

# The Upper Volgian Substage in Northeast Siberia (Nordvik Peninsula) and Its Panboreal Correlation Based on Ammonites

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**Abstract**—Section of the middle and upper Volgian substages and basal Boreal Berriasian in the Cape Urdyuk-Khaya (Nordvik Peninsula) is largely composed of dark argillites substantially enriched in C org. Characteristic of the section is a continuous succession of ammonite, foraminiferal, ostracode, and dinocyst zones known also in the other Arctic areas. Boundaries of the upper Volgian Substage are recognizable only based on biostratigraphic criteria. The succession of the middle Volgian *Taimyrosphinctes excentricus* to basal Ryazanian *Hectoceras kochi* zones is characterized. The range of the substage is revised. Based on finds of, The lower *Exoticus* Zone, where ammonites characteristic of the *Nikitini* Zone upper part in the East European platform have been found, is referred to the middle Volgian Substage. Newly found ammonites are figured. Two possible positions of the Jurassic–Cretaceous boundary in the Arctic region, i.e., at the lower and upper boundaries of the *Chetae* Zone at the top of the upper Volgian Substage, are discussed.

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**Key words:** Volgian Stage, upper Volgian Substage, ammonites, biostratigraphy, Jurassic–Cretaceous boundary, northern Siberia, Panboreal correlation.

## INTRODUCTION

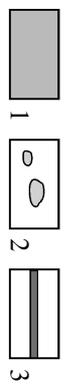
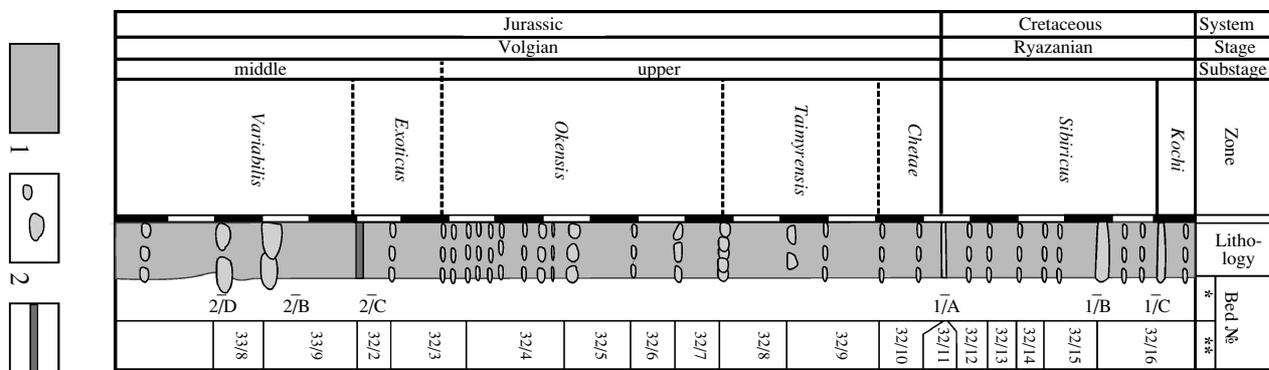
It would be no overstatement to say that future positioning of the Jurassic–Cretaceous boundary in Boreal sections depends on stratigraphic “fortune” of the upper Volgian Substage. It was exactly this unit proposed by Casey (1963) to be transferred from the Jurassic to the Cretaceous System. In his opinion, such a “shift” should solve the problem of Boreal–Tethyan correlation between the Tithonian and Volgian stages. This idea first gained no support of specialists. It appeared to be attractive nevertheless, and soon Kutek and Zeiss (1975) backed this proposal based on co-occurrence of Boreal and Subtethyan ammonites in the lower–middle Volgian boundary beds of Poland. During many years, Zeiss (1979, 2003) agitated for placing the lower boundary of the Cretaceous System at the base of the upper Volgian Substage (base of the *Kachpurites fulgens* Zone) in the Boreal realm instead of the Ryazanian Stage base. In Russia, the idea of Volgian Stage subdivision into the Jurassic and Cretaceous parts was supported first by Sazonova and Sazonov (1979a, 1979b), then by Sei and Kalacheva (1993), and recently by Baraboshkin (2004).

Over 10 years ago, the Interdepartmental Stratigraphic Committee of the Russian Federation decided to subdivide the Volgian Stage in two parts and attribute the upper Volgian Substage to the Cretaceous (Rostovtsev and Prozorovsky, 1997; Zhamoida and Prozo-

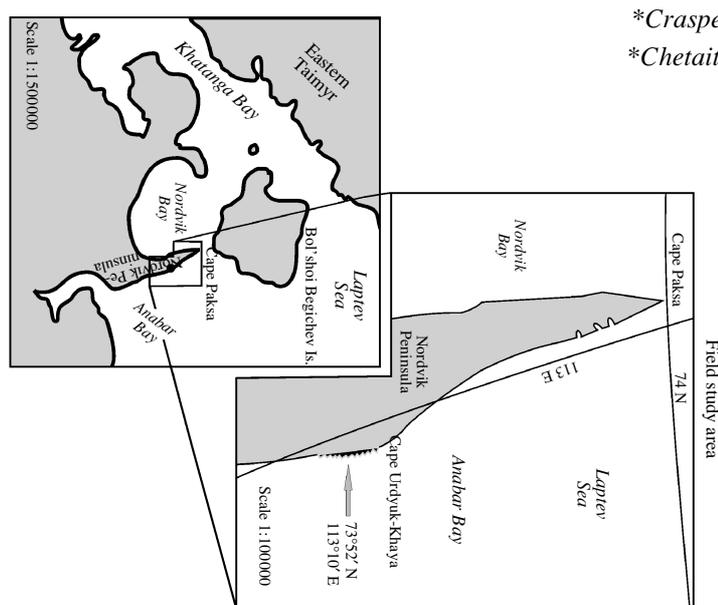
rovskaya, 1997). We challenged validity of this action (Zakharov, 2003; Zakharov and Rogov, 2005), because it was insufficiently substantiated and taken prior to the GSSP establishment for the Berriasian base by the International Commission on Stratigraphy.

In collaboration with Czech geophysicists and paleontologists, we studied magnetostratigraphy of the section at the Cape Urdyuk-Khaya (Nordvik Peninsula, Anabar Bay, Laptev Sea, Fig. 1), one of the most complete Jurassic–Cretaceous boundary sections in the Arctic region. Based on results of this study we propose a new, better substantiated version of correlation of the upper Volgian Substage and the Boreal Berriasian base Stage with upper Tithonian and basal Berriasian chronozones of southeastern Spain (Cordoba Province), central Italy (Umbria Province), and Slovakia (West Carpathians). The data obtained indicate that the base of the lower Berriasian *Jacobi* Zone in southeastern Spain corresponds to the level inside the *Taimyrensis* Zone of the upper Volgian Substage in the Arctic region (Houša et al., 2007).

In addition to paleomagnetic samples, we also collected molluscan remains (primarily, ammonites). Ammonites confirm zonal biostratigraphy of the upper Volgian Substage suggested previously, enhance faunal characteristic of the section, and refine the substage scope (Zakharov and Rogov, 2005).



- *Taimyrosphinctes* ?sp.
- *Epivirgatites variabilis*
- *Epilaugeites vogulicus*
- *Laugeites* sp. juv.
- *Laugeites* sp. nov. aff. *parvus* (=L. *parvus* in Kiselev&Rogov, 2005)
- *Praechetaites exoticus*
- *Praechetaires* cf. *bicostatus* [M]
- *Laugeites* sp.
- *?Praechetaites* sp.
- "Lytoceras" sp.
- *Pseudophylloceras* cf. *knoxvillense*
- *Craspedites okensis*
- *?Laugeites* sp. (=Jeletzky, 1965, pl. VIII, f. 7)
- \**Craspedites canadensis*●
- \**Chetaites* sp. (cf. *chetae*) ●●
- Praetollia despar* ●
- \**Praetollia maynci* ●●
- Chetaites* sp. nov. [M] ●
- Chetaites sibiricus* ●●●
- Craspedites* cf. *canadensis*●
- Praetollia contigua* ●●●
- Craspedites* sp. ind ●
- Chetaites* cf. *sibiricus* ●
- Hectoroceras kochi* ●●●
- Boreiophylloceras* sp. ●
- Bochianites* cf. *glennensis* ●
- "Lytoceras" sp. ●
- Praesurites* sp. juv. ●



## THE UPPER VOLGIAN SUBSTAGE IN THE ARCTIC REGION

Ammonites of the Boreal family Craspeditidae (*Kachpurites*, *Craspedites*, *Subcraspedites*, *Volgidiscus*, *Schulginites*, *Garniericeras*) are of key significance for biostratigraphy of the upper Volgian Substage in the Arctic region. Based on succession of Craspeditidae species, the upper Volgian Substage is subdivided into zones and subzones. The substage top only is defined in northern Siberia by occurrence of *Chetaites chetae*, a representative of the family Dorsoplanitidae, while Craspeditidae were widespread in the Arctic region up to the Hauterivian.

