

The Middle-Upper Jurassic Boundary in the North of Siberia: Problems of the Evidence

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Abstract—The grounds for identifying the *Eboraceras subordinarium* Zone in the Upper Callovian of Siberia are critically discussed. The key sections of this zone and the ammonite assemblage that characterizes it are examined in detail. It is concluded that it is impossible to recognize the *Eboraceras subordinarium* Zone and its further use in stratigraphic schemes is not suggested. North Siberian taxa, previously identified as Late Callovian *Eboraceras*, are mostly assigned to *Rondiceras* and indicate a Middle Callovian age of the host rocks. Beds with *Cadoquenstedtoceras begichevi* have been proposed as an approximate equivalent of the European *Q. lamberti* Zone in the Upper Callovian of Siberia.

Keywords: ammonites, zone scale, upper Callovian, *Eboraceras*

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INTRODUCTION

Since the identification of the *Eboraceras subordinarium* Zone in the Siberian Callovian, and *Cardioceras obliteratum* in the Oxfordian (Knyazev, 1975; Meledina, 1977), the boundary between these zones coincides with the boundary of stages in the zonal scales of the Jurassic of Siberia. The recognition of both zones in sections in northern Siberia was considered justified. They were used in stratigraphic schemes and compilation of the boreal standard (Zakharov et al., 1997; Shurygin et al., 2000; *Reshenie...*, 2004; Nikitenko et al., 2013). In recent years, the authors of this paper have been revising the system of Callovian ammonites in Siberia (Knyazev et al., 2020; Knyazev and Alifirov, 2022; Alifirov and Knyazev, 2020) and were faced with the problem of substantiating the *Eboraceras subordinarium* Zone, which will be described in detail below. In Western Europe an equivalent of the Subordinarium Zone is considered to be the Lamberti Zone, which is present in the stratigraphic scheme of Western Siberia and in some versions of the Boreal standard (*Reshenie...*, 2004; Zakharov and Rogov, 2014).

Callomon and Wright (1989) questioned the full correspondence of the Subordinarium and Lamberti zones; they did not accept the presence in Siberia of the genus *Eboraceras* Buckman, to which ammonites were assigned by Meledina (1977, 1994; etc.). The ideas of Callomon and Wright (1989) were not accepted in the Russian literature until the publication of papers by Repin (2002, 2008) and Repin et al. (2006), assigning the Siberian “*Eboraceras*” to the new genus *Dol-*

ganites Repin, and identifying in the Upper Callovian, the new *Adzvensis* and *Adzvavomense* zones, correlated to the Lamberti Zone differently from the Subordinarium Zone.

The problem of identifying the genus *Eboraceras* in Siberia was considered by Knyazev and Alifirov (2022). As a result, *Cadoquenstedtoceras* Knyazev et Alifirov, a new genus of cardioceratids was established. This paper examines in detail the key Siberian sections for the Callovian-Oxfordian boundary interval in order to clarify the position of the boundary of these stages.

MATERIAL

The authors have at their disposal a rich collection of ammonites from the Callovian-Oxfordian boundary deposits of Siberia, collected by V.G. Knyazev (IGABM SB RAS), S.V. Meledina (INGG SB RAS), A.N. Aleinikov (SNIIGGiMS), and A.S. Alifirov (INGG SB RAS) for five decades and represented by numerous specimens of excellent preservation. The work uses paleontological and stratigraphic data on the Callovian and Oxfordian sections on the Anabar River, eastern shore of Anabar Bay, Bolshoy Begichev Island, Eastern Taimyr (Chernokhrebetnaya River).

STRATIGRAPHY

History of Study

In 1972, Beds with *Eboraceras* were recognized (Sax et al., 1972), in the Upper Callovian of Siberia

above the Keyserlingi Zone, which were characterized by the following ammonite assemblage: *Quenstedtoceras* (*Q.*) aff. *novosemelicum* (Bodylevsky), *Q.* (*Eboracicer*) *innocentii* (Bodylevsky), *Q.* (*E.*) *subordinarium* (Buckman), *Cadoceras* (*Stenocadoceras*) *stenolobum* (Keyserling), *C.* (*S.*) spp., *Longaeviceras* *bodylevskiyi* Meledina, *Pseudocadoceras* spp. (Knyazev et al., 1973, table 1). This ammonite assemblage was identified by S.V. Meledina and used by V.G. Knyazev in his monograph (1975).

In the rank of the Subordinarium Zone, this unit was first identified by Meledina (*Stratigrafiya...*, 1976, pp. 224–226) in Callovian sections of northern Siberia: in Eastern Taimyr, Anabar River and Bolshoy Begichev Island. The ammonite assemblage of the zone included *Eboracicer* *subordinarium* Buckman, *E. ordinarium* Buckman, *E. taimyrense* Meledina, *E. nikolaevi* (Bodylevsky), *E. bjegitschevi* (Bodylevsky), *Longaeviceras* sp. nov., *Quenstedtoceras* (*Soanicer*) *subgen. nov.*, *Q.* (*Q.*) *leachi* (Sowerby), *Vertumnicer* *nikitinanum* (Lahusen), *V. woodhamense* Arkell, *V. holtedahli* Salfeld et Frebald. A detailed description of the Subordinarium Zone was given by Meledina (1977, 1994).

In 1977, Meledina reported that the lower boundary of the *Eboracicer* *subordinarium* Zone, gradually, without visible gaps, overlapping the Keyserlingi Zone, is established on Bolshoy Begichev Island (Meledina, 1977, p. 208). Note that the description and characteristic ammonite assemblage are given from an isolated outcrop on the Innokentyevka River (outcrop 3), all ammonite finds here “are confined to the nodule horizon 6 m above the base of the unit” of sandy siltstones with a thickness of 7.2 m (Meledina, 1977, p. 209). The taxonomic composition of ammonites was supplemented by the species *Longaeviceras* *filorum* Meledina, *Quenstedtoceras* (*Soanicer*) *angustatum* Meledina, *Q.* (*S.*) *parvulum* Meledina, and *Stenocadoceras* *multicostatum* Imlay. In 1994, the description of the Subordinarium Zone remained virtually unchanged, with the exception of one, but important circumstance – the species *Eboracicer* *taimyrense*, originally described from a section of this zone on the Chernokhrebetnaya River (Eastern Taimyr), was re-assigned by Meledina (1994) to the genus *Rondicer* *Troizkaya* and was considered to be an indicator of the Middle Callovian. In subsequent works, the Subordinarium Zone, as part of the Boreal zonal standard (Zakharov et al., 1997), was used in stratigraphic schemes (Shurygin et al., 2000; Reshenie..., 2004) and for Callovian stratigraphy in boreholes (Alifirov and Meledina, 2010).

