrofaunal assemblage of the carbonate body reveal that environmental conditions became less reducing during the deposition of the background shales that enclose the carbonate body, but the palaeoenvironment was overall mostly characterized by high productivity and episodically euxinic bottom waters. This study provides an insight into the evolution of a hydrocarbon seep that was situated within a shallow continental sea in the aftermath of OAE 2, and sheds light on how these environmental factors influenced carbonate formation and the ecology at the seep site.