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Article

The Ryazanian (basal Lower Cretaceous) standard zonation: state of knowledge and potential for correlation with the Berriasian primary standard

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With 5 figures

Abstract: The chronostratigraphic zonal succession of the ammonoid-based biostratigraphic subdivision of the Ryazanian stage in its type region (the Russian Platform) is discussed. It is proposed to recognize (in ascending order) the Kochi, Rjasanensis, Spasskensis, and Tzikwinianus zones, as the Ryazanian standard. The chronostratigraphic ranges of the genus *Riasanites* and other ammonites of Tethyan origin in the Rjasanensis and Spasskensis zones apparently correspond to the interval from the Occitanica Zone to the Boissieri Zone (Paramimounum Subzone) of the Berriasian primary standard. The correlation of the basal Lower Cretaceous of the Russian Platform with synchronous beds of Poland, Mangyshlak, Northern Caucasus, Crimea, and direct correlation with the Occitanica Chronozone has promising prospects, making the base of this zone a preferred choice for the Jurassic–Cretaceous boundary. The Central Russian ecotone, therefore, has considerable potential for the Boreal-Tethyan correlation.

Key words: Jurassic, Cretaceous, Berriasian, Ryazanian, Volgian, ammonites, biostratigraphy, Russian Platform.

1. Introduction

The Ryazanian Stage is a stage name commonly used by many authors working on the Jurassic–Cretaceous boundary beds in the Boreal and Subboreal regions. It has been considered a useful secondary stage name more or less parallel to the Berriasian Stage of the lowermost Cretaceous. Secondary stages are used preferably in areas with pronounced bioprovincialism (e.g., Callomon 2003; Cope 1993, 2013). These stages should be maintained at least until the primary standard is defined and correlation clarified, which is not yet the case for the Jurassic/Cretaceous boundary. The deposits assigned to the Ryazanian Stage are unique for their fossil content, combining ammonite taxa of Boreal and Tethyan origin.

It is well known that at the end of the Jurassic, differentiation of marine basins resulted in faunal separation and the development of endemic biotas. Differentiation continued into the earliest Cretaceous, and, for only a short duration, a Boreal-Tethyan ecotone with faunas of different geographical provenance developed on the Russian Platform and adjacent regions. Hence, the study of organisms of this ecotone, primarily ammonites, provides a rare means of correlation of Mediterranean-type deposits (comprising the Berriasian primary standard) with the Boreal succession (up until very recently recognized as the "Boreal Berriasian"). This stratigraphic subdivision was first established in the Subboreal regions of European Russia as the Ryazanian "Horizon" (Bogoslowsky 1895), and was subsequently proposed as a regional stage of the

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Russian Platform (Sasonov 1951; Sasonova & Sasonov 1979). Later it was used in England (Casey 1973), the North Sea (Abbink et al. 2001), Greenland (Surlyk 1973; Alsen 2006), and recently in northern Siberia (Dzyuba et al. 2013; Bragin et al. 2013; Shurygin & Dzyuba 2015). After Rawson (1973) and Casey (1973), the Ryazanian Stage has therefore been used for almost the entire Boreal Realm.

The purpose of this paper is to give a review of the current state of knowledge of the ammonite assemblages and stratigraphic ranges in the uppermost Volgian – Ryazanian interval within a zonal framework on the Russian Platform, and discuss the potential for Boreal–Tethyan correlations.

2. History of studies

The study of Ryazanian ammonites and the establishment of an ammonite zonation can be subdivided into several periods, briefly summarized below.

The first period (end of the 19th – beginning of the 20th centuries) is associated with the first records of the Jurassic–Cretaceous boundary beds in the Ryazan Region of Russia (middle reaches of the Oka River) and the establishment of the Ryazanian "Horizon" (Lahusen 1883; Nikitin 1888; Krischtafowitsch 1892; Bogoslowsky 1893, 1895; Pavlow 1894, 1907), which was almost immediately correlated with the upper Tithonian and/or Berriasian. Nikitin (1888) described several ammonite species, whereas Bogoslowsky's (1895, 1902) monographs laid the foundation for further studies of Ryazanian deposits and ammonites. At that time, the Ryazanian Horizon was subdivided into two zones – the lower Hoplites rjasanensis Zone and the overlying Olcostephanus spasskensis Zone in the basin of the Oka River and the Olcostephanus stenomphalus Zone in the middle reaches of the Volga River.

The second period (second half of the 20th century). At this period Sasonov (1951) and Sasonova (1971, 1972, 1977) systematically described Ryazanian and Valanginian ammonites, mainly from the Middle Volga Region (basin of the Sura River), and partly from the Ryazan Region (Oka River). Casey (1973) revised the ammonites from the Jurassic-Cretaceous boundary beds of Eastern England and substantiated recognition of several taxa from the synchronous interval of the Mesozoic of Russia. Later, Casey et al. (1977, 1988), Mesezhnikov et al. (1979), and Mesezhnikov (1984) reexamined several sections of the basin of the Oka River and of the middle reaches of the Volga River. At this stage, it was suggested that the Surites tzikwinianus Zone was recognized following above the Riasanites rjasanensis Zone, instead of the Surites spasskensis Zone (Gerasimov 1971). Apart from that, the second research period is marked by the recognition of a vast number of new ammonite genera.

Mitta (2002, 2005, 2007a, 2014) described in detail the taxonomic composition of Ryazanian ammonite assemblages in the Moscow and Ryazan regions and the ammonite zonation including a review of records of Ryazanian ammonites in the literature. In addition, there have been many papers to some extent dealing with the taxonomy of Ryazanian ammonites and Ryazanian stratigraphy based solely on field observations and/or analysis of published literature, without full descriptions of ammonites. Some of these papers are discussed below.

3. Material

This review is based on a long-term study (1980-2015) of the sections of the Jurassic–Cretaceous boundary beds on the Russian Platform by the present author, mainly in the Moscow, Ryazan, Kostroma, Ulyanovsk, and Samara regions of Russia, as well as the study of collections of previous authors in the museums of Moscow and St. Petersburg. Ammonites from contemporaneous successions in Western and Northern Europe have been studied in museum collections in Paris, Lyon, Granada and Warsaw. Berriasian sections have been examined in France, Tunisia and the northern Caucasus.

In Central Russia the Ryazanian deposits are widespread in natural outcrops of riverbanks and quarries. A general characterization and photographs of the main sections of this age from the Moscow Basin are given by Mitta (2014). Despite the small thickness (a few meters) due to their condensed nature, Ryazanian deposits frequently contain abundant fossils, primarily ammonites and bivalves, often poorly preserved. The lithology and thickness of these deposits are markedly inconsistent, especially in the type sections in the basin of the Oka River, where the geology can vary laterally within just a few meters.

Outcrops near the Nikitino and Kuzminskoe villages along the Oka River in the Ryazan Region (representing the south-Ryazan and north-Ryazan types of section, respectively), sections of the Lopatinsky Phosphorite Mine in the Moscow Region (Voskresensk type), outcrops near the Efimovo and Ogarkovo villages on the Unzha River in the Kostroma Region (Unzha type), sections on the Menya River (basin of the Sura River) in Chuvashia (Menya type), and outcrops near the Kashpir Village on the Volga, Samara region, and near Maryevka village, Ulyanovsk region (Kashpir type) (Fig. 1) are the key sections for the Ryazanian Stage. All these sections show certain similarities and differences, supplementing each other and allowing the reconstruction of the chronostratigraphic succession of ammonite associations. These sections and the ammonites found there are briefly discussed below.