In the early 2000s, ammonites *Pavloviceras* Buckman and *Anabariceras* Stolyarova from the Subordinarium Zone on the Anabar river were described (Stolyarova and Meledina, 2004; Stolyarova, 2007). However, no data were provided confirming the co-occurrence of *Anabariceras* with *Eboracicer* *subordinarium*.

In 2006, Yu.S. Repin proposed an alternative approach to the division of the Upper Callovian of Siberia, using re-assignment of Siberian specimens of “*Eboracicer*” to *Dolganites* Repin. Instead of the Subordinarium Zone, he identified two units: the lower one is *Dolganites* *sibiricus*, the upper one is indicated by the sign “?” (Repin, 2005; Repin et al., 2006, table 4).

Eboracicer *Subordinarium* Zone in Callovian Sections of Siberia

Anabar River. One of the recent works on the Jurassic of the Anabar region discusses in detail the evolution of views on the zonal division of local Callovian sections (Nikitenko et al., 2022, text-fig. 3). Outcrops of Jurassic rocks are known on the right bank of the Anabar River, between the mouths of the Srednyaya and Sodiemykha rivers (Fig. 1), where over a distance of 24 km they show significant facies variability.

In the combined section (*Stratigrafiya...*, 1976), Member 39 of glauconite sandstone with a thickness of 1.6 m (Outcrop 8) is assigned to the Subordinarium Zone. At the base of the member there are lens-shaped accumulations of pebbles containing pieces of fossil wood and trunks up to 0.2–0.3 m in diameter. It is possible that a specimen of *Eboracicer* *subordinarium* originates from this locality (Knyazev et al., 1973, text-fig. 1, text-fig. 2, specimen no. 489-1), which was figured without an exact stratigraphic reference. A more precise description of the Bathonian-Volgian deposits in this area were published by Knyazev et al. (2017). The authors show that the aforementioned sandstone member (no. 39) with pieces of wood at the base cannot contain the assemblage of Late Callovian ammonites previously cited by Meledina (1977), since *Arcticoceras* *ishmae* (Keyserling) was found in the bed above it (Knyazev et al., 2017, pl. 4, fig. 3, pl. 5, fig. 4, pl. 6, fig. 3). Beds immediately below the Oxfordian deposits yielded ammonites of the genus *Cadochamousetia* Mitter (Knyazev et al., 2017, pls. I, II, III), which D.N. Kiselev (2022, p. 484) classified as other groups of cadoceratins.

When describing the species *Eboracicer* *subordinarium*, Meledina (1977, pp. 107–111) reported six specimens from the Anabar River, Outcrop 3 (collections of V.G. Knyazev). A single specimen no. 489-1 was found in the collection (Knyazev et al., 1973, text-fig. 1, text-fig. 2), which we assigned to the genus *Cadoquenedtoceras* Knyazev et Alifirov (Knyazev and Alifirov, 2022). The species *Quenstedtoceras* *angustatum* Meledina is represented by one specimen no. 489-115 (Outcrop 1, Bed 1). In addition, Meledina mentioned one specimen each of *Quenstedtoceras* (*Soanicer*) *parvulum* Meledina (not found in the collection) and *Vertumnicer* *nikitinanum* (Lahusen), associated with Outcrop 8. Thus, Member 39 (Outcrop 8, Beds 2, 3) is assigned by Meledina (1977, p. 185) to the Subordinarium Zone using specimens from dif-

Table 1. A list of identifications of Callovian ammonites from sections on Bolshoy Begichev Island and Eastern Taimyr in the works of S.V. Meledina and A.N. Aleinikov with the author's interpretation

Meledina, 1977	Meledina and Aleinikov, 1995	This study	Remarks
Bolshoy Begichev Island, Innokentyevka River, Outcrop 3			
Specimen 489/1, <i>Eboraceras subordinarium</i> Buckm.		<i>Cadoquenstedtoceras begichevi</i> Knyazev et Alifirov	Illustrated in (Knyazev et al., 1973, text-fig. 1, fig. 2)
Specimen 489/7, <i>Eboraceras subordinarium</i> Buckm. (pl. 43, fig. 1)		<i>Protolongaeviceras</i> sp.	<i>Dolganites sibiricus</i> Repin (Repin, 2002)
Specimen 489/2, <i>Eboraceras subordinarium</i> Buckm. (not figured)		<i>Protolongaeviceras</i> sp.	
Specimen 489/18, <i>Eboraceras subordinarium</i> Buckman (pl. 5, fig. 2)		<i>R. nikolaevi</i> (Bodylevskiy)	
Specimen 489/13–489/17, <i>Eboraceras subordinarium</i> Buckman (not illustrated)		<i>R. nikolaevi</i> (Bodylevskiy)	
Eastern Taimyr, Chernokhrebetnaya River			
	specimen 489/343, <i>Cadoceras</i> aff. <i>septentrionale</i> Frebold (pl. 2, fig. 2)	<i>Rondiceras</i> ex gr. <i>nikolaevi</i> (Bodylevskiy)	
	specimen 489/42, <i>Cadoceras septentrionale</i> Frebold (pl. 1, fig. 2)	<i>Rondiceras</i> ex gr. <i>nikolaevi</i> (Bodylevskiy)	
	specimen 489/284, <i>Eboraceras stenolobum</i> (Keyserling)	<i>Rondiceras stenolobum</i> (Keyserling)	
	specimen 489/347, <i>Longaeviceras keyserlingi</i> (Sokolov)	<i>Cardioceras</i> (<i>Scarburgiceras</i>) <i>scarburgense</i> (Young et Bird)	
Specimen 489/4, <i>Eboraceras subordinarium</i> (Bodyl.)		<i>Protolongaeviceras innocentii</i> (Bodyl.)	<i>Quenstedtoceras</i> (<i>Eboraceras</i>) <i>innocentii</i> (Bodylevskiy) in (Meledina, 1977 p. 111); <i>Dolganites sibiricus</i> Repin (Repin, 2002)
Specimen 489/299, <i>Rondiceras tschefkini</i> (d'Orbigny) (pl. 30, fig. 1, pl. 33, fig. 1)	<i>Stenocadoceras multicoatum</i> Imlay	<i>Rondiceras nikolaevi</i> (Bodylevskiy)	
All specimens <i>Quenstedtoceras</i> (<i>Soaniceras</i>) <i>parvulum</i> Meledina (pl. 44, fig. 3a, 3b, etc.)	<i>Quenstedtoceras</i> (<i>Soaniceras</i>) <i>parvulum</i> Meledina	<i>Pseudocadoceras parvulum</i> (Meledina)	
	<i>Longaeviceras filarum</i> Meledina (not illustrated)	? <i>Rondiceras nikolaevi</i> (Bodylevskiy)	

