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The Callovian and Late Jurassic ammonite-based chronostratigraphy of West Siberia: important findings, biostratigraphic review, and basin correlation West Siberia-South England

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Abstract This study reviews the Callovian to Volgian biozonation in West Siberia and discusses the problems related to zonations of Jurassic sequences relying only on well core data. The West Siberian Callovian to Volgian formations are correlated with its coeval analogs in South England for the first time. The sequences within the Corallian Group and Vasyugan Suite are very similar in their age and sequence interpretation. Four event levels are proposed using revised ammonite biozonations: (1) the base of the Cornbrash Fm.—the bottom of the U_2^0 Layer; (2) the base of the Oxford Clay Fm.—the base of the Vasyugan Suite—the bottom of the Jason Zone; (3) the Berkshire/Nothe Grit boundary—the top of the U_1^3 Layer—the bottom of Densiplicatum Zone; (4) the base of the Kimmeridge Clay Fm.– the Vasyugan/Georgiev boundary—the bottom of the Baylei Zone. The authors aim to demonstrate that a detailed and reliable biozonal basis is required to correlate events.

Keywords West Siberia · Ammonites · Lithostratigraphy · Biozonation · Late Jurassic

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Introduction

The West Siberian sedimentary basin has been intensively explored by drilling since the middle of the XIXth century. The deposition of the Callovian to Volgian marine sediments occurred during a boreal marine transgression which covered almost 1.5 million km^2. Mesezhnikov et al. (1984) proposed the West Siberian ammonite biozonations using 500 specimens from the core data only. The stratigraphic subdivision of West Siberian wells was performed using East Siberian outcrops (Mesezhnikov 1984; Krymholts et al. 1988). The Callovian to Volgian zonation of the East Siberia region has been used as a model for the studied area where Jurassic outcrops are absent (Nesterov 2004). This study reviews the West Siberian ammonite biozonation with its taxonomic characteristics.

It is well known that the boundaries of the Siberian lithostratigraphical units do not coincide with those of the stages. At the same time, these stratigraphic units can be correlated to many adjacent and even remote regions including the Russian Platform, the Northern Caucasus, the Barents Sea shelf and others. The authors aim to correlate the Siberian lithostratigraphical units with those in the stratotype region of the Callovian, Oxfordian, and Kimmeridgian in southern England (sections in Dorset, Oxfordshire and others). All correlations are based on modern schemes of ammonite zonation (Ogg and Hinnov 2012).

Material

During this study, the authors created a database of West Siberian Callovian—Volgian ammonites using published data and new findings from cores (Fig. 1; Vyachkileva

Fig. 1 Map of West Siberia with the boreholes (wells) mentioned in the text

et al. 1990; Alifirov and Meledina 2010; Meledina et al. 2014). More than 1200 specimens have been documented recording the name and number of the boreholes, depth of collection, genus and species name. Ammonite specimens are stored in the paleontological departments of three West Siberian institutes such as IPGG SB RAS (Trofimuk Institute of Petroleum Geology and geophysics of Siberian branch of Russian Academy of Sciences), SIGGMR (Siberian Institute of Geology, Geophysics and Mineral Resources, Novosibirsk), and TSOGU (Tyumen State Oil and Gas University).

Most ammonite specimens are poorly preserved lacking morphological features such as suture lines, cross sections, ventral sides, body chambers, and umbilicus. As a result, open nomenclature had often to be used for ammonite identification. However, some features of the ribbing and shell shape (width of umbilicus) allow to identify the ammonite genera and occasionally the ammonite species. Poorly preserved fragmented specimens limited further subdivision of some intervals from the Callovian up to the Volgian.

The abundance of ammonites varies from substage to substage. A more complete documentation of ammonite characteristics was made representing the Oxfordian and Volgian Stages (about 500 specimens per stage) compared to the Callovian and Kimmeridgian Stages with collections of 100–200 specimens per stage.

Please note that for reasons of coherence with Russian stratigraphy, the use of “Lower” and “Upper” is used in combination with stage names (e.g. Callovian) instead of “Early” and “Late”. For the same reason, in Fig. 4 “Portlandian” is used instead of Tithonian.

