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Jurassic Benthic Foraminiferal Biostratigraphy & Palaeoecology at the Shtokman Structure, Barents Sea

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ABSTRACT

A biostratigraphical scheme for Jurassic deposits of the Shtokman Structure of the Barents Sea is constructed based on foraminiferal assemblages recovered from core samples and ditch cutting samples from five exploration wells. This study concentrates on biostratigraphical analyses and palaeoenvironmental interpretations from studies of foraminifera from the Middle-Upper Jurassic deposits, a siliciclastic succession attaining a thickness of 960m.

Seven foraminiferal zones ranging in age from Aalenian to Volgian are recognised in the Jurassic sequence. For this study, Jurassic foraminifera from the Ludlovskaya structure and from two wells in the Nordkapp Basin were used for comparison. Foraminiferal assemblages are correlated between the Shtokman area wells and Jurassic assemblages from Siberia, the Pechora basin, Spitsbergen, and the Nordkapp Basin.

INTRODUCTION

A biostratigraphical scheme of benthic foraminifera for the Jurassic deposits of the Shtokman Structure (Fig. 1) is here described based on core samples and ditch cutting samples from five exploration wells (Fig. 2). The present report concentrates on biostratigraphical and palaeoecological analyses with emphasis on interpretations from studies of foraminiferal assemblages from Middle to Upper Jurassic deposits that consisting predominantly of dark grey sandstones, siltstones, clays and black bituminous clays (on the top) with thickness up to 960 m.

Foraminiferal distribution in the southern part of the Barents Sea is based mainly on ditch cutting material from wells in the Kurentsovskaya, Murmanskaya, Arkticheskaya and Severo-Kildinskaya areas. A preliminary biostratigraphic scheme from this area has been published by Bassov *et al.* (1984). A zonal subdivision of the Jurassic succession based on foraminifera from the Shtokman and Ludlovskaya structures was published by Yakovleva (1994a, 1994b) and Kozlova *et al.* (1994). The macrofossil content, mainly ammonites and bivalves, from Callovian, Kimmeridgian and Berriasian strata were studied by N.I. Shulgina (VNII Okeangeologia).

The Aalenian to Upper Volgian (=Lower Berriasian) assemblages contain predominantly agglutinated foraminifera. An exception is the Callovian assemblage characterised by diverse mixure of calcareous and agglutinated species. Unfortunately, there is no information about the Oxfordian foraminifera, except in the Nordkapp Basin. Seven foraminiferal zones have been determined within the Jurassic sequence of the Barents Sea. For this study, Jurassic foraminifera from the Ludlovskaya structure and from two wells in the Nordkapp Basin were used for comparison (Fig. 1). For the first time, the Jurassic foraminiferal assemblages are correlated between wells in the Shtokman area and with Jurassic assemblages the Pechora Basin of northern Russia. These assemblages show close taxonomic affinity to coeval assemblages from the Nordkapp Basin, Siberia, Spitsbergen, the Canadian Arctic Archipelago, as well as with the Pechora Basin. By this correlation, we aim to provide a more precise chronostratigraphical control for the Jurassic intervals recovered from the Shtockman wells in the Barents Sea.

PREVIOUS STUDIES

Taxonomy

The Middle Jurassic boreal foraminiferal assemblages are known to extend in a broad arch from the Viking Graben northwards to Spitsbergen, eastwards through the Barents Sea and Pechora Basin regions to northern Siberia; and westwards to the Sverdrup Basin and Arctic Canada. The foraminiferal taxonomy adopted for this study is based to a large extent on studies of the Pechora Basin (Yakovleva,

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Figure 1. Location of studied wells and sections in the Barents Sea region.

1984), western Siberia (Dain *et al.*, 1972, Bulynnikova *et al.*, 1990), and Central Spitsbergen (Nagy *et al.* 1990; Nagy & Basov, 1998). We also made a comparison with the taxonomy developed by Morris & Coleman (1989) for the northern Viking Graben. Several species reported by Morris & Coleman (1989) appear to be synonymous with species previously described by Russian workers (see below). Other important studies of Boreal Middle and Late Jurassic foraminifera include the work of Brooke & Braun (1981) on the microfaunas from British Columbia, Wall (1960) on the Jurassic of Saskatchewan, and Hedinger (1993) on the Oxfordian–Volgian of Arctic Canada. The "Practical Manual" (Azbel & Grigalis, 1991) provides a compilation of the taxonomy of index taxa used by Russian workers, and briefly descibes the palaeobathymetry and palaeoecology of the assemblages in the Arctic shelf seas of northern Russia and Siberia.

Biostratigraphical Framework

Biostratigraphical zonations have been established in several regions, including the Pechora Basin (Yakovleva, 1994), Central Spitsbergen (Nagy *et al.,* 1990; Nagy & Basov, 1998), the southern Barents Sea and Franz Josef Land (Basov *et al.,* 1989) and Western Siberia (Dain *et al.* 1972; Azbel & Grigalis, 1991). An informal zonation based on stratigraphically significant assemblages was proposed by Morris & Coleman (1989) and Morris & Dyer (1990) for the Magnus and Don fields of the northern Viking Graben.

Our interpretations of the chronostratigraphic significance of foraminiferal assemblages from the Barents Sea wells is based upon comparisions with the Pechora Basin. Jurassic sediments are widely exposed in the Timan–Pechora region (Pechora River Basin), and are represented by sandstones and grey silty claystones up to 300 m in thickness. The suc-

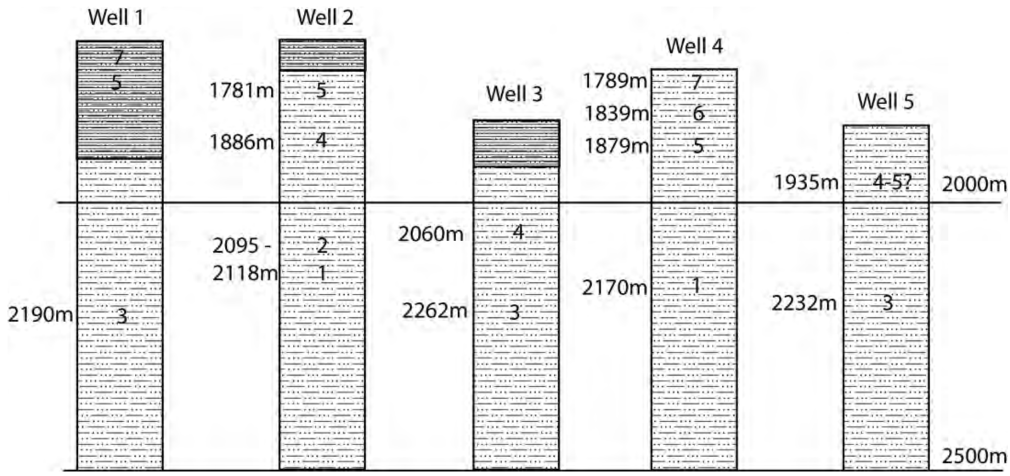

Figure 2. Aalenian to Berriasian foraminiferal assemblages in five wells on the Shtokman Structure, Barents Sea. Depth of characteristic assemblages given in metres.

