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Organic carbon in Cenozoic Arctic Ocean sediments: Origin, paleoenvironment, burial, and source-rock potential

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In the modern (Quaternary to Neogene) „glacial“ Arctic Ocean organic-carbon (OC) accumulation is predominantly controlled by terrigenous (riverine, sea-ice- and current-controlled) input whereas increased primary production or increased preservation under oxygen-deficient conditions are of secondary/local significance. On the basis of sediment thickness obtained from acoustic profiles, AMS^{14}C-dated sediment cores and OC data, Stein and Macdonald (2004) put together a first-order estimate of OC burial in the Arctic marginal seas and the central Arctic Ocean for the Holocene time interval (Fig. 1; for data sources and references as well as background and limitations of estimates see Stein and Macdonald, 2004). The average Holocene OC burial rates vary widely between the different marginal seas and the central Arctic Ocean. In total, about 11 x 10^6 t y^{-1} of OC have been buried annually in the entire Arctic Ocean. Based on the origin of the OC, the OC burial rates can be divided into terrigenous and marine proportions. Whereas terrigenous OC is predominant in the sediments from the Beaufort, East Siberian, Laptev and Kara seas as well as the central Arctic Ocean, marine OC is much more important in the Chukchi Sea and, especially, the Barents Sea. These differences are related to different environmental situations, i.e., differences in river discharge, sea-ice cover, warm-water inflow, and primary production (Fig. 1; Stein and Macdonald, 2004; Stein, 2008).

In the (late Cretaceous to) Paleogene „preglacial“ central Arctic Ocean, OC accumulation was controlled by very different processes, as known from recent studies of the 430 m thick sequence of upper Cretaceous to Quaternary sediments that has been drilled in the central Arctic Ocean on Lomonosov Ridge near 88°N during the Integrated Ocean Drilling Program (IODP) Expedition 302 or „Arctic Coring Expedition (ACEX) (Fig. 2; Backman, Moran et al., 2006). The lower 230 m of the ACEX sequence consist of unique, very dark gray biosiliceous oozes and mudstones (“black shales“ in a broader sense) of Campanian and Paleogene (late Paleocene to middle Eocene) age, which are distinctly enriched in organic carbon reaching values of about 1 to 14% (Fig. 3; Stein et al., 2006; Stein, 2007). Significant amounts of the organic matter preserved in these sediments is of algae-type origin and accumulated under anoxic/euxinic conditions in an ocean basin relatively isolated from the world ocean at that time (Fig.2). During the middle Eocene, OC accumulation rates were an order of magnitude higher than those determined for modern central Arctic Ocean sediments.

Detailed data on the source-rock potential of these black shales indicate that most of the Eocene sediments have a (fair to) good source-rock potential, prone to generate a gas/oil mixture (Fig. 3). The source-rock potential of the Campanian and upper Paleocene sediments, on the other hand, is rather low. The presence of oil or gas already generated in-situ from the Campanian and Paleogene ACEX sediments at this part of Lomonosov Ridge, however, can be ruled out due to the immaturity of the ACEX sediments. If these sediments are buried more deeply, however, in-situ hydrocarbon formation is possible. This situation might occur in the more southern part of Lomonosov Ridge closer to the Eurasian continental margin, where sedimentation rates are significantly higher. The results of this study does also not mean that in the underlying deeper (Mesozoic) sedimentary rocks from the Lomonosov Ridge belonging to the rifted continental crustal block of the Eurasian continental margin, hydrocarbons could not have been generated (Stein, 2007, 2008 and references therein).

