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New Ammonite Zonation of the Lower Callovian in North Siberia

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Abstract—The lower Callovian succession observable in cliffs of Anabar Bay and Bolshoi Begichev Island is described with consideration of zonal subdivisions and beds with ammonites. The unified summary biozonation suggested for North Siberia includes the Cadoceras elatmae Zone with C. frearsi and C. elatmae (instead former C. anabarense) subzones, subsequent C. tschernyschewi and C. tolype zones, and successive C. cf. sublaeve, Rondiceras milaschevici, and Cadoceras ex gr. durum (formerly part of the middle Callovian) beds. As in Siberia and East Europe there are species in common *C. elatmae* (Nik.), *C. frearsi* (Orb.), *C. tolype* Buck., and *C. emelianzevi* Vor.; certain ammonite zones of Siberian succession are directly correlated with the East European, East Greenland and standard zonations. It is concluded that the lower Callovian is completely represented in Siberia. The lower part of the interval, formerly attributed to the middle Callovian, represents the upper part of the lower Callovian Substage. Zones established in the lower Callovian succession of Siberia are contiguous, whereas equivalents of the Elatmae Subzone and Tschernyschewi Zone have not been distinguished in sections of East Greenland. Evolutionary trends of species in subfamily Cadoceratinae are preliminary discussed.

Key words: ammonites, Cadoceratinae, zonation, lower Callovian, North Siberia.

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INTRODUCTION

A vast transgression in the Northern Hemisphere marked the Bathonian and Callovian ages. An indication of this event is the early Callovian expansion of the ammonites from the Cardioceratidae family that originated in the high-latitude seas of the Arctic. Cardioceratid genera and species characteristic of the Bajocian–Kimmeridgian deposits in Siberia occur as well, along with other families, in concurrent deposits of West and East Europe, East Greenland, Alaska, and Canada. The Bathonian *Arcticoceras* and *Cataca-doceras* are known from the Pechora River basin and Middle Volga region, whereas the genus *Cadoceras* was more widespread in European Russia, where its distribution area extended far southward up to the Caucasus. Common genera and species of cardioceratids are evidence of stable communications during the terminal Bathonian–initial Callovian time between the marginal seas of the Panboreal Superrealm, in particular between the North Siberian and East European seas. At the same time, there are many local ammonite species considered in publications, which, on the one hand, is a consequence of their regional isolation and specifics and, on the other, is due to some subjective researchers' opinions, which have historical roots and concern nomenclature of practically identical species. Accumulation of paleontological data on the Jurassic in different regions of the Panboreal Superrealm results in the necessity to correct the compositions and distribution of certain genera and to make an inventory of their species.

In recent years, interest in the Bathonian–Callovian boundary interval in the Boreal Jurassic has grown. Many ammonite specimens have been found precisely in this interval of sections studied for a long time and recently in North Siberia, and West and East Europe. The Callovian biostratigraphic scale of West Europe is of extremely high resolution, as successions of biohorizons that cannot be differentiated further have been distinguished in its zones and subzones. This approach, first used by West European researchers (Callomon, 1964, 1984, 1985, 1993, 2003; Page, 1995; and others), became widely adopted by stratigraphers who studied Jurassic deposits, the Callovian in particular, in European Russia (Mitta and Starodubtseva, 1998; Gulyaev, 1999, 2001, 2005, 2007; Kiselev and Rogov, 2007a, 2007b; Mitta, 2000, 2008).

Variable sets of zones, subzones, and biohorizons are included in the biozonations suggested by different researchers for the lower Callovian of European Russia. To some extent, the discordance in number and nomenclature of distinguished biostratigraphic units is connected with difficulties in species identification and variably evaluated correlation potentials of certain taxa.

This is especially obvious in the case of the subdivision of the lower part of the Callovian, which is represented in the international standard by the Macrocephalites herveyi Zone, containing species of the following families: the Cardioceratidae, Kosmoceratidae, and Macrocephalitidae in West and East Europe, the Cardioceratidae, and Kosmoceratidae in East Greenland, and only the Cardioceratids in Siberia.

Hence, the zonal subdivision of the Callovian Stage in Siberia and the correlation of Siberian biostratigraphic units with the other ammonite (regional and standard) zonations are feasible, based solely on Cardioceratidae genera and species. Accordingly, a sophisticated approach to understanding the composition of cardioceratid genera and species is a priority for Siberian researchers, as it can solve problems of disagreements in taxonomy, which hinders works aimed at the creation of a biozonation. After the revision of a greatly enlarged collection of Siberian *Cadoceras* forms, we established the identity of certain Siberian and East European species and had the possibility to discard a series of habitual species names and broaden the understanding of certain taxa. Our results prove that separate zones of the lower Callovian in Siberia have their analogs in East Europe. A detailed zonation of the lower Callovian in Siberia illustrated the completeness of this substage in the Siberian sections (see the table).

The large paleontological collection at our disposal includes ammonites of the Cardioceratidae family, which is in a unique state of preservation and characterize bed-by-bed uninterrupted successions of the upper Bathonian–lower Callovian in North Siberia. At present, this collection is undergoing a detailed monographic examination. We have temporarily discarded the subgeneric differentiation of the *Cadoceras* genus, because previously it had been carried out without proper attention to the real phylogenetic relations between the genus species. When the onto-phylogenetic study of the species will be completed, the subgeneric division of the respective genera can be itemized. Shells with morphology characteristic of the early Callovian *C. frearsi* (Orb.), *C. elatmae* (Nik.) and others, which presumably originated from *C. variabile* Spath, are still unknown from younger deposits. We have now clearly distinguished a series of species with an abruptly increasing shell thickness during ontogenesis and having therefore a wide and deep umbo (Fig. 3). The other characteristic morphological features are long-lasting coarse wide-spaced ribs and oblique bullae on the living chamber. Morphotype of this kind first appeared in the late Bathonian *C. calyx* Spath and *C.* sp. nov., found in association with the former. At the end of the *C. elatmae* phase, this morphotype developed in *C. falsum* Vor. and afterward was characteristic of *C. tschernyschewi* and *C. tolype* in

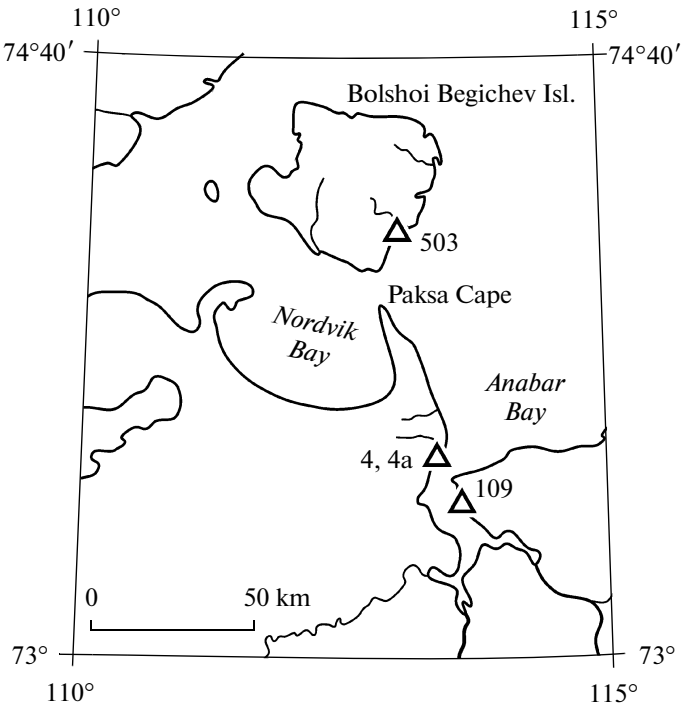

Fig. 1. Geographic localities of principal lower Callovian sections in North Siberia.

their respective phases. Species *C. durum* is the latest representative of the morphotype under consideration. Species *C. emelianzevi* Vor., which existed concurrently with *C. tolype* Buck, became an ancestor of the other lineage represented by *C. sublaeve* (Sow.), *C. septentrionale* Freb., *C. septentrionale* var. *latidorsata* Freb., and the subsequent *Rondiceras* genus. These ammonites, externally similar to *C. tolype* Buck, had strongly swollen smooth shells with comparatively thin and frequent ribs on the inner whorls.

DESCRIPTION OF SECTIONS

The lower Callovian ammonite zonation of Siberia is based on a succession of cardioceratids, collected bed-by-bed from natural outcrops of the Middle Jurassic deposits, observable in the eastern and western coastal cliffs of Anabar Bay and Bolshoi Begichev Island (Figs. 1, 2). Successive beds of separate exposures, their lithology, and geological profile of Anabar Bay's eastern coast have been described in several works (*Stratigraphy...*, 1976; Meledina, 1977, 1994; and others). The numbering of exposures and beds described below correspond to those in the work by Meledina (1994). Our arguments in favor of nomenclatural changes introduced in the zonation of the upper Bathonian are presented in earlier works (Knyazev et al., 2006, 2007, 2009a, 2009b).