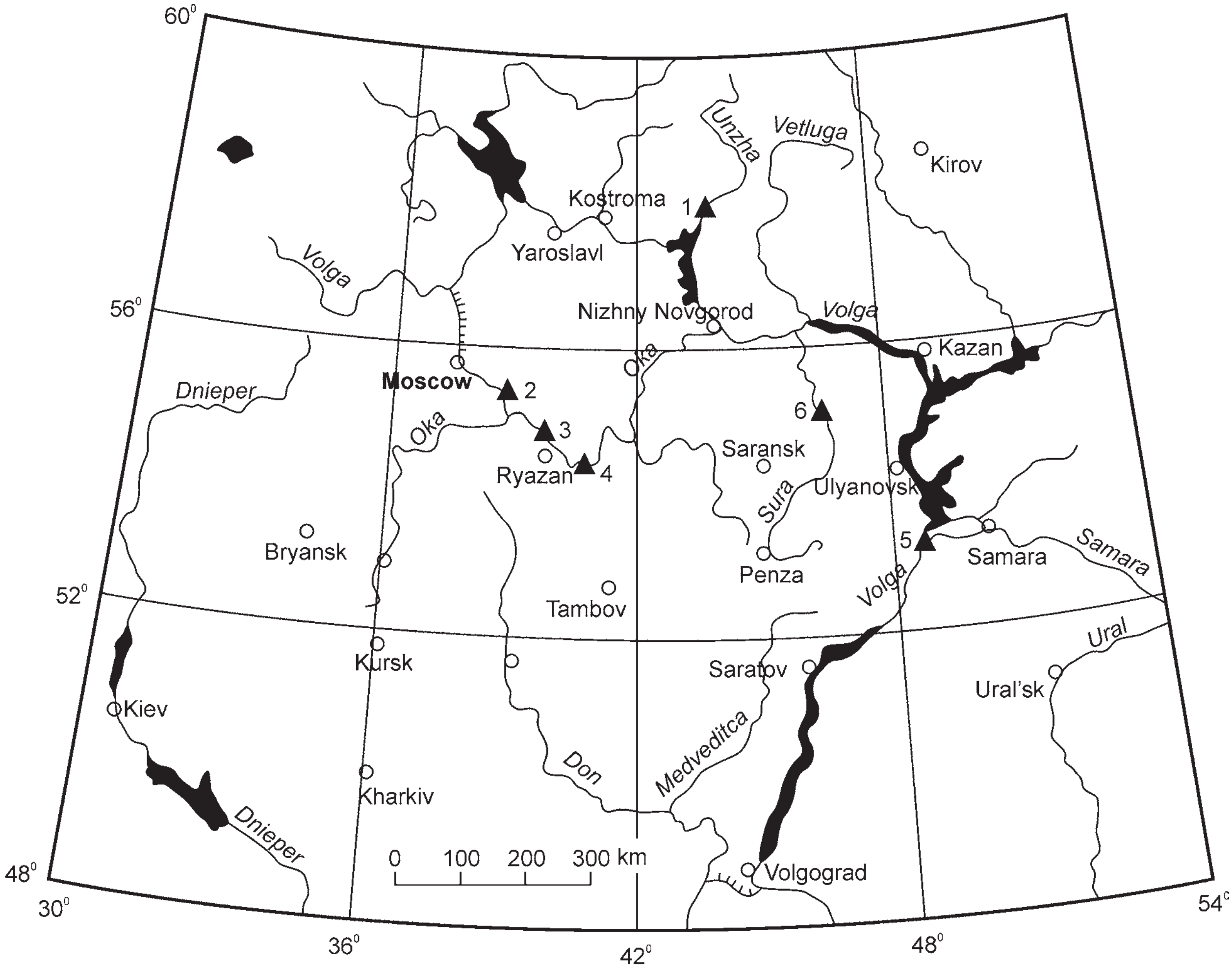

Fig. 1. Location of the key sections of the Ryazanian in the Russian Platform. The numbers show: 1 – Ogarkovo at the Unzha River, 2 – Quarry no. 12/2 of the Lopatinsky Phosphorite Mine, 3 – Kuzminskoe at the Oka River, 4 – Nikitino at the Oka River, 5 – Kashpir at the Volga River, 6 – Mishukovo at the Menya River.

4. Key sections of the Ryazanian Stage of the Russian Platform

4.1. Unzha type (Fig. 2A)

The outcrops between the Efimovo and Ogarkovo villages, at the right bank of the Unzha River, Makariev District of the Kostroma Region, are known since Nikitin (1885). The Jurassic–Cretaceous boundary beds are represented by (see Mitta 2015 for a complete description):

Upper Volgian, Nodiger Zone
Bed 5. Sandstone, stained yellowish-reddish-grey-brown, platy, glauconite-phosphorite, basally and laterally becoming argillaceous glauconite with nodules of dark-gray phosphorites. The basal part of the bed (5a, Mosquensis Subzone) mainly containing *Craspedites mosquensis* Gerasimov, less commonly *Garniericeras subclypeiforme* (Milaschewitch), and rare *G. catenulatum* (Fischer). The upper part (5b, *Nodiger* Subzone) contains numerous *C. nodiger* (Eichwald), *C. parakaschpuricus* Gerasimov, *C. okensis* (d'Orbigny), and *Garniericeras subclypeiforme* (Milaschewitch). The upper 0.15 m contains *Craspedites triptychus* (Nikitin), *Praesurites* spp. and *Hectoroceras* aff. *tolijense* (Nikitin). The ammonites are preserved as phosphatized shells retaining nacre; in Bed 5b the shells are usually preserved in calcite. The eroded bedding plane