Results

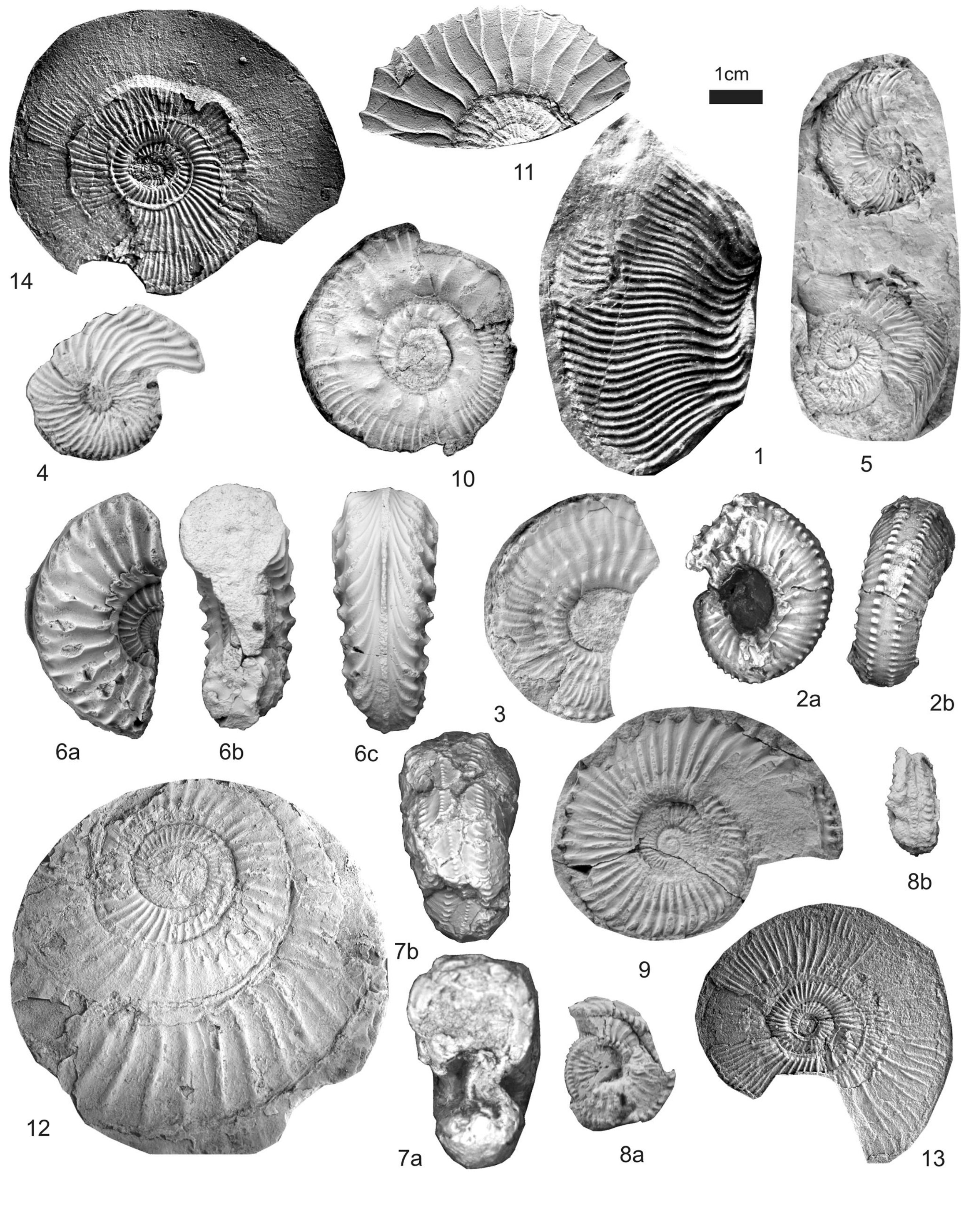
Ammonites

Cardioceratidae, Kosmoceratidae, Aulacostephanidae, Dorsoplanitidae, and Craspeditidae inhabited the West Siberian marine basin from the Upper Bathonian to the Volgian. The Lower and Middle Callovian is characterized by Cadoceratinae, which could not be identified at the generic or species level. The specimens of the Cadoceratinae from the West Siberian cores have a small shell size and simple ribbing. As a result, there are no reliable definitions for the Lower and Middle Callovian genera *Cadoceras*, *Rondiceras* and *Pseudocadoceras*. However, two genera of the Cardioceratidae—*Longaeviceras* and *Quenstedtoceras* (Fig. 2.5), are common for the West Siberian Callovian. Most specimens of the former genus are identified as *Longaeviceras* sp. but some indicate affinities to *L. keyserlingi* (Fig. 2.4). Several specimens identified as *Eboraciceras* (e.g. Vyachkileva et al. 1990, pl. 43, fig. 15–17) likely do not belong to this genus, because of their ribbing that resembles other Callovian genera such as *Cadoceras* or *Quenstedtoceras*. By contrast, West Siberian Callovian ammonite assemblages include subboreal fauna namely Kosmoceratidae (*Kepplerites,* Fig. 2.1; *Kosmoceras,* Fig. 2.2, 3; *Sigaloceras*). Occurrences of kosmoceratids are rare compared to cardioceratids and very difficult to identify.

The Oxfordian Stage of West Siberia is represented exclusively by Cardioceratidae belonging to the genera *Cardioceras* and *Amoeboceras*. However, the genus *Ringstedia* (Aulacostephanidae) appears in the uppermost Oxfordian strata. Recently we found and discussed many ammonite nuclei from West Siberian wells close to the index species from most Siberian Oxfordian ammonite Zones (Fig. 2.6; Meledina et al. 2014).

