An infrazonal ammonite biostratigraphy for the Kimmeridgian of Spitsbergen

Mikhail A. Rogov

Geological Institute of Rusiian Academy of Science (RAS), Moscow, Russia, e-mail: russianjurassic@gmail.com

An infrazonal ammonite-based *biostratigraphy* for the Kimmeridgian of Spitsbergen is reviewed in detail. The *Bauhini Zone*, *bayi* horizon, aff. *beaugrandi* and *norvegicum* horizon have been recognized in this area for the first time. The presence of separate *decipiens* and *elegans* horizons has been demonstrated for the Myklegardfjellet section. The Kimmeridgian ammonite succession of Spitsbergen resembles that of Franz Josef Land and consists mainly from Boreal cardioceratids and oppeliids. In contrast to East Greenland and the Norwegian Sea, the sub-Boreal aulacostephanids are restricted to a few narrow stratigraphic intervals. This difference suggests a very limited exchange by ammonite faunas through the Greenland-Norwegian Seaway during the Kimmeridgian. The evolutionary trend of Boreal oppeliid genus *Suboxydiscites* is briefly outlined.

Key words: Kimmeridgian, Jurassic, Spitsbergen, Svalbard, Ammonites, Infrazonal biostratigraphy.

Introduction

Numerous studies of Kimmeridgian high-latitude ammonite successions have been conducted during the previous three decades. Successions of biohorizons, mainly based on the cardioceratid lineage, were established through the whole Arctic from East Greenland to Barents Sea, and north of Siberia (Birkelund and Callomon, 1985; Wierzbowski and Smelror, 1993; Rogov and Wierzbowski, 2009; Wierzbowski et al., 2002). Spitsbergen is well-known for its rich Jurassic ammonite faunas (including Kimmeridgian ones) and geographical position along the migrational pathways of ammonites, making study of ammonite successions of this region very important for both stratigraphical and paleogeographical aims.

The first data on Kimmeridgian ammonites of the region were published by Spath (1921), who recorded some species of *Pictonia*, *Rasenia* and *Amoeboceras*, collected at Festningen[1] by Dr. J. W. Gregory during the 1896 expedition led by Martin Conway. Re-examination of ammonites from this collection, currently curated at the British Museum of Natural History, reveals the presence of at least one specimen of *Pictonia* (pl.1, fig. 4.1). Additional Kimmeridgian ammonites from the same section were reported by Frebold (1928), who recognized a few species of Kimmeridgian "*Cardioceras*" from bed 7. Two years later, Frebold described Kimmeridgian ammonites from various localities on Spitsbergen, including *Cardioceras* cf. *nathorsti* var. *robusta* (Frebold, 1930, pl. VIII, figs.1-2 = *Euprionoceras sokolovi* (Bodylevski)), *Rasenia* sp. indet. aff. *groenlandica* (Frebold, 1930, pl. IX, fig. 3-4; fig.3 = *Zonovia* sp., fig.4 = *Zenostephanus* (*Xenostephanoides*) cf. *thurrelli* (Arkell et Callomon)), *Rasenia* sp. indet. cf. *groenlandica* (Frebold, 1930, pl. XXII, fig. 2 = *Zenostephanus* (*Xenostephanoides*) *thurrelli* (Arkell et Callomon)) and *Cardioceras* sp. indet. aff. *cricki* (Frebold, 1930, pl. IX, figs. 1-2; fig. 1 = *Amoebites* ex gr. *subkitchini* Spath) The following year, Sokolov and Bodylevski (1931) published a description of Jurassic and Cretaceous fossils from Spitsbergen, collected primarily from the Festningen section (including all described Kimmeridgian ammonites). They figured numerous specimens of *Amoebites* cf. *subkitchini* (Spath) (as *Cardioceras* cf. *kitchini*) and described a new species *A. sokolovi* (Bodylevski).

[1] Jurassic and Cretaceous ammonites from this collection are mainly labeled as collected from "Kapp Starostin", but only Paleozoic rocks are cropped out near to this cape, while Jurassic and Cretaceous deposits are exposed some three kilometers eastwards, near to Cape Festningen.

Rogov, M.A.: An infrazonal ammonite biostratigraphy for the Kimmeridgian of Spitsbergen. *Norwegian Petroleum Directorate Bulletin,* No. 11, pp. 153–165. Stavanger 2014, ISSN Online 1894-7670, ISBN 978-82-7257-117-6.

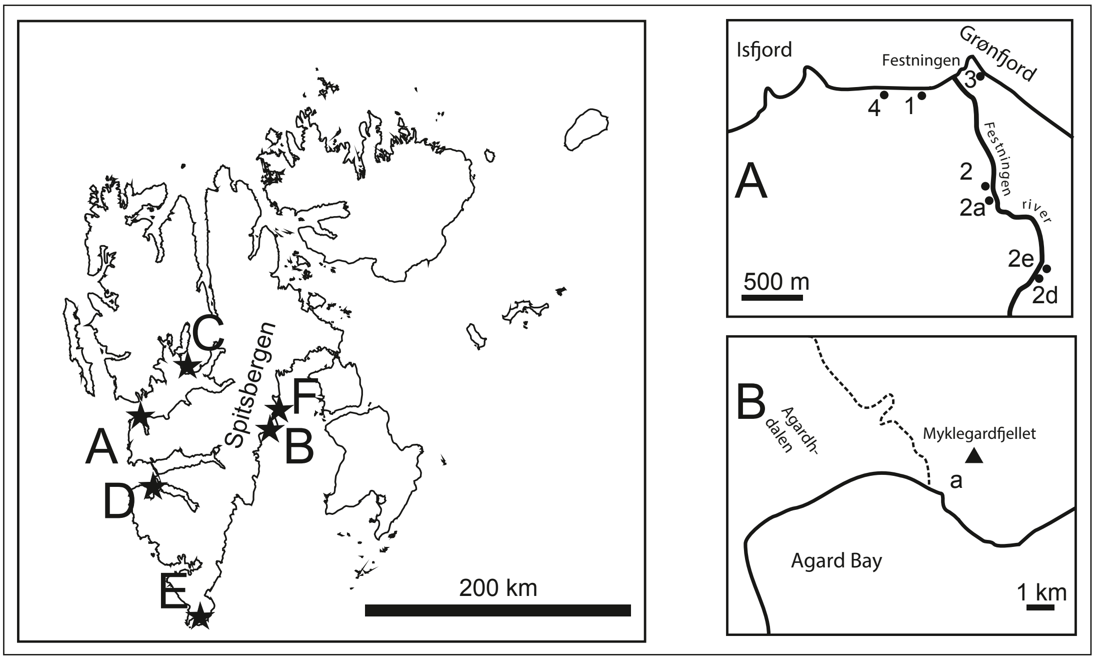

Figure 1. Map of the studied and mentioned Kimmeridgian localities in Spitsbergen. A – Festningen, B – Myklegardfjellet, C – Janusfjellet, D – Van Keulenfjorden, E – Sørkapp land, F – Duner Bay. Coordinates of the studied sections: Festningen 1 - 78°5'53" N, 13°55'35" E; Festningen 2E - 78°5'2" N, 13°57'40" E; Myklegardfjellet section - 78°02'56" N, 18°40'10" E.

