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Article

Ammonites from hydrocarbon seep carbonate bodies from the uppermost Jurassic – lowermost Cretaceous of Spitsbergen and their biostratigraphical importance

Andrzej Wierzbowski, Krzysztof Hryniewicz, Øyvind Hammer, Hans Arne Nakrem and Crispin T.S. Little

With 9 figures

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Abstract: A collection of 55 well preserved ammonite specimens from hydrocarbon seep carbonate bodies from the Slottsmøya Member, Agardhfjellet Formation, in the Sassenfjorden area, Spitsbergen, is described and used as a basis for a chronostratigraphical interpretation of the seep deposits. The ammonites enable us to give a detailed biostratigraphical framework for the carbonates, showing that they range through the Upper Volgian Substage (Okensis Zone), and the Upper Ryazanian (the Analogus, Tzikwinianus and Tolli zones). The stratigraphical interval from the topmost part of the Upper Volgian (Taimyrensis Zone) to Lower Ryazanian (Kochi Zone) is very poorly represented. This absence may correspond to non deposition at the time or erosion by tsunami waves from the Mjølnir meteorite impact. The ammonites described include several genera and species that have not previously been reported from Spitsbergen, and provide new constraints on the timing of hydrocarbon seepage through the latest Jurassic – earliest Cretaceous time interval in Spitsbergen.

Key words: Ammonites, Craspeditinae, Tollinae, biostratigraphy, Volgian, Ryazanian, Spitsbergen, hydrocarbon seeps, Boreal Realm.

1. Introduction

This paper presents a systematic and biostratigraphical description of 55 ammonites collected during field work in the Sassenfjorden area, Spitsbergen from 2007 to 2010. While excavating marine reptiles from Upper Jurassic black shales of the Agardhfjellet Formation, fieldworkers of the Svalbard Jurassic Research Group (Natural History Museum, University of Oslo and University of Alaska, Fairbanks) encountered 15 carbonate bodies of uncertain origin, later interpreted as fossil hydrocarbon seeps (Hammer et al. 2011). Together with an abundant bivalve, gastropod and brachiopod fauna, several of the seep bodies yielded numerous and well preserved ammonites of Late Volgian to latest Ryazanian age.

2. Geological setting

Jurassic and lowermost Cretaceous rocks of Spitsbergen form a triangular outcrop belt from Isfjorden in the central part of the island to Sørkapp at its southernmost end (Fig. 1). Structurally they belong to the NNW-SSE trending synclinorium of the Spitsbergen Central Basin

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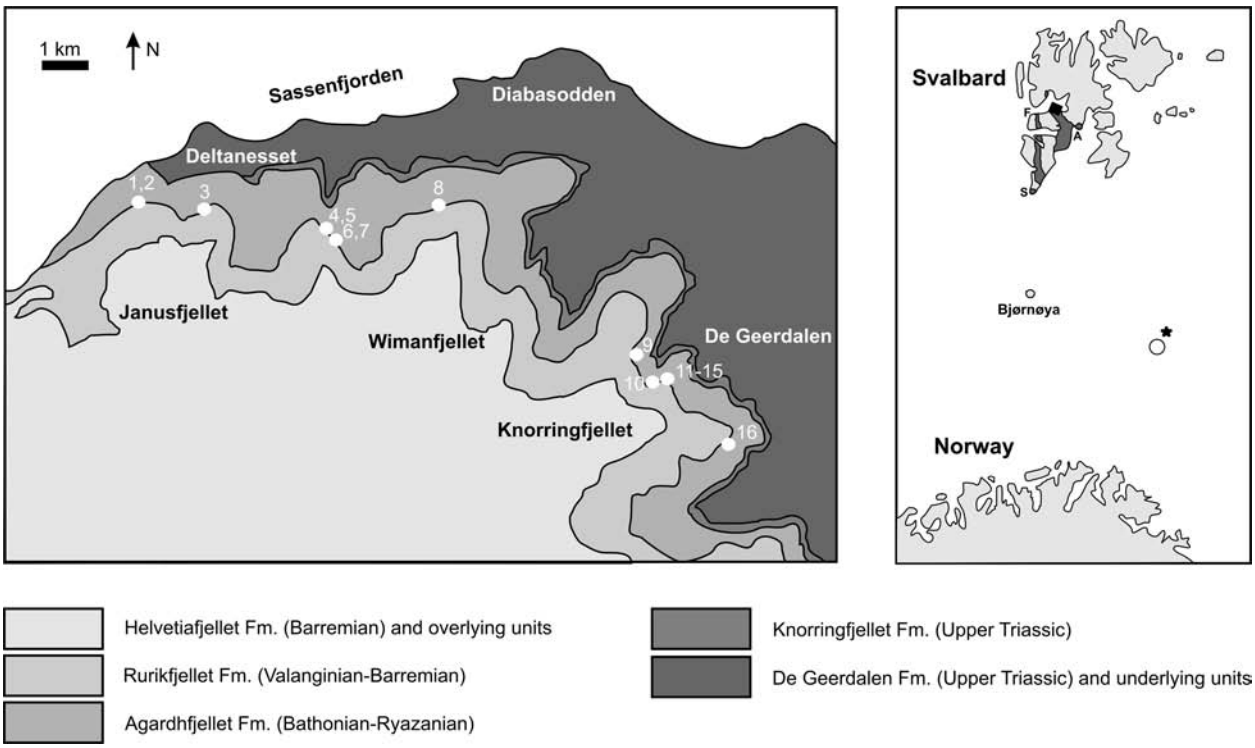

Fig. 1. Geological map of the Sassenfjorden area, central Spitsbergen (after Hammer et al. 2011) showing the location of the hydrocarbon seep carbonate bodies (1-15) which yielded ammonite faunas. The general map shows Svalbard and the Barents Sea with the location of the studied area (black rectangle), borehole 7430/10-U-01 (asterisk) and the Mjølnir impact crater (circle). A: Agardhbukta, F: Festningen, S: Sørkapp.

(Harland 1997), with Upper Paleozoic to Mesozoic rocks forming the flanks and Paleogene sediments filling the axis of the structure (Dallmann 1999). The basin was formed during the Paleogene compressional tectonic phase, leading to the formation of the Western Spitsbergen Orogenic Belt.

The Jurassic rocks on Spitsbergen are divided into two lithostratigraphical units (Harland 1997): the Knorringfjellet Formation and the Agardhfjellet Formation. The former is up to 75 m thick and represents shallow marine deposits (Mørk et al. 1999). These sediments contain major hiatuses and the Jurassic is often only partially preserved. The Knorringfjellet Formation is overlain by Middle Jurassic to lowermost Cretaceous black shales and siltstones of the Agardhfjellet Formation, deposited in a restricted shelf environment (Dypvik et al. 1991). The thickness of this formation ranges from 90 to 350 m (Mørk et al. 1999).

The Agardhfjellet Formation is traditionally divided into four members (Dypvik et al. 1991): the Oppdalen, Lardyfjellet, Oppdalsåta and Slottsmøya members, respectively. The ammonite bearing seep carbonate bodies are preserved in the Slottsmøya Member which consists of primarily grey and black shales and is regarded as Volgian in age (Fig. 2; Dypvik et al. 1991; Nagy & Basov 1998; Rogov 2010). The boundary with the underlying siltstones and sandstones of the Oppdalsåta Member, tentatively dated as Late Kimmeridgian – Early Volgian (Fig. 2; Nagy & Basov 1998), is gradational, and has not been defined precisely in the area of study. In the lower part of the Slottsmøya Member the ammonite record is very scarce and only single forms like *Paravirgatites* cf. *boidini* have been found (Pchelina 1965), suggesting the presence of the Lower Volgian. The Middle Volgian in the Slottsmøya Member is much better represented and ammonites indicative of the Rugosa, Ilovaiskii, Maximus, Anguinus, Groenlandicus and Exoticus zones have been found in the Agardhbukta area (Ershova & Pchelina 1979; Rogov 2010, figs. 2-3). The best record is provided by a shelly sideritic

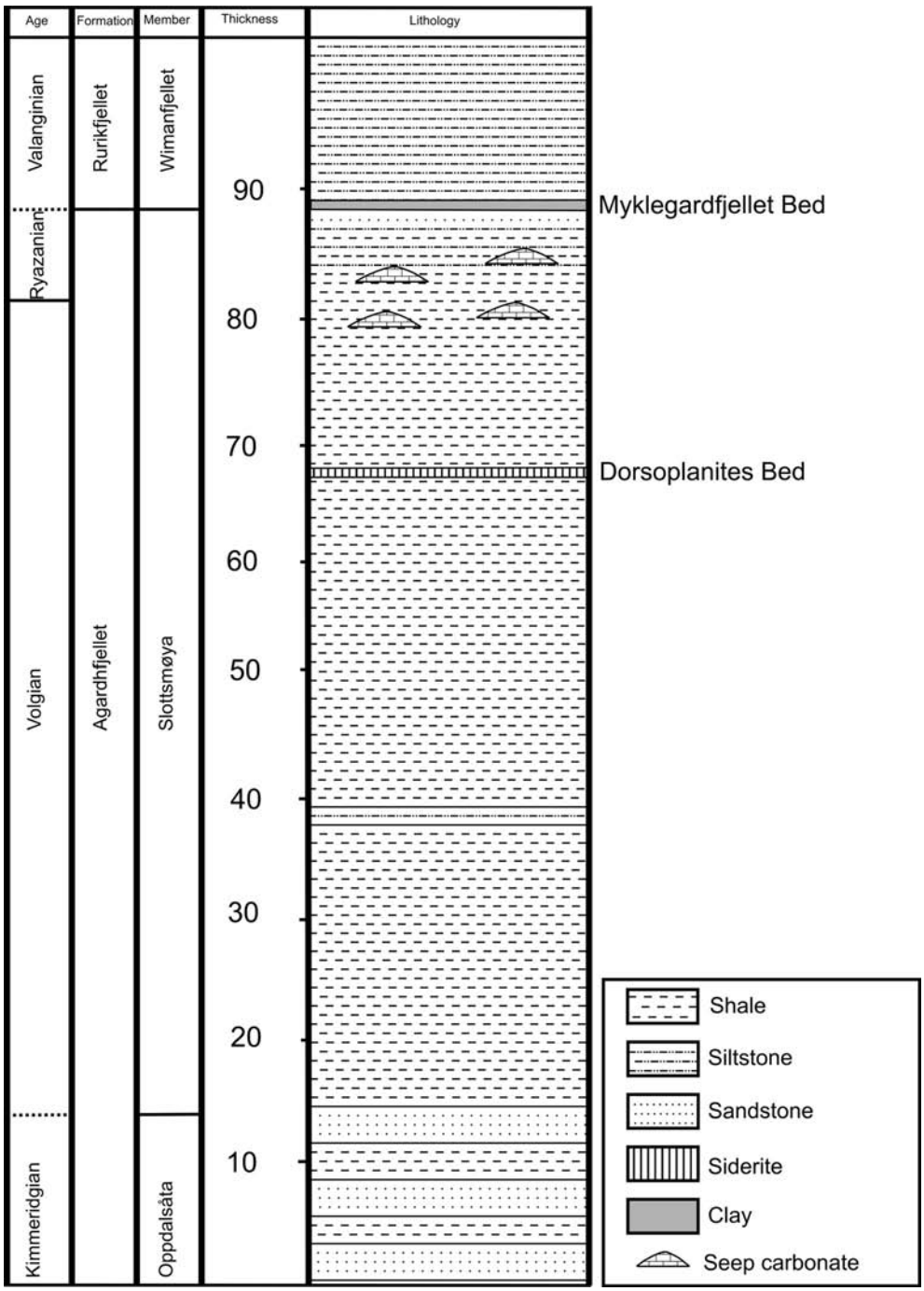

Fig. 2. Simplified stratigraphy of the transition between the Agardhfjellet and Rurikfjellet formations in the Sassenfjorden area. Thickness of Slottsmøya Member after Hammer et al. (2011).

bed, the so-called Dorsoplanites Bed (Fig. 2), with abundant specimens of the perisphinctid Middle Volgian ammonite *Dorsoplanites* spp.