Table 1. Correlated regional ammonite zonations in the lower Callovian Substage

Stage	Substagec	West European standard zonation		Boreal ammonite standard (*State of...*, 2008)		East Greenland (Callomon, 1985, 1993)	North Siberia (this work)	
Callovian	Middle	*Kosmoceras jason*		*Cadoceras milaschevici*	*Kosmoceras jason*	*Kosmoceras jason*	Beds Rondiceras sp. ind.	
	Lower	*Sigaloceras calloviense*	enodatum	*Cadoceras tscheffkini*	*Sigaloceras calloviense*	*Sigaloceras calloviense*	Beds Rondiceras milaschevici–Cadoceras ex gr. durum	
			calloviense				Beds Cadoceras cf. sublaeve	
		Proplanulites koenigi		*Cadoceras tolype*	*Cadoceras nordenskjoeldi*	*Proplanulites koenigi*	*Cadoceras tolype*	
		Macrocephalites herveyi	kamptus	*Cadochamoussetia subpatruus*		?	*Cadoceras tschernyschewi*	
			terebratus				*Cadoceras elatmae*	*C. elatmae*
			keppleri	*Cadoceras elatmae*		*Cadoceras nordenskjoeldi*		*C. frearsi*
					Cadoceras apertum	*Cadoceras apertum*		
Bathonian	Upper	*Clydoniceras discus*		*Cadoceras calyx*		*Cadoceras calyx*	*Cadoceras calyx*	

On the eastern coast of Anabar Bay (Exposure 109), Bed 44 of the lower Callovian is composed of sandy aleurolite with spheroidal carbonate concretions (up to 0.4 m in diameter) and overlies the Cadoceras calyx Zone of the upper Bathonian. At a level of 3.7 m above the base of the bed, there is a persistent interlayer (0.2 to 0.3-m thick) of calcareous aleurolite concretions. The bed as a whole is 5.2-m thick.

In lower concretions, we found *Cadoceras elatmae* (Nik.), *C. frearsi* (Orb.), *C.* aff. *frearsi* (Orb.), and *Costacadoceras* sp.; concretions of the interlayer contain *C. elatmae* (Nik.), *C. frearsi* (Orb.), *Costacadoceras mundum* (Sas.), and *C insolitum* (Mel.). The same ammonite assemblage is characteristic of separate concretions occurring immediately below the interlayer.

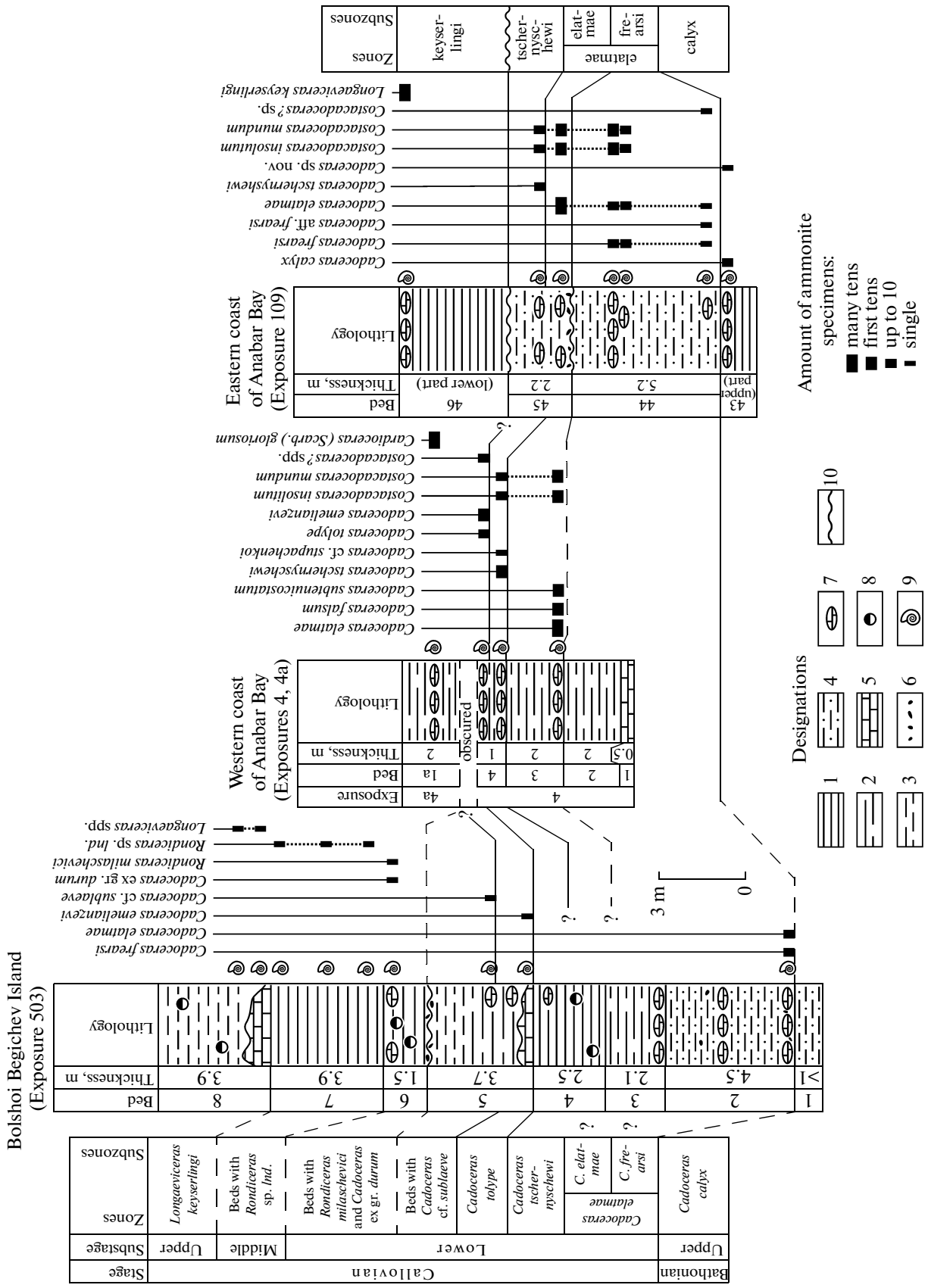

Fig. 2. Biostratigraphy of lower Callovian sections in Siberia; symbols for lithology: (1) argillite, clay; (2) argillite (clay) silty, aleurolite clayey; (3) aleurolite, aleurite; (4) aleurolite (aleurite) sandy; (5) aleurolite calcareous; (6) pebbles; (7) concretions; (8) coal interlayer; (9) level with ammonites; (10) scouring marks.

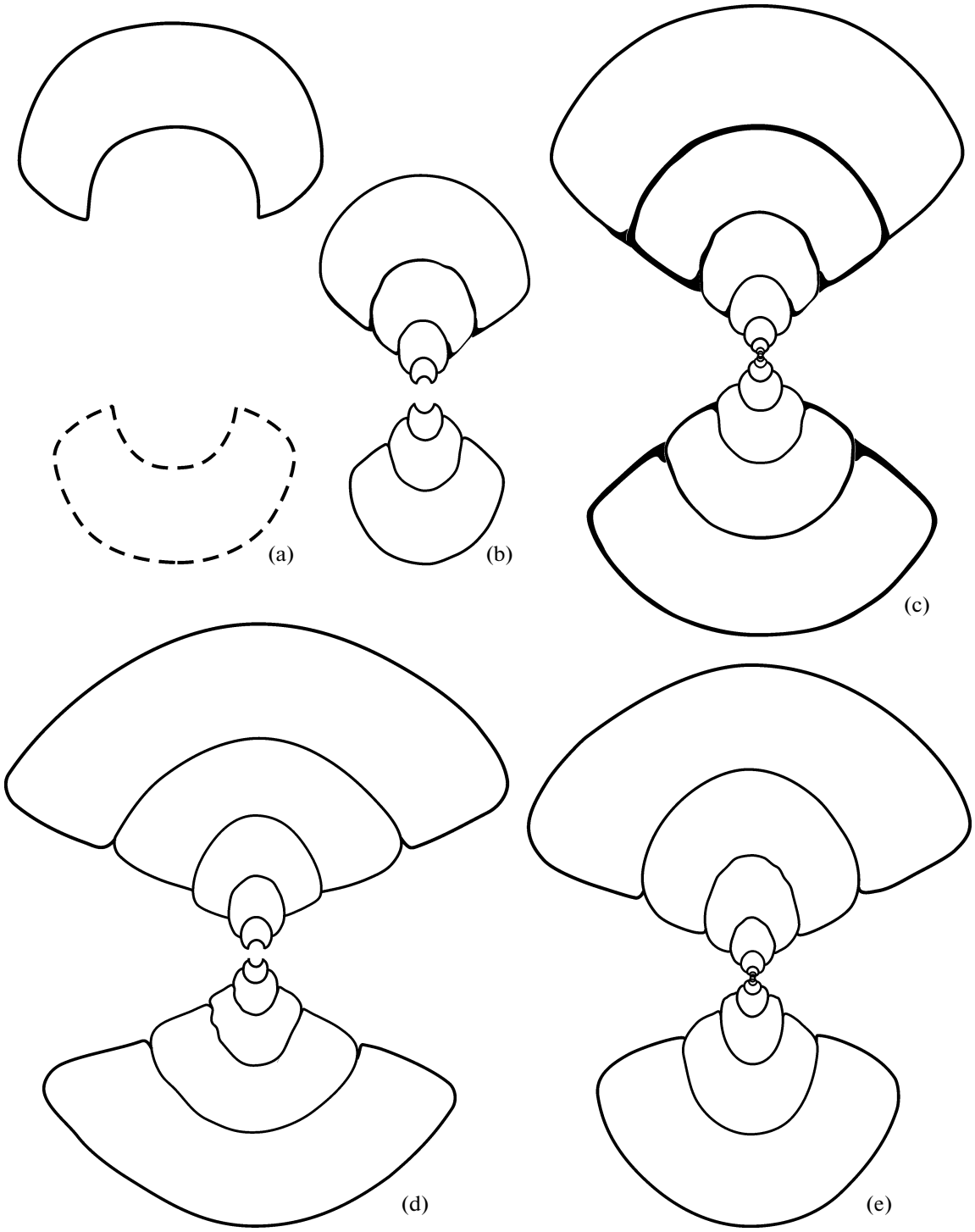

Fig. 3. Cross sections of *Cadoceras frearsi* (a, b), *C. elatmae* (c), *C. tschernyschewi* (d), and *C. emelianzevi* (e) shells: (a) specimen no. 177/223, western coast of Anabar Bay, Exposure 4, talus; (b) specimen no. 177/723, eastern coast of Anabar Bay, Exposure 109, base of Member 44, Frearsi Subzone; (c) specimen no. 177/21, western coast of Anabar Bay, Exposure 4, base of Bed 3, Elatmae Subzone; (d) specimen no. 177/118, ditto, Bed 4, level of lower concretions, Tschernyschewi Zone; (e) specimen no. 177/63, ditto, Bed 4, level of upper concretions, Tolype Zone.