The Kimmeridgian stage is characterized by cardioceratids and aulacostephanids. The subboreal ammonite faunal assemblage of the West Siberian Kimmeridgian includes *Pictonia*, *Rasenia*, *Prorasenia*, *Aulacostephanus*, *Zonovia* and *Zenostephanus*. The genus *Pictonia* is found only as poorly preserved juvenile specimens in the Tatarskaya 1 well (Vyachkileva et al. 1990, pl. 52, fig. 14) and the Malokhetskaya 1 well (Bodylevskyi and Shulgina 1958, pl. II, fig. 1). Specimens of *Rasenia* cf. *optima* and *Rasenia* sp. occur more frequently (Meledina 2006, pl., fig. 6; Vyachkileva et al. 1990, pl. 53, fig. 2). The most common occurrences in the Lower Kimmeridgian strata belong to the ammonite subgenus *Amoeboceras* (*Amoebites*) (Fig. 2.9). Sometimes, these ammonites have been found with subboreal *Rasenia* (Fig. 2.10). Recently, we found (Otor’inskaya 42 well, Verkhnechaselskaya 153 well) three ammonites with shell characters and ribbing style close to the *Amoeboceras* (*Amoebites*) in the TSOGU collection. However, those specimens could be associated with *Plasmatites* (Fig. 2.7, 8). The Upper Kimmeridgian *Euprionoceras* and *Hoplocardioceras* are extremely rare in the West Siberian wells (besides Bodylevskyi and Shulgina 1958, pl. 6, fig. 4, 5). Meledina (2005) showed that samples of genus *Aulacostephanus* can rarely be identified at species level. New paleontological revision of the Kimmeridgian West Siberian cardioceratids is required to establish a zonation that will be more suitable for correlation with that in other Arctic regions: Barents Sea (Wierzbowski and Smelror 1993), Spitsbergen, Franz-Josef Land (Rogov 2014a), and East Greenland (Birkelund, Callomon 1985).

The Volgian stage is represented by Dorsoplanitidae and Craspeditidae. The total number of specimens in the database is close to 500. Ammonites are poorly represented in the Lower Volgian substage. There are only three fragments of *Pectinatites* sp. in our database: Yaraynerskaya three well (Braduchan et al. 1986, pl. 1, fig. 3), Beregovaya 2 well (Vyachkileva et al. 1990, pl. 55, fig. 1),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◀**Fig. 2** Jurassic ammonites from West Siberian wells. *1 Kepplerites* sp., TSOGU (there are no specimen numbers), Yendyrskaya 10 well (2918.1 m), Lower Callovian. *2 Kosmoceras* sp. juv. (×6), TSOGU, Severo-Pyamyaliakhskaya 31 well (3298.8). Middle-Upper Callovian; *2a* lateral view, *2b* ventral view (refigured from Vyachkileva et al. 1990, pl. 43, fig. 6). *3 Kosmocers* sp., TSOGU, Snegirinaya 291 well (2644.7 m), Middle-Upper Callovian (Coronatum-Athleta Zones). *4 Longaeviceras* cf. *keyserlingi* (Sokolov), TSOGU, Rogozhnikovskaya 713 well (2586 m), Upper Callovian, Keyserlingi Zone. *5 Quenstedtoceras lamberti* (Sowerby), TSOGU, Fedyushkinskaya 6 well (2896.1 m), Upper Callovian, Lamberti Zone. *6 Cardioceras densiplicatum* Boden, TSOGU, Larlomkinskaya 18 well (2524.3 m), Middle Oxfordian, Densiplicatum Zone; *6a* lateral view, *6b* ventral view, *6c* cross section. *7, 8* TSOGU, Otor'inskaya 42 well (60.6 m), Lower Kimmeridgian, ? Bauhini/Kitchini Zone; *7 Amoeboceras* (*Plasmatites*/*Amoebites*) sp. juv. (×5) *7a* ventral view, *7b* cross section. *8 Amoeboceras* (*Plasmatites*) *gerassimovi* (Kalacheva et Mesezhnikov), *8a* lateral view, *8b* ventral view. *9 Amoebites subkitchini* Spath, TSOGU, Yumantylskaya 925 well (3442 m), Lower Kimmeridgian, Kitchini Zone. *10 Rasenia* cf. *optima* Mesezhnikov, TSOGU, Spasskaya 21 well (2880.2 m), Lower Kimmeridgian, Evoluta Zone. *11 Pavlovia* sp., TSOGU, Severo-Demyanskaya 2 well (2873.9 m), Middle Volgian, Iatriensis Zone. *12 Dorsoplanites* cf. *maximus* (Spath), IPGG SB RAS, Druzhnaya 161 well (2865–2875 m), Middle Volgian, Maximus Zone. *13, 14 Laugeites* sp. ind., IPGG SB RAS, Lontynyakhskaya 69 well (2518.5; 2518.3 m), Middle Volgian, Beds with L. groenlandicus—Vogulicus Zone

Severo-Danilovskaya 10009 well. West Siberian dorsoplanitids occur most frequently in the Middle Volgian substage. Eight genera are known including: *Pavlovia* (Fig. 2.11), *Strajevskya*, *Dorsoplanites* (Fig. 2.12), *Taimyrosphinctes*, *Laugeites* (Fig. 2.13, 14), *Epilaugeites*, *Praechetaites* and ? *Craspedites*. Alifirov (2009a) discussed the difficulties of identification of these genera in cores due to preservation. The Upper Volgian West Siberian craspeditids include *Craspedites*, *Kachpurites*, *Shulginites*, *Praechetaites*, *Chetaites*, and *Subcraspedites*. The most common West Siberian Upper Volgian species are *Craspedites taimyrensis* (Bodylevsky) and *Craspedites shulginae* Alifirov (Alifirov 2009b). The rest of the Upper Volgian genera are rarer than *Craspedites* and difficult to identify to the species level.