First Craspeditidae from the Arctic region (Subpolar Urals, Tol'ya River) were probably described by Eichwald (1865–1868) as *Ammonites sagitta*, *A. septentrionalis* (= *Craspedites* cf. *okensis*), and *A. catenulatus* (= *Shulginites* cf. *tolijensis*). At the end of the 19th century, E.S. Fedorov collected here additional samples with ammonites. S.N. Nikitin, who studied his collection of Mesozoic fossils, identified among them *Oxynticeras* (= *Shulginites*) *tolijensis* and suggested the late Volgian age of this taxon (Nikitin, 1884). V.I. Bodylevskii, who defined the upper Volgian Substage in the Tol'ya River basin and established the *Fulgens* Zone in Novaya Zemlya and Subpolar Urals, was first to determine *Craspedites okensis* and *Kachpurites* from the latter region (Bodylevskii and Kiparisova, 1940).

In the early 1920s, *Craspedites* were found in Spitsbergen by Spath (1921), although examination of that ammonite collection stored at the Natural History Museum of London showed that his identification was erroneous. Subsequently, Spath himself (1924) considered the *Craspedites* forms he described as the Cretaceous (infra-Valanginian) ammonites. Later on, *Craspedites* from this area were described and figured by Frebold (1930) and Ershova (1969).

Bodylevskii (1936) was next to report on *Craspedites* from Novaya Zemlya. He described also the new genus *Taimyroceras* from the upper Volgian sediments of northern Siberia (Bodylevskii, 1956), although now it is considered as a subgenus of the genus *Craspedites*. Subsequently *Taimyroceras* was discovered in the Yenisei Depression (Bodylevskii and Shul'gina, 1958). First data on occurrence of this genus in the upper Volgian sediments of the Khatanga Depression and Nordvik Peninsula appeared at that time as well (Saks et al., 1959). Then a complete succession of biostratigraphic ammonite units of the upper Volgian was established in northern East Siberia (Saks et al., 1965; Basov et al., 1970; Zakharov et al., 1983;

Shul'gina, 1985; and others). Spath (1936) reported first on the upper Volgian Craspeditidae and *Subcraspedites* from eastern Greenland, and later on they were found here on the north (Peary Land, Håkansson et al., 1981). In the early 1960s, Craspeditidae were found in Arctic Canada (Jeletzky, 1965) and slightly later in northeastern Russia (Paraketsov, 1970). The upper Volgian *Craspedites* occur also beyond the Arctic region: they are frequently dominate among fossils in Boreal areas of Europe (East European platform, the North Sea, eastern England).

The upper Volgian Dorsoplanitidae are distributed mostly in Arctic regions. An exception is the genus *Chetaites* occurring also in the East European platform. This ammonoid group studied insufficiently is of prime importance for defining boundaries of the upper Volgian Substage.

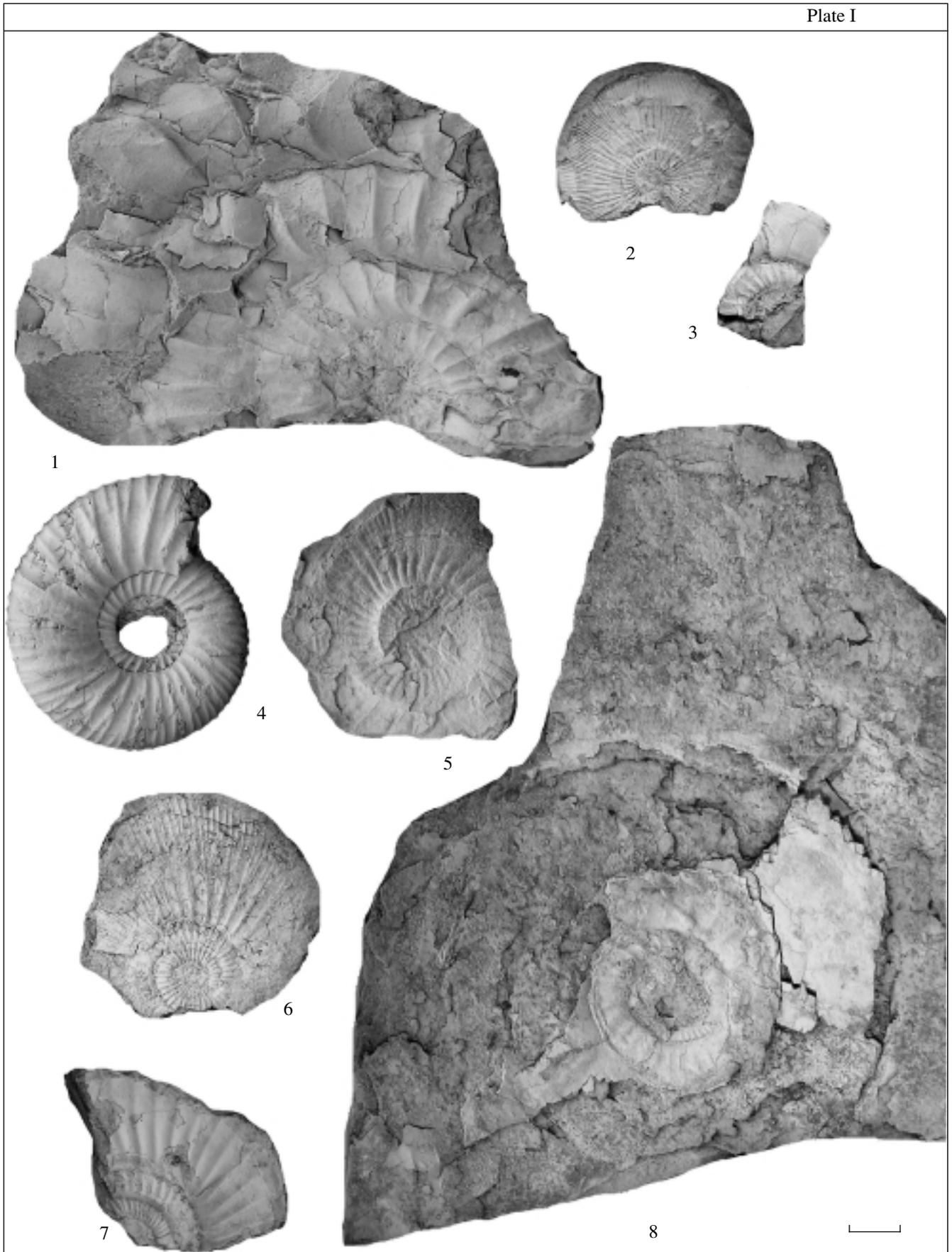
## THE VOLGIAN STAGE SCOPE ACCORDING TO NEW AMMONITES FOUND IN THE CAPE URDYUK-KHAYA (NORDVIK PENINSULA)

In the Nordvik Peninsula, the Volgian Stage is represented by part of the middle and complete upper Volgian substages. We found new evidence for occurrence of an equivalent of the middle Volgian *Taimyrosphinctes* (*Taimyrosphinctes*) *excentricus* Zone in this area and for correspondence of the *Praechetaites exoticus* Zone to the middle Volgian Substage.

In the Cape Urdyuk-Khaya, many fossils were found in talus and should be used for solving stratigraphic problems with a great caution. Nevertheless, ammonites found previously facilitate recognition of a complete succession of the upper middle Volgian to lower Valanginian zones (Zakharov et al., 1983; Bogomolov, 1989; and others). The fossils (largely, ammonites and belemnites) were sampled with the reference to particular marker beds (levels 1A–C, 2B–D in the section) and simultaneous correlation with previously defined beds (Zakharov et al., 1983).