Bed 45 of sandy glauconite aleurolite with fragments of coalified wood and nodules of pyritized calcareous aleurolite hosts lentils of ammonite coquina, consisting of *Cadoceras* and *Costacadoceras* shells, with a thickness of 2.2 m. During recovery from the rock, the shells usually disintegrate, leaving only internal casts of the living chambers and casts of large cadicones, whose umbilical funnels contain accumula-

tions of small allogenic ammonite shells. The lower and upper boundaries of the member display scouring marks, e.g., an uneven surface and pebble occurrence; rounded ammonite shells occur on top. Species *C. elatmae* (Nik.), *C. mundum* (Sas.), and *C. insolitum* (Mel.) are widespread. Concretions in the middle of the bed contain *C. tschernyschewi* (Sok.) and *C.* aff. *bathomphalum* Imlay, the former attributed earlier by Meledina (1977) to *C. emelianzevi* (Vor.). *Costacadoceras* forms still occur. *Costacadoceras* ("Pseudocadoceras") *grewingki* (Pomp.), determined earlier, was regarded as partly indicative of the middle Callovian age of the bed, but later on Bed 45 was attributed to the lower Callovian (Meledina, 1994). In this work, Bed 45 is divided into lower *C. elatmae* and upper *C. tschernyschewi* zones.

Bed 45 is overlain by black clay with *Longaeviceras* spp. of the upper Callovian (Bed 46).

A formerly unknown part of the lower Callovian succession is established on the western coast of Anabar Bay, in the upper part of the low coastal cliffs, south of the Samaskaiskaya River mouth (Exposure 4). In aleurolites with an apparent thickness of 5.5 m, Knyazev distinguished the following beds:

Bed 1. Clayey aleurolite (0.5-m thick) with rare bivalves;

Bed 2. Ferruginous clayey aleurolite 2.0-m thick.

Bed 3. Ferruginous clayey aleurolite (2.0-m thick) with ellipsoidal carbonate concretions at the base, which contain abundant *C. elatmae* (Nik.), *C. falsum* Vor., *C. subtenuicostatum* Vor., *C.* sp. nov. and diverse *Costacadoceras* forms, *C. mundum* (Sas.), and *C. insolitum* (Mel.).

Bed 4. Aleurolite (apparent thickness 1.0 m) with interlayers (0.1 to 0.3-m thick) of carbonate concretions at the base and top; in concretions of the lower interlayer, numerous *C. tschernyschewi* (Sok.) and *Costacadoceras* forms were found, as well as one small shell classed with *C.* cf. *stupachenkoi* Mitta.

Concretions of the upper interlayer contain an abundance of large swollen smooth shells *C. emelianzevi* Vor. and *C. tolype* (Buckm.).

The higher part of the slope is obscured by soil. Black aleurolite beds, which are exposed 75-m northward in the right wall of the Samaskaiskaya River valley close to its mouth contain concretions that yield *Cardioceras (Scarburgiceras) gloriosum* Arkell (Exposure 4a).

Thus, the lower Callovian succession overlying the cliffs of Anabar Bay, the C. calyx Zone of the upper Bathonian is divisible into the following biostratigraphic units: the C. elatmae Zone (Exposure 109, beds 44 and 45, lower part; Exposure 4, beds 1–3), with the lower part attributed to the C. frearsi Subzone (Bed 44) and the upper part corresponding to the C. elatmae Subzone (Exposure 109, Bed 45, lower part; Exposure 4, Bed 3); the C. tschernyschewi Zone (Exposure 109, Bed 45, upper part; Exposure 4, Bed 4, lower 0.5 to 0.7 m); and the C. tolype Zone (Exposure 4, Bed 4, upper 0.1 to 0.3 m). After a break in the outcrops, the lower Oxfordian Cardioceras gloriosum Zone is exposed.

A more complete succession of the lower Callovian (Exposure 503 initially described by Meledina, 1977; completed and revised by Knyazev) is known on the southeastern coast of the Bolshoi Begichev Island, eastward of the Innokent'evka River mouth.

The following beds are visible here from the base upward:

Bed 1. Sandy aleurolite (apparent thickness, 1.0 m); species *?Pseudocadoceras* sp. ind. has been found in the talus.

Bed 2. Sandy aleurolite with jarosite stains, pyrite nodules, and an interlayer of spheroidal or elongated carbonate concretions (0.1 to 0.4 m in diameter); large shells found in concretions containing fragments of coalified wood were formerly attributed to *C. anabarense* Bodyl., but presently they are defined as *C. elatmae* (Nik.) and *C. frearsi* (Orb.); thickness 4.5 m.

Bed 3. Aleurolite, sandy, with spheroidal carbonate concretions at the base; thickness 2.1 m.

Bed 4. Clay, argillite-like, with splintery fracture and pyrite nodules of variable shape; thickness 2.5 m.

Bed 5. Clay, aleuritic, grading upward into aleurolite; at the base there is a persistent lenticular interlayer of compact calcareous aleurolite containing *C. emelianzevi* Vor. Dispersed carbonate concretions occurring 1.5 m higher bear *C.* cf. *sublaeve* (Sow.). The upper boundary of the bed is uneven; thickness 3.7 m.

Bed 6. Clay, splintery, with abundant small worm-shaped pyrite nodules and horizons of spheroidal or flattened carbonate concretions; the latter range in size from a few centimeters across to 0.1–0.15 × 1.0 m. Rare aleurolite pebbles are confined to the bed base. Ammonites found near the base and in concretions of the top interval are classed with *Rondiceras milaschevici* (Nik.), *R.* cf. *milaschevici* (Nik.), and *Erymnoceras (?Rollierites)* sp. (Meledina, 1977, Pl. 20, Fig. 2; Pl. 29, Fig. 3). Knyazev confirmed the occurrence of *Rondiceras milaschevici* (Nik.) and first identified *Cadoceras* ex gr. *durum* Buck. with a coarse ribbing on the inner whorls. The latter was attributed earlier to *Erymnoceras (?Rollierites)* sp.; thickness 1.5 m.

Bed 7. Clay, coarse-splintery, with compressed casts of *Rondiceras* sp. ind., which are partly replaced by gypsum; thickness 3.9 m.

Bed 8. Basal lenticular interlayer (1.0-m thick) of compact calcareous aleurolite; higher in the bed, there are abundant small pyrite nodules (2–3-cm thick) of intricate shape and stellate calcite aggregates of the same size dispersed in an aleurolite matrix. *Longaeviceras* spp. were found at the bed base and at different levels higher; thickness 3.9 m.