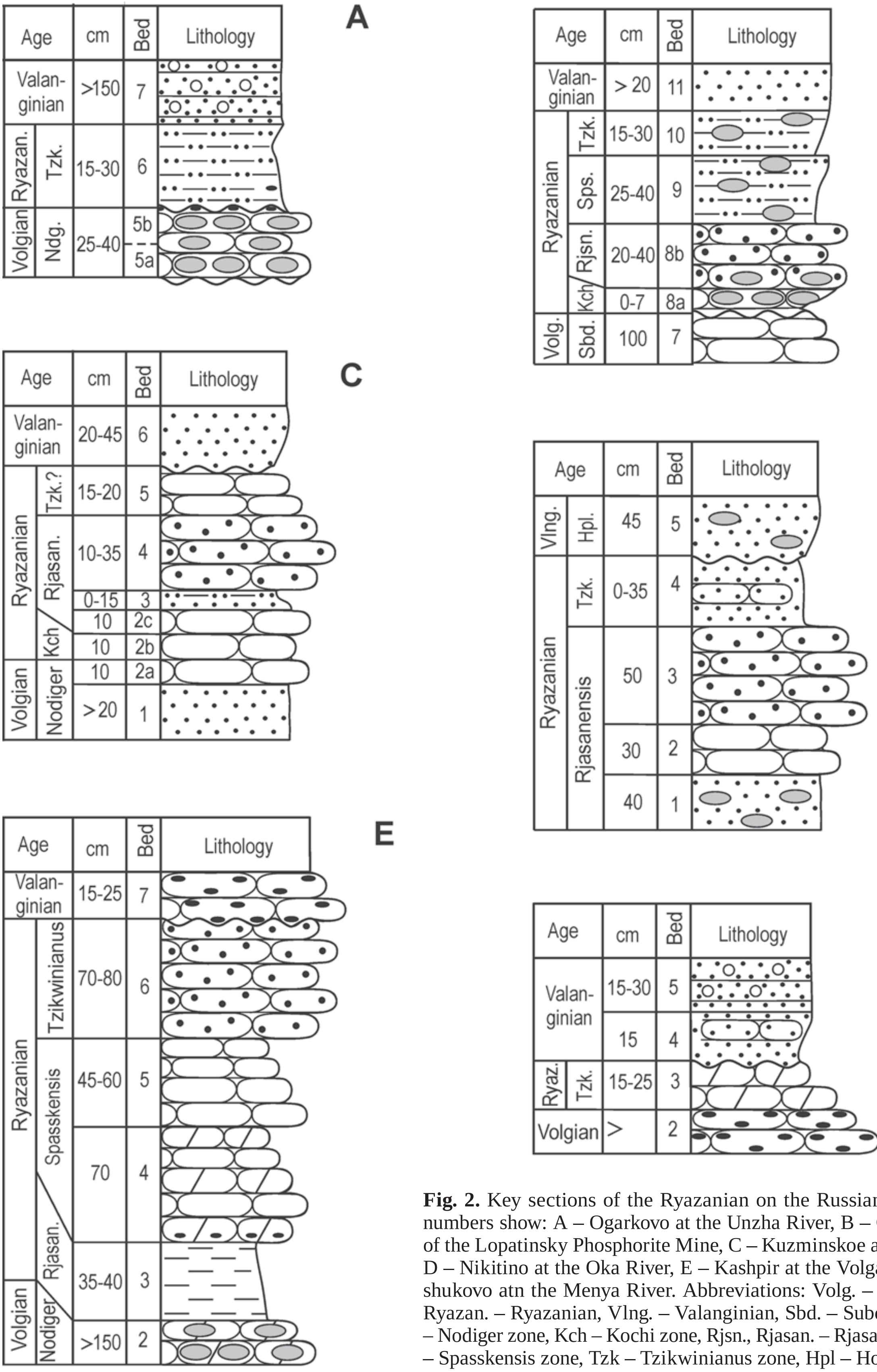

Fig. 2. Key sections of the Ryazanian on the Russian Platform. The numbers show: A – Ogarkovo at the Unzha River, B – Quarry no. 12/2 of the Lopatinsky Phosphorite Mine, C – Kuzminskoe at the Oka River, D – Nikitino at the Oka River, E – Kashpir at the Volga River, F – Mishukovo atn the Menya River. Abbreviations: Volg. – Volgian, Ryaz., Ryazan. – Ryazanian, Vlng. – Valanginian, Sbd. – Subditus zone, Ndg. – Nodiger zone, Kch – Kochi zone, Rjsn., Rjasan. – Rjasanensis zone, Sps – Spasskensis zone, Tzk – Tzikwinianus zone, Hpl – Hoplitoides zone.

of this bed also contains eroded phosphorite moulds of *Praesurites* spp., less commonly *Hectoroceras* sp. Total thickness: 0.25-0.40 m.

Ryazanian, Tzikwinianus Zone
Bed 6. Clay, bluish-gray and brown, dense, arenaceous, laterally becoming argillaceous sand and poorly consolidated sand. This bed contains argillaceous moulds of *Caseyiceras* cf. *caseyi* Sasonova, *Surites tzikwinianus* (Bogoslowsky), and re-deposited phosphorite moulds of *Praesurites* sp. Thickness: 0.15-0.3 m.

Valanginian, Undulatoplicatilis Zone
Bed 7. Sand, reddish-yellowish-brown, argillaceous, with ferrugineous ooids, in places and in some interlayers cemented in sandstone, becoming arenaceous oolitic clay. The bed contains concretions of gray, very compact sandstone. Ammonites: *Surites simplex* (Bogoslowsky), *Menjaites laevis* Sasonova. Thickness: 1.5-1.8 m.

4.2. Voskresensk type (Fig. 2B)

Quarry no. 12/2 of the Lopatinsky Phosphorite Mine, Voskresensky District of the Moscow Region, the following beds overlie dark- and greenish-gray phosphatized sandstone of the Craspedites subditus Zone of the Upper Volgian Substage (observations of 2002-2012); for a description of a lithologically similar section in quarry no. 10 see Mitta (2005).

Ryazanian, Kochi Zone
Bed 8a. Sandstone, black, indistinctly bedded, phosphatized, with rare shells and imprints of *Hectoroceras kochi* Spath and *Praesurites* sp. Thickness: 0-0.07 m.

Rjasanensis Zone
Bed 8b. Sandstone, greyish-yellow and brown, phosphatized, argillaceous, nacreous shells and moulds of *Riasanites swistowianus* (Nikitin), *R. rjasanensis* (Nikitin), *Subalpinites* spp., *Malbosiceras* spp., *Mazenoticeras* sp., *Riasanella* spp., *Praesurites nikitini* Gerasimov & Mitta, *Pseudocraspedites bogomolovi* Mitta, and *Hectoroceras* aff. *larwoodi* Casey. Thickness: 0.2-0.4 m.

Spasskensis Zone
9. Clay, dark-gray arenaceous, upwards becoming argillaceous sand, with numerous concretions of dark-gray phosphorite with sparse moulds of *Surites spasskensis* (Nikitin) and *Pronjaites* aff. *bidevexus* (Bogoslowsky). Thickness: 0.25-0.4 m.

Tzikwinianus Zone
10. Clay yellowish-gray and brown, arenaceous, laterally becoming strongly argillaceous sand with phosphorite concretions containing *Surites tzikwinianus* (Bogoslowsky), *Caseyiceras caseyi* Sasonova, *Pronjaites bidevexus* (Bogoslovsky), and *Peregrinoceras* sp. Thickness: 0.15-0.3 m.

These beds are overlain by a thick series of light-colored and yellowish quartz sands lacking fossils.

4.3. North-Ryazan type (Fig. 2C)

In an outcrop on the right bank of the Oka River downstream of the Kuzminskoe village, Rybinsk district of the Ryazan Region, the greenish-dark-gray glauconite sandstones are overlain by the following succession (Mitta & Sha 2011):

Upper Volgian, Nodiger Zone – Berriasian, Rjasanensis Zone
Bed 2. Sandstone indistinctly platy, reddish-brown externally and black or dark-gray on the freshly broken surface, represented by three inter-beds, each of it 0.1 m thick. The lower inter-bed (2a) is strongly ferruginous sandstone. It containes *Craspedites nodiger* (Eichwald), *C. kachpuricus* (Trautschold), and *Garniericeras subclypeiforme* (Milaschewitch). Fossils have not been found in the middle inter-bed (2b), but the rock matrix is similar to that of the inter-bed, which, according to A.A. Pavlow, contained *Hectoroceras tolijense* (Nikitin) (Mitta 2007a). The upper inter-bed (2c) contains numerous poorly preserved *R. swistowianus* (Nikitin), and sole records of *R.* cf. *rjasanensis* (Nikitin), *Chetaites sibiricus* Schulgina, and *Craspedites* cf. *ultimus* Mitta & Sha. Thickness: 0.3 m.

Ryazanian, Rjasanensis Zone
Bed 3. Sand brownish-gray and brown, argillaceous, laterally becoming arenaceous clay. Thickness: 0.0-0.15 m.
Bed 4. Sandstone-conglomerate, mottled brown and gray, phosphoritic, with sparse *Riasanites rjasanensis* (Nikitin). Thickness: 0.1-0.35 m.

? Tzikwinianus Zone
Bed 5. Quartz sandstone, brownish-yellow, loosely cemented. Thickness: 0.15-0.2 m.

? Valanginian Stage, Hoplitoides Zone
Bed 6. Quartz sand, light-colored and yellow. Thickness: 0.45 m is still preserved at the top of the section.

4.4. South-Ryazan type (Fig. 2D)

An outcrop on the right bank of the Oka River, downstream of the Nikitino village, Spassk District, Ryazan Region, contains the following succession (after Mitta 2007a):

Ryazanian, Rjasanensis Zone
Bed 1. Sand dark greenish-gray, in places brown, small-grained, argillaceous glauconitic, with sparse moulds of *Riasanites* sp. in concretions of loose arenaceous phosphorite. Visible thickness: 0.4 m.

