Environmental perturbations during the Oceanic Anoxic Event 1a (Early Aptian) in the epeiric sea of the Eastern Russian Platform

S O Zorina¹, K I Nikashin¹

¹Institute of Geology and Petroleum Technologies, Kazan Federal University, Kazan, Russian Federation

E-mail: svzorina@yandex.ru

Abstract. Toxic environments are reconstructed during the OAE 1a in the epeiric sea of the Northeastern Peri-Tethys. Very high toxicity of sediments in conjunction with lack of oxygen could therefore result in conditions not suitable for benthic fauna dwelling. Black shales should be considered as one of the most important sources of the light carbon isotope in the atmosphere and oceans and the strongest emitters of methane. These data should be taken into account while estimating greenhouse effect in the Early Aptian. The environmental models constructed for the pre-OAE-1a, OAE-1a, and post-OAE-1a conditions may help to better understand modern climate changes using comprehensive analyses of oxic and euxinic conditions in the oceans and interpret the greenhouse processes from the geological past to the present time.

1. Introduction

The Late Jurassic–Late Cretaceous is considered to be a period of increasing temperatures and “greenhouse” conditions. This period is marked by several episodes of widespread anoxia in the oceans [10, 2], resulted in black shale deposits known in the Cretaceous as Oceanic anoxic events (OAE) [3]. At the moment, deposits rich in organic matter are of increasing interest since they are a potential source of hydrocarbons and an indicator of climate and environmental changes, but also a source of greenhouse gases, such as methane.

Isotopic data suggest that the onset of global anoxia coincided with a short-term drop in δ¹³C values in marine carbonates [3] which could be caused by an activation of magmatic provinces leading to sudden addition of isotopically light volcanic CO₂ to the atmosphere and oceans [4] or dissociation of methane gas hydrate trapped in oceanic sediments [5]. Noteworthy, fossil fuels may be regarded as a far larger source of atmospheric methane than generally thought [6]. The calculations of methane emissions from the Lower Aptian (OAE-1a) black shales [7] were used to confirm this statement.

As the OAEs have been well studied and described in many studies, the general presentation of the consequences of these events is characterized by: (a) climatic maximum, leading to extensive transgressions and the demolition of biophilic elements from the continent to the ocean leading to a significant increase in the oceanic productivity; (b) stagnation of hydrodynamic regime of basins and
stratification of water masses; (c) decrease in dissolved oxygen in the water; and (d) conditions under which the organic matter (OM) does not dissolve and persist in the sediment arise [3].

In addition to the above-mentioned consequences, it should be noted that the most pernicious outcome for benthic and plankton fauna was a wide-spread hydrogen sulfide and toxic metals contamination of sediments, where marine benthic biota could not exist [8], [9]. In order to generalize the data obtained the task was to provide an environmental modeling for the pre-OAE-1a, OAE-1a, and post-OAE-1a conditions in the studied basin in order to interpret the greenhouse processes from the geological past to the present time and better understand modern climate changes.

2. Geologic setting, chronostratigraphy and paleogeography

The Tatar-Shatrashany borehole was chosen as a reference section comprising siliciclastic succession with globally traced anoxic horizon. The studied section is located in the eastern Russian Platform (northeastern Peri-Tethys) within an epeiric sea acting as a marine strait connecting the Tethys Ocean with the Boreal-Arctic Sea during the Early Aptian (Figure 1a) [2]. Tectonically, the section belongs to the Uljanovsk-Saratov Trough (Figure 1b) which stretches in its eastern part for more than 850 km being filled with Middle Jurassic–Paleogene deposits [10].

