ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА ANNALES GÉOLOGIQUES DE LA PÉNINSULE BALKANIQUE	70	1–8	БЕОГРАД, децембар 2009 BELGRADE, December 2009

DOI: 10.2298/GABP0970001Z

A condensed succession at the Jurassic/Cretaceous transition in a shallowing basin on the eastern Russian Platform

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Abstract. The eastern periphery of the Russian Platform houses an exceptional record of the Jurassic/Cretaceous transition, which is represented by very thin sandstone beds. The presence of glaucony grains, phosphorite concretions and shark teeth indicates that the transitional sediments constitute a condensed succession, although the allochtonous origin of the glaucony grains in itself is not a reliable indicator. The combination with thin ammonite zones and a strongly diminished sedimentation rate, as low as ~0.05 cm/ka are, however, convincing evidence. The Jurassic/Cretaceous transitional deposits accumulated in a basin the depth of which decreased simultaneously with a global eustatic sea-level fall. This coincidence suggests that condensed successions may form in shallowing environments, which contradicts the sequence-stratigraphic concept. Considering the character of the sediments under study, it appears that both stratigraphic and taphonomic condensation patterns occur in this part of the eastern Russian Platform.

Key words: condensed succession, shallowing, ammonite zones, Jurassic, Cretaceous, Russian Platform.

Апстракт. Источни обод Руске Платформе показује изузетан податак о јурско-кредном прелазу, који је представљен веома танким слојевима пешчара. Присуство глауконитских зрна, фосфорних конкреција и зуби ајкула указују да прелазни седименти изграђују кондензовану сукцесију и ако алохтоно порекло глауконитских зрна није увек поуздан показатељ. Комбинација уских амонитских зона и јако смањење брзине седиментације од ~0.05 cm/ka су свакако убедљив доказ. Прелазни јурско-кредни седименти депоновани су у басен чија се дубина истовремено повећава са падом еустатичког нивоа светског мора. Ова коинциденција указује да се кондензоване сукцесије могу формирати у плитким срединама, а која је у супротности са концептом секвентне стратиграфије. Разматрајући проучавани карактер седимената, произилази да су се и стратиграфска и тафономска кондензација дешавале у овом делу источне Руске Платформе.

Кључне речи: кондензована сукцесија, оплићавање, амонитске зоне, јура, креда, Руска Платформа.

Introduction

Condensed successions result from an exceptionally low sedimentation rate. Although HEIM (1934) was the first to study this phenomenon, its present-day concept is rooted in sequence stratigraphy (LOUTIT *et al.* 1988). Sequence stratigraphy establishes links between condensed sections and maximum flooding surfaces, which separate transgressive systems tracts and highstand systems tracts (LOUTIT *et al.* 1988, CATUNEANU 2006).

Another significant contribution to the understanding of condensed successions comes from theoretical investigations of fossil concentrations (e.g., KIDWELL *et al.* 1986, KIDWELL 1993, KONDO *et al.* 1998). The most comprehensive characteristics of this phenomenon were provided by GÓMEZ & FERNÁNDEZ-LÓPEZ (1994) and FERNÁNDEZ-LÓPEZ (2000), who distinguished between sedimentary, stratigraphic, and taphonomic condensation and who also emphasized the possible occurrence of condensed successions in a variety of sedimentary environments. KITAMURA (1998) and AMOROSI (2003) showed that the presence of glaucony grains is not always a reliable indicator of condensed successions, which is in disagreement with the sequence-stratigraphic concept (LOUTIT *et al.* 1988).

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In the present contribution, an example of intense condensation in a shallowing sedimentary succession, is provided, *viz*. that at the Jurassic/Cretaceous transition on the eastern Russian Platform (Fig. 1). Previous studies (ZORINA 2005, ZORINA & RUBAN 2007) documented a concentration of several ammonite zones within thin siliciclastic beds of this succession, as well as a general basin shallowing. The linking of these two phenomena represents an example of an unusual condensation mechanism.