cession is richly fossiliferous, with ammonites, bivalves, belemnites, ostracods, foraminifera, and calcareous nannofossils. In the area of Timan and the west Ural Mountains, these deposits are exposed, while in the central part of the basin they are only known from exploration wells. A detailed study of the ammonites and foraminifera from outcrops enabled the calibration of the foraminiferal biostratigraphy of the Bajocian to Volgian succession (Yakovleva, 1980; 1982; 1994) with the ammonite zonation established by Mesezhnikov (1984, 1989). The Bajocian to Volgian foraminiferal assemblages are unusually rich and well-preserved, and contain over 800 species of agglutinated and calcareous benthic taxa. Agglutinated foraminifera are predominant in Bajocian to Lower Callovian assemblages, and consist mainly of ammodiscids, lituolids, *Haplophragmoides*, *Recurvoides*, and ataxophragmiids. In middle to upper Callovian strata the calcareous benthic component becomes more abundant and sometimes dominate the assemblage, though agglutinated species are still diverse. Vaginulinids, nodosariids, and polymorphinids are typically common in middle-upper Callovian assemblages. The upper Callovian to Volgian assemblages additionally contain aragonitic epistominids and ceratobuliminids. The fauna has a distinctly Boreal aspect and is comparable to assemblages known from Siberia, the Canadian Arctic Archipelago, and to Boreal-Atlantic assemblages from the Russian Platform.

MATERIAL

This study of Jurassic foraminifera is based on the analysis of 174 core samples and a few ditch cutting samples from five wells drilled by the Russian petroleum company AMNGR (in Murmansk) on the Shtokman structure during the period 1990-1994. The lithology and position of the samples are shown in figures 3–7.

RESULTS

Biostratigraphy

The Lower to Upper Jurassic succession on the Shtokman Structure consists of sandstone, siltstones, clays, and bituminous clay with a total thickness of 960 m. The lower part of the Jurassic, which probably represents Lower Jurassic sediments, was sampled for foraminifera, but the samples were barren. Overall, about 35% of samples are barren or with a few poorly preserved foraminifera. Agglutinated foraminifera are the major microfossil component in Aalenian-Lower Berriasian sediments in the Barents Sea. Calcareous species are more common in Callovian deposits. These are also found in a few restricted horizons in Bathonian and Volgian strata. All samples collected below the Aalenian Riyadhella syndascoensis Zone are barren or with 1-3 strongly deformed foraminifera (Fig. 3).

Seven foraminiferal zones are defined in the studied area. Six of these are found in Middle Jurassic siltstone deposits, and one zone is recognised in Upper Jurassic dark clays, and one zone is recognised in the Lower Berriasian (= Upper Volgian) bituminous clay (Sey & Kalacheva, 1999). The Aalenian to Lower Callovian foraminiferal assemblages are generally comprised exclusively of agglutinated species. Toward the upper Callovian, the calcareous group is highly diverse, but the number of agglutinated specimens is much higher than that of the calcareous specimens. Kimmeridgian? foraminifera are poorly preserved and include a few species, both agglutinated and calcareous. Lower Berriasian assemblages with numerous agglutinated foraminifera were found in the bituminous clay. The assemblages are described below:

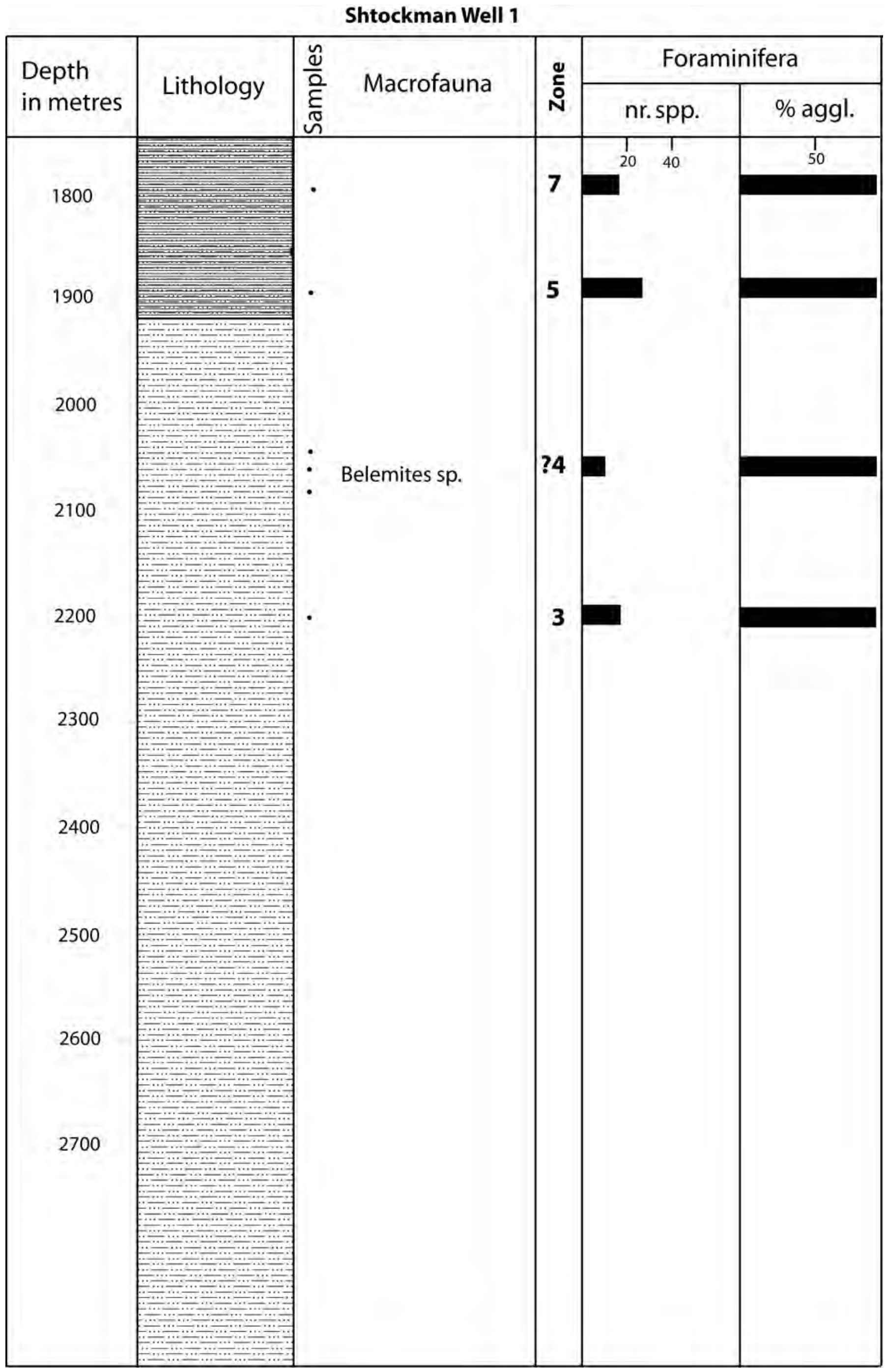

Figure 3. Depth, lithology, and foraminiferal assemblages from Well 1 on the Shtokman Structure.

The Riyadhella syndascoensis Zone.

