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Ammonite- and bivalve-based biostratigraphy and Panboreal correlation of the Volgian Stage

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The current ammonite- and buchiid-based biostratigraphical successions of the Volgian Stage are outlined, with an analysis of the most important data that support correlation throughout the Panboreal Superrealm. Updated ammonite zonal schemes were proposed for the Volgian of the type region (the Russian Platform) and Svalbard. The lower Volgian successions in all areas except the Russian Platform, with its eudemic[1)] virgatitid lineage and Submediterranean faunal elements, were dominated by *Pectinatites* and *Eosphinctoceras-Subdichotomoceras.* The last two genera were especially common eastwards from the Ural Mountains. During the middle Volgian, provincialism developed quickly within the ammonites, and unified assemblages with early *Palvovia* and *Dorsoplanites* at the base of the substage were replaced by numerous local eudemic faunas. Despite this, migrations of species of *Crendonites*, *Laugeites*, *Epivirgatites Epipallasiceras*, *Epilaugeites,* and *Taimyrosphinctes* occurred at regular intervals and these enable precise correlations between the faunal sub-provinces. The zonation of the upper Volgian is mainly based upon the succession of *Craspedites* (on *Subcraspedites* in England and North Sea), and can be traced throughout the Arctic. Zonation based on the bivalve *Buchia* enables correlations to be made between the successions over much of the Northern Hemisphere, including Northern California, British Columbia, Arctic areas, and the Russian Platform. Each substage of the Volgian is characterized by buchiids with different types of the ontogenetic development. Research on the infrazonal subdivision of the Volgian Stage based on buchiids is currently in progress. Our analyses of the ammonite and buchiid successions of the Panboreal Superrealm lead us to conclude that there are no major faunal gaps in Volgian successions of the Russian Platform and Northern Siberia.

Volgian, Portlandian, Panboreal Superrealm, ammonites, buchiids, correlation.

The Volgian Stage, the terminal Jurassic Stage of the Panboreal Superrealm, has attracted much attention by its enormous oil and gas resources, its unique fossils, and its relationship to discussion of the position of the Jurassic-Cretaceous (J/K) boundary. During the last few decades, the Volgian biostratigraphical successions in the different regions within the Boreal Province have been described in detail, and have been correlated with some of the Tithonian-Berriasian successions of the Tethyan Province.

Marked provincialism in the marine faunas in the latest Jurassic-earliest Cretaceous has led to the use of different stages in different regions, and has lead to difficulties in correlation around the J/K boundary. Two stages have been used in the Boreal terminal Jurassic, the Portlandian Stage (for a small area in southern England and north-west France) and the Volgian Stage (for

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1) The term "eudemic" is used in this article following Callomon[1]: "… useful to refer to an area in which an ammonite biospecies probably lived and bred …, and an area in which a succession of biospecies forming a lineage evolved, as areas in which the (bio) species and (phylo) genus were eudemic". It seems useful for determination of ammonites and their populations belonging to lineages that existed and evolved for a long time in the separated areas.

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the remainder of the Boreal Realm) (Figure 1). The present review of current Volgian ammonite- and bivalve-based biostratigraphy emphasizes the possibilities of the wide correlation throughout the Northern Hemisphere, and briefly discusses Volgian bio-events.

1 Ammonite biostratigraphy and correlation (by Mikhail Rogov)

In recent years, much new data has been obtained about Volgian ammonite ranges in space and in time, and this has enabled correlations to be made between Volgian successions throughout the Boreal Province[2,3]. The results of more recent research, including a brief discussion of correlations of the uppermost middle-upper Volgian and basal Ryazanian based on ammonites[4], are described and expanded on in the present account.

1.1 Russian Platform and Polish Lowland

The Volgian deposits in its type area, the Russian Platform, usually are thin (ca. 10—15 m), but their biostratigraphical succession seems complete and contains a continuous succession of zonal and infrazonal units. The Volgian Stage is subdivided into three substages. The lower Volgian is characterized by mixed Subboreal (eudemic) and Submediterranean faunas; the middle Volgian by Subboreal to Panboreal faunas; and the upper Volgian by Panboreal faunas. The standard zonal succession is based on lineages of eudemic taxa that are mostly restricted in European Russia, but the position of this region in the seaway connected to the Boreal and Tethyan realms led to common occurrence of mixed faunal elements, typical for wide Subboreal ecotone[5,6].

In Poland, the lower Volgian and earliest middle Vol-

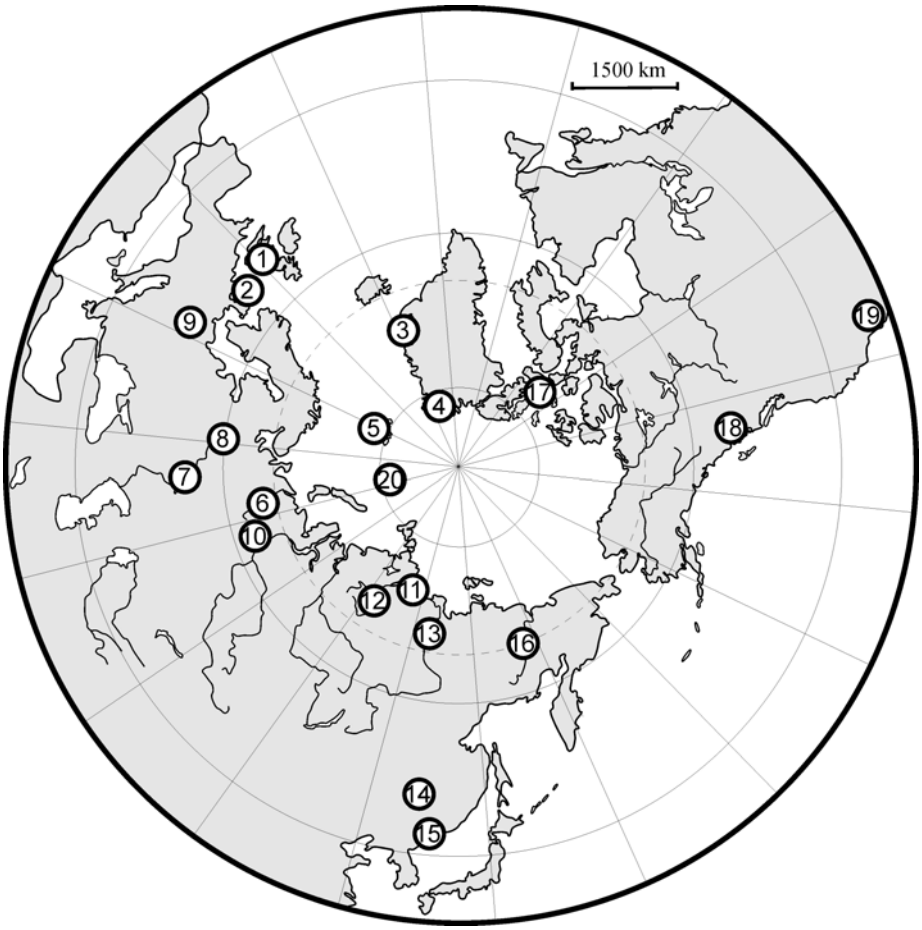

Figure 1 Map showing the study regions and sections. 1, England; 2, North Sea; 3, East Greenland; 4, North Greenland; 5, Spitsbergen; 6, Petshora river basin; 7, Middla Volga area (including Gorodischi, Kashpir sections); 8, Upper Volga area (including Voscow, Glebovo and Sut sections); 9, Poland; 10, Subpolar Ural; 11—13, Northern Siberia (11, Nordvik section; 12, Kheta & Bojarka sections; 13, Lena lower flows, including Besjuke river); 14, North China (Eastern Heilongjiang); 15, Russian Far East; 16, North-East Russian (Anuj river basin); 17, Arctic Canada (Sverdrup Basin); 18, British Columbia; 19, Northern California; 20, Franz-Josef Land.

gian successions were described by Kutek[7], and Kutek and Zeiss[8]. The zonal succession is closely similar to that of the Russian Platform. Some of the unique features of the Polish succession are described below.

1.1.1 Lower Volgian

The lower Volgian succession of the Russian Platform has been divided into ammonite zones and ammonite faunal horizons[9−11] as follows:

(1) *I. klimovi* Zone

N. cf. *nodulosum* horizon: characterized by appearance of *Neochetoceras* cf. *nodulosum* Berckh. & Hoeld., *N.* cf. *praecursor* Zeiss, *Taramelliceras* cf. *franciscanum* (Font.), *Lingulaticeras* sp., and transition from *Sarmatisphinctes* to *Ilowaiskya*, i.e., the First Appearance Datum (FAD) of *Ilowaiskya*.

N. steraspis horizon: characterized by *Ilowaiskya klimovi* (Ilov.), *Lingulaticeras solenoides* (Quenst.), *Sutneria* cf. *eugyra* Berckh., and numerous *Neochetoceras steraspis* (Opp.), accompanied by rare *Eosphinctoceras* sp.

P. (*R.*) *efimovi* horizon: base of this horizon is well-recognized by mass occurrence of eudemic dwarf *Paralingulaticeras (Rogoviceras) efimovi* Rogov (Figures 2 and 3), accompanied by *Ilowaiskya klimovi* (Ilov.), uncommon *Neochetoceras steraspis* (Opp.), *Fontannesiella* sp., *Eosphinctoceras* and (near to the top of horizon) by *Subdichotomoceras* (*Sphinctoceras*) sp. In Poland, *Paralingulaticeras (Rogoviceras) efimovi* Rogov is very rare, but few of their records were studied by the author in the Kutek's collection. The same species also was recorded recently in Crimea[12].

(2) *I. sokolovi* Zone

I. sokolovi horizon: *Ilowaiskya sokolovi* (Ilov.), and last *Paralingulaticeras* (*Rogoviceras*) *efimovi* Rogov. In Poland, this horizon as well as upper part of the *I. klimovi* zone is characterized by occurrence of *Neochetoceras mucronatum* Berckh. et Hoelder.

I. pavida horizon: *Ilowaiskya pavida* (Ilow.), *Subdichotomoceras (Sphinctoceras)* sp.

(3) *I. sokolovi* and *pseudoscythica* Zone

Franconites horizon: its typical "immigrational" horizon marked by occurrence of *Franconites* spp. (fig. 4[10]; pl.XI, fig.1[13]) accompanied by rare *Ilowaiskya* sp.