Biostratigraphy

The Callovian Stage of West Siberia can be divided into four biostratigraphical subdivisions (Fig. 3). The lowermost Beds with Cadoceratinae have a stratigraphically long range and includes the main part of the Callovian (and the Upper Bathonian) deposits. Only poorly preserved Cadoceratinae are found within these deposits. Beds with *Sigaloceras* sp. and beds with *Kosmoceras* ex gr. *jason* are established for the uppermost Lower and the Middle Callovian, respectively. Most of West Siberian Callovian ammonites are indicative of the Upper Callovian substage. This substage is divided into the Longaeviceras keyserlingi and Quenstedtoceras lamberti ammonite Zones.

A recent study by Meledina et al. (2014) showed that most of the boreal ammonite standard zones can be recognized in the Oxfordian of West Siberia (Fig. 3). The Scarburgense, Gloriosum, Percaelatum and Cordatum Zones are present in the Lower Oxfordian; Densiplicatum and Tenuiserratum Zones are present in the Middle Oxfordian; Glosense, Serratum, Regulare Zones including beds with *Amoeboceras rozenkrantzi* are present in the Upper Oxfordian. It should be noted that the Upper Oxfordian contains beds with *Ringsteadia marstonensis*, which is similar to of ammonite assemblages in Northern Urals.

The lowermost zone of the Kimmeridgian Stage (Fig. 4) is the Bauhini Zone according to boreal succession of cardioceratids (Wierzbowski and Smelror 1993; Matyja et al. 2006; Wierzbowski and Rogov 2013). V. G. Knyazev (in Nikitenko et al. 2013) discussed the use of this zone for the Boreal realm. We propose the Bauhini Zone represents the base of the West Siberian Kimmeridgian. The overlying Kitchini Zone is fixed in numerous wells by the occurrence of *Amoeboceras*. (*Amoebites*) *kitchini* Salf. (Kharampurskaya 303 well, Vyachkileva et al. 1990, pl. 49, fig. 4), *A*. (*A*.) cf. *subkitchini* Spath (Ust-Chaselskaya 208 well), *A*. (*A*.) *pulchrum* Mesezhn. et Romm (Kharasaveyskaya 48 well, Vyachkileva et al. 1990, pl. 50, fig. 14, 15), *A*. (*A*.) *modestum* Mesezhn. et Romm (Sukhodudinskaya 1 well, Vyachkileva et al. 1990, pl. 50, fig. 4). The Upper Kimmeridgian Sokolovi and Decipiens Zones are poorly represented in wells as time-sensitive ammonites are scarce. They might be shown in the scale after paleontological revision. The uppermost Kimmeridgian Taimyrensis Zone has not been documented in West Siberia, but its analog is probably present. The Lower Kimmeridgian Siberian zones Involuta and Borealis can be used for biozonation in West Siberia but paleontological reexamination is needed to clarify its correlation with North-West European Baylei and Cymodoce Zones. Furthermore, the Eudoxus and Autissiodorensis Zones can not be recognized in wells due to poor preservation. In this study, we propose the Beds with *Aulacostephanus* for the Kimmeridgian deposits observed in the wells instead of three zones (Sosvaensis, Eudoxus, Autissiodorensis). However, the Kimmeridgian in the north-western part of Western Siberia (Northern Urals) has a full aulacostephanid zonal succession based on well-preserved ammonites from outcrops.

The Lower Volgian substage in the studied region is divided into three zones in the Northern Urals (Fig. 4). This zonal subdivision is not applicable for the main area of West Siberia, due to the lack of ammonites. The review of the Volgian West Siberian ammonites suggests that only the Pectinatites Beds could be recognized in the lower substage. The Middle Volgian substage zonal succession is similar to Northern Urals zones and less similar to East