The lower Volgian ammonites have not been found in the Nordvik section so far. All the middle Volgian forms of stratigraphic significance, except for rare specimens, were sampled from talus. Some of them suggest occurrence of sediments underlying the *Variabilis* Zone that was previously assumed based on occurrence of *?Dorsoplanites* sp. (Zakharov et al., 1983). We found also several small ammonites, which can be referred to *Taimyrosphinctes* (*Udschasphinctes*) sp. (Plate II, fig. 4) based on peculiar ornamentation (very frequent ribs slightly inclined anteriorly and

**Fig. 1.** The Jurassic–Cretaceous boundary section of the Nordvik Peninsula (Cape Urdyuk-Khaya), stratigraphy after Zakharov et al. (1983) and Zakharov and Rogov (2006); all the ammonites, except for designated by asterisk, are found by authors; marker horizons 1A–C and 2B–D (field observations by Rogov) and bed numbers after Zakharov et al. (1983) are designated in columns marked by one and two asterisks respectively: (1) dark gray argillite-like clay; (2) phosphate–carbonate concretions; (3) bed enriched in glauconite.



diverging in two or three branches less commonly) and shape of their shells (high-oval cross section of whorls with flattened ventral side, stepwise umbilicus, and abrupt uncoiling). An impression of such a form was found 0.3 m below Bed 2D. In distinction from all the known representatives of the genus (Mesezhnikov, 1972, 1984b), the found form exhibits a very early uncoiling and slightly rounded cross section. Although remains of *Taimyrosphinctes* occur in the Subpolar Urals up to the lower part of the *Vogulicus* Zone (Mesezhnikov, 1984b), in the northeastern Taimyr Peninsula they are known only from the *Maxumus* (rare) and *Excentricus* zones (Mesezhnikov, 1984b). *Epivirgatites variabilis* (Plate I, fig. 4; Plate II, fig. 5) occurs in association with species of the genus *Epilaugeites* characterizing higher layers of the middle Volgian Substage (Fig. 2, A–B). The species are close to *E. vogulicus* being different from it owing to more distinct constrictions only. Actual overlapping of stratigraphic ranges of *Epivirgatites variabilis*, *Laugeites*, and *Epilaugeites* is unknown so far. In the section under consideration, *Epilaugeites* appear higher than *Epivirgatites* (the only find at 0.2 m below level 2B). This is well consistent with correlation between *Vogulicus* and *Variabilis* zones suggested by Mesezhnikov.

Representatives of the genus *Laugeites* are rare among fossils from the Nordvik section. Some of them (small pyritized molds) were collected from talus along with *Epivirgatites* and *Epilaugeites*. By their peculiar ornamentation (changes in rib ratio and relative thickness of ribs in the ontogenesis, ornamentation preserved on the body chamber), these *Laugeites* forms (Plate II, fig. 3) are identical to *L. planus* described by Mesezhnikov from the Subpolar Urals (Zakharov and Mesezhnikov, 1974), where this species characterizes basal part of the *Groenlandicus* Zone. The *Laugeites* forms found stratigraphically above the last occurrence of *Epivirgatites* are quite different. All of them, except for a single pyritized mold (Plate II, fig. 6) and ammonite from a concretion, are represented by deformed impressions suitable only for examination of ornamentation details. It is also remarkable that *Laugeites* with early disappearing ornamentation (Plate I, figs. 3, 8) was found along with *Praechetaites*, which has in contrast the body chamber with distinct biplicate ribs (= *Virgatosphinctes bicostatus*, Zakharov et al., 1983, Plate II, fig. 1), in the *Exoticus* Zone (its position and correlation are discussed below). These *Praechetaites*

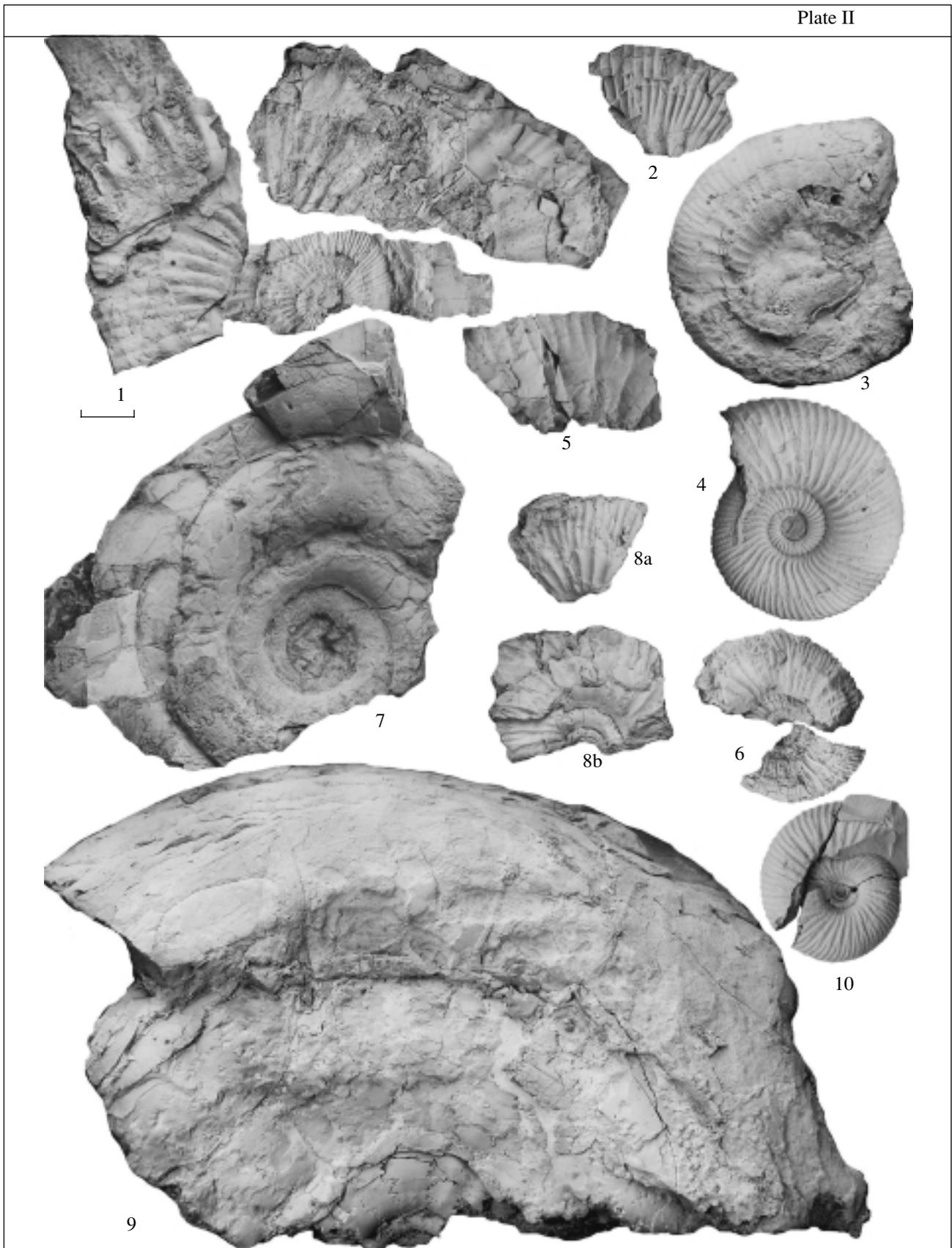
forms should probably be attributed to a new species since they are represented, in contrast to the type series of *P. bicostatus*, by macroconchs with substantially smoothed ornamentation on early whorls. *Laugeites* forms from the interval in question are similar to ammonites from the *Nikitini* Zone of the Gorodishchi section, where they co-occur with early *Kachpurites*. We identified these forms with *L. parvus* (Kiselev and Rogov, 2005). Their comparison with *L. parvus* from Greenland and Taimyr (Donvan, 1964; Mesezhnikov, 1984b) shows that, despite some features in common, ammonites from Taimyr and Middle Volga region are significantly larger in size and ribbing on their shells disappears earlier and rapidly. Moreover, it seems that two morphotypes have different stratigraphic positions, since some specimens from the *L. parvus* type series originate from the *Crendonites anguinus* Zone (Fauna 46b, Birkelund et al., 1984), while the others are from the *Groenlandicus* Zone, i.e., they are *a fortiori* older than ammonites of the *Vogulicus* Zone. A specimen of *Laugeites* found in talus shows even earlier disappearance of ornamentation (Plate II, fig. 7; Fig. 2, C). This specimen is similar to *Laugeites* sp. nov. known from uppermost layers of the *Nikitini* Zone of the East European platform (Kiselev and Rogov, 2005). Several small *Praechetaites exoticus* (Plate II, fig. 1) and *Praechetaites* cf. *exoticus* with more evolute coiling (Plate I, fig. 5) have been also found close to the designated level. Specimens of *P. tenuicosatus* (Shulg.) sampled from the talus (Plate I, figs. 2, 6) are most likely confined to a close stratigraphic level.

Ammonite with unusually rough ribs (Plate I, fig. 1) found in a concretion from talus originates most likely from the *Exoticus* Zone or basal part of the *Okensis* Zone. In its ornamentation, this specimen certainly differs from *Epivirgatites*, *Epilaugeites*, *Laugeites*, and *Praechetaites* species. Having coarse, sharp, widely spaced ribs with a high bifurcation point, it resembles some *Lomonossovella* forms being most close to the genus *Glottoptychinites* from England (Buckman, 1909–1930, Plates CDIII, DCCXVII; *Subcraspedites* sp. in: Gerasimov, 1969, Plate XXX, fig. 3) that is characteristic of the middle–upper Volgian boundary beds (Casey, 1973; Kiselev and Rogov, 2005).

Basal part of the *Okensis* Zone yielded a small ammonite shell ornamented with ribs in lower part of lateral side only (Plate I, fig. 7). According to this feature, it resembles a form from uppermost part of the

**Plate I.** Volgian ammonites from the Nordvik Peninsula. All the specimens pictured in plates I and II are stored at the Vernadsky Geological Museum (Moscow), Collection no. 00. Hereinafter, scale bar is 1 cm.