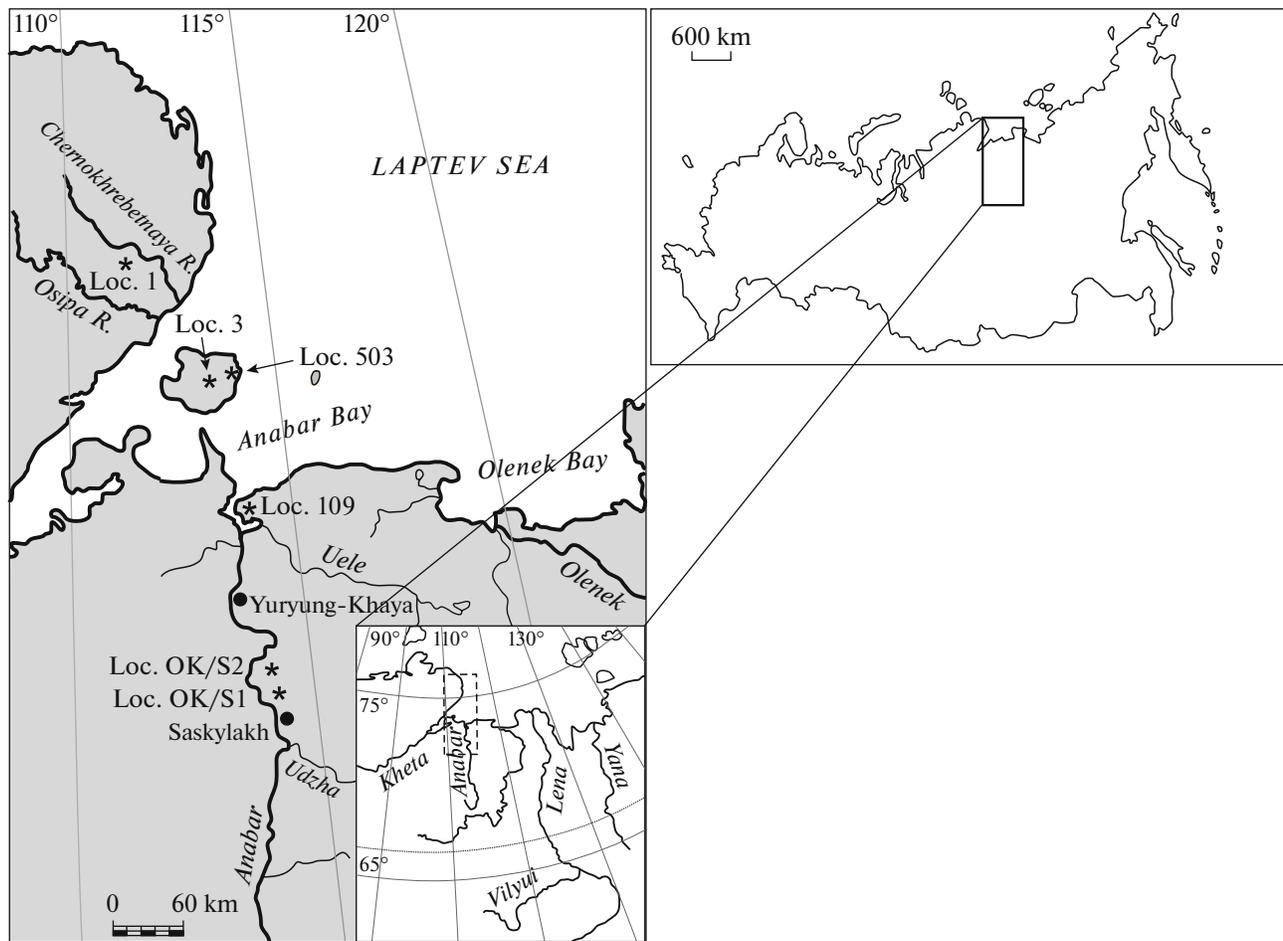


Fig. 1. Upper Callovian sections in northern Siberia. Outcrops are indicated by an asterisk (*).