(4) *I. pseudoscythica* Zone

I. pseudoscythica horizon: characterized by index-species and (at the lower part) by *Ilowaiskya schashkovae* (Ilov.).

S. neoburgense horizon: uppermost Volgian level of mass occurrence of taxa with Mediterranean affinities (which in the middle Volga area attain to 50% of the whole assemblage[10]), i.e., *Schaireria neoburgense* (Opp.), *Sutneria asema* (Opp.), ?*Lingulaticeras* sp., accompanied by eudemic *Ilowaiskya* cf. *pseudoscythica* (Ilov.) below and "*Pseudovirgatites*" *tenuicostatum* (Michlv.) above.

P. puschi horizon: dominated by eudemic "*Pseudovirgatites*" spp. ("*P.*" *arkelli* (Michlv.), "*P.*" *puschi* Kutek & Zeiss et other close related species). These ammonites perhaps represent homeomorphs of true Submediterranean *Pseudovirgatites*. Also small coarse-ribbed ammonites resembling *Danubisphinctes* and *Pavlovia* occur at the upper part of this horizon in Gorodischi and Polevye-Bikshiki sections.

1.1.2 Middle Volgian

The standard zonal succession for the middle Volgian in its current state has been proposed during the last decades of the 20th century[14,15]. Biohorizons were described in the *D. panderi* Zone by Kutek[7] and Rogov[10], and in the *E. nikitini* Zone by Kiselev and Rogov[16] and by Rogov and Kiselev[17], but these remain unsupported by published ammonite descriptions. Ammonites of the Mediterranean affinities (*Sutneria*, *Glochiceras*, *Haploceras*) described from the *D. panderi* Zone of the Ulianovsk Volga area and Per-Caspian region by Blom et al.[18] and Mesezhnikov[19], but the specimens were not figured or described and cannot be traced.

(i) *D. panderi* (*Z. scythicus*) Zone

(1) *Z. scythicus* Subzone

Faunal horizons of this zone, first recognized in Poland by Kutek[7], occur throughout in the Russian Platform except its northern part, where the continuous succession of *Zaraiskites* is absent. In Poland, the whole *Scythicus* Zone characterized by *Zaraiskites* lineage with exception of suspected *Danubisphinctes*, ranged through its lower portion.

Z. quenstedti horizon: this horizon is well-recognized by mass appearance of ammonites with Boreal affinities, i.e., *Pavlovia pavlovi* (Michalski), *Dorsoplanites panderi* (d'Orb.), and *D. dorsoplanus* (Vischn.), accompanied by earliest *Zaraiskites* species, *Z. quenstedti* (Vischn.). Within the latter species, two geographical subspecies could be recognized by different characters of ribbing at their body chamber. In the Polish Lowland and the Moscow region, subspecies with high rib ratio (4−6) at outer whorls is most common, whereas at the

Volga area, from Orenburg to Ulianovsk (and sometimes at Moscow region), subspecies with lower rib ratio (2—3) occur. Zeiss[20] has suggested that basal horizon of the middle Volgian, *quenstedti* horizon, is substituted in the Russian Platform by "beds, containing *Zaraiskites diprosopa* and *Isterites* (?) *contradictionis*", based upon species of *Zaraiskites* figured and described by Ilovaisky[21]. But, recent studies of the Volgian in the Orenburg region showed that *Zaraiskites contradictionis* (Ilov.) is typical for much more young part of the *D. panderi* Zone, while basal portion of the *D. panderi* Zone in the Orenburg region is dominated by *Pavlovia* and *Dorsoplanites* albeit uncommon *Zaraiskites* cf. *quenstedti* (Rouill.) also occur.

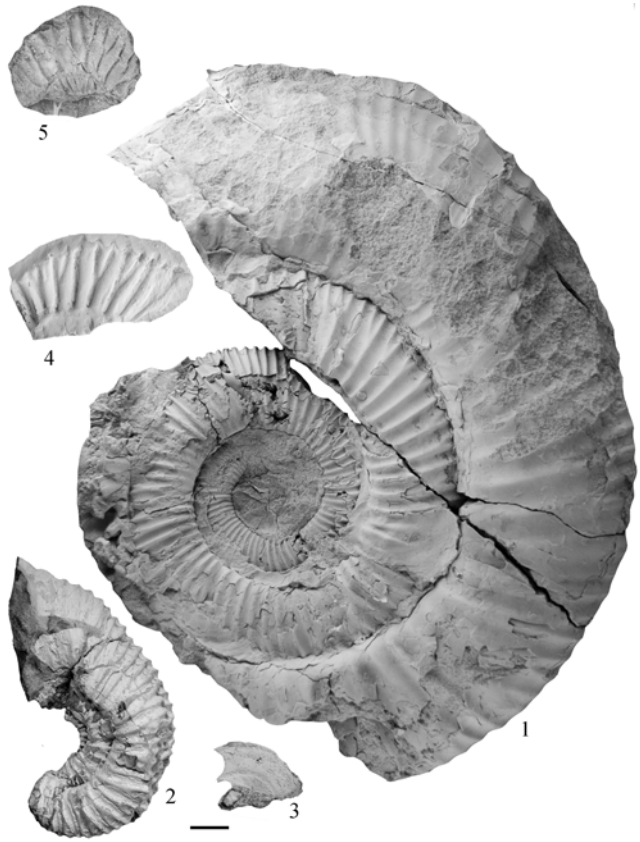

Figure 2 All specimens collected and photographed by Mikhail Rogov and stored in the Geological Institute of RAS (numbers MK) unless noted otherwise. 1. *Pectinatites magnum* Cope [M], fully septated, no. MK2772, Northern Siberia, Bojarka river, section 23, Lower Volgian, from loose block; 2. *Pectinatites* cf. *arkelli* Cope [m], no. MK620, Subpolar Ural, Yatria river, section 1/1, Lower Volgian, *P. magnum* Zone (?), from loose block; 3. *Paralingulaticeras (Rogoviceras) efimovi* Rogov [m], no. MK2138, Russian Platform, Gorodischi section, 0,2 m above the base of bed 1/13, Lower Volgian, *I. klimovi* Zone, *efimovi* horizon; 4, 5. *Pavlovia rugosa* Spath, Spitsbergen, Middle Volgian, *P. rugosa* Zone (4. No. MK2773, Myclegard Mt section, from loose block; 5. No. MK2431, Festningen section, bed 1/128). Scale bar =1 cm.

Z. scythicus horizon: *Zaraiskites scythicus* (Vischn.), *Zaraiskites* spp., accompanied by *Pavlovia* and *Dorsoplanites*, is very common. Upper part of this horizon could be further recognized as a separate unit (previously named *pommerania* horizon after *Zaraiskites pommerania* (Arkell))

(2) *Z. zarajskensis* Subzone

Z. regularis horizon: *Zaraiskites regularis* Kutek, which perhaps includes two transients[22], is very common. First *Acuticostites* also appears at this level. *Dorsoplanites* and *Pavlovia* usually are more or less rare except sections from the northern part of the Russian Platform, where these Boreal ammonites co-occur with *Zaraiskites regularis* Kutek. The latter species extends its range northward at least to the Petchora river basin.

Z. zarajskensis horizon: this horizon mainly was destroyed during the early Virgatus Chron, and represented by a thin lower member, if present at all. Most characteristic ammonite at this level is *Zaraiskites zarajskensis* (Michalski), accompanied by *Dorsoplanites*.

(ii) *V. virgatus* Zone

The whole zone is characterized by occurrence of *Virgatites pallasianus* (d'Orb.), *V. sosia* (Vischn.), *Lomonossovella lomonossovi* (Vischn.), *Dorsoplanites* spp.[15], while fossils mentioned below are typical for separated subzones. *Lomonossovella* records within the Virgatus Zone are mainly restricted in Moscow and Yaroslavl regions, but these ammonite are absent in middle Volga and Saratov Volga area.

V. gerassimovi Subzone: *Virgatites gerassimovi* Mitta.

V. virgatus Subzone: characterized by *Virgatites virgatus* (Buch), *Serbarinovella* spp.

C. ivanovi Subzone: marked by first appearance of dwarf ammonites described as *"Craspedites" ivanovi* Geras. and *"C." pseudofragilis* by Gerasimov[23]. These ammonites are poorly studied. They resemble some microconchs of typical upper Volgian *Craspedites*, but strictly differ from macroconchiate *Craspedites* ex gr. *okensis* (d'Orb.). They are also unknown from the upper portion of the *E. nikitini* Zone, and thus these ammonites can be tentatively considered as homoeomorphs of true upper Volgian *Craspedites*.

(iii) *E. nikitini* Zone

In spite of numerous attempts to subdivide the *E. nikitini* Zone[14,24,25], hitherto this zone is considered as a non-divided unit[15]. Only recently has presence of thin separate horizons within this zone been shown for Volga