The lowest samples with foraminifera were taken from dark gray siltstones and claystones that are slightly calcareous in Well 2 (interval 2188-2170 m) and in gray claystones in Well 4 (int. 2095-2118 m) (Figs. 4, 6), where the Riyadhella sindascoensis Zone is recognised. The zone is defined by the range of *R. syndascoensis* (Scharovskaya). The total number of species is more than 25, and these are grouped into 8 genera. The determined assemblage includes numerous agglutinated forms such as *Ammodiscus* ex gr. *pseudoinfimus* Gerke & Sossipatrova, *Ammodiscus* ex gr. *septentrionalis* Scharovskaya, *Ammobaculites lapidosus* Gerke & Scharovskaya, *Recurvoides* spp., *Kutsevella* sp. Different species of *Riyadhella* are dominant.

The dark grey clay layers sometimes contain thousands of specimens belonging mainly to *Riyadhella*. The 0.1 mm fraction of the washed sample consists entirely of foraminifera. A similar very rich assemblage was founded in the Ludlovskaya structure (Fig. 1). Most of the named species are recorded from

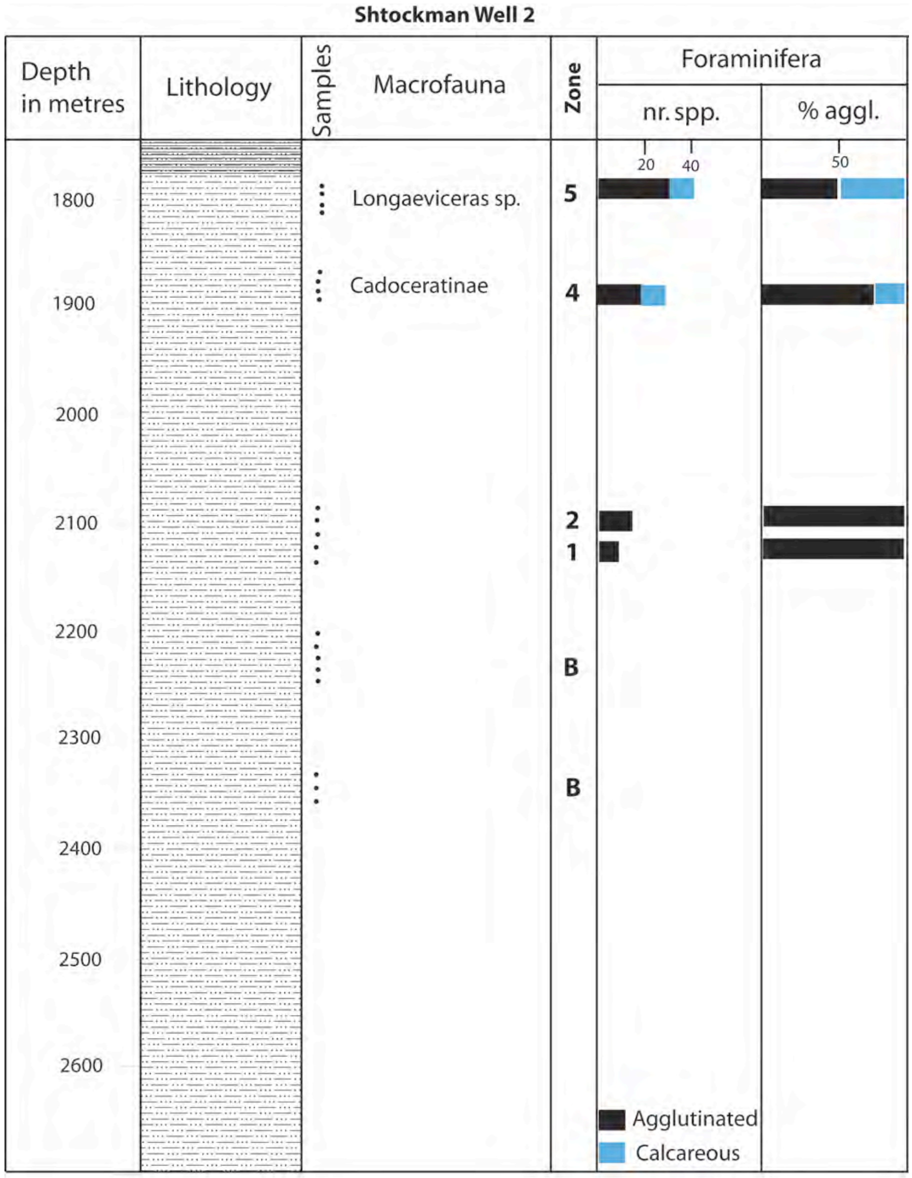

Figure 4. Depth, Lithology, and foraminiferal assemblages from Well 2 on the Shtokman Structure.

Bajocian sediments of central Siberia. *Riyadhella syndascoensis* was described by Scharovskaya (1958) from the Aalenian of Eastern Siberia (the Sindasco area). In the outcrops of Anabar Bay (Eastern Siberia), *R. syndascoensis* is found in the upper part of the lower Aalenian. On the Kelimjar River in Eastern Siberia, the Aalenian age of the beds with *R. sindascoensis* was determined by the occurrence of *Tugurites* cf. *whitevesi* (White). Therefore, the *R. syndascoensis* Zone is regarded as Aalenin-Bajocian.

The Riyadhella ex gr. tertia-Trochammina praesquamata Zone.

The zone occupies the upper part of the interval 2095-2118 m. in Well 2 (Fig. 4). The assemblage includes about 10 agglutinated species. The base is defined by numerous specimens of *Riyadhella* ex gr. *tertia* (Gerke & Scharovskaya) and the first appearance *Trochammina praesquamata* Scharovskaya. In addition to the index species, *Ammodiscus* forma *granulata* (Gerke), *Recurvoides* aff. *scherkalyensis* Levina, *Recurvoides* spp., *Trochammina rushlakensis* Wall, and *Kutsevella* sp. are numerous. Lituolidae are dominant. The Bajocian-Bathonian age of this zone is determined by relative position in the section (above the *R. syndascoensis* Zone and below the *R. sibirica* Zone).

The Riyadhella sibirica Zone.