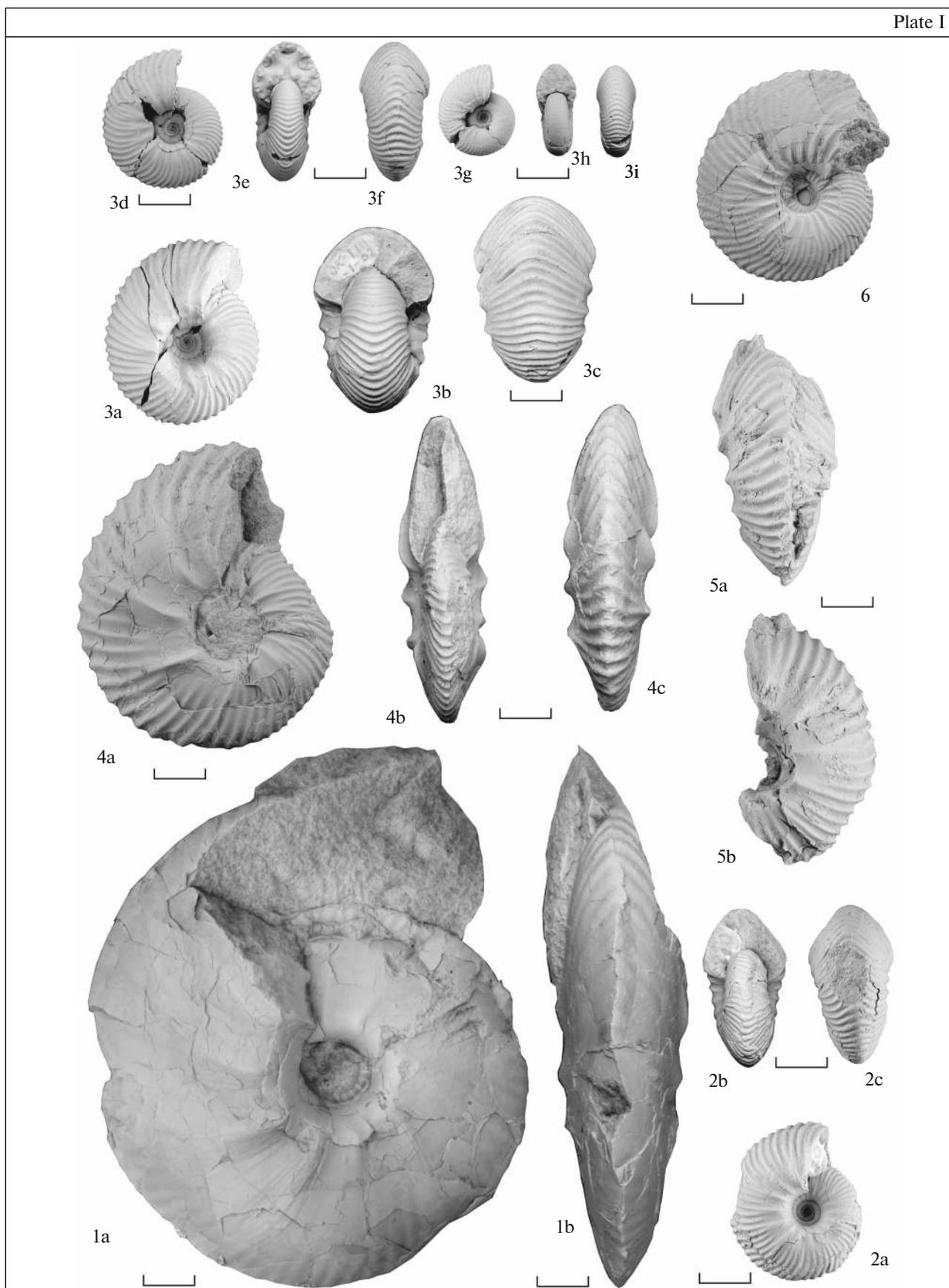
ferent outcrops, probably found not in situ. New data we obtained in 2013 (see Discussion) suggests that some areas between the mouths of the Polovinnaya and Sodiemykha rivers on the right bank of the Anabar River have Upper Callovian outcrops.

Eastern coast of Anabar Bay. In the Callovian section on the eastern shore of the Anabar Bay to the Subordinarium Zone along the Meledina (1994) assigned Member 47b (Outcrop 109, text-fig. 1), at the base of which there was an erosion surface with pebbles and pieces of silicified wood. She identified *Eboraceras*

subordinarium (which was not illustrated) from concretions within this member. The present authors re-examined this section in different years (Alifirov and Knyazev, 2020), and the presence of *E. subordinarium* was not confirmed. We identified large ammonites from Member 47b as *Longaeviceras nikitini* (Sokolov) (Alifirov and Knyazev, 2020, pl. I, fig. 1).

Bolshoy Begichev Island. According to Meledina (1977), deposits on Bolshoy Begichev Island show the most complete taxonomic characteristics of the Subordinarium Zone and has its lower boundary with the

Plate I. Here and in Plate II all illustrated specimens were collected by the authors, except where specifically noted. The collection is housed at the Center for Geological Collections "GEOCHRON" INGG SB RAS, coll. no. 2060. All specimens are figured at natural size. Scale bar 1 cm. (1, 4) *Quenstedtoceras nikitinianum* (Lahusen, 1883): (1a, 1b) no specimen. 2060/100, (1a) lateral view, (1b) ventral view; (4a–4c) specimen no. 2060/101: (4a) lateral view, (4b) apertural view, (4c) ventral view; Anabar River, Outcrop OK/S2, Bed 3, 0.4 m above the base, Lower Oxfordian, *Cardioceras obliteratum*–*Cardioceras scarburgense* Zone; (2–3) *Cadoquenedtoceras* sp. juv. (2a–2b) specimen no. 2060/10: (2a) lateral view, (2b) cross section, (2c) ventral view; (3a–3h) specimen no. 2060/11, (3a, 3d, 3g) lateral view, (3b, 3d, 3h) cross section, (3c, 3f, 3i) ventral view; Anabar River, Outcrop OK/S1, Bed 2, 0.2 m above the base, Upper Callovian, Beds with *Cadoquenedtoceras begichevi*; (5) *Cadoquenedtoceras begichevi* Knyazev et Alifirov: (5a–5b) specimen no. 2060/12, (5a) lateral view, (5b) ventral view; Anabar River, Outcrop OK/S1, Bed 2, 0.2 m above the base, Upper Callovian, Beds with *Cadoquenedtoceras begichevi*; (6) *Scarburgiceras scarburgense* (Young et Bird, 1828), specimen no. 2060/13, lateral view (specimen completely compressed); Anabar River, Outcrop OK/S2, Bed 3, 0.4 m above the base, Lower Oxfordian, *Cardioceras obliteratum*–*Cardioceras scarburgense* Zone.



Keyserlingi Zone. A continuous sequence of rocks is exposed in an coastal outcrop (Outcrop 503, Fig. 1). However, the entire ammonite assemblage, cited in many publications as characteristic of the Subordinarium Zone, was discovered in an isolated outcrop on the Innokentyevka River (Outcrop 3) (Meledina, 1977, p. 184). The authors of the present paper (Knyazev et al., 2020; Knyazev and Alifirov, 2022), as well as Kiselev (2022) concluded that ammonites from Outcrop 3 on the Innokentyevka River allow us to attribute the host strata to the Middle Callovian. Meledina (1977, p. 111) mentioned nine specimens of *Eboraceras subordinarium* in Bed 2, Outcrop 3 on the Innokentyevka River. In the monograph (Meledina, 1977, pl. 43, fig. 1), a single specimen no. 489-7 is illustrated from this outcrop, which was attributed by Yu.S. Repin to *Dolganites sibiricus* Repin, and by us to the Middle Callovian genus *Protolongaeviceras* Knyazev, Alifirov et Meledina (Knyazev et al., 2019; Knyazev and Alifirov, 2022).

Our revision of previous collections allowed us to establish the following.