Spasskensis Zone
Bed 2. Sandstone, greenish-brown glauconitic, loosely cemented, with numerous *Surites spasskensis* (Nikitin), *Externiceras solovaticum* (Bogoslowsky), *Gerassimovia mostjae* (Bogoslowsky), *Caseyiceras caseyi* Sasonova, *Riasanites rjasanensis* (Nikitin), *R. rulevae* (Mitta), *Transcaspiites transfigurabilis* (Bogoslowsky), *Subalpinites* spp., still poorly known "*Malbosiceras*" cf. *macphersoni* (Kilian), *Dalmasiceras* ? sp., and *Pronjaites* cf./aff. *bidevexus* (Bogoslowsky). Thickness: 0.3 m.
Bed 3. Conglomerate, mottled, formed by concretions of dark-brown sandy phosphorites, cemente dorange-brown sandy-clayey matrix of inconsistent density. The bed contains sparse, poorly preserved ammonites (*Riasanites* ? sp., *Surites* spp.) in the basal part. Thickness: 0.5 m.

Tzikwinianus Zone
Bed 4. Sand greenish-gray, with inclusions of reddish-yellow ferruginous, medium-grained, weakly argillaceous, in places cemented into relatively compact sandstone with sparse *Surites* ex gr. *tzikwinianus* (Bogoslowsky), *Peregrinoceras* spp. Thickness: 0-0.35 m.

Valanginian, Hoplitoides Zone
Bed 5. Sand, reddish-yellow, quartz, variously grained with small rounded pebbles and gravel of sandstone and concretions of dark-gray and gray, compact, arenaceous, poorly sorted, contains phosphorite concretions with *Nikitinoceras lgowense* (Nikitin), *N. hoplitoides* (Nikitin), and *Menjaites glaber* (Nikitin). The basal levels contain a thin (2-3 cm) layer of pebbles (5a) of dark sandstone. Visible thickness to the ground level: 0.35 m.

4.5. Kashpir type (Fig. 2E)

In an outcrop near the Kashpir village on the right bank of the Volga, Syzran District of the Samara Region, the following succession overlies gray calcareous sandstone with phosphorite moulds of *Craspedites* spp., *Garniericeras subclypeiforme* (Milaschewitsch) (Upper Volgian Nodiger Zone and Subzone) (observations 1994-2012):

Ryazanian, Kochi ? and Rjasanensis? zones
Bed 3. Clay brown, fissured, and bituminous. Thickness: 0.35-0.4 m.

Spasskensis Zone
Bed 4. Sandstone, light-gray, in places greenish-yellowish-brown, indistinctly bedded, calcareous, glauconitic, basally with numerous coalified remains and phosphorite pebbles. Ammonites are scarce; they mainly occur in the upper third of the bed and are represented by completely flattened shells of *Surites* cf. *spasskensis* (Nikitin) and *Pronjaites* cf. *bidevexus* (Bogoslowsky). Thickness: 0.7 m.
Bed 5. Sandstone gray, compact, with sparse incomplete *Surites* spp. Thickness: 0.45-0.6 m.

Tzikwinianus Zone
Bed 6. Sandstone-conglomerate rusty-brown and reddish-brown, phosphoritic, with argillaceous cement, with sparse moulds of *Surites kozakowianus* (Bogoslowsky) and *Peregrinoceras* sp. Thickness: 0.7-0.8 m.

Valanginian, Hoplitoides Zone
Bed 7. Conglomerate formed by phosphorite pebbles in greenish-gray calcareous glauconitic sandstone formed by the phosphorite pebble in sandstone, with abundant *Nikitinoceras* spp. and *Menjaites* sp. Thickness: 0.15-0.25 m.

The conglomerate is overlain by dark-grey clay of the Hauterivian, with *Speetoniceras* ex gr. *versicolor* (Trautschold).

4.6. Menya type (Fig. 2F)

In the flank of a small anticline on the right bank of the Menya River downstream of the Mishukovo village, Poretsky District, Chuvashia, the dark-gray Middle Volgian clay is overlain by a bed of phosphoritic conglomerate and by the following succession (observations 1992-2002; a description of this section is also presented in Sasonova 1977):

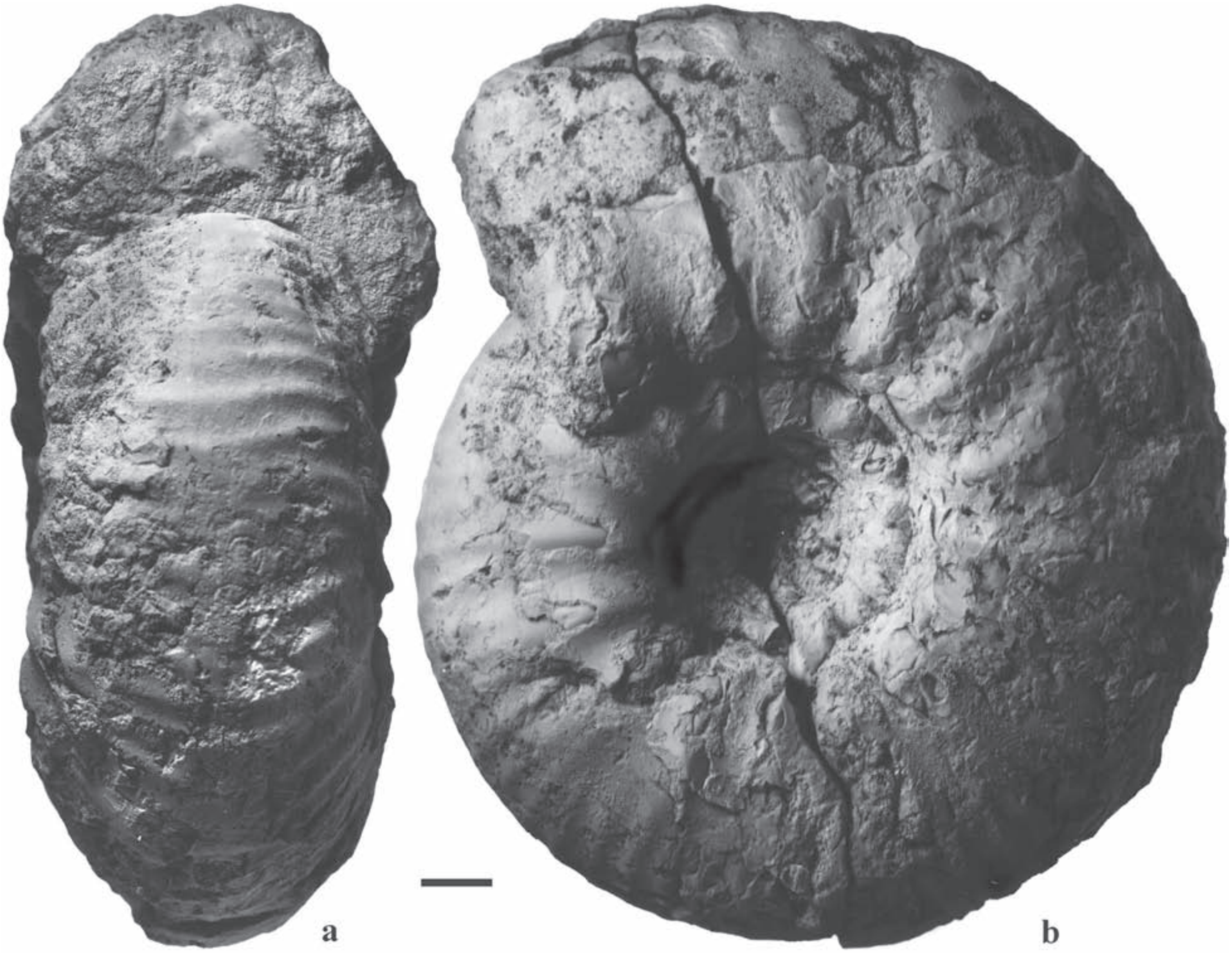

Fig. 3. *Praesurites craspeditoides* (GIRMOUNSKY, 1914), holotype; Moscow, Vernadsky State Geological Museum, no. VI-124/1; Kostroma Region, bank of the Unzha River near the Ivanovo village (downstream of the Ogarkovo village); phosphorite slab from the top of the Volgian (see as well GIRMOUNSKY 1914, pl. 5, figs. 1-3). Scale bar equals 10 mm.