This zone is recorded from siltstones and clays in Well 1 (2190 m, ditch cutting), Well 3 (int. 2262.6-2270.6 m) and Well 5 (int. 2232-2242 m). The number of species (7-15) and specimens (from 10 to 100) varies from well to well (Figs. 3, 5, 7). The assem-

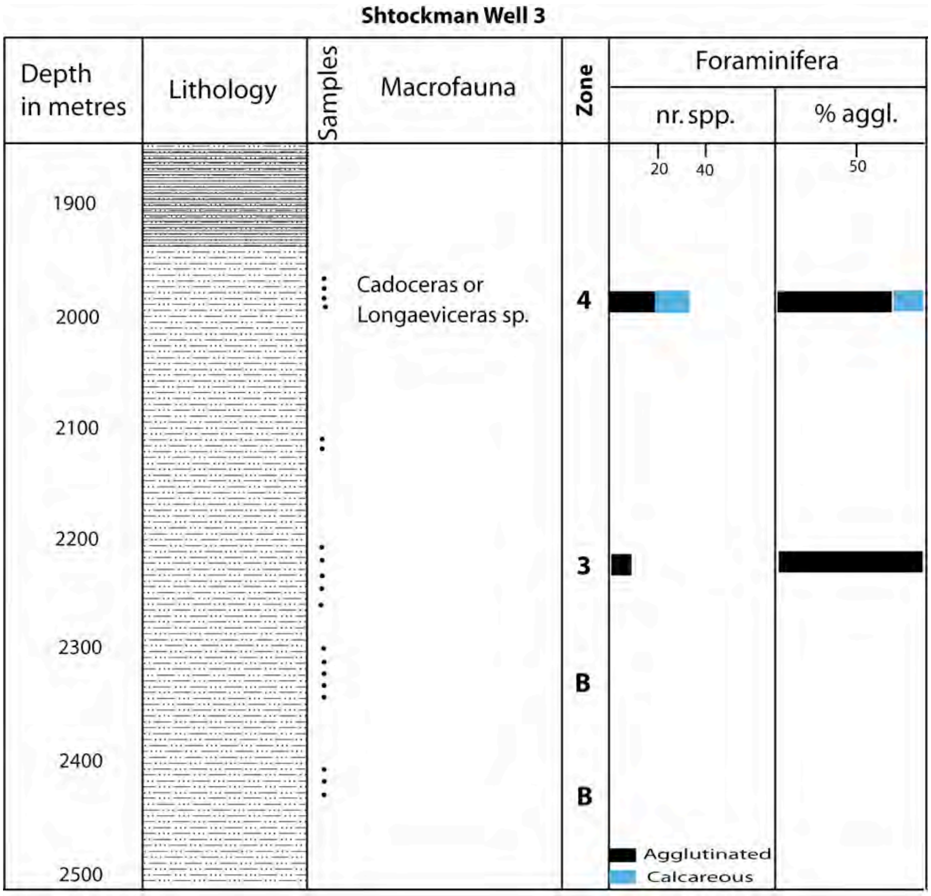

Figure 5. Depth, Lithology, and foraminiferal assemblages from Well 3 on the Shtokman Structure.

blage contains a large proportion of Lituolidae and Ataxophragmiidae. The zone is defined by the range of the zonal index species. Stratigraphically significant events include the vast development of *R. sibirica* (Mjatliuk), *R. shapkinaensis* (Yakovleva), *Ammodiscus arangastahiensis* Sokolov, *Recurvoides singularis* Lutova, and *R. anabarensis* Bassov & Sokolov. Similar assemblages were found in wells drilled on the Ludlovskaya structure (Fig. 8).

The Riyadhella sibirica Zone is described from the Pechora basin (Fig. 9), with the type locality on the Pizhma River (Yakovleva, 1982). Here the foraminifera are highly diverse and consist of agglutinated species (about 50) with some calcareous forms. In the Pechora basin, the *R. sibirica* zone was determined as Bathonian based on the combined occurrence of the Bathonian ammonites *Oraniceras* and *Gonolkites* in outcrops along the Pizhma River (Meledina, 1994).

The R. sibirica Zone is widely distributed in the Pechora basin, the Barents Sea, Siberia, Spitsbergen (Nagy *et al.,* 1990) offshore mid-Norway (Kaminski *et al.,* 1997, unpublished), in the Viking Graben (Morris & Dyer, 1990) and in the Canadian Arctic Archipelago. The stratigraphical interval of the *Riyadhella sibirica* Zone in Siberia is slightly wider and determined as Bajocian-Bathonian because the main Middle Jurassic transgression in Siberia began earlier.

The Kutsevella instabile – Guttulina tatariensis Zone

This zone occurs in Well 2 (int. 1886-1892 m) and Well 3 (2060-2067m) (Figs. 4, 5) in dark grey siltstones with calcareous layers. The total number of species is more than 40. The most interesting species for distinguishing the age are *Ammodiscus proprius* Yakovleva, *Recurvoides singularis* Lutova, *Kutsevella instabile* Yakovleva, *Bulbobaculites callosus* Yakovleva, *Dorothia concinna* Yakovleva, *Darbiella erviei* Levina, *Saracenella juganica* Tylkia, and *Guttulina tatariensis* Mjatliuk. The base of the zone is defined by the first appearance of the index species, while its top is placed at the highest occurrence of *G. tatariensis*. A significant feature of this assemblage is the large variety of calcareous taxa. Although the number of species with agglutinated and calcareous wall is roughly equal, the agglutinated component make up more than 80% of the assemblage. Most of the recognised species are described from lower or middle Callovian deposits in the Pechora Basin

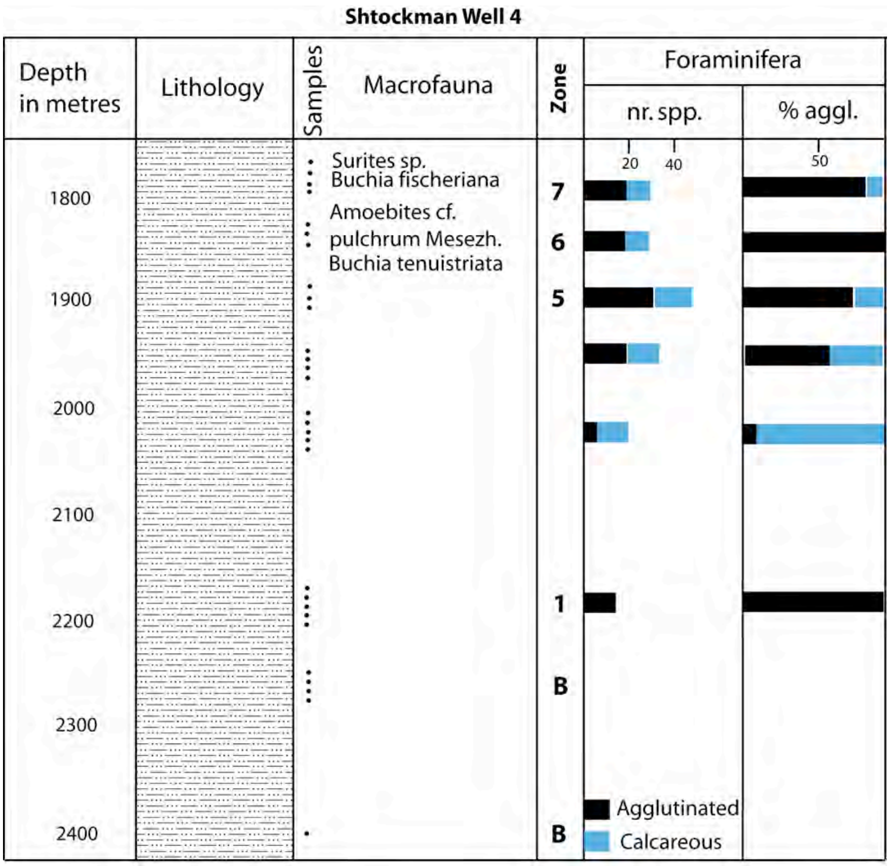

Figure 6. Depth, Lithology, and foraminiferal assemblages from Well 4 on the Shtokman Structure.