(1) Most specimens collected from Outcrop 3 (Bed 2) on the Innokentyevka River, belongs to *Rondiceras nikolaevi* (Bodylevskiy). This species probably also includes specimens identified as *Eboraceras stenolumbum* (Keyserling) and *Longaeviceras filarum* Meledina. It is noted that almost all specimens of these species (about 40 specimens), both large cadicones and medium (small) platycones (suboxycones), do not have body chambers. However, ornamentation and shape of the shells of different growth stages observed in our specimens does not allow us to assign them to the genera *Eboraceras* and *Longaeviceras*. The type of ribbing up to a diameter of 45–50 mm is generally identical to that in typical *Catacadoceras* (Imlay, 1953), after which ribs become smoothed, starting from the umbilical shoulder. The shell shape of the inner and middle whorls has some variability in the degree of flattening; however, before reaching the adult living chamber, it begins to acquire the shape of a cadicone or spherocone, characteristic of *Rondiceras*, while the shells of *Stenocadoceras* at this stage remain compressed. Repin (Repin et al., 2006; Repin, 2008) placed the above species in the genus *Rondiceras*, the assignment we agree with.

(2) The sample of specimens of *E. subordinarium* Buckman sensu Meledina, 1977 is divided into two groups: I—specimens no. 489/7 (Meledina, 1977, pl. 43, figs. 1a, 1b) and 489/2 (not illustrated) and II—specimen. no. 489/13–489/18 (Meledina, 1977, pl. 5,

figs. 2a, 2b, only specimen no. 489/18). The first group has large final shell dimensions (more than 65 mm), differentiated ornamentation with reinforced primary ribs and a high ribbing coefficient. The bending of the ribs on the flanks and venter is similar to that of *Longaeviceras*. The shell shape up to 65 mm has the appearance of a pointed oval, but later it becomes wider, close to the shape of *R. nikolaevi*. We assign these specimens to the genus *Protolongaeviceras*. The second group is represented by shells with a diameter of up to 50 mm without body chambers. It is characterized by slightly strengthened primary ribs on the last observed half-whorl (Meledina, 1977, pl. 5, fig. 2), however, the shape of the section, the width of the umbilicus as a whole and the ribbing of the previous stages indicate the similarity of these specimens with the inner whorls of *R. nikolaevi* from this location.

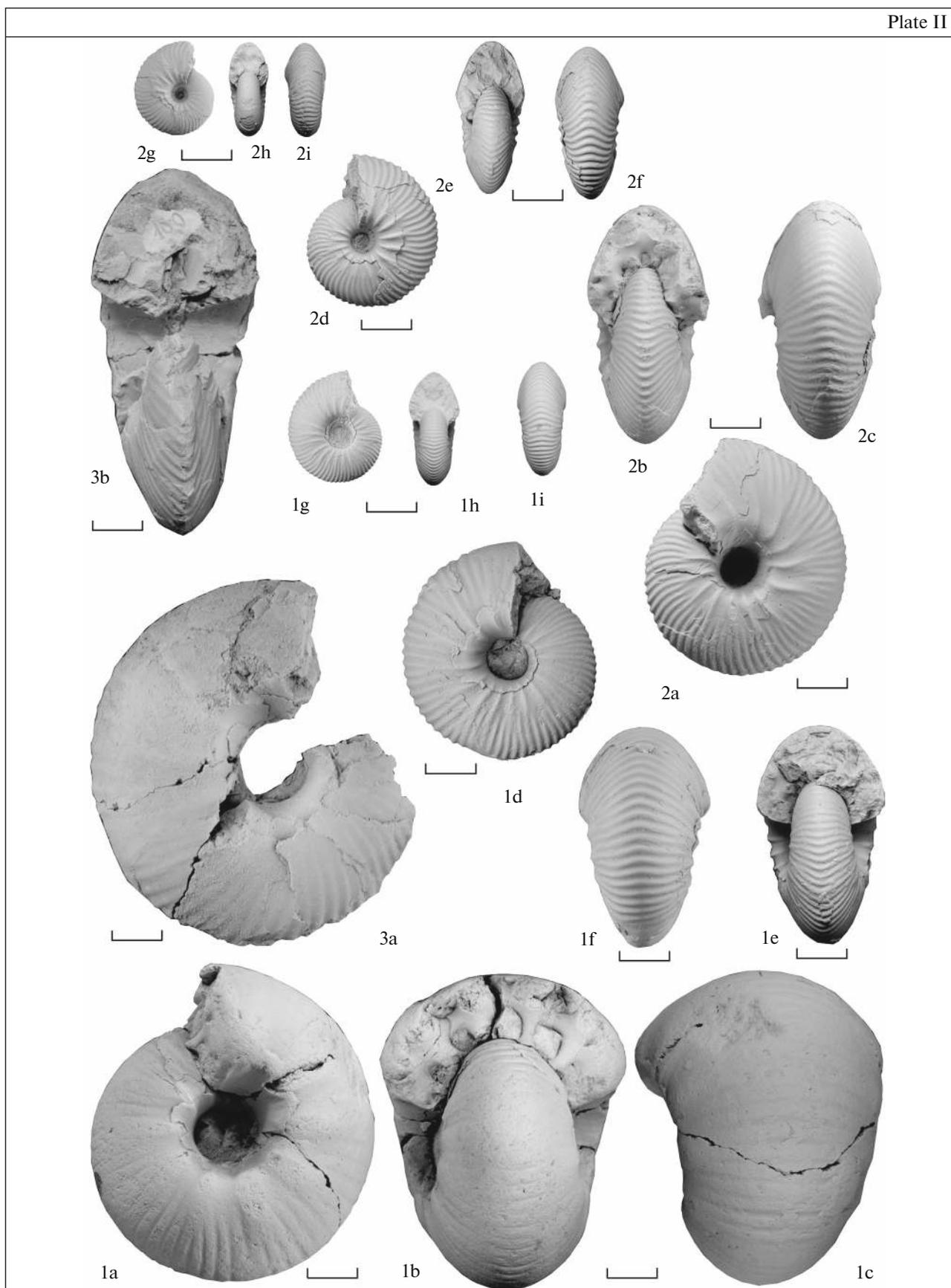
(3) The species *E. taimyrense* Meledina (Meledina, 1977, pl. 34, fig. 1, pl. 35, fig. 1, pl. 42, fig. 1, pl. 45, fig. 1, pl. 47, fig. 1) and *E. aff. taimyrense* (Meledina, 1977, pl. 42, fig. 2, pl. 45, fig. 3) should be assigned to *Rondiceras* (Meledina, 1994, etc.).

