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Palaeoecological and post-depositional changes recorded in Campanian–Maastrichtian black shales, Abu Tartur plateau, Egypt

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ABSTRACT

The Upper Cretaceous black shales of Egypt are part of the worldwide belt of Late Cretaceous organic-rich shales. Black shales are particularly prominent in North Africa and the Middle East. In Egypt, these shales occur in an east-west trending belt extending from the Quseir-Safaga district along the Red Sea to the Kharga-Dakhla land-stretch passing through the Nile Valley. The black shales are hosted mainly in the Campanian to Maastrichtian Duwi and Dakhla formations. In order to reconstruct palaeoenvironmental conditions, the present work focuses on the distribution of organic matter including lipid biomarkers within the Abu Tartur borehole section, which was drilled in 2007 in the Maghrabi-Liffya area. The kerogen in the Abu Tartur section is of type III with the exception of sedimentary deposits at the Duwi/Dakhla transition. Low T_{max}, odd-over-even predominance of *n*-alkanes with a commonly high Carbon Preference Index, good preservation of carboxylic acids and abundant 17β,21β-hopanes and -hopanoic acids indicate immaturity of the organic constituents in the bitumen. Although thermal maturation was only low, the preponderance of rearranged steranes (diasterenes) over regular steranes indicates enhanced clay catalysis. Significant allochthonous input typifies the Abu Tartur section deposits, which are characterized by high contents of long-chain *n*-alkanes and low carbonate contents. The high content of desmethyl steranes and diasterenes suggests that marine algae were the main marine primary producers. The presence of different isomers of hopanes (C_{27}, C_{29}–C_{31}) and hopanoic acids (C_{31}–C_{33}) reveals input from various bacteria. The observed variation in the abundance of biomarkers corresponds to changes in planktic algal assemblages associated with sea level change and episodic photic zone anoxia, which are indicated by the occurrence of aryl isoprenoids, biomarkers of green sulphur bacteria.

1. Introduction

Black shales are dark, finely laminated, fine-grained argillaceous, calcareous and sometimes siliceous deposits that formed under anoxic conditions. They are rich in organic matter, mainly preserved as kerogen, and contain abundant sulphide minerals (e.g., pyrite). Black shales commonly have high contents of redox-sensitive trace elements such as V, Cu, Cd, Ni, Co, Mo, U and rare earth elements (Brumsack, 2006; Loukola-Ruskeeniemi and Lahtinen, 2013).

Black shales are deposited predominantly in oxygen minimum zones, where depositional environments are characterized by low current speeds and low oxygen levels (Killops and Killops, 2005; Takashima et al., 2006), favouring the preservation of organic matter. On the other hand, high-energy systems can be considered as alternative settings for black shale deposition (Alexandre et al., 2012). The main environments of black shale deposition are classified according to Tourtelot (1979) into three categories, (1) the restricted circulation type, (2) the open ocean type and (3) the continental shelf type.

The Campanian–Maastrichtian was characterized by increased pCO_2 from prominent global igneous activity and is known as a typical greenhouse period (Takashima et al., 2006) with moderate to high pCO_2 levels from the Late Cretaceous until the early Eocene (Kent and Muttoni, 2013). Increased burial was accompanied by changes in the composition of the phytoplankton community (coccolithophores, dinoflagellates and diatoms), associated with

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increased storage capacities caused by the opening of the Atlantic Ocean basin (Katz, 2005). Phytoplankton diversity was rapidly detached from the long-term sea-level trends at the Cretaceous–Palaeogene boundary (Falkowski et al., 2004).

In northern Africa and the Middle East, deposition of organic-rich black shales was widespread in the Late Cretaceous to Palaeocene. During this period, the sedimentation processes were influenced by greenhouse climate, favouring the establishment of anoxic conditions in many marine basins along a broad marine continental shelf across northeast Africa (Robinson and Engel, 1993). Apart from organic-rich shales, phosphorites, carbonates, glauconitic deposits and cherts dominate the shelf sequences (Bein and Amit, 1982; Tröger, 1984; Germann et al., 1985; Mikbel and Abed, 1985; Notholt, 1985; Ganz et al., 1987; Abed and Al-Agha, 1989; Glenn and Arthur, 1990; El-Kammar 1993). Black shales and marls reflect periods of high primary productivity on the shallow shelves, favouring the preservation of organic matter. As a consequence of the absence of a pronounced catagenesis, massive black shale successions have been preserved in Egypt and elsewhere in North Africa.

Some work on organic geochemical proxies in the Egyptian sequences of the Red Sea area has been conducted by Ganz (1987) and Ganz et al. (1990). Samples from the Abu Tartur mine were previously studied by El-Kammar (1993), who did some biomarker work, pointing to deposition in saline to hypersaline waters under anoxic conditions with high primary productivity. This interpretation was based on the presence of abundant acyclic isoprenoids, gammacerane, hopane/sterane and pristane/phytane ratios <1, as well as C_{27}/C_{29} steranes ratios >1. In addition, El-Kammar (1993) found that the largest part of the extracts consisted of hetero-compounds and asphaltenes with the presence of naphthenes (C_{25} and C_{30}).