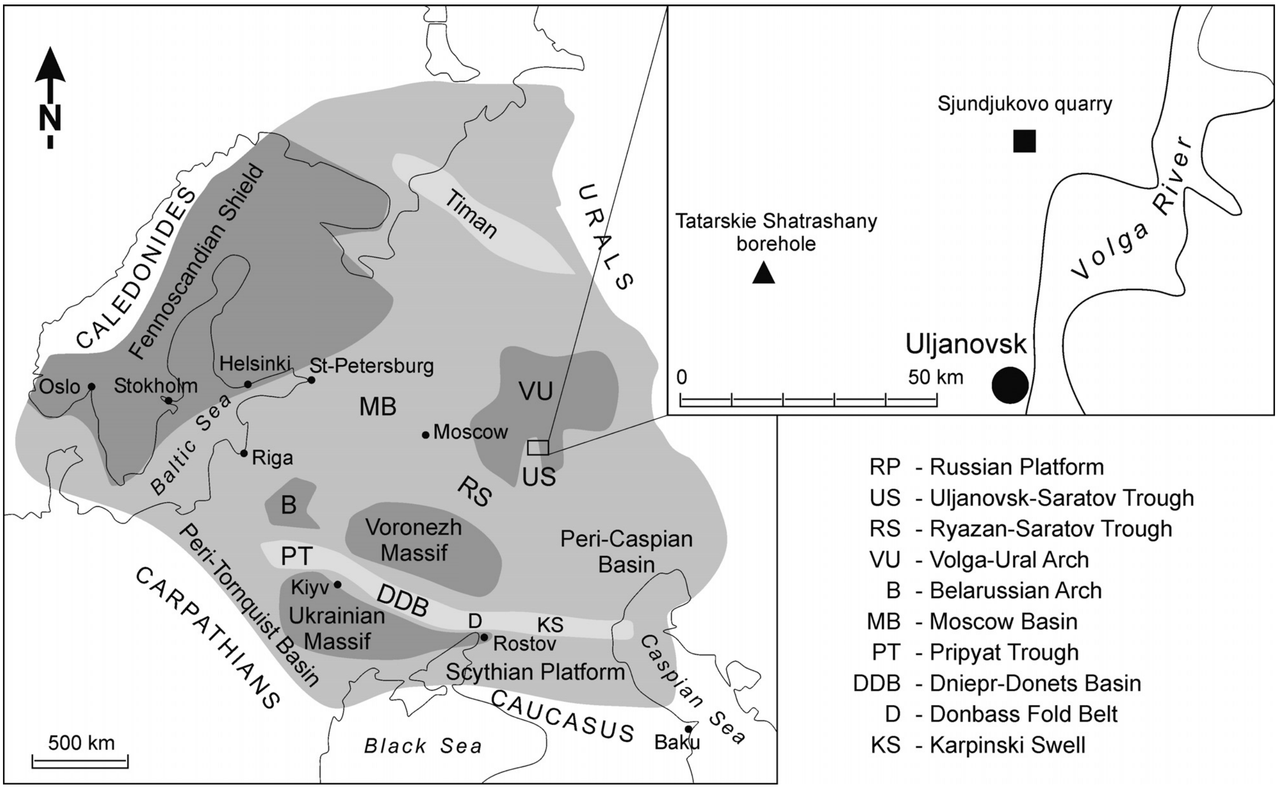

Fig. 1. Location of the study area. Sketch of the Russian Platform adapted from NIKISHIN *et al*. (1996), SAHAGIAN *et al*. (1996) and ZORINA & RUBAN (2007).

Geological setting

The eastern periphery of the Russian Platform is surrounded by the large watershed of the Volga River and its main tributaries. The study area is the north-eastern part of the Uljanovsk–Saratov Basin (Fig. 2), which is a trough incised in the southern periphery of the Volga–Ural Arch (SAHAGIAN *et al*. 1996). This basin is filled up with Middle Jurassic-Paleogene deposits with a total thickness of about 450 m (ZORINA 2005). The Jurassic/Cretaceous transition in this region was reviewed comprehensively by ZORINA (2005) and ZORINA & RUBAN (2007). Detailed palaeoenvironmental reconstructions were presented by RIBOULLEAU *et al*. (1998, 2003).