(1) *Glottoptychinites?* sp., MK959, talus of Outcrop 33, middle Volgian Substage; (2, 6) *Praechetaites tenuicosatus* (Shulg.), talus of Outcrop 33, middle Volgian Substage, *Exoticus* Zone; (2) MK1033, (6) MK1032; (3) *Laugeites* cf. *parvus* Donovan, MK994, Outcrop 33, 2C↑155; middle Volgian Substage, *Exoticus* Zone; (4) *Epivirgatites variabilis* Shulg., middle Volgian Substage, *Variabilis* Zone, MK1028, talus of Outcrop 33; (5) *Praechetaites* cf. *exoticus* (Shulg.) [m]; middle Volgian Substage, ?*Exoticus* Zone; (3) MK1004, Outcrop 32, 1A↓990; (7) *Praechetaites* sp., MK1148, Outcrop 32, 1A↓947; middle Volgian Substage, *Exoticus* Zone; (8) *Laugeites* aff. *parvus* Donovan (= *parvus* in Kiselev and Rogov, 2005) [M], MK1081, Outcrop 33, 2C↑123; middle Volgian Substage, *Exoticus* Zone.



middle Volgian Substage of Canada, which was determined as *Laugeites* sp. (Jeletzky, 1965, p. 23, Plate VIII, fig. 7). On the other hand, the early disappearance of ribbing is characteristic also of some *Praechetaites* (Shul'gina, 1967, Plates I–III) and *Subcraspedites* species (Abbink et al., 2001, Figs. 4B, 4E). We identified this specimen as *Praechetaites* sp.

Many new ammonites have been found in lower part of the Ryazanian Stage lower part. We managed to prove occurrence of *Praetollia* at the stage base. Approximately 3 m higher in the section, we collected predominantly *Chetaites* and *Praetollia* species (Plate II, figs. 2, 8, 9). In the first genus, we distinguished two forms each likely belonging to new species. One of them is represented by a half of very large shell with widely spaced ribs (Plate II, fig. 9). According to this feature, this form sharply differs from ammonites of the *Chetaites sibiricus* type series that includes only microconchs with the largest shell diameter less than 8 cm (Shul'gina, 1962). In addition, we found small *Chetaites* forms near the *Sibiricus*–*Kochi* boundary, which are similar to ammonites described earlier from Bed 23 of the Exposure 33 (Zakharov et al., 1983, Plate IV, figs. 5–7) and differ from typical representatives of the *sibiricus* species owing to earlier appearance of tripartite ribs with splitting rib bunches (Plate II, fig. 8).

Despite the convincing evidence of last decades that *Craspedites* occur in basal layers of the Ryazanian Stage (Zakharov et al., 1983; Mesezhnikov, 1984a; Shul'gina, 1985), these ammonites were never described and figured. We found a well-preserved *Craspedites* specimen very similar to *C. canadiensis* Jeletzky (Fig. 3) and *Craspedites* sp. indet. approximately 1.5 m above the base of the *Sibiricus* Zone and almost 1.5 m higher in the section (Bed 1B), respectively.

An unusual ammonite assemblage and first *Hectoroceras* discovered in basal part of the *Kochi* Zone. Like the assemblage from the *Exoticus*–*Okensis* boundary layers, this one includes lycoceratids and phylloceratids (Rogov, 2004). In addition, a small ammonite resembling *Bochianites glennensis* Anderson from California is a component of this assemblage. This may be an indication of direct connections between the Arctic and Pacific oceans that was previously assumed for the Valanginian time (Saks et al., 1964). Another very important record is a small *Praesurites* found stratigraphically above the occurrence level of *Hectoroceras kochi* (Plate II, fig. 10). Until recently, it was thought that rep-

resentatives of this genus are characteristic of the concurrent *Sibiricus* (Subpolar Urals) and *Runctori* (England) zones (Casey et al., 1988). Mitta (2005) assumed the same age for *Praesurites* forms from the Ryazanian Stage of the East European platform too. Later on, he reported on co-occurrence of this and *Hectoroceras* genera (Mitta, 2007). Shul'gina (1985) mentioned *Surites nikitini* (= *Praesurites*) from the *Kochi* and *Analogus* zones of northern Siberia.

## ZONATION AND PANBOREAL CORRELATION

### VOLGIAN STAGE

#### *Middle Volgian Substage*

*Taimyrosphinctes excentricus* Zone (Mesezhnikov in Saks, 1976)

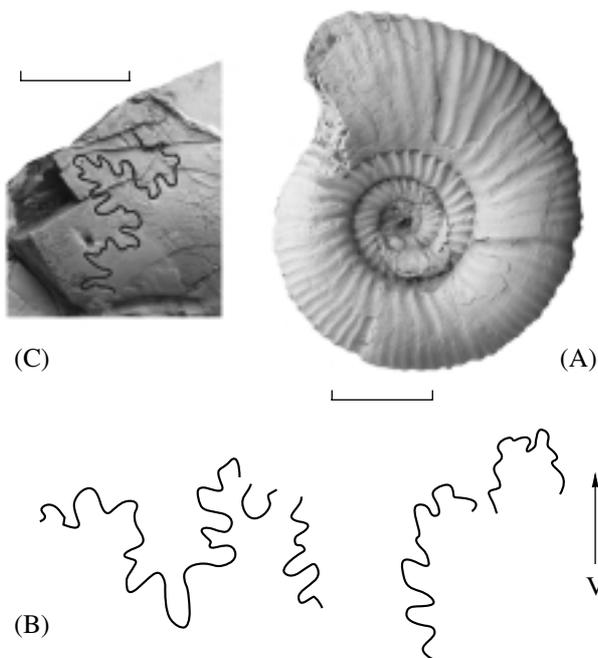
The zone, which is conditionally defined in the section of the Cape Urdyuk-Khaya based on finds of *Taimyrosphinctes (Udschasphinctes)* sp. and *Dorsoplanites* sp., likely corresponds to the upper part of Bed 7 in the Exposure 33 (Zakharov et al., 1983). Species characteristic of this zone occur also in underlying (*Dorsoplanites*) and overlying (*Taimyrosphinctes*, *Praechetaites*) strata. Thus, the zone lacking *Laugeites* and *Epivirgatites* forms is above the *Maximus* Zone, which is correlated with the *Pseudoapertum* Zone of Greenland based on occurrence of *D. maximus* and *D. gracilis* (Callomon and Birkelund, 1982).

*Epivirgatites variabilis* Zone (Saks et al., 1968)

The zone is reliably recognized based on index species found in beds 7–9, Exposure 33. Although the early *Laugeites* have not been found in these beds, it is admissible to think that specimens sampled from talus originate from lower part of the *Variabilis* Zone. In the East European platform, ammonites close to *E. variabilis* are known from the *Nikitini* s.l. Zone (Ivanov et al., 1987, p. 56, Plate 5, fig. 1; Kiselev et al., 2003, Plate 33, figs. 1, 5, 6). In the *lahuseni* faunal horizon of the Gorodishche section, "*Paracraspedites*" sp. Occur in association with ammonites resembling *E. variabilis* (Kiselev and Rogov, 2005). Judging from the fact that late *Laugeites* occur in the *Exoticus* Zone of the section under consideration, it is reasonable to assume that stratigraphic range of *E. variabilis* in the East European platform corresponds to upper part of this unit in Siberia. The *Variabilis* Zone top corresponds approximately to boundary between the *lahuseni* and *nikitini* faunal horizons in the stratotype.

#### Plate II. Volgian and Ryazanian ammonites from the Nordvik Peninsula.

(1) *Praechetaites exoticus* (Shulg.), MK1778, Outcrop 33, 2C↑135; middle Volgian Substage, *Exoticus* Zone; (2) *Praetollia contigua* Spath, MK1069, Outcrop 32, 1A↑200; Ryazanian Stage, *Sibiricus* Zone; (3) *Laugeites planus* Mes., MK1022, Outcrop 32, talus, middle Volgian Substage; (4) *Taimyrosphinctes (Udschasphinctes)* sp., MK1030, Outcrop 32, talus; (5) *Epivirgatites variabilis* Shulg., middle Volgian Substage, *Variabilis* Zone, MK 1114, 2B↓70; (6) *Laugeites* sp. juv., MK1093, Outcrop 33, 2C↑110; middle Volgian Substage, *Exoticus* Zone; (7) *Laugeites* sp. nov. (=cf. *parvus* in Kiselev and Rogov, 2005), Outcrop 32, talus; (8a, 8b) *Chetaites* cf. *sibiricus* Shulg., MK1146, Outcrop 32, 1C↓10, *Sibiricus* Zone; (9) *Chetaites* aff. *sibiricus* Shulg. [M], MK1009, Outcrop 32, 1A↑50; Ryazanian Stage, *Sibiricus* Zone; (10) *Praesurites* sp., MK1018, Outcrop 32, 1C↑30, *Kochi* Zone.