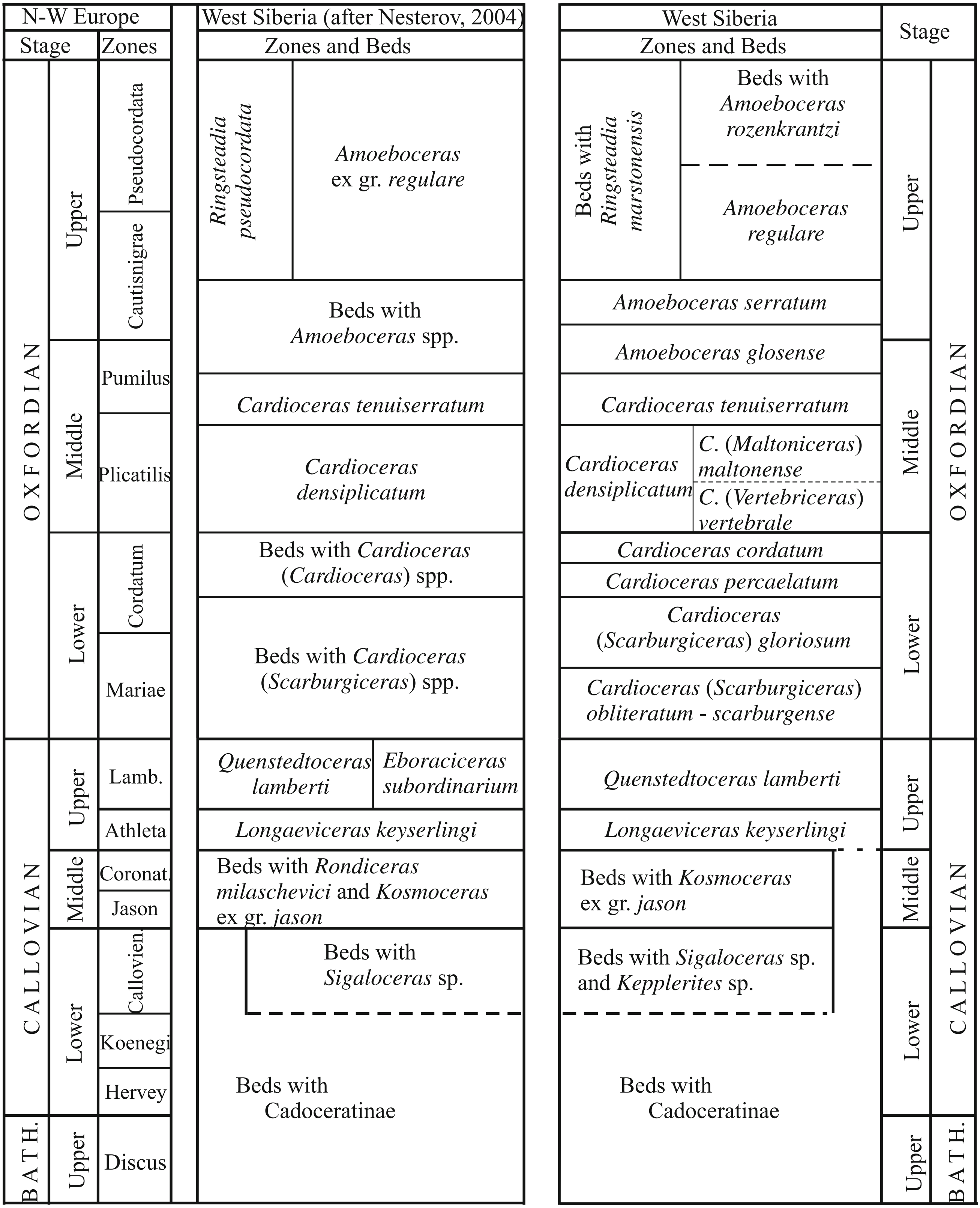


Fig. 3 The ammonite zonation of the Callovian and Oxfordian stages. Zonal succession established by authors (*right column*) and another one used by Russian geological services (Nesterov 2004; *left column*). North-West European zonation and its correlation with the West Siberian one is shown according to Ogg and Hinnov (2012) and Nikitenko et al. (2015)

