Microbiostratigraphy of the Berriasian–Valanginian boundary in eastern Crimea: foraminifers, ostracods, organic-walled dinoflagellate cysts

YULIYA N. SAVELIEVA[1], OLGA V. SHUREKOVA[1], ANNA A. FEODOROVA[1], VLADIMIR V. ARKADIEV[2], VLADIMIR A. GRISHCHENKO[3], ANDREI YU.GUZHIKOV[3] and ALEKSEY G. MANIKIN[3]

[1]AO "Geologorazvedka", Fayansovaya str. 20/10, 192019 Saint-Petersburg, Russia; julia-savelieva7@mail.ru; o.antonen@gmail.com; annafedoroff@yandex.ru;
[2]Saint-Petersburg State University, University emb., 7/9, 199034 Saint-Petersburg, Russia; arkadievvv@mail.ru
[3]Saratov State University, Astrakhanskaya str., 83, 410012 Saratov, Russia; grishenko-vladimir@bk.ru; aguzhikov@yandex.ru; agmanikin@mail.ru

(Manuscript received February 10, 2017; accepted in revised form September 28, 2017)

Abstract: Thorough study of foraminifers, ostracods and dinoflagellate remnants from the Zavodskaya Balka and Koklyuk sections helps to characterize the detailed biostratigraphic division of the Berriasian/Valanginian boundary sequence in the Feodosiya district of eastern Crimea. The foraminifer and dinocyst associations from the lower part of the sequence are clearly comparable with common Berriasian associations throughout all Mountain Crimea. On the other hand, foraminifer, ostracod and dinocyst associations from its upper part have been recorded only in eastern Crimea. The upper foraminifer level corresponds to the boreal ammonite zones from the Tauricum–Verrucosum (Upper Berriasian–Valanginian). Most of the ostracod species are endemic. The base of the uppermost dinocyst level correlates with the Lower Valanginian Paratollia zone from north-western Europe.

Keywords: Eastern Crimea, Berriasian, Valanginian, biostratigraphy, foraminifers, ostracods, organic-walled dinoflagellate cysts.

Introduction

The Berriasian–Valanginian boundary in the Mediterranean region is currently established at the base of the *Thurmanniceras pertransiens* ammonite zone (Reboulet et al. 2014). Eastern Crimea is one of the areas where there are uninterrupted Berriasian–Valanginian sections that can be found on the surface. The authors of this paper prepared a bio- and magnetostratigraphic study of the sections "Zavodskaya Balka" and "Koklyuk Mountain" in Eastern Crimea (Fig.1) to make a more precise biostratigraphical scheme that can be correlated with Tethyan or Boreal standards. Parts of the magnetostratigraphic and ammonite data from these sections were already published earlier (Arkadiev et al. 2016). The present paper summarizes foraminifera, ostracoda, and dinocyst data from the studied sections. The investigation of nannofossils in the framework of this project was not planned.

Geological setting

The Berriasian–Valanginian boundary sediments in eastern Crimea are represented by monotonous grey clays with rare intercalations of marls and limestones. In the studied sections of Eastern Crimea the standard ammonite zones of Jacobi, Occitanica and Boissieri have been demonstrated by Bogdanova et al. (1999); Arkadiev et al. (2012) and Reboulet et al. (2014). The upper part of the Occitanica zone locally can be assigned to the *Dalmasiceras tauricum* subzone. The Boissieri zone is divided into local subzones of *Neocosmoceras euthymi*, *Risanites crassicostatum* and *Berriasella callisto* according to the results of Arkadiev et al. (2015b, 2017). Data on the locations of the studied sections (Fig.1) and on the geological settings has been presented in Arkadiev et al. (2017, this volume: Location of the studied sections).

Methods

54 samples (0.5 kg on the average) have been investigated in the course of micropalaeontological analysis. The samples for micropalaeontology were processed with the standard extraction technique for foraminifera and ostracods. The palynological samples were processed with the use of standard HF/HCl acid preparation method. The foraminifers were identified by A. Feodorova, ostracods by Y. Savelieva and palynomorphs by O. Shurekova. Ostracods were photographed under electronic scanning microscope (Botanical Institute and Palaeontological Institute of the Russian Academy of Science (BIN RAN and PIN RAN)), dinocysts — under light microscope. Foraminifer and ostracod collections as well as palynological slides are kept at the Petroleum

Geology Department of the AO "Geologorazvedka", Saint-Petersburg, Russia.