**Fig. 2.** Septal sutures of middle Volgian ammonites: (A, B) *Epilaugeites* cf. *vogulicus* (Ilov. in Mikh.), Exposure 32, talus, Specimen MK1031, (A) general view, (B) fragment of suture line, whorl height ~1.4 cm; (C) suture line of *Laugeites* sp. Nov. aff. *parvus* Donovan in Kiselev and Rogov, 2005 (specimen is figured in Plate II, fig. 7); scale bar 1 cm.

*Laugeites*, *Epilaugeites*, and *Epivirgatites* co-occurring in the studied section enable correlation of the *Variabilis* Zone with ammonite zonations of the Subpolar Urals and eastern Greenland. The *Variabilis* Zone necessarily includes equivalents of the *Groenlandicus* and *Vogulicus* zones of the Subpolar Urals, but the idea of Mesezhnikov (1984b) that top levels of the *Vogulicus* and *Variabilis* zones coincide according to “their positions in the section” is unrealistic (see below).

#### *Praechetaites exoticus* Zone (Shul’gina, 1967)

Shul’gina (1967) ranked the respective biostratigraphic interval as the *Virgatosphinctes exoticus* Beds of the *Okensis* Zone. The late Volgian age of the beds was initially suggested based on the found *Craspedites* sp. and “*Aucella* of the Volgian type” (Saks et al., 1959).<sup>1</sup> Somewhat later, Saks et al. (1963) noted more cautiously: “...these beds... may be attributed to either basal part of the upper Volgian or uppermost part of the lower Volgian.” Despite the fact that *Craspedites* were unknown from the “*Exoticus* Subzone,” the latter was attributed, though “with reservations,” to the upper Volgian Substage with remark that *Virgatosphinctes* occurring in the subzone are rare in the middle Volgian but

<sup>1</sup> These are species *Buchia tenuicolis* close to upper Volgian *B. piochi* and *B. fisheriana* first occurring in the *Maximus* Zone (Zakharov, 1981). Judging from lists of fauna, they were identified as the upper Volgian *B. terebratuloides* and *B. lahusei* (Saks and Sanin, 1976).

fairly abundant in the upper Volgian sediments (Saks et al., 1968). Later on, it was doubted that Siberian ammonites belong to the genus *Virgatosphinctes*, and representatives of the “*exoticus* group” were attributed to a new genus *Praechetaites* (Sasonova and Sasonov, 1979a). Nevertheless, species of this genus (except for the type species *P. exoticus*) have not been listed and systematics of Siberian “*Berriasella*” and “*Aulacosphinctes*” has not been discussed.

Stratigraphic rank of the unit was formally raised without substantiation, up to the zone in the early 1980s (Callomon and Birkelund, 1982). Baraboshkin (2004) also ranks it as a zone appealing that the unit is barren of *Craspedites okensis*, and this found a place in the project of Boreal standard (Zakharov et al., 2005). Kiselev and Rogov (2005) established that *Craspedites okensis* appears at the base of the *Fulgens* Zone in the East European platform and assumed that this level is a good marker of boundary between the middle and upper Volgian substages, being well recognizable throughout the Arctic regions.<sup>2</sup>

Investigation of the Nordvik section provided new evidence for middle Volgian age of the *Exoticus* Zone. In this section, *Laugeites* with smoothed ornamentation, which are identical to ammonites from uppermost part of the *Nikitini* Zone in the Gorodishche section (Kiselev and Rogov, 2005), have been found along with *Praechetaites exoticus* and *P. aff. bicostatus*. Stratigraphic equivalent of the *Laugeites* sp. nov. horizon that crowns the middle Volgian Substage in the Gorodishchi section (Kiselev and Rogov, 2005) is likely present near the boundary between *Exoticus* and *Okensis* zones, as we found *Laugeites* sp. nov. in the talus of Exposure 32. Upper part of the *Vogulicus* Zone is probably correlative with the *Exoticus* Zone of the Subpolar Urals, although its equivalents are not established there so far. The *Exoticus* Zone corresponds to the *Praechetaites tenuicostatus* Beds in Greenland and Spitsbergen (Surlyk, 1978; Ershova, 1983), and this is confirmed by field observations in Spitsbergen (Rogov, 2007).

#### Upper Volgian Substage

*Craspedites okensis* Zone (Saks et al., 1965, emend Baraboshkin, 2004)

We did not obtain new data on correlation of the *Okensis* Zone, its position in the Nordvik section, and possibility to subdivide it into subzones were. Basal layers of the zone bear *Pseudophylloceras knoxvillense* also known from Alaska and California. A close stratigraphic level yielded *Praechetaites* sp. very similar to *Laugeites?* sp. indet. from Canada (Jeletzky, 1965),

<sup>2</sup> When discussing migration routs of the late Volgian ammonites, Baraboshkin (2004) assumed that *C. okensis* migrated very quickly eastward from the East European platform and almost synchronously appeared in the regions under consideration.

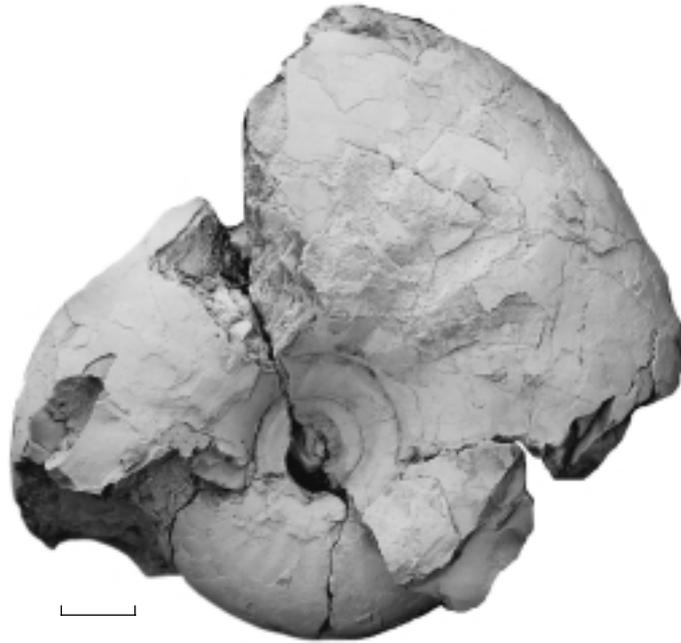


Fig. 3. *Craspedites* cf. *canadensis*, specimen MK1008, Exposure 32, 1B↓150; Ryazanian Stage, *Sibiricus* Zone; scale bar 1 cm.

where it occurs also in the upper part of the middle Volgian Substage. was not discussed.

*Craspedites taimyrensis* Zone (Shul'gina in Saks et al., 1963)

No ammonite taxa characteristic of this zone were found in the study section. It was long believed that the zone is an equivalent of the *Nodiger* Zone in the East European platform. According to alternative assumption, its lower subzone only corresponds to the *Taimyrensis* Zone (Mesezhnikov et al., 1983; Baraboshkin, 2004). In our opinion, the variant by Shul'gina (1985) is more correct for the following reasons. First, *Craspedites psedonodiger* occurs in both the *Taimyrensis* Zone of the Khatanga River basin and the *Nodiger* Zone of Kachpir (Shul'gina, 1969). Our observations showed that this species is confined in the latter area to a narrow interval within the upper *Nodiger* Subzone. Second, in layers above the *Nodiger* Zone (*Volgidiscus singularis* Beds), Kiselev (2003) found ammonites, which are close to *Volgidiscus* from the *Subcraspedites mauryniensis* Beds of the Subpolar Urals (Casey et al., 1988).

*Chetaites chetae* Zone (Shul'gina in Saks et al., 1963)

Stratigraphic position the *Chetae* Zone was topic of discussions because of transitional morphology of ammonites occurring in this unit. Based on distribution of the upper Volgian *Craspedites* (*Taimyroceras*) and "*Virgatosphinctes*", this zone was attributed to the upper Volgian Substage (Saks et al., 1968, 1969; Shul'gina, 1969). Bodylevskii (1974) and then Sazonova and Sazonov (1979b) argued that both

*Chetaites* zones are the Cretaceous in age. Considering ammonite assemblages from the *Chetae* and *Sibiricus* zones, it is difficult to find unambiguous solution with due account for currently known distribution of ammonites. In the *Sibiricus* Zone, ammonites attributed to the genus *Craspedites* have been found recently in association with *Praetollia* forms of the Lower Cretaceous. Characteristic of both zones are widespread genera *Volgidsicus* and *Praetollia*, which provide a reliable Panboreal correlation.

#### RYAZANIAN STAGE (BOREAL BERRIASIAN)

*Chetaites sibiricus* Zone (Shul'gina in: Saks et al., 1963) = *Praetollia maynci* Zone (Surlyk, 1978)

Owing to previous detailed sampling (Shul'gina, 1972; Zakharov et al., 1983), boundaries and characteristic ammonite species of the zone are well known. We collected additional *Chetaites* and *Praetollia* specimens and refined stratigraphic range of the latest *Craspedites* forms. It is remarkable that *Craspedites* forms from the zone are very close to counterparts from the upper Volgian (Plate II, figs. 3, 5).