(Yakovleva, 1982) and Siberia (Dain, 1972), where the stratigraphy has been determined by ammonites. *Guttulina tatariensis* is a common species within lower Callovian sediments in the central and northern parts of European Russia (Mjatliuk, 1959, Yakovleva, 1984). Some species are known from Callovian deposits in Canada (Wall, 1960), the USA (Dakota) (Loeblich & Tappan, 1950), Alaska (Tappan, 1955), and the Canadian Arctic Archipelago. The early–middle? Callovian age of this zone is also determined by the ammonite *Cadoceratina* in well 2 (Fig. 4).

The Ammobaculites tobolskensis-Lenticulina polonica Zone

This zone is recorded from gray calcareous siltstones in Well 1 (1935 m ditch cutting, int. 1894-1875m), Well 2 (int. 1781-1785m), and Well 4 (1879-1890 m) (Figs. 3, 4, 6) and possibly Well 5 (1935m, ditch cutting) (Fig. 7). The zone is determined by the stratigraphical distribution of *A. tobolskensis* Levina and *L. polonica* (Wisniowski). The foraminiferal assemblage is very rich in calcareous taxa such as Nodosariidae (30 species and 10 genera), Polymorphinidae (4 species) and Ceratobuliminidae (2 species). Same of the Nodosariidae such as *Lenticulina* ex gr. *cultratiformis* Mjatliuk, *L. pseudocrassa* Mjatliuk, *L.* ex gr. *tumida* Mjatliuk, and *Marginulina batrakiensis* Mjatliuk are very common in upper Callovian assemblages of the Saratovskii region in the southern part of the Russian Platform. The number of agglutinated taxa is less (about 20 species), but they dominate in abundance (60-80%). Among them are *Ammobaculites, Kutsevella, Recurvoides* and very small forms belonging to different species of Ataxophragmiidae are especially numerous. The stratigraphically significant species, apart from the index species, are *Recurvoides scherkalyensis* Levina, *Ammobaculites* ex gr. *igrimensis* Levina, *Trochammina rostovcevi* Levina, *Plectina terra* Bykova & Azbel, *Dorothia concinna* Yakovleva, *Lenticulina polonica* (Wisniowski), *Pseudolamarckina* cf. *rjasanensis* Mjatliuk. The main part of the assemblage consists of species known from upper Callovian deposits in Siberia and the Pechora Basin. The late Callovian age of the assemblage is also determined by upper Callovian ammonites *Longaeviceras*? sp., and *Longaeviceras* sp. juv. in Well 2 (Fig. 2, 4).

The *Evolutinella* sp.–*Ammodiscus* sp. Zone.

This zone occurs in Well 4 (top of int. 1839-1846 m) (Fig. 6) in black clay with the lower Kimmeridgian

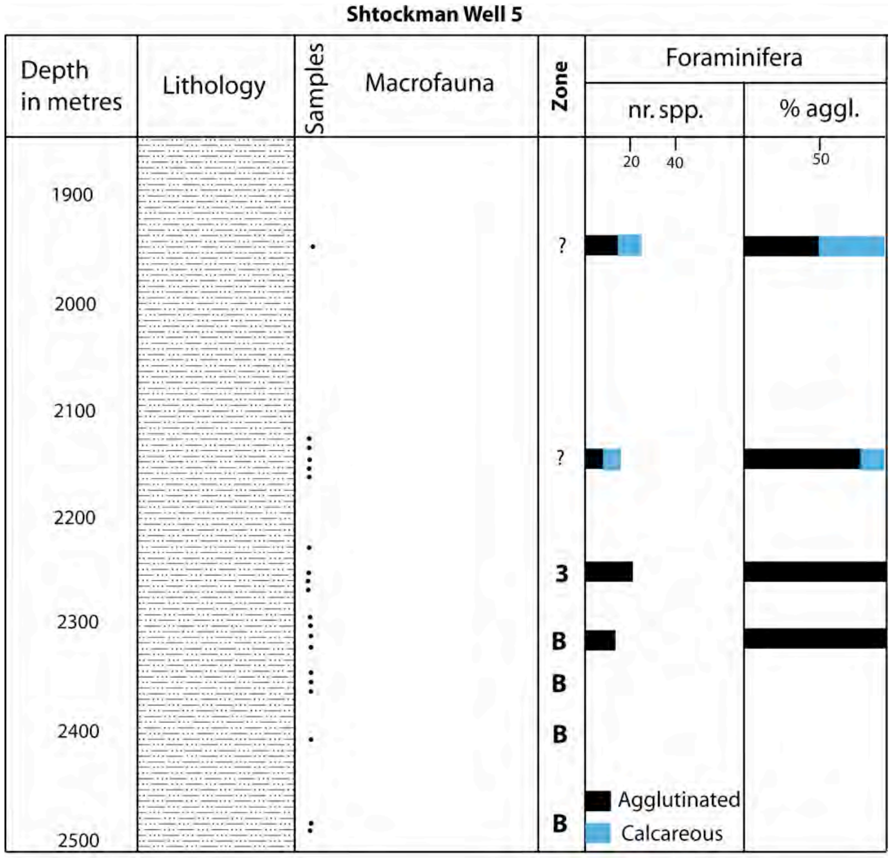

Figure 7. Depth, Lithology, and foraminiferal assemblages from Well 5 on the Shtokman Structure.

ammonite *Amoeboceras (Amoebites)* cf. *pulchrum* Mesezhnikov & Rom and the bivalve *Buchia tenuistriata* (Lahusen). Foraminifera are numerous. They have a very thin grained wall and are strongly deformed. *Evolutinella* sp., *Ammodiscus* sp. and *Kutsevella* sp. are dominant. There are lots of badly preserved white radiolarians that are pressed into the foraminifera. Below the *Evolutinella* sp.–*Ammodiscus* sp. assemblage at the same interval single badly preserved *Vaginulinopsis* cf. *rjavkinaensis* Kosyreva, *Trochammina* sp. and *Evolutinella* sp. were found. The Kimmeridgian age of the zone was determined by the occurrence of Kimmeridgian ammonites and also possibly radiolarians (*Crucella crassa* Zone) (Kozlova, 1971), which are very typical for lower Kimmeridgian deposits in the Pechora Basin.

The *Evolutinella emeljancevi–Ammogloborotalia septentrionalis* Zone.

This zone is present in dark, bituminous, slightly calcareous clay with traces of pyritization in Well 4 (int. 1789-1802 m), and in ditch cuttings in Well 1 (1855 m, 1875 m) (Figs. 3, 6). The Berriasian ammonite *Surites*(?) sp. ind. was found in Well 4 at the top of the 1789-1802 m interval. The base and the top of the zone are defined by the first and last appearance of the index species. The assemblage includes 13 species. Agglutinated taxa are dominant in the lower 6 samples in the interval. Among them are numerous *Ammogloborotalia septentrionalis* (Scharovskaya), *Trochammina* ex gr. *rosacea* Zaspelova, *Ammodiscus veteranus* Kosyreva, *Kutsevella praegoodlandensis* Bulynnikova, *Evolutinella schleiferi* Mjatliuk, and singular occurrences of *Lenticulina* sp. and *Ceratobulimina* sp. ind. Agglutinated species are fine grained and infilled with crystals of pyrite. The stratigraphical position of the *Evolutinella emeljancevi-Ammogloborotalia septentrionalis* assemblage was determined by comparison with coeval foraminifera in Western and Central Siberia and Spitsbergen. In Western Siberia, the *E. emeljancevi–A. septentrionalis* assemblage has been found together with the Berriasian ammonite *Hectoroceras* cf. *kochi* Spath (Tatarskaya area, Well 1). In spite of this, the age of the assemblage was determined for many years as Late Volgian (Bulynnikova *et al.*, 1990). In the present report the association is dated by means of ammonites and foraminifera as Early Berriasian (= Late Volgian). In the same interval in Well 4 a few centimeters higher than *E. emeljancevi–A. septentrionalis* the Berriasian ammonite *Surites* sp. and *Buchia fisheriana* (d'Orbigny) were found.