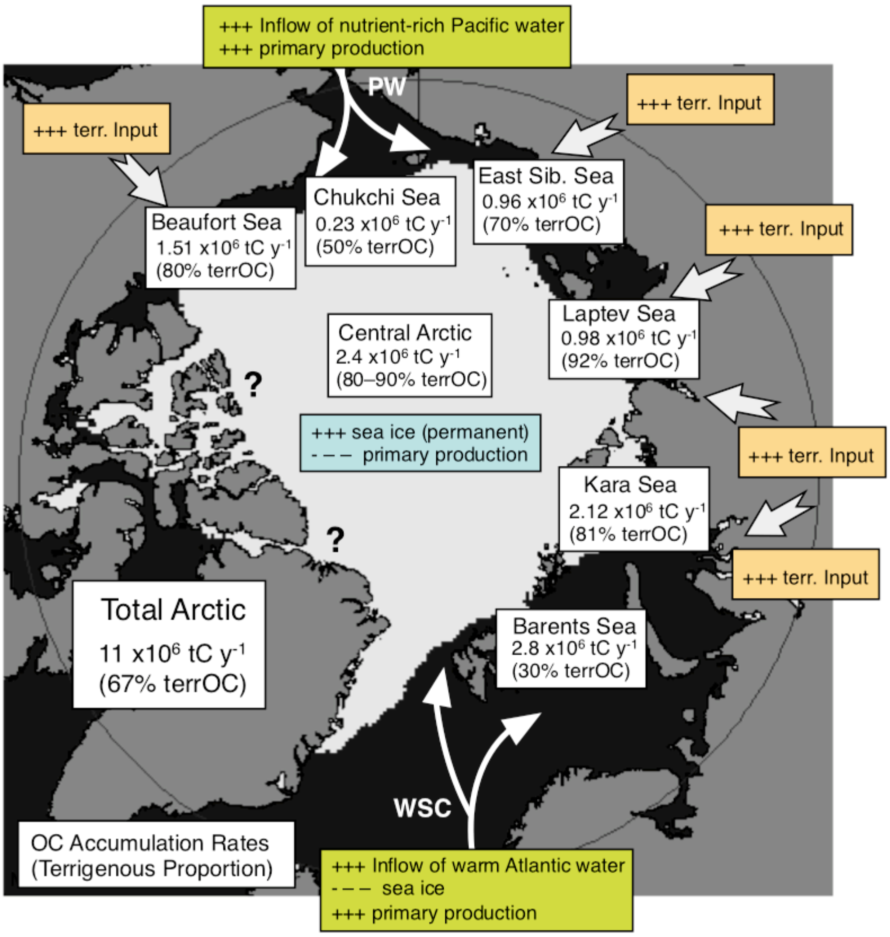

Fig. 1. Average Holocene burial rates (10^6 t y^{-1}) of organic carbon (OC) and proportions of terrigenous OC over the marginal seas and basins of the Arctic Ocean (based on Stein and Macdonald, 2004). Base map with average sea-ice cover (September 1979-2004) according to Maurer (2007; http://nsidc.org/data/atlas/). Figure from Stein (2008).

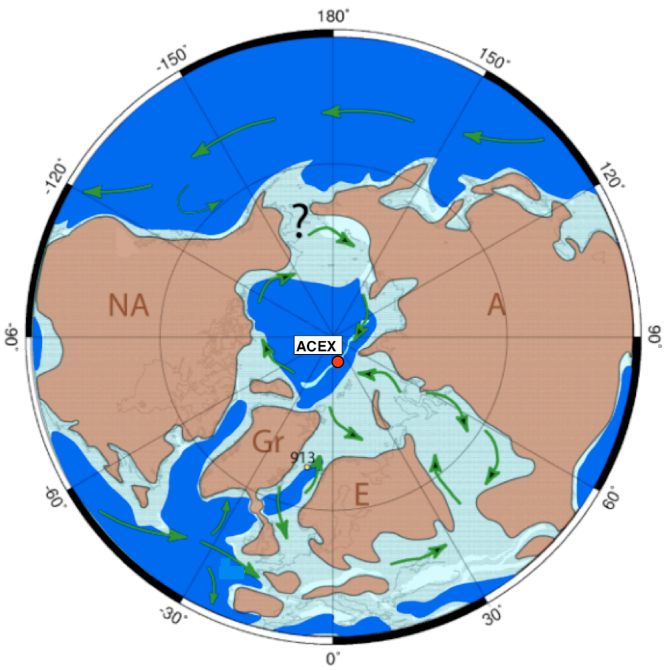

Fig. 2. Map showing a paleogeographic reconstruction of the High Northern Latitudes around 50 Ma and the location of the ACEX drill site on Lomonosov Ridge (from Backman, Moran, et al., 2006).