Although the zone is subdivided in two subzones in many sections of the Panboreal Superrealm (Alekseev, 1984; Casey et al., 1983), this is impossible so far in the Nordvik section. Moreover, the main criterion used for subdivision (absence of *Praetollia* in the upper subzone) is questionably valid. At any rate, the section studied (Zakharov et al., 1983) and sections of eastern Greenland (Surlyk et al., 1973) contain joint records of *Praetollia* and *Hectoroceras* forms. Based on ammonites found in the Nordvik section, it is possible to

Correlation of middle Volgian-Ryazanian sediments from different areas of the Panboreal Superrealm

Central areas of the East European Platform (Mitta, 1993, 2007; Baraboshkin 2004; Kiselev and Rogov, 2005, with modifications)			Northern Siberia (Mesezhnikov, 1984; Casey <i>et al.</i> , Zakharov and Rogov, 2006)		Subpolar Urals (Mesezhnikov, 1984; Casey <i>et al.</i> , 1988)		Eastern Greenland (Surlyk <i>et al.</i> , 1973; Callomon and Birkelund, 1982; Birkelund <i>et al.</i> , 1984), with additions	
Substage	Zone	Subzone	Biohorizon	Zone, subzone		Zone, subzone		“Fauna”
Ryazanian (part)	Rjasanensis	<i>Riasanites swistowianus</i> Beds		<i>Hectoroceras kochi</i>	<i>Caseyiceras praeanalagus</i>	<i>Hectoroceras kochi</i>	<i>Hectoroceras–Borealites</i> Beds	<i>Hectoroceras kochi</i>
		<i>Hectoroceras kochi</i> Beds			<i>Borealites constans</i>		<i>Hectoroceras–Shulginites</i> Beds	
		<i>Shulginites tolijense</i> Beds		<i>Chetaites sibiricus</i>	<i>Hectoroceras kochi</i>	<i>Chetaites sibiricus</i>	<i>Chetaites sibiricus</i>	<i>Praetollia maynci</i>
		<i>Praetollia–Chetaites</i> (?) Beds			<i>Chetaites sibiricus</i>		<i>Praetollia maynci</i>	
Upper Volgian	Nodiger	<i>Volgidiscus singularis</i> Beds		<i>Craspedites okensis</i>	<i>Chetaites chetae</i>	<i>Subcraspedites mauryntiensis</i> Beds	<i>Chetaites aff. chetae</i> Beds	3
		<i>Craspedites milkovensis</i>			<i>Craspedites taimyrensis</i>		<i>Craspedites taimyrensis</i>	2
		<i>Craspedites mosquensis</i>			<i>Craspedites taimyrensis</i>		<i>Craspedites taimyrensis</i>	1
	Subditus	<i>Craspedites subditus</i>		<i>Craspedites originalis</i>	<i>Craspedites subditus</i>	<i>Subcraspedites</i> sp. Beds	?	
		Fulgens	<i>Craspedites nekrassovi</i>		<i>Craspedites okensis</i>	<i>Craspedites okensis</i>	<i>Kachpurites fulgens</i>	
	<i>Kachpurites fulgens</i>							
Middle Volgian (part)	Nikitini	<i>Laugeites</i> sp. nov.		<i>Praechetaites exotica</i>		?	<i>Praechetaites tenuicostatus</i> Beds	
		<i>Laugeites</i> sp.n.aff.parvus						
		<i>Nikitini</i>						
		<i>E. lahuseni</i>	<i>Lahuseni</i>	<i>Epivirgatites variabilis</i>	<i>Epilaugeites vogulicus</i>	<i>Epilaugeites vogulicus</i>		
		<i>E. bipliciformis</i>	<i>Bipliciformis</i>		<i>Laugeites groenlandicus</i>	<i>Laugeites groenlandicus</i>	47 <i>L. groenlandicus</i>	

Note. the Tithonian--Berriasian boundary based on paleomagnetic data (Housa *et al.*, 2007); (2, 3) two possible positions of the boundary between the Volgian Stage and Boreal Berriasian

 intervals directly correlative based on ammonites

define both the *Sibiricus* and *Maynci* zones of equal stratigraphic ranges.

*Hectoroceras kochi* Zone (Spath, 1952)

The *Kochi* Zone is recognized only in basal part (approximately 0.5 m) of the section. Small *Praesurites* form was found here in addition to *Hectoroceras* and some other stratigraphically insignificant ammonites (*Bochianites*, *Boreiophylloceras*, "*Lytoceras*"). Despite small size, the form is readily attributable to the genus.

#### JUASSIC–CRETACEOUS BOUNDARY IN ARCTIC REGIONS

In northern Siberia, the Jurassic–Cretaceous boundary is traditionally defined between the *Chetaites chetae* and *Chetaites sibiricus* zones (Saks et al., 1963, 1965). In the East European platform, the type region of the Volgian Stage, the *Nodiger* Zone was long considered as the uppermost zonal unit of the Volgian Stage. It has been shown recently, however, that the last zone is overlain by sediments containing *Volgidiscus* (Kiselev, 2003) and *Chetaites* probably (Mitta, 2005). According to magnetostratigraphic data, the base of the Tethyan Berriasian (= the *Jacobi* Zone base) corresponds in the Nordvik section to the level inside the upper Volgian *Taimyrense* Zone, while the boundary between the *Chetae* and *Sibiricus* zones is inside the *Jacobi* Zone (Houša et al., 2007). In turn, the *Taimyrense* Zone is correlative in its whole range with the *Nodiger* Zone (Shul'gina, 1985).

One of two levels, either the base or top of the *Chetae* Zone may represent the Jurassic–Cretaceous boundary in Arctic regions. Each of the levels has its advantages. In the case of the boundary defining in the Tethyan Realm at the base of the *Jacobi* Zone, we would see both levels slightly above it, though within one zone of the Tethyan ammonoid and calpionellid zonations.

The *Chetae* Zone base is closer to the Jurassic–Cretaceous boundary in the Tethyan Realm and very close to its traditional position in the East European platform, the type region of the Volgian and Ryazanian stages.

The level of the *Chetae* Zone top has other advantages. First, the zone top corresponding to the first occurrence level of *Praetollia* distributed throughout Arctic regions is of a high correlation potential. Second, the *Sibiricus* zone base is at the level of iridium anomaly well recognizable in Arctic sections from the Barents shelf to northern Siberia (Zakharov et al., 1993; Dypvik et al., 2006).

#### CONCLUSIONS

Section of the Nordvik Peninsula spans the complete succession of Jurassic–Cretaceous boundary zones from the uppermost middle Volgian to the Boreal Berriasian. Ammonites occurring in the section have wide geographic and narrow stratigraphic ranges and

enable direct correlation of the studied succession with concurrent successions in other Arctic areas and boundary zones of the Panboreal Superrealm in general.

The *Exoticus* Zone containing ammonite taxa characteristic of the *Nikitini* Zone upper part in the East European platform is attributed to the middle Volgian Substage. Pelagic ammonoids (primarily, phylloceratids) occurring in the middle–upper Volgian boundary strata and in basal layers of the *Kochi* Zone offer opportunity to consider these levels as event markers characterizing a brief episode of enhanced connections between the Arctic and Pacific oceans.

Like their equivalents in the Subpolar Urals and East European platform, the middle and upper Volgian substages in the Nordvik Peninsula are lacking significant hiatuses recognizable by biostratigraphic methods. This is evident from occurrence of the same or close ammonoid assemblages throughout spacious regions, which were remarkably successive in terms of phylogeny during the middle–late Volgian time.

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#### REFERENCES

1. O. A. Abbink, J. H. Callomon, J. B. Riding, et al., "Biostratigraphy of Jurassic–Cretaceous Boundary Strata in the Terschelling Basin, the Netherlands," *Proc. Yorkshire Geol. Soc.* **53**, 275–302 (2001).
2. S. N. Alekseev, "New Data on Zonal Subdivision of the Berriasian Stage in Northern Siberia," *Tr. IGiG SO AN SSSR*, **644**, 81–106 (1984).
3. E. Yu. Baraboshkin, "Lower Cretaceous Ammonite Zonal Standard of the Boreal Belt," *Byull. MIOP, Ser. Geol.* **79** (3), 44–68 (2004).
4. V. F. Basov, V. A. Zakharov, E. F. Ivanova, et al., "Zonal Biostratigraphy of Upper Jurassic and Lower Cretaceous Sediments in the Cape Urdyuk-Khaya (Paksa Peninsula, Anabar Bay)," *Uchenye Zapiski NIIGA. Paleontologiya, Stratigrafiya*, **29**, 14–31 (1970).
5. T. Birkelund, J. H. Callomon, and F. T. Fürsich, "The Stratigraphy of the Upper Jurassic and Lower Cretaceous Sediments of Milne Land, Central East Greenland," *Bull. Grønl. Geol. Undersøg.*, No. 47, 1–56 (1984).
6. V. I. Bodylevskii, "The Fauna of the Upper Volgian Stage in Novaya Zemlya, Tr. Arkticheskogo In-ta" **49**, 113–136 (1936).