Ryazanian, Tzikwinianus Zone
Bed 3. Sandstone, gray and dark-gray, calcareous, very compact, with inclusions of yellowish-gray argillaceous sand, with moulds of *Surites tzikwinianus* (BOGOSLOWSKY), *Caseyiceras caseyi* SASONOVA, and *Peregrinoceras* spp. Thickness: 0.15-0.25 m.

Valanginian, Undulatoplicatilis Zone
4. Sand, grey and orange-brown, argillaceous, in places cemented into yellowish-gray poorly sorted calcareous sandstone with numerous shells of *Surites* spp., less common *Menjaites* spp. and *Delphinites* spp. Thickness: 0.15 m.

5. Sand, yellowish-brown, strongly argillaceous, with sparse oolites and phosphoritic concretions, sometime containing calcite shells of *Surites* spp., *Menjaites* spp., and less common *Delphinites* spp. The observed/preserved thickness at the top of the section is 0.15-0.3 m.

5. Stratigraphic distribution of ammonites

Pre-Cretaceous erosion has removed the Volgian-Ryazanian boundary beds throughout the majority of the Russian Platform. The majority of authors working on the Volgian-Ryazanian boundary beds indicated a stratigraphic hiatus at the boundary level. Recent data from sections of rarely preserved ammonite bearing strata of this interval to some extent fills the gap in the ammonite succession. Ammonites in this interval are all representatives of the Boreal Realm and belong to the families Craspeditidae and Polyptychitidae.

The genus *Craspedites* Pavlow characterizes mainly the Upper Volgian Substage of the Russian Platform (Gerasimov 1969). However, recently the last representatives of this genus were recorded from the Rjasanensis Zone in the Ryazanian of Central Russia (Mitta & Sha 2011), and from the Sibiricus Zone in northern Siberia (Igolnikov 2012).

The genus *Garniericeras* Spath has a similar stratigraphic distribution in all three zones of the Upper Volgian. Reports of the occurrence of this genus in the Ryazanian (Casey et al. 1977; Mesezhnikov et al. 1979) are erroneous (Mitta 2006; Mitta & Sha 2011).

The genus *Praesurites* Mesezhnikov & Alekseev was first established for the Sibiricus Zone of the Subpolar Urals (Mesezhnikov et al. 1983). Later, *P. nikitini* Gerasimov & Mitta were identified from the Rjasanensis Zone of Moscow and the Kostroma regions of Central Russia (Mitta 2004, 2005). The study of collections from the Unzha River showed that this taxon is similar to ammonites described from a condensed interval at the top of the Nodiger Zone as "*Olcostephanus*" *tryptychus* Nikitin, "*O*". *unschensis* Nikitin, and "*Polyptychites*" *craspeditoides* Girmounsky (Fig. 3). These taxa are in need of taxonomic revision, but in modern nomenclature they should be partly assigned to *Praesurites*, partly to *Craspedites*.

The genus *Hectoroceras* Spath occurs in the lower part of the Ryazanian of East Greenland (Spath 1947), Siberia (Schulgina 1972), England (Casey 1973), Central Russia (Casey et al. 1977). In the sections of the Moscow region, representatives of *H. kochi* Spath are found directly below an interval with *Riasanites* (and other ammonites of Tethyan origin), i.e., below the Rjasanensis Zone (Mitta 2007a; Mitta & Sha 2011). The Rjasanensis Zone contains another species, *H.*aff. *larwoodi* Casey [= *H.* cf. *kochi* in Mitta 2005, 2007a; *H.* sp. nov. in Mitta & Sha 2011], found in association with *Riasanites swistowianus*.

I consider *Shulginites* Casey, 1973 (type species: *Oxynoticeras tolijense* Nikitin) a junior subjective synonym of *Hectoroceras* Spath, 1947. The species *H. tolijense* (Nikitin) was identified in old collections of Pavlow from the Kuzminskoe section at the Oka River. Based on the similarity of the rock matrix these originated either from the top of the Nodiger Zone, or slightly above (Mitta 2007a; Mitta & Sha 2011). Later specimens identified as *H.* sp. nov. aff. *tolijense* were found at the top of the Volgian *Nodiger* Zone at the Unzha River (Mitta 2015). The stratigraphic succession of the occurrences of *Hectoroceras* s. l. (*H.* sp. nov. → *H. tolijense* → *H. kochi* → *H.* aff. *larwoodi*), recognized fragmentarily in different Boreal regions, is also likely to reflect phylogeny.

A representative of the Boreal genus *Pseudocraspedites* Casey, Mesezhnikov & Schulgina (*P. bogomolovi* see Mitta 2004, 2005) is also found in the basal part of the Rjasanensis Zone of the Moscow Region (4.1).

Surites spasskensis (Nikitin) and *Pronjaites* sp. become abundant higher up in the Spasskensis zone, in the sections of the Voskresensk type. Sections of the South-Ryazan type at this zone, apart from that, they abundantly contain *Externiceras solovaticum* (Bogoslovsky) and *Gerassimovia mostjae* (Bogoslovsky) (Sasonova 1971, 1977).

Sections of the upper part of the Ryazanian in the Moscow Syneclise (4.1, 2.2, 4.3, 4.4) contain *Surites tzikwinianus* (Bogoslowsky), *Caseyiceras caseyi* Sazonova, *Pronjaites bidevexus* (Bogoslowsky), and *Peregrinoceras* spp. These taxa are also typical of the upper part of the Ryazanian Stage of the sections of the Kaship and Menya types. The upper boundary of the Ryazanian is recognized (even though not very clearly) in the sections of the Menya type (4.6), and is characterized by the appearance of *Delphinites* spp. and, apparently, *Tollia* (Bogomolov et al. 2011), which replaces the taxa *Pronjaites*, *Peregrinoceras*, and *Caseyiceras*. In sections of other types on the Russian Platform, the basal beds of the Valanginian are missing due to erosion.

Published records of ammonites of Tethyan origin (families Neocomitidae and Himalayitidae) mostly originate from the sections of the Ryazan and Moscow regions; only sparse occurrences of *Riasanites* are known from the periphery of the Russian Platform.

The genus *Riasanites* Spath occurs in the low and middle parts of the "Ryazanian Horizon" as it was originally interpreted by Bogoslowsky. The revision of this taxon allowed the recognition of the main lineage in its evolution in the Central Russian Basin: *R. swistowianus* → *R. rjasanensis* morph α → *R. rjasanensis* morph β → *R. rulevae* (Mitta 2008, 2011a). In addition, the genus *Riasanella*, a likely ancestor of *Riasanites*, occurs in the basal part of the Rjasanensis Zone in the Moscow Region (Mitta 2011a).

The genus *Transcaspiites* Luppov occurs only in the middle part of the Ryazanian in the sections of the South-Ryazan type. The species *T. transfigurabilis* (Bogoslowsky), *T. micheicus* (Bogoslowsky), *T. hospes* (Bogoslowsky) are poorly studied, but new material has been illustrated (Mitta 2007a; Mitta & Bogomolov 2008).

The genus *Subalpinites* Mazenot, with numerous representatives, was found throughout the *Riasanites* genus range interval in several localities in the Moscow and Ryazan regions (Mitta 2002; 2009). Several species of *Dalmasiceras* Djanelidze, *Mazenoticeras* Nikolov, *Malbosiceras* Grigorieva and *Pomeliceras* Grigorieva were identified from the basal part of the Rjasanensis Zone (Mitta 2005, 2011b). The bulk of taxa are referred to in open nomenclature.