Plate I

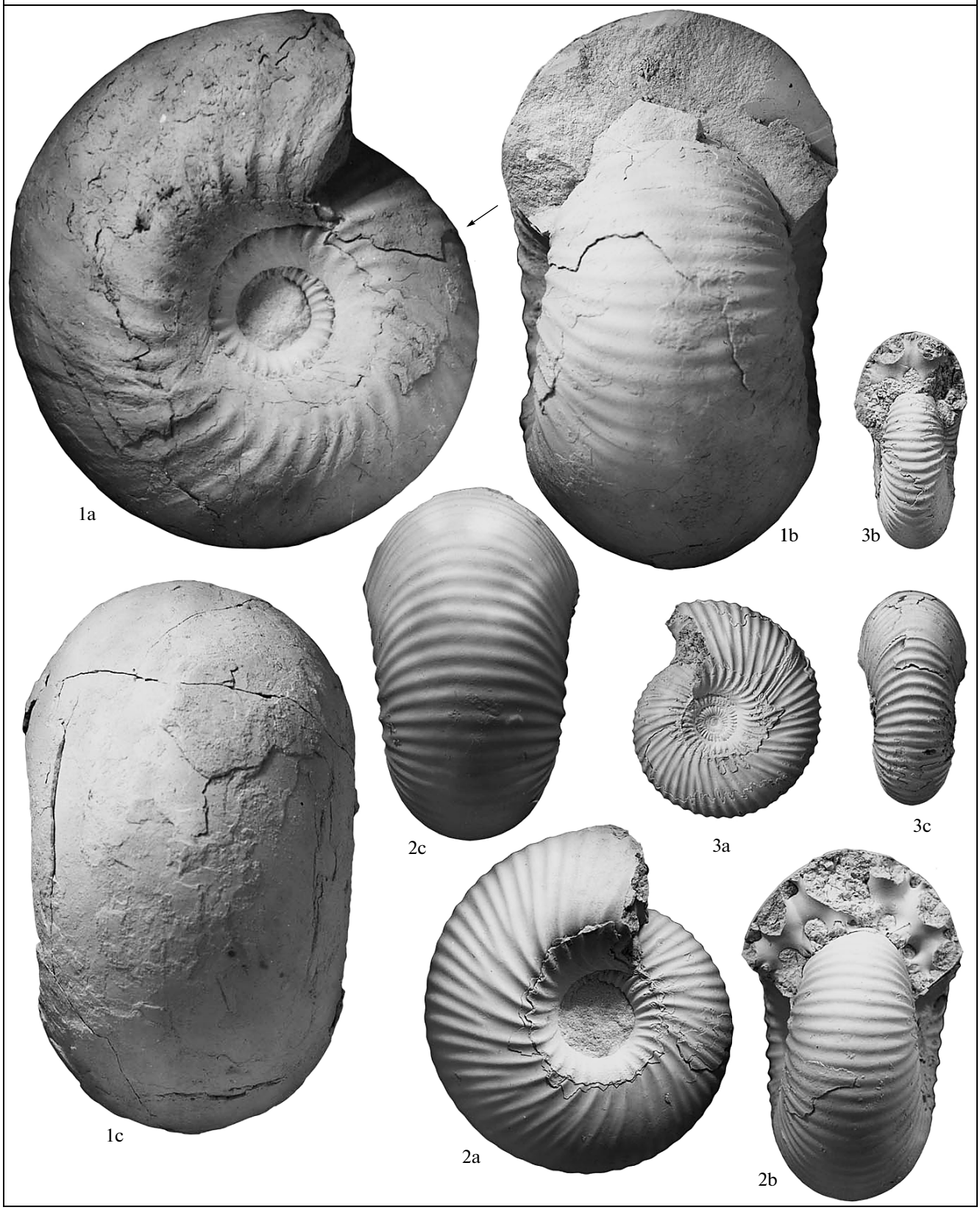

Plate I. *Cadoceras frearsi* (Orbignyi, 1845):

(1) specimen no. 177/2-1: (a) lateral side, (b) apertural side, (c) ventral side; (2) the same specimen: (a) lateral side, (b) apertural side, (c) ventral side; (3) the same specimen: (a) lateral side, (b) apertural side, (c) ventral side; eastern coast of Anabar Bay, Exposure 109, Bed 44, 3.7 m above the base; lower Callovian, Cadoceras elatmae Zone, C. frearsi Subzone. Specimen is hosted in the Geological Museum IGABM, Siberian Division, Russian Academy of Sciences, Yakutsk (collection no. 177).

Here and in Plates II–VI, all specimens are figured in their natural size. Their occurrence levels and geographic localities are quoted from a description of Callovian sections published earlier (Meledina, 1994); an exception is the Callovian section on the western coast of Anabar Bay (Exposure 4) described in this work.

In the Callovian succession of the Bolshoi Begichev Island, ammonite characterize the C. elatmae Zone and the C. frearsi Subzone (base of Bed 2); the C. tolype Zone (according to the occurrence of *C. emelianzevi* Vor. near the base of Bed 5, thickness 1.5 m); C. cf. sublaeve Beds (upper interval 2.2-m thick in Bed 5); and R. milaschevici–C. ex gr. durum beds (Bed 6, thickness 1.5 m).

In the last succession, the interval corresponding to the C. elatmae Subzone and overlying the C. tschernyschewi Zone, established in the Anabar sections (greater part of Bed 2 and Beds 3 and 4) is barren of ammonites. To the C. cf. sublaeve Beds, we tentatively also attributed the upper part of Bed 5 above the level of the occurrence of the *C.* cf. *sublaeve*, where ammonites have not been found. Bed 6, containing determinable ammonite species, corresponds to the R. milaschevici–C. ex gr. durum Beds, whereas Bed 7 (thickness 3.9 m) with *Rondiceras* sp. ind. represents as before part of the middle Callovian.

LOWER CALLOVIAN ZONATION OF NORTH SIBERIA AND ITS CORRELATION WITH EAST EUROPEAN AND STANDARD ZONATIONS

The lower Callovian composite zonation is based in Siberia on the ammonite succession established in the Middle Jurassic sections of Anabar Bay and Bolshoi Begichev Island. The zonation includes the following biostratigraphic units: the Cadoceras elatmae Zone with subzones C. frearsi and C. elatmae, C. tschernyschewi Zone, C. tolype Zone, C. cf. sublaeve Beds, and Rondiceras milaschevici–Cadoceras ex gr. durum beds.

The Cadoceras elatmae Zone

Index species: *Cadoceras elatmae* (Nikitin, 1878). Neotype: TSNIGRMuseum, specimen no. 34/1344 (Nikitin, 1881, Pl. 11(4), Fig. 20). Ryazan oblast, Elatma section; lower Callovian, C. elatmae Zone.

Nomenclature. Nikitin (1881) was the first to distinguish this unit as "Etage mit *Stephanoceras elatmae"* in the Volga region. Saks et al. (1963), who established this zone in Siberia, regarded it as corresponding in range to the lower Callovian, as a whole. That range was reduced, when the upper part of the zone was defined as an individual C. emelianzevi Zone (*Stratigraphy*..., 1976; Meledina, 1977). Subsequently, individualized units (zones) containing *C. (Catacadoceras) barnstoni* Meek, *C. (C.) variabile* Spath, and *C. falsum* Vor. were also established in the lower part of the zone. Index C. elatmae was retained only for the upper part of the former zone (Meledina, 1991). Then, the name C. elatmae Zone was changed in Siberia for C. anabarense Zone (Meledina, 1994; Shurygin et al., 2000; and others) to avoid a different understanding of the *C. elatmae* (Nik.) species and the proclaimed opinion that the distribution area of the latter is constrained only by European Russia (Sey and Kalacheva, 1992). Representative collections of *Cadoceras* from the Anabar sections, which have been studied in recent years, provided the possibility to refine tge nomenclature of morphologically close species and to revise their stratigraphic ranges. We arrived at the conclusion that the names of certain species, in particular *C. anabarense* Bodyl. and *C. multiforme* Imlay et al. are unnecessary, because they are younger synonyms of well-known East European species *C. frearsi* (Orb.) and *C. elatmae* (Nik.). Accordingly, we suggest restoring the abandoned name C. elatmae Zone.

Type locality in Siberia: Anabar Bay, and the western and eastern coasts.

Boundaries. The lower boundary is at the first occurrence level of *C. frearsi* (Orb.) and *C. elatmae* (Nik.), which replace the *C. calyx* Spath. The upper boundary is marked by the appearance of *C. tschernyschewi* (Sok.).

Composition. The zone is divided into subzones *C. frearsi* below (the eastern coast of Anabar Bay) and *C. elatmae* above it (both coasts of Anabar Bay). The boundary between subzones is at the last occurrence of *C. frearsi* (Orb.).

Characteristic ammonites: *C. elatmae* (Nik.) (Pl. II, Figs. 1, 2), *C. frearsi* (Orb.) (Pl. I, Figs. 1–3), *C. subtenuicostatum* Vor., *C. falsum* Vor., *C.* sp. nov., *Costacadoceras mundum* (Sas.), *C. insolitum* (Mel.), and *C.* aff. *insolitum* (Mel.)

Remarks. Our revision of *Cadoceras* forms exhaustively represented in new and older collections of ammonites from deposits overlying the C. calyx Zone of the upper Bathonian in North Siberian sections and the analysis of available published data on the other distribution areas of the Boreal Callovian showed that

Plate II

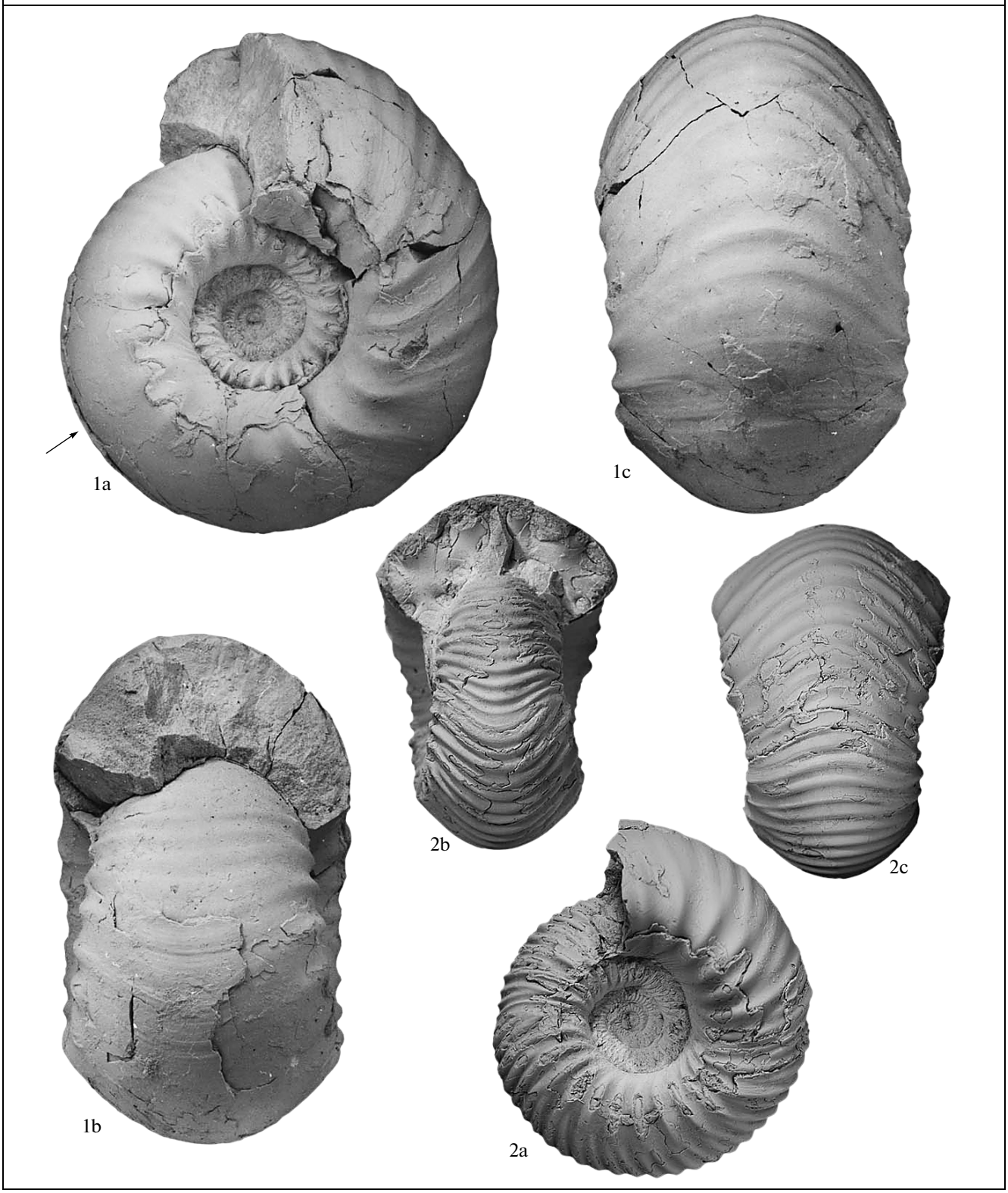

Plate II. *Cadoceras elatmae* (Nikitin, 1878):