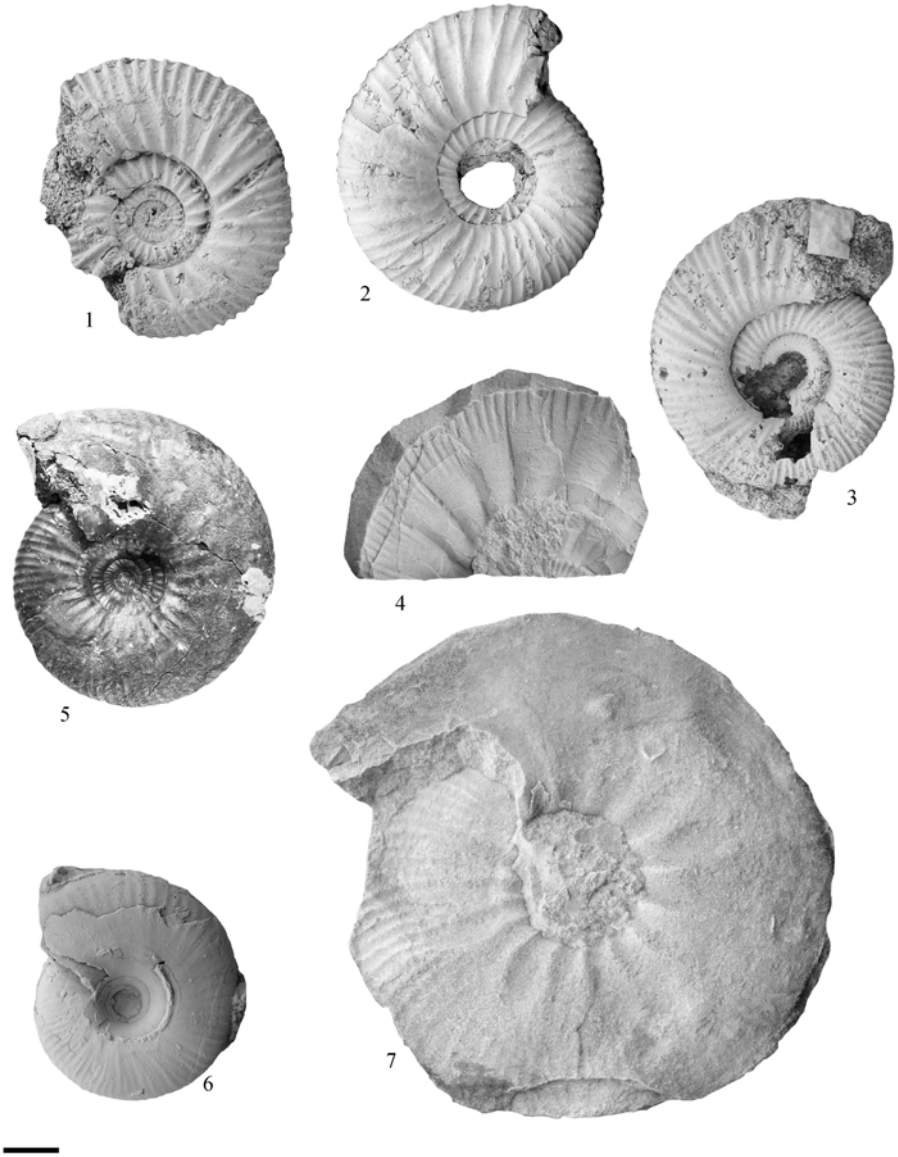

Figure 3 1, 2. *Epivirgatites variabilis* Shulg., middle Volgian (1. Without number, collection of YSPU, Russian Platform, Yaroslavl region, Glebovo section, *E. nikitini* Zone, ?*E. lahuseni* horizon; 2. No. SGM MK1028, Northern Siberia, Nordvik section, *E. variabilis* Zone); 3. *Epilaugeites vogulicus* (Ilov. emend. Michlv.), No. YSPU 3-8, Yaroslavl region, Sut river, middle Volgian, *E. nikitini* Zone, ? *E. lahuseni* horizon; 4. *Dorsoplanites sachsi* Michlv., No. MK2726, Spitsbergen, Myclegard section, bed AC20, middle Volgian, *D. maximus* Zone; 5. *Craspedites* cf. *subditus* (Trd.), No. NHM C69168, Spilsbi Sandstone, Lamplugh collection, upper Portlandian; 6. *Craspedites agardensis* Erschova, No. MK2658, Spitsbergen, Myclegard section, bed AD30, upper Volgian, *C. taymyrensis* Zone; 7. *Subcraspedites* sp., No. MK1911, Russian Platform, Kashpir section, bed 2/4-5 b, collected by *E. Molostovsky,* upper Volgian, *C. subditus* Zone. YSPU, Yaroslavl State Pedagogical University, Yaroslavl; SGM, Vernadsky State Geological Museum, Moscow; NHM, Natural History Museum, London. Scale bar=1 cm.

area[16,17], and now some of these units are also traced at the Moscow area.

E. bipliciformis horizon: with *Epivirgatites bipliciformis* (Nik.) and *Lomonossovella lomonossovi* (Vischn.) as well as first huge ammonites with thick ribbing, resembling *Galbanites*.

E. lahuseni ("*Paracraspedites*"*)* horizon: *Epivirgatites lahuseni* (Nik.), *E. variabilis* Shulgina (Figure 3-1), *E.* aff. *bipliciformis* (Nik.), *Epilaugeites* sp. (Figure 3-3), *Lomonossovella lomonossovi* (Vischn.), "*Paracraspedites*" sp., *Taimyrosphinctes* spp. (Figure 4-3), *Galbanites* sp., *Laugeites stchurowskii* (Nik.), *Laugeites* sp. (*Laugeites* at this level is known from Moscow and Yaroslavl regions only and absent in middle Volga area).

E. nikitini horizon: type horizon of *Epivirgatites nikitini* (Mich.), characterized by numerous *E. nikitini* (Mich.), *E.* cf. *lahuseni* (Nik.), rare *Kachpurites* sp. A. and "*Titanites*" sp.

Kachpurites sp. A horizon: numerous *Kachpurites* sp. A and rare *E. nikitini* (*Mich*), "*Titanites*" sp.

Laugeites sp. nov.1 horizon: *Laugeites* sp. nov.1, *Kachpurites* sp. B., *Epivirgatites nikitini* (Mich.) (extremely rare), *Subcraspedites sowerbyi* (Swinn.), *S.* cf. *preplicomphalus* (Swinn.).

Laugeites sp. nov. 2 horizon: *Laugeites* sp. nov. 2, *Kachpurites* sp. B.; in Kashpir this level also characterized by small coarse-ribbed *Subcraspedites* sp. (pl. XXX, fig. 3)[26].

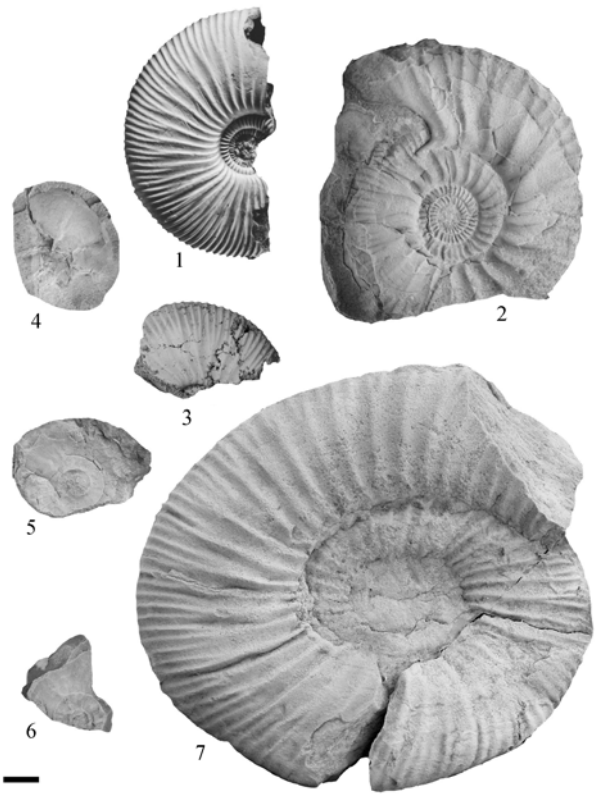

Figure 4 1—3. *Taimyrosphinctes* spp., middle Volgian (1. No. VNIIO 32I-858*, Northern Siberia, Hadyga river, collected by Osipova; 2. No. MK2618, Spitsbergen, Myclegard section, bed AC8, ? *D. maximus* Zone; 3. No.2561-1, Moscow, Kuntcevo section, lower part of the *E. nikitini* Zone, *E. bipliciformis* or *E. lahuseni* horizons); 4. *Pseudophylloceras* sp. juv. cf. *knoxvillense* (Stanton), No. MK2416, Spitsbergen, Festningen section, section 2, bed 3, *P. exoticus* Zone; 5, 6. *Kachpurites* cf. *fulgens* (Trd.), lowermost upper Volgian, Northern Siberia, Lena river basin (precise locality is unknown), sample 31/6b, collected by I.I.Tuchkov (5. No. SGM TI 6; 6. No. SGM TI 7); 7. *Pectinatites* cf. *wheatleyensis* (Neaverson), No. SGM TI 1, Northern Siberia, Besjuke river, locality 133, sample 133d, collected by I. I. Tuchkov (unpublished, 1959). VNIIO, VNIIO keangeologia, Saint Petersburg; photographs from collection by N. I. Shulgina (VNIIO) marked by asterisk. Scale bar=1 cm.

1.1.3 Upper Volgian

The ammonite biostratigraphy of the upper Volgian in the type area is mainly based on Gerasimov[26], with additions by Baraboshkin[27], Kiselev[28], and Mitta[29].

K. fulgens Zone

K. fulgens Subzone: *Kachpurites fulgens* (Trd.), accompanied by *Craspedites okensis* (d'Orb) are very typical. First *Garniericeras* also occurs in this subzone.

C. nekrassovi Subzone: *Craspedites nekrassovi* (Prig.), *Craspedites okensis* (d'Orb) (this species also occurs through the *C. subditus* Zone)), *K. subfulgens* (Nik.), *Garniericeras.*

C. subditus Zone: *Craspedites subditus* (Trd.), *C. subditoides* (Nik.), *Subcraspedites* sp. (Figure 3-7), *Garniericeras catenulatum* (Fisch.) below and *G. subclypeiforme* (Mil.) above.

C. nodiger Zone: Subdivided into two subzones (*C. mosquensis* below and *C. milkovensis* above), differing by presence of the *Craspedites mosquensis* Geras. at the lower subzone[30]. Both subzones rich in Craspedites with remarkable nodes at the umbilical seam (*Craspedites nodiger* (Eichwald), *C. kaschpuricus* (Trautsch.), *C. parakaschpuricus* Geras., *C. milkovensis* (Strem.), *C. kuznetzovi* (Sokolov), accompanied by *Garniericeras subclypeiforme* (Milash.). Near to the boundary of subzones at the Kashpir section, typical Siberian species *Craspedites pseudonodiger* Schulg. occurs.

Volgidiscus singularis beds: recognized at the single section only[28], these beds characterized by *Anivanovia mola* Kiselev and *Volgidiscus singularis* Kiselev.

Perhaps uppermost part of the upper Volgian, corresponding to the Chetae Zone of Siberia, was eroded at the Russian Platform and only rare reworked *Chetaites* cf. *chetae* Schulg. is known from condensed Volgian-Ryazanian transition beds[26].

1.2 Subpolar Urals

The Volgian deposits situated on the east slope of Subpolar Ural Mountains have been known for more than 100 years. Last decades these deposits were intensively studied through localities along banks of rivers Yatria, Lopsia, and Tol'ja. Current zonal succession was proposed mainly by Meseznikov[2] and Mesezhnikov et al.[31].

1.2.1 Lower Volgian

E. magnum Zone: *Eosphinctoceras* spp. (very common), *Gravesia gravesiana* (d'Orb.), *Tolvericeras* (*Pseudogravesia*) *hahni* Hantz., *Pectinatites* cf. *damoni* Cope, *P.* cf. *arkelli* Cope (Figure 2-2). *Pectinatites* cf.

elegans Cope was also found at the loose block[32].