6. Discussion

6.1. The ammonite zonation of the uppermost Volgian – lowest Valanginian

The upper part of the Volgian in the Russian Platform is recognized as the Craspedites nodiger Zone (Nikitin 1884). Stremooukhov (1892) and Rosanow (1909) recognized its upper part as the Milkovensis Subzone, and later Gerasimov (in Gerasimov & Mikhailov 1966) proposed a subdivision of the Nodiger Zone into the lower Mosquensis Subzone and upper Nodiger Subzone. My own records show that *Craspedites milkovensis* (Stremooukhov) is very rarely found together with *C. nodiger* (Eichwald), and possibly represents an aberrant variety. In contrast, *C. mosquensis* Gerasimov is a species with a wide geographical distribution. Gerasimov's two-fold subdivision of the Nodiger Zone, with the Mosquensis and Nodiger subzones is thus preferable.

The occurrences of *Craspedites*, *Praesurites*, and *Hectoroceras* s. l. (including *Shulginites*) point to the presence of a poorly studied interval (because it is missing in most places) between the uppermost Volgian and lowest Ryazanian, containing ammonites exclusively of Boreal origin. This interval formally belongs neither to the Volgian, the top of which coincides with the top of the Nodiger Zone, nor to the Ryazanian, the base of which coincides with the appearance of the first *Riasanites*, and it is characterized by only three craspeditid genera, the species composition of which still needs clarification. Therefore, it is reasonable to propose *Hectoroceras kochi*, the only taxon identified at species level, as an index species of this zone (Mitta & Sha 2011), although the last representatives of *Hectoroceras*, *Praesurites*, and *Craspedites* (other species) continue up to the basal part of the Rjasanensis Zone, whereas the basal part of Central Russian Kochi zone is likely to be slightly older than in NW Europe.

Higher up in the ammonite succession, two ammonite associations are recognized within the range of *Riasanites*. The lower assemblage contains *R. swistowianus*, *Riasanella* spp., various *Subalpinites*, *Malbosiceras*, *Mazenoticeras*, *Pomeliceras*, and sparse *Dalmasiceras*, *Pseudocraspedites*, *Craspedites*, *Praesurites*, and *Hectoroceras*. The higher assemblage contains *Surites* (including *S. spasskensis*), *Externiceras*, *Gerassimovia*, *Pronjaites*, and *Transcaspiites*; these beds also contain sparse *Subalpinites*, *Pomeliceras*, and *Caseyiceras*. *Riasanites rjasanensis* is the only species that ranges throughout the entire interval, although it is represented by two different morphs in the lower and upper assemblages, respectively.

The history of recognition of the *Rjasanensis* and *Spasskensis* strata begins with Nikitin's (1888: 85) work, where he described for the first time a section near Staraya Ryazan on the Oka River, including two beds – one an assemblage including "*Hoplites*" *rjasanensis*, and an assemblage including "*Olcostephanus*" *spasskensis*. This section belongs to the South Ryzan type and was later thoroughly described by Bogoslowsky (1895) and Mesezhnikov et al. (1979). The lower two beds of this section (glauconitic sand with phosphorite nodules, overlain by glauconitic sandstone) correspond to the range of *Riasanites*, which Pavlow (1907) subdivided into the Rjasanensis and Spasskensis zones. Recently, *Surites* cf. *tzikwinianus* and *Peregrinoceras* spp. were recorded in the overlying argillaceous, ferruginous sandstone of section Nikitino (Fig. 2D, bed 4). In other sections of the South Ryazan type (Staraya Ryazan, Chernaya Rechka), this sandstone laterally becomes argillaceous ferruginous sand, also containing *Surites* ex gr. *tzikwinianus*, *Peregrinoceras* spp., *Pronjaites*, and *Caseyiceras caseyi*; the same composition of ammonites is recorded in the equivalent beds in the sections of the Voskresensk type.

The species *Surites spasskensis* and *S. tzikwinianus* were originally described from the middle part of the Ryazanian and from its top, respectively, in the adjacent outcrops of the South Ryazan type at the Oka River. However, the taxonomic understanding of the species varies considerably. This mainly results from deficiencies of the original descriptions, as both species were based on single specimens. In addition Bogoslowsky's (1895, pl. 2, fig. 6d) drawing shows a cross-section with

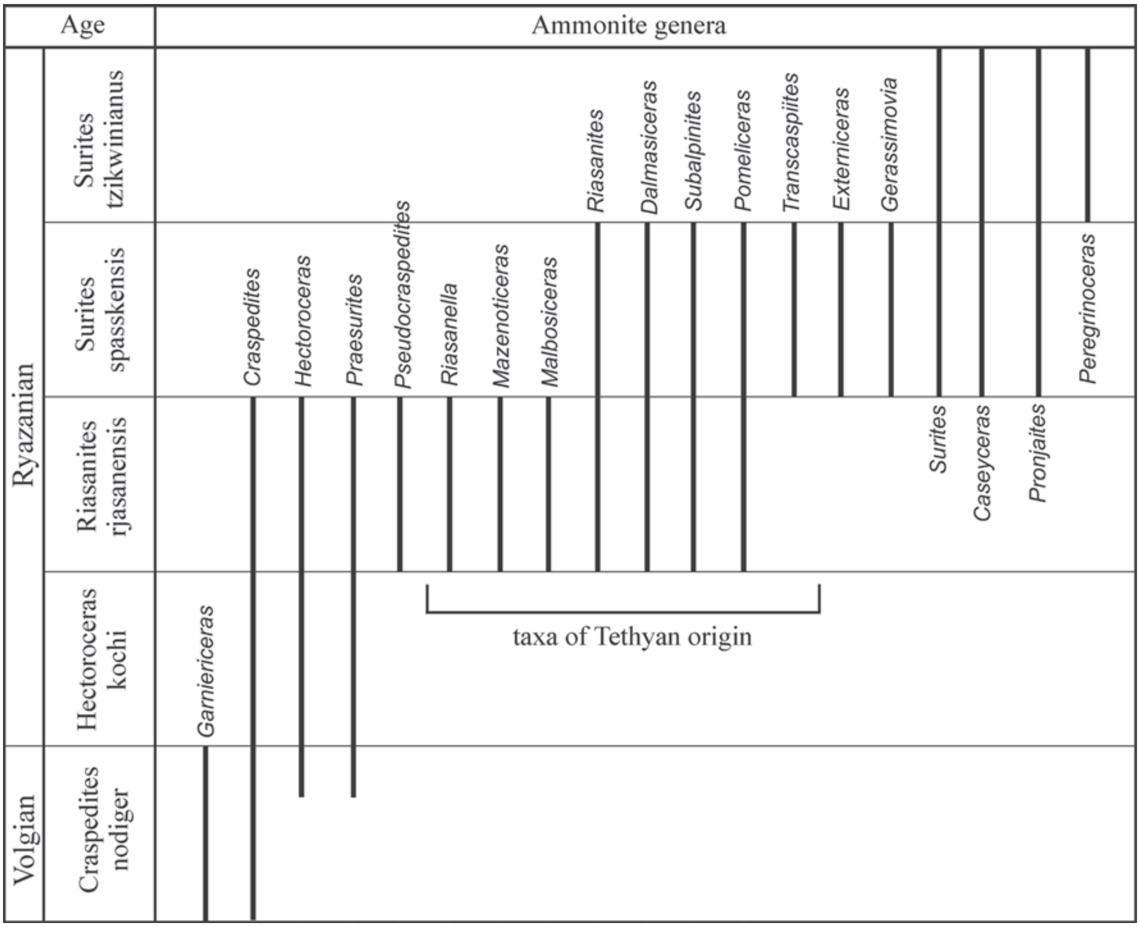

Fig. 4. Zonal scheme and distribution of the Ryazanian ammonite genera on the Russian Platform.

flanks that are too convex. GERASIMOV's (1971) opinion that the two species co-occur is based solely on field determinations, and is definitely incorrect.