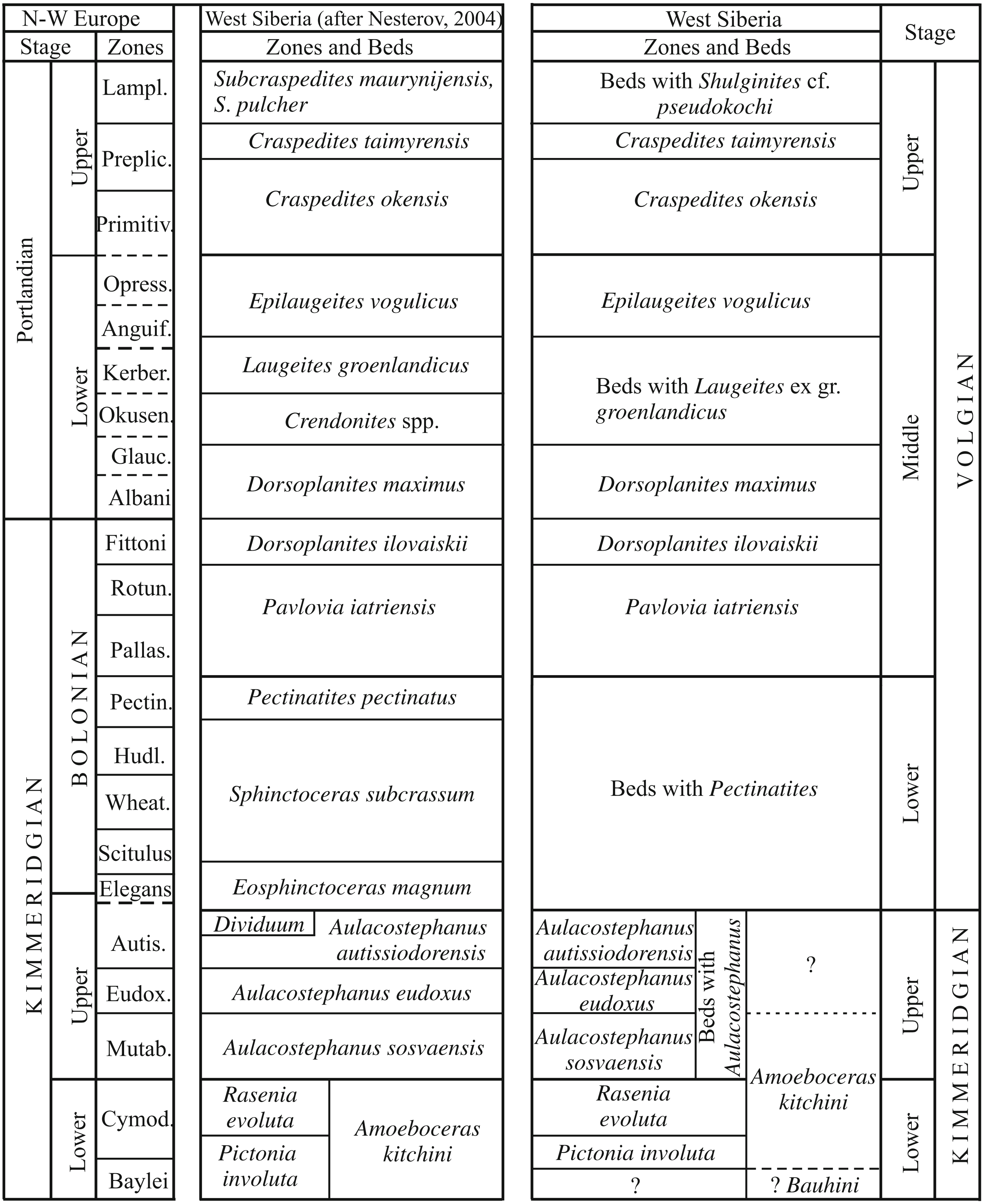


Fig. 4 The ammonite zonation of the Kimmeridgian and Volgian stages. Zonal succession established by authors (*right column*) and another one used by Russian geological services (Nesterov 2004; *left column*). North-West European zonation and its correlation with the West Siberian one is shown according to Ogg and Hinnov (2012); Rogov and Zakharov (2009) and Mesezhnikov (1984)

Greenland zones. The paleontological revision allowed us to combine Groenlandicus and Crendoites spp. Zones into the Beds with *Laugeites* ex gr. *groenlandicus* (Alifirov 2009a). Additional refinement of the Upper Volgian zonation is needed. Only the Taimyrensis Zone is well documented whereas the presence of other zones is supported by rare occurrences of *Kachpurites* (?) or *Craspedites originalis* Shulgina (for Okensis Zone) and *Chetaites* sp. or *Shulginites* cf. *pseudokochi* (for the uppermost Volgian).

Lithostratigraphy and sequences

The Callovian and the Late Jurassic of Western Siberia were a time of extensive regional marine transgression. The transgression began at the end of the Bathonian, reached an intermediate peak in the Callovian, and then was followed by repeated relatively small fluctuations in sea level. These fluctuations resulted in the deposition of repetitive sedimentary deposits. These sedimentary cycles are part of the development of the sedimentary basin and serve as a basis for the identification of major lithostratigraphic units, and regional formations such as the Vasyugan, Georgiev, and Bazhenov Formations.

We developed a special model of the genesis of sedimentary cycle, which only partially overlaps with the sequence-stratigraphic concept (Beisel 2006). This model is close to the genetic stratigraphy of Galloway (1989) differing in interpretation of communications with marginal sequences. In our model, sequences are explained by classic concepts of geographic cycles proposed by W. Davis and developed by Blair and Bilodeau (1988) rather than by sea level fluctuations that play a secondary role. Tectonic activity rejuvenates the relief while exogenous processes smooth the landscape providing the source of sediments for sedimentary, climatic, geomorphological and other observed cycles. Periods of tectonic activity are very short and vary in intensity determining the cycles of a different order. By contrast, exogenous processes are continuous during periods of tectonic quiescence, resulting in the leveling of mountains and filling of sedimentary basins. The latter leads to the shallowing of the reservoirs at a constant sea level (decrease in accommodation space). Relative sea level is primarily affected by tectonics. Thus, the coincidence of individual sequences and parasequences and their boundaries in remote basins can often be explained by similar tectonic histories (Beisel 2006).