The present work focuses on the organic matter distribution within the Abu Tartur black shale sequence, analysing a complete core that was drilled in 2007 in the Maghrabi-Liffya area. We put particular emphasis on the lipid biomarker inventory of the strata at the transition from the Duwi to the Dakhla Formation, covering the transition from the Campanian to the Maastrichtian. At this transition, changes in sedimentation, primary productivity and preservation of organic matter are observed based on the quantification of biomarkers including *n*-alkanes, *n*-fatty acids, steroids, hopanoids and isoprenoids. The overall palaeoenvironmental conditions during the deposition of the studied strata are finally reconstructed, combining the interpretation of lipid biomarker patterns and organic and inorganic bulk parameters.

2. Geologic setting

The black shales of the Upper Cretaceous to lower Palaeocene in Egypt occur in an east-west trending belt from Quseir-Safaga in the east along the Red Sea to the Kharga-Dakhla land-stretch toward the west, passing through the Nile Valley (Fig. 1; see also Baioumy and Tada, 2005; El-Azabi and Farouk, 2010 for detailed maps). The organic-rich shales are hosted in two formations. The Duwi Formation is a phosphorite-bearing formation with intercalations of marls, chert-rich deposits along the Red Sea, and glauconite-bearing horizons in the Kharga-Dakhla area including the Abu Tartur plateau. The Duwi Formation is well known for its numerous phosphorite mines, which have been active since the beginning of the last century. The superjacent Dakhla Formation is characterized by abundant foraminifera-rich shales and marls with limestone and rare siltstone intercalations.

According to Glenn and Arthur (1990), two major modes prevailed during the deposition of these Upper Cretaceous strata: (1) shallow hemipelagic deposition, representing the initial stages of marine transgression conducive for the formation of organic carbon-rich shales and massive phosphorites; (2) high energy deposition, representing regressive stages with advancing deltas, seawards reworked glauconites and prograding brackish oyster banks in the Red Sea area.

According to Baioumy and Tada (2005), the Duwi Formation in the Red Sea, Nile Valley and Abu-Tartur areas can be subdivided into four subunits: lower, middle, upper and uppermost members. The Duwi Formation ranges in age from late Campanian–late Maastrichtian, in the Red Sea (Zalat et al., 2008) to late Campanian in the Kharga-Dakhla area. The Duwi Formation has been suggested to be unconformably overlain by the Dakhla Formation, which is early Maastrichtian to early Thanetian in age in the Dakhla-Kharga region (El-Azabi and Farouk, 2010). The inferred unconformity was believed to have been caused by a tectonic movement coupled to a regression that took place during the latest Campanian, resulting in a hiatus in the Kharga-Abu Tartur district (Barthel and Herrmann-Degen, 1981). This area was probably a palaeohigh at that time. Sedimentation has been suggested to commence again in the early late Maastrichtian, resulting in the deposition of Dakhla shales overlying the Duwi Formation (Mansour et al., 1982; Hendriks et al., 1984; El-Azabi and Farouk, 2010).

The Dakhla Formation in the Dakhla-Kharga area has been subdivided by Awad and Ghobrial (1965) into Mawhoob, Baris and Kharga members in ascending order. The Kharga shale member has been further subdivided by Luger (1985) into two subunits, the lower and upper Kharga shales. These subunits are separated by an unconformity representing the Cretaceous/Palaeocene boundary. On the Abu Tartur plateau, the lower part of the upper Kharga shale is replaced laterally by limestones with shale interbeds named the Kurkur Formation (Issawi, 1968).

3. Material and methods

Black shales weather readily and weathering may have a significant effect on chemical composition, introducing artefacts in samples collected in outcrops (e.g., El-Kammar and El-Kammar 1996). Accordingly, the black shales studied here were taken from a drilled core that was not affected by surficial weathering. The borehole was drilled by the Egyptian Mineral Resources Authority (EMRA). Ten cores were drilled in the course of a project aiming to evaluate the potential of Egyptian black shales as unconventional source rocks. Among these cores, only one core was drilled in the Western Desert of Egypt. This study focuses on this drill core taken on the Abu Tartur plateau (Maghrabi-Liffiya sector) in the Western Desert (Fig. 1). Drilling was done in cooperation of the Ministry of Petroleum and DanaGas© Egypt.

3.1. Sampling

Two sampling strategies were applied during the present study. First, down-core samples were collected every 10 cm and subsequently 10 successive samples were mixed and homogenized to obtain representative bulk samples for homogeneous 1 m transects for routine analyses. However, additional samples were taken in case of lithology changes in the transects. The obtained rock pieces were ground to a suitable mesh size for bulk analyses (TOC% and Rock Eval). Secondly, lower resolution sampling (every 2–6 m) was made to monitor lithology or facies changes. These samples were used for biomarker and XRD analyses.

3.2. X-ray diffraction

About 35 X-ray diffraction (XRD) analyses were performed on bitumen-free samples to determine the bulk mineralogy. The X-ray