Biostratigraphy

The term "Beds" is used for the subdivision of the sediments on the basis of foraminifera, ostracods and dinocysts. It is an auxiliary biostratigraphic unit (Zhamoida 2006) and is used according to similar principles as "assemblage zones" (Salvador 2013). These sediments contain the remains of organisms or are composed of them, but do not meet the requirements of the biostratigraphic zone (justification of the lower and upper boundaries and their traceability in other sections). The name of the "beds" is taken from the most characteristic taxon within the range provided — since it has either FAD (First Appearance Datum), LAD (Last Appearance Datum) or acme within the interval.

Foraminifers:

They are mostly in good or satisfactory states of preservation and were encountered in all samples. Beds with Textularia crimica–Belorussiella taurica were revealed in the Koklyuk section (sample 3030-8–sample 3030-24) (Fig.2). Two foraminifer assemblages may be distinguished by the changes of taxonomic composition and quantitative characteristics within the occurrences of the beds: *Quadratina tunassica* and *Lenticulina macrodisca*. Those assemblages were described in detail during examination of the Zavodskaya Balka (Arkadiev et al. 2015b).

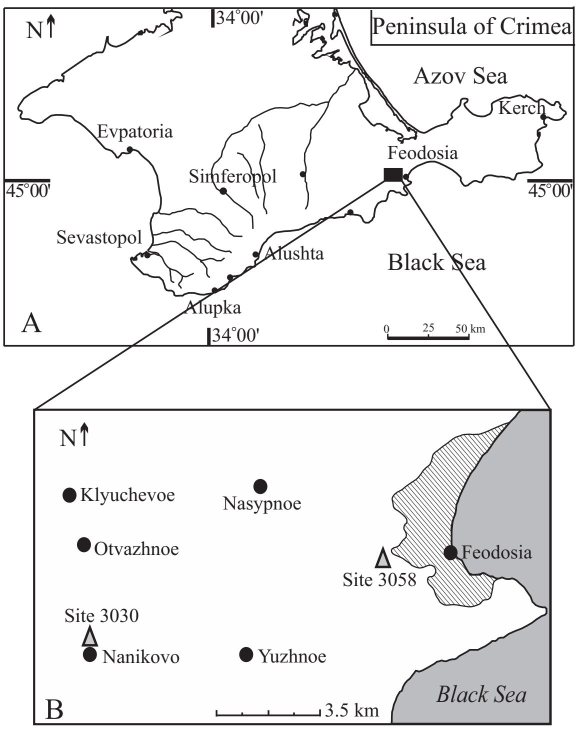

Fig. 1. Location chart of the examined sections. **A** — Location of studied area; **B** — Location of Berriasian/Valanginian studied outcrops (3030 – Koklyuk section, 3058 – Zavodskaya Balka section)

The assemblage with ***Quadratina tunassica*** was revealed in the Koklyuk section (sample 3030-8–sample 3030-12). Beside the index species — *Quadratina tunassica*, *Textularia crimica, Belorussiella taurica* — the assemblage is peculiar for domination of representatives of the *Dentalina* and *Haplophragmoides* genera and of the Epistominidae family. The assemblage comprises a number of Late Tithonian to Valanginian species and species characteristic only of the Berriasian: *Verneuilina angularis*, *Pseudosaracenaria truncata*, *Q. (Tristix) tunassica*, *B. taurica*. An assemblage with *Q. tunassica* was encountered earlier in the lower part of the Zavodskaya Balka section in association with *Neocosmoceras euthymi* (Arkadiev et al. 2015b) and in central Crimea jointly with ammonites from the *Dalmasiceras tauricum* subzone (Savelieva et al. 2014). In the Koklyuk section, an assemblage with *Q. tunassica* was encountered in association with Boissieri zone ammonites.

The assemblage with ***Lenticulina macrodisca*** was distinguished in the Koklyuk section (sample 3030-14–sample 3030-24) from the presence of numerous specimens of index species. The assemblage is peculiar for domination of agglutinating benthos, a great number of primitive forms, relatively meagre diversity and dwarfism in the representatives of the *Planularia* and *Lenticulina* genera.