The amount of silt increases in the upper part of the Volgian succession of the Slottsmøya Member, indicating a shallowing trend (Dypvik et al. 1991). Although the Okensis Zone of the basal Upper Volgian is commonly present in the Slottsmøya Member and confirmed by taxa such as *Craspedites (C.) okensis* and *Craspedites (C.)* aff. *fragilis* (Ershova 1969), the

higher Taimyrense Zone, indicated by *Craspedites (C.)* cf. *mosquensis*, *Craspedites (C.) nodiger* and *Craspedites (C.) taimyrensis* has only been recorded in some sections (Ershova 1969; Rogov 2010). The Siberian Chetae Zone of the uppermost Volgian has not been unequivocally recorded on Spitsbergen so far.

The Ryazanian ammonite record on Spitsbergen is scarce. One of the first descriptions of Cretaceous ammonites was given by Frebold (1929) and by Sokolov & Bodylevsky (1931), who described Valanginian forms, later attributed to both the Ryazanian and the Valanginian (Ershova 1972). Ershova (1983) published new records from the western, eastern and southern coasts of Spitsbergen and proposed a biostratigraphical zonation, relying both on ammonites and *Buchia* bivalves. Nonetheless, the fragmentary ammonite data from Lower Cretaceous sediments on Svalbard impeded attempts to establish a more detailed biozonation.

A benthic foraminiferans biozonation for the whole Agardhfjellet Formation was presented by Nagy & Basov (1998), who proposed eight zones from the Bathonian to the Ryazanian/Valanginian transition. However, the foraminiferal record in the uppermost part of the Agardhfjellet Formation consists only of long-ranging taxa, and therefore, is of little use dating the upper boundary of the formation. Using benthic foraminiferans, the base of the overlying Rurikfjellet Formation has been assigned to the Ryazanian, and the underlying part of the Agardhfjellet Formation has been confined to the Volgian only (Dypvik et al. 1992, fig. 10). This age determination contradicts both this study and some previous ammonite works.

It should be also remembered that the ammonite "*Subcraspedites* (*Borealites*) aff. *suprasubditus*" from a carbonate concretion considered as coming from the basal part of the Rurikfjellet Formation (the Myklegardfjellet Bed) was reported by Basov et al. (1997: 43-44) from the Janusfjellet area. The presence of this ammonite has been treated as indicative of the lower "Boreal Berriasian" = Ryazanian, and accordingly the base of the Rurikfjellet Formation was claimed by Basov et al. (1997: 44-45) to correspond to the boundary between the Upper Volgian and Ryazanian. However, another stratigraphical interpretation of this ammonite occurrence can be made. The occurrence of large carbonate concretions is not recorded in the Myklegardfjellet Bed – which is represented by soft clays – but rather in the topmost part of the underlying Agardhfjellet Formation (see description of the type section of the Myklegardfjellet Bed by Birkenmajer 1980), and thus the ammonite (unfortunately not figured) can be compared with late representatives of the subgenus *Bojarkia* (cf. description of *S. tzikwinianus* herein), indicating a Late Ryazanian age.

3. Slottsmøya Member seep carbonate biostratigraphy

The difficulty in correlation between the ammonite subdivisions across faunal provinces from the end of the Jurassic to the beginning of the Cretaceous makes it necessary for the time being to retain the local chronostratigraphical subdivisions (e.g. Abbink et al. 2001). As the Tithonian/Berriasian boundary of the Mediterranean succession, considered as the primary standard for the Jurassic/Cretaceous boundary, cannot be unequivocally recognized in the studied Boreal succession, the stratigraphical classification used here includes the Upper Volgian and the Ryazanian (cf. e.g. Abbink et al. 2001; Zakharov & Rogov 2008).

Possibly the oldest ammonite in the collection studied is *Kachpurites* sp. from seep carbonate body 3 (Figs. 1, 3). The genus *Kachpurites* occurs in the Fulgens Zone of the lowermost Upper Volgian on the Russian Platform. This zone corresponds to the lower part of the Okensis Zone, i.e. the Okensis Subzone of the Siberian sections (Baraboshkin 2004; Zakharov & Rogov 2008 and references therein).

A younger assemblage of Upper Volgian ammonites was found in carbonate bodies 8 and 13 and consists of representatives of the genus *Craspedites*: both *C.* (*Craspedites*) *okensis* (d'Orbigny) and *C.* (*Taimyroceras*) *originalis* Schulgina (Figs. 1, 3). The co-occurrence of these two species is indicative of the Originalis Subzone from the upper part of the Okensis Zone (see Saks et al. 1969; Baraboshkin 2004).

No ammonites indicative of the Upper Volgian Taimyrensis Zone have been discovered in the studied material. It should be mentioned that ammonites of this zone were discovered only on the western and eastern coasts of Spitsbergen (see Ershova 1969, 1983 who distinguished the Nodiger Zone corresponding to the Taimyrensis Zone; see also Rogov & Guzhikov 2009; Rogov 2010).

A single poorly preserved specimen referred to as *Hectoroceras* (?*Shulginites*) sp. from seep carbonate body 7 suggests the presence of the uppermost Upper Volgian or the lowermost Ryazanian (Figs. 1, 3). Although the genus *Hectoroceras* ranges up to the top of the Lower Ryazanian, i.e. the top of the Kochi Zone (see e.g. Alekseev 1984; Schulgina 1985), the

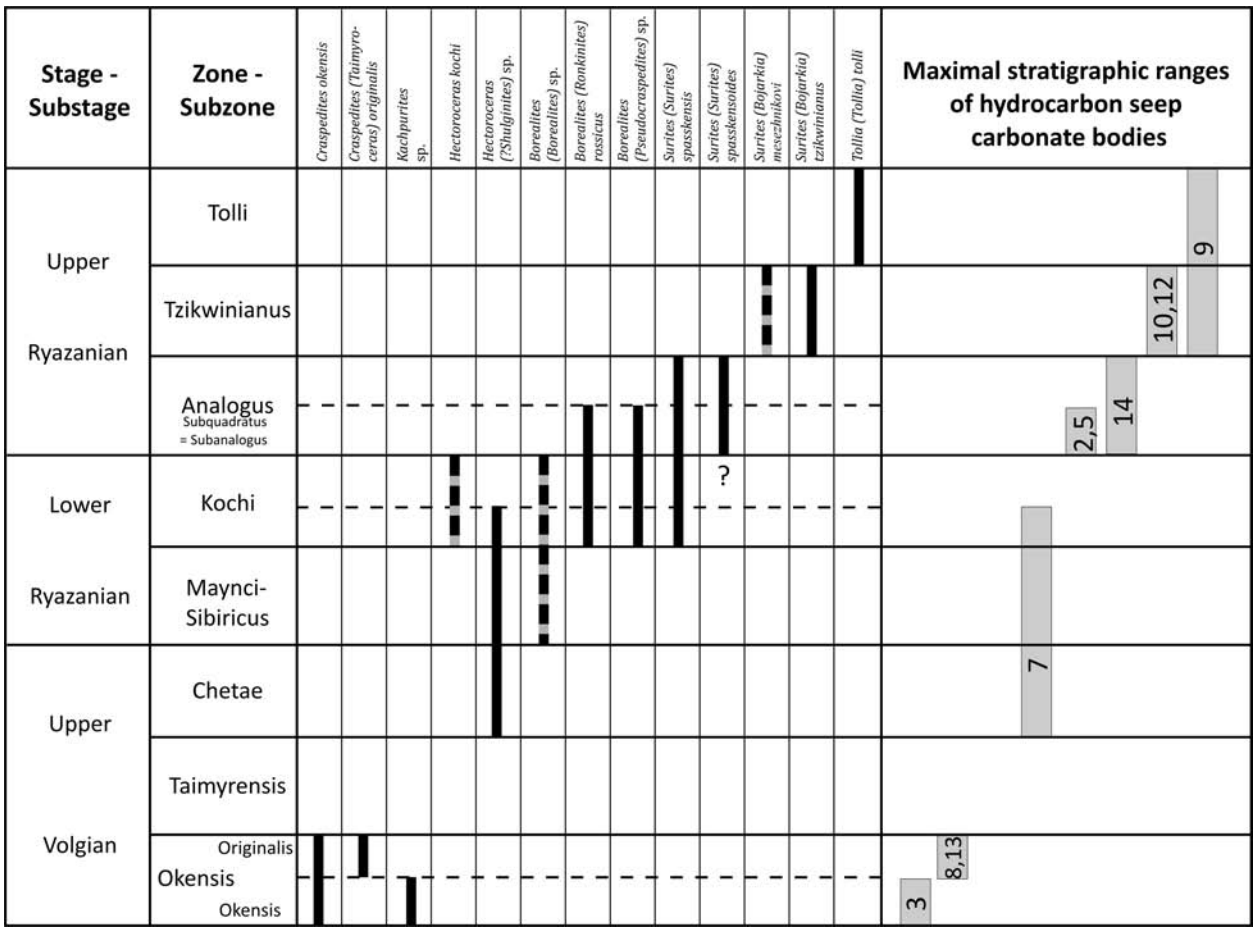

Fig. 3. Chronostratigraphic interpretation of the carbonate bodies from the Agardhfjellet Formation in the Sassenfjorden area. Ammonite ranges are given after Alekseev (1984), Mesezhnikov (1984), Mesezhnikov et al. (1983), Schulgina (1985) and Zakharov & Rogov (2008). Black continuous bars indicate stratigraphic ranges of ammonites recognized in the collection studied; stippled bars indicate stratigraphic ranges of selected ammonites not found in the collected material. "?" represents uncertainty in the stratigraphic distribution of *Surites (Surites) spasskensoides* (Schulgina, 1972).

subgenus *Shulginites* has a narrower stratigraphical range, appearing in the Chetae Zone of the uppermost Upper Volgian Substage, and ranging up into the Maynci-Sibiricus Zone, and possibly also to the lowermost part of the Kochi Zone of the lowermost Ryazanian (Mesezhnikov et al.1983; Alekseev 1984). The studied material did not yield any other ammonites (such as the subgenera *Hectoroceras* and/or *Borealites*) unequivocally indicative of the Lower Ryazanian. It should be noted that the stratigraphical interval from the topmost part of the Upper Volgian Substage up to the top of the Lower Ryazanian is not only very poorly represented in the studied material but also elsewhere in Spitsbergen (cf. e.g. Ershova 1983). Possibly most important are occurrences of the subgenus *Borealites*, as well as *Pseudocraspedites* close to *P. anglicus* (Schulgina), on the western coast of Spitsbergen (Ershova 1972; Rogov & Guzhikov 2009), which may be treated as indicative of the Kochi Zone or even the Maynci-Sibiricus Zone. Such a stratigraphical interpretation may also be given to a single specimen referred to as *Praetollia* sp. from the Sørkapp Land by Ershova (1972, pl. 2, fig. 10), which according to Rogov & Guzhikov (2009) should be placed in the genus *Hectoroceras*.