7. V. I. Bodylevskii, "Genus *Taimyroceras* Bodylevskii gen. nov. *Taimyroceras taimyrense* Bodylevskii gen. et sp. nov.," in *Materials on Paleontology. New Families and Genera* (Gosgeoltekhizdat, Moscow, 1956), pp. 82–84 [in Russian].
8. V. I. Bodylevskii, "On the Jurassic–Cretaceous Boundary in the Boreal Realm," in *Proceedings of the International Symposium on Problems of the Upper Jurassic Stratigraphy, Moscow, 1967* (GIN AN SSSR, Moscow, 1974), pp. 129–132 [in Russian].
9. V. I. Bodylevskii and L. D. Kiparisova, "Mesozoic Stratigraphy of the Soviet Arctic," in *Proceedings of the International Geological Congress, XVII Session* (1940), Vol. V, pp. 219–234 [in Russian].
10. V. I. Bodylevskii and N. I. Shul'gina, "Jurassic and Cretaceous Faunas from the Yenisei River Lower Reaches," *Tr. NIIGA* **93**, 1–196 (1958).
11. Yu. I. Bogomolov, "Polyptychitidae (Ammonites) and Biostratigraphy of the Boreal Valanginian," *Tr. IGiG SO AN SSSR*, **696**, 1–200 (1989).
12. S. S. Buckman, *Yorkshire Type Ammonites, Vols. 1–7* (Wesley et Sons, London, 1909–1930).
13. J. H. Callomon and T. Birkelund, "The Ammonite Zones of the Boreal Volgian (Upper Jurassic) in East Greenland," *Mem. Canad. Soc. Petrol. Geol.* **8**, 349–369 (1982).
14. R. Casey, "The Dawn of the Cretaceous Period in Britain," *Bull. South-East. Un. Sci. Soc.*, No. CXVII, 1–15 (1963).
15. R. Casey, "The Ammonite Succession at the Jurassic - Cretaceous Boundary in Eastern England," *Geol. J. Spec. Issue*, No. 5, 193–266 (1973).
16. R. Casey, M. S. Mesezhnikov, and N. I. Shul'gina, "Ammonite Zones in Jurassic–Cretaceous Boundary Sediments of the Boreal Realm," *Izv. AN SSSR. Ser. Geol.*, No. 10, 71–84 (1988).
17. D. T. Donovan, "Stratigraphy and Ammonite Fauna of the Volgian and Berriasian Rocks of East Greenland," *Medd. om Grøn.* **154** (4), 1–34 (1964).
18. H. Dypvik, M. Smelror, P. T. Sandbakken, et al., "Traces of the Marine Mjølnir Impact Event," *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **241** 521–636 (2006).
19. E. Eichwald, *Lethaea Rossica ou paléontologie de la Russie, décrite et figurée. Vol. 2. Période moyenne* (Schweizerbart, Stuttgart, 1865–1868).
20. E. S. Ershova, "New Late Volgian Ammonites from Western Spitsbergen," *Uchen. Zap. NIIGA*, **26**, 52–67 (1969).
21. E. S. Ershova, *Explanatory Notes to Bistatigraphic Scheme of Jurassic and Cretaceous Sediments of the Spitsbergen Archipelago* (PGO Sevmorgeologiya, Leningrad, 1983) [in Russian].
22. H. Frebold, "Verbreitung und Ausbildung des Mosozoi-kums in Spitsbergen," *Skrift. om Svalbard og Ishavet*, No. 31, 1–127 (1930)..
23. P. A. Gerasimov, *Upper Volgian Substage of the Central Russian Platform* (Nauka, Moscow, 1969) [in Russian].
24. E. Häkansson, T. Birkelund, S. Piasecki, et al., "Jurassic-Cretaceous Boundary Strata of the Extreme Arctic (Peary Land, North Greenland)," *Bull. Geol. Soc. Denmark* **30** 11–42 (1981).
25. V. Houša, P. Pruner, V. A. Zakharov, et al., "Boreal–Tethyan Correlation of the Jurassic–Cretaceous Boundary Interval by Magneto- and Biostratigraphy," *Stratigr. Geol. Korrelyatsiya* **15** (3) 63–76 (2007) [*Stratigr. Geol. Correlation* **15**, 297–309 (2007)].
26. A. N. Ivanov, V. N. Baranov, and E. S. Muravin, *Natural Monuments and the Earth's Record (Glebovo Village and Its Outskirts). Tutorial Manual* (YaGPU, Yaroslavl, 1987) [in Russian].
27. J. A. Jeletzky, "Upper Volgian (Latest Jurassic) Ammonites and Buchias of Arctic Canada," *Bull. Geol. Surv. Canada*, No. 128, 1–51 (1965).
28. D. N. Kiselev, "Sel'tso-Voskresenskoe," in *Atlas of Geological Monuments in the Yaroslavl Region* (YaGPU, Yaroslavl, 2003), pp. 58–62 [in Russian].
29. D. N. Kiselev, V. N. Baranov, and E. S. Muravin, "Glebovo," in *Atlas of Geological Monuments in the Yaroslavl Region* (YaGPU, Yaroslavl, 2003), pp. 63–75 [in Russian].
30. D. N. Kiselev and M. A. Rogov, "Infrazonal Stratigraphy and Ammonites of Middle–Upper Volgian Boundary Strata in European Russia," in *Proceedings of the First All-Russian Meeting on "Jurassic System of Russia: Stratigraphic and Paleogeographic Problems"* (GIN RAN, Moscow, 2005), pp. 135–139 [in Russian].
31. J. Kutek and A. Zeiss, "A Contribution to the Correlation of the Tithonian and Volgian Stages. The Ammonite Fauna from Brzostowka, near Tomaszom Mazowiecki, Central Poland," *Mem. B. R. Geol. Min.*, No. 86, 123–128 (1975).
32. M. S. Mesezhnikov, "New Arctic Genus of Middle Volgian Dorsoplanitinae," *Tr. IGiG SO AN SSSR*, **111**, 119–131 (1972).
33. M. S. Mesezhnikov, "Zonal Subdivision of the Ryazan Horizon," *Tr. IG-G SO AN SSSR*, **644**, 54–66 (1984a).
34. M. S. Mesezhnikov, *Kimmeridgian and Volgian Stages of the Northern USSR* (Nedra, Leningrad, 1984b) [in Russian].
35. M. S. Mesezhnikov, S. N. Alekseev, I. G. Klimova, et al., "On Development of Some Craspeditidae across the Jurassic–Cretaceous Transition," *Tr. IGiG SO AN SSSR*, **555**, 103–125 (1983).
36. V. V. Mitta, *Ammonites and Zonal Stratigraphy of Middle Volgian Sediments in Central Russia* (Geoprognoz, Kiev, 1993) [in Russian].
37. V. V. Mitta, "New Data on Age of the Ryazanian Stage Basal Layers," *Stratigr. Geol. Korrelyatsiya* **13** (5) 51–59 (2005) [*Stratigr. Geol. Correlation* **13**, 503–511 (2005)].
38. V. V. Mitta, "Ammonite Assemblages from the Basal Part of the Ryazanian Stage (Lower Cretaceous) in Central Russia," *Stratigr. Geol. Korrelyatsiya* **15** (2) 80–92 (2007) [*Stratigr. Geol. Correlation* **15**, 193–205 (2007)].
39. S. N. Nikitin, "General Geological Map of Russia. Sheet 56. Yaroslavl," *Tr. Geol. Kom.* **1** (2) 1–153 (1884).
40. K. V. Paraketsov, "Detailed Section of the Volgian Stage at the Pezhenka River (Bol'shoi Anyui River Basin)," *Tr. SVKNII*, **37**, 141–156 (1970).
41. M. A. Rogov, "Oceanic Ammonites of Northern Siberia at the Jurassic–Cretaceous Transition: Taxonomy, Biogeographic and Stratigraphic Significance," in *Proceedings of the Second All-Russian Meeting "Cretaceous System of Russia: Stratigraphic and Paleogeographic*