Lower Cretaceous (Upper Hauterivian–Middle Aptian) deposits are consisted of highly bioturbated dark gray, mostly carbonate-free mudrocks, with rare interlayers of sandstones and siltstones. The total thickness of the section is up to 450 m (Figure 2). This monotonous succession includes the Lower Aptian black shales (Uljanovsk Formation (Fm)), 4.2 m in thickness. It consists of dark brown thinly-laminated bituminous mudrocks (1–5 mm thick) with pyrite interlayers, composed of high-carbon closely-packed pyrite frambooids reported to indicate euxinic conditions [8]. The TOC values vary in between 6.1–10.0 %. Black shales are interbedded by concretionary limestones, 1.2 m in thickness with the TOC content of 1.3 %. The Uljanovsk Fm is reported to correlate with the Early Aptian OAE 1a [8], [11] (Figure 2).
Ammonites are abundant in the studied section, thus a detailed zonation was obtained previously [12] allowing to correlate the section with the Geological time scale (Gradstein et al., 2012) and accurately date the anoxic event identified [12], [13]. Benthic foraminifers are also abundant except the Lower Aptian black shales where they were not found. The concretionary limestones include assemblages of well-preserved coccolith skeletons, belonging to the Lower Aptian *Rhagodiscus angustus* nannofossil zone [8].

Noteworthy, the host mudrocks and the black shales contain significant amount of montmorillonite and mixed-layered mineral which together with albite, microcline, and diopside made it possible to propose significant flow of pyroclastic material into the sea in the Early Cretaceous [14]. Among the possible sources of the pyroclastics delivered to the basin, the Armavir basaltic massif could be proposed. It was formed during the activity of the Ciscaucasic backarc volcanism (Northern Caucasus) and is presented by the basalt and diorite lavas and the pyroclastic flows, more than 500 m thick [15].

**Figure 2.** The Lower Cretaceous deposits of the Tatar-Shatrashany Borehole section (modified from [12]). Legend: 1 - sandstones; 2 - mudrocks; 3 - marlstones; 4 - bituminous shales.
3. Modeling the depositional paleoenvironments in the early Aptian Peri-Tethys

As OAEs are interpreted as a concatenation of sedimentary, geochemical and biological events [1], the OAE 1a may cause massive environmental changes from the pre-OAE-1a to the post-OAE-1a in the north-eastern Peri-Tethys (Figure 3). The latest Barremian-earliest Aptian (pre-event) conditions were flavor for the inhabitants (ammonites, belemnites, benthic micro fauna, and burying organisms) due to normal oxygen circulation. Bioturbated dark gray mudrocks and siltstones were accumulated accompanied by the terrigenous and volcanic ash influxes, so the latest was partly transformed to montmorillonite (Figure 3a).

Accompanied by global warming the OAE-1a has been manifested in the studied region by a rise in a sea floor temperature from 16–18°C in the earliest Aptian to 27°C during the OAE-1a [16] and basin deepening up to 250 m [8], [17] (Figure 3b). Normal oxygen circulation was changed by water stagnation having led to strata thin lamination, organic matter burying (TOC 7.55%; δ13Corg -29‰), dense high carbon pyrite frambooids forming, and euxinia spreading throughout the basin. Moreover, as
it was recently proposed the sediments were evaluated as very toxic due to very high concentration of Mo and other toxic metals and therefore, not suitable for benthic fauna dwelling [9].

The intercalations of concretionary limestone within the bituminous shales are of great interest, because they are composed of assemblages of well-preserved coccolith skeletons [9]. Studied limestones indicate episodic cessation of stagnation, rapid oxygenation, and restoration of normal marine conditions for a short period (Figure 3c). Stagnation and euxinic conditions recurred as quickly as they stopped. This is evidenced by the renewed accumulation of bituminous shales overlying limestones (Figure 3d).

Along with a very high toxicity, the bituminous sediments are regarded to be a source of methane emission. The calculated volume of this greenhouse gas released to the sea during the OAE-1a is about 4.5 Tt [7] (Figure 3b).

The post-OAE-1a conditions are proposed to be a resumption of normal oxygen circulation in the studied basin (Figure 3d) where bioturbated dark gray mudrocks were accumulated. As the whole complex of benthic foraminifera from the Lower Aptian Mjatliukaena aptiensis – Haplophragmoides aptiensis zone is fully restored directly above the bituminous shales, toxic and disastrous consequences of the OAE-1a euxinia hence reached completion and then changed by suitable conditions for the basin inhabitants.

4. Conclusions

Toxic environments are reconstructed during the OAE 1a in the epeiric sea of the Northeastern Peri-Tethys. Very high toxicity of sediments in conjunction with lack of oxygen could therefore result in conditions not suitable for benthic fauna dwelling.