A younger assemblage of ammonites in the material studied consists of *Surites* (*Surites*) *spasskensis* (Nikitin): *S.* (*S.*) aff. *spasskensis* (Nikitin) and *Borealites* (*Pseudocraspedites)* sp. (seep carbonate body 5); *Borealites* (*Ronkinites*) *rossicus* (Schulgina) (seep carbonate body 2); and *Surites* (*Surites*) *spasskensoides* Schulgina (seep carbonate body 14) (Fig. 1). These

ammonites are known to occur in the Kochi Zone of the Lower Ryazanian, and in the Analogus Zone representing a lower part of the Upper Ryazanian. Because the ammonite assemblage does not contain any species of *Hectoroceras* or *Borealites* (*Borealites*), whose stratigraphical ranges are restricted of the Lower Ryazanian, it seems therefore that the seep carbonates 2, 5 and 14 in the Slottsmøya Member should be correlated with a higher part of the indicated stratigraphical interval, i.e. the Analogus Zone of the Upper Ryazanian (Fig. 3). Moreover, as *Borealites* (*Pseudocraspedites)* and *Borealites* (*Ronkinites*) do not range stratigraphically higher than the Subquadratus = Subanalogus Subzone of the lower part of the Analogus Zone (see Alekseev 1984: 88-89, but see also Igolnikov (2006) who recognized *Surites subquadratus* Alekseev, 1984 as a younger synonym of *S. subanalogus* Schulgina, 1972), such a stratigraphical interpretation for carbonate bodies 2 and 5 seems highly probable. The stratigraphical position of the carbonate body 14 is more equivocal as the stratigraphical range of *S. spasskensoides* is not well known. However, as the species possibly occurs in the Analogus Zone (see systematic part of the paper), and carbonate body 14 is located close to those of the directly overlying Tzikwinianus Zone (carbonate bodies 10 and 12), it seems logical that it should not be an older deposit.

An assemblage consisting of numerous specimens of *Surites* (*Bojarkia*) *tzikwinianus* (Bogoslovsky) occurs in carbonate bodies 9, 10 and 12 (Fig. 1). The species as interpreted herein (see systematic part) includes forms previously treated as independent species: *S. tzikwinianus*, *S. subtzikwinianus* and *S. hoeli*, but representing instead one continuously variable coarsely ribbed bojarkiid species. It is indicative of the Tzikwinianus Zone (Fig. 3) distinguished on the Russian Platform above the Rjazanensis-Spasskenis Zone and below the Unduloplicatis Zone corresponding to the Tolli Zone (e.g. Mesezhnikov 1984), and in East Greenland above the Analogus Zone, and below the Mesezhnikovi Zone (Surlyk 1978) or below the Albidum Zone (Alsen 2006). The ammonites of the Albidum Zone of East Greenland are, however, not representatives of the genus *Peregrinoceras* but rather representatives of the genus *Bojarkia* (M. Rogov, pers. comm.). This calls into question the validity of the Albidum Zone and indicates a close affinity of the East Greenland ammonites to ammonite assemblages of the Tzikwinianus Zone and the Mesehznikovi Zone, which are dominated by bojarkiid species. The Tzikwinianus Zone is thus characterized by the occurrence of ammonites of the subgenus *Bojarkia* well above the upper range of the subgenus *Surites*. It seems to correspond to the Mesezhnikovi Zone of the Upper Ryazanian of Siberia (cf. Saks & Shulgina 1969). It is highly probable that the occurrence of the coarsely ribbed species *Surites* (*Bojarkia*) *tzikwinianus* indicative of the Tzikwinianus Zone, and the finely ribbed *S.* (*B.*) *mesezhnikovi* indicative of the Mesezhnikovi Zone, were synchronous, and the distribution of the two species was controlled by environmental factors.

The youngest ammonite is *Tollia* (*Tollia*) *tolli* Pavlow found in carbonate body 9 (Fig. 1). This species indicates the Tolli Zone, which has been treated as the lowermost Zone of the Boreal Valanginian (Baraboshkin 2004; Bogomolov et al. 2011). It seems, however, that the Tolli Zone should instead be placed in the uppermost Ryazanian, because it corresponds to the Otopeta Zone of the Mediterranean subdivision (see Baraboshkin 2004, and earlier papers cited therein); the latter as recently proposed should not be treated as a basal zone of the Valanginian, but rather as the topmost subzone of the Berriasian (Hoedemaker et al. 2003). The placing of the Tolli Zone in the uppermost Ryazanian makes possible close correlation of the upper boundary of the Boreal Ryazanian Stage with that of the Mediterranean Berriasian Stage. The occurrence of *Tollia tolli* in seep body 9 together with *Surites* (*Bojarkia*) *tzikwinianus* thus indicates a stratigraphical interval corresponding to the uppermost Ryazanian, at the Ryazanian/Valanginian boundary (Fig. 3).

4. Discussion

The ammonites collected in the central Spitsbergen Sassenfjorden area seep carbonate bodies represent the most complete biostratigraphical records so far of the Upper Volgian to uppermost Ryazanian interval in Spitsbergen. These ammonites prove within the Slottsmøya Member of the Agardhfjellet Formation in the Sassenfjorden area the presence of the Okensis Zone (with the Okensis Subzone below, and the Originalis Subzone above), the Analogus and Tzikwinianus zones of the Upper Ryazanian, and the Tolli Zone of the uppermost Ryazanian. In contrast, the stratigraphical interval from the upper part of the Upper Volgian Substage (Taimyrensis to Chetae zones) up to the Lower Ryazanian (Maynci-Sibiricus Zone to Kochi Zone) is very poorly represented in the material studied. In the western and the eastern parts

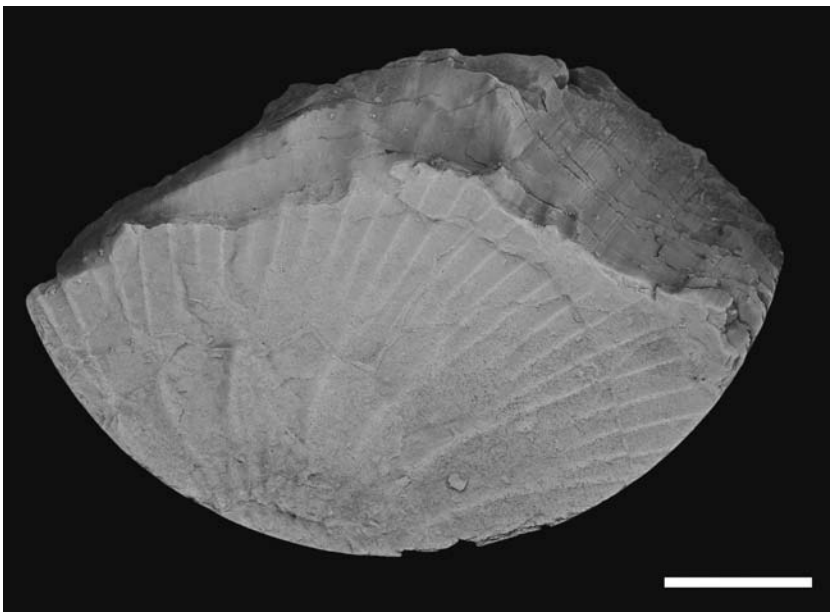

Fig. 4. *Borealites* (*Borealites*) sp. of the Lower Ryazanian from the core 7430/10-U-01 (depth 44.10 m) in the southern Barents Sea, PMO 217.500, scale bar 10 mm.

of Spitsbergen, this stratigraphical interval is better documented by ammonites, especially in its lower (Taimyrensis Zone) and upper parts (Kochi Zone), but even there the presence of Upper Volgian/Ryazanian transitional boundary beds are very poorly proven by ammonites.

One explanation for the phenomenon of poor representation of latest Late Volgian and earliest Ryazanian ammonites in the Sassenfjorden area may be contemporary tectonic activity which could have occurred at that time (see Parker 1966). In Greenland the major phase of block tilting occurred in the latest Volgian and continued during the Ryazanian (Surlyk 1978). The marked differences in thickness of the Agardhfjellet Formation in central Spitsbergen could be related to synsedimentary tectonic activity at that time (Parker 1967). It should be noted that such synsedimentary thickness variations during sedimentation of the Mesozoic deposits have been questioned by Haremo et al. (1993) who rather interpreted the observed thickness difference as post-depositional, related to Paleogene compressional tectonics. Recent stratigraphical results indicate, however, that in central Spitsbergen at least some thinning of latest Jurassic to earliest Cretaceous deposits did indeed occur. For example, according to Haremo et al. (1993: 790-791, fig. 9) the markedly thin deposits of the Slottsmøya Member in the Wimanfjellet section are of Kimmeridgian age only, said to result from "thin-skinned décollement thrusting". We show here that in the same area, the Slottsmøya Member is actually much more complete, and includes a condensed Upper Volgian-uppermost Ryazanian section.

The formation of the ~40 km diameter submarine Mjølnir meteorite impact crater on the Barents Shelf south of Spitsbergen, near the Volgian/Ryazanian boundary, may have also influenced the development of the Sassenfjorden hydrocarbon seep carbonates and the surrounding sediments of the Slottsmøya Member (Dypvik et al. 2004). The ejecta bearing strata formed during this impact, called the Sindre Bed, have been discovered in a few places far from the crater, including in cores from the southern Barents Sea, such as core 7430/10-U-01 (Fig. 1; e.g. Smelror et al. 2001; Dypvik et al. 2004), but also in Spitsbergen in the Janusfjellet section (Dypvik et al. 2000; Smelror & Dypvik 2005). Core 7430/10-U-01 yielded ammonites studied by one of the authors (AW) first mentioned in an internal SINTEF Petroleum Research (Trondheim, Norway) report, and partly published thereafter by Smelror et al. (2001: 136, fig. 5). One of these ammonites found directly above the Sindre Bed at 44.10 m in the core is *Borealites* (*Borealites*) sp. (Fig. 4) which indicates the Lower Ryazanian Kochi Zone, or possibly even Maynci–Sibiricus Zone, precisely dating the impact.

Whereas the deposits which originated from the Mjølnir crater in its direct neighborhood are diversified breccias, slump and mass flow deposits (the Ragnarok Formation; Dypvik et al. 2004), there is no doubt that large tsunami waves were formed during the event which would have affected older deposits, especially on elevated areas such as central Spitsbergen. This may possibly explain why the stratigraphical gap in central Spitsbergen spans not only the lowermost Ryazanian but also partly ranges down into the Upper Volgian. This phenomenon may also have been in part responsible for a drastic reduction of sedimentary strata near the Jurassic/Cretaceous boundary in many parts of the Boreal Basin (e.g. Zakharov et al. 1993; Dypvik & Zakharov 2010).

Another stratigraphical problem appears when one compares different chronostratigraphical interpretations of the boundary beds between the Agardhfjellet Formation and the Rurikfjellet Formation in central Spitsbergen. According to a commonly accepted definition (Dypvik et al. 1991), the contact between the two formations is marked by a gray yellow plastic clay called the Myklegardfjellet Bed (Fig. 2), the origin of which has been connected with submarine weathering of volcanic rocks (Birkenmajer 1980). However geochemical analysis indicates that decomposition and weathering of clay minerals, especially glauconite (Dypvik et al. 1992) seems a more plausible explanation for the formation of the Myklegardfjellet Bed. Siltstones and shales of the Slottsmøya Member immediately below the Myklegardfjellet Bed yield benthic foraminiferans characteristic of both the Volgian and the Ryazanian. Foraminiferans in the Myklegardfjellet Bed represent a stratigraphical interval from the Volgian up to the Lower Hauterivian (Dypvik et al. 1992: 30). These data inclined Dypvik et al. (1992) to assign the Myklegardfjellet Bed to the basal Ryazanian, and, hence, to confine the age of the upper part of the Agardhfjellet Formation to the Volgian only, and to attribute the overlying deposits of the Rurikfjellet Formation to the Ryazanian. A similar stratigraphical interpretation of the Myklegardfjellet Bed was given by Basov et al. (1997), based on ammonites (see comments in section 1). However, the ammonite bearing seep carbonate bodies of the Slottsmøya Member are from the upper part of the Agardhfjellet Formation and indicate a stratigraphical interval ranging from the Upper Volgian to the uppermost Ryazanian. Thus, the overlying Rurikfjellet Formation has to be younger, and its lower parts cannot be assigned to the Berriasian/Ryazanian, as presented in some stratigraphical correlations (see e.g. Dypvik et al. 2002), but possibly to the Valanginian (cf. Århus 1988). This is also supported by the Valanginian age of the regional counterparts of the Myklegardfjellet Bed, which most likely represent the same marker bed of sequence stratigraphical importance (cf. Smith et al. 1976; Århus et al. 1990; Dypvik et al. 1992) and favors a wider stratigraphical range of the Agardhfjellet Formation than assumed by Dypvik et al. (1992).