(4) Large specimens identified as *E. mologae* (Nikitin), *E. aff. grande* (R. Douville), have a shell shape that is not characteristic of the Late Callovian *Eboraceras*, and in internal whorls they are close to the Middle Callovian *Stenocadoceras* from the work of Imlay (1953).

(5) Several specimens assigned to *Vertumniceras nikitinianum* (Lahusen) (Meledina, 1977, pl. 9, fig. 3, pl. 10, fig. 2, pl. 16, fig. 3) and *V. woodhamense* Arkell (Meledina, 1977, pl. 17, figs. 3, 4), apparently belong to the genus *Percacosticeras* (Kiselev, 1999, 2022). Thus, the reference section for the Subordinarium Zone, namely Bed 2, containing the entire ammonite assemblage, belongs to the Middle Callovian, and according to our data, there is no index species. No data on the Subordinarium Zone in Outcrop 503 of Bolshoy Begichev Island are included Meledina's works.

Eastern Taimyr (Chernokhrebetnaya River). Outcrops of the Jurassic of Eastern Taimyr on the Chernokhrebetnaya River were considered as the most complete section of the Callovian-Oxfordian boundary beds in northern Siberia (Meledina, 1977, 1994; Meledina and Aleinikov, 1995). The Subordinarium Zone, discovered in the coastal cliff of the right bank of the Chernokhrebetnaya River, 17.2 km from the mouth, was initially considered to include Beds 1–5, Outcrop 1 with an apparent thickness of “not less than” 40 m (Meledina, 1977, pp. 181, 182). Note that the contact with underlying beds (lower boundary of the zone) was not observed in this section.

Plate II. (1, 2) *Cadoquenstedtoceras begichevi* Knyazev et Alifirov, 2022: (1a–1h) specimen no. 2060/14: (1a, 1d, 1g) lateral view, (1b, 1e, 1h) cross section, (1c, 1f, 1i) ventral view; (2a–2h) specimen no. 2060/15: (2a, 2d, 2g) lateral view view, (2b, 2d, 2h) cross section, (2c, 2f, 2i) ventral view; Bolshoy Begichev Island, Outcrop 503, scree, Upper Callovian, Beds with *Cadoquenstedtoceras begichevi*; (3) *Soaniceras cf. angustatum* (Meledina, 1977): (3a–3b) specimen no. 2060/102: (3a) lateral view, (3b) cross-section, Anabar River, Outcrop OK/S2, Bed 3, 0.4 m above the base, Lower Oxfordian, *Cardioceras obliteratum*–*Cardioceras scarburghense* Zone.



Later, it was suggested that it was erroneous to attribute Bed 1 (Member 1) (Meledina, 1994; Meledina and Aleinikov, 1995) to the Upper Callovian. Taking into account the data of A.N. Aleinikov, this member (35 m thick) was divided into five parts (with letter symbols a–e), bounded by five concretionary horizons identified here (Meledina, 1994, text-fig. 21; Meledina and Aleinikov, 1995, text-fig. 2). Based on the findings of *Cadoceras* aff. *septentrionale* Frebold (Meledina and Aleinikov, 1995; level 1a; pl. II, fig. 2) and *C. septentrionale* (Meledina and Aleinikov, 1995; levels 1a and 1c; pl. I, fig. 2) the Septentrionale Zone (Meledina, 1994; Meledina and Aleinikov, 1995). Examination of the specimens cited in the works cited above, the last of which was lost, suggests that, in fact, in terms of shell shape and the umbilicus width, they are typical of the Middle Callovian *Rondiceras* ex gr. *nikolaevi*.

Eboraceras cf. *subordinarium*, *E. taimyrense* and *E. stenolobum* (Keyserling) now included in the genus *Rondiceras* (Meledina, 1994), as well as *Quenstedtoceras* (*Soaniceras*) sp. (Meledina, 1977) were previously listed from level 1d (specimen no. 489–284 from the collections of T.P. Kochetkov from Eastern Taimyr, without exact locality reference). The latter, judging by their appearance (all specimens are rounded and worn), most likely were not found in situ. Later these forms were listed from Bed 2 (Meledina, 1994; Meledina and Aleinikov, 1995). Thus, in Outcrop 1 on the Chernokhrebetnaya River to the middle substage of the Callovian includes levels 1a–1d. The thickness of the Middle Callovian here may be 3–5 m (Meledina, 1994, p. 76), but this assumption needs to be confirmed.

In the overlying sediments (level 1e), Meledina and Aleinikov (1995, pl. II, fig. 4) listed *Longaeviceras keyserlingi* (Sokolov) morphologically not different from *Cardioceras* (*Scarburgiceras*) *scarburgense* (Young et Bird) (Meledina and Aleinikov, 1995, pl. I, fig. 3), listed from Bed 7, attributed to the Lower Oxfordian (Obliteratum Zone) (Meledina and Aleinikov, 1995).

According to the latest data in the area of the Chernokhrebetnaya River to the *Eboraceras* subordinarium Zone includes Members 2–5, Outcrop 1 (Meledina, 1994; Meledina and Aleinikov, 1995). Meledina (1977) indicates the presence of three specimens of *Eboraceras subordinarium* from the Callovian on the Chernokhrebetnaya River (1/1a, 1/2, 5/2). Only one specimen no. 489–4, was illustrated from Outcrop 5, Bed 2 (Meledina, 1977, pl. 39, fig. 4, pl. 41, fig. 2, pl. 43, fig. 2). Previously this specimen was attributed by Meledina (see Kaplan et al., 1974, p. 74) to *Quenstedtoceras* (*Eboraceras*) *innocentii* (Bodylevskiy) (Kaplan et al., 1974, pp. 107, 111), which, in our opinion, was correct, except for the generic affiliation of this species. According to the present authors (Knyazev et al., 2019), this species belongs to the Middle Callovian genus *Protolongae-*

viceras. Examination of numerous small shells not illustrated from Beds 2–5, Outcrop 1, identified as *Eboraceras* spp. and *Longaeviceras filarum* Meledina from the collections of Meledina (1977) and Meledina and Aleinikov (1995), made it possible to establish their assignment to the Early Oxfordian *Cardioceras* (*Scarburgiceras*) spp.