Formation names for the rocks in this area have been proposed by JAKOVLEVA (1993) but their definition is not clear. Therefore, ZORINA & RUBAN (2007) suggested alternative lithostratigraphic units that are related to the local ammonite-based biozones and that can be fitted in a chronostratigraphical context (Fig. 3). The transitional Jurassic/Cretaceous strata are represented in the north-eastern part of the Uljanovsk–Saratov Basin by green and greenish-grey sandstones with a total thickness of up to 2.5 m. These deposits contain the ammonites: *Virgatites pallasianus* (ORBIGNY), *V. sosia* (VISHNIAKOFF), *Virgatites* cf. *gerassimovi* MITTA, *V. pussilus* MICHALSKY, *Epivirgatites nikitini* (MICHALSKY), *E.* sp., *Kachpurites fulgens* (TRAUTSCHOLD), *Craspedites okensis* (ORBIGNY), and *C.* cf. *okensis* (ORGBIGNY). This combination of taxa indicates a stratigraphic interval

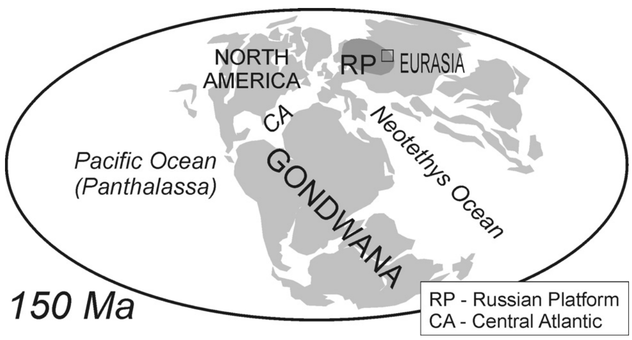

Fig. 2. Palaeotectonic position of the study area (simplified from SCOTESE, 2004).

ranging from the *Virgatites virgatus* Zone to the *Craspedites subditus* Zone. In addition to the ammonites, bivalves and belemnites are found in the deposits under study. The transitional Jurassic/Cretaceous strata overlie sometimes conformably, sometimes disconformably, the organic-rich clays of the *Dorsoplanites panderi* Zone. A significant hiatus follows and the *Dorsoplanites panderi* Zone is overlain by Hauterivian deposits.

Materials and methods

A representative section from the eastern Russian Platform, in the form of cores from the Tatarskie Shatrashany borehole, was investigated (Fig. 1). Analysis of the lithological characteristics and the fossil assemblages in each bed of the Jurassic/Cretaceous transitional interval resulted in a detailed stratigraphic framework for the site. The emphasis of the analyses was on the transitional Beds 21–25 (Fig. 3A). The data thus obtained were compared with those from the nearby Sjundjukovo Quarry.