It is worth noting that the uppermost part of the Slottmøya Member shows a marked shallowing trend, expressed by change of lithology from shales to siltstones and fine grained sandstones (e.g. Dypvik et al. 1991, 2002). Further, layers, enriched in phosphate and glauconite in the hydrocarbon seep carbonates (Krzysztof Hryniewicz, personal observation) and surrounding sediments (e.g. Pchelina 1965; Collignon 2011), suggest very low sedimentation rates in the uppermost Slottsmøya Member. These observations may be connected with either tectonic uplift of Spitsbergen (e.g. Parker 1966; Harland 1997) and/or with eustatic sea level fall at the Volgian/Ryazanian boundary as recorded on the Russian Platform (Sahagian et al. 1996) and in the North Sea area during the Middle Volgian-Late Ryazanian interval (Rawson & Riley 1982). The shallowing in the uppermost Slottsmøya Member starts at least around earliest Late Volgian and continues into the Ryazanian, culminating near the top of the Slottsmøya Member (cf. Dypvik et al. 2002, and this study). Because the Volgian/Ryazanian boundary is located in the middle part of this shallowing-upward trend, it is difficult to connect the poor representation of Volgian/Ryazanian boundary strata with emersion and erosion at that time.

5. Systematic palaeontology

The following abbreviations are used in descriptions of the ammonites: D – diameter of specimen in mm; Wh – whorl height as percentage of D; Ud – umbilical diameter as percentage of D; Wb – whorl breadth as percentage of D; PR – number of primary ribs per whorl, SR/PR secondary/primary ribs ratio calculated at 10 primary ribs at given diameter.

Dimorphism is usually difficult to recognize in the ammonites studied. Possibly (cf. Wright et al. 1996), it is expressed morphotaxonomically at the subgeneric level in the genus *Borealites* where corresponding groups of macro- and microconchs are *Pseudocraspedites* (M) and *Ronkinites* (m) respectively. In other groups of ammonites, such as in the *Surites* – *Bojarkia* – *Tollia* lineage, the dimorphism is not expressed taxonomically, but is shown by the occurrence of closely related isocostate microconchs

and variocostate macroconchs, usually placed in a single species (cf. e.g. Schulgina 1972).

The studied ammonites are housed in the Natural History Museum, University of Oslo. (PMO).

Family Polyptychidae Wedekind, 1918
Subfamily Craspeditinae Spath, 1924
Genus *Craspedites* Pavlow, 1892

Type species: *Ammonites okensis* d'Orbigny, 1845.

Subgenus *Craspedites* Pavlow, 1892

Remarks: According to Wright et al. (1996) this subgenus includes a wide spectrum of forms that are "usually involute and inflated, with smooth outer whorls". The lectotype of the type species, *Craspedites okensis*, is one of the specimens illustrated by d'Orbigny (1845: 436, pl. 34: 15-17) which was collected at an unknown location on the Russian Platform (see Nikitin 1881; cf. Schulgina 1969). This specimen shows the "presence of weakening (or even a complete interruption) of ribs in the middle of the venter" (Jeletzky 1966: 5). This observation inclined Schulgina (1985) to split the genus *Craspedites* into two separate subgenera: *Craspedites* sensu stricto with type species *C. okensis* (d'Orbigny) having a smooth venter, and the subgenus *Vitaliites* Schulgina, 1985 (type species *Ammonites subditus* Trautschold) with ribbing crossing the venter. Moreover, Schulgina (1985), according to this definition, interpreted the name *Taimyroceras* Bodylevsky, 1956 as a younger synonym of *Craspedites*. This opinion was not accepted by Wright et al. (1996) who treated subgenus *Craspedites* (and *Vitaliites* as its younger synonym) independently of subgenus *Taimyroceras* (see also comments below).

Craspedites (*Craspedites*) *okensis* (d'Orbigny, 1845)
Fig. 5.1a-1b

1845 *Ammonites okensis*. – d'Orbigny, p. 436, pl. 34, figs. 15-17, non 13-14.
?1881 *Perisphinctes okensis* d'Orbigny. – Nikitin, p. 312-314, pl. 11, fig. 58.
1969 *Craspedites* (*Craspedites*) *okensis* (d'Orbigny). – Schulgina, p. 138-142, pl. 26, figs. 1, 3; pl. 27, figs. 1-2; pl. 28, figs. 1-2; pl. 29, figs. 4-5.
1969 *Craspedites* (*Craspedites*) *okensis* (d'Orbigny). – Ershova, p. 54-56, pl. 1, fig. 1; pl. 2, fig. 1; pl. 3, figs. 1-3; text-fig. 1.
1983 *Craspedites* (*Craspedites*) *okensis* (d'Orbigny). – Ershova, pl. 26, fig.1.
2009 *Craspedites* (*Craspedites*) *okensis* (d'Orbigny). – Rogov & Guzhikov, pl. 1, figs. 4-5.
2010 *Craspedites* (*Craspedites*) *okensis* (d'Orbigny). – Rogov, p. 7, figs. 1-3.

Material: Five specimens – four from carbonate body 8 (PMO 217.159; PMO 217.253; PMO 217.153; PMO 217.159) and one from carbonate body 13 (PMO 217.252).

Description: The specimens studied are 24-85 mm in diameter, and represent phragmocones either with partly preserved or nearly complete body chambers, the most complete body chamber is about one whorl long. The phragmocone/body chamber boundary is at 23-52 mm diameter. The coiling is moderately involute (at D = 50-70 mm, Wh = 38.8-42.4%, Ud = 28.3-32.7%). The whorl section is compressed (at D = 50-70 mm, Wb = 28.3-32.7%), oval in innermost whorls, and markedly narrowed towards the ventral side in middle whorls. Ornamentation consists of primary ribs which disappear at around 20 mm diameter. The side of whorls then becomes smooth, and the secondary ribs disappear successively towards the venter at much larger diameter. The number of secondary ribs is about 35-40 per half whorl at D = 45-55 mm. The secondaries cross the venter without any weakening up to about 50 mm diameter, but at 55 mm diameter the ribs gets weaker.

Discussion: Some specimens considered in the past (cf. synonymy in Schulgina 1969) as belonging to the species *C. okensis* differ somewhat from the lectotype in their whorl section, and in earlier or later weakening of ornamentation on the venter. This is the case of two specimens illustrated by Nikitin (1881, pl. 11, figs. 57, 58) which differ from the lectotype of *C. okensis* in having a more compressed whorl section and/or a longer retention of the ornamentation on the venter (see e.g. Jeletzky 1966). A smaller of these specimens showing the well developed ornamentation on the outer part of whorl (i.e. that illustrated by Nikitin 1881 in pl. 11, fig. 57) was assigned as the type of a new species, attributed to a new subgenus – *Craspedites* (*Vitaliites*) *pseudookensis* Schulgina by Schulgina (1985: 114). The larger of specimens of Nikitin (1881, pl. 11, fig. 58), however, seems to be closely related (if not conspecific) with *C. okensis* (d'Orbigny) because it has the most important characters for that species, which include an early disappearance of ornamentation on the dorsal side of whorls, resulting in the development of a completely smooth side and umbilical wall, a feature that distinguishes these specimens markedly from completely ribbed craspeditids (cf. Jeletzky 1966).

Occurrence: The species is indicative of the Okensis Zone of the Upper Volgian, which is treated recently as the lowest zone of this substage (Zakharov & Rogov 2008). The species has a wide geographical range being known from the Russian Platform, western and northern Siberia (see e.g. Saks et al. 1969; Zakharov & Rogov 2008) and Spitsbergen, where it occurs in the Agardhfjellet Formation at Agardhbukta (Ershova 1969; Rogov & Guzhikov 2009; Rogov 2010) and at Festningen (Rogov & Guzhikov 2009; Rogov 2010).

Subgenus *Taimyroceras* Bodylevsky, 1956

Type species: *Taimyroceras taimyrense* Bodylevsky, 1956.

Craspedites (*Taimyroceras*) *originalis* Schulgina, 1969
Fig. 5.2a-2b

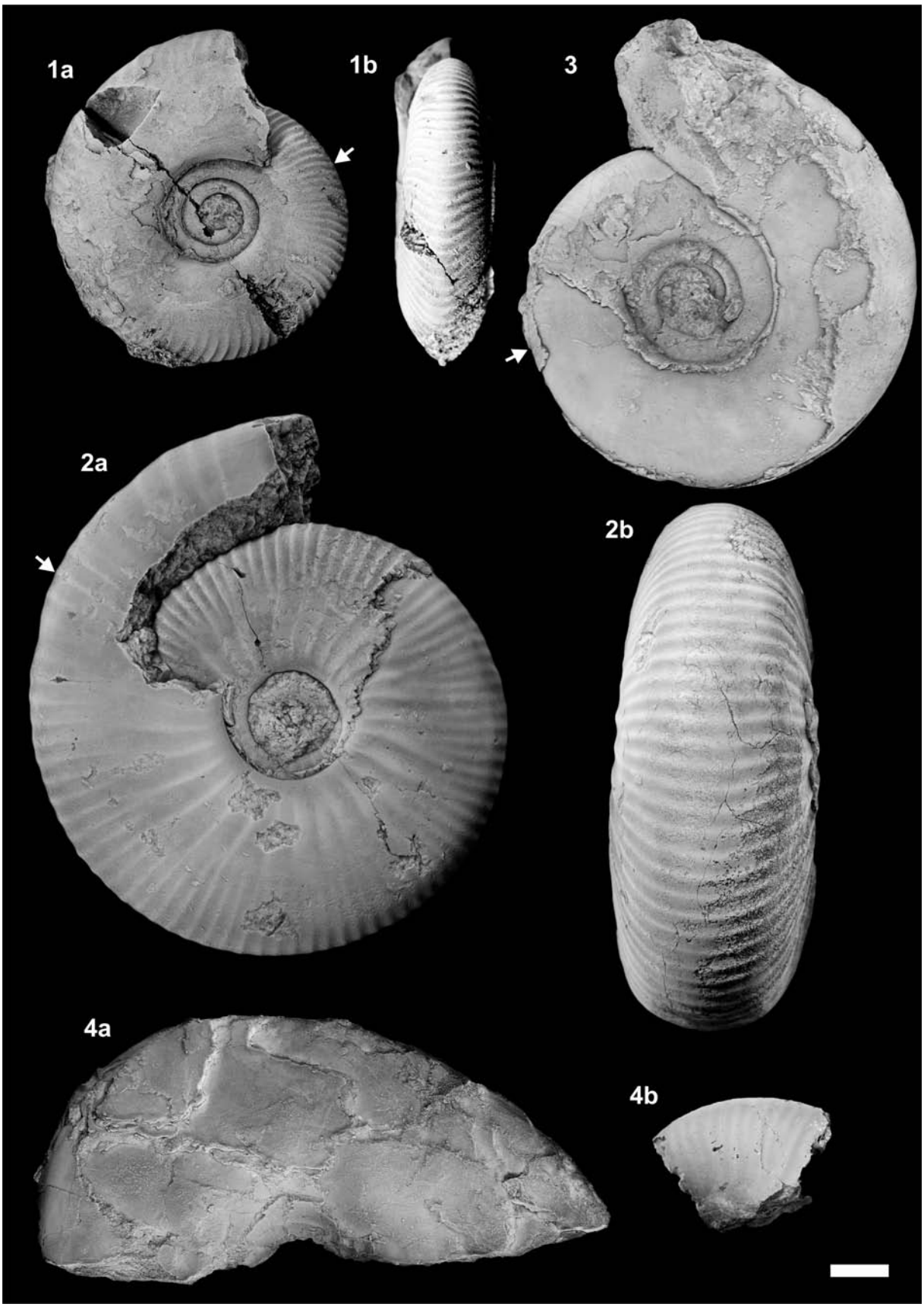

Fig. 5.