Black shales should be considered as one of the most important sources of the light carbon isotope in the atmosphere and oceans and the strongest emitters of methane. These data should be taken into account while estimating greenhouse effect in the Early Aptian.

The paleoenvironmental models constructed may help to better understand modern climate changes due to analyses of oxic and euxinic environments in the oceans and margin seas and interpret the greenhouse processes of the geological past to the present time.

Acknowledgements

The work is performed according to the Russian Government program of competitive growth of Kazan federal university. The work was supported by the Ministry of science and high education of the Russian Federation contract No. 14.Y26.31.0029 in the framework of the Resolution No.220 of the Government of the Russian Federation.

References

[1] Jenkyns H C 2010 Geochemistry of oceanic anoxic events Geochem Geophys Geosyst 11 (3) Q03004
[2] Scotese C R 2014 Atlas of Early Cretaceous Paleogeographic Maps PALEOMAP Atlas for ArcGIS vol 2 The Cretaceous Maps 23–31. (Mollweide Projection PALEOMAP Project Evanston IL)
[3] Schlanger S O and Jenkyns H C 1976 Cretaceous oceanic anoxic events: causes and consequences Geologieen Mijnbouw 55 179–184
[4] Tejada M L G et al 2009 Ontong Java Plateau eruption as a trigger for the early Aptian oceanic anoxic event Geology 37 855–858
[5] Jahren A H et al 2001 Terrestrial record of methane hydrate dissociation in the Early Cretaceous Geology 29 159–162
[6] Lassey K R et al 2007 The atmospheric cycling of radiomethane and the “fossil fraction” of the methane source Atmospheric Chem Phys 7 2141–2149
[7] Maksyutova et al 2018 New data on greenhouse-gas footprint from black shales of Russian and West Siberian Platforms, Russia Proceedings of Kazan Golovkinsky Stratigraphic Meeting 2017 (Bologna: Filodiritto Editore) pp 375–380
[8] Zorina S. O et al 2017 Euxinia as a dominant process during OAE1a (Early Aptian) on the Eastern Russian Platform and during OAE1b (Early Albian) in the Middle Caspian Sci china earth sci 60 (1) 58–70
[9] Galiakberov A et al., 2018 Toxicity of High-Carbon Sediments: Case Study from Anoxic Basins of the East European and West Siberian Platforms Proceedings of Kazan Golovkinsky Stratigraphic Meeting 2017 (Bologna: Filodiritto Editore) pp 340-343
[10] Olferiev A G et al 2008 Problems of chronostatigraphy and regional geological history Stratigr geo correl 16 267–294.
[11] Gavrilov et al 2002 The Early Cretaceaeous anoxic basin of the Russian Plate: sedimentology and geochemistry Lithology and Mineral Resources 37 (4) 310–329
[12] Zorina S O 2016 Sea-level and climatic controls on Aptian depositional environments of the Eastern Russian Platform Palaeogeogr Palaeoclimatol Palaeoecol 441 (3) 599–609
[13] Zorina S O 2014 Eustatic, tectonic, and climatic signatures in the Lower Cretaceous siliciclastic succession on the Eastern Russian Platform Palaeogeogr Palaeoclimatol Palaeoecol 412 91–98
[14] Zorina S and Nikashin K 2019 Volcanogenic Influx into the Epeiric Sea of the Russian Platform Proceedings Kazan Golovkinsky Stratigraphic Meeting, 2019 (Bologna: Filodiritto Editore) pp 293-298
[15] Grekov I I et al 2004 The main Phanerozoic tectonic and magmatic activity zones (seat zones) of the North Caucasus Lithosphera 3 127–136
[16] Zakharov Y D et al 2013 Late Barremian–early Aptian climate of the northern middle latitudes: Stable isotope evidence from bivalve and cephalopod molluscs of the Russian Platform Cretac Res 44 183-201
[17] Zorina S 2019 Early Cretaceous Microbiofacies and Paleobathymetry in the Eastern Russian Platform Proceedings Kazan Golovkinsky Stratigraphic Meeting, 2019 (Bologna: Filodiritto Editore) pp 288-292