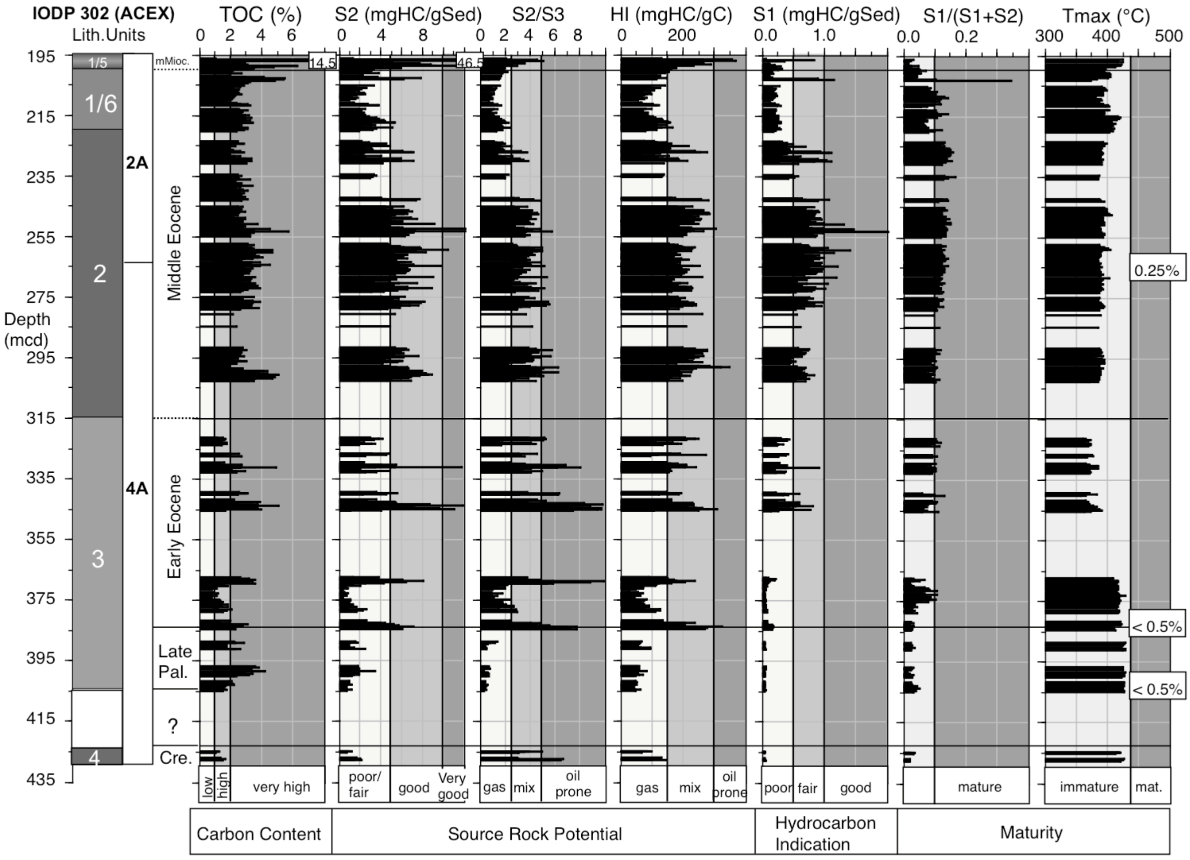

Fig. 3. Total organic carbon (TOC) content and Rock-Eval parameters S1, S2, S3, S2/S3, S1/(S1+S2), hydrogen index (HI), and T_{max} determined in lower 230 m of the ACEX drill site, and interpretation in terms of source-rock potential, hydrocarbon indication, and maturity according to Peters (1986). Numbers in the Tmax record are vitrinite reflectance values. Left, the stratigraphy and the lithological units are shown (Backman, Moran, et al., 2006). Figure from Stein (2007).

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