S. (*S.*) *Subcrassum* Zone: *Subdichotomoceras (Sphinctoceras)* spp., uncommon *Eosphinctoceras gravesiforme* Mesezhn., *Pectinatites* (*Arkellites*) *hudlestoni* Cope (= *Subplanites (Ilowaiskya)* sp. in Zakharov and Mesezhnikov[33], pl. IV, fig. 3), *P*. cf. *donovani* Cope (= *Subplanites (Ilowaiskya)* sp. in Zakharov and Mesezhnikov[33], pl. IV, fig. 2), *P. groenlandicus* Spath.

"*P. pectinatus*" Zone: this zone was first called Lideri Zone by Mesezhnikov, after eudemic species *Pectinatites lideri*, and afterwards renamed due to records of *Pectinatites* from the *pectinatus* group[2], but range of this zone in the Siberian section, perhaps, only partially coincides with its full range (see also at correlation section below). *Pectinatites fedorovi* Mesezhn., *P. lopsiensis* (Michlv.), *Paravirgatites* sp., *Pectinatiies* aff. *pyriticus* Neav., *P*. cf. *boidini* (Lor.), *P.* cf. *devillei* (Lor.).

1.2.2 Middle Volgian (after Mesezhnikov[2])

P. iatriensis Zone

P. iatriensis Subzone: *Pavlovia* (*Pallasiceras*) spp., incuding *P. iatriensis* Ilov., *P. turgens* (Michlv.), *P. raricostata* (Ilov.) and rare *P. hypophantica* Ilov., *Strajevskya* spp.

S. strajevskyi Subzone: *Strajevskya strajevskyi* (Ilov.), *S. hypophantiformis* Mich1v., *S. hoffmanni* (Ilov.), *Pavlovia* (*Pallasiceras*) *hypophantica* Ilov., *P. (P.) raricostata* Ilov., *P. (P.) romanovae* Mesezhn.

D. ilovaiskyi Zone: *Dorsoplanites ilovaiskii* Mesezhn., *D.antiquus* Spath, *D.* aff. *gracilis* Spath, *Pavlovia (Pallasiceras)* sp., *P. (Pavlovia)* ex gr. *jubilans* Spath, *Strajevskya hypophantiformis* Mich1v., *S*. cf. *strajevskyi* (Ilov.), at the upper portion of the zone, the following ammonites also added: *D.crassus* Spath, *D.* aff. *transitorius* Spath, *D. ovalis* Mesezhn.

D. maximus Zone: *Dorsoplanites* spp., including *D. maximus* Spath, *D. panderiformis* MichIv., *D. crassus* Spath, *Pavlovia (?Epipallasiceras)* sp. below, accompanied by *D. subdorsoplanus* Mesezhn., *D. nalivkini* Mesezhn above, and with *D.antiquus* Spath, *D. dainae* Mesezhn., *D. liapinensis* Mesezhn., *Pavlovia* (*P.*) *ponomarevi* Ilov. em. Michlv., *P*. (*P*.) *romanovae* Mesezhn. at the top.

Crendonites spp. Zone: *Crendonites subleslie* Mesezhn., *C*. cf. *anguinus* Spath, *Laugeites* sp. ind.

L. groenlandicus Zone: *Laugeites borealis* Mesezhn., *L. planus* Mesezhn., *L. biplicatus* Mesezhn., *L. groenlandicus* Spath.

E. vogulicus Zone: *Epilaugeites vogulicus* (Ilov.), *E. iatriensis* Mesezhn., accompanied by rare *Laugeites* aff. *borealis* Mesezhn, *L. biplicatus* Mesezhn., *Taimyrosphinctes* (*T.*) aff. *excentricus* Mesezhn.

1.2.3 Upper Volgian

K. fulgens Zone: *Kachpurites fulgens* (Trd.), *K.* cf. *sulfulgens* (Nik.), *Craspedites* cf. *fragilis* (Trd.)

C. subditus Zone: *Craspedites okensis* (d'Orb.), *Garniericeras* sp.

C. taimyrensis Zone: *Craspedites* cf. *taimyrensis* (Bodyl.), *Subcraspedites turbinae* Klim.

C. chetae Zone: Golbert et al.[34] mentioned records of *Chetaites chetae* Schulg. and "*Virgatosphinctes*" (=*Praechetaites*) sp. from the terminal Jurassic of this region. Alternatively used name "Subcraspedites mauryniensis Beds" was proposed by Mesezhnikov et al.[31] for succession of the Maurynja river, based on co-occurrence of *Subcraspedites maurynijensis* Mesezhn. et Alekseev, *Schulginites tolijese* (Nik.), *Sch. pseudokocki* Mesezhn.

1.3 Spitsbergen

Volgian zonation of Spitsbergen was based upon numerous ammonite records, summarized by Ershova[35], but details concerning precise ranges of taxa are rare because most of these ammonites were collected during the geological survey and only a few have their precise position indicated in a measured section. Fieldwork in 2006—2007 enabled the zonal succession to be revised on the basis of newly collected ammonites[36,37].

1.3.1 Lower Volgian

The range of the lower Volgian deposits of Spitsbergen is still unknown. There is only figure of *Pectinatites* from the Agardbukta (Birkenmajer et al.[38], pl. 37, fig. 8) but due to very high position within the section and some morphological features, this ammonite apparently belongs to middle to upper Volgian *Praechetaites* resembling *P. exoticus* (Schulg.). Other lower Vo1gian ammonites, such as *Subplanites* and *Pectinatites*, were mentioned by Ershova[35], but without data concerning their precise position within the sections. These ammonites were not found in the collection of the VNII-Okeangeologia. Lower Vo1gian rocks may be at least partially eroded at Svalbard during the middle Vo1gian, as widely occurred in Arctic.

1.3.2 Middle Volgian

P. rugosa Zone: for the lowermost middle Volgian beds of Svalbard hitherto name Panderi Zone was used, based upon records of "*Dorsoplanites panderi*" and "*Zaraiskites* cf. *scythicus*", which first appears in early papers by Sokolov & Bodylevski[39] and Frebold[40], when rich East Greenland and Siberian dorsoplanitid faunas were unknown. These *Dorsolpanites* belongs to Arctic species of *Dorsoplanites*, such as *D. flavus* Spath (*Perisphinctes* cf. *panderi* in Frebold, pl. XII, fig. 2)[40], *D.* cf. *maxumus* Spath (*Perisphinctes* cf. *panderi* in Frebold, pl. XIII, fig. 1)[40], *D. mutabilis* Spath (*Perisphinctes* cf. *panderi* in Frebold, pl. XI, fig. 2)[40], *D. ilovaiskii* Mesezhn. (*Perisphinctes* cf. *panderi* in Frebold, pl. X, figs. 2, 4, 5)[40], while "*Zaraiskites*" (*Virgatites* cf. *scythicus*: Sokolov, Bodylevski, pl. VIII, fig. 6)[39] should be determined as *Praechetaites* cf. *tenuicostatus* (Schulg.). *Dorsoplanites panderi* (d'Orb.) figured by Erschova (pl. XVI, fig.1-2; pl. XVII, fig. 1)[35] remarkably differs from typical *D. panderi* (d'Orb.) and perhaps belongs to a new species. Thus, lower zone of the middle Volgian of Svalbard should be replaced. The author[36] proposed new name *P. rugosa* Zone for this level, which characterized by numerous records of *Pavlovia rugosa* Spath (Figure 2-4 and 5), accompanied by rare *Dorsoplanites* sp., and overlying unit was named *D. ilovaiskii* Zone (see below)

D. ilovaiskii Zone: characterized by *Dorsoplanites gracilis* Spath, *D. subovalis* Mesezhn., *D.* cf. *mutabilis* Spath, *D. sibiriakovi* Michlv., *D.* cf. *ilovaiskii* Mesezhn., *Praechetaites* sp., *Epipallasiceras* sp.

D. maximus Zone: *Dorsoplanites maximus* Spath, *D. sachsi* Michlv., *Glaucolithites* cf. *groenlandicus* (Spath) (= *Pavlovia* aff. *kochi* in Erschova[35], pl. XXII, fig. 1), *Taimyrosphinctes* sp. (Figure 4-2), *Praechetaites* sp., ?*Epipallasiceras* sp.

Crendonites spp. Zone: recognized for the first time by single record of *Crendonites* sp.[36] (Figure 5-1), and now supported by *Crendonites* specimen from Spath's collection (London, NHM C26975).

L. groenlandicus Zone: Small-sized *Laugeites* spp. is very typical, accompanied by *L.* cf. *groenlandicus* (Spath) and *Taimyrosphinctes* sp.

P. exoticus Zone (pro *Virgatosphinctes tenuicostatus* beds in Ershova, Pchelina[44]) *Praechetaites tenuicostatus* (Schulg.), *P.* cf. *exoticus* (Schulg.) (Figure 6-1),

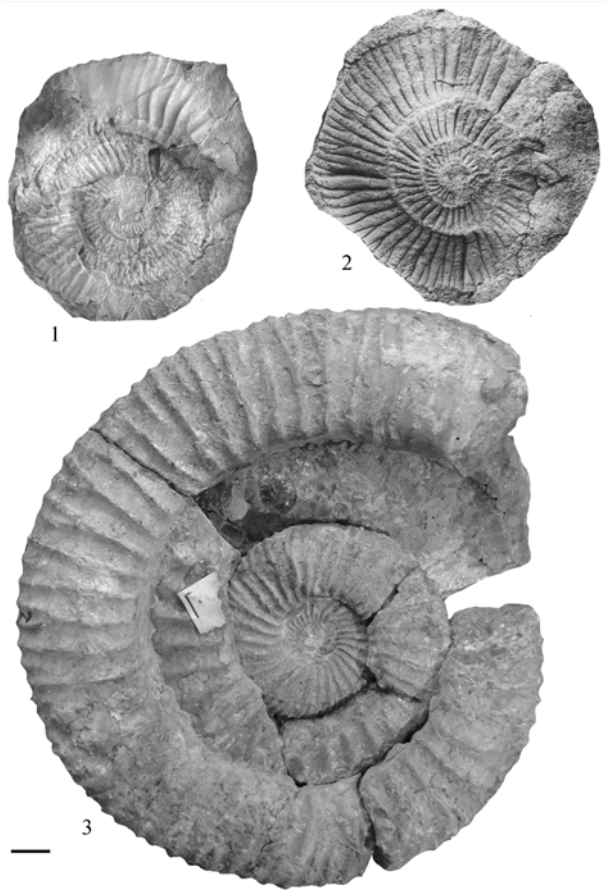

Figure 5 1. *Crendonites* sp., No. MK2450-1, Spitsbergen, Festningen section, 9.5 m above the base of bed 1/131, middle Volgian, *Crendonites* spp. Zone; 2. *Crendonites* sp.*, specimen lost, Franz Josef Land, Wilczek Land, Lamont Cape, section 1, bed 23, middle Volgian, *Crendonites* spp. Zone (collected by N. Shulgina (figured in refs. [41, 42]); 3. *Crendonites elegans* Spath, holotype, No NHM C36607, Portland Stone, Okus Quarry, Swindon, Portlandian (inner whorls were figured by Spath; pl. 8, fig. 6[43]). Scale bar=1 cm.