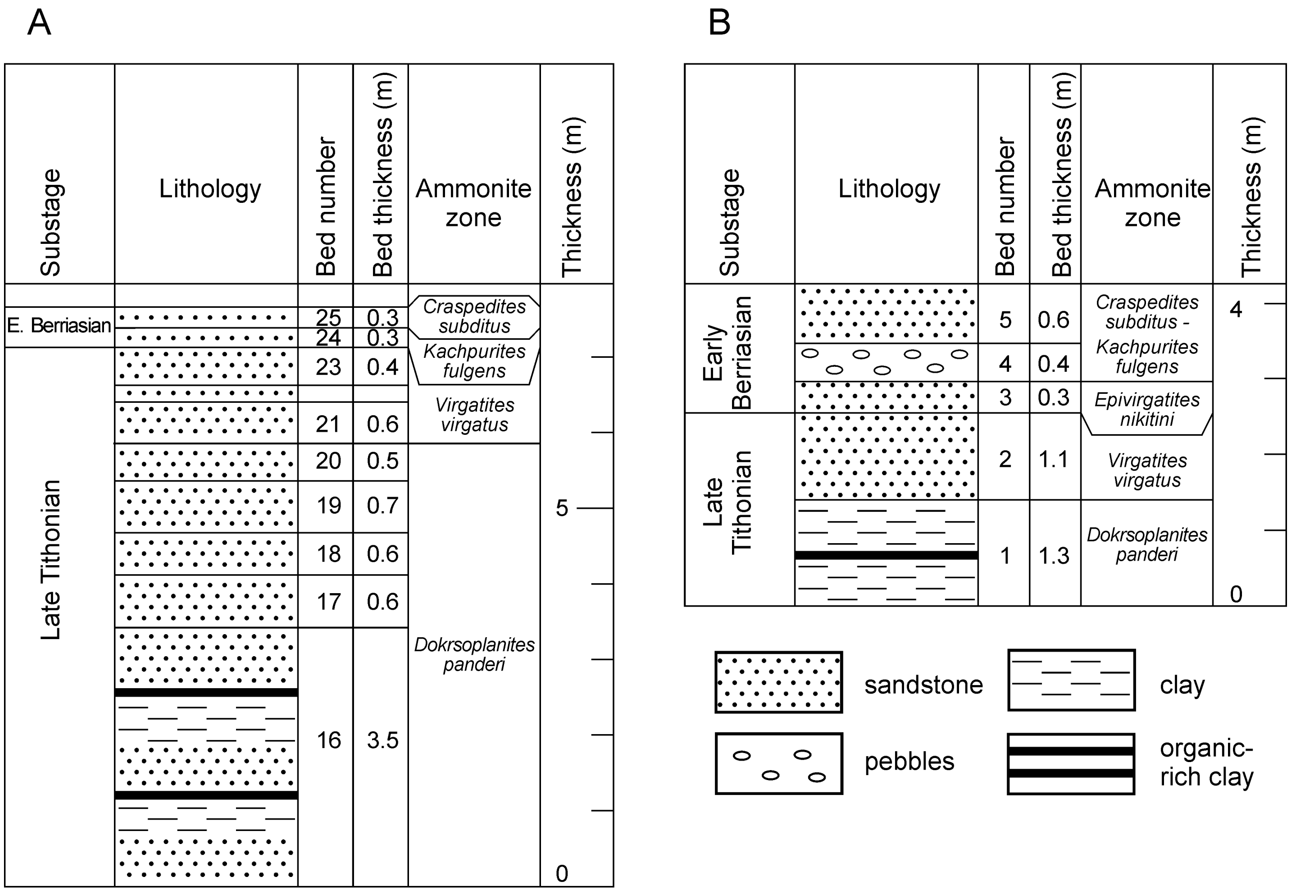

Fig. 3. Schematic chrono-, litho- and biostratigraphy of the two sections under study.

In general, the study territory is situated between the Tethyan and Boreal Regions, in the middle of western Eurasia (Fig. 2). The transitional Jurassic/Cretaceous deposits accumulated in the shallow Interior Russian Sea (Jasamanov 1978), which had a strongly fluctuating sea level (Sahagian *et al.* 1996, Zorina & Ruban 2007). This sea had wide connections with Boreal water masses but its connections with the Caucasian Sea to the South were intermittent (Baraboshkin *et al.* 2003, Rogov *et al.* 2006). The sea water was warm, with a normal salinity (Jasamanov 1978, Riboulleau *et al.* 1998). Analysis of the clay mineralogy indicates an arid climate (Riboulleau *et al.* 2003). Wave activity along the shore, in combination with bottom currents, frequently resulted in erosion, commonly followed by resedimentation of the particles (Zorina & Ruban 2007).

The analyses were aimed at finding lithological evidence for the presence of a condensed succession based on the sedimentological criteria proposed by Loutit *et al.* (1988) and Catuneanu (2006). These include the occurrence of glaucony grains, phosphorite concretions and shark teeth. However, it must be emphasized, in this context, that none of these criteria is sufficient in itself to recognize a condensed succession (Gómez & Fernández-López 1994, Kitamura 1998, Amorosi 2003). On the other hand, intraformational disconformities seem to be reliable indicators of a decreased sedimentation rate (*cf.* Gómez & Fernández-López 1994). The possible occurrence of a condensed succession was, therefore, investigated by analysis of the local sedimentation rate (*sensu* GÓMEZ & FERNÁNDEZ-LÓPEZ 1994). This sedimentation rate (*SR*) is defined here as $SR = T_{lu}/t_{lu}$, with T_{lu} being the thickness of the entire lithological unit and t_{lu} being the total duration of the deposition of the unit involved (including minor hiatuses).