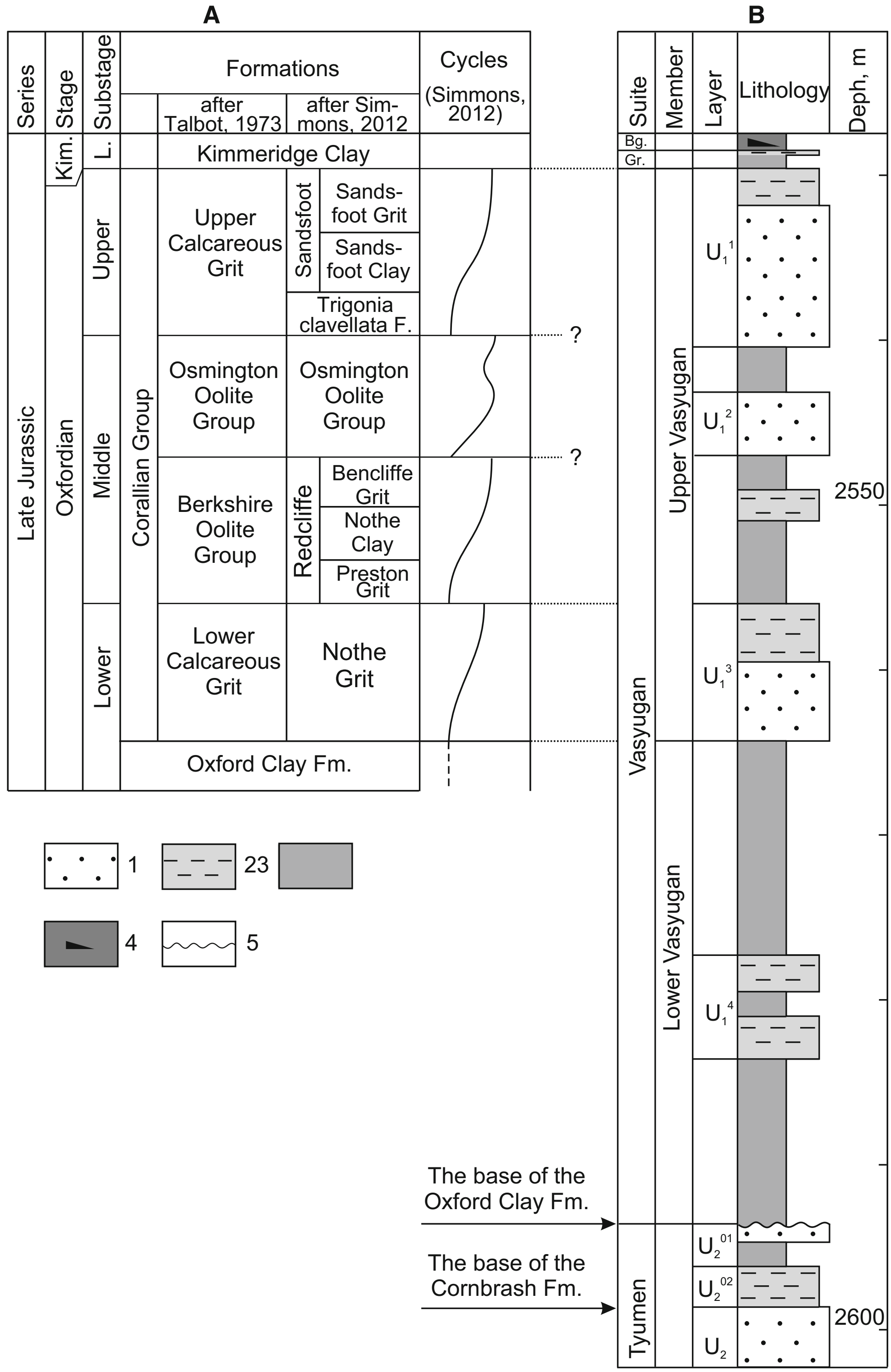
For formations, we identified such a correlation: one of the richest oil-producing formations in Western Siberia, the Upper Vasyugan Member, matches the British Corallian Group in its stratigraphic position and lithological characteristics (Beisel and Alifirov 2013). A strong correlation is also shown by the Oxford Clay Formation and the clayey Lower Vasyugan Member. The difference between them is that the transgressive branch includes the upper part of the Upper Bathonian–Lower Callovian (the so-called U_2^0 Layer). In Western Siberia, it is a part of the Vasyugan Suite, whereas the transgressive Cornbrash and Kellaways Formations in Southern England are independent. In Siberia, the presence of a regional unconformity at the base of the Middle Callovian (Jason event) is established. Thus, the beginning of a regional transgression in the upper part of the Upper Bathonian and the intermediate maximum at the base of the Middle Callovian, as well as the Middle-Upper Oxfordian regression in England and Western Siberia are the same.

It should be noted that in England, the base of the Oxford Clay Formation in different sections is dated in a few different ways. The Oxford Clay has been deposited diachronously with the Kellaway Rock (Callomon and Cope 1995, p. 80). However, we do not believe this is a strong contradiction to our assertion of synchronicity of the lower boundaries of the Oxford Clay and the Vasyugan Fms. The degree of boundary synchronicity depends on the resolution of the used biostratigraphic scales. The more detailed an ammonite zonation is, the less likely is the coincidence of geological boundaries. For example, the Enodatum zone has been subdivided into four biohorizons (Callomon et al. 1988). It is difficult to establish precisely, which of them matches the base of the Oxford Clay. Identification of this boundary in West Siberia seems to be impossible. Some dispersion of chronostratigraphic dating analogs of the base of the Oxford Clay Fm. can be objectively related to the nature of tectonic events that caused the change in the conditions of sedimentation and habitat of fauna. This issue does not touch the topic, but we believe that the eustasy was not the cause. Another objective of this study is to correlate type sections of West European stages at a more detailed level.