Taimyrosphinctes sp., *Laugeites* sp. At the same level, single *Pseudophylloceras* cf. *knoxvillense* (Stanton) was found (Figure 4-4). Middle Volgian age of this Zone was proven recently by records of *Laugeites*, representing species known from the uppermost *E. nikitini* Zone[45].

1.3.3 Upper Volgian

C. okensis Zone: well recognized by occurrence of *Craspedites okensis* (d'Orb.), *Craspedites* sp.

C. taimyrensis Zone: *Craspedites agardensis* Erschova (Figure 3-6), *C. pseudonodiger* Schulg., *C. bodylevskyi* Erschova, *C. canadensis* Jeletz.

Uppermost part of the Volgian, corresponding to Chetae Zone of Siberia, not found in Svalbard. Ammonite figured by Sokolov and Bodylevski (pl. IX, fig. 3)[39] was assigned to *Chetaites* by Sachs and Shulgina[46], but

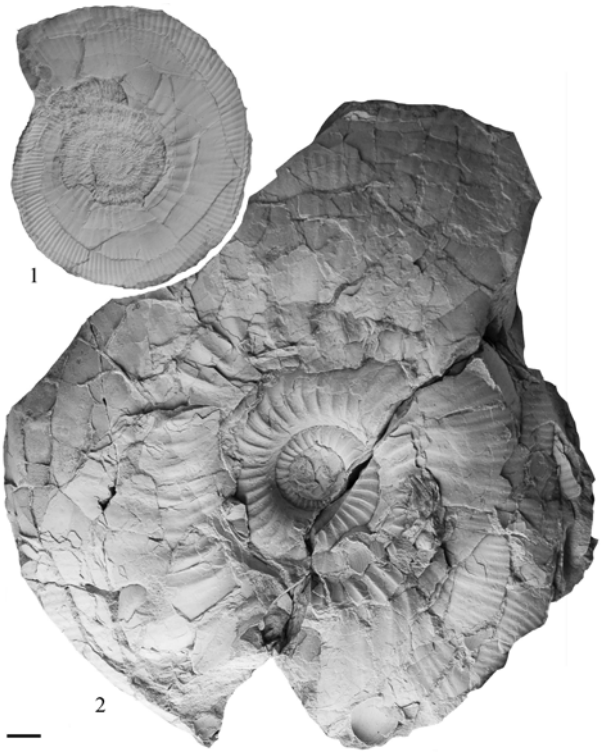

Figure 6 1. *Praechetaites* cf. *exoticus* (Shulg.), No. MK2649, Spitsbergen, Festningen section, section 2, bed 5, *P. exoticus* Zone; 2. *Praechetaites exoticus* (Shulg.), No. MK2771, Northern Siberia, Bojarka River, section 23, middle Volgian, *P. exoticus* Zone, from loose block. Scale bar=1 cm.

this ammonite seems to be more close to *Epivirgatites*.

1.4 Northern Siberia

First data about Volgian succession of Northern Siberia appeared ~50 years ago, but in spite of difficulties in studying such Arctic sites, Volgian deposits of this area remain among the best studied. Lower-middle Volgian ammonite biostratigraphy of Northern Siberia was proposed by Mikhailov[47], Shulgina[48], Mesezhnikov[2] and includes both regionally traceable and widely-ranged units. Upper Volgian succession was studied in details by Shulgina[48,49]. Ammonite biostratigraphy of the middle-upper Volgian boundary beds were recently updated by Zakharov and Rogov[45].

1.4.1 Lower Volgian

These deposits mainly were destroyed during the latest early Volgian to middle Volgian transgression, and only "*P. pectinatus*" Zone can be traced at the Khatanga depression[2]. On the other hand, ammonites typical for *P. magnum* and *S* (*S.*) *subcrassum* Zones (*Eosphinctoceras* cf. *gracilecostatum* Mesezhn., and *Subdichotomoceras* (*S.*) cf. *michailovi* Mesezh., *S.* (*S.*) *grande* Mesezh., respectively) are also encountered in this area; thus *P. magnum* and *S* (*S.*) *subcrassum* zones were proposed for Northern Siberian succession[2]. Additional records of *Pectinatites magnum* Cope (Figure 2-1) and *P. groenlandicus* Spath at the Left Bojarka River also support this proposal. From the lower flows of Lena river, joint records of *Ilowaiskya* and *Subdichotomoceras* were mentioned[2,47,50,51], but these ammonites were not described or figured, and collections mainly are lost. Re-studying of small collection from this area by I.I.Tuchkov reveals the presence of *Pectinatites* spp. (Figure 4-7) and the absence of *Ilowaiskya*, which perhaps were misidentified.

1.4.2 Middle Volgian

P. iatriensis Zone: its presence suggested by occurrence of *Pavlovia (Pallasiceras) hypophantica* Ilov. em. Mich1v. and *Pavlovia* sp.

D. ilovaiskii Zone: recognized only in the Dyabakatara river (Byrranga Mts, Eastern Taimyr) by records of *Dorsoplanites byrrangensis* Mesezh., *D. subovalis* Mesezhn., *D.* cf. *antiquus* Spath, *D.* cf. *dainae* Mesezhn.

D. maximus Zone: *Dorsoplanites maximus* Spath, *D.* cf. *crassus* Spath, *D. subpanderi* Spath, *D.* cf. *flavus* Spath, *D.* cf. *triplex* Spath, *D. molodoensis* Michlv., *D. sachsi* Michlv., *Epipallasiceras costatus* Spath, *Praechetaites subtenuicostatus* (Mesezhn.), *Taimyrospinctes pachycostatus* Mesezhn., *T. nudus* Mesezhn., *T. pavloviformis* Mesezhn., *T. elegans* Mesezhn.

T. excentricum Zone: characterized by abundant *Taimorosphinctes* spp. (Figure 4-1), accompanied by uncommon *Dorsoplanites* sp. and *Praechetaites* sp.

E. variabilis Zone: *Epivirgatites variabilis* Schulg. is very common, while *Laugeites* sp., *Praechetaites* sp. and *Epilaugeites* sp. (in the upper part of the zone) are rare.

P. exoticus Zone: most characteristic for this zone is aenigmatic *Praechetaites* spp. (Figure 6-2), characterized by fine ribbing resembling those of *Virgatosphinctes.* Additionally, *Laugeites* spp., belonging to species known from the two uppermost horizons of Nikitini Zone at the Russian platform, occurred at the upper part of the zone (in Nordvik section, see Zakharov and Rogov[45]), and near its top, big *Pseudophylloceras* cf. *knoxvillense* (Stanton) appears. Rare *Taimyrosphinctes* cf. *trikraniformoides* Mesezhn. is known from this level at the Kheta river.

1.4.3 Upper Volgian

C. okensis Zone

C. okensis Subzone: *Craspedites okensis* (d'Orb.), *Praechetaites exoticus* Schu1g., *P. tenuicosiatus* Schu1g., *P. rudicostatus* Schu1g., *Schulginites* (?) *margaritae* (Schulg.). *Kachpurites* sp. records from the Lena River (Figure 4-5 and 6) also perhaps belong to this zone.

C. originalis Subzone: *Craspedites originalis* Schulg., C. cf. *okensis* (d'Orb.), *Praechetaites tenuicostatus* Schulg., *Subcraspedites arcticus* (Schulg.)

C. taimyrensis Zone: *Craspedites taimyrensis* (Bodyl.), *C. planus* Schulg., *C. pseudonodiger* Schulg., *C. canadensis* Jeletz., *Schulginites* sp., *Sch.* (?) *margaritae* (Schulg.), *Praechetaites* sp.

C. chetae Zone: *Chetaites chetae* Schulg., *Craspedites singularis* (Schulg.), *Schulginites* (?) *margaritae* (Schulg.), *Praechetaites* sp.

1.5 Greenland

The Volgian succession of the East Greenland was studied by Spath[43], Donovan[52], Surlyk et al.[53], Surlyk[54] and Callomon & Birkelund[55]. In the last account, the ammonite succession was summarized in terms of faunas, corresponding more or less precisely to faunal horizons. The North Greenland ammonite succession is poorly known, but includes important records, such as upper Volgian *Craspedites okensis* (d'Orb)[56]. Below are brief characteristics of the zones based on Callomon and Birkelund[55] and Surlyk[54], with minor changes.

1.5.1 Lower Volgian

P. elegans Zone: fauna 24, *Pectinatites elegans* Cope, *P. major* Cope, *P.* cf. *damoni* Cope (pl. I, fig. 1)[43].

P. wheatleyensis Zone: fauna 25, *Pectinatites smedmorensis* Cope, *P. laticostatus* Cope, *Eosphinctoceras*) cf./aff. *magnum* Mesezhn. / *E. distans* Neaverson.

P. hudlestoni Zone: fauna 26, *Pectinatites* cf./aff. *abbreviatus* Cope.

P. pectinatus Zone, faunas 27—30, indicating both subzones of the *P. pectinatus* Zone, with *Pectinatites groenlandicus* Spath, *P. eastlecottensis* Salf., *P. cornutifer* (Buckman), *P.* cf. *pectinatus* (Phillips), *P. rarescens* Buckman. *Paravirgatites* spp.

1.5.2 Middle Volgian

D. primus Zone: fauna 31, *Dorsoplanites primus* Callomon & Birkelund, *Pavlovia* sp.

P. iatriensis Zone: fauna 32, *Pavlovia iatriensis* Ilov., *Dorsoplanites* cf. and aff. *dorsoplanus* (Vishn.).

P. rugosa Zone: fauna 33, *Pavlovia rugosa* Spath, *P. alterneplicata* Spath/*P. kochi* Spath, *P. inflata* Spath, *P. allovirgatoides* Spath/*similis* Spath, *P. variabilis* Spath, *Dorsoplanites* sp.