1969 *Craspedites* (*Taimyroceras*) *originalis*. – Schulgina p. 155-157, pl. 35, figs. 1-2; pl. 36, figs. 2, 4-5.

Material: Eight specimens – three from carbonate body 8 (PMO 217.230; PMO 217.254; PMO 217.211) and five from carbonate body 13 (PMO 217.156; PMO 217.189; PMO 217.212, PMO 217.205; PMO 217.207).

Description: Specimens 30-90 mm in diameter, mostly representing the phragmocone, but the two largest specimens have part of the body chamber preserved. In these the phragmocone/body chamber boundary is at 80 mm diameter. The coiling is involute: at D = 30-90 mm, Wh = 42-48.4% (median value is 45.3%), Ud = 21.6-28.7% (median value is 24.0%). The whorl section is compressed with flattened sides and a wide, weakly rounded venter, which becomes flattened at larger diameter: at D = 30-90 mm, Wb = 32.7-44% (median value is 40.6%). Ornamentation consists of primary ribs and secondary ribs appearing about the mid-height of the whorl. Whereas the primary ribs are prorsiradiate, the secondary ribs are more rectiradiate, which results in a change of the rib course in the middle of the whorl height. The number of primary ribs per half whorl is about 32-37 at D=30-55 mm, and about 30 at D = 80-90 mm. The secondary ribs are fairly numerous, and the secondary/primary ribs ratio changes from about 2.3 to 2.8 at D = 30-50 mm, and from 3.0 to 3.5 at D = 80-90 mm. The ribs cross the venter without any weakening in inner and middle whorls; sometimes an indistinct weakening of ribs is observed on the venter at larger diameters only.

Discussion: The ammonites of the subgenus *Taimyroceras* differ from those of the nominative subgenus of *Craspedites* (see Bodylevsky 1956; see also Schulgina 1969; Wright et al. 1996) in having semi-rectangular whorl sections, a broad and flattened venter at larger diameters, in weakening to fading of ribbing on the venter, and a special course of ribs on the whorl-sides (prorsiradiate primaries to rectiradiate secondaries). The studied specimens show most of the general features of the subgenus *Taimyroceras*, but weakening of ribs on the body chamber is poorly developed. This last feature, as well as a lower secondary/primary rib ratio, distinguished the species *C*. (*T.*) *originalis* Schulgina from *C*. (*T.*) *taimyrensis* (Bodylevsky) (see Schulgina 1969).

Occurrence: The species is indicative of the Originalis Subzone which represents the upper part of the Okensis Zone of the Upper Volgian (Saks et al. 1969). The species is known from northern Siberia (see e.g. Saks et al. 1969), and its presence is now also demonstrated in Spitsbergen.

Genus *Kachpurites* Spath, 1923

Type species: *Ammonites fulgens* Trautschold, 1861.

Kachpurites sp.
Fig. 5.3

Material: A single specimen (PMO 217.155) from carbonate body 3. This is 70 mm in final diameter, with final peristome preceded by a wide constriction. The body chamber is about three quarters of a whorl in length. Whorl height and umbilical diameter are nearly equal (at D = 66 mm, Wh = 38%, Ud = 38%), but at the end of the last whorl the umbilicus becomes somewhat wider than the whorl height. Whorl section is high oval with somewhat flattened whorl sides; the largest whorl thickness is a little below the mid-height of the whorl (at D = 66 mm, Wb = 31%). The umbilicus is shallow. Inner whorls show the presence of weakly developed ribs; on the outer whorl thin ribs occur at the ventral side of the whorl, but the whole final half of whorl is covered with poorly individualized sets of riblets.

This unique specimen differs in ribbing, whorl section, and in coiling character from weakly ornamented representatives of *Craspedites* such as *C*. *okensis* including its very weakly ornamented and more evolute morphotype (*C*. *okensis* morphotype A in: Rogov 2010). It seems to be similar to the most evolute representatives of the genus *Kachpurites* such as *Kachpurites fulgens* (Trautschold), see e.g. Gerasimov (1969) or Mitta et al. (1999). The range of variability within this species is fairly wide (e.g. Gerasimov 1969 or Mitta et al. 1999), and the studied specimen could be easily accommodated in that species. It should be remembered, however, that the representatives of the genus have not been reported so far from Spitsbergen, except a single, small, poorly preserved specimen recently illustrated by Rogov (2010, pl. 3, fig. 3). Thus, as the occurrence of the genus in Spitsbergen is unusual, the specimen studied is for the time identified to the genus level only.

Occurrence: The genus *Kachpurites* occurs in the Fulgens Zone, i.e. the lowermost part of the Upper Volgian on the Russian Platform, and recently has been discovered also in Siberia (Rogov & Zakharov 2009). Due to the limited stratigraphical and geographical range of occurrence

Fig. 5. Upper Volgian ammonites from the Okensis Zone and uppermost Volgian-lowermost Ryazanian ammonite from the Chetae-lower Kochi interval, Sassenfjorden hydrocarbon seep carbonates, Spitsbergen; arrow marks the onset of the body chamber, scale bar 10 mm (Fig. 5.1-5.4a) or 5 mm (Fig. 5.4b). **1** – *Craspedites okensis* (d'Orbigny, 1845): a) lateral view, b) ventral view; Okensis Zone; Originalis Subzone, PMO 217.159, locality 8. **2** – *Craspedites (Taimyroceras) originalis* Schulgina, 1969: a: lateral view, b: ventral view; Okensis Zone, Originalis Subzone, PMO 217.230, locality 8. **3** – *Kachpurites* sp., lateral view, lower Okensis Zone, PMO 217.155, locality 3. **4** – *Hectoroceras (?Shulginites)* sp., a-b: lateral view of the fragmentarily preserved specimen and its inner whorls; outer whorl – body chamber, inner whorls – phragmocone; Chetae-lower Kochi Zone interval, PMO 217.166, locality 7.

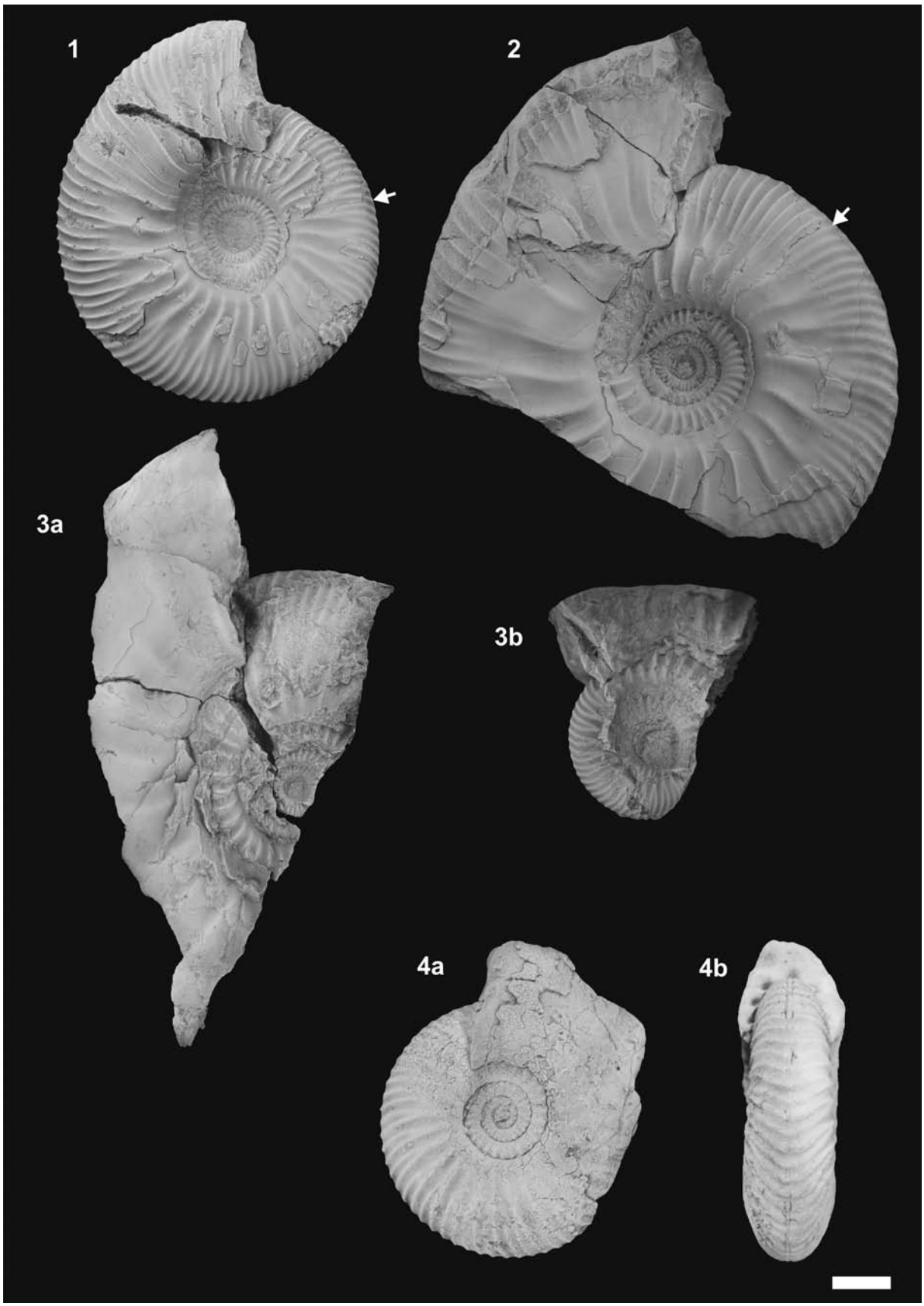

Fig. 6.

of *Kachpurites* it cannot be treated as a microconch of *Craspedites* (*Craspedites*), as has been suggested recently (cf. Wright et al. 1996).

Genus *Hectoroceras* Spath, 1947
Subgenus *Shulginites* Casey, 1973

Type species: *Oxynoticeras tolijense* Nikitin, 1884.

Hectoroceras (?Shulginites) sp.
Fig. 5.4a-4b

Material: A single specimen (PMO 217.166) from carbonate body 7. This is about 80 mm in diameter, fragmentarily preserved and deformed; it shows worn (originally smooth or nearly smooth) outer whorl (body chamber), with a preserved fragment of an inner whorl (phragmocone). Coiling is very involute; whorl section is highly compressed with flattened whorl sides. A fragment of inner whorl about 10 mm in height shows presence of densely spaced, biplicate and single falcoid ribs. The poor preservation makes impossible closer determination of the specimen although the smooth (?) body chamber suggests affinity to *Shulginites* Casey, 1973, which is treated as subgenus of *Hectoroceras* (see Wright et al. 1996). The subgenus *Hectoroceras* occurs in the Kochi Zone of Siberia, Russian Platform, North Sea, England and East Greenland, but the subgenus *Shulginites* occurs also below, in the lowermost Ryazanian (in the Maynci-Sibiricus Zone), and even in the uppermost part of the Upper Volgian Substage (Mesezhnikov et al. 1983; Alfirov & Igolnikov 2007).