Earlier investigations have shown the beds with *Textularia crimica–Belorussiella taurica* in Crimea to correlate with the uppermost part of the Grandis subzone of the Jacobi zone and with the Occitanica and Boissieri zones (Feodorova 2004; Arkadiev et al. 2015a). Ammonites from the Euthymi subzone were encountered in the Koklyuk section, at the level of occurrence of the assemblage with *Lenticulina macrodisca*.

An assemblage with ***Lenticulina andromede*** has been discovered in the Zavodskaya Balka section (sample 3058-1–sample 3058-17). Agglutinating benthos dominates, the assemblage, which is peculiar for the presence of numerous *L. andromede*. The greatest species diversity is recorded among Nodosariidae (*Astacolus*, *Lenticulina*, *Pseudonodosaria*). There are large species of Epistominidae but poor preservation. Several specimens of *Orthokarstenia* aff. *fenestralis* have also been discovered. The first occurrences of *Orthokarstenia* genus representatives are recorded in the Valanginian from the East European Platform and Crimea (Bystrova 1990; Kuznetsova & Gorbatchik 1985). The assemblage with *L. andromede* was recognized earlier in central Crimea (Savelieva et al. 2014) within sediments comprising beds with *T. crimica–B. taurica*, since it has similar species composition at the level of the representatives of the *Astacolus*, *Dentalina*, *Lenticulina*, *Pseudonodosaria* genera. In the Zavodskaya Balka from eastern Crimea, however, the *L. andromede* assemblage comprises solitary specimens of other genera of the Nodosariidae and Epistominidae families (Arkadiev et al. 2015b). Moreover, the presence of *Orthokarstenia* and the lack of index-species *T. crimica, B. taurica* prevent direct correlations of the assemblages with