P. communis Zone: faunas 34—35, *Pavlovia communis* Spath, *P. regularis* Spath, *P. subaperta* Spath, *P. perinflata* Spath, *P. variocostata* Callomon & Birkelund, *Dorsoplanites gracilis* Spath.

D. liostracus Zone: faunas 36—37, *Dorsoplanites gracilis* Spath, *D. liostracus* Callomon & Birkelund, *Pavlovia corona* Callomon & Birkelund.

D. gracilis Zone: faunas 38—40, *Dorsoplanites antiquus* Spath/*transitorius* Spath, *D. gracilis* Spath, *D. aldingeri* Spath, *D. crassus* Spath, *D. mutabilis* Spath, *Epipallasiceras rotundiformis* Spath, *Epipallasiceras* aff. *costatum* (Spath), *Pavlovia* sp.

E. pseudapertum Zone: faunas 41—44, rich in *Epipallasiceras*, including *E. acutifurcatum* Callomon & Birkelund, *E. pseudapertum* Spath, *E. praecox* Spath. *Dorsoplanites* represented by *Dorsoplanites maximus* Spath, *D. gracilis* Spath, *D. intermissus* Callomon & Birkelund. *Glaucolithites groenlandicus* (Spath) also occurs at this zone.

C. alguinus Zone: faunas 45—46, *Crendonites* aff. *subgorei* Spath, *C. anguinus* Spath, *Dorsoplanites* sp.

L. groenlandicus Zone: *Laugeites groenlandicus* (Spath), *Crendonites* cf./aff. *subgorei* Spath/*elegans* Spath. In the Kuhn Island fauna of *Laugeites* represented by other species[52], which, from data from Svalbard, are younger in comparison with typical *L. groenlandicus.* These are *L.parvus* Donovan and *L. jamesoni* Donovan, cooccurred with *Swinnertonia* (*S. intermedius* Donovan).

E. vogulicus Zone: *Epilaugeites* cf. *vogulicus* (Ilovaisky).

Praechetaites tenuicostatus beds: *Praechetaites tenuicostatus* (Schulg.).

1.5.3 Upper Volgian

Subcraspedites sowerbyi beds: *Subcraspedites sowerbyi* Spath (= *S.* cf. *plicomphalus* in Surlyk et al., pl. 3, fig. 2)[53].

Chetaites chetae beds: *Chetaites chetae* (Schulg.).

1.6 Brief review of the Volgian ammonite succession of Arctic Canada and Franz-Josef Land

Both these regions contain only separated small parts of the Volgian succession that are not included within cor-

relation chart, but some elements of their ammonite faunas are interesting for stratigraphical and paleobiogeographical purposes.

The Volgian of Franz-Josef Land is represented by the middle substage only[41,42]. Firstly, zones were not recognized here; instead, *Dorsoplanites* spp. beds and *Laugeites* beds were in use. Recently Repin et al.[57] proposed in zonal scheme succession of *Dorsoplanites* cf. *ovale* zone below (which was named *D. ilovaiskii* Zone in explanations to plates with ammonites) and *Dorsoplanites* aff. *maximus* zone above, but without any data about their ammonite contents, type sections etc. Perhaps *Dorsoplanites ovale* Mesezhn. and *D. subovale* Mesezhn (pl. V, figs. 4, 6, 10)[57] belong to *D. ilovaiskii* Zone, while next zone characterized by *D.* aff. *triplex* Spath (fig. 3.4.15.1)[44] and *Epipallasiceras* sp. Ammonites from collections of VNIIOkeangeologia and figured specimens (from references given above) indicates presence of *Crendonites* level (*Crendonites* sp. (Figure 5-2)), and, perhaps, basal part of the middle Volgian with *Pavlovia* spp.

Volgian ammonite succession of Arctic Canada (Sverdrup Basin) includes at least partial middle Volgian containing *Dorsoplanites* cf. *gracilis* Spath (pl. VIII, fig. 10)[58], *D.* cf. *flavus* Spath (pl. L, fig. 1)[59] as well as *Laugeites* spp. (pl. VIII, figs. 1, 7)[58], and upper Volgian. Within the upper Volgian, concurrent occurrence of *Subcraspedites sowerbyi* Spath (pl. V, fig. 1)[60] and *Craspedites* cf. *thurrelli* Casey (= *Craspedites* n. sp. aff. *subditus* in Jeletzky (pl. V, fig. 5)[60]) is recognized at Northern Ellesmere Island, while *Craspedites canadensis* Jeletz., indicative for *C. taimyrensis* Zone of Northern Siberia, is known from Western Ellesmere Island[58].

1.7 Comments on Volgian (Bolonian-Purbeckian) ammonite succession of England

The lithostratigraphy of the uppermost Jurassic succession of southern England is known in detail, but the biostratigraphical zonation is based mainly on eudemic taxa. Those from the upper part of the succession (the Portlandian of some authors) are known only from specimens figured by Buckman[61], and many of the genera lack detailed diagnoses. The biostratigraphy of the lower and early middle Volgian part of the succession, the Bolonian Stage of Cope[62], was described by Cope[63,64] (this unit is also considered as a part of the Volgian Stage, see recent paper by Zeiss[20] for example). The current zonation of the higher part of the succession is that proposed by Wimbledon and Cope[65] and Wimbledon[66]. The youngest beds were assigned to the upper Volgian by Casey[67] based on correlations with middle and upper Volgian successions proved in eastern England.

The correlation of the eastern England zonal scheme (see below) with the succession in the isolated Portland Formation basin remains controversial. Casey[67] recorded *Paracraspedites oppressus* in the highest part of the Portland Stone (the Shrimp Bed), and *Paracraspedites* was mentioned from the basal portion of Spilsbi Sandstone, but Wimbledon and Cope[65] disagreed on his identification of latter records. In a response to Wimbledon's suggestion that the Spilsby Sandstone fauna was a mixture derived from two or three Portlandian zones, Casey and Mesezhnikov[14] reiterated Casey's[67] original conclusion that the *Paracraspedites* assemblages in the Spilsby Sandstone were indigenous and that they occurred with phosphatized moulds of *Kerberites* that had been derived from an earlier 'Portlandian' zone.

Ammonite succession of the middle-upper Volgian (sensu Casey[67]) of the eastern England includes important taxa providing correlation with other Boreal areas. Upper Volgian is mainly dominated by *Subcraspedites* with rare addition of *Craspedites*, and virtually the same ammonite assemblages were also recently recognized through the North Sea[68].

2 Ammonite-based Panboreal correlation of the Volgian Stage (by Mikhaiul Rogov)

Although remarkable ammonite provincialism leads to existence of different zonal successions proposed for the Volgian Stage, there are numerous ammonite marker beds (numbers 1—15 in Table 1) that can be traced over large areas and can be used for precise correlation throughout the Panboreal Superrealm. The more important of these are as follows.

(1) The basal part of the Volgian succession of the Subpolar Urals is characterized by the co-occurrence of *Eosphinctoceras magnum* Mesezhn. with early *Pectinatites* (*P.* cf. *damoni* Cope, *P.* cf. *elegans* Cope, etc), indicating the coinciding of the base of the Volgian and Bolonian stages. Mesezhnikov proved lower Volgian age of the *E. magnum* Zone by *Gravesia* records and ab-

Table 1 Panboreal ammonite-based correlation of the Volgian Stage

Russian Platform[11,15,16,17,28,30]				Northern Siberia[2,42,48]	Subpolar Urals[2,34]	Spitsbergen[35,36]	East Greenland[53,55]		England, N.France, North Sea[63,64,66,67,68]	
SUB-STAGE	Zone	Subzone	*Biohorizon*	Zone, Subzone	Zone, Subzone	Zone	Zone, Subzone	"Fauna"	Zone, Subzone	STAGE
UPPER VOLGIAN		*Volgidiscus singularis* Beds	15	15 *Chetaites chetae*	15 *Chetaites chetae*		*Chetaites chetae* Beds 15		15 *Volgidiscus lamplughi*	PORTLANDIAN
	C. Nodiger	*Craspedites milkovensis*	14	14 *Craspedites taimyrensis*	14 *Craspedites taimyrensis*	14 *Craspedites taimyrensis*	14 ? *Subcraspedites sowerbyi* Beds		14	
		Craspedites mosquensis								
	C. Subditus	*Craspedites subditus*	13	*Craspedites okensis*: *Craspedites originalis*	*Craspedites subditus*	*Craspedites okensis*			13 *Subcraspedites preplicomphalus*	
	K. Fulgens	*Craspedites nekrassovi*		*Craspedites okensis*: *Craspedites okensis*						
		Kachpurites fulgens	12	12	12 *Kachpurites fulgens*					
MIDDLE VOLGIAN	*E. Nikitini*	*Epivirgatites nikitini*	*Laugeites* sp. nov. 2; *Laugeites* sp. nov. 1; *Kachpurites* sp.A; *Nikitini*	11 *Praechetaites exoticus*	?	11 *Praechetaites exoticus*	*Praechetaites temucostatus* Beds		11 *Subcraspedites primitivus*	
		E. lahuseni	10 *Lahuseni*	10 *Epivirgatites variabilis*	10 *Epilaugeites vogulicus*	*Laugeites groenlandicus*	10 *Epilaugeites vogulicus*		10 *?Paracraspedites oppressus*; *Titanites anguiformis*	
		E. bipliciformis	*Bipliciformis*	9	9 *Laugeites groenlandicus*	9	9 *Laugeites groenlandicus*	47 *L.groenlandicus*	*Kerberites kerberus*	
	V. Virgatus	*?Crasp.ivanovi*		*Taimyrosphinctes excentricus*	*Crendonites* spp. 8	*Crendonites* spp. 8	*Crendonites anguinus* 8	46 *C.anguinus* 8; 45 *P.*aff.*subgorei*	8 *Galbanites okusensis*	
		V.virgatus		*Dorsoplanites maximus*	7 *Dorsoplanites maximus*	*Dorsoplanites maximus*	7 *Epipallasiceras pseudapertum*	44 *D.intermissus*; 43 *P.groenlandica*; 42 *E.pseudapertum*; 41 *E.acutifurcatum*	7 *Glaucolithites glaucolithus*	
		Virgatites gerassimovi							7 *Progalbanites albani*	
	Panderi	*Zaraiskites zarajskensis*	*Zarajskensis*; *Regularis*	6 *Dorsoplanites ilovaiskii*	*Dorsoplanites ilovaiskii*	6 *Dorsoplanites ilovaiskii*	*Dorsoplanites gracilis*	6 38–40	*Virgatopavlovia fittoni*	BOLONIAN
		Zaraiskites scythicus	*Scythicus*; *Quenstedti* 5	*Pavlovia iatriensis* 5	*Pavlovia iatriensis*: *S.strajewskii*; *P.iatriensis*	*Pavlovia rugosa* 5	*Dorsoplanites liostracus*; *Pavlovia communis*; *Pavlovia rugosa*; *Pavlovia iatriensis*; *Dorsoplanites primus* 5	36-37 *D.liostracus*, *D.gracilis*; 34-35 *P.varioc.*,*P.communis*; 33 *P.rugosa*; 32 *P.iatriensis*; 31 *D.primus*	*Pavlovia rotunda*; 5 *Pavlovia pallasioides*	
LOWER VOLGIAN	*I. pseudosc*	*'P.' tenuicostatum*	*Puschi*	"*Pectinatites pectinatus*"	"*Pectinatites pectinatus*"	Beds with *Pectinatites*	*Pectinatites pectinatus*	30 *Paravirgatites* sp. B; 29 *Paravirgatites* sp. A; 28 *P.eastlecottensis*; 27 *P.groenlandicus* 4	*Pectinatites pectinatus* 4	
		I. pseudoscythica	*Neoburgense*; *'Franconites'*	4 *Sphinctoceras subcrassum*	4 *Sphinctoceras subcrassum*		*Pect.hudlestoni*	26 *P.* cf. *abbreviatus*	*Pect.hudlestoni*	
	Ilowaiskya sokolovi		*Pavida* 3; *Sokolovi*		3		*Pectinatites wheatleyensis* 3	25 *Sphinctoceras* sp.	*Pectinatites wheatleyensis* 3	
	Ilowaiskya klimovi		*Efimovi* 2; *Steraspis*	*Eosphinctoceras magnum* 1	2 *Eosphinctoceras magnum* 1		*Pectinatites elegans*	24 *P. elegans* 1	*Pectinatites scitulus*; *Pectinatites elegans* 1	