An additional ammonite assemblage from the Subordinarium Zone, which was collected from isolated outcrops on an unnamed left-bank creek (Meledina and Aleinikov, 1995, Outcrop 4, 5), contains *Eboraceras subordinarium* (aforementioned specimen no. 489–4); *E. nikolaevi* (Bodylevskiy) (currently *Rondiceras*); *Stenocadoceras multicostatum* Imlay, originally (Meledina, 1977, pl. 30, fig. 1, pl. 33, fig. 1) correctly identified as *Rondiceras*; *Q.* (*Soaniceras*) *parvulum* Meledina that in our opinion should be assigned to *Percacosticeras* Kiselev; *L. filarum* Meledina; ?Middle Callovian *R. nikolaevi*; *Longaeviceras novosemelicum* (Bodylevskiy) (in Meledina, 1994, p. 77—this is “*Vertumniceras*” *nikitinianum* (Lahusen)). Thus, Early Callovian–Early Oxfordian ammonites of different ages are brought together into a single assemblage of the Subordinarium Zone.

Quenstedtoceras (*Soaniceras*) *angustatum* Meledina (Meledina, 1977, p. 209) mentioned in the same assemblage is the type species of the genus *Soaniceras* Meledina, 1977 (subjective synonym—*Anabariceras* Stolyarova, 2007). We question the vertical range of distribution of the genus *Soaniceras* (Late Callovian (Subordinarium Zone)—Early Oxfordian (Obliteratum Zone)) due to the following circumstances: the holotype of the type species *Soaniceras angustatum*, judging by its state of preservation (rounded and worn), was not found in situ (Meledina, 1977, pl. 46, figs. 1a–1d), which is confirmed by a field label indicating the discovery of the sample in the river bed of the Innokentyevka River (Bolshoy Begichev Island) near the mouth. The shell is represented only by a phragmocone. The most complete characteristics of *Soaniceras* were compiled taking into account the detailed ontogeny of *S. meledinae* (Stolyarova), the type species of the genus *Anabariceras* (Stolyarova, 2007, pl. 4), originating from a section on the right bank of the Anabar River (between the mouths of the Polovinnaya and Sodiemykha rivers). Analysis of the vertical distribution of *Anabariceras* specimens (including *A. meledinae*) suggests their Early Oxfordian age, which is confirmed by numerous co-occurrences with *Cardioceras* (*Scarburgiceras*) *obliteratum* Knyazev, while co-occurrence with *E. subordinarium* Buckman has not been established. Thus, species of the genus *Soaniceras* cannot be used as indicators of the Subordinarium Zone. Revision of the taxonomic composition of cardioceratids from Callovian–Oxfordian outcrops on the Chernokhrebetnaya River allowed the following conclusions: In Outcrop 1, the Middle Callovian (Bed 1a–1d) is overlain by the Lower Oxfordian (Bed 1e). Layers 2–5 belong to the Lower

Oxfordian, Obliteratum–Scarburgense Zone. The Subordinarium Zone is not confirmed by the findings of the index species, while the ammonite assemblage by Meledina and Aleinikov (1995) cannot be used to recognize it.

DISCUSSION

The above analysis of Callovian sections examining the possibility of establishing the Subordinarium Zone shows that such sections have not been reliably found in the north of Siberia. Inaccuracies in the identifications of ammonites and unreliable stratigraphic reference do not leave the possibility of identifying the Subordinarium Zone in the Upper Callovian of Siberia on the basis of previous data (Meledina, 1977, 1994; Meledina and Aleinikov, 1995). Outcrop 503 on Bolshoy Begichev Island is the only section discussed in this paper in which a continuous sequence of Upper Callovian zones can be recognized (Fig. 2a). Here at the base of Bed 15, as well as in the scree, V.G. Knyazev collected ammonites, which we described under the new generic name *Cadoquenedtoceras* Knyazev et Alifirov (Knyazev, Alifirov, 2022). The underlying deposits (members 9–14) belong to the *Longaeviceras keyserlingi* Zone based on finds of *Longaeviceras* sp. ind. (Alifirov et al., 2017). Overlying Member 16 contains *Cardioceras arcticum* Pavlov, which allows this member to be assigned to the Lower Oxfordian Percaelatum and Cordatum zones.

As shown by Knyazev and Alifirov (2022), specimens of *Cadoquenedtoceras* have *Quenedtoceras*-like inner whorls (subtriangular shell shape, differentiated ribbing), while the outer whorls are similar to the shell of *Cadoceras sublaeve* (Sowerby). We suggest that ammonites of this genus are characteristic of the terminal Callovian of Siberia. The closest to *Cadoquenedtoceras* in terms of shell shape are representatives of the genera *Goliathiceras* Buckman and *Pavloviceras* Buckman, from which it differs in the ontogeny of ornamentation (Knyazev and Alifirov, 2022). On the Anabar River, the Oxfordian Stage apparently rests on different Callovian horizons. Knyazev et al. (2017) described Outcrop OK/S2 (Fig. 2c), in which the Lower Oxfordian beds with *Cardioceras oblitteratum* Knyazev are underlain by the Lower Callovian deposits with *Cadochamousetia* Mitter. We have established the presence of a new Late Callovian genus, *Cadoquenedtoceras*, in this area. The lens-shaped outcrop of carbonated sandstone (Outcrop OK/S1) (Fig. 2b) contained *Cadoquenedtoceras* sp. juv. (pl. I, figs. 2, 3) and *Cadoquenedtoceras begichevi* Knyazev et Alifirov (pl. I, fig. 5). The species *Cadoquenedtoceras begichevi* (without exact stratigraphic reference) was also discovered in the Chernokhrebetnaya River basin, indicating the presence in this area of possible equivalents of the Lamberti Zone (Knyazev and Alifirov, 2022, pl. II, fig. 1).

Callovian–Oxfordian Boundary in Siberia

In the sections discussed in this paper, Lower Oxfordian deposits have been reliably established. However, contact of the Beds with *C. begichevi* and the basal Oxfordian Obliteratum Zone was not found in any of them.

On Bolshoy Begichev Island in Outcrop 503, the lowest Oxfordian Obliteratum–Scarburgense Zone is not exposed. On the Chernokhrebetnaya River, the lower boundary of the Oxfordian Stage in Outcrop 1 must be lowered from the base of Member 6 to level 1d (see Meledina and Aleinikov, 1995), at which *Cardioceras scarburgense* and *C. oblitteratum* (= *Quenedtoceras (Soanicerias) parvulum* Meledina) appear. Late Callovian ammonites were found here in scree (not even associated with the outcrop), so the transition from the Upper Callovian to the Lower Oxfordian on the Chernokhrebetnaya river is not explicitly established. On the Anabar River, the lower boundary of the Oxfordian Stage is marked by the appearance of the ammonite assemblage: *Soanicerias* cf. *angustatum* (Meledina) (Pl. II, fig. 3), *Quenedtoceras nikitinatum* (Lahusen) (Pl. I, figs. 1, 4), *Cardioceras scarburgense* (Yong et Bird). Findings of *Cadoquenedtoceras* sp. juv. and *C. begichevi* come from an isolated outcrop (OK/S1).