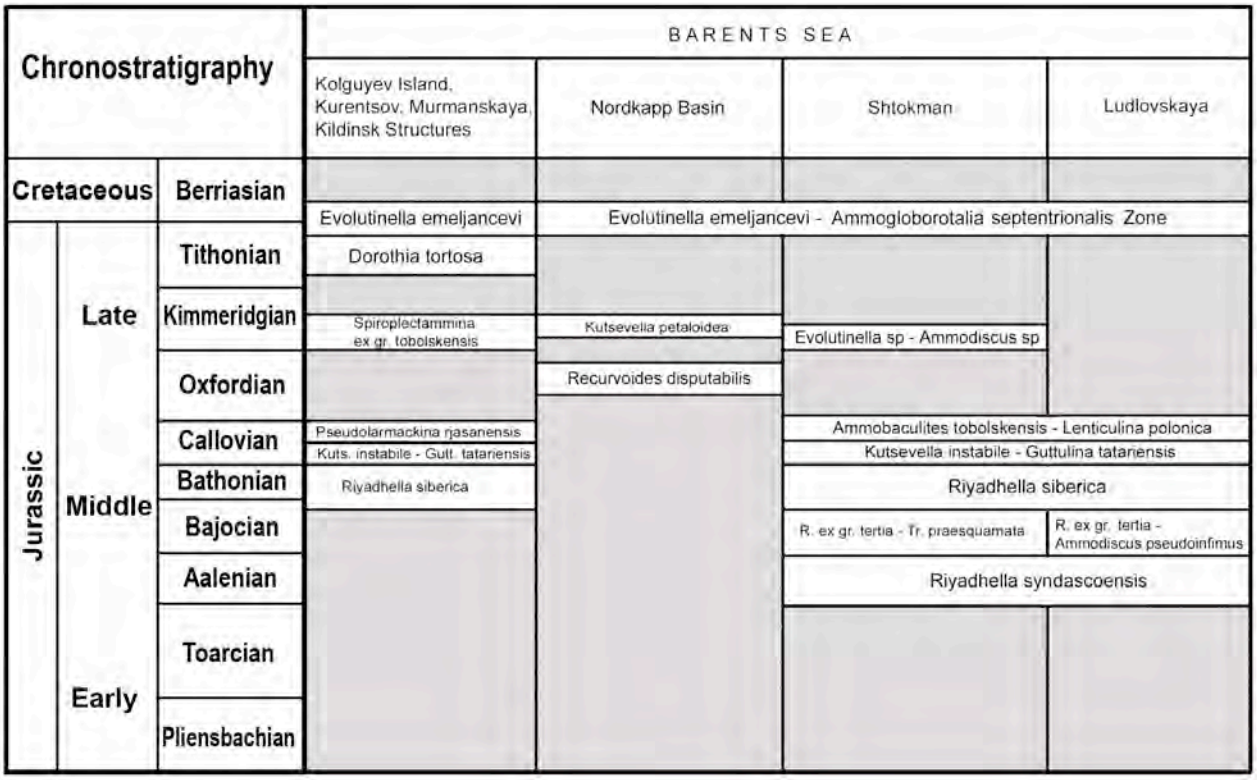

Figure 8. Middle to Upper Jurassic foraminiferal zones in the Barents Sea.

DISCUSSION

The foraminiferal assemblages of the Middle-Upper Jurassic consist mainly of agglutinated forms. Calcareous species are common in Callovian deposits, and these also occur in a few restricted levels. The predominantly agglutinated nature of the foraminiferal assemblages further suggests at least periodically lower salinity on a shallow shelf.

In the studied area, transgression in the studied area possibly started near the beginning of the Aalenian. The main direction of the transgression was from the northeast, therefore many Siberian species migrated into the Barents Sea, such as numerous *Riyadhella, Ammodiscus, trochamminids, Recurvoides*, and *Evolutinella*. The depositional succession represents a transgression from littoral to deeper shelf conditions, and was formed during the Middle–Late Jurassic transgression. The increased diversity in Callovian times suggests that the depositional area had a normal marine aspect. Mixed calcareous-agglutinated assemblages and high diversity indicates that more or less normal marine conditions developed during middle to late Callovian time.

Black shales and bituminous clays (Kimmeridgian and Lower Berriasian) are usually ascribed to anaerobic and dysaerobic depositional environments. The development of low diversity agglutinated foraminiferal assemblages in sediments formed under dysaerobic conditions seems to have two main causes: 1) Agglutinated species have an apparently varying, but generally greater tolerance for low oxygen levels than calcareous species, and 2) High CO2 contents, commonly associated with a large organic supply, excludes calcareous foraminifera by reducing their ability to extract calcium carbonate.

The foraminiferal fauna of the Kimmeridgian interval shows a minimum in diversity (down to 2-3 species per sample) with the total dominance of *Ammodiscus, Evolutinella,* and *Kutsevella*, which are abundant, flattened, and fine-grained. Such features are usually explained by stagnant low energy fairly deep conditions. Consequently, these genera must be regarded as especially tolerant of bottom conditions developed during the deposition of mud that was particularly rich in organic matter. Apart from this, the abundance of radiolarians suggests open marine and deep-water conditions.

The genera *Trochammina, Evolutinella,* and *Haplophragmoides* display the highest tolerance to environmental conditions during the deposition of organic rich Berriasian (Upper Volgian) bituminous clay.

During the Middle Jurassic the Pechora Basin and the Barents Sea region formed a single basin. Its northern part (Shtokman, Ludlovskaya structure) shows typical features of an Arctic foraminiferal faunal province in the north, while a mixture of Arctic and Boreal-Atlantic foraminifera populated the Pechora Basin to the south, where the foraminiferal assemblages were calibrated to the Boreal ammonite zonation (Fig. 9).