During the last few decades, abundant new data regarding Kimmeridgian ammonites and biostratigraphy of Spitsbergen has been gained during the geological survey by Russian geologists (since early 60s) and by field trips by Polish Spitsbergen Expedition. New data published in 1980s, significantly improved the existing knowledge of the Kimmeridgian ammonite succession of Spitsbergen. Birkenmajer et al. (1982) described the Jurassic and Lower Cretaceous succession of Myklegardfjellet. Fossils were collected from 20 fossiliferous horizons from this section, including two levels with Kimmeridgian ammonites ; the lower level with *Amoebites* cf. *kitchini* and *Zonovia evoluta* (re-identified by Wierzbowski (1989) as *A. subkitchini* and *Rasenia cymodoce*) and the upper level with *Amoebites* cf. *salfeldi* (re-classified as *A. kitchini* by Wierzbowski, 1989). The following year, "Explanatory notes on the biostratigraphical scheme for the Jurassic and Cretaceous of Spitsbergen" were published by Ershova (1983). This included a description of all Jurassic-Lower Cretaceous zones and beds recognized during the geological survey, and figured most of the typical ammonite taxa. Ershova subdivided the Kimmeridgian Stage of Spitsbergen based on beds with *Rasenia borealis* and *Amoeboceras kitchini* (Lower Kimmeridgian), overlain by the *Mutabilis* Zone and beds containing *Amoeboceras decipiens* and *A. kochi* above (Upper Kimmeridgian). Unfortunately, this paper lacks accurate data regarding the ammonite ranges in the sections and their relative stratigraphical positions within zones and beds. The most important ammonites, figured in the paper by Ershova (1983), are index-taxa of zones, subzones and biohorizons, recently recognized in the Boreal Kimmeridgian by Birkelund and Callomon (1985) and Wierzbowski (Wierzbowski, 1989; Wierzbowski and Smelror, 1993; Wierzbowski et al., 2002). These are *Plasmatites bauhini* (Opp.) (*Amoeboceras bauhini* in Ershova, 1983, pl. V, fig. 7 only; refigured herein, Fig. 4. 2), *Amoebites pingueforme* (Mesezhn. et Romm), *A. subkitchini* (Spath), *A. kitchini* (Salf.), *Rasenia* spp., *Zenostephanus* spp. (for details see Wierzbowski, 1989), *Euprionoceras sokolovi* (Bodyl) (= *A. sokolovi* (Bodyl.) and *A. kochi* (Spath)), and *Hoplocardioceras* spp. Ershova also reported *Aulacostephanus* from the Upper Kimmeridgian. However, all ammonites from her collection recorded as *Aulacostephanus* (including those figured in Ershova, 1983, pl. XV, fig.5) should be re-classified as *Zenostephanus* and therefore could be assigned to the separate *Zenostephanus* horizon, as has been proposed previously by Wierzbowski (1989). Among stratigraphically important taxa, which were not figured, Ershova mentioned "*Streblites* sp." from the Upper Kimmeridgian, reassigned to the Boreal oppeliid genus *Suboxydiscites* (see below). Later, Wierzbowski (1989) described the Kimmeridgian ammonite succession of the Sassenfjorden area. Here he recognized a succession of ammonite faunal horizons similar to that from East Greenland, but also noted differences including the relative scarcity of aulacostephanids, which are common in two levels only, and the impossibility to subdivide *decipiens* and *elegans* horizons. Wierzbowski also critically reassessed previous indentifications and age assignments of Kimmeridgian ammonites from Spitsbergen. A paper devoted to analysis of very interesting Kimmeridgian ammonite assemblage has been published by Birkenmajer and Wierzbowski (1991). All ammonites described here were collected by K. Birkenmajer from the relatively thin band (~1 m in thickness) in the southern part of Holmgardfjellet, ca. 7 km NW from the Myklegardfjellet section. This ammonite assemblage includes only cardioceratids showing high intraspecific variability and including morphologies close to *Hoplocardioceras elegans*, *H. decipiens*, *Euprionoceras sokolovi* and ?*E. uralense*. Wierzbowski interpreted this assemblage as a highly variable biospecies *A. uralense* and concluded that this assemblage is probably slightly older than the fauna with *H. elegans* and *H. decipiens* which he previously described, and that close phyletic relations are suggested between *Amoebites* s.s., *Hoplocardioceras* and *Euprionoceras*. Alternatively, the record of strictly separated *decipiens* and *elegans* faunas in East Greenland (Birkelund and Callomon, 1985) and in Spitsbergen (Rogov, 2010b) suggests a revised age interpretation for assemblages with *H. elegans* and *H. decipiens* as described from Janusfjellet (Wierzbowski, 1989) and Holmgardfjellet (Birkenmajer and Wierzbowski, 1991). These assemblages could correspond to the intermediate level between *decipiens* and *elegans* faunas.

This study is based on the results of the field works of the years 2006 and 2007 (conducted at the famous Festnngen and Myklagardfjellet sections, see Fig. 1), which were part of joint project by NPD (Norway) and Geological Institute of RAS (Moscow, Russia). Fieldwork and analysis of published data and results of studying of collections from Spitsbergen, collected during the geological survey are presented. Ammonites are not very common in either of the studied sections, and their records are mainly restricted to particular beds or their parts only. Ammonite ranges and recognized zonal and infrazonal units are shown in Figs. 2 and 3. In terms of lithostratigraphical units the Kimmeridgian includes the Lardyfjellet and Oppdalssåta members of the

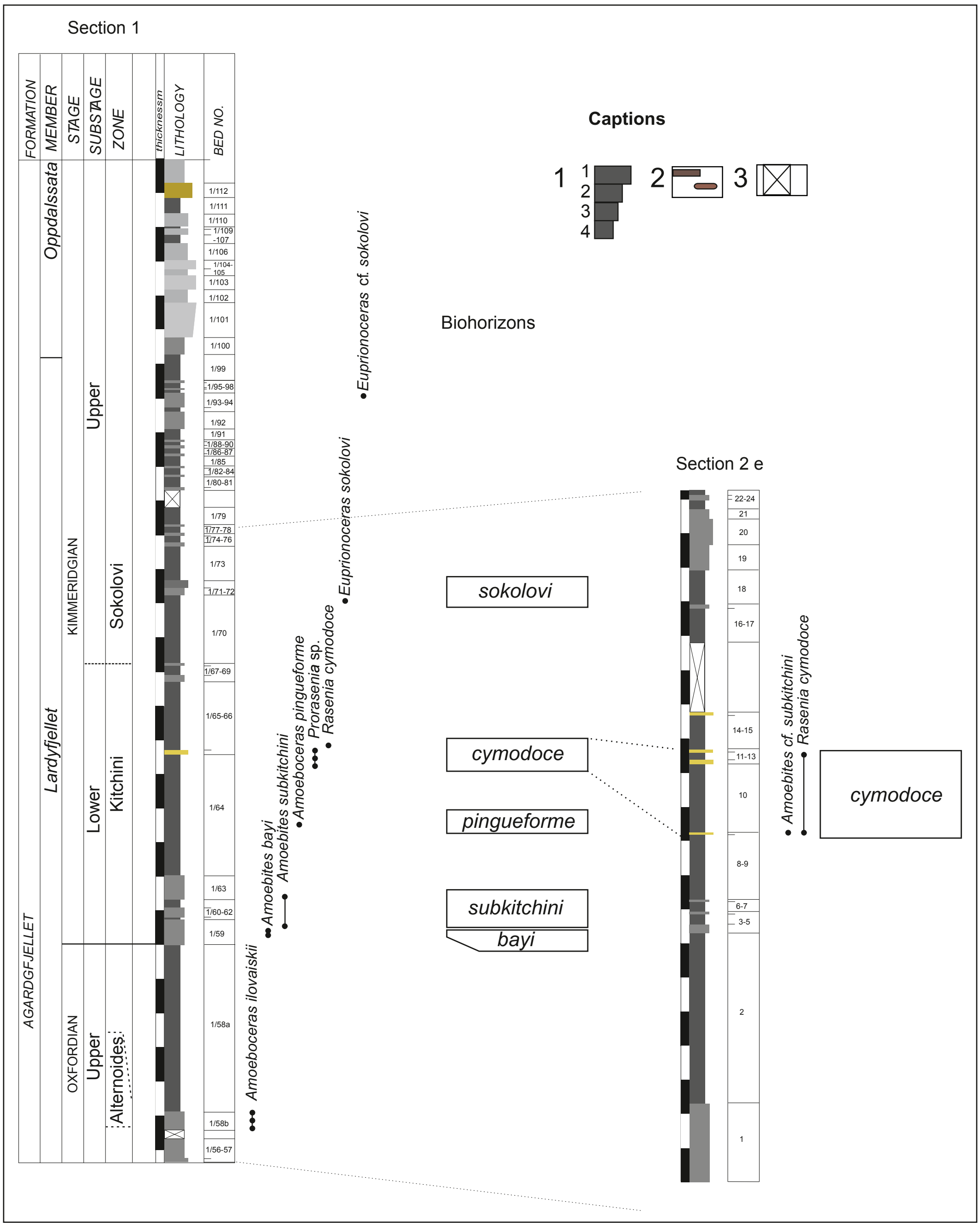

Figure 2. *Kimmeridgian ammonite ranges, litho- and biostratigraphy of the Festningen sections 1 and 2e. 1 - thickness of beds in the log corresponding to the granulometric composition of rocks: (1) sandstones, (2) siltstone, (3) silty shale, (4) shale; 2 carbonate nodules (mainly dolomite), 3 gaps in observations.*

Agardhfjellet Formation (Dypvik et al., 1991). The more coarse-grained Oppdalssåta Member is easily recognized in the Festningen section by the occurrence of thick sandstone bands, but in Myklegardfjellet it could only be tentatively recognized by the presence of relatively coarse-grained siltstone bands.

Ammonites studied in this investigation are currently curated in the Vernadsky State Geological Museum in Moscow (SGM…), in the VNIGRI Museum, Saint-Petersburg (VNIGRI…), CNIGR Museum, Saint-Petersburg (CNIGR…), Geological Museum of the University of Copenhagen (MGUH...) and in the Natural History Museum, London (NHM…).