Based on the above, I propose to recognize the Rjasanensis, Spasskensis, and Tzikwinianus zones above the Kochi Zone. Each zone is characterized by a specific content of ammonites, and the rank of these strata should be similar. At the same time, these strata are connected by several transitional taxa indicating continuity of these units, and the absence of significant gaps.

Strata of the basal Valanginian are preserved only on the eastern Russian Platform, in the sections of the Menya type (4.6), where there are beds with *Surites*, *Caseyiceras*, *Peregrinoceras*, etc. The Tzikwinianus Zone is overlain by the Undulatoplicatilis Zone. The Simplex Subzone was identified in the upper part of the Tzikwinianus Zone (SASONOVA 1977). However, *Surites simplex* (BOGOSLOWSKY) ranges from the basal part of the Valanginian and thus cannot be accepted as the index species for the Ryazanian.

It is noteworthy that many proposed Ryazanian ammonite zonations are insufficiently based on field identifications or are literature-based lacking thorough taxonomic revisions, e.g. the recently published guidebook of ROGOV et al. (2015). This guidebook contains one plate showing Ryazanian ammonites identified in open nomenclature due to their incomplete preservation. Therein, the Ryazanian Stage is subdivided into the Rjasanensis Zone (with the Kochi and Transfigurabilis subzones), and the Tzikwinianus, and Albidum zones. The recognition of the Kochi and Transfigurabilis subzones has previously been proposed (BARABOSHKIN 1999). However, species of the genus *Transcaspi-*

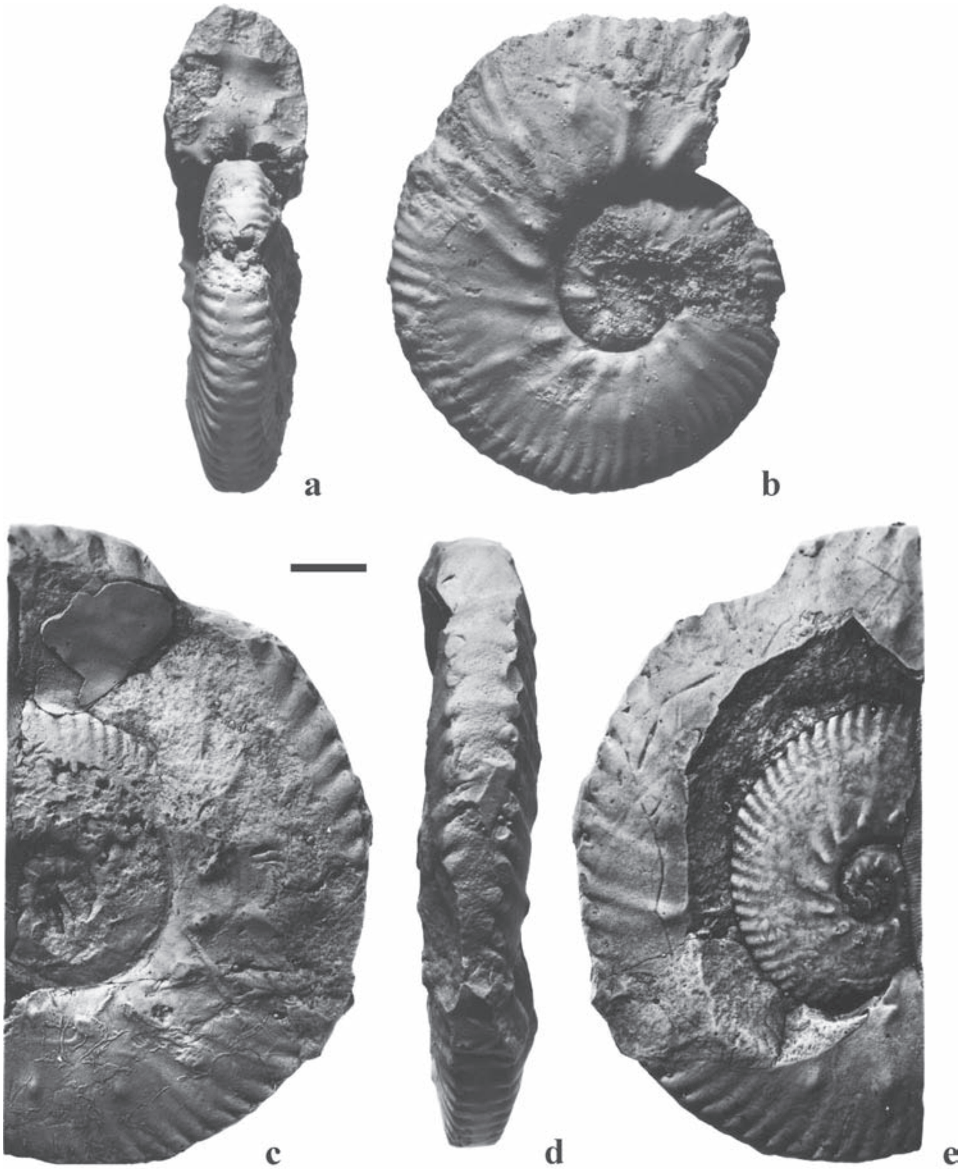

Fig. 5. a, b – *Dalmasiceras* aff. *crassicostatum* (Djanelidze): Borissiak Paleontological Institute, no. 3990/247, Moscow Region, Lopatinsky Phosphorite Mine, Ryazanian stage, *Rjasanensis* Zone; **c-e** – *Dalmasiceras crassicostatum* (Djanelidze), cast of the holotype (France, La Faurie, Berriasian). Scale bar equals 10 mm.

ites are known on the Russian Platform from a very restricted region of sections of the South Ryazan type, and have not been re-examined since the 19th Century. It would be more reasonable to retain index species for the zones and subzones proposed by the previous authors, at least for reasons of priority.

The recognition of the Peregrinoceras albidum Zone above the Tzikwinianus Zone in the sections of the Kashpir types (4.5) (Baraboshkin in Rogov et al. 2015) is probably wrong. Casey et al. (1977: 32, pl. 1, fig. 1) illustrated *Peregrinoceras* aff. *albidum* Casey, found in the "upper part of the Tzikwinianus Zone of the Kashpir section", and suggested that in the future the English *Albidum* Zone could probably be recognized on the Russian Platform. Later, Mesezhnikov et al. (1979), Schulgina (1984) and Casey et al. (1988)

recognized beds with *Peregrinoceras* aff. *albidum* within the upper part of the Tzikwinianus Zone, but no records of new finds of ammonites apart from the one mentioned above by Casey et al. (1977). A specimen of *Peregrinoceras* figured in Rogov et. al. (2015, pl. 7, fig. 7) as *P.* cf. *albidum* Casey, is a juvenile shell and cannot be identified more precisely than *Peregrinoceras* sp. juv.; *Peregrinoceras* is characteristic throughout the Tzikwinianus Zone, and further arguments are needed for a subdivision of the Tzikwinianus zone.

Figure 4 shows the distribution of taxa of generic rank in the zones of the top of the Jurassic and lower part of the Cretaceous on the Russian Platform. The Ryazanian ammonite zonation of this region is proposed here as secondary standard.