sence of the Kimmeridgian *Aulacostephanus* (at this time Kimmeridgian records of *Gravesia* were poorly known). Re-interpretation of some *Gravesia*, figured by Zakharov & Mesezhnikov[33] and by Hantzpergue[69] and Schweigert[70], which was referred to Kimmeridgian species, along with the ammonites close to *Eosphinctoceras magnum* in the upper Kimmeridgian of Germany led Schweigert[70] to conclusion concerning Kimmeridgian age of the *E. magnum* Zone. However, this *Gravesia* was recorded in the isolated site without other ammonites and cannot be used for age determination of the *E. magnum* Zone[32], while German *Eosphinctoceras* (fig.8)[70] strictly differs from *E. magnum* by its bifurcate ribbing and should belong to other genus. Recently, *Pectinatites* species typically from lowermost part of Bolonian was also found in Northern Siberia (*P. major* Cope). Uncommon but badly preserved *Eosphinctoceras* also was recorded from the *I. klimovi* Zone of the Gorodischi section.

(2) Recently, small-sized *Sphinctoceras*, very close to microconchs figured in Zakharov & Mesezhnikov[33], was recorded from the Sokolovi (*I. pavida* horizon) and uppermost *I. klimovi* Zones of Gorodischi section[10,71]. These records can serve to indicate at least partial range of the *S* (*S.*) *subcrassum* Zone in comparison with succession of the Russian Platform. *Sphinctoceras* and *Eosphinctoceras* records from England mainly were derived from nodules of the *P. wheatleyensis* Zone of Neaverson[72], which corresponds to the *P. scitulus*- *P. wheatleyensis* zones in Cope's scheme[63]. Joint records of *Eosphinctoceras* and *Sphinctoceras* are known from the lower part of the *S* (*S.*) *subcrassum* Zone[2], and its partial correlation with *P. wheatleyensis* Zone also suggested by *Eosphinctoceras* records in East Greenland[53].

(3) A record of *Pectinatites groenlandicus* Spath (pl. 2, fig. 3)[73] from the *S* (*S.*) *subcrassum* Zone of the Subpolar Urals leads to the conclusion that this zone is partially overlapped with basal portion of the *P. pectinatus* Zone of England and East Greenland.

(4) The base of the middle Volgian is marked throughout in Panboreal Superrealm by mass occurrence of small-sized *Pavlovia*.

(5) The *D. ilovaiskii* Zone of Svalbard and the Subpolar Urals share many common species (*Dorsoplanites gracilis* Spath, *D. antiquus* Spath, *Dorsoplanites crassus* Spath) with the Gracilis Zone of East Greenland.

(6) Correlation of the *D. maximus* and *E. pseudapertum* zones supported by joint records by *Epipallasiceras costatum* Spath with *Dorsoplanites maximus* Spath in the Eastern Taymyr[2] and presence of *D. maximus* Spath in the fauna 42 of East Greenland[55]. Correlation of these zones with *Albani* and *Glaucolithus* zones of southern England is supported by records of *Epipallasiceras* in the *Albani* Zone and by presence of *Glaucolithites* in the *D. maximus* Zone of Svalbard and East Greenland. These are at variance with records of "*Epivirgatites*" in the *Albani* Zone and with the proposed correlation of the *Albani* and *E. nikitini* Zones, suggested by English authors[64,66,74−76]. This correlation was first proposed by Casey[77], but he subsequently rejected it[25]. Cope[64,74] identified the English specimens by the presence of a "unique rib style of this genus, having constrictions preceded by a four-branched rib"[74]. However, this type of four-branched rib is different in the English examples (triplicate and a simple rib) and the Russian examples (mostly a bidichotomous rib)[17]. Moreover, this kind of ribbing is very rare in true *Epivirgatites*. In *E. nikitini* (Mich.) constrictions are usually bounded by bifurcate or trifurcate ribs. This feature is clearly indicated in diagnosis of *E. nikitini* species by Mitta (see also his illustrations)[15], who drew attention to constrictions of this species, bounded by simple and triplicate ribs. This feature also entirely absent in the earliest species of *Epivirgatites*, i.e., *E. bipliciformis* (Nik.) and *E. lahuseni* (Nik.). Moreover, the type of ribbing ascribing to *E. nikitini* by Cope is not unique. Four-branched ribs adjacent to constrictions are normal in other dorsoplanitids, such as *Dorsoplanites* (pl. 29, fig.2)[43] and *Epipallasiceras* (pl. 4, fig. 1)[55]. Thus, the "*Epivirgatites*" from the *Albani* Zone is probably a homoeomorph of true *Epivirgatites*[4,17]. The English examples may belong to *Epipallasiceras* or related genera. This misidentification contributed to the widely held belief among non-Russian authors that the condensed Volgian succession at Gorodischi contains major breaks in the ammonite succession. Detailed studies of the ammonite and buchiid faunas have shown that there are more or less gradual transitions between successive assemblages and that the only abrupt change in the Volgian succession is that at the junction with the overlying Ryazanian Stage. The same succession of faunal horizons within the most disputed part of the succession, the *E. nikitini* Zone, is present in different facies and tectonic settings throughout the Russian Platform[17]. In addition to the evidence presented here, we have recog-

nized at least four faunal horizons (*E. bipliciformis*, *E. lahuseni*, *Kachpurites* sp.

A and *Laugeites* sp.1, respectively) that can be traced from the middle Volga area to the Moscow region.

(7) The occurrence of *Crendonites* (Figure 5-1—3) provides correlation of the *Portlandian okusensis* Zone with the *C. anguinus* Zone of Greenland and *Crendonites* zone of Subpolar Urals, Svalbard and Franz-Josef Land. Among the Arctic species of *Crendonites*, those from Greenland are most close to typical English *Crendonites*. Ammonites from other areas are characterized by smaller size and absence of remarkable uncoiling in the inner whorls, perhaps representing separate lineage. Alternatively, such small *Crendonites* may indicate correlative of the lower part of *P. okusensis* Zone, because in England and France small *Crendonites* are typical for this level[66].

(8) The appearance of *Laugeites* is well traced throughout in Arctic at the base of *L. groenlandicus* or *E. variabilis* zones. In the Russian Platform, the earliest *Laugeites* perhaps co-occurs with *Epivirgatites lahuseni* in Yaroslavl and Moscow regions, whereas in the middle Volga area, this genus appears later. Giant Portlandian-like ammonites (called *Titanites* by Sasonova and Sasonov[78]), typical for *E. bipliciformis* and *E. lahuseni* horizons (and sometimes also occurred at the lower part of the *E. nikitini* Subzone), cannot be used for correlation due to limited data about English Portlandian giants, which are mainly known only from Buckman's figures[61].

(9) Records of *Epilaugeites*, which are restricted to the *E. vogulicus* Zone of the Subpolar Urals, are known from the same level in East Greenland and from the *E. lahuseni* horizon of the Russian Platform. The precise range of *Epilaugeites* recorded in England is not known. Casey et al.[25] ascribed it to *P. oppressus* Zone, but Wimbledon[66] suggested that it came from the *P. okusensis* Zone. Data from the Russian Platform (see below) supports the conclusion of Casey et al.[25]. The *E. lahuseni* horizon is also characterized by *Taimyrosphintes*, which is known from the *E. vogulicus* Zone of Subpolar Urals, indicating rapid westwards immigration of these ammonites from Northern Siberia. The co-occurrence of *Epivirgatites variabilis* Shulg. with *Epilaugeites* at the same horizon of the Russian Platform and also in the Northern Siberia[45] suggests at least partial overlapping of *E. variabilis* and *E. vogulicus* zones. "*Paracraspedites*", typical of the *E. lahuseni* horizon, is similar to those from England, but it also resembles *Taimyrosphinctes* and needs further investigation.

(10) *Laugeites* sp. nov. 1 horizon of the Russian Platform succession is characterized by an interesting ammonite assemblage that includes *Epivirgatites nikitini* (Mich.), *Laugeites* sp. nov. 1 (=*Laugeites* aff. *parvus*, pl. I, fig. 8)[42], *Kachpurites* sp. B, and *Subcraspedites* spp. The same species of *Laugeites* was recently obtained from the *P. exoticus* Zone of Northern Siberia[45], which is well traced through the Arctic by occurrence of numerous *Praechetaites.* In the Gorodischi section, this level is also characterized by *Subcraspedites* spp. (including *S. sowerbyi* Spath and *Subcraspedites* cf. *preplicomphalus* Swinn, indicating *Preplicomphalus* Zone[16,17]. Co-occurrence of *Laugeites* and *Subcraspedites* within *Laugeites* beds of Kuhn Island[52] also well corresponds to such correlation.