(1) specimen no. 177/61: (a) lateral side, (b) apertural side, (c) ventral side; (2) the same specimen: (a) lateral side, (b) apertural side, (c) ventral side; western coast of Anabar Bay, Exposure 4, Bed 3, base; Cadoceras elatmae Zone, C. elatmae Subzone.

quite a number of ammonites known under different species names are in fact identical forms. The younger synonyms of species *C. frearsi* (Orbigny, 1845) include *C. anabarense* (Bodylevskii, 1960; Meledina, 1977, 1994), *C. multiforme* (Imlay, 1953; Meledina, 1977, 1994), *C. poultoni* (Gulyaev et el., 2002), and *C. pischmae* (Meledina, 1994). Morphological analogs of *C. elatmae* (Nikitin, 1881) are *C. apertum* (Callomon and Birkelund, 1985), *C. glabrum* (Imlay, 1953), *C. chisikense* (Imlay, 1953), *C. suevicum* (Callomon et al., 1989), and some others.

The other inference of great importance is the recognition of a wider distribution area of *C. frearsi* (Orb.) and *C. elatmae* (Nik.), characteristic of the lower Callovian in North Siberia. As we concluded, the geographic range of both species having a high correlation potential extends beyond European Russia.

Zone C. elatmae of Siberian sections is an age analog of a synonymous zone in European Russia. In the latter region, this zone bears, in addition to species common in Siberia and listed above, the following ammonites: *C. simulans* Spath, *Cadochamoussetia subpatruus* (Nik.), *Chamoussetia chamousseti* (Orb.), and representatives of genera *Macrocephalites* and *Kepplerites*. In the initial definition, the C. elatmae Zone was supplemented with a second index *Macrocephalites macrocephalus* (*Resolutions*..., 1962). Later on, the Macrocephalites Beds of the basal Callovian were excluded from the C. elatmae Zone (*Resolution*..., 1978; *Zones*..., 1982; *Unified*..., 1993). It was also suggested to divide the C. elatmae Zone into the Macrocephalites ex gr. jacquoti and C. elatmae subzones and to change its name for the Costacadoceras mundum Zone (Alekseev and Repin, 1989; Repin and Rashvan, 1996).

At present, researchers are still discussing different proposals concerning the lower Callovian subdivision in European Russia. It has been suggested, for instance, to regard the C. elatmae Zone as consisting of C. elatmae and Cadochamoussetia subpatruus subzones (Mitta and Starodubtseva, 1998) or to divide it into three subzones, adding the Kepplerites keppleri Subzone from below (Mitta, 2000, 2008). Other researchers distinguish up to six biohorizons in the zone (Gulyaev, 1997, 2001, 2005; Kiselev and Rogov, 2007a, 20076; Mitta, 2004, 2008). In the last version of the Boreal standard zonation (Zakharov et al., 2005) the individualized Cadochamoussetia subpatruus Zone is differentiated from the C. elatmae Zone according to a proposal of Gulyaev (2005).

Restoring the C. elatmae Zone in the lower Callovian of the Siberian zonation, we take into consideration that it contains species in common with ammonites from a synonymous zone of European Russia. First of all, these are *C. frearsi* (Orb.) and its synonym *C. primaevum* (Sas.) in the opinion of Mitta (2000), Kiselev and Rogov (2007a, 2007b). Both latter species are fixed in all zonations, being confined to the lower Macrocephalites jacquoti Subzone of the C. elatmae Zone. The base of this subzone corresponds to the Callovian lower boundary. In Siberia, the same boundary coincides with the base of the C. frearsi Subzone.

In all zonations of the lower Callovian suggested at present for European Russia, the index species *C. elatmae* (Nik.) is recorded above the base of the synonymous zone. In zonation by Gulyaev, this index species is missing from the M. jacquoti Biohorizon, the basal one in the C. elatmae Zone. The Bodylevskyi and Falsum biohorizons of the same zone are deprived of *C. elatmae* (Nik.) in the zonation by Mitta (2000), whereas Kiselev and Rogov (2007a, 2007b) reported on the *C. elatmae* (Nik.) occurrence above three lower biohorizons (Breve, Frearsi, Quenstedti) of the zone.

We should also note that in European Russia, species *C. elatmae* (Nik.) are found above the occurrence level of *C. frearsi* (Orb.) (Mitta, 2000). In contrast, index species of the Elatmae Zone and the Frearsi Subzone appear concurrently in Siberian sections above the C. calyx Zone, whose upper boundary is simultaneously the base of the C. elatmae Zone. This discordance in occurrence levels, which are established for the designated *Cadoceras* species of the lower Callovian in two adjacent regions, indicates, we believe, an earlier origin of *C. elatmae* (Nik.) in the seas of Siberia than in East European basins.

Correlation. Zone C. elatmae in its whole range is recognizable not only in European Russia, but also in Siberia based on the *Cadoceras* species in common. In sections of European Russia, this zone is reliably correlated with the lower part of the Macrocephalites herveyi Zone in the international standard, and this circumstance determines its position in North Siberia relative to the M. herveyi Zone (see the table).

Species close in morphology to *C. frearsi* (Orb.) and *C. elatmae (Nik.)* or even identical to the former without doubt are known from northern sections of European Russia (*C. pischmae* Mel.), where the relevant zone is present apparently.

In East Greenland and Alaska there are clearly recognizable equivalents of the C. frearsi Subzone in Siberian sections (*C. apertum* Call. et Birk., *C. multiforme* Imlay, *C. glabrum* Imlay, *C. chisikense* Imlay; Imlay, 1953), whereas ammonites of the upper C. elatmae Subzone of the synonymous zone are unknown from these regions. Judging from its position in the succession, the C. nordenskjoeldi Zone of East Greenland is presumably an analog of the upper subzone. However, ammonites from the latter zone differ from species *C. elatmae* that are widespread in Siberia. Describing *C. nordenskjoeldi*, Callomon (1985, 1993) noted that this endemic species occurring in two biohorizons at least is closer to perisphinctids than to car-