A decrease in the sedimentation rate can be caused by: (1) a longer time interval between the accumulation of individual sedimentary particles (or thin successions, for instance laminae, formed by them); (2) interruptions in sedimentation or (3) a combination of these two factors. A condensed character cannot be established if only one single unit is considered, as the sedimentation rate is always relative (GÓMEZ & FERNÁNDEZ-LÓPEZ 1994). In the present study, the sedimentation rate of the potentially condensed interval was compared with that of the likely uncondensed underlying strata. It is possible to measure the sedimentation rate semi-quantitatively using ammonite zones, or quantitatively by obtaining absolute ages. Both types of analysis were performed for the present study; the applied chronostratigraphic framework was taken from the work of GRADSTEIN *et al.* (2004).

Condensation patterns

The transitional Jurassic/Cretaceous strata in the Tatarskie Shatrashany borehole (= Beds 21–25) consist of very fine-grained sandstones with a total thickness of 1.75 m (Fig. 3A). The size of individual grains varies little (from 0.05 to 0.12 mm) but their roundness shows large variations. The sandstones consist of glaucony grains (36–74 %), quartz grains (3–16 %) and rare feldspar grains; the sement consists of carbonates, clay particles and collophane, whereas the matrix is constituted of mineral clasts and glaucony. The joint amount of cement and matrix amounts to 35–68 %. The sandstones contain abundant phosphorite concretions and grains. In the Sjundjukovo Quarry, the size of the phosphorite concretions varies between 2 and 5 cm. The total content of P_2O_5 varies from 2.7 to 16.4 %. The total amount of P_2O_5 increases upwards in the succession (ZORINA & VALITOV 2007). The collophane constitutes up to 35 % of the sandstone and it is present in both concretions and cement. Phosphorite-bearing matter also encrusts some invertebrate remains, which are present both as clasts and as part of the matrix. Shark teeth are abundant within the transitional Jurassic/Cretaceous sandstones of both the borehole and the quarry. Their total amount attains a maximum of 3 % in the sandstones of Bed 24 of the Tatarskie Shatrashany borehole, where also numerous intraformational disconformities are present (as in the entire section under study). These features are typical of condensed successions (LOUTIT *et al.* 1988, CATUNEANU 2006). However, the glaucony grains seem to be allochtonous and, therefore, cannot be used as a proper indicator of a condensed succession (*cf.* AMOROSI 2003).

Beds 21–23 in the Tatarskie Shatrashany borehole belong to the *Virgatites virgatus* Zone, whereas Beds 24–25 are attributed to the interval of the *Kachpurites fulgens* - *Craspedites subditus* Zones (Fig. 3A); the *Epivirgatites nikitini* Zone is absent in this succession, which must be ascribed to a hiatus. The deposition of the section with the transitional beds thus corresponds to four ammonite zones (including the lacking *Epivirgatites nikitini* Zone). In comparison, the five underlying beds (Beds 16–20) with a combined total thickness of 5.9 m were deposited during a time span representing only one ammonite zone (the *Dorsoplanites panderi* Zone). This is clear evidence that the transitional beds (21–25) form a condensed succession.

A preliminary correlation of the local biostratigraphic units with the global chronostratigraphy (ZORINA 2007) indicates that Beds 21–25 were deposited during ~3.5 Ma, which implies a sedimentation rate of ~0.05 cm/ka. In comparison, the sedimentation rate during the deposition of the underlying *Dorsoplanites panderi* Zone was 0.8 cm/ka. These simple calculations, although being only approximate, also strongly support condensation at the Jurassic/Cretaceous transition in the study area.