- Problems, St. Petersburg, April 12–15, 2004* St. Petersburg, 2004), p.16 [in Russian].
42. M. A. Rogov, "News on the Volgian of Spitsbergen: ammonite ranges, zonal subdivision and correlation with adjacent areas," in *4th Symposium IGCP-506, University of Bristol, 4-8 July 2007* (Bristol, 2007), pp. 33–34.
  43. K. O. Rostovtsev and V. A. Prozorovsky, "Information on Resolution of Standing Commissions of the Interdepartmental Stratigraphic Committee (JSC) on the Jurassic and Cretaceous Systems," *Newsl. Stratigr.* **24**, 48–52 (1997).
  44. V. N. Saks *Stratigraphy of the Jurassic System in the Northern USSR* (Nauka, Moscow, 1976) [in Russian].
  45. V. N. Saks and V. Ya. Sanin, "Boyarka and Kheta Rivers," in *Stratigraphy of the Jurassic System in the Northern USSR* (AN SSSR, Moscow, 1963), pp. 50–55 [in Russian].
  46. V. N. Saks, V. A. Basov, and M. S. Mesezhnikov, "Stratigraphic Correlation and Inferences," in *Reference Section of Upper Jurassic Sediments in the Kheta River Basin (Khatanga Depression)* (Nauka, Leningrad, 1969), pp.64–92 [in Russian].
  47. V. N. Saks, M. S. Mesezhnikov, and N. I. Shul'gina, "On Connections of Jurassic and Cretaceous Basins in Northern and Southern Eurasia," in *Intern. Geol. Congr. XXII Session. Reports of Soviet Geologists* (Nauka, Moscow, 1964), pp. 163–174 [in Russian].
  48. V. N. Saks, M. S. Mesezhnikov, and N. I. Shul'gina, "Volgian Stage and Position of the Jurassic–Cretaceous Boundary in the Arctic Zoogeographic Region," in *Mesozoic Marine Faunas of the USSR North and Far East and Their Stratigraphic Significance* (Nauka, Moscow, 1968), pp. 101–107 [in Russian].
  49. V. N. Saks, V. A. Basov, V. A. Zakharov, et al., "Stratigraphy of Upper Jurassic and Lower Cretaceous Sediments of the Khatanga Depression," in *Stratigraphy and Paleontology of Mesozoic Sediment of Northern Siberia* (Nauka, Moscow, 1965), pp. 27–60 [in Russian].
  50. V. I. Saks, I. S. Gramberg, Z. Z. Ronkina, et al., "Mesozoic Sediments of the Khatanga Depression," *Tr. NIIGA* **99**, 1–226 (1959).
  51. V. I. Saks, Z. Z. Ronkina, N. I. Shul'gina, et al., *Stratigraphy of the Jurassic System in the Northern USSR* (AN SSSR, Moscow, 1963) [in Russian].
  52. I. G. Sazonova and N. T. Sazonov, "The Jurassic–Cretaceous Boundary in the East European Platform," in *Aspekte der Kreide Europas* (Intern. Union Geol. Sci., 1979a), Ser. A, No. 6, pp. 487–496.
  53. I. G. Sazonova and N. T. Sazonov, "The Recognition Problem of the Uppermost Jurassic and Lowermost Cretaceous Stages in the East European Platform," in *The Upper Jurassic and Its Boundary with the Cretaceous System* (Nauka, Novosibirsk, 1979b), pp. 86–93 [in Russian].
  54. I. I. Sey and E. D. Kalacheva, *Biostratigraphic Criteria of the Jurassic–Cretaceous Boundary in Russia. Information Notes* (VSEGEI, St. Petersburg, 1993) [in Russian].
  55. N. I. Shul'gina, "New Late Jurassic Ammonites from Northern Siberia," *Tr. NIIGA* **127**, 197–202 (1962).
  56. N. I. Shul'gina, "Tithonian Ammonites from Northern Siberia," in *Problems of Paleontological Substantiation of Detailed Mesozoic Stratigraphy in Siberia and the Far East* (Nauka, Leningrad, 1967), pp. 131–177 [in Russian].
  57. N. I. Shul'gina, "Volgian Ammonites," in *Reference Section of Jurassic sediments in the Kheta River Basin (Khatanga Depression)* (Nauka, Leningrad, 1969), pp. 125–162 [in Russian].
  58. N. I. Shul'gina, "Berriasian Marine Fauna. Ammonites of the Northern Central Siberia," in *The Jurassic–Cretaceous Boundary and Berriasian Stage in the Boreal Belt* (Nauka, Novosibirsk, 1972), pp.137–175 [in Russian].
  59. N. I. Shul'gina, "Boreal Basins at the Jurassic–Cretaceous Transition," *Tr. VNIIOkeangeologiya* **195**, 1–161 (1985).
  60. L. F. Spath, "On Ammonites from Spitzbergen," *Geol. Mag.* **58**, 297–305, 347–356 (1921).
  61. L. F. Spath, "On the Ammonites of the Speeton Clay and the Subdivisions of the Neocomian," *Geol. Mag.* **61**, 73–89 (1924).
  62. L. F. Spath, "The Upper Jurassic Invertebrate Faunas of Cape Leslie, Milne Land. II. Upper Kimmeridgian and Portlandian," *Medd. om Grøn.* **99** (3) 1–180 (1936).
  63. L. F. Spath, "Additional Observations on the Invertebrates (Chiefly Ammonites) of the Jurassic and Cretaceous of East Greenland. II. Some Infra-Valanginian Ammonites from Lindeman-Fjord, Wollaston Foreland; with a Note on the Base of the Cretaceous," *Medd. om Grøn.* **133** (4) 1–40 (1952).
  64. F. Surlyk, "Submarine Fan Sedimentation along Fault-Scarps on Tilted Fault-blocks (Jurassic–Cretaceous Boundary, East Greenland)," *Bull. Grøn. Geol. Unders.*, No. 128, 1–128 (1978).
  65. F. Surlyk, J. H. Callomon, R. G. Bromley, et al., "Stratigraphy of the Jurassic–Lower Cretaceous Sediments of Jameson Land and Scoresby Land, East Greenland," *Bull. Grøn. Geol. Unders.*, No. 105, 1–76 (1973).
  66. V. A. Zakharov, "Buchiids and Biostratigraphy of the Boreal Upper Jurassic and Neocomian," *Tr. IGiG SO AN SSSR*, **458**, 1–271 (1981).
  67. V. A. Zakharov, "In Defense of the Volgian Stage," *Stratigr. Geol. Korrelyatsiya* **11** (2), 58–66 (2003) [*Stratigr. Geol. Correlation* **11**, 585–593 (2003)].
  68. V. A. Zakharov and M. S. Mesezhnikov, "The Volgian Stage of the Subpolar Urals," *Tr. IGiG SO AN SSSR*, **196**, 5–176 (1974).
  69. V. A. Zakharov and M. A. Rogov, "Nature of the International Stratigraphic Scale and the Volgian Stage (Comments to Paper by V. A. Prozorovsky "To the Problem of the Volgian Stage")," *Stratigr. Geol. Korrelyatsiya* **13** (5), 96–101 (2005) [*Stratigr. Geol. Correlation* **13**, 547–551 (2005)].
  70. V. A. Zakharov and M. A. Rogov, "New Data on Jurassic–Cretaceous Sediments in the Arctic Region (Nordvik Peninsula, Northern Siberia)," in *Proceedings of the Third All-Russian Meeting "Cretaceous System of Russia and Adjacent Regions: Problems of Stratigraphy and Paleogeography*, September 26–30, 2006, Saratov (SO EAGO, Saratov, 2006), **528**, pp. 61–63 [in Russian].
  71. V. A. Zakharov, A. S. Lapukhov, and O. V. Shenfil, "Iridium Anomaly at the Jurassic–Cretaceous Boundary in Northern Siberia," *Geol. Geofiz.*, No. 1, 102–109 (1993).

72. V. A. Zakharov, T. I. Nal'nyaeva, and N. I. Shul'gina, "New Data on Biostratigraphy of Upper Jurassic and Lower Cretaceous sediments in the Paksa Peninsula, Anabar Bay (Northern Central Siberia), Tr. IGI SO AN SSSR, **528**, 56–99 (1983).
73. V. A. Zakharov, B. N. Shurygin, S. V. Meledina, et al., "Boreal Zonal Standard of the Jurassic: Discussion of a New Version," in *Proceedings of the First All-Russian Meeting "Jurassic System of Russia: Stratigraphic and Paleogeographic Problems"* (GIN RAN, Moscow, 2005), pp. 89–96 [in Russian].
74. A. Zeiss, "Problem of Upper Jurassic Correlations and Some Thoughts on the Jurassic–Cretaceous Boundary," in *The Upper Jurassic and Its Boundary with the Cretaceous System* (Nauka, Novosibirsk, 1979), pp. 14–27 [in Russian].
75. A. Zeiss, "The Upper Jurassic in Europe: Its Subdivision and Correlation," *Bull. Geol. Surv. Denmark and Greenland* **1**, 75–114 (2003).
76. A. I. Zhamoida and E. L. Prozorovskaya, "Resolution on Specified Position of the Jurassic–Cretaceous Boundary in the Boreal Realm and Statute of the Volgian Stage," in *Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions* (VSEGEI, St. Petersburg, 1997), **29**, pp. 5–7 [in Russian].

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