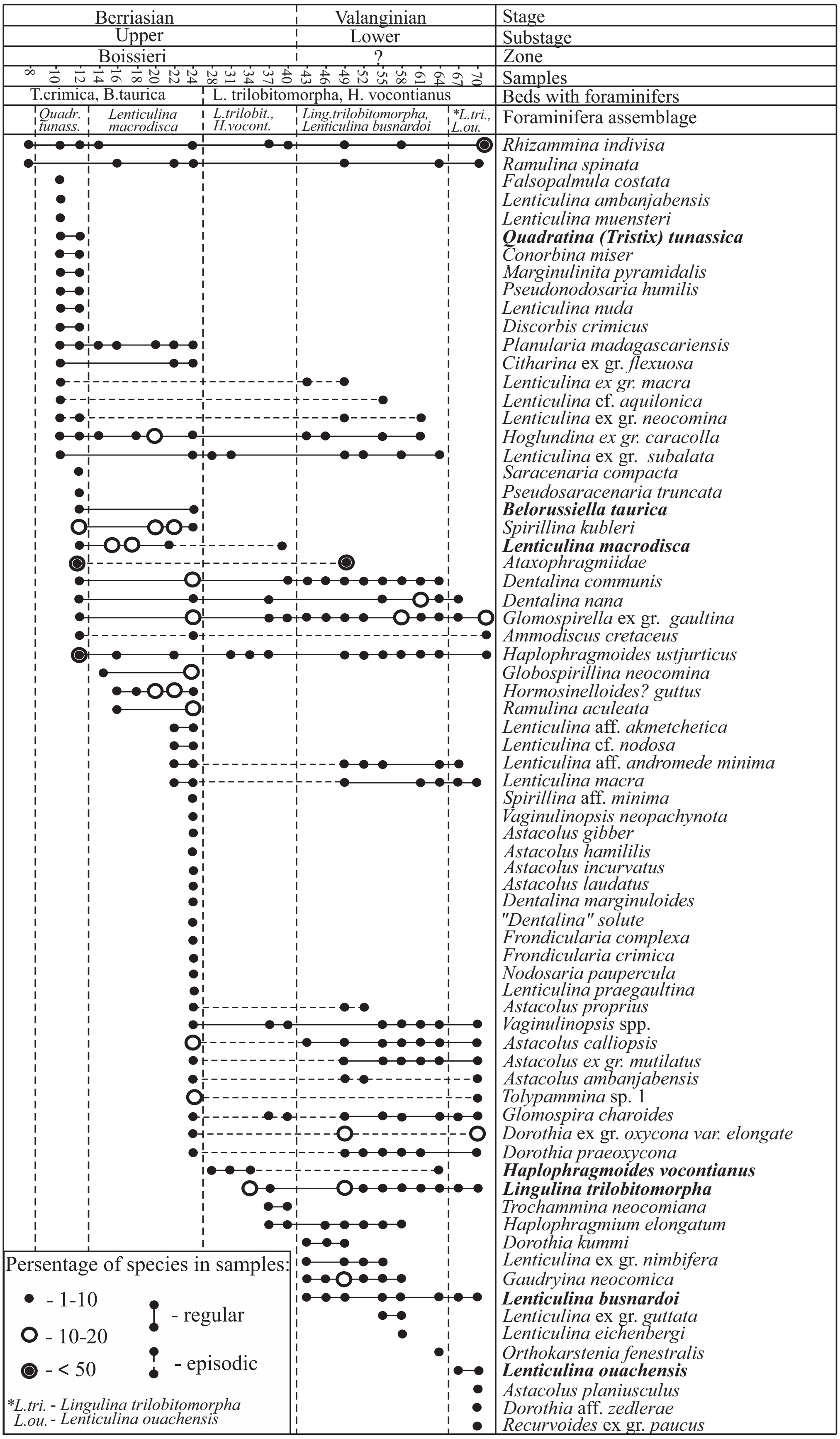

Fig. 2. Distribution of foraminifers from the Berriasian–Valanginian of the Koklyuk section (site 3030). Index species are in bold.

Lenticulina andromede from central and eastern Crimea. Therefore, in this paper the assemblage is considered separately and not within the beds with *T. crimica–B. taurica*. Ammonites from the *Riasanites crassicostatum* subzone have been encountered in the Zavodskaya Balka in the upper part of the assemblage with *L. andromede.*

Beds with ***Lingulina trilobitomorpha*** and ***Haplophragmoides vocontianus*** have been recorded in the Zavodskaya Balka (sample 3058-20–sample 3058-51) and Koklyuk sections (sample 3030-28–sample 3030-69). This biostraton was earlier recognized as an assemblage with foraminifers in the Zavodskaya Balka (Arkadiev et al. 2015b). The new data from an additional section have made it possible to widen its description and to advance it to the rank of beds. Over 130 species from 33 foraminifer genera have been specified in the complex. The assemblage is peculiar for the highest species diversity among Nodosariidae (*Astacolus*, *Dentalina*, *Lenticulina*, *Pseudonodosaria*). Representatives of *Haplophragmoides*, *Haplophragmium* and *Recurvoides* genera are subdominant. Increased numbers of the species and specimens of *Dorothia*, *Gaudryina* and *Verneuilinoides* genera are observed in the assemblage. The principal association is composed of the species first encountered in the uppermost part of the Berriasian and developed mostly in the Valanginian: *Lenticulina saxonica*, *L. guttata*, *L. busnardoi*, *Conorboides hofkeri*. Some species known since the Valanginian also occur: *H. vocontianus*, *H. ustjurticus*, *Gaudryina alternans*, *Dorothia pseudocostata*, *L. trilobitomorpha*, *L. nodosaria*, *Lenticulina lideri*, *O. fenestralis* and others. Those comprise the index species of the *L. trilobitomorpha*, *H. vocontianus* Zone, specified by T.N. Gorbatchik for the Valanginian sediments of the Crimea. Finds of Valanginian ammonites *Neocomites neocomiensis* are known from that level (Druschits & Gorbatchik 1979; Kuznetsova & Gorbatchik 1985; Azbel' et al. 1991). Analysis of the taxonomic and quantitative compositions of benthic foraminifers have shown that within the beds with *Lingulina trilobitomorpha–Haplophragmoides vocontianus* in the Koklyuk section (sample 3030-28–sample 3030-69), three assemblages may be specified, with one of those traceable in the Zavodskaya Balka section as well.