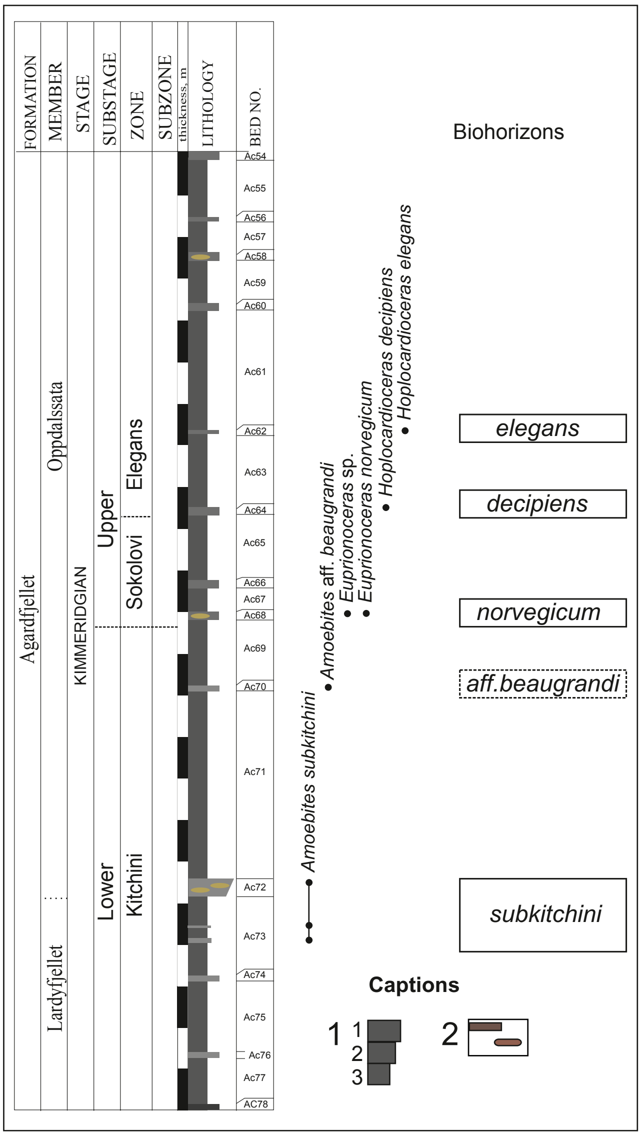

Figure 3. Kimmeridgian ammonite ranges, litho- and biostratigraphy of the Myklegardfjellet section. 1 - thickness of beds in the log corresponding to the granulometric composition of rocks: (1) siltstone, (2) silty shale, (3) shale; 2 - carbonate nodules and bands (mainly dolomite).

Ammonite succession and infrazonal biostratigraphy

The ammonite succession and preliminary zonal scheme is summarized below. The rarity of aulacostephanid ammonites and abundance of cardioceratids allows using cardioceratid-based zonal and infrazonal schemes (Wierzbowski and Smelror, 1993) and, in some cases only, the sub-Boreal aulacostephanid-based zonation (Table 1).

Lower Kimmeridgian

Bauhini Zone

Ammonites typical of this interval, were absent in both studied sections, but were recognized previously by Ershova (1983), who figured *Plasmatites bauhini* (Opp.) (Ershova 1983, pl.V, fig.7, refigured here: Fig. 4.2) from Van Keulenfjorden. *Pictonia* (*Pictonia*) sp. from Spath's collection (Fig. 4.1) could be also assigned to this zone or, alternatively, to the overlying *bayi* horizon of the *Kitchini* Zone.

Kitchini Zone

This zone is well-recognized based on the range of *Amoebites* sensu stricto. Aulacostephanid ammonites (*Rasenia cymodoce* (d'Orb.) and corresponding microconchiate *Prorasenia*) occur within a relatively narrow interval within the zone. The upper boundary of the *Kitchini* Zone closely coincides with upper boundary of the *Mitabilis* Zone in Subboreal succession. Subdivision of the *Kitchini* Zone in 3 subzones, proposed by Wierzbowski and Rogov (2013) is used here.

Bayi Subzone

Bayi horizon: *Amoebites bayi* (Birkelund & Callomon) has been recognized at Festningen section (Figs. 4.3-4).

Subkitchini Subzone

Subkitchini horizon: This subzone is well-exposed at Janusfjellet section (Wierzbowski, 1989) as well as at Myklegardfjellet (Figs. 4.6-7). At Festningen, small-sized *Amoebites subkitchini* (Spath) with looped ribs (Fig. 4.5, comparable with records from the East Taimyr, Fig. 4.9) appear directly above *A. bayi*. A small ammonite with narrow umbilicus, found above the figured specimen (Fig. 4.8), could be assigned to fine-ribbed variety of this species. There are some uncertainties regarding the full range of the *A. subkitchini* species, which co-occurs with *Rasenia cymodoce* in East Greenland (Birkelund and Callomon, 1985) and (at least *A.* ex. gr. *subkitchini*) in Spitsbergen. Earliest forms of *A. subkitchini* are characterized by a narrower umbilicus and could be compared with *A. alticarinatum* (Mesezhnikov & Romm). In Spitsbergen, the range of *A. subkitchini* possibly overlaps with the ranges of coarse-ribbed small-sized *A. mesezhnikovi* and *A. pingueforme* species.

Table 1. *Kimmeridgian ammonite zonation of Spitsbergen (preliminary) and East Greenland.*

Subboreal zonation	East Greenland horizons (cardioceratid horizons were chosen when possible; succession after Birkelund, Callomon, 1985)	Spitsbergen horizons (letters indicates sections: M - Myklegardfjellet, F - Festningen, J - Janusfjellet (Wierzbowski,1989))	Franz-Josef Land horizons (based on data published by Shulgina, 1960; Mesezhnikov, Shulgina, 1982; Repin et al. 2007)	Boreal zonation
Aulacostephanus autissiodorensis	Aulacostephanus cf.kirghisensis			Suboxydiscites taimyrensis
Aulacoste-phanus eudoxus	Hoplocardioceras elegans	Hoplocardioceras elegans	Hoplocardioceras elegans	Hoplocardio-ceras decipiens
	Hoplocardioceras decipiens	Hoplocardioceras decipiens	Hoplocardioceras decipiens	
	Amoebites kochi	Euprionoceras sokolovi	Euprionoceras sokolovi	Euprionoceras sokolovi
Aulacostepha-noides mutabilis		Euprionoceras norvegicum		
	Aulacostephanoides mutabilis	Zenostephanus sachsi	Zenostephanus sachsi	Amoebites kitchini
	Amoebites cf. beaugrandi	Amoebites aff.beaugrandi		
Rasenia cymodoce	Amoebites aff. rasenense			
		Rasenia cymodoce; Amoebites pingueforme		
	Amoebites aff. subkitchini			
	"Pachypictonia"	Amoebites mesezhnikovi		
	Amoebites subkitchini	Amoebites subkitchini	Amoebites subkitchini	
Pictonia baylei	Amoebites bayi	Amoebites bayi		Plasmatites bauhini

Mesezhnikovi horizon: recognized at Janusfjellet by Wierzbowski (1989), characterized by *Amoebites mesezhnikovi* (Sykes & Surlyk).

Pingueforme horizon: Firstly recognized at Janusfjellet (Wierzbowski, 1989) as *Rasenia cymodoce - Amoebites pingueforme* horizon and also recognized at Festningen by the presence of *Amoebites pingueforme* (Mesezhn.). Additional specimens of *A. pingueforme* from other parts of Spitsbergen were also figured by Ershova (1983). A photo of a previously unpublished specimen of *A. pingueforme* from Van Keulenfjord is given here (Fig. 4.12). At Festningen the ranges of coarse-ribbed *A. pingueforme* (Figs. 4.10-11) and aulacostephanids, assigned to *Rasenia cymodoce*, do not overlap in contrast to Janusfjellet, where their ranges coincide. Perhaps the ranges of *R. cymodoce* and *A. pingueforme* horizons overlap only partially and thus it may be possibly to recognize two concurrent biohorizons, based on different lineages. Birkenmajer et al. (1982) also mentioned *Rasenia cymodoce* (figured as *R. evoluta* and later re-determined by Wierzbowski, 1989) from the Myklegardfjellet section, but neither *Amoebites pingueforme* nor *Rasenia* were found during the studies of the same section undertaken by the current author.

Cymodoce horizon: *Rasenia cymodoce* (d'Orb.) and corresponding *Prorasenia* microconchs are among the most common aulacostephanid ammonites in the Kimmeridgian of Spitsbergen (Figs. 5.1-4). The occurrence of these ammonites is restricted to a narrow interval, within which they are relatively abundant. In some cases other ammonites are absent, for instance section 1A in Wierzbowski (1989), and interval between uppermost part of the bed 1/64 and lower part of the bed 1/66 in Festningen. Such a brief migrational event could be caused by short-term climate oscillation and/or palaegeographical changes. It should also be noted that full-grown macroconchs of *Rasenia cymodoce* (d'Orb.) from Spitsbergen (Figs. 5.1-2) are characterized by a ribbed body chamber, while typical smooth bodied forms of *R. cymodoce* (d'Orb.) are unknown here. Specimens from Spitsbergen resemble *R. evoluta* Spath in this respect but are distinguishable by more involute whorls and the usual occurrence of relatively smooth middle whorls. Such ribbed morphotypes of *R. cymodoce* (d'Orb.) co-occur with typical specimens of this species in East Greenland (Birkelund and Callomon, 1985, pl.17, fig.2). In addition to aulacostephanids, *Amoebites* ex gr. *subkitchini* (Spath) also occurs in this horizon (Fig. 5.5). It is notable, that aulacostephanids occur only sporadically in Franz-Josef Land as well as in Spitsbergen, but *Rasenia cymodoce* (d'Orb.) is absent in Franz-Josef Land. Instead this region is characterized by records of *Rasenia inconstans* Spath (Mesezhnikov and Shulgina, 1982, pl.1, fig.6, pl.2, fig.3), which is typical of the underlying biohorizon in East Greenland (Birkelund and Callomon, 1985).

