Early Cretaceous sea-level changes and major palaeoclimate events in the Northeastern Peri-Tethys

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Abstract. The Early Cretaceous quantitative sea-level curve constructed for the epeiric basin of the Eastern Russian Platform (Northeastern Peri-Tethys) is based on the results of facial analysis and quantitative paleo-depth assessment. The detailed evaluation of the Early Cretaceous sea-level cycles results in recognition of the sea-level and climate changes as controlling factors on depositional environments in the basin. Major climatic events are identified by the comparison between the global and regional sea level curves. “The cold snaps” coincide with simultaneous global and regional sea level lowstands, peak shallowing and the almost complete absence of strata. The Late Berriasian and Late Aptian “cold snaps” were identified in the Eastern Russian Platform. The Lower Aptian bituminous shales are interpreted as being a regional manifestation of the OAE 1a. The forcing mechanism behind this OAE is an abrupt rise in temperature.

1. Introduction

Sea-level fluctuations and the reconstruction of climate changes are important issues that need to be addressed in the identification of controls on the evolution of marine sedimentary basins. In this respect, a number of recent publications have provided relevant information on genetic relationships between the lithology of Cretaceous marine sedimentary strata, depositional environments, volcanic activity, sea-level fluctuation, and climatic changes [1], [2], [3].

Similar studies have been carried out on the Russian Platform (Northeastern Peri-Tethys), albeit to a limited extent. Thus, numerous eustatic and tectonic signals have been defined in the Cretaceous deposits of the Russian Platform from a considerable amount of data available from well and outcrop studies. Sahagian and coauthors [4] developed the first regional sea-level curve for the central part of the Russian Platform, which was considered by the authors as being a tectonically passive region with a relatively continuous sedimentary succession [4]. Moreover, the authors proposed this curve to be valid for the entire platform.

At the same time, it is well known that the Eastern Russian Platform cannot be attributed to tectonically passive regions. For example, the eastern part of the platform (Figure 1) was influenced in the Mesozoic by vertical tectonic movements of significant amplitudes [5], [6], [7], [8]. The tectono-eustatic regime in this region was unstable, notably differing from that in the central part of the platform, which resulted in the formation of several troughs and depressions filled with asynchronous strata [5]. Consequently, the above mentioned curve [4] cannot reflect the dynamics of sea level changes for the entire Russian
Platform. To eliminate gaps found and reconcile any discrepancies the Barremian-Albian detailed sea-level curve was created recently for the Eastern Russian Platform [8]. The curve was based on the paleobathymetric zonation of benthic foraminifers, moreover, transgressive-regressive episodes and paleoclimate events were identified as well.

Figure 1. Location of studied area: a – on the Early Aptian Paleogeographic Map (simplified from [9]); b – on the Eastern part of European Russia; c – on the Eastern part of the Russian Platform with structural zoning of the Lower Cretaceous deposits.

Legend: 1 – occurrence of the Lower Cretaceous deposits; 2 – border of structural-geological zones; 3 – border of structural-geological subzones; 4 – location of boreholes and outcrops. Structural-geological zones and subzones according to the Stratigraphic Scheme of the Lower Cretaceous Deposits of the Russian Plate (modified by [10]): I – Vyatka-Kama Depression; II – Moscow Synecline; III – Kovernin Depression; IV – Oka-Don Depression; V – Murom-Lomov Trough; VI – Uljanovsk-Saratov Trough; VII – Cheboksary Volga Region, VI2 – NE part of the Uljanovsk-Saratov Trough, VI3 – Uljanovsk-Samara Volga Region, VI4 – Saratov Right Bank Region, VI5 – Saratov Left Bank Region; VII – Buzuluk Depression.