CONCLUSIONS

The Subordinarium zone has long been considered to be well founded and used in the Callovian Boreal standard. However, as our research has shown, in the north of Siberia there are no ammonites that belong to the genus *Eboraceras*. The sections used to substantiate this zone, as it turned out, do not have direct contacts with the underlying and overlying sediments and therefore cannot be used to identify it. The Upper Callovian is partially or completely absent in a number of outcrops in northern Siberia (Anabar River, eastern shore of Anabar Bay, Chernokhrebetnaya River), and the ammonite assemblage from which it was established currently belongs to the Middle Callovian (Knyazev et al., 2020).

Using finds of *Cadoquenedtoceras* in Callovian sections on Bolshoy Begichev Island, Anabar river, Chernokhrebetnaya River, the Beds with *C. begichevi* can be distinguished in the studied area.

We consider the most suitable section as a stratotype to be Outcrop 503 on Bolshoy Begichev Island, Bed 15. The characteristic ammonite assemblage includes only the index species. The stratigraphic extent and correlation of the Beds with *C. begichevi* remain largely uncertain. It is necessary to conduct additional studies on the previously studied sections.

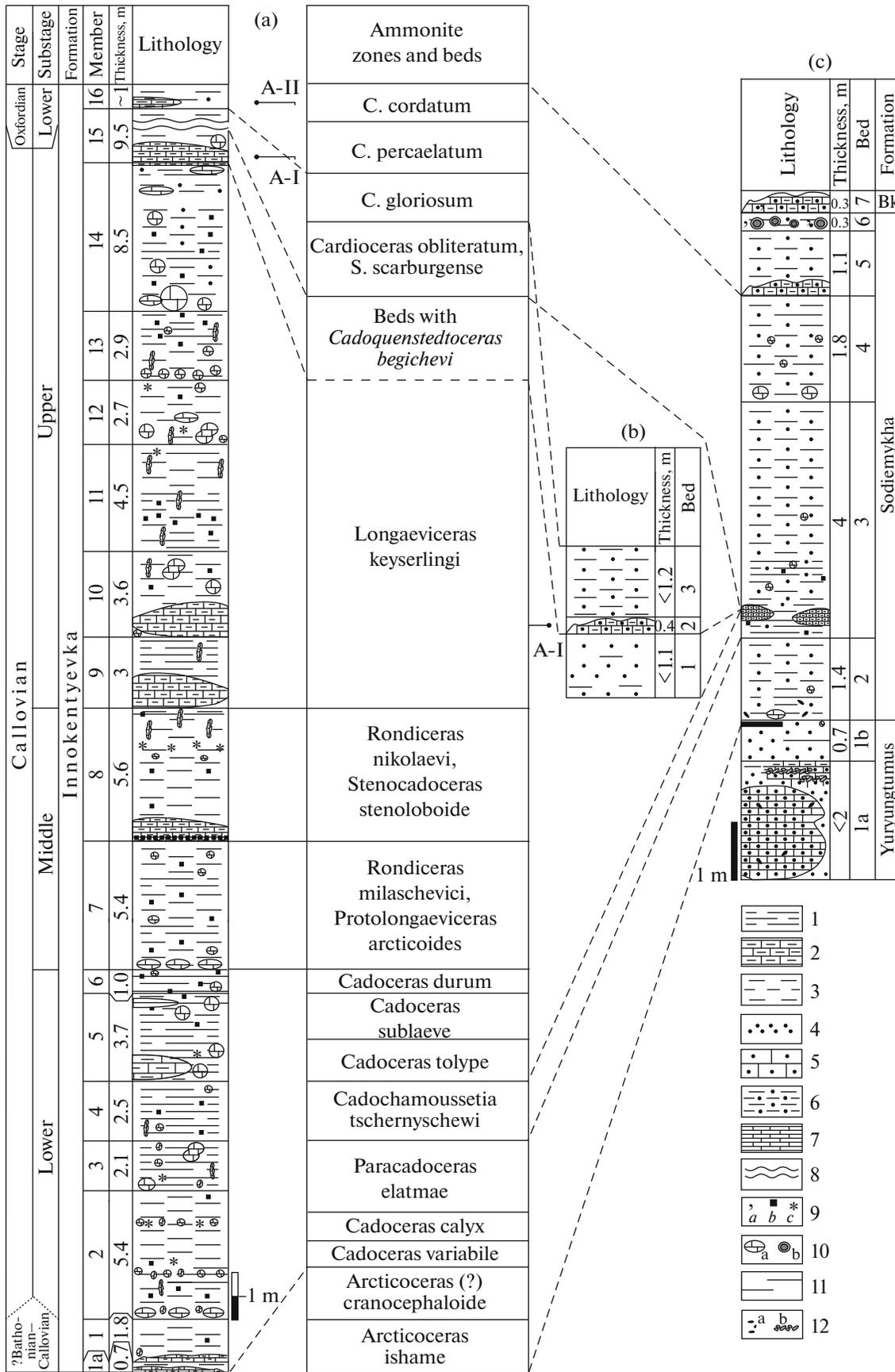


Fig. 2. Correlation of sections with Callovian–Oxfordian boundary beds in northern Siberia: Bolshoy Begichev (a), Anabar River, Outcrop OK/S1 (b) Anabar River, Outcrop OK/S2 (c). Zonation according to Nikitenko et al. (2022), with emendations by present authors. 1—Silty clays; 2—calcareous siltstones; 3—siltstones; 4—sands; 5—calcareous sandstones; 6—silty sands; 7—limestones and marls; 8—scale break; 9a—glauconite, 9b—pyrite, 9c—glendonites; 10—nodules: a—calcareous, b—phosphate; 11—carbonaceous beds; 12a—pebbles, 12b—brecciated rocks. Abbreviations: Bk—Buolkalakh Formation, A-I—*Cadoquenedtoceras begichevi*, A-II—*Cardioceras praecordatum*.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflict of interest.

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