Stage	PECHORA BASIN: AMMONITE ZONES (After Mesezhnikov)	PECHORA BASIN: Foraminiferal Zones (after Yakovleva, 1994; and this study	BARENTS SEA
VOLGIAN	Craspedites nodiger	Bullopora viveae - Ammobaculites diligens	7 Evolutinella emeljanzevi Ammogloborotalia septentrionalis
VOLGIAN	Craspedites subditus		
VOLGIAN	Kachpurites fulgens		
VOLGIAN	Paracraspedites opressus	Spirofrondicularia - Lenticulina ponderosa	
VOLGIAN	Epivinopedites nikitini		
VOLGIAN	No ammonites		
VOLGIAN	Dorsoplanites maximus	Dorothia tortuosa - Astacolus orbicularis	
VOLGIAN	Dorsoplanites panderi	Dorothia tortuosa - Saracenaria pravoslavlevi	
VOLGIAN	Ilowaiskia pseudoscythica	Verneuilinoides kirillae - Lenticulina sokolovi	
VOLGIAN	? Subdicot. subcrassum		
VOLGIAN	? Eosphinctoceras magnum		
KIMMERIDGIAN	Aulocosteph. autissiodorensis	Haplophragmium petroplicatus - Lenticulina besairiei	
KIMMERIDGIAN	Aulacostephanus eudoxus		
KIMMERIDGIAN	Aulacostephanus sp.		
KIMMERIDGIAN	Amoeboceras kitchini	Epistomina praetatarensis Lenticulina kuznetsovae	6 Evolutinella sp. - Ammodiscus sp.

Figure 9. Barents Sea foraminiferal zones correlated to Ammonite zones determined in the Pechora Basin by Mesezhnikov and co-workers.

CONCLUSIONS

This study demonstrates the applicability of benthic foraminifera, mainly agglutinated, for stratigraphical zonation in wells in the Shtokman area, where other microfossils and macrofossils are sparse. The following seven foraminiferal zones are proposed: (1) *Riyadhella syndascoensis* Zone, Aalenian–Bajocian (partly) recognised at the base of the Middle Jurassic; (2) *Riyadhella* ex gr. t*ertia-Trochammina praesquamata* Zone tentatively assigned to the Bajocian; (3) *Riyadhella sibirica* Zone-Bathonian partly assigned to the late Bajocian; (4) *Kutsevella instabile-Guttulina tatariensis* Zone of early to middle Callovian age; (5) *Ammobaculites tobolskensis-Lenticulina polonica* Zone of late Callovian age; (6) *Evolutinella* sp.-*Ammodiscus* sp. Zone assigned to the Kimmeridgian (probably early Kimmeridgian); (7) *Evolutinella emeljancevi-Ammogloborotalia septentrionalis* Zone of early Berriasian (= late Volgian) age.

The Aalenian and Bajocian sedimentary succession is very rich in typical Arctic agglutinated foraminifera. The foraminiferal diversity within the Middle Jurassic part increases upward toward the Callovian, where the Arctic agglutinated species are found together with Boreal-Atlantic calcareous species.

Agglutinated assemblages of the Shtokman area show strong taxonomic affinity with the Middle and Upper Jurassic faunas described from high latitude localities including Siberia, Svalbard, Western Canada, Nordkapp, and the Viking Graben. These areas belong to the same major palaeogeographical province, the Boreal Realm. However, in the Callovian time of maximum transgression, many Boreal-Atlantic calcareous species migrated from the central and northern European parts of Russia and Eastern Europe into the Barents Sea.

SYSTEMATIC TAXONOMY

Ammobaculites tobolskensis Levina, 1962

Ammobaculites tobolskiensis Levina, 1962, p. 61, pl. 15, figs 3-7. –Bulynnikova *et al.*, 1990, p. 61, pl. 19, fig. 5, pl. 21, fig. 5.

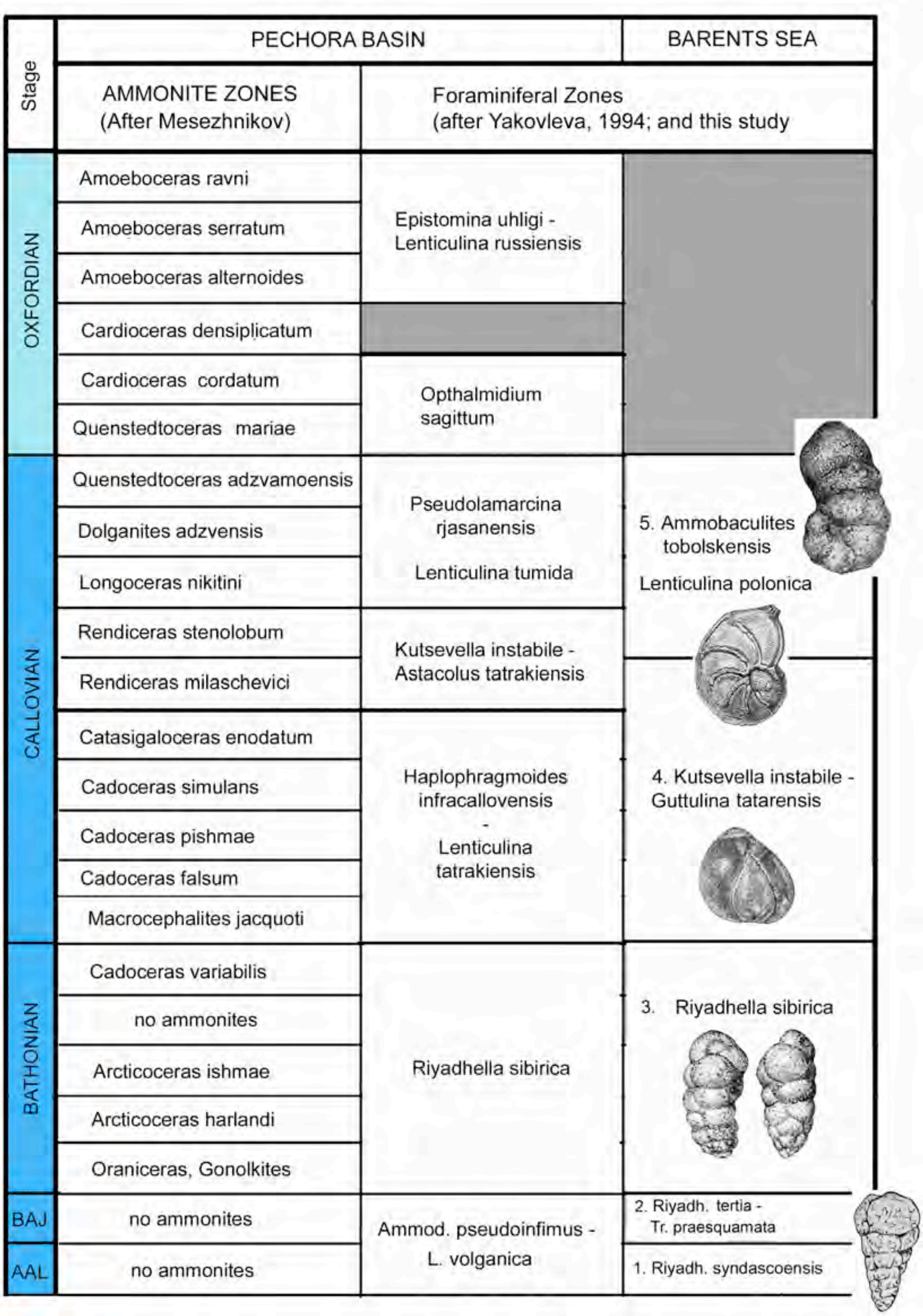

Figure 9. (continued)

Description. This species is characterised by large dimensions, few chambers in the planispiral part, depressed umbilicus, and only one or two chambers in the uncoiled part.