6.2. Potential of the correlation of the Ryazanian with the standard Berriasian

The Tethyan origin of the genus *Riasanites* has been questioned by the Western European and North American authors since Donovan et al. (1981) and Jeletzky (1984) and remains to be discussed (Frau et al. 2016). Nevertheless, the occurrences of numerous certainly Tethyan genera such as *Subalpinites*, *Mazenoticeras* and others published in the last decade demonstrate a mid-Berriasian immigration of Peri-Tethyan ammonites into the Central Russian Basin. Initially, during the Rjasanensis phase (=? beginning of the Occitanica chron) the immigration route was from the West through the Polish Corridor to the East establishing a faunal connection between the Sub-Mediterranean and Central Russian Basin. Close to the end of this phase, the Caucasian-Mangyshlak Strait opened in the southeast, which resulted in significant faunal exchange; Boreal *Surites* at the *Spasskensis* and *Tzikwinianus* time reached Poland in the west and Mangyshlak in the south (Mitta 2007b). The *Subalpinites* and *Mazenoticeras* are common mainly in the middle part of the Berriasian in southern France (Privasensis – Paramimounum subzones) (Le Hégarat 1973). Those genera are found in the Ryazanian Stage of the Russian Platform in the Rjasanensis and Spasskensis zones, and some Russian species of *Subalpinites* (*S. faurieformis* Mitta, *S. remaneiformis* Mitta) from the lower part of the Rjasanensis Zone are very similar to *S. fauriensis* Mazenot and *S. remanei* Le Hégarat, which are typical mainly of the Privasensis Subzone of the standard Berriasian.

The lower part of the Rjasanensis Zone also rarely contains ammonites similar to the type specimens of species described from the Berriasian of southeastern France, such as *Dalmasiceras djanelidzei* Mazenot, *D. crassicostatum* (Djanelidze), *Malbosiceras nikolovi* Le Hégarat (Mitta, 2005, pl. 2, figs. 2-4). The holotype of *D. crassicostatum* and a specimen of this species from central Russia are shown for comparison in Fig. 5.

Kilian (1889, pl. 31, fig. 2) established the monotypic *Hoplites macphersoni* from the “Upper Tithonian” of Andalusia. It was later reassigned to the genus *Berriasella* (Mazenot 1939: 102, pl. 10, fig. 2). This species is very similar to the paratype of *Subalpinites bajarunasi* Luppov, originating from the “Neocosmoceras and Septaliphoria semenovi regional zone” of Mountainous Mangyshlak (Luppov et al. 1988, pl. 15, fig. 1), and a fragment of an ammonite described from the Spasskensis Zone of the basin of the Oka River as *Malbosiceras* cf. *macphersoni* (Kilian) (Mitta 2007a, pl. 2, fig. 6). The exact stratigraphic levels of the holotype of Kilian’s species and of some of the abovementioned French species remain unclear. The assignment of Kilian’s species to *Subalpinites*, *Malbosiceras* or *Protacanthodiscus* (Boughdiri 1994; Klein 2005) is doubtful. Those ammonite genera from Spain, Russia and Kazakhstan appear to belong to at least the same genus. Hence, the collecting of more material in Andalusia would like be important for interregional correlation.

Ammonite assemblages in the regions along the periphery of the Boreal-Tethyan ecotone, i.e. Poland and Kazakhstan, increase the correlation potential of the standard Ryazanian to the standard Berriasian. Even the presence of some still insufficiently studied ammonites from the Ryazanian of the Mountainous Mangyshlak (Bogdanova et al. 1985; Luppov et al. 1988) suggests equivalents of the Rjasanensis and Spasskensis zones, and higher horizons of the Ryazanian. The revision of Polish material (published by Marek 1967 and Raszyńska 1967) showed that the Polish Basin contains ammonites typical of the Rjasanensis and Tzikwinianus zones (Mitta & Ploch 2012).

The occurrences of *Riasanites*, *Subalpinites* and *Transcaspiites* in Berriasian sections of the Northern Caucasus and Mountainous Crimea (Grigorieva 1938; Kolpenskaya et al. 2000; Arkadiev & Bogdanova 2012), can also be relatively precisely correlated to the Ryazanian even though ammonites of Boreal origin are not found in this region. The recent discovery of ammonites similar to the Central Russian *Riasanites* and *Riasanella* (Vašíček & Skupien 2016), and the new genus *Pratumidiscus*, which is in the view of its authors

(Bulot et al. 2014; Frau et al. 2016) a probable ancestor of these taxa, in the Tithonian–Berriasian boundary beds of the Czech Republic and France, is significant.

Enay et al. (1998a; b), Frau et al. (2016) and Bulot et al. (2014) demonstrated that accounting for sexual dimorphism and intraspecific variation change the views of the ammonites across the Jurassic-Cretaceous boundary in the Mediterranean Region having important impact on the understanding of assemblage diversity and stratigraphic ranges. Accordingly, Berriasian ammonites of the type region certainly need a modern revision.

6.3. Some remarks on the Jurassic/Cretaceous boundary

The Jurassic–Cretaceous boundary is currently accepted by ammonite researchers at the base of the Jacobi Zone of the standard Berriasian scale (Hoedemaeker et al. 1993; Reboulet et al. 2011, 2014). This zone in its modern interpretation unites the Jacobi Zone (previously the terminal zone of the Tithonian) and the Grandis Zone (previously the basal zone of the Berriasian). The Berriasian Working Group (BWG) of the International Subcommission for Cretaceous Stratigraphy (ISCS/IUGS) under the leadership of W.A.P. Wimbledon, proposes a succession of calpionellids within the Jacobi Zone, and the base of the Calpionella alpina Zone as a marker of the base of the Berriasian and simultaneously of the base of the Cretaceous (Wimbledon et al. 2011).

The appearance of a system of straits connecting, for a short time, the Boreal and Tethyan basins was probably the largest event in the Jurassic–Cretaceous boundary interval. The formation of this Boreal-Tethyan ecotone represents a unique possibility of a global correlation of the entire Northern Hemisphere. The choice and the official fixation of the GSSP should not be a task of itself. The Jurassic-Cretaceous boundary should be easily recognizable in different regions irrespectively of paleogeography or any other affinity. Ammonites remain the best material for correlations of the mid-Mesozoic successions.

The outlined difficulties in identifying the range of the Jacobi Zone and stratigraphic distribution of the key ammonite taxa across the entire Jacobi Zone (Frau et al. 2016; Wimbledon, letter to members of BWG, 2016) certainly indicate that the choice of this zone for defining the boundary between the systems was erroneous. The lower boundary of the Occitanica Zone was considered as a candidate for the Jurassic–Cretaceous boundary (Hoedemaeker 1979; Zakharov 1987). If that proposal is accepted, the more or less synchronous base of the Ryazanian Rjasanensis Zone is well defined both in the Russian Platform, and in the Boreal regions (England, Greenland, and northern Siberia) (based on the distribution of *Hectoroceras* spp.). In that case, the Jacobi Zone of the European standard succession would be assigned to the Jurassic, and the Kochi Zone would terminate the Volgian.

7. Conclusions

The interval between the Volgian Craspedites nodiger Zone and the Lower Valanginian Delphinites undulatoplicatilis Zone on the Russian Platform is represented by a succession of the Kochi, Rjasanensis, Spasskensis, and Tzikwinianus zones. A few taxa range over more than one zone and demonstrate that the zonal succession is complete. The presence of both Boreal and Tethyan ammonites in the Central Russian Basin allows the recognition of the Ryazanian stage in the basal part of the Cretaceous. The Ryazanian ammonite zonation of the Russian Platform is proposed as a secondary standard.

During the Berriasian, the region of the Russian Platform represented an ecotone of high potential for Boreal–Tethyan correlation. The Ryazanian Rjasanensis and Spasskensis zones approximately correspond to the Occitanica – lower Boissieri interval of the Berriasian primary standard. The base of the Berriasian Occitanica Zone corresponds approximately to the base of the Ryazanian Rjasanensis Zone and is considered the preferred level for the Jurassic–Cretaceous boundary.

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