Subfamily Tolliinae Spath, 1952
Genus *Borealites* Klimova, 1969

Type species: *Borealites fedorovi* Klimova, 1969.

Remarks: The genus includes three subgenera (cf. Wright et al. 1996): the subgenus *Borealites* Klimova, 1969, the subgenus *Ronkinites* Schulgina, 1972, and the subgenus *Pseudocraspedites* Casey, Mesezhnikov & Schulgina, 1977. Previously (e.g. Schulgina 1972, 1985) all these taxa have been treated as subgenera of the genus *Subcraspedites* Spath, 1924. *Subcraspedites* is, however, an earlier representative of the subfamily Craspeditinae, mostly endemic of the eastern England (Spilsby Province; Abbink et al. 2001), and should not be included in the *Borealites* group.

Subgenus *Ronkinites* Schulgina, 1972

Type species: *Subcraspedites* (*Ronkinites*) *rossicus* Schulgina, 1972.

Borealites (*Ronkinites*) *rossicus* (Schulgina,1972)
Fig. 6.1-6.2

1972 *Subcraspedites* (*Ronkinites*) *rossicus*. – Schulgina, p. 148-150; pl. 6, fig. 2; pl. 7, figs. 1-3; text-fig. 10.2.

Material: Five specimens, all from carbonate body 2 (PMO 217.186; PMO 217.206; PMO 217.167; PMO 217.208; PMO 217.165).

Description: The specimens are from 40 to 96 mm in diameter and represent phragmocones with either part or whole body chambers preserved. The latter is about two thirds of a whorl in length. Two specimens (Fig.6.1-6.2) are possibly fully grown attaining final size at 65 and 90 mm diameter, respectively, as shown by modification of the ribbing at the peristome. The coiling of the phragmocone is moderately involute (at D = 55-60 mm, Wh = 40-42%, Ud = 27-32%), whereas that of body chamber is weakly involute (at D = 65-80, Wh = 37.5-38.5%, Ud = 32-34%). Whorl section is markedly compressed with flattened whorl sides and gently rounded venter (Wb is about 35% at the end of phragmocone, and 29% on the body chamber). The primary ribs on inner whorls are rather densely spaced numbering 31-38 per whorl at D = 30-40 mm; the primary ribs become more loosely spaced on the outer whorl (about 25-30 at 60-80 mm diameter); the primary ribs are split into two and later three secondary ribs about mid-height of whorl; the intercalatory ribs are fairly numerous on the outer whorl. The secondary/primary ribs ratio changes from about 2.0 on the inner whorls, up to 2.8 and 3.9 on the outer whorl. The 2-3 shallow but fairly wide constrictions are well visible on the outer whorl; the ribbing near constrictions becomes less regular and dischizotomous rib divisions appear.

Discussion: The species *B.* (*R.*) *rossicus* attains rather moderate final size from about 65 to 90 mm confirming observation by Schulgina (1972). The general character of ornamentation of this species is similar to that of *Borealites fedorovi* Klimova, the type species of the genus *Borealites*

Fig. 6. Ryazanian ammonites from the Analogus Zone, Sassenfjorden hydrocarbon seep carbonates, Spitsbergen; arrow marks the onset of the body chamber, scale bar 10 mm (Fig. 6.1-6.3a, 6.4a-6.4b) or 5 mm (Fig. 6.3b). **1-2** – *Borealites (Ronkinites) rossicus* (Schulgina, 1972), lateral view; Analogus Zone, Subquadratus = Subanalogus Subzone; Fig. 1 – PMO 217.186, Fig. 2 – PMO 217.165; locality 2. **3** – *Borealites* (*Pseudocraspedites*) sp., a-b: lateral view of the fragmentarily preserved specimen and its inner whorls: outer whorl – body chamber, inner whorls – phragmocone; Analogus Zone, Subquadratus = Subanalogus Subzone, PMO 217.151, locality 45. **4** – *Surites (Surites) spasskensis* (Nikitin, 1888), a: lateral view, phragmocone; b: ventral view; Analogus Zone; PMO 217.231, locality 45.

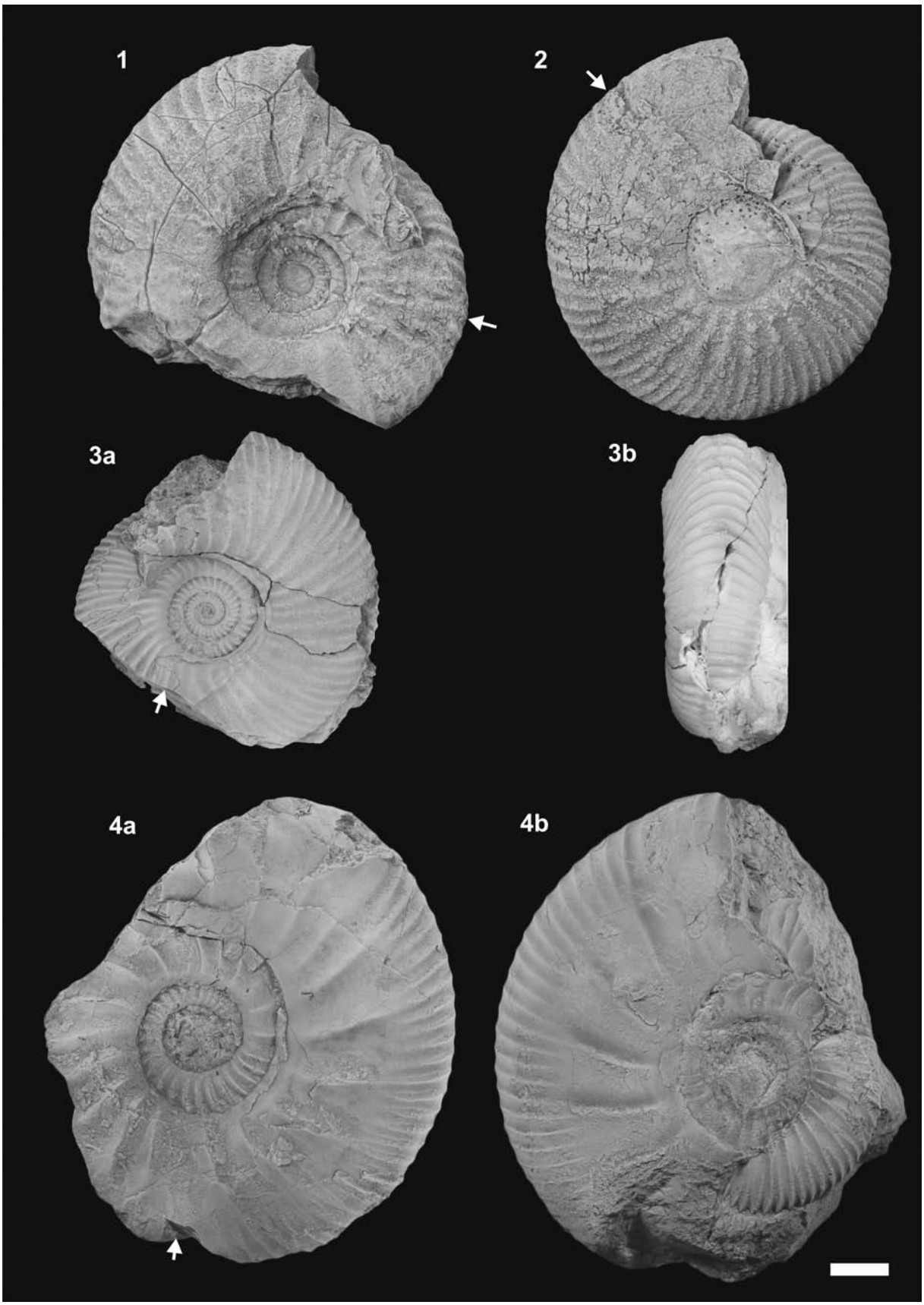

Fig. 7.

(see Klimova 1969). This makes it possible to treat *Ronkinites* as a subgenus of *Borealites* (see Casey 1973; Casey et al. 1977). The subgenus *Ronkinites* differs from the subgenus *Borealites* in a lower secondary/primary ribs ratio, less strongly developed primary ribs on outer whorl, as well as in more flattened whorl sides (Schulgina 1985). According to Wright et al. (1996) the subgenus *Ronkinites* possibly represents the microconch of *Pseudocraspedites*.

Occurrence: The species occurs in the Kochi Zone of the Lower Ryazanian and the lower part of the Analogus Zone of the Upper Ryazanian in northern Siberia (Schulgina 1972; Alekseev 1984). It is reported here for the first time from Spitsbergen.

Subgenus *Pseudocraspedites* Casey, Mesezhnikov & Schulgina, 1977

Type species: *Subcraspedites anglicus* Schulgina, 1972.

Borealites (*Pseudocraspedites*) sp.
Fig. 6.3a-3b

Material: A single fragmentary specimen (PMO 217.151) from carbonate body 5. The ribbing of innermost whorls at 15 mm diameter consists of fairly densely spaced biplicate ribs showing a marked forward sweep of the secondaries on the venter. On middle whorls the primary and secondary ribs are thin and slightly prorsiradiate. The number of secondaries corresponding to one primary rib equals about 3.5-4. The whorl section is rounded. The fragmentarily preserved outer whorl at about 110 mm diameter shows the presence of swollen primary ribs on the dorsal side of whorl, while the ventral side is smooth.

Remarks: The general characters of the specimen indicate its affinity to the subgenus *Pseudocraspedites* (see Casey et al. 1977; Schulgina 1985), but it is not well enough preserved to be closely identified further. The subgenus *Pseudocraspedites* ranges from the Kochi Zone of the Lower Ryazanian (Schulgina 1985) into the lower part of the Analogus Zone of the Upper Ryazanian (Alekseev 1984: 88) in Siberia. It was also reported from the Festningen section in western Spitsbergen (Rogov & Guzhikov 2009), although lithostratigraphical provenance of the specimen mentioned therein remains unknown.

Genus *Surites* Sazonov, 1951

Type species: *Surites pechorensis* Sazonov, 1951.

Remarks. Representatives of two subgenera occur in the material studied: the nominative subgenus and the subgenus *Bojarkia* Schulgina, 1969. The latter was originally treated as an independent genus (Saks & Shulgina 1969; Schulgina 1985) but growing evidence of its close affinity with *Surites* sensu stricto resulted in an interpretation of that taxon as a subgenus of *Surites* (see Casey 1973; Alekseev 1984; Wright et al. 1996).

Subgenus *Surites* Sazonov, 1951

Surites (*Surites*) *spasskensis* (Nikitin, 1888)
Figs. 6.4a-4b, 7.1

1888 *Olcostephanus spasskensis*. – Nikitin, p. 95, pl. 1, figs. 9-11.
1972 *Surites* (*Surites*) *spasskensis* Nikitin (non Bogoslovsky). – Schulgina, p. 151-152, pl. 5, fig. 3; pl. 9, fig. 1; pl. 10, fig. 1; pl. 11, fig. 1 (with synonymy therein).

Material: Four specimens from carbonate body 5: two well preserved (PMO 217.231 and PMO 217.232 and two fragments referred to as cf. *spasskensis* (PMO 217.204 and PMO 217.209). In addition, two specimens from the same carbonate body (PMO 217.213 and PMO 217.1630) are referred to as *Surites* aff. *spaskensis* (see comments in discussion).