In the present study, a new detailed and modified Berriasian-Albian regional sea-level (RSL) curve of zonal resolution is presented for the Eastern Russian Platform (Northeastern Peri-Tethys). Using the previously proposed method of comparison between the global sea-level and the RSL curves [7], the interpretation of sea-level and climatic controls on depositional environments was provided. Widely discussed causes and consequences of the Late Aptian “cold snap” and the Oceanic Anoxic Event 1a (OAE 1a) [11], are also considered.
2. Geologic setting and biostratigraphy

Current understanding of the occurrence and distribution of the Lower Cretaceous deposits within the eastern Russian Platform (Figure 1) is mainly the result of voluminous stratigraphic data that have been compiled and published [10]. In the Early Cretaceous, the Eastern Russian Platform was an area of inner shelf sea, which was connected episodically by N-S oriented channels with the South and Boreal seas [9] (Figure 1a). The Lower Cretaceous siliciclastic deposits are represented mainly by mudrocks, with a maximum thickness of 450 m. In general, the studied succession stacks to form three siliciclastic megasequences that were developed as a result of RSL fluctuations and climate changes [5], [12].

Meanwhile, a reliable and accurate chronostratigraphic basis for sequence stratigraphic and paleoenvironmental reconstructions was prepared as a results of the comprehensive litho- and biostratigraphic investigations of more than 200 bore hole sections and outcrops (Figure 2). More than 100 sections were used to compile a composite section of the Northeastern Ulyanovsk-Saratov Trough [5] (Figure 3). The chronostratigraphic section obtained comprises continuously accumulating series of strata divided by large stratigraphic hiatuses (Figure 3). These series can be distinguished as megasequences as their duration varies from 5 to 20 Myr [13].

As it is shown in Figure 3, three megasequences are clearly identified in the Lower Cretaceous strata: the Valanginian, the Upper Hauterivian–Aptian, and the Albian. They are well characterized by ammonite Zones and can be therefore, easily correlated with the Geological Time Scale [14] providing correct ages for the eustatic and climatic events.

3. Methods

According to recent paleobathymetric investigations [8], [15], two facies can be distinguished in the Lower Cretaceous succession of the Eastern Russian Platform: (a) coastal sandstones and conglomerates; (b) shallow water mudstones (Figure 3). The analysis of spatio-temporal distribution of facies in the studied area resulted in construction a first-ever RSL curve [5]. Relative depth interpretations were then improved by the paleobathymetric reconstructions based on a quantitative analysis of the Lower Cretaceous benthic foraminifers in conjunction with the evaluations of their habitat characteristics [6], [15].

The obtained RSL curve was synchronized with the Early Cretaceous global sea level curve [16] in order to identify global and regional lowstands and highstands. Global “cold snaps” are reported to coincide with simultaneous eustatic lowstands, peak shallowing of the basin, and the almost complete absence of deposits [1].

4. Results and Discussions

4.1. Regional sea-level curve

It was demonstrated previously [6], [8] that the epeiric sea of the Eastern Russian Platform was influenced by three impulses of tectono-eustatic activity in the Early Cretaceous, during which the Valanginian, the Upper Hauterivian–Aptian, and the Albian Megasequences were formed (Figure 3). All of them are separated from each other by asynchronous hiatuses, the duration of which can be comparable with or exceeds the time intervals required for the formation of these megasequences.
Figure 2. N-S correlation between borehole sections, based on lithology, facies, major ammonites, and distribution of benthic foraminifers
Figure 3. Chronostratigraphic scheme of the Lower Cretaceous deposits from the Eastern Russian Platform, regional sea-level changes, and major climate and anoxic events.

Legend: 1 – coastal sandstones and conglomerates; 2 – shallow water mudrocks; 3 – bituminous shales; 4 – intercalations of: a) sandstones and siltstones, b) marls, c) mudrocks; 5 – boundaries of megasequences; 6 – climate and anoxic events.

In general, the depth of the basin is estimated at about 200 m, varying in the range of 150–350 m (Figure 3). In the Berriasian and Valanginian, when the sandstones and conglomerates were accumulated in the high-energy hydrodynamic environments, the depth of the basin did not exceed 50 m. In the Late Hauterivian–Middle Aptian, the depth increased to 200 m and varied slightly all the time around this level, resulting in accumulation a homogeneous succession of dark-gray carbonate-free mudrocks.
The Lower Aptian black shales were formed in the upper bathyal zone at a depth of approximately 250 m. The Albian strata were likely deposited in deeper environments, at a depth of about 350 m.