Plate III

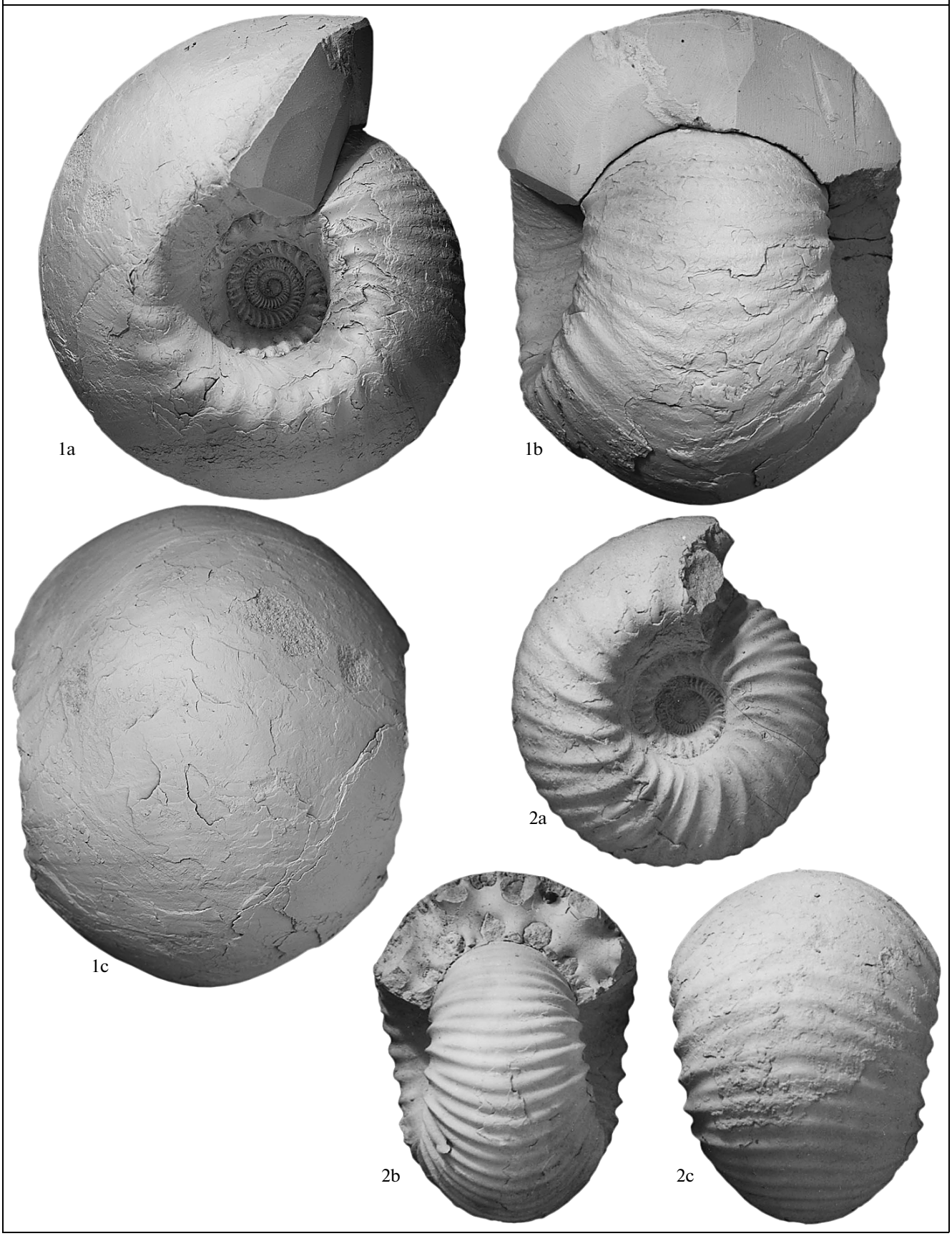

Plate III. *Cadoceras tschernyschewi* (Sokolov, 1912):
(1) specimen no. 177/114, (a) lateral side; (b) apertural side, (c) ventral side; (2) specimen no. 177/8, (a) lateral side, (b) apertural side, (c) ventral side; western coast of Anabar Bay, Exposure 4, Bed 4, lower interlayer of concretions; Cadoceras tschernyschewi Zone.

dioceratids. According to the recently published opinion of Mitta (2008), who displaced the C. apertum Zone into the Bathonian C. nordenskjoeldi Zone, the former zone corresponds to the K. keppleri Subzone, established in the C. elatmae Zone of European Russia. Kiselev and Rogov (2007a, 2007b), who accept the traditional subdivision of the Bathonian and Callovian in East Greenland (Callomon, 1993), define, following Callomon, (in 2003) the boundary between these stages inside the C. apertum Zone at the top of the C. apertum α Beds.

Distribution: European Russia, North Siberia, Franz-Josef Land, Novaya Zemlya (occurrence of *C. anabarense* Bodyl. in the last case).

Cadoceras tschernyschewi Zone

Index species: *Cadoceras tschernyschewi* (Sokolov, 1912). Lectotype: TSNIGRMuseum, specimen no. 4/1370 (Sokolov, 1912, Pl. 1, Fig. 2). Pechora River basin, Tsilma River; lower Callovian.

Nomenclature. Mitta first distinguished the *C. tschernyschewi* Biohorizon in the *C. elatmae* Subzone of East European sections (Mitta and Starodubtseva, 1998). Gulyaev (1999, 2005, 2007) considered the synonymous biohorizon as part of the Subpatruus Zone, interpreted by Mitta (2000) in the rank of the upper subzone of the C. elatmae Zone. We include the tschernyschewi Zone in our zonation, which was recently suggested for North Siberia (Knyazev et al., 2009a, 2009b). In this work, its discrimination is substantiated more completely.

The **stratotype of the zone** is on the western coast of Anabar Bay, Exposure 4, Bed 4, in the lower horizon of calcareous aleurolite concretions.

Boundaries. The lower boundary is defined at the first occurrence level of index species and *C.* cf. *stupachenkoi* Mitta; the upper one, at the appearance datum of *C. emelianzevi* Vor. and *C. tolype* Buck.

Characteristic ammonites: *C. tschernyschewi* (Sok.) (Pl. III, Fig. 1, 2), *C.* cf. *stupachenkoi* Mitta, and *Costacadoceras* spp.

Remark. In Eastern Europe, Mitta defined a synonymous biohorizon in the *C. elatmae* Subzone (Mitta and Starodubtseva, 1998). Gulyaev (1999, 2005, 2007) considered the same interval of deposits as the Tschernyschewi Biohorizon of the Subpatruus Zone.

Correlation. The Tschernyschewi Zone established in the Anabar region corresponds to interval of the *C. tschernyschewi* Biohorizon in the *C. subpatruus* Zone. The latter is analogous in age to the upper part in the standard Macrocephalites herveyi Zone.

Distribution: North Siberia; presumably recognizable in European Russia.

Cadoceras tolype Zone

Index species: *Cadoceras tolype* (Buckman, 1923); the holotype figures in the work by Buckman (1923, pl. CDVI, Figs. 1, 2; England, lower Callovian, Zone Proplanulites koenigi, Subzone Kepplerites curtilobus (Callomon et al, 1989).

Nomenclature. This zone was first introduced in the project of the Boreal standard zonation (Zakharov et al., 2005). In Siberia, it represents the lower part of the Emelianzevi Zone established earlier (Zakharov et al., 1997).

Stratotype is on western coast of Anabar Bay, Exposure 4, top horizon of concretions in Bed 4.

Boundaries. The lower boundary is at the appearance level of strongly swollen smooth shells of the index species and *C. emelianzevi* Vor.; the upper one marks the appearance of *C.* cf. *sublaeve* (Sow.).

Characteristic ammonites: *C. tolype* Buck. (Pl. IV, Figs. 1, 2) and *C. emelianzevi* Vor. (Pl. V, Figs. 1–3).

Remark. Distinct individualization of two morphotypes in the genus *Cadoceras* took place at the onset of the Tolype Phase. Species *C. tolype* Buck., exemplifying one morphotype, represented by large smooth cadicones with distinct umbilical thickenings and a narrow umbilicus; the intermediate and inner whorls are decorated with thick straight ribs broadly spaced. The other morphotype is inherent of *C. emelianzevi* Vor. with more frequent and thin ribbing on intermediated and inner whorls. D.N. Kiselev kindly donated for our examination small "C. tolype" shells from the lower Callovian of the Isada locality (Middle Volga region). These shells are very close in morphology to the Siberian *C. emelianzevi*, which presumably indicates the latter species' distribution beyond North Siberia.

Correlation. The Zone C. tolype is correlative with the Zone P. koenigi in the lower Callovian standard zonation accepted in England. The synonymous zone included in the lower Callovian is also accepted in the Boreal standard for Jurassic deposits (Zakharov et al., 2005) with due regard given to phylogenetic considerations of Kiselev (2005) who established the C. tolype Biohorizon in European Russia and correlated it with

Plate IV

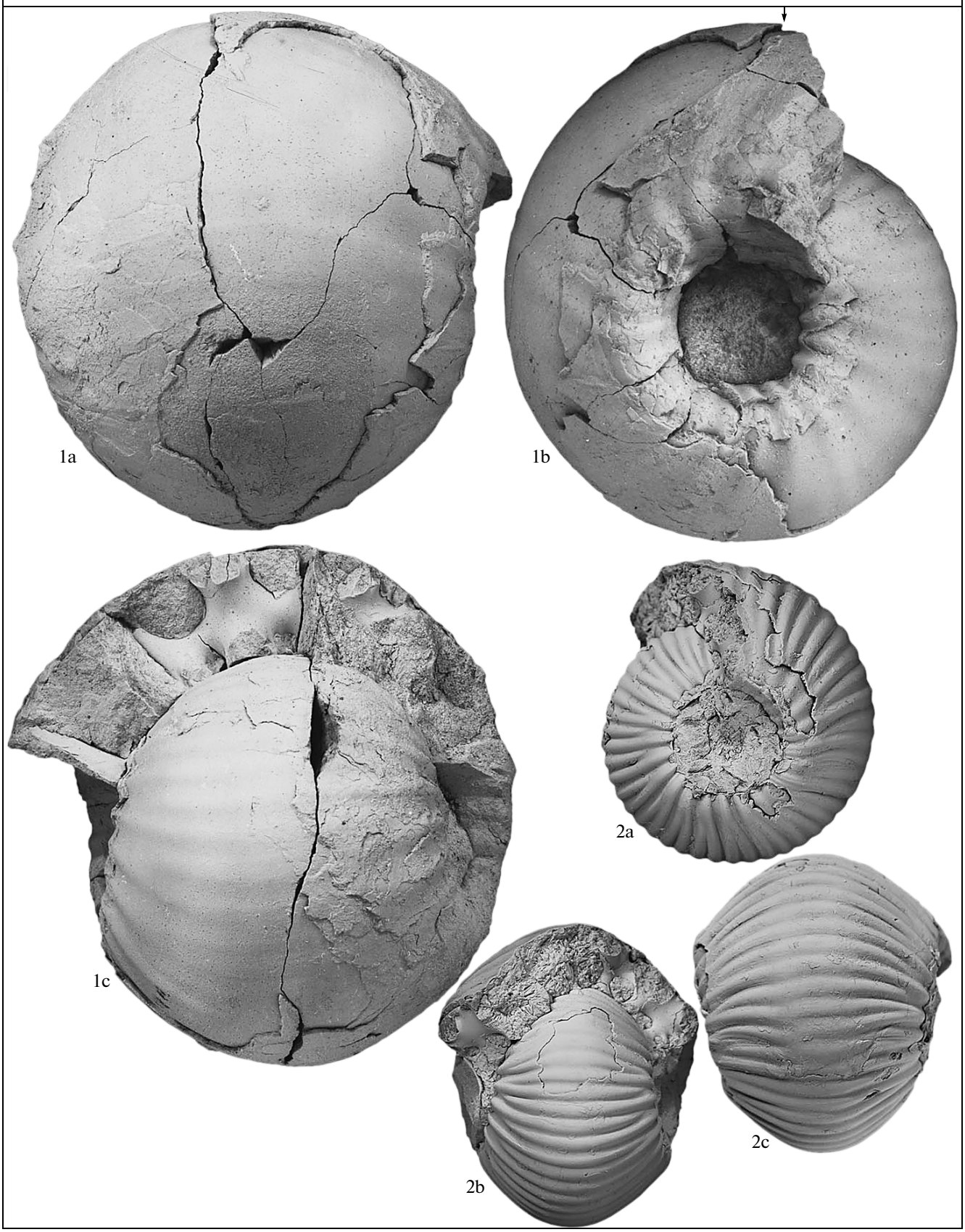

Plate IV. *Cadoceras tolype* Buckman, 1923:
(1) specimen no. 177/324: (a) ventral side, (b) lateral side, (c) apertural side; (2) specimen no. 177/86: (a) lateral side, (b) apertural side, (c) ventral side; western coast of Anabar Bay, Exposure 4, Bed 4, upper interlayer of concretions; Cadoceras tolype Zone.

the C. emelianzevi Zone in Siberia and partly with the P. koenigi Zone in England.