Modestum **Subzone**

The provisional *Amoebites* aff. *beaugrandi* biohorizon is tentatively recognized at Myklegardfjellet, where a single poorly preserved specimen of *A.* aff. *beaugrandi* (Sauvage et Rigoux) was recovered a few beds above the level with numerous *A. subkitchini* (Fig. 5.6). The stratigraphical range of this taxon is similar to that of *A.* aff. *beaugrandi*

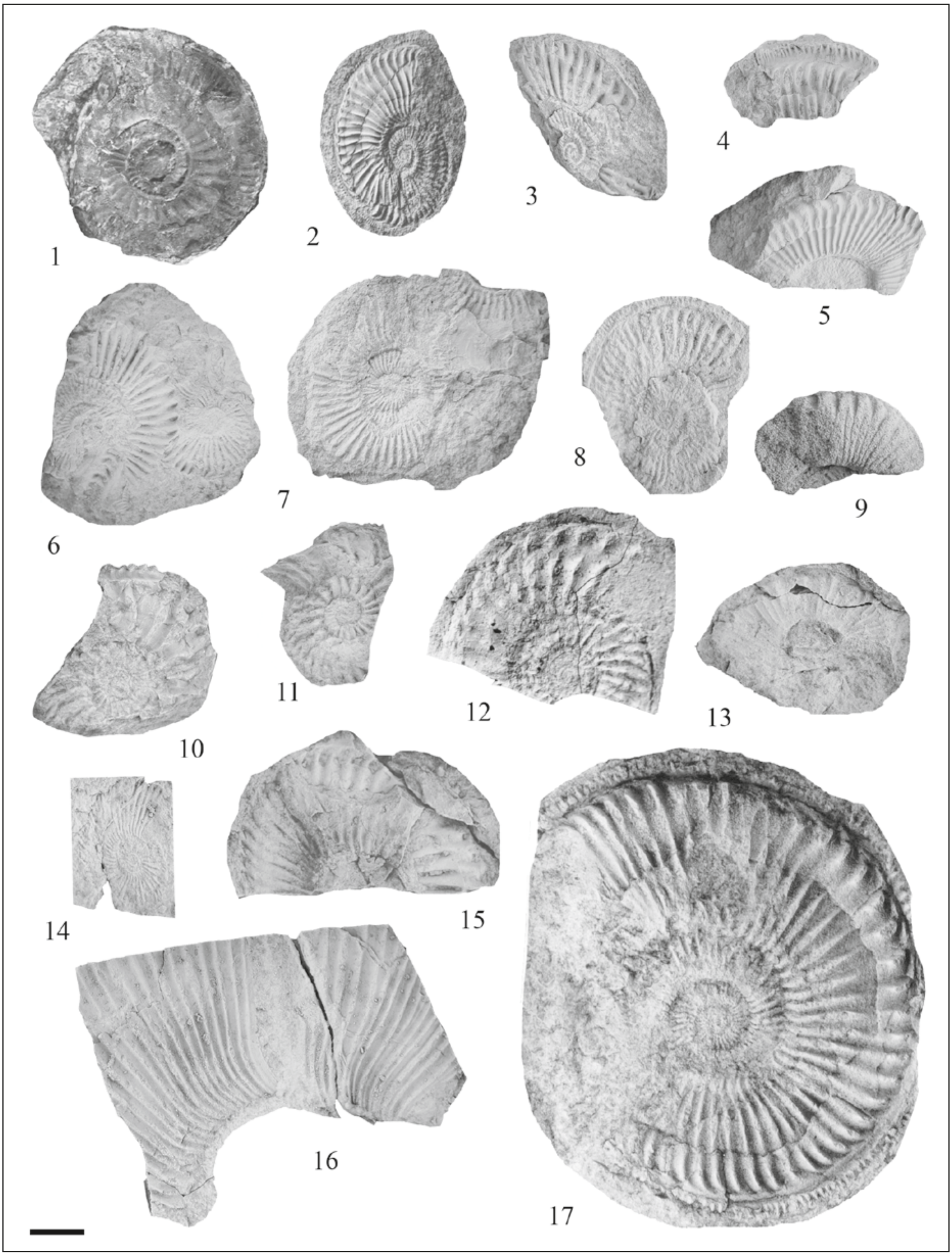

Figure 4. *Scale bar =1 cm (as well as in Figs. 5, 6, 8).* ***1.*** Pictonia *(*Pictonia*) sp., NHM C26969, Festningen, Lower Kimmeridgian, collected by Dr. J.W. Gregory (1896), mentioned by Spath (1921);* ***2.*** Plasmatites bauhini *(Opp.), CNIGR 32/12210, Van Keulenfjord, collected by Pchelina (1979), figured by Ershova, 1983, pl. lV, fig. 7; 3-4 –* Amoebites bayi *(Birkelund et Callomon), Festningen, bayi horizon,* ***3*** *– SGM-1409-23/10356, 0.7 m above the base of bed 1/59;* ***4*** *– SGM-1409-24/10357, 0.5 m above the base of bed 1/59; 5-9.* Amoebites subkitchini *(Spath),* subkitchini *horizon,* ***5*** *– SGM-1409-05/10338, Festningen, 1 m above the base of bed 1/59;* ***6-7.*** *SGM MK2776 (fig. 6), SGM-1409-49/10382 (fig. 7), Myklegardfjellet, 2 m below the top of the bed AC73;* ***8*** *– SGM-1409-12/ 10345, Festningen, 0.2 m above the base of the bed 1/63;* ***9*** *– SGM MK43, Chernokhrebetnaya river, East Taimyr, collected by V. Egorov, 2006;* ***10-12.*** Amoebites pingueforme *(Mesezhn. et Romm),* pingueforme *horizon;* ***10-11.*** *Festningen, 3 m below the top of the bed 1/64,* ***10*** *– SGM-1409-11/10344;* ***11*** *– SGM-1409-04/10337;* ***12*** *– specimen lost, Duner Bay, collected by M. Burdykina, 1988;* ***13.*** Euprionoceras *cf.* sokolovi *(Bodylevski), SGM-1409-25/10358, Festningen, bed 1/94,* Sokolovi *Zone;* ***14-17.*** Euprionoceras sokolovi *(Bodylevski),* sokolovi *horizon,* ***14-16.*** *Festningen, 0.5 m below the top of the bed 70,* ***14*** *- SGM-1409-17/10350,* ***15*** *– SGM-1409-16/10349,* ***16*** *– SGM-1409-15/10348;* ***17*** *– CNIGR 77/12210, Van Keulenfjord, figured by Ershova, 1983, pl.XII, f4.*