The identification of analogs of the sandy productive strata in U_1 Horizon (the Upper Vasyugan Member) and their boundaries with formations, suites, and levels of unconformities within the Corallian Group is of great interest. We have established the possibility of mapping U_1^3 Layer with the Berkshire Oolite Fm (Fig. 5). This formation in the Corallian Group of Southern England forms a major sedimentary cycle established by Talbot (1973). Comparative analysis of cycle schemes of the Corallian Group, provided by different authors, is given in Simmons (2012). Some of the schemes show satisfactory convergence and generally correspond to the cyclic structure of the Upper Vasyugan Member in Western Siberia.

The transgressive stage of the West Siberian Basin in the upper part of the Upper Bathonian up to the Lower Callovian stands out as a special unit: the U_2^0 Layer (Pakhomov Bed). It contains at least two clearly expressed

Fig. 5 Correlation of the Corallian Group (modified from Talbot 1973) **a** and its cycles and the Vasyugan Suite of West Siberia (Pervomaiskaya Well-268) **b** *1* sand, *2* silt, *3* shale, *4* black shales, *5* unconformities



sedimentary cycles, which can be defined as U_2^{01} and U_2^{02} Layers. In the central part of Western Siberia, the lower layer (U_2^{02}) represents a lagoonal depositional environment and the top layer represents a shallow marine depositional environment with a diverse fauna that includes cephalopods. In the north, close to the latitude of the Lower Ob River, marine facies replaces lagoonal facies with both deposits merging forming a single U_2^0 Layer. These cycles could correspond to the English Cornbrash and Kellaways Formations. However, more index ammonites are needed for an accurate correlation. The age of the U_2^0 Layer bottom in the western Siberia is defined as the upper part of the

Upper Bathonian based on the microfossil assemblage *Kutsevella memorabilis*, *Guttulina tatarensis* (JF28 in Nikitenko 2009).

The highest cycles within the Upper Vasyugan Member (U_1^2 and U_1^1 Layers) in Western Siberia form a new transgressive sequence. In the stratotype area of the Kimmeridgian, this sequence corresponds to the transgressive phase of the first half of the Kimmeridge Clay Formation. The U_1^0 Layer seems to correspond to the Ringstead Bed at the top of the Corallian. The maximum flooding surface of the Late Jurassic is observed within the Lower Volgian followed by a regression starting in the Pectinatus Zone. In England, this regression was expressed in the alteration of clayey sediments of the upper part of the Kimmeridge Clay formation by sandy rocks of the Portland and then by lagoonal facies of the Purbeck. Regression in the Volgian is well expressed on the East European platform, and in the Urals. The scenario of the Callovian—Volgian transgression reveals a surprising similarity in the basins of southern England and western Siberia.

Discussion and conclusion

The revision of the West Siberian Callovian—Volgian ammonite biostratigraphy resulted in a more refined biozonation of the Oxfordian Stage providing the opportunity for fine scale correlation across the Arctic. At the same time, the low stratigraphic resolution intervals with rare and poorly-preserved ammonites referred to as "Beds with fauna (ammonite taxa)" are remained through the Callovian, Kimmeridgian and Volgian (Figs. 3, 4). Siberian ammonite zones such as Elatmae—Stenolobum, Mutabilis—Autissiodorensis, Taimyrensis, Magnum—Pectinatus, Crendonites spp. from the Callovian to Volgian in North Siberia and northern Urals still cannot be used for stratigraphic correlation with West Siberia. Therefore, direct correlation of these zones for the entire region of West Siberia cannot be performed as it was done previously (Nesterov 2004). Nevertheless, extensive collections of West Siberian ammonites show a strong similarity with the Callovian to Volgian ammonite succession from western Europe, eastern Greenland, northern Siberia, Russian platform, Barents Sea and Spitsbergen. The Western Siberian marine basin was part of the Arctic biogeographic realm during the Callovian, Oxfordian, Early Kimmeridgian and Volgian. Kosmoceratids and aulacostephanids indicate connections with other marine basins such as the Russian Platform and North-West Europe (Alifirov and Meledina 2013; Zakharov et al. 2003). A succession of ammonite biohorizons has been created for certain intervals of the upper Middle Jurassic to Late Jurassic in the regions mentioned above (Callomon 1985; Birkelund and Callomon 1985; Wierzbowski and Smelror 1993; Matyja et al. 2006; Rogov et al. 2012; Rogov 2014a, b). In the West Siberian region, Jurassic ammonite biohorizons are poorly constrained. The most refined biostratigraphy in western Siberia is presented within the Kimmeridgian.

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