In Arctic Canada and East Taimyr probably, age analogs of the C. tolype Zone are represented by the C. septentrionale Beds (Frebold, 1964; Callomon, 1984; Meledina and Aleinikov, 1995).

Distribution. The Zone C. tolype is established in North Siberia (Anabar Bay, Bolshoi Begichev Island, the lower reaches of the Lena River), Franz-Josef Land, and Novaya Zemlya; and the concurrent C. septentrionale Beds in the East Taimyr and Arctic Canada. In European Russia, Kiselev (2005) distinguished a synonymous subdivision, the C. tolype Biohorizon of the P. koenigi Zone. In the project of Boreal standard zonation, this biohorizon is included in the rank of a zone (Zakharov et al., 2005).

Cadoceras cf. sublaeve Beds

Index species: *Cadoceras* cf. *sublaeve* (Sowerby, 1814) (Knyazev et al., 2009a, Pl. IV, Fig. 2).

Nomenclature. Knyazev distinguished first the nominated beds on the Bolshoi Begichev Island, where he found *C.* cf. *sublaeve* (Sow.) below beds with *Rondiceras milaschevici* and *Cadoceras* ex gr. *durum*. Earlier, the beds were regarded as part of the C. emelianzevi Zone (Meledina, 1977, 1994).

Boundaries. The lower boundary is defined at the base of the clay interval with concretions containing *C.* cf. *sulaeve* (Sow.); the upper boundary corresponds to the appearance level of *Rondiceras milaschevici* (Nik.) and *Cadoceras* ex gr. *durum* Buckm.

Characteristic ammonites: *C.* cf. *sublaeve* (Sow.).

Type locality: Bolshoi Begichev Island, Exposure 503, Bed 5, upper part 2.2-m thick.

Correlation. The C. cf. sublaeve Beds correspond in range to the Zone and Subzone Sigaloceras calloviense, because species *C. sublaeve* (Sow.) is found in England precisely in the designated subzone (Callomon et al., 1988; Page, 1988; Callomon, 1993). The same stratigraphic position of the species is established in East Greenland (Callomon, 1985, 1993). In European Russia, the stratigraphic range of the species corresponds to the entire S. calloviense Zone (Gulyaev, 2001, 2005). In the last version of the Boreal standard (Zakharov et al., 2005), the C. cf. sublaeve Beds correspond to the C. tscheffkini Zone situated between zones C. tolype and C. milaschevici.

Beds bearing *C.* cf. *sublaeve* can be correlated with part of the so-called "Upper Cadoceras Beds" established on the Axel Heiberg Island and in the northeastern Richardson Mountains, the Canadian Arctic, where species *C. septentrionale* Freb. and *C. septentrionale* var. *latidorsata* Freb. have been described (Frebold, 1964). The author of both species and Callomon (1985, 1993) are of the opinion that they belong to the *C. sublaeve* group. The beds were originally correlated with the S. calloviense Zone (Frebold, 1964). However, the joint occurrence of *C. septentrionale* var. *latidorsata* Freb. and *C. (Stenocadoceras) canadense* Freb. is an important fact suggesting the higher position of two designated ammonites above the S. calloviense Zone, because the subgenus *Stenocadoceras* is a typical taxon of the middle Callovian. A more precise correlation between the beds under consideration and their equivalents in the Canadian Arctic would be speculative.

Rondiceras milaschevici–Cadoceras ex gr. durum Beds

Index species: *Rondiceras milaschevici* (Nikitin, 1881) and *Cadoceras* ex gr. *durum* (Buckman, 1922); Pl. VI, Figs. 1, 2. Lectotype: *Stephanoceras milaschevici* Nikitin, 1881, Pl. 3, Fig. 25. TSNIGRMuseum, specimen no. 60/1369. Yaroslavl oblast, Rybinsk section; middle Callovian, Zone Kosmoceras jason.

Nomenclature. The biostratigraphic unit is first distinguished.

Boundaries. The lower boundary is at the appearance level of index species; the upper one presumably corresponds to the extinction level of *Cadoceras* ex gr. *durum* (Buckman).

Characteristic ammonites: *Rondiceras milaschevici* (Nik.) and *Cadoceras* ex gr. *durum* (Buckman) (Pl. VI, Fig. 1,2).

Type locality: Bolshoi Begichev Island, Exposure 503, Bed 6; thickness 1.5 m.

Remark. In stratigraphic charts currently used in Siberia (Shurygin et al., 2000; *Regional*..., 2004), the respective biostratigraphic unit is designated as the Rondiceras milaschevici–Erymnoceras (?Rollierites) sp. Beds of the middle Callovian. We changed the second index for *Cadoceras* ex gr. *durum* (Buck.), because the well-preserved ammonites first discovered by Knyazev are determined at present under this taxonomic name. Formerly, similar ammonites with coarse ribbing on deformed inner whorls were classed with species of the genus *Erymnoceras (?Roilierites)* (Meledina, 1977).

Correlation. The Rondiceras milaschevici–Cadoceras ex gr. durum Beds correspond to the S. call-

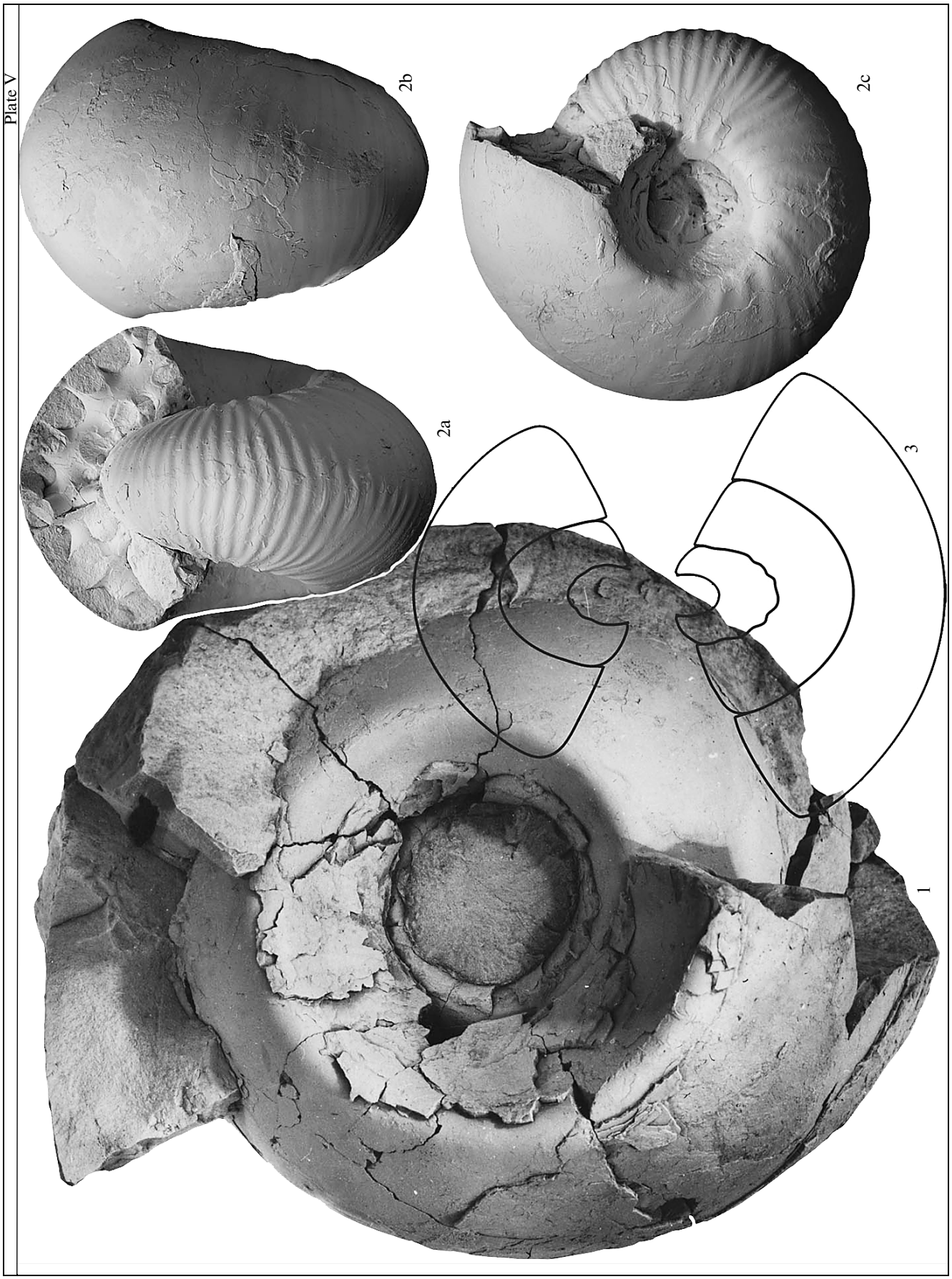
Plate V
2b
2a
2c
3
1

Plate V. *Cadoceras emelianzevi* Voronez, 1962:
(1) specimen no. 177/55-1, lateral side; (2) the same specimen: (a) apertural side; (b) lateral side, (c) ventral side; (3) cross section of inner whorls in the same specimen; western coast of Anabar Bay, Exposure 4, Bed 4, upper interlayer of concretions; Cadoceras tolype Zone.