Description: The two well preserved specimens (Figs. 6.4a-4b, 7.1) are about 60 and 85 mm in diameter. The smaller represents a phragmocone, whereas the larger is a phragmocone with a partly preserved body chamber (the phragmocone/body chamber boundary is at 55 mm diameter). Coiling is moderately involute (at D = 55-60 mm, Wh = 39.2-41.7%, Ud = 28.3-31.6%). The whorl section is compressed, with flattened sides, and the largest thickness at about one third of the whorl height (at D = 45-80 mm, Wb = 32-34.5%). Ribbing of inner and middle whorls consists of biplicate ribs, which are prorsiradiate and split somewhat above the mid-height of whorl; the secondary ribs show a marked forward sweep at the venter; at about 70-80 mm diameter there appear additional secondary ribs, and the secondary/primary ribs ratio increases to 2.2, and even 3.0. The number of primary ribs per whorl is fairly constant, 25-30 at 30-80 mm diameter.

Fig. 7. Ryazanian ammonites from the Analogus and Tzikwinianus zones, Sassenfjorden hydrocarbon seep carbonates, Spitsbergen; arrow marks the onset of the body chamber, scale bar 10 mm. **1** – *Surites (Surites) spasskensis* (Nikitin, 1888), lateral view; Analogus Zone; PMO 217.232, locality 45. **2** – *Surites (Surites)* aff. *spasskensis* (Nikitin, 1888), lateral view; Analogus Zone; PMO 217.213, locality 45. **3** – *Surites (Surites) spasskensoides* (Schulgina, 1972), a: lateral view; b: ventral view; Analogus Zone; PMO 217.210, locality 14. **4** – *Surites (Bojarkia) tzikwinianus* (Bogoslovsky, 1896), a-b: right and left view of the same specimen; Tzikwinianus Zone; PMO 217.190, locality 12.

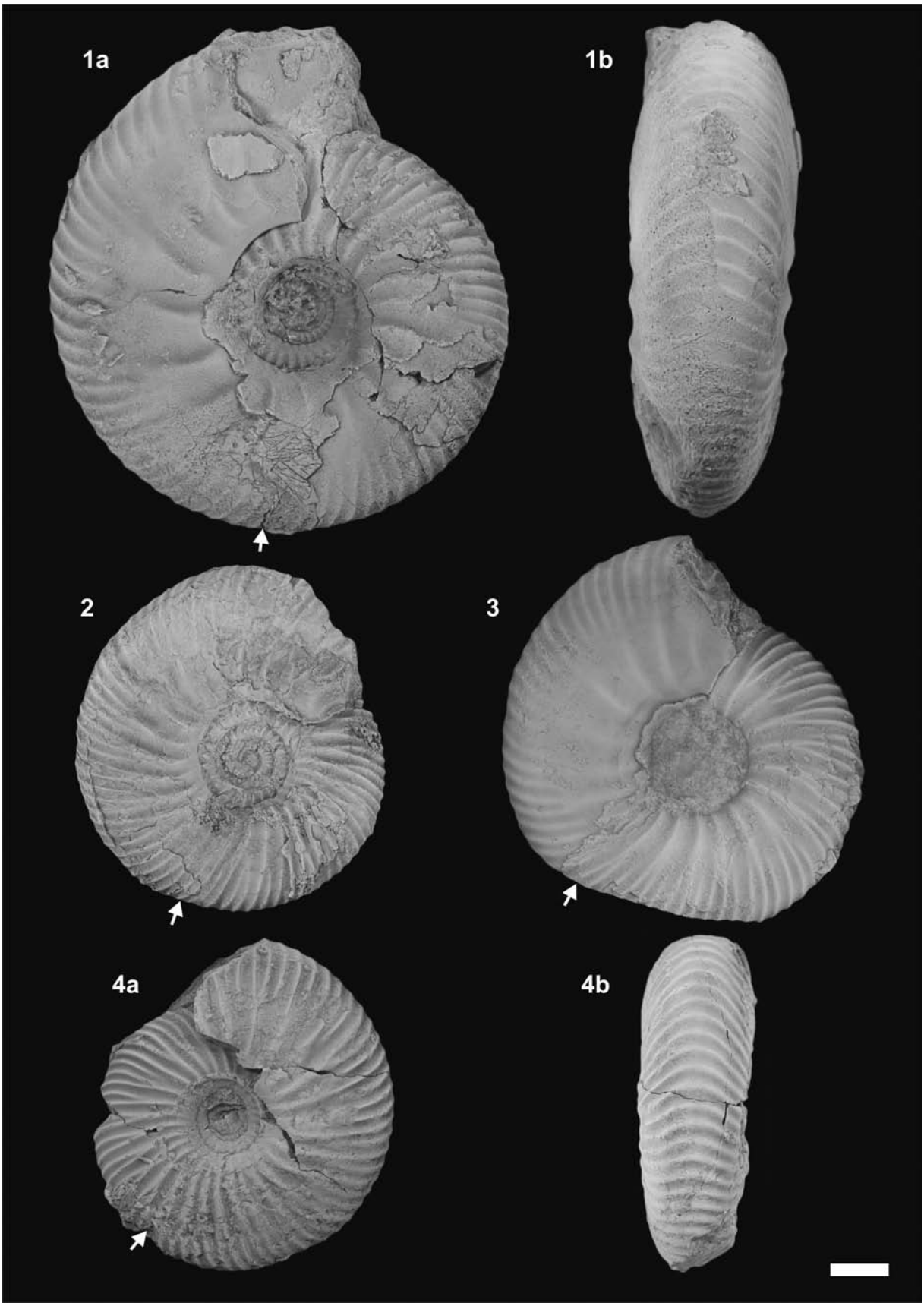

Fig. 8.

Discussion: *S. spasskensis*, as described originally by Nikitin (1888), is very close to some other species, such as *S. pechorensis* Sazonov and *S. poreckoensis* Sazonov, differing only in somewhat less dense ribbing and earlier appearance of triplicate ribs (Schulgina 1972); the latter are sometimes treated as conspecific with *S. spasskensis* (see Alekseev 1984).

Two specimens in the material studied (e.g. Fig. 7.2) are similar to those described above, but differ in the early appearance of triplicate ribs at 35-40 mm diameter. This results in a fairly high secondary/primary ribs ratio which equals about 2.3-2.4 at 50 mm diameter, and about 2.6 at 70 mm diameter. These specimens are referred to here as *Surites* aff. *spasskensis*.

Occurrence: The species occurs in the upper part of the Rjasanensis Zone, and below the Tzikwinianus Zone on the Russian Platform (see e.g. Mesezhnikov 1984). It occurs in the Kochi Zone and in the Analogus Zone of northern Siberia, i.e. in the uppermost part of the Lower, and lowermost part of the Upper Ryzanian (Alekseev 1984; Schulgina 1985). A poorly preserved specimen referred to as *Surites* sp. indet. but similiar to *S. spasskensis* has been reported from the Festningen section (see Ershova 1972: 87, pl. 2, fig. 5).

Surites (*Surites*) *spasskensoides* Schulgina, 1972
Fig. 7.3a-3b

1896 *Olcostephanus spasskensis* Nikitin. – Bogoslovsky, p. 50-52, pl. 2, fig. 1a-1b.
1972 *Surites* (*Surites*) *spasskensoides* Schulgina, p. 152.
1985 *Surites* (*Surites*) *subspasskensis* Schulgina, p. 134.

Material: A single specimen from carbonate body 14 (PMO 217.210).

Discussion: The specimen of Bogoslovsky (1896) referred to originally as *Surites spasskensis* (Nikitin) differs from representatives of *S. spasskensis* in having more delicate and dense ribbing, and in the secondary ribs being weakly projected on the venter. This was the reason that Schulgina (1972) proposed the new name *Surites spasskensoides* for Bogoslovsky 's specimen. This was later replaced by the name *Surites subspasskensis* (Schulgina 1985), being, however, evidently a younger synonym of the former.

The studied specimen closely resembles that of Bogoslovsky (1896). Our specimen (Figs.7.3a-3b) represents a phragmocone with a part of the body chamber; the phragmocone/body chamber boundary is at 40 mm diameter, and the body chamber occupies a half of whorl. Coiling is moderately involute (at D = 60 mm, Wh = 39%, Ud = 27.5%). Whorl section is high oval with largest thickness at about one third of whorl height. The ribs are prorsiradiate and split mostly into two secondary ribs showing a weak forward sweep. At the end of the last whorl there appear additional secondary ribs. The ribs are densely spaced and their number oscillates from 31 primaries per whorl at 20 mm diameter, up to 35 primaries per whorl at 40-60 mm diameter.

Occurrence: The specimen of Bogoslovsky (1896: 36) comes from near Shathrischi Village on the Russian Platform, occurring with "*Olcostephanus*" = *Surites kozakowianus* Bogoslovsky and *Surites analogus* Bogoslovsky, and as such it may be treated as occurring in the Analogus Zone of the Upper Ryazanian.

Subgenus *Bojarkia* Schulgina, 1969

Type species: *Bojarkia mesezhnikovi* Schulgina, 1969.

Surites (*Bojarkia*) *tzikwinianus* (Bogoslovsky, 1896)
Figs. 7.4a-4b, 8.1-8.4

1896 *Olcostephanus tzikwinianus*. – Bogoslovsky, p. 59-61, pl. 2, fig. 6a-6c.
1902 *Olcostephanus subtzwikinianus*. – Bogoslovsky, p. 26-27, pl. 5, fig. 2a-2b; pl. 6, fig. 1a-1b.
1929 *Polyptychites* (?) *hoeli*. – Frebold, p. 13-14, pl. 2, fig. 3.
1964 *Surites tzikwinianus* (Bogoslovsky). – Donovan, p. 31, pl. 7, fig. 1.
1972 *Surites hoeli* (Frebold). – Ershova, p. 84.
?1972 *Surites* sp. (ex gr. *subtzikwinianus* Bogoslovsky). – Ershova, p. 87, pl. 2, figs. 2-4.
1978 *Surites tzikwinianus* (Bogoslovsky). – Surlyk, p. 32, pl. 7, fig. 1.

Material: 13 specimens: three from carbonate body 9 (PMO 217.233; PMO 217.152; PMO 217.162), eight from carbonate body 12 (PMO 217.221; PMO 217.190; PMO 217.224; PMO 217.223; PMO 217.222; PMO 217.187; PMO 217.256; PMO 217.255) and two from carbonate body 10 (PMO 217.161; PMO 217.158). Four fragmentary specimens from carbonate body 12 are referred to as *Surites* (*Bojarkia*) cf. *tzikwinianus*.

Fig. 8. Ryazanian ammonites from the Tzikwinianus Zone, Sassenfjorden hydrocarbon seep carbonates, Spitsbergen; arrow marks the onset of the body chamber, scale bar 10 mm. **1** – *Surites (Bojarkia) tzikwinianus* (Bogoslovsky, 1896); a. lateral view, b: ventral view; Tzikwinianus Zone; PMO 217.223, locality 12. **2** – *Surites (Bojarkia) tzikwinianus* (Bogoslovsky, 1896), lateral view; Tzikwinianus Zone; PMO 217.161, locality 10. **3** – *Surites (Bojarkia) tzikwinianus* (Bogoslovsky, 1896), lateral view; Tzikwinianus Zone; PMO 217.233, locality 9. **4** – *Surites (Bojarkia) tzikwinianus* (Bogoslovsky, 1896), a: lateral view, b: ventral view; Tzikwinianus Zone; PMO 217.187, locality 12.