In the Sjundjukovo Quarry, beds 2–4 belong to the interval of the *Virgatites virgatus* and the *Craspedites subditus* Zones (Fig. 3B). In this section, the *Epivirgatites nikitini* Zone is present in the sedimentary record. The total thickness of beds 2–4 is 1.8 m, hence the sedimentation rate can be calculated to be also ~0.05 cm/ka, which implies a similar degree of condensation as found for the transitional beds in the Tatarskie Shatrashany borehole.

Relationship between condensation rate and basin depth

The depth of the sea around the north-eastern part of the Uljanovsk–Saratov Basin can be reconstructed accurately with the criteria proposed by SAHAGIAN *et al.* (1996), as already discussed by ZORINA & RUBAN (2007). The presence of phosphorites in the very fine sands indicates that the depth was less than 20 m and, thus, most commonly, above the storm wave base. This is supported by the presence of phosphorite gravels and pebbles (ZORINA & RUBAN 2007). Although autochthonous glaucony indicates a depth of 50–500 m, allochtonous grains tend to accumulate close to the shoreline when in a regressive setting (AMOROSI 2003). In this case, the grains were reworked by waves and bottom currents. In comparison, the deposits of the *Dorsoplanites panderi* Zone were deposited at a depth of over 40–50 m, as suggested by the dominance of organic-rich clays and sulphides (SAHAGIAN *et al.* 1996, ZORINA & RUBAN 2007).

The above-mentioned changes in basin depth reflect a significant shallowing trend (Fig. 4). The sea retreated from the study area for a long time already in the earliest Cretaceous, as indicated by the middle Berriasian to early Hauterivian hiatus (ZORINA 2005). It must, consequently, be deduced that the strong condensation coincided with a basin shallowing during an accentuated regressive episode. The regional sea-level changes coincided with the global eustatic drop documented by HAQ *et al.* (1987) and HAQ & AL-QAHTANI (2005) (Fig. 4).

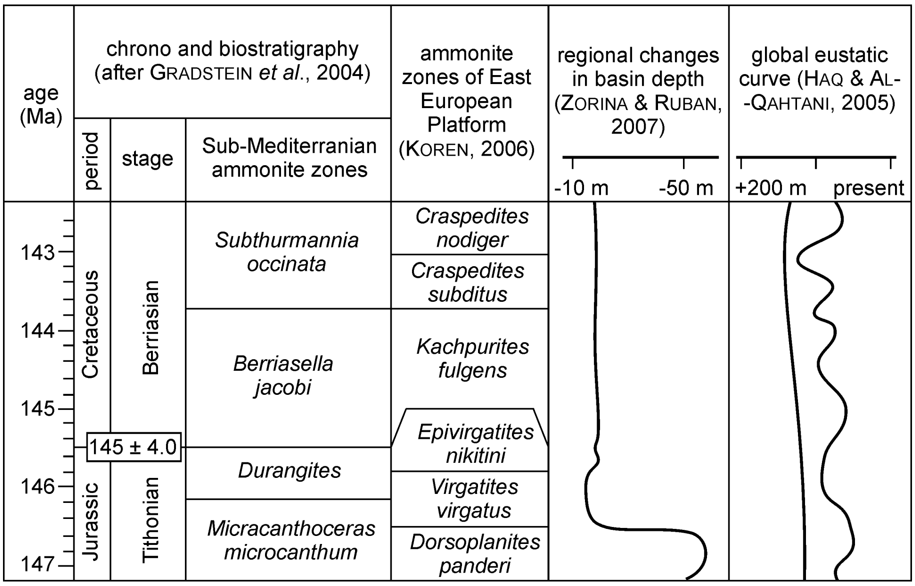

Fig. 4. Changes in basin depth and global eustatic sea-level fluctuations.

ZORINA & RUBAN (2007), following an assumption by HALLAM (2001), hypothesized that the end-Jurassic shallowing and the regression were tectonically-controlled and coincided with similar phenomena documented just occasionally in other regions. However, ZORINA *et al.* (2008) advocated a global extent of the sedimentary break at the Jurassic/Cretaceous transition. If so, the condensed section in the Uljanovsk–Saratov Basin reflects a global eustatic drop of the sea level.