Distribution. The species is known from the lower Oxfordian in Western Siberia (Bulynnikova *et al.*, 1990) and from the Oxfordian to lower Kimmeridgian in the Pechora Basin.

Kutsevella instabile Yakovleva

Kutsevella instabile Yakovleva, 1980, p. 41, pl. 7, figs 10-11. –Nagy & Basov, 1998, pl. 4, figs. 1-5.

Description. This species is characterised by its flattened test and moderately open umbilical area. The test is comprised of 2.5 to 3 whorls with 7-8 chambers in the final whorl.

Remarks. *Kutsevella instabile* differs from *Kutsevella calloviensis* in its thinner test and smaller dimensions. In the latter species the chambers are subglobular and the periphery is more lobate.

Distribution. The species is found abundantly and characteristic of the mid Callovian of the Pechora Basin, but it may also be present in the lower and upper parts of the Callovian. It is also found in the Callovian of the Barents Sea. In Spitsbergen the species is found in the lowermost part of the Agardhfjellet Formation (upper Bathonian to Callovian).

Ammogloborotalia septentrionalis (Scharovskaya), **n.comb.**

Trochammina septentrionalis Scharovskaya, 1961, p. 35, pl. 3, figs 5-7. –Bulynnikova et al., 1990, p. 89, pl. 33, fig. 10, pl. 34, fig. 1.

Description. This species is characterised by its flattened test, circular outline, and open umbilical area, strongly curved sutures and 10-12 chambers in the final whorl.

Remarks. Because of the strongly compressed nature of the test, we transfer the species to the genus *Ammogloborotalia* Zheng, 2001. The species *Trochammina omskensis* Kosyrevae from the Kimmeridgian of Siberia (Dain, 1972) also likely belongs to this genus. The Cretaceous species of *Ammogloborotalia* were reviewed by Kaminski *et al.* (2008).

Distribution. This species is found in the lower to middle Volgian in Central and Western Siberia (Bulynnikova *et al.,* 1990), in middle to upper Volgian of the Agardhfjellet Formation in Spitsbergen (Nagy & Basov, 1998),

? Riyadhella sibirica (Mjatliuk)

Verneuilina sibirica Mjatliuk, 1939, p. 232, pl. 1, fig. 9a,b.
Riyadhella sibirica (Mjatliuk). –Yakovleva, 1973, pl. 6, figs 8a,b,c; 9; 10. –Basov *et al.* 1989, textfig. 2, fig. 13. –Azbel & Grigalis, 1991, pl. 24, fig. 5.
Verneuilinoides sp. 2. –Morris & Coleman, 1989, p. 234, pl. 6.3.12, figs 10, 11, 12.

Description. Test large, high trochospiral, initially conical, later with subparallel sides. The early portion of the test is trochospirally coiled with four to five chambers per whorl. The number of chambers reduces to three per whorl in the latter part of the test. Chambers are rounded, with depressed sutures, and arranged in three rows that are curved spirally along the growth axis. Aperture a low interiomarginal arch, umbilical in position.

Remarks. This species appears identical with *Verneuilinoides* sp. 2. as illustrated by Morris & Coleman (1989). It differs from *Riyadhella shapkinaensis* Yakovleva in its narrower test and in possessing chambers that are aligned in rows. We only tentatively assign it to the genus *Riyadhella*, because its cement was originally organic, rather than calcareous.

Distribution. *Riyadhella sibirica* was first described from the "middle" Jurassic interval of an exploration well drilled on the Nordvik Peninsula. It is the nominate taxon of the upper Bajocian to Bathonian *Riyadhella sibirica* Zone in northern Siberia, the Pechora Basin, the Barents Sea, and Spitsbergen. In the Viking Graben the species occurs in Bathonian strata (the lower Heather Formation), and we observed it in the Bathonian to lower Callovian Melke Formation offshore mid-Norway.

? Riyadhella shapkinaensis Yakovleva

Riyadhella shapkinensis Yakovleva, 1973, p. 103, pl. 1, figs 4,7.
Riyadhella schapkinaensis Yakovleva. –Basov *et al.* 1989, textfig. 2, fig. 14 (nom. corr.). –Azbel & Grigelis, 1991, pl. 24, fig. 2. –Nagy & Basov, 1998, p. 44, pl. 7, figs 25-26.
Riyadhella sibirica (Mjatliuk). –Lutova, 1981, p. 26, pl. 3, fig. 5.

Description. Test is high trochospiral, wide, and usually consists of 4 chambers (rarely 3) per whorl in the adult stage. Chambers are rounded with depressed sutures. Wall is fine to coarsely agglutinated, depending upon the substrate. Aperture a low interiomarginal arch.

Remarks. This species is generally wider than *R. sibirica*, and increases in width with ontogeny, while *R. sibirica* has parallel sides. We only tentatively assign it to the genus *Riyadhella*, because its cement was originally organic.

Distribution. *Riyadhella shapkinaensis* usually occurs together with *R. sibirica*, and can be very abundant. It is known from the R. sibirica Zone in the Pechora Basin, Barents Sea, and in northern Siberia. In Spitsbergen the species was found in Bathonian strata in the basal beds of the Agardhfjellet Formation.

? Riyadhella* ex gr. *tertia (Gerke & Scharovskaya)

Verneuilina tertia Gerke & Scharovskaya *in* Scharovskaya, 1958, p. 42, pl. 1, figs 3a,b.

Distribution. *Riyadhella tertia* was originally described from the middle Jurassic (?Aalenian Lenticulina nordvikensis Zone) of the Nordvik Basin. It is known from Aalenian-Bathonian deposits of northern Siberia.

Guttulina tatarensis Mjatliuk

Guttulina tatarensis Mjatliuk, 1954, p. 115, pl. 30, figs 48a-49c.

Distribution. *Guttulina tatarensis* was first described from the Bathonian to lower Callovian in Gorki District, Russia. It also occurs in the lower Callovian of the Pechora Basin (Yakovleva, 1994b).

Lenticulina polonica Wisnowski

Cristellaria polonica Wisniowski, 1890, p. 222, pl. 10, figs 3a-c.

Lenticulina polonica (Wisniowski). –Hanzlíková, 1965, p. 70, pl. 4, figs 2, 3a-b, 4, 13 a-b.

Description. Test medium sized, 5-6 chambers arranged in a slightly involute biconvex planispiral. Most specimens are close coiled, but some are uncoiling in the latter portion. Sutures depressed, with strong ribs along the margins.

Remarks. This species has often been synonymised with *Lenticulina quenstedti* (Gümbel). Hanzlikova gave a differential diagnosis separating the two species, a conceipt we follow here.

Distribution. *Lenticulina polonica* was originally described from the upper Callovian (*ornatus* zone) of the Kraków district, southern Poland. Hanzlíková (1965) recorded it from the Kimmeridgian to lower Volgian of the Klentnice Beds in the Czech Republic. It is typical of upper Callovian strata of the Russian Platform, the Pechora Basin, and the Barents Sea region, but it can also be found in the middle Callovian in the latter regions. We have also observed the species in the mid to upper Callovian of the Melke Formation, offshore mid Norway.

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