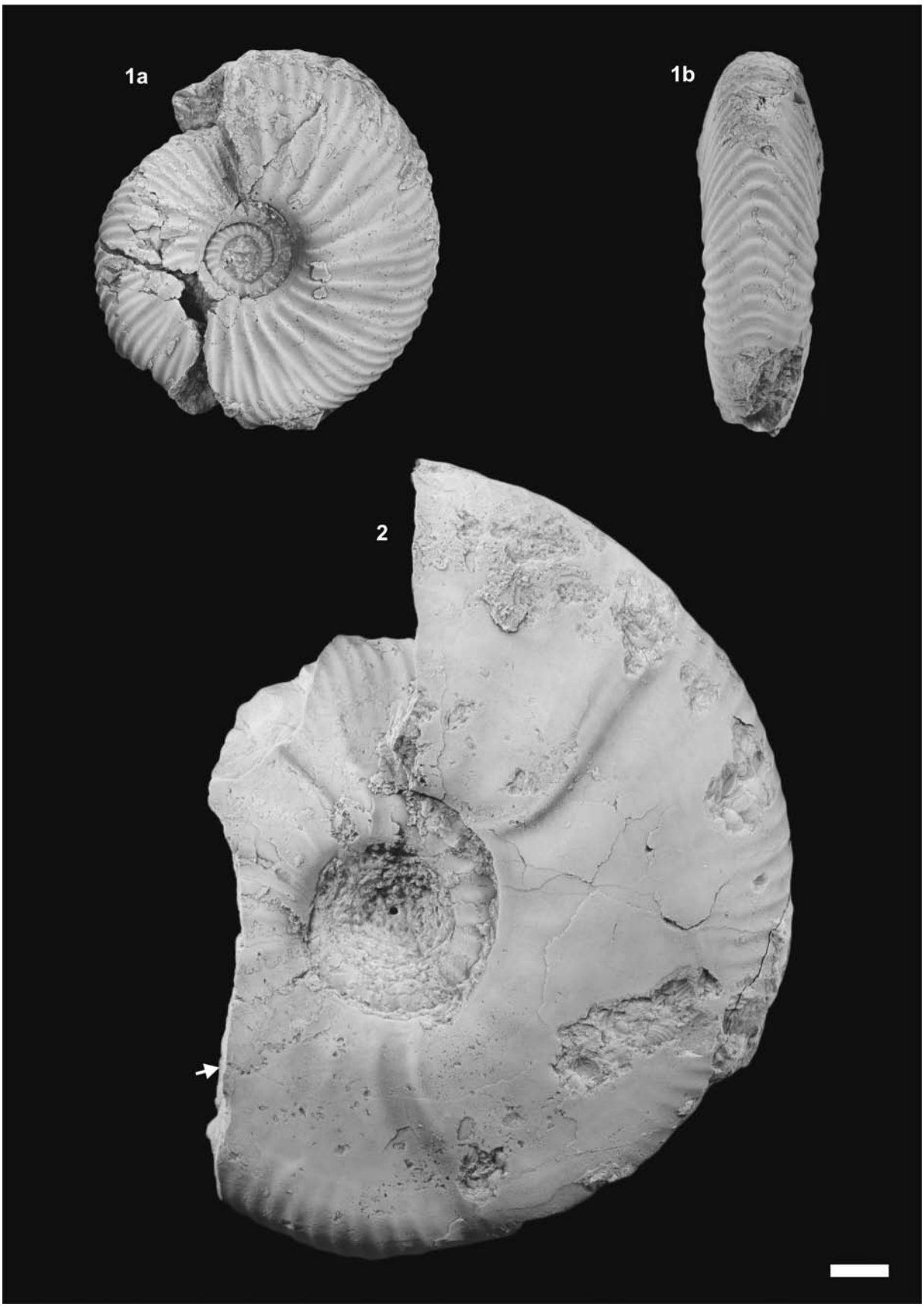

Fig. 9.

Description: The specimens are from about 60 to 100 mm in diameter. They represent phragmocones with partly preserved body chamber; phragmocone/body chamber boundary is at 45-70 mm diameter. Coiling is moderately involute (at D = 45-70 mm, Wh = 38-44 % – median 41.8 %, Ud = 23.7-32.2 % – median 27.9 %). Whorl section is compressed, with flattened whorl sides, and the largest thickness at about on third of the whorl height (at D = 45-70 mm, Wb = 29.8-37.7% – median 34.42 %). Ribbing on inner whorls consists of biplicate ribs which are prorsiradiate and split about the mid-height of whorl; the secondary ribs show a marked forward sweep at the venter. This type of ribbing may continue up to about 40-45 mm diameter; then the triplicate ribs appear, as well as additional secondary ribs, numbers of which increases with growing diameter; the secondary/primary ribs ratio ranges from about 2.3 to 3.0 at D = 55-60 mm and from 3.5 to 4.5 at D = 70-90 mm. The number of primary ribs per whorl is about 27-30 at 30-50 mm diameter, and it diminishes with growing diameter to about 20-26 at D = 70-90 mm. At larger diameters the ribbing becomes weaker at the mid-point of the whorl height, which results in the appearance of a spiral band of only slightly raised ribs.

Discussion: The species *Surites tzikwinianus* differs from *Surites subtzikwinianus* according to Bogoslovsky (1902) in somewhat more involute coiling, a larger whorl thickness and smaller number of secondary ribs. The differences are, however, within the range of variability of the specimens studied (see also Alekseev 1984). The same is the case of "*Polyptychites* (?)" *hoeli* = *Surites hoeli* (Frebold) which differs only in a larger size (102 mm diameter of the specimen wholly represented by phragmocone) when compared with specimens studied. Thus, all these names are treated herein as synonymous. The forms *S. tzikwinianus* and *S. subtzikwinianus* show the general features of *Bojarkia* shown by Casey (1973), and later by Alekseev (1984).

The strongly developed primary ribs on outer whorls of large specimens in the collection studied are similar to those of the stratigraphically older subgenus *Borealites*, but the ornamentation differs among others features in a forward sweep of secondary ribs on the venter which is typical for the genus *Surites*. The problem is here similar to that of a large specimen of "*Olcostephanus*" *suprasubditus* of Bogoslovsky (1896, pl. 1, fig. 1) being the lectotype of the species which shows the outer whorls only, and is therefore somehow doubtful systematically. It is placed either in the subgenus *Borealites* (see e.g. Klimova 1969; Schulgina 1972, 1985) or in the subgenus *Bojarkia* of the genus *Surites* (see e.g. Casey 1973). The latter determination seems, however, more probable (cf. also Alekseev 1984).

Occurrence: The species defines the Tzikwinianus Zone, well above the Rjasanensis Zone in the Russian Platform (e.g. Mesezhnikov 1984). It is known from East Greenland where it defines the Tzikwinianus Zone (Surlyk 1978; see also Donovan 1964). The specimen of *Polyptychites* (?) *hoeli* of Frebold (1929) attributed herein to that species was found in shales at Festningen in Spitsbergen. Fragmentarily preserved specimens referred to as *Surites* sp. ex gr. *subtzikwinianus* (Bogoslovsky) by Ershova (1972, pl. 2, figs. 2-4; 1983, pl. 28, fig. 5) found in black shales at Sørkapp Land in Spitsbergen could also belong to the species. An ammonite fragment found in core level 13.20 m in Sklinnabanken, Norwegian Sea, has been also tentatively compared with that species (Aarhus et al. 1986).

Genus *Tollia* Pavlow, 1914
Subgenus *Tollia* Pavlow, 1914

Type species: *Tollia tolli* Pavlow, 1914.

Tollia (*Tollia*) *tolli* Pavlow, 1914
Fig. 9.1-9.2

1972 *Tollia tolli* Pavlow. – Schulgina, p. 162-164, pl. 5, fig. 4; pl. 17, fig. 1; pl. 18, fig. 2; text-figs 10-12 (with synonymy therein).

Material: Two well preserved specimens from carbonate body 9 (PMO 217.185 and PMO 217.154).

Description: The smaller specimen is about 60 mm in diameter and represents a phragmocone (Fig. 9.1a-1b), the larger specimen is about 135 mm in diameter and is a phragmocone with a part (half a whorl long) of the body chamber preserved (Fig. 9.2). Coiling is strongly involute (at D = 60 mm, Wh = 45.8 %, Ud = 25 %; at D = 130 mm, Wh = 42.3 %, Ud = 26.1%). Whorl section is compressed, oval in shape with flattened sides, and the largest whorl thickness at about one third of whorl height (at D = 60 mm, Wb = 33.3 %; at D = 130 mm, Wb = 28.5 %). Ribbing is fairly dense on inner and middle whorls (about 25 primary ribs per whorl) consisting of prorsiradiate and strong primary ribs which split into 2-3 secondary ribs with some intercalatory ribs appearing about the mid-height of whorl (the secondary/primary ribs ratio equals 2.7 at 60 mm diameter). The secondary ribs are prorsiradiate and strongly projected on the venter. The ribbing tends to disappear on the middle of the whorl side already on middle whorls (in larger specimen at about 70 mm diameter). The outer whorl

Fig. 9. Uppermost Ryazanian ammonites from the Tolli Zone, Sassenfjorden hydrocarbon seep carbonates, Spitsbergen; arrow marks the onset of the body chamber, scale bar 10 mm. **1** – *Tollia (Tollia) tolli* Pavlow, 1914, a: lateral view, phragmocone, b: ventral view; Tolli Zone; PMO 217.185, locality 9. **2** – *Tollia (Tollia) tolli* Pavlow, 1914, lateral view; Tolli Zone; PMO 217.154, locality 9.

of the large specimen shows the succeeding disappearance of ribbing, initially on a large part of whorl side except the periumbilical part and the ventrolateral part of whorl, but afterwards from about 130 mm diameter the whole whorl becomes smooth. The outer whorl of the larger specimens shows well developed constrictions (three per whorl).

Discussion: The characters of the specimens studied are in full agreement with those of *Tollia tolli* (cf. description of the species in Schulgina 1972).

Occurrence: The species was previously treated as occurring in the uppermost Ryazanian, in the upper part of the Mesezhnikovi Zone, but it was reported also from the lowermost Valanginian (e.g. Schulgina 1985; Bogomolov et al. 2011) in Russian Platform and Siberian sections and from the same stratigraphic position in the Canadian Arctic Archipelago (Jeletzky 1973: 46, fig. 2). However, according to Alekseev (1984) the species appears at the top of the Mesezhnikovi Zone well above the upper range of the ammonites of the subgenus *Bojarkia*. A form referred to as *Tollia* cf. *tolli* was described from East Greenland (Surlyk 1978, pl. 8, fig. 1) where it was correlated with the Tolli Zone above the Mesezhnikovi Zone. Fragmentary specimens referred to as *Tollia* sp. were reported also from the Festningen section of western Spitsbergen by Ershova (1972, pl. 2, figs. 6-9; 1983, pl. 28, fig. 4). Recent biostratigraphical correlations indicate that the Tolli Zone should be placed in the uppermost Ryazanian (see comments in chapter 3).

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Addresses of the authors

Andrzej Wierzbowski, Institute of Geology, University of Warsaw, ul. Żwirki i Wigury 93, 02-089 Warszawa, Poland;
e-mail: andrzej.wierzbowski@uw.edu.pl

Polish Geological Institute – National Research Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland.
e-mail: andrzej.wierzbowski@pgi.gov.pl

Krzysztof Hryniewicz, Natural History Museum, Box 1172 Blindern, 0318 Oslo, Norway;
e-mail: krzysztof.hryniewicz@nhm.uio.no

Øyvind Hammer, Natural History Museum, Box 1172 Blindern, 0318 Oslo, Norway;
e-mail: ohammer@nhm.uio.no

Hans Arne Nakrem, Natural History Museum, Box 1172 Blindern, 0318 Oslo, Norway;
e-mail: h.a.nakrem@nhm.uio.no

Crispin T.S. Little, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK;
e-mail: c.little@see.leeds.ac.uk