oviense Zone in England, whose characteristic ammonites belong to genera *Cadoceras*, *Rondiceras, Catasigaloceras*, and others. The occurrence of *C.* ex gr. *durum* (Buck.) above the C. cf. sublaeve Beds suggests that Siberian sections include age equivalents of the standard Catasigaloceras enodatum Subzone (Callomon, 1985; Page, 1988, 1995). The concurrent occurrence of *R. milaschevici* (Nik.) does not contradict this inference, because this species, widespread in the middle Callovian also occurs, according to recent data, in the upper part of the lower Callovian (Kiselev, 2005, 2006; Zakharov et al., 2005).

Distribution: North Siberia, Bolshoi Begichev Island.

CONCLUSIONS

In North Siberia, the upper part of the Bathonian Stage is divided into three biostratigraphic intervals: the Arcticoceras (?) cranocephaloide Zone (with C. barnstoni Beds at the top) and zones C. variabile and C. calyx (Knyazev et al., 2006, 2009a, 2009b). The Bathonian–Callovian boundary is defined in this work between zones C. calyx and C. elatmae. The succession of zones and beds with ammonites suggested for the lower Callovian is as follows: the C. elatmae Zone with subzones C. frearsi and C. elatmae; the C. tschernyschewi Zone; the C. tolype Zone; the C. cf. sublaeve Beds; and the Rondiceras milaschevici–C. ex gr. durum Beds. The lower–middle Callovian boundary is tentatively defined at present between the R. milaschevici–C. ex gr. durum and R. sp. ind. beds. The interval of R. milaschevici–Erymnoceras (?Rollierites) Beds formerly attributed to the middle Callovian is ranked in this work as the R. milaschevici–C. ex gr. durum Beds of the lower Callovian, which are correlated with the standard Enodatum Subzone. As is proved, the lower Callovian Substage is completely represented in North Siberian sections in contrast to the earlier conclusion that they are lacking equivalents of the S. calloviense Zone (Meledina, 1994; Shurygin et al., 2000). In most cases, zonal subdivisions, as they are defined at present, can be directly correlated with zones of the lower Callovian standard zonation and with biostratigraphic units distinguished in sections of European Russia, East Greenland, and the Canadian Arctic. Further investigation of genera *Rondiceras* and *Longaeviceras* will show if there are grounds for distinguishing the middle Callovian in North Siberia.

As is shown in this work, the C. elatmae Zone established in North Siberia is of inhomogeneous taxonomic composition and can be divided into two subzones, which is an important result. The index species of the lower C. frearsi (Orb.) Subzone is practically identical to most specimens *C. apertum* Call. et Birk. from East Greenland, except for the holotype itself, a typical *C. elatmae* (Nik.), in our opinion. Accordingly, it is possible to suggest the isochronism of the C. frearsi Subzone and C. apertum Zone, which are correlative with the K. keppleri Subzone in Zone M. herveyi of the standard zonation. We should note also the similarity in the successions of cardioceratid genera and species since the moment of the appearance of their first representatives in North Siberia and East Greenland (*Boreiocephalites*, *Cranocephalites, Arctocephalites, Arcticoceras, Catacadoceras*, and *Cadoceras*). In East Greenland, the succession is interrupted above the C. apertum Zone, and a corresponding break extends up to the P. koenigi Zone, i.e., through the interval corresponding to the C. elatmae Subzone and the C. tschernyschewi Zone. Later, after the P. koenigi phase, successions of biostratigraphic units, which are distinguished, based on cardioceratids, are again identical in both regions under comparison.

The lower Callovian ammonite zonation in East Greenland considered formerly as most complete was included in its time into the Boreal standard for Jurassic deposits (Zakharov et al., 1997). In its later version (Zakharov et al., 2005), the standard includes two parallel scales characterizing ammonite successions in East Greenland and European Russia.

As is shown in this work, the succession of species from the *Cadoceras* and *Rondiceras* genera is as complete in North Siberia (sections of Anabar Bay and Bolshoi Begichev Island) as in European Russia. Certain ammonite species of a wide geographic range discovered in Siberia (*C. elatmae, C. frearsi, C. tolype, C. emelianzevi*) provide grounds for a direct correlation between the zones of the studied sections and international standard zonation. The other species known far away from Siberia are important for correlation between the ammonite zonations in Siberia, East Greenland, European Russia, Canadian Arctic, and Alaska.

ACKNOWLEDGMENTS

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Plate VI

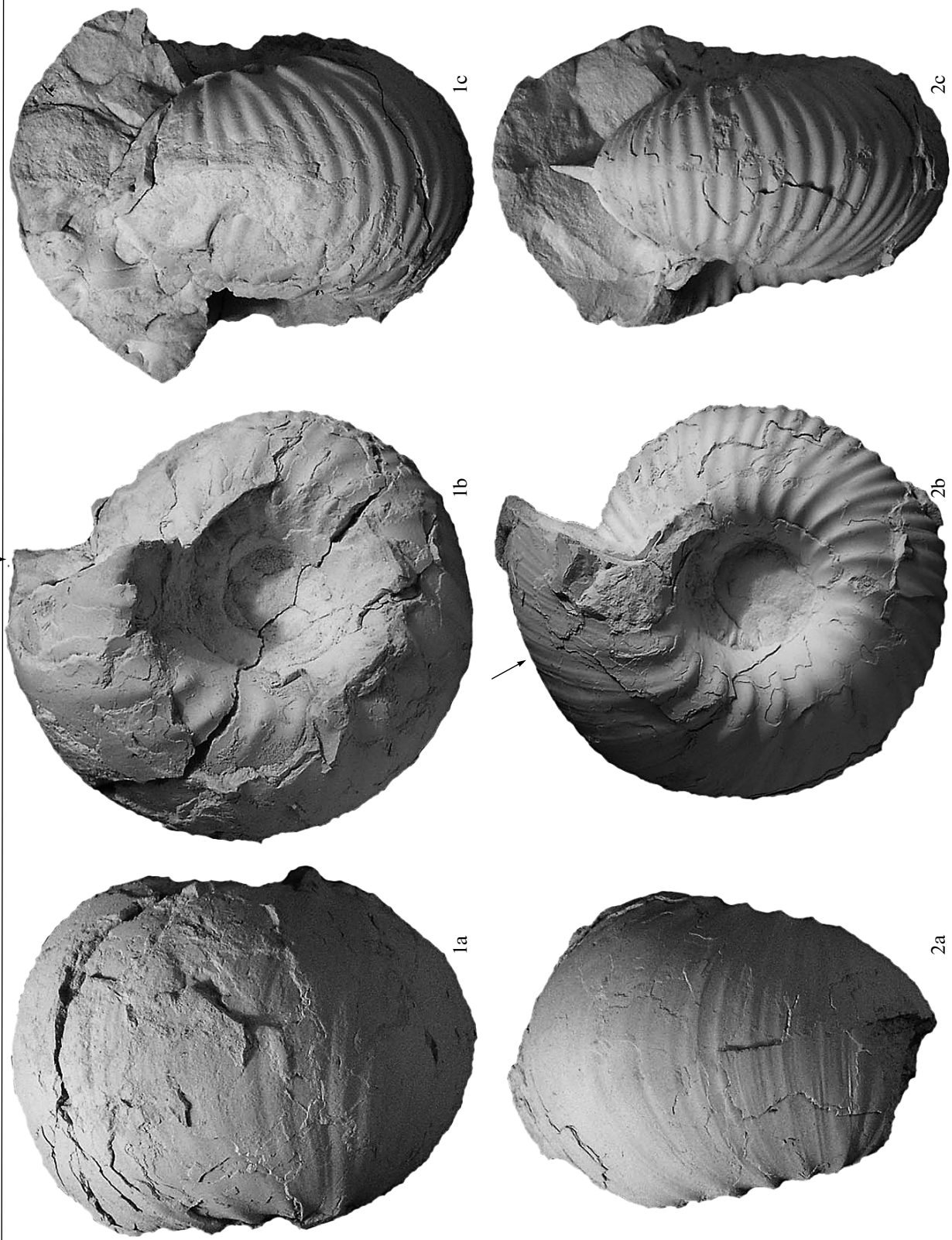

Plate VI. *Cadoceras* ex gr. *durum* Buckman, 1922:
(1) specimen no. 177/640: (a) ventral side; (b) lateral side; (c) apertural side; (2) specimen no. 177/642: (a) ventral side; (b) lateral side; (c) apertural side; Bolshoi Begichev Island, Exposure 503, top of Bed 6; Rondiceras milaschevici and Cadoceras ex gr. durum Beds.

comments, and to A.G. Stepanov who photographed the reproduced ammonite shells.

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V.A. Zakharov, and M.A. Rogov

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