Discussion

GÓMEZ & FERNÁNDEZ-LÓPEZ (1994) distinguished three condensation types. The first type (which is the most common) is stratigraphic condensation, which can be expressed by the SR index (the value representing the average net deposition per time unit). The second type is sedimentary condensation, which is somewhat more complex (Fig. 5); it is determined by the real rate of accumulation, which is the ratio between the thickness of a lithological unit without hiatuses on the one hand, and the duration of its formation on the other hand. As noted by GÓMEZ & FERNÁNDEZ-LÓPEZ (1994), a strong stratigraphic condensation does not always imply a similarly strong (or even any) sedimentary condensation. The third type is taphonomic condensation, which is only an apparent feature because of re-sedimentation or re-working of index taxa.

Our data from the Tatarskie Shatrashany borehole and the Sjundjukovo Quarry indicate strong stratigraphic condensation of the Jurassic/Cretaceous transitional beds. The presence of numerous intraformational disconformities, especially in the interval of the *K. fulgens* and *C. subditus* Zones (Beds 24–25), suggests that the condensed character resulted mainly from multiple interruptions of the local depositional process. Intense re-sedimentation occurred by waves and bottom currents, which produced erosional surfaces in the marine succession. The accumulation rate responsible for the deposition of the various beds may, consequently, not have been truly low (but it cannot be determined with any reasonable accuracy how much sediment was removed during the erosional phases). In any case, stratigraphic condensation is in the transitional beds much more emphasized than sedimentary condensation. The role of the latter is likely to be greater in the lower interval of the studied interval, where the number of intraformational disconformities is lower.

Many reworked ammonites are present in the transitional Jurassic/Cretaceous strata. Their concentration is particularly high in bed 24 of the *K. fulgens* Zone. It should therefore be emphasized here that only those ammonites not bearing any evidence of reworking were used to establish the age of the transitional strata. The presence of reworked taxa indicates taphonomic condensation of the succession. Although the transitional Jurassic/Cretaceous beds of the eastern Russian Platform most probably show a very strong condensation of this type, this does not affect significantly the above interpretations of stratigraphic and sedimentary condensation because both types of condensation are based on reliable dating of the various beds under study.

Conclusions

The present study indicates relatively strong condensation of the transitional Jurassic/Cretaceous beds on the eastern Russian Platform. The condensation coincided with basin shallowing induced by a global eustatic drop in the sea level. It appears that the entire transitional Jurassic/Cretaceous succession in the study area is condensed in both a stratigraphic and a taphonomic respect, whereas sedimentary condensation may be relevant only in the lower part of the succession under study.

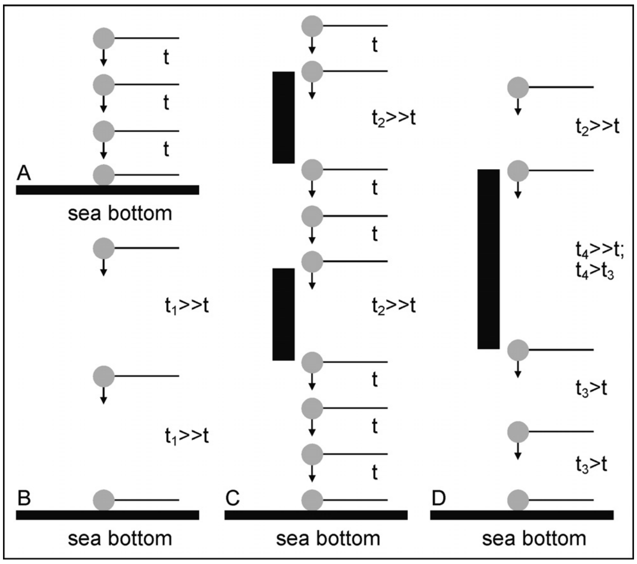

Fig. 5. Condensation mechanisms. A, uncondensed sedimentation; **B,** stratigraphic condensation; **C,** sedimentary condensation; **D,** stratigraphic condensation with a reduction in accumulation rate. t = time intervals between accumulation of sedimentary particles (grey circles); black rectangles mark interruptions in sedimentation, which now form hiatuses.