The Russian Platform is proved to be characterized by the diverse tectono-eustatic regimes reconstructed in its different structural-geological zones (Figure 1). Thus, the most significant difference can be found in RSL curves created for its central [4] and eastern parts (this study) as in the Central Russian Platform the depth of the basin in the Early Cretaceous does not exceed 110 m, but in its eastern part it varied in a range of 200–350 m. The other substantial differences are evident from the asynchrony and different ranks of the tectono-eustatic cycles reflected in the RSL curves of both regions. This inconsistency can be easily explained by the different tectonic conditions in these regions in the Early Cretaceous.

4.2. Major “cold snaps”

The comparison between the global [16] and the RSL curves reveals two main lowstands in the Late Berriasian and Late Aptian (Figure 3). These periods are manifested by hiatuses in most structural-geological zones on the Eastern Russian Platform except few depressions. Presumably, these lowstands could be caused by the so-called “cold snaps” interrupted the Cretaceous greenhouse world, which are widely discussed and have been confirmed by various methods [1]. The Late Aptian lowstand is among the most well-known ones. Being found in many sections worldwide (e.g., in the Arabian Plate, Australia) it is regarded to be the most likely related to the global climate cooling [1] (Figure 3).

Although there are no very many examples of the manifestation of the Late Berriasian lowstand in geological sections globally, the both lowstand and associated hiatus are identified in many sections in the Eastern Russian Platform [5] and in North America [17]. The Late Berriasian deposits therefore need further investigation by detailed paleoecological studies and isotope analyses in various sedimentary basins.

It should be noted that unlike the common methods applied for identification “the cold snaps” in geological sections, such as by finding various climate-sensitive biotic and isotope signals, these events were easily identified in the Eastern Russian Platform by the comparison between the global and RSL curves and detecting intervals at which both curves show simultaneous minimums (Figure 3). The main consequence of the two “cold snaps” revealed was a rapid sea level fall with almost total termination of sedimentation.

4.3. Oceanic Anoxic Event – 1a

The comparison of the Early Aptian global sea-level and RSL curves helps to find out the similarity of both curves comprising two cycles (Figure 3). The rising part of the first cycle coincides with the OAE 1a during which the Lower Aptian bituminous strata were formed in studied basin [5], [6], [18]. The onset of deposition of bituminous shales is interpreted to reflect the completion of the early Aptian transgressive part of the regional 3-rd order cycle that may have triggered acceleration of marine transgression in the Eastern Russian Platform ubiquitously. Importantly, this regional transgression is synchronous with the transgressive phase of the first short-term Aptian global cycle (Figure 3).

The Lower Aptian black shales were formed in the upper bathyal zone at an estimated depth of about 250 m [15]. Recently, major isotope investigations of the aragonitic bivalve shells and heteromorph ammonites from these strata were undertaken by Zakharov and coauthors [19]. Paleo-temperatures calculated from oxygen-isotope analyses showed extremely warm conditions: 24–33.2°C (δ18O values fluctuate from -3.6 to -2.2‰). Carbon isotopic data (δ13C values fluctuate from -3.8 to +1.88‰) from the Russian region agree well with the isotopic analyses obtained from the black shales of Greece, Italy, Germany, France, Spain, England, Tunisia, USA, and mid-Pacific where a similar negative C-isotope
anomaly was also recorded at the onset of the Early Aptian OAE 1a [20]. Extremely warm paleo-temperatures related to a global sea-level highstand such as in the Early Aptian compared to a major sea-level lowstand during cooler Late Aptian times also support the idea of glacio-eustasy even during hot greenhouse phases of Earth climate [21].

5. Conclusions

The Early Cretaceous RSL curve of zonal resolution is constructed for the Eastern Russian Platform based on the results of facial analysis and quantitative paleo-depth assessment.

Major climatic and anoxic events can be identified by the comparison between the global and RSL curves. “The cold snaps” interfering the Early Cretaceous greenhouse world probably coincide with simultaneous global and RSL lowstands, peak shallowing of the basin, and the almost complete absence of deposits.

The Late Berriasian and Late Aptian “cold snaps” are identified in the Eastern Russian Platform.

The Lower Aptian black shales accumulated in the epeiric basin of the Eastern Russian Platform are confirmed to be a regional manifestation of the OAE-1a. The most believable forcing mechanism behind OAE 1a is an abrupt rise in temperature.

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