The first assemblage, with *Lingulina trilobitomorpha–Haplophragmoides vocontianus* (sample 3030-28–sample 3030-40), is peculiar for its wide species diversity of Ataxophragmiidae and simple Lituolidae. The second assemblage, with *Lingulina trilobitomorpha–Lenticulina busnardoi* (sample 3030-43–sample 3030-64 and sample 3058-20–sample 3058-51), with relatively depleted taxonomic composition, is peculiar for the presence of several agglutinating genera, *Dorothia* and *Gaudryina*, and a few secreting species, mostly *Lenticulina*, represented by solitary specimens. Ammonites of the B. callisto subzone were encountered in the Zavodskaya Balka at the level of that assemblage occurrence.

In the uppermost part of the study interval, the third assemblage with *Lingulina trilobitomorpha–Lenticulina ouachensis* (sample 3030-67–sample 3030-69) is determined. It is peculiar for expanded species and quantitative compositions, and for the appearance of numerous specimens of *L. ouachensis* and *Dorothia* aff. *zedlerae*, which is characteristic of the Tethyan beds in the interval of the Otopeta–Verrucosum ammonite subzones (Reboulet et al. 2014).

The foraminifer species encountered in the Berriasian–Valanginian boundary interval are known from Crimea, the Caucasus, Caspian Region, Pechora Region, Siberia, Atlantic, Germany, France and Madagascar (Espitalie & Sigal 1963; Kuznetsova & Seibold 1978; Mjatlyuk 1980; Kuznetsova & Gorbatchik 1985; Azbel' et al. 1991; Ogg et al. 2012, etc.).

Ostracods:

They were encountered in practically all the samples from the examined sections. Shells are generally well preserved. Beds with Robsoniella obovata–Robsoniella longa have been established in the Zavodskaya Balka (sample 3058-1–sample 3058-51) and Koklyuk sections (sample 3030-16–sample 3030-69). The lower boundary of the beds is determined from the appearance of the index species. On the whole, over 80 species from 29 genera have been found in the assemblage, many of them new (Fig. 3). *Robsoniella* and *Bairdia* dominate among the smooth forms, *Eucytherura* among the sculptured ones. There are also many *Sigillium, Loxoella* and *Cytheropteron*. The most characteristic species are: *Robsoniella longa*, *R. obovata*, *R. minima*, *Sigillium procerum*, *Bairdia* sp.1, *B*. ex gr. *luminosa*, *Paracypris caerulea*, *P.* sp. 1, *Loxoella variealveolata*, *Eucytherura ardescae*, *E. soror*, *E. paula*, *Hemicytherura moorei*, *Procytherura*? *baculumbajula*, *Cytheropteron* sp. 4, *Acrocythere alexandrae*. The majority of species have been previously known mostly from the Lower Cretaceous (Berriasian–Aptian) from Mountain Crimea, the Caucasus, Central Asia, England, France and Germany (Neale 1967; Babinot et al. 1985; Kolpenskaya 2000; Slipper 2009; Savelieva & Shurekova 2014, etc.). In both sections, the studied assemblage is similar to the ostracod complex from the *R. obovata–R. longa* beds. The complex was recognized earlier in the Zavodskaya Balka, with the volume of beds corresponding to the Boissieri zone (Arkadiev et al. 2012, 2015b). The assemblage, enlarged via the new finds, turned to be more diverse and to comprise a greater number of specimens, especially from the uppermost of the Koklyuk section. That has allowed us to extend the characteristics of the beds. It was in the uppermost part of the Koklyuk section, that the *Hemicytherura moorei* species was first discovered in Crimea. The species has previously been described from the Berriasian stratotype (Neale 1967) and later on determined in the Lower Valanginian from central Poland (Kubiatowicz 1983) and in the Berriasian–Valanginian from France (uppermost of the Grandis–Otopeta Standard Tethyan ammonite subzones) (Babinot et al. 1985).

This assemblage is similar to those from the Klentnice Tithonian(?) formation in the Czech Republic (Pokorny 1973) — 13 common genera and 5 species, from the Berriasian stratotype in France (Ardèche) — 10 common genera and 2 species, in total, 20 genera and 4 species from the Berriasian in