New data from the eastern Russian Platform confirm that even strong condensation does not occur preferably in deep-marine settings at a time of transgression maximums. Further studies should be aimed at developing more precise models regarding the glaucony and phosphorite accumulations. Such studies might provide the data required for a deeper insight into regional condensation patterns.

Acknowledgements

The authors gratefully thank the Editor V. RADULOVIĆ (Serbia) and the other "GABP" staff for their technical support, I. ZAGORCHEV (Bulgaria) and the other anonymous reviewer for their improvements, and also S. R. FERNÁNDEZ-LÓPEZ (Spain), N.M.M. JANSSEN (Netherlands), A. KITAMURA (Japan), A. RIBOULLEAU (France), and W. RIEGRAF (Germany) for their help with the literature. The help with fossil identification by E.YU. BARABOSHKIN (Russia) is also appreciated.

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Резиме

Кондензована сукцесија на прелазу јура/креда у плитководном басену на источној Руској Платформи

Источни обод Руске Платформе је изузетан пример за прелазне јурско-кредне седименте, а такође и за дискусију о феномену кондензације. Секвентна стратиграфија успоставља везу између кондензованих изданака и максимума трансгресије, које представљају границе између трансгресивних просторних система и високог нивоа надирања мора. Међутим, нека проучавања истичу могућност појаве кондензованих сукцесија у зависности од различитости седиментационих средина. Проучавана област припада североисточном делу Уљановско-саратовског басена који представља трог усечен у јужни обод Волгско-уралског лука. Прелазни јурско-кредни слојеви су представљени у североисточном делу Уљановско-саратовског базена са зеленим и зеленкастосивим пешчарима са укупном дебљином до 2,5 m. Амонитски таксони указују на стратиграфски интервал од *Virgatites virgatus* до *Craspedites subditus* зона (горњи титон–доњи беријас). Присуство глауконитских зрна, фосфорита и ајкулиних зуба је литолошки доказ кондензације, мада алохтоно порекло глауконитских зрна није увек поуздан показатељ. Седименти профила са прелазним слојевима одговарају четири амонитске зоне (укључујући одсуство *Epivirgatites nikitini* зоне) које указују на снажну кондензацију. Корелација локалних биостратиграфских јединица са светском хроностратиграфијом указује да су слојеви 21-25 Татарско-шатрашанске бушотине стварани за време од ~3,5 Ma, што указује на принос од ~0,05 cm/ka. Седиментациони принос за време депоновања подинске *Dorsoplanites panderi* зоне је био 0.8 cm/ka. Ова проста рачуница, и ако је само приближна, јако подржава кондензацију јурско-кредних прелазних слојеве у проучаваној области. Исти степен кондензације је познат из Сјундјуковског каменолома. Присуство фосфорита у јакоситнозрним пешчарима указује да је дубина била мања од 20 m, која је најчешће била изнад базе олујних таласа. На ово указује и присуство валутака фосфорита. И ако аутохтони глауконити указују на дубину од 50-500 m, у регресивним околностима алохтона зрна теже да се акумулирају ближе обалској линији. У овом случају зрна су премештена таласим и подводним струјама. Горе поменуте промене у дубини басена су се одразиле на значајно продубљавање. Кондензовани профил Уљановско-саратовског басена одражава општи еустатички пад нивоа мора. Овај феномен је у супротности са досадашњим знањима о секвентној стратиграфији. Подаци из Татарско-шатрашанске бушотине и Сјундјуковског каменолома указује

на јаку стратиграфску кондензацију јурско-кредних прелазних слојева. Присуство многобројних интраформационих дискорданција, нарочито у интервалу *K. fulgens* и *C. subditus* зона, указује да је кондензациони карактер проузрокован углавном вишеструким прекидима локалних депозиционих процеса. Принос кондезованих седимената остаје дискутабилан. Присуство реседиментованих таксона указује на тафономску кондензацију сукцесије. И ако прелазни јурско-кредни слојеви источне Руске Платформе највероватније показују веома јаку кондензацију, што не умањује значај горе поменуте интерпретације стратиграфске и седиментолошке кондензације, јер оба типа кондензације су засновани на поуздано одређеним старостима проучаваних слојева.