(11) The base of the upper Volgian is marked by the rapid spread of *Craspedites okensis* (d'Orb.) throughout the Arctic. Baraboshkin[79] suggested quick westwards immigration of this species from Northern Siberia. In the Russian Platform, this species appeared at the base of the Fulgens Zone.

(12) The occurrence of *Subcraspedites* in the *C. subditus* Zone of the Russian Platform and records of *Craspedites* from the *C. subditus* group in England indicate a possible connection between these basins.

(13) The latest *Craspedites* of the *nodiger* group characterized by remarkable nodes near to umbilical seam is known also from England (*C. plicomphalus* (Sow.). Occurrence of *C. pseudonodiger* Schulg. in the middle part of the *C. nodiger* Zone in Kashpir provides additional support for the correlation of the *C. taimyrensis* Zone with the *C. nodiger* Zone and indicates the upper limit of the *Preplicomphalus* Zone. Following recent magnetostratigraphical data[80], the Jurassic/Cretaceous boundary determined by calpionellids (i.e., the base of the B zone) coincides with level within the *C. taimyrensis* Zone.

(14) The uppermost Volgian, characterized by *Volgidiscus* and *Chetaites chetae* Schulg., can be traced throughout the Panboreal Superrealm. Both are known from the Russian Platform and Subpolar Urals, and perhaps from Northern Siberia. *Volgidiscus* is only characteristic of the terminal Jurassic in England and the North Sea, and *Chetaites chetae* Schulg has been recorded from East Greenland.

Overlying Ryazanian usually lies on the Volgian de-

posits with sedimentary break, but some continuous succession with gradually changed ammonite faunas and known from Subpolar Urals (with *Schulginites* and *Chetaites* characterizing both uppermost Volgian and basal Ryazanian) and Northern Siberia (with succession of *Chetaites* species). Base of the Ryazanian is well traced throughout in Arctic by appearance of *Praetollia.*

3 Buchiazones and their Panboreal correlation (by Victor Zakharov)

3.1 Introduction

Biostratigraphical units based upon the succession of genera and species belonging to the family Buchiidae and especially on the lineage of *Buchia* (co-called buchiazones) are recognized through the Upper Jurassic to lowest Cretaceous Boreal deposits. Such zones represent an effective tool for Panboreal correlation for at least seven stages (from Oxfordian to lower part of the Hauterivian). Buchiazones are especially important for subdivision and correlation of the Boreal Volgian Stage (Table 2) because over large areas of North-East Asia and the Pacific coast of the North America, Volgian ammonites are extremely rare and age determinations are based on *Buchia* records. Complete buchiazones have been established for most of the continuous sections of northern part of the East Siberia[81].

3.2 Reliability of identification and strength of validity of lower boundaries of buchiazones

The Volgian Stage is divided into six zones and subzones based on *Buchia*: *B. mosquensis*, *B. rugosa* (lower Volgian Substage) *B. russiensis*, *B. taimyrensis* (middle Volgian Substage) *B. obliqua*, *B. unschensis* (pars) (upper Volgian Substage). Analysis of mass occurrences of these bivalves, which permits recognition of intrapopulational and interpopulational variability, enables species of the genus *Buchia* to be made with complete reliability. Buchiazones are mostly defined by the occurrences of a few species, among which the index-species is stratigraphically most important. It has smaller range (i.e., a narrow biozone) and a wide geographical distribution that is independent of facies. The lower boundaries of buchiazones are established by two main criteria: the FAD of the index-species (=phylozones), as in the case of the *B. russiensis*, *B. taimyrensis*, *B. obliqua*, *B. unschensis* zones, or by an abundance of specimens (=acmezones), such as in the *B. mosquensis* and *B. rugosa* zones. The lower boundary of each zone coincides with the top of the underlying zone. The phyletic type of Buchiazones mostly has a sharp boundary, but the boundaries of acme-zones, which are more subjective, are commonly "diffuse". For this reason, the lower boundary of the Volgian Stage, as determined in terms of buchiazones, cannot be considered as isochronous throughout the Boreal Realm. Uncertainty related to the base of *B. mosquensis* Zone arises partly because of the absence of continuous sections in north of Eastern Siberia, and partly because the lowermost part of the Volgian there coincides with non-sequence in the ammonite succession. The upper boundary of the Volgian Stage cannot be recognized on the basis of buchiids alone because the youngest Volgian *B. unschensis* buchiazone spans the Volgian-Ryanzanian boundary. This zone is characterized by the occurrence of typical Upper Volgian buchiids, such as *Buchia terebratuloides* (Lahusen), *B. fischeriana* (d'Orb.), *B. piochii* (Gabb), that cross the J/K boundary but become less numerous in the Cretaceous of the Russian Platform and north of East Siberia. The lower boundaries of the middle and upper Volgian substages are most reliably fixed by buchiids. At the lower boundary of the Iatriensis ammonite zone, *B. russiensis* (Pavlow) appeared, which is easily distinguished from accompanying species *B. mosquensis* (Buch) and *B. rugosa* (Fisher) by morphology and kind of ontogeny. At the base of the upper Volgian Substage, i.e., of the Okensis Zone, buchiid species with inversoid kind of ontogeny of the right valve appeared for the first time, such as *B. terebratuloides* (Lahusen) and *B. obliqua* (Tullberg).

3.3 Correlative potential of buchiazones

The biostratigraphical core of the Volgian Stage is represented by Boreal taxa, and a detailed chronostratigraphical framework of this stage based on ammonite zonation. Buchiids permit the recognition of all three substages of the Volgian. The lower Volgian is characterized by two species with curvoid ontogeny: *B. mosquensis* (Buch) and *B. rugosa* (Fisher). The middle Volgian can be reliably traced by records of *B. russiensis* (Pavlow), *B. fischeriana* (d'Orb.), *B. taimyrensis* Zakharov, *B. elderensis* (Anderson), *B. colombiana* Grey, Haggart et Smith, characterized by mainly orthoid ontogeny of the right valve and curvoid ontogeny of the left one. The upper Volgian Substage is characterized by the occurrence of species with inversoid ontogeny of the right valve and orthoid ontogeny of left valve, typical for species *B. terebratuloides* (Lahusen) and *B. obliqua*

Table 2 Panboreal correlation of the Volgian Stage by Buchiids

Northern Siberia ammonite succession			Regions and Buchiazones									
SUB-STAGE	Zone, Subzone		Northern Siberia[81]		East Greenland[82]	Spitsbergen, Franz Josef Land[35],corrected		Petshora River basin[81]	Arctic Canada[60]	Western British Columbia[60,83]	Northern California[60], corrected	NE Asia[84], corrected	Russian Far East[85], N.China[86–89], corrected
UPPER VOLGIAN	*Chetaites chetae*		*B. unschensis* (pars)		*B. unschensis-terebratuloides* (pars)	*B. fischeriana*	*B. unschensis* (pars)	*B. unschensis* (pars)	*B. unschensis* (pars)	*B.* aff. *okensis* (pars)	*B. terebratuloides*	*B. unschensis* (pars)	*B. unschensis* *B. piochii* (pars)
	Craspedites taimyrensis											*B. terebratuloides* *B. tenuicollis*	
	Craspedites okensis	*Craspedites originalis*	*B. obliqua*		*B. fischeriana*		*B. obliqua*	*B. obliqua*	*B. fischeriana*	?	*B. fischeriana*		*B. piochii* *B. terebratuloides*
		Craspedites okensis											
MIDDLE VOLGIAN	*Praechetaites exoticus*		*B. mosquensis*	?	?								*B. fischeriana* *B. russiensis*
	Epivirgatites variabilis			*B. taimyrensis*	*B. russiensis*			*B. taimyrensis*		*B. colombiana*		*B. fischeriana* *B. piochii*	
	Taimyrosphinctes excentricus								*B. piochii*		*B. elderensis*		
	Dorsoplanites maximus			*B. russiensis*	*B. mosquensis*	*B. russiensis*		*B. russiensis*		*B. russiensis*			*B. russiensis* *B. mosquensis*
	Dorsoplanites ilovaiskii												
	Pavlovia iatriensis												
LOWER VOLGIAN	"*Pectinatites pectinatus*"			*B. rugosa*		*B. rugosa* *B. mosquensis*		*B. mosquensis*	*B. mosquensis*	*B. mosquensis*	?	*B. mosquensis* *B. mosquensis* spp. *B. piochii*	*B. mosquensis* *B. rugosa*
	Sphinctoceras subcrassum												
	Eosphinctoceras magnum			*B. mosquensis*									

(Tullberg), by species *B. unschensis* (Pavlow) (with orthoid ontogeny) and by widely ranged *B. fischeriana* (d'Orb.). Despite circum-Boreal distribution of the bulk of the index-species of the buchiazones (Table 2, see also Zakharov[81,90]), in some areas they are either substituted by vicarious species or occur at a different stratigraphical level. In the second case, the quantity of records of these taxa plays a significant role in the decision made by the specialist: abundant accumulations or high frequency of records at some stratigraphical levels. For example, abundant *B. unschensis* (Pavlow) occurs in practically all facies of the upper Volgian and Ryazanian at the north of East Siberia, Petshora region and Arctic Canada. However, in the Russian Platform, this species is significantly less common compared to *B. terebratuloides* (Lahusen) in the upper Volgian and became extremely rare in the base of the Ryazanian[91]. This species was never found in Subpolar Urals. Conversely, *B. fischeriana* (d'Orb.) is numerous in the middle Volgian-Ryazanian deposits of the Russian Platform but relatively rare in Northern Siberia. Upper part of the middle Volgian Substage of north of Siberia is characterized by *B. taimyrensis* Zakharov, whereas in British Columbia, *B. colombiana* Grey, Haggart et Smith apparently is typical for the same level[83]. However, southwards both these species are absent. Zonal scale based on buchiids works most effectively when succession of buchiazones but not separate biostratigraphical units are compared.

4 Conclusion and tasks for further studies of the Volgian Stage

The ammonite and buchiid successions provide well-correlated frameworks for the Volgian Stage within all areas of its development. Nevertheless, at some levels, different correlation charts have been proposed. Recent progress in the infrazonal ammonite biostratigraphy of the Volgian Stage has permitted an increase in the detailed subdivision and precision of correlation in areas such as the Russian Platform and East Greenland. However, there are still large regions that lack detailed schemes, and there are still no faunal horizons recognized within the upper Volgian Substage. An additional problem when making correlations in the Volgian based on ammonites is the presence of numerous homeomorphic taxa that cannot be reliably separated without further research on their ontogeny and the paleogeographical aspects of their distribution.

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