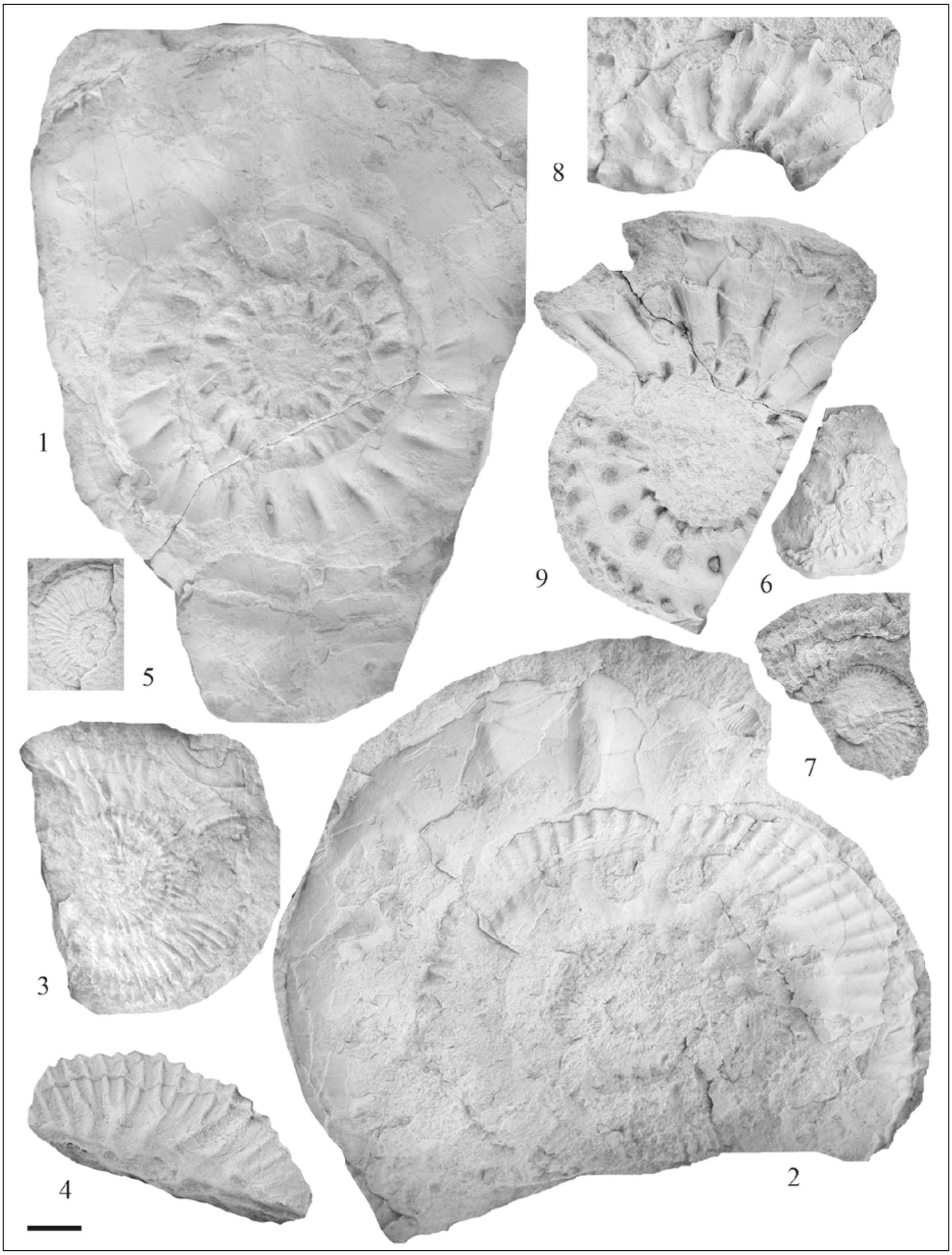

Figure 5.1-2. Rasenia cymodoce *(d'Orb.) [M], Festningen,* cymodoce *horizon;* ***1*** *– SGM-1409-22/10355, bed 2E/9;* ***2*** *– SGM-1409-01/10334, bed 2E/13;* ***3-4.*** Prorasenia *sp. [m], Festningen,* cymodoce *horizon;* ***3*** *– SGM-1409-14/10347, 0,7 m below top of the bed 1/64;* ***4*** *– SGM-1409-02/10335, bed 1/65;* ***5.*** Amoebites *cf.* subkitchini *(Spath), SGM-1409-18/10351, Festningen, bed 2E/9,* cymodoce *horizon;* ***6.*** A. *aff.* beaugrandi *(Savauge et Rigaux), SGM-1409-45/10378, Myklegardfjellet, bed AC70, aff.* beaugrandi *horizon;* ***7.*** Euprionoceras norvegicum *(Wierzbowski), SGM-1409-29/10362, Myclegardfjellet, bed AC68,* norvegicum *horizon;* ***8-9.*** Hoplocardioceras decipiens *(Spath), Myclegardfjellet, bed AC64,* decipiens *horizon,* ***8*** *– SGM-1409-51/10384,* ***9*** *– SGM-1409-46/10379.*

(Sauvage & Rigoux) from East Greenland (Birkelund and Callomon, 1985, pl.4, fig. 6-8), however, the latter ammonites are characterized by more dense and regular ribbing. Thus the precise stratigraphical relationship between the "aff. *beaugrandi*" horizon of East Greenland and the level with *A.* aff. *beaugrandi* in Spitsbergen remains still uncertain but may be closely correlatable. Anyway these records marked older stratigraphical level compared with those of true *Hoplocardioceras beaugrandi* (Sauvage et Rigoux) which came from the *Eudoxus* Zone, and "*A.* aff. *beaugrandi*" from East Greenland and Spitsbergen should be ascribed to new species.

The precise position of the provisional *Xenostephanus* (=*Zenostephanus sachsi*, corrected) horizon proposed by Wierzbowski (1989) is uncertain, because although *Zenostephanus* (including species *Z. sachsi*, which is widely ranged in Arctic) are known from Spitsbergen (Fig. 6.6), these ammonites were collected by our precursors during the geological survey and their precise stratigraphic position within the succession is unclear. During 2012 new records of *Zenostephanus* at Sassenfjord were made by our colleagues, directly above the *Rasenia* occurrences. The same level, characterized by *Zenostephanus sachsi* in Franz-Josef Land (Repin et al., 2007, pl. XII, fig.1-2, pl.XIII, fig. 1,3,4; pl.XIV, fig.1,2,4,5) has been recently recognized as the "*Sachsi* Zone" (Repin et al., 2007), but this "zone" has been erected without reference to its type section and biostratigraphical characteristics, and is presented in the correlation chart only. In this author's opinion, this unit may be comparable with the *Zenostephanus* horizon of Spitsbergen, and *Z. sachsi* (Fig. 6.6) could be used as its index species.

Sokolovi Zone

The *Sokolovi* Zone (proposed by Spath, 1935 as *Kochi* Zone) corresponds to the total range of the *Euprionoceras*. Its correlation with sub-Boreal aulacostephanid zonation still remains unclear. All known records of cardioceratids typical of this zone were known until now from the levels between records of *Aulacostephanus* of the *A. mutabilis* group and *Aulacostephanus* of the *A. eudoxus* (Birkelund and Callomon, 1985; Wierzbowski et al., 2002) or from the *Eudoxus* Zone (Mesezhnikov in Sachs, 1969). Recently, specimens of *Euprionoceras sokolovi* (Bodylevski) were recorded in the *Eudoxus* Zone of the Middle Volga area (Rogov and Shchepetova, 2011), but the full range of *Euprionoceras* in terms of sub-Boreal zonation still remains unclear.

Norvegicum horizon. *Euprionoceras norvegicum* (Wierzbowski) was designated as the marker species of a separate horizon of the Barents Sea Kimmeridgian (Wierzbowski and Smelror, 1993) recently reclassfied as a subzone (Wierzbowski et al., 2002). This distinctive species is characterized by weakly ribbed inner whorls which became strongly ribbed on the outer whorls. The presence of this horizon at Spitsbergen could be inferred on the basis of presence of *E. norvegicum* at the Myklegardfjellet section (Fig. 5.7), where it co-occurs with poorly preserved specimens of coarse-ribbed cardioceratid ammonites (*Euprionoceras* sp.)

Sokolovi horizon: *Euprionoceras sokolovi* (Bodylevski), considered here as senior synonym of the *E. kochi* (see Birkelund and Callomon, 1985; Wierzbowski and Rogov, 2013), is a very characteristic ammonite for Spitsbergen. A few specimens of this species have been collected at the Festningen section (Figs. 4.13-16) and more specimens were found in collections of VNIIOkeangeologiya (Saint-Petersburg) (Fig. 4.17).

Decipiens Zone

In the Boreal zonal succession of the Kimmeridgian Stage this zone is usually referred to as the *Elegans* Zone, as has been proposed by Wierzbowski (in Wierzbowski and Smelror, 1993). However, Spath (1935) previously recognized *Decipiens* assemblage (based on the other species of *Hoplocardioceras*) in highest part of Boreal Kimmeridgian. Thus the *Decipiens* Zone has a priority over the *Elegans* Zone. Previously, Wierzbowski (1989) based on his observations at Janusfjellet, suggested that in Spitsbergen the *decipiens* and *elegans* horizons, which are recognized in East Greenland, cannot be distinguished. Ammonites are rare in the upper part of the Kimmeridgian of the Festningen section, only a few ammonites resembling *Euprionoceras sokolovi* has been found here (Fig. 4.13). But at the Myklegardfjellet section late *Hoplocardioceras elegans* (Spath) (=*H. bodylevskii* (Schulgina)) occurs in the uppermost fossiliferous horizon within the Kimmeridgian ammonite succession and is clearly separated from band with *Hoplocardioceras decipiens* (Spath) which is located some 3.5 m below. These horizons are also clearly separated in the sub-Boreal succession of the Middle Volga area. Alternatively, the co-occurrence of both morphotypes of *Hoplocardioceras* within a narrow fossiliferous band (Wierzbowski, 1989; Birkenmajer and Wierzbowski, 1991, see above) suggests their ranges overlap. In Franz-Josef Land, Shulgina (1960) recognized a similar ammonite succession, with *H. decipiens* and *H. elegans* (=*bodylevskii* Schulgina) below and only *H. elegans* above (Figs. 6.4-5). Records of *H. elegans* and *H. decipiens* in reversed succession has been reported by Wierzbowski (in Wierzbowski and Smelror, fig.3, 5) from the Barents Sea cores 7227/08-U-03 and 7231/01-U-01, but in my opinion figured *H. elegans* (Spath) (loc.cit., pl.2, fig.9-12), characterized by absence of looped and rursiradiate ribs and presence of elongated secondaries seems to be more close to *E. sokolovi* (Bodylevski).

Decipiens horizon: typical specimens of *Hoplocardioceras decipiens* (Spath) were recognized from the bed AC64 at Myklegardfjellet (Figs. 5.8-9). This species is also known from the other sites of Spitsbergen.

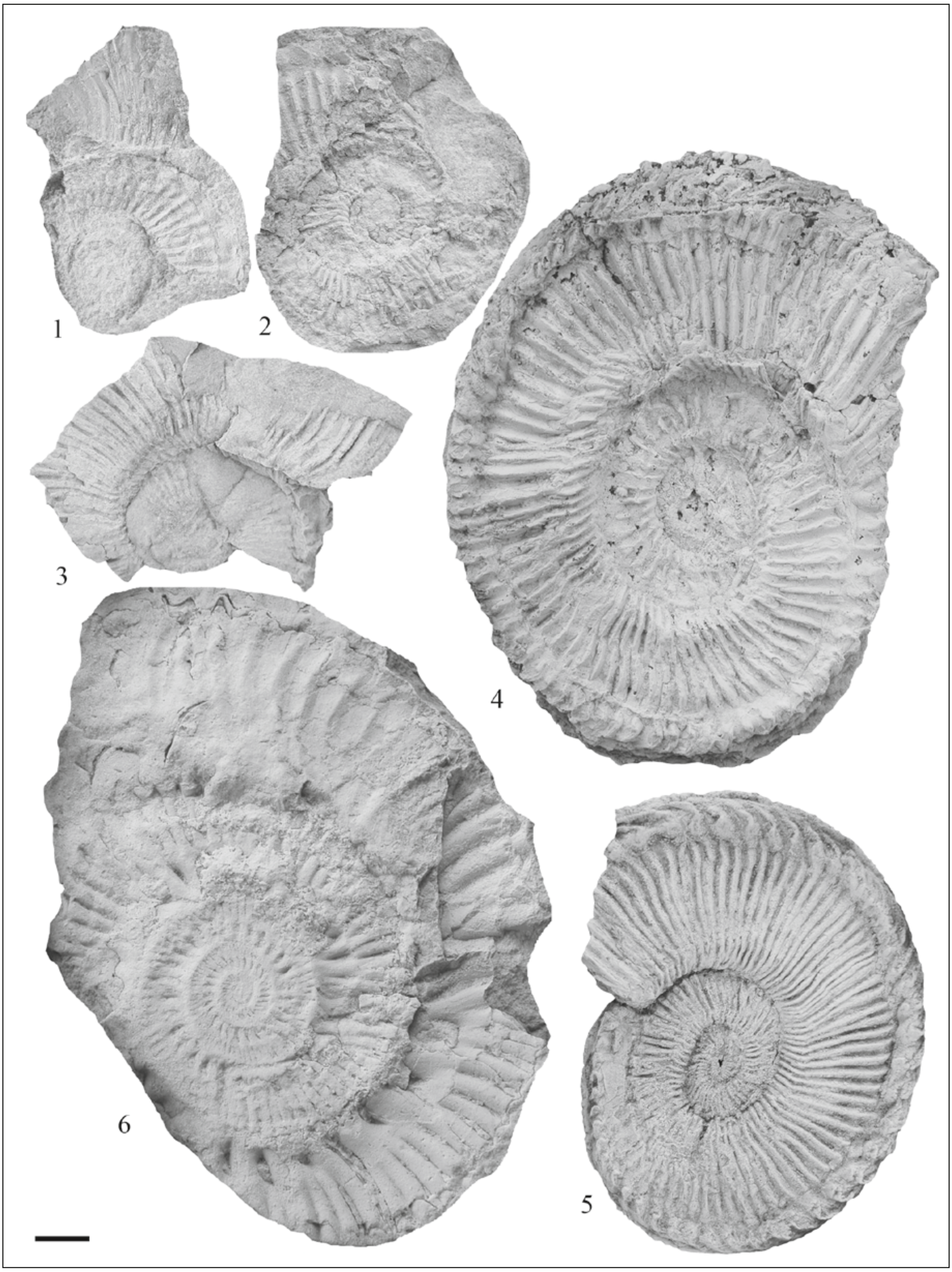

Figure 6.1-5. Hoplocardioceras elegans *(Spath),* elegans *horizon;* ***1-3.*** *Myklegardfjellet, bed AC/62,* ***1*** *– SGM-1409-41/10374,* ***2*** *– SGM-1409-48/10381,* ***3*** *– SGM-1409-27/10360;* ***4-5.*** *Franz-Josef Land, Wilczek Land, Cape Hanza,* ***4*** *– SGM-1392-08/10327 (=*Amoeboceras *(*Amoebites*)* bodylevskii *sp. nov. var. nov.: Shulgina, 1960, pl. IV, fig. 2).* ***5*** *– SGM 652p/448 (= holotype of* Amoeboceras *(*Amoebites*)* bodylevskii *Shulgina: Shulgina, 1960, pl. IV, fig. 1);* ***6.*** *Zenostephanus sachsi (Mesezhn.) SGM-1409-30/10363, Spitsbergen, precise locality unknown, sachsi horizon.*

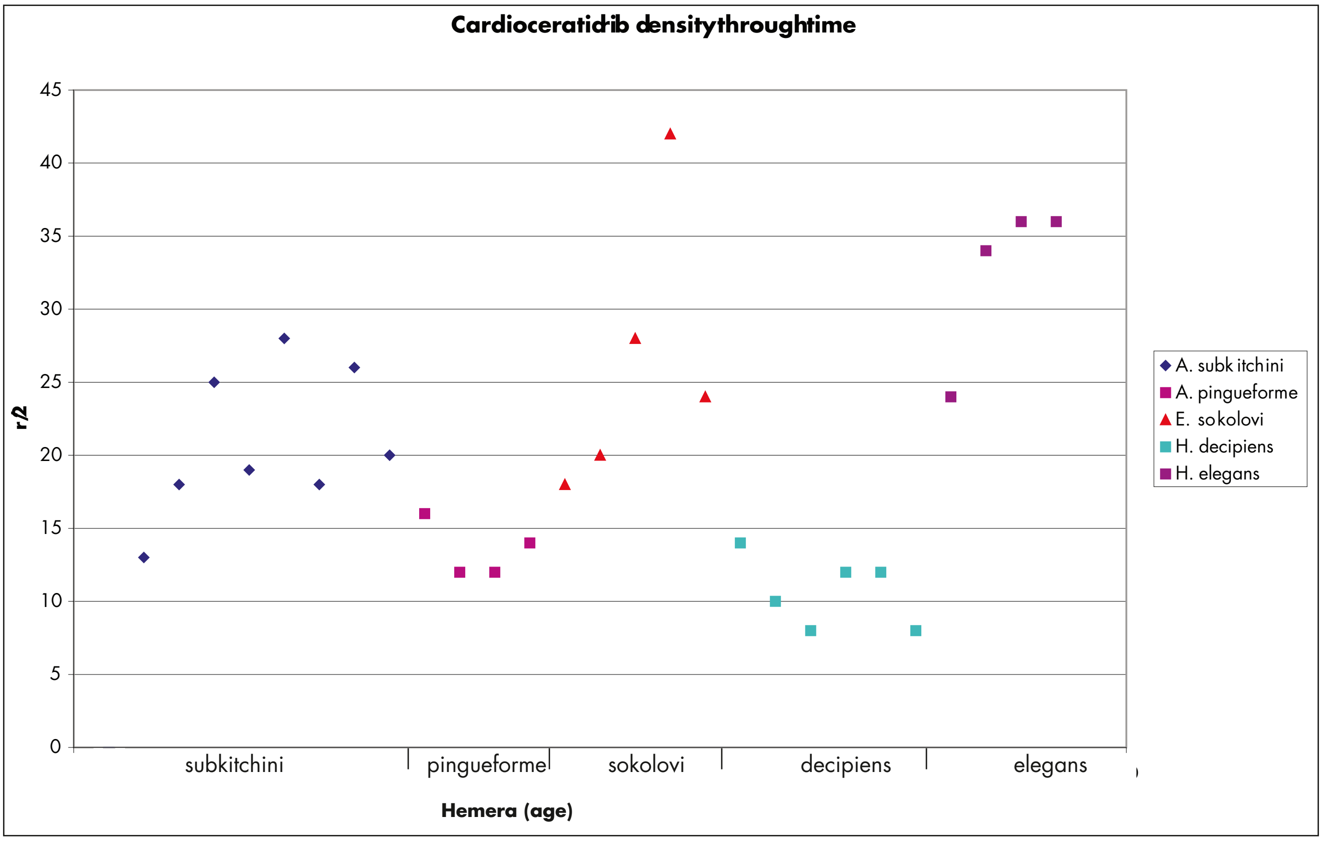

***Figure 7.** Oscillations in rib density through time within Kimmeridgian cardioceratid lineage of Spitsbergen.*

Elegans horizon: *Hoplocardioceras* elegans (Spath) characterizes the uppermost fossiliferous level in the Kimmeridgian of Myklegardfjellet (Figs. 6.1-3).

Interestingly, through the Kimmeridgian cardioceratid succession recognized in Spitsbergen, changes of fine and densely ribbed taxa to those with rare and relatively thick ribbing and back occurs few times (Fig. 7). Such oscillations in development of one feature through evolution of the lineage have been recognized recently in cardioceratids from the Bathonian/Callovian boundary beds (Kiselev and Rogov, 2007).

Taimyrensis Zone

The Boreal oppeliid ammonite *Suboxydiscites taimyrensis* (Mesezhn.), is restricted in the Arctic to the uppermost zone of the Kimmeridgian. In the type succession in the Kheta depression the lower boundary of this zone is recognized by the disappearance of aulacostephanids. Cardioceratid ammonites from this zone in north Central Siberia were not figured or described and are missing in Mesezhnikov's collection. But taking into account the presence of *Hoplocardioceras* and *Nannocardioceras* in the lower part of zone (Mesezhnikov, 1984), at least a partial overlap of this zone with *Decipiens* Zone could be suggested. The upper part of *Taimyrensis* Zone lacks cardioceratids and is closely comparable to the *Autissiodorensis* Zone, which is characterized by cardioceratid ammonites in the two lowermost horizons only (Rogov, 2010a). This conclusion is further supported by rare occurrences of *Suboxydiscites* in the *Fallax* Subzone of the *Autissiodorensis* Zone (Rogov, 2010a). It should be noted that the genus *Suboxydiscites*, as has been shown recently, ranged through the whole Kimmeridgian Stage and its successive species are very poorly known. Studying of the Ershova's collection revealed presence of few *Suboxydiscites* cf. *taimyrensis* (Mesezhn.) (Fig. 8.1), but their precise position within the succession remains unclear. *Suboxydiscites* is the single example of a true Boreal genus among oppeliids, which probably originated from sub-Mediterranean *Ochetoceras* (Rogov, 2001). Oppeliids occasionally inhabited Arctic regions during the Middle Jurassic, but these were short-time migrations which did not lead to the existence of eudemic lineage. The oldest *Suboxydiscites* are known from the Upper Oxfordian of East Greenland (based on re-examination of an undescribed collection stored in CASP, Cambridge). Typical macroconchs, resembling *S. taimyrense* by shell coiling, but with a slightly wider umbilicus, weaker ribbing and smaller size, are known from the basal Kimmeridgian (*bauhini* horizon) of Swabia, where they co-occur with other ammonites of Boreal and sub-Boreal origin (Schweigert and Jantschke, 2001). These ammonites should be described as a new species. Lower Kimmeridgian *Suboxydiscites* were also recorded recently from Northern Siberia (Rogov and Wierzbowski, 2009),

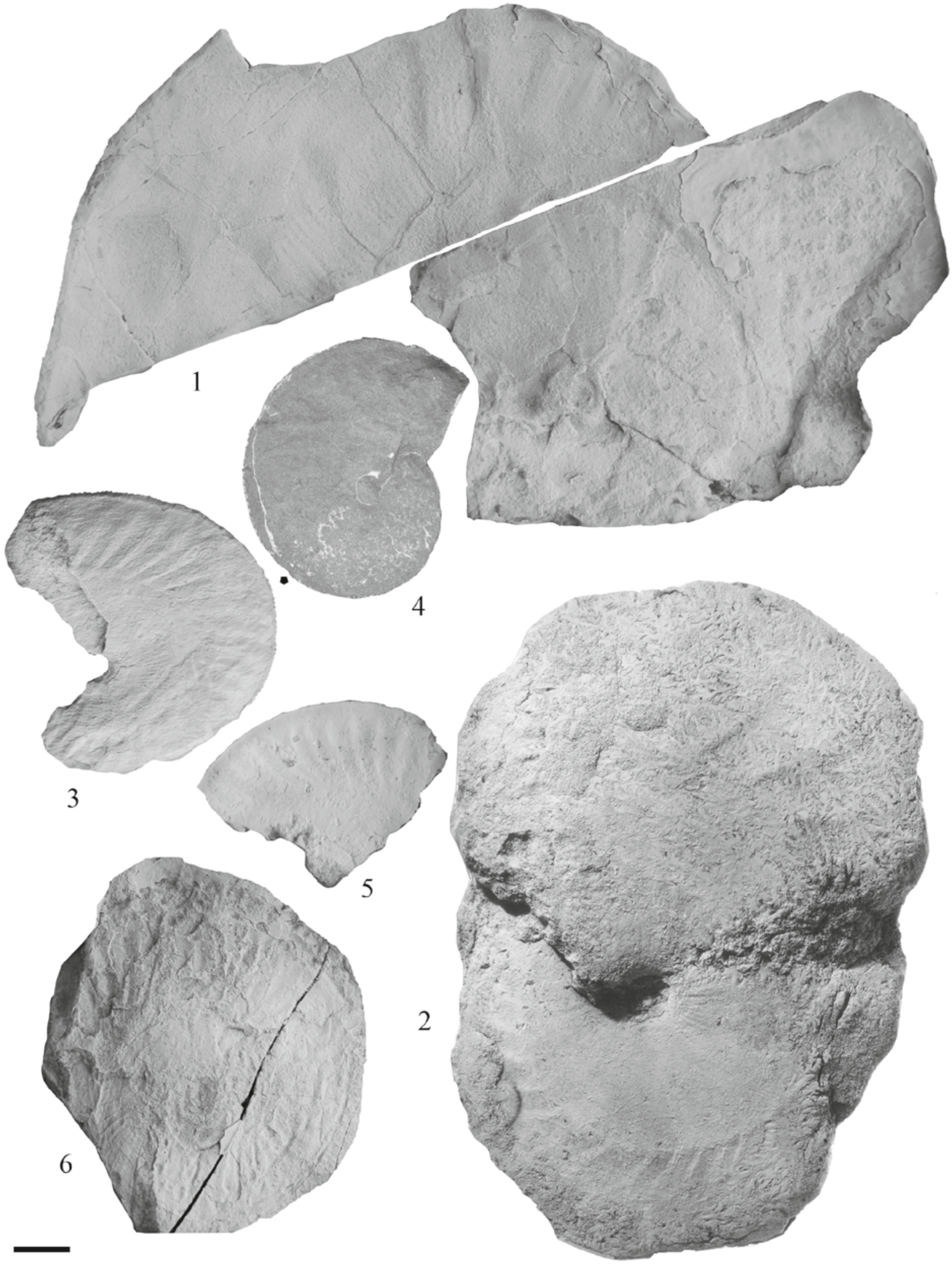

Figure 8.1. Suboxydiscites *cf.* taimyrensis *(Mesezhn.) [M], SGM-1409-39/10372, Upper Kimmeridgian, Sørkapp Land, collected by E.S. Ershova in 1965;* ***2, 5.*** Suboxydiscites taimyrensis *(Mesezhn.) [M], Eudoxus or Autissiodorensis Zone, Pechora area, left bank of the Pizhma river near Vyartkina spring; 2 – SGM MIV237, 5 – SGM-1409-66/10399 inner whorls of macroconch;* ***3.*** Suboxydiscites *sp. [m], VNIGRI (specimen without number),* Taimyrensis *Zone, Malaya Podkamennaya river, East Taimyr, collected by M.S. Mesezhnikov;* ***4.*** Suboxydiscites *sp. [m], MGUH 14348; East Greenland, Section 32, beds with fauna 19, Cardioceraskøft Member, Mutabilis Zone, black dot indicated beginning of the body chamber (=*Streblites *? (*Oxydiscites *?) cf.* taimyrensis *Mesezhnikov (m) in Callomon and Birkelund, 1980, pl.3, fig.5;* Streblites*? cf.* S. taimyrensis *in Birkelund and Callomon, 1985, fig.7);* ***6.*** Suboxydiscites *sp. [m], SGM-1409-19/10352, Upper Kimmeridgian, Sørkapp Land, collected by E.S. Ershova.*

but are typically badly preserved. Upper Kimmeridgian *Suboxydiscites* have a wide geographical distribution through the Arctic. They are known from the entire Upper Kimeridgian of Northern Siberia (Sachs et al., 1969) and from the *Eudoxus-Autissiodorensis* zones of the north of European part of Russia (Mesezhnikov, 1984) and Middle Volga area (Rogov, 2010a). Additionally, microconchiate populations are known from the Upper Kimmeridgian of the Russian Far East (*S. elgense* (Chudoley & Kalacheva)), British Columbia (*S. manningense* (Poulton, Zeiss & Jeletzky)) and East Greenland ("*Streblites*? (*Oxydiscites*?) cf. *taimyrensis* Mesezhnikov (m)" in Callomon and Birkelund, 1980; Birkelund and Callomon, 1985). Through the evolution of the both micro- and macroconchs of *Suboxydiscites* their ribbing became more coarse and regular. Ribbing is unclear in early macroconchs (Schweigert and Jantschke, 2001, fig. 2-3) and microconchs from the *Mutabilis* Zone and (Callomon and Birkelund, 1980, pl.3, fig.5 a,b, refigured here in Fig. 8.4) but became well-revealed and regular in *Suboxydiscites* during the latest Kimmeridgian (Figs. 8.1-3, 5-6).

Some biogeographical remarks

Spitsbergen is a key region for understanding the peculiarities of the faunal exchange through Greenland-Norwegian Seaway (GNS) during the Kimmeridgian. As has been demonstrated recently from analysis of ammonite latitudinal diversity gradient and presence of sub-Boreal/sub-Mediterranean faunal elements in Boreal faunal associations, Middle Russian Sea influence over the Arctic was of great importance, while Greenland-Norwegian Seaway was of minor significance (Rogov, 2012). Kimmeridgian assemblages of both East Greenland and the Norwegian Sea (Birkelund and Callomon, 1985; Wierzbowski et al., 2002) consist of a mixture of the Boreal cardioceratids and sub-Boreal aulacostephanids. The latter ammonites became rare in the Spitsbergen, Barents Sea shelf and Franz-Josef Land. Two well-recognized levels containing aulacostephanids recognized in Spitsbergen (*cymodoce* and *sachsi* horizons) perhaps can also be traced through the Barents Sea region, because both *Rasenia* and *Zonovia* are known from Barents Sea cores (Shulgina and Burdykina, 1992). Mutterlose et al. (2003) suggested that the Greenland-Norwegian Seaway during the Late Jurassic was relatively shallow and only became deeper in the Valanginian-Hauterivian. This interpretation corresponds well with the peculiarities of ammonite distribution around this seaway. It is possible that during the Late Jurassic ammonite migration through the Greenland-Norwegian Seaway were very restricted and mainly southward in direction, providing penetration of Boreal faunas to NW Europe. The appearance of aulacostephanids in Svalbard and Barents Sea shelf could be related to a brief migrational event from the Middle Russian Sea, coinciding with a warming climate. In the Middle Volga area and Kostroma region this warming is marked by appearance of sub-Mediterranean ammonites, especially aspidoceratids.

Acknowledgements.
This study has been supported by RFBR grant 12-05-00380 and Earth Science Division of RAS Program no.1. This is the part of the project "Late Mesozoic-Cenozoic tectono-magmatic history of the Barents Sea shelf and slope as a clue to paleodynamic reconstructions in the Arctic Ocean". The author also expresses his thanks to colleagues who helped him during the field trip held at Spitsbergen and to those who help with access to collections in museums (Drs. S. Nikolaeva, A. McGowan, NHM London; A.R. Sokolov, CNIGR Museum, V.A. Basov, G.A. Cherkashov, VNIIOkeangeologiya, T.V. Dmitrieva, V.V. Bystrova, VNIGRI, Saint-Petersburg; P. Alsen, Geological Museum of the University of Copenhagen, S.R.A. Kelly, CASP, Cambridge).

References

Birkelund, T. & Callomon, J.H. 1985: The Kimmeridgian ammonite faunas of Milne Land, central East Greenland. *Grønlands Geologiske Undersøgelse Bulletin, 153*, 1–56.

Birkenmajer, K., Pugaczewska, H. & Weirzbowski, A. 1982: The Janusfjellet Formation (Jurassic-Lower Cretaceous) at Myklegardfjellet, east Spitsbergen. *Palaeontologia Polonica, 43*, 107-140.

Birkenmajer, K. & Wierzbowski, A. 1991: New Kimmeridgian ammonite fauna from east Spitsbergen and its phyletic significance. *Polar Research, 9*, 169-179. doi: 10.1111/j.1751-8369.1991.tb00612.x

Callomon, J.H. & Birkelund, T. 1980: The Jurassic transgression and the mid-late Jurassic succession in Milne Land, central East Greenland. *Geological Magazine, 117*, 211-226.
doi: 10.1017/S0016756800030442

Dypvik, H., Nagy, J., Eikeland, T.A., Backer-Owe, K., Andresen, K., Haremo, P., Bjærke, T., Johansen, H. & Elverhøi, A. 1991: The Janusfjellet Subgroup (Bathonian to Hauterivian) on central Spitsbergen: a revised lithostratigraphy. *Polar Research, 9*, 21-43.
doi: 0.1111/j.1751-8369.1991.tb00400.x

Ershova, E.S. 1983: *Explanatory notes for the biostratigraphical scheme of the Jurassic and Lower Cretaceous deposits of Spitsbergen archipelago.* Leningrad, PGO Sevmorgeologia, 88 pp. (In Russian).

Frebold, H. 1928: Das Festnungsprofil auf Spitzbergen. Jura und Kreide. II. Die Stratigraphie. *Skrifter om Svalbard og Ishavet, 19*, 1-39.

Frebold, H. 1930: Verbreitung und Ausbildung des Mesozoikums in Spitsbergen. *Skrifter om Svalbard og Ishavet, 31*, 1-127.

Kiselev, D.N. & Rogov, M.A. 2007: Stratigraphy of the Bathonian–callovian boundary deposits in the Prosek Section (Middle Volga Region). Article 1. Ammonites and Infrazonal Biostratigraphy. *Stratigraphy and Geological Correlation, 15*, 485–515.
doi: 10.1134/S0869593807050036

Mesezhnikov, M.S., 1984: *Kimmeridgian and Volgian Stages of north of the USSR*. Leningrad, Nedra, 224 pp. (In Russian).

Mesezhnikov, M.S. & Shulgina N.I. 1975: On ecology of Late Jurassic and Neocomian Boreal ammonites. *Institute of marine biology, collection of papers, 4*, 66-81. (In Russian).

Mesezhnikov, M.S. & Shulgina, N.I. 1982: On the Kimmeridgian ammonites and new data on the stratigraphy of the north of USSR. *Soviet Geology and Geophysics, 10*, 20-29. (In Russian).

Mutterlose, J., Brumsack, H., Flögel, S., Hay, W., Klein, C., Langrock, U., Lipinski, M. Ricken, W., Söding, E., Stein, R. & Swientek, O. 2003: The Greenland-Norwegian Seaway: a key area for understanding Late Jurassic to Early Cretaceous paleoenvironments. *Paleoceanography, 18*, 1, 1010. 26 pp. doi: 10.1029/2001PA000625

Repin, Yu.S. Fedorova, A.A., Bystrova, V.V., Kulikova, N.K. & Polubotko, I.V. 2007: Mesozoic of the Barents sea sedimentological basin. *In* Kirichkova, A.V. & Dmitrieva, T.V. (eds.): *Stratigraphy and its role in development of the oil and gas complex of Russia*, 112-161. VNIGRI, Saint-Petersburg. (In Russian).

Rogov, M.A. 2001: Phylogenetic relations within Jurassic Ochetoceratinae (Ammonoidea, Oppeliidae). *Bulletin of Moscow Society of Naturalists, series geology, 75, 5*, 38-42. (In Russian).

Rogov, M.A. 2010a: A precise ammonite biostratigraphy through the Kimmeridgian-Volgian boundary beds in the Gorodischi section (Middle Volga area, Russia), and the base of the Volgian Stage in its type area. *Volumina Jurassica VIII*, 103-130.

Rogov, M.A. 2010b: New data on the Kimmeridgian ammonite biostratigraphy of Spitsbergen. *Earth Science Frontiers 17*, Special Issue, 94-95.

Rogov, M.A. 2012: Latitudinal gradient of taxonomic richness of ammonites in the Kimmeridgian–Volgian in the Northern Hemisphere. *Paleontological Journal, 46*, 148–156. doi: 10.1134/S0031030112020104

Rogov, M.A. & Shchepetova, E.V. 2011: New data on sedimentology and biostratigraphy of the Upepr Kimmeridgian Eudoxus Zone near the border of Ulianovsk region and Tatarstan. *In* Zakharov V.A., Rogov M.A., Ippolitov A.P. (eds.): *Jurassic System of Russia: Problems of stratigraphy and paleogeography. Fourth All-Russian meeting. September 26-30, 2011, St.-Petersburg. Scientific materials.* 186-189. Lema, Saint-Petersburg. (In Russian).

Rogov, M. & Wierzbowski, A. 2009: The succession of ammonites of the genus *Amoeboceras* in the Upper Oxfordian – Kimmeridgian of the Nordvik section in northern Siberia. *Volumina Jurassica VII*, 147-156.

Sachs, V.N. (ed.), 1969: *Fundamental section of the Upper Jurassic of Kheta river basin*. Leningrad, Nauka. 207 pp. (In Russian).

Schweigert, G. & Jantschke, H. 2001: Erstnachweis von *Suboxydiscites* Poulton, Zeiss & Jeletzky (Ammonitina, Oppeliidae) im Schwäbischen Oberjura (Hauffianum-Subzone, bauhini-Horizont). *Neues Jahrbuch für Geologie und Paläontologie – Monatshefte, 11*, 659-668.

Shulgina, N.I. 1960: Ammoinites from the Franz-Josef Land and Taimyr and their significance for zonal subdivision of the Kimmeridgian in Arctic. *Transactions of the Institute of the Geology of Arctic, 111*, 136-144. (In Russian).

Shulgina, N.I. & Burdykina, M.D. 1992: Biostratigraphical scheme of Jurassic and Lower Cretaceous of shelves of Barents, Norwegian and North seas. *In Geological history of Arctic in Mesozoic and Cenozoic. Volume 1*. Materials of lectures in memory of V.N. Sachs, 106-114. VNIIOkeangeologia. Saint-Petersburg. (In Russian).

Sokolov, D. & Bodylevsky, W. 1931: Jura- und Kreideformationen von Spitzbergen. *Skrifter om Svalbard og Ishavet, 35*, 1-151.

Spath, L.F. 1921: On Ammonites from Spitsbergen. *Geological Magazine, 58*, 347-356. doi: 10.1017/S0016756800104662

Spath, L.F. 1935: The Upper Jurassic invertebrate faunas of Cape Leslie, Milne Land. I. Oxfordian and Lower Kimmeridgian. *Meddelelser om Grønland, 99 (2)*, 1-78.

Wierzbowski, A., 1989: Ammonites and stratigraphy of the Kimmeridgian at Wimanfjellet, Sassenfjorden. Spitsbergen. *Acta Palaeontologica Polonica, 34*, 355-378.

Wierzbowski, A. & Rogov, M. 2013: Biostratigraphy and ammonites of Middle Oxfordian to lowermost Upper Kimmeridgian in northern Central Siberia. *Russian Geology and Geophysics, 54*, 1083–1102. doi: 10.1016/j.rgg.2013.07.021

Wierzbowski, A. & Smelror, M. 1993: Ammonite succession in the Kimmeridgian of southwest Barents Sea, and the *Amoeboceras* zonation of the Boreal Kimmeridgian. *Acta Geologica Polonica, 43*, 229-249.

Wierzbowski, A., Smelror, M. & Mørk, A. 2002: Ammonites and dinoflagellate cysts in the Upper Oxfordian and Kimmeridgian of the northeastern Norwegian Sea (Nordland VII offshore area): biostratigraphical and biogeographical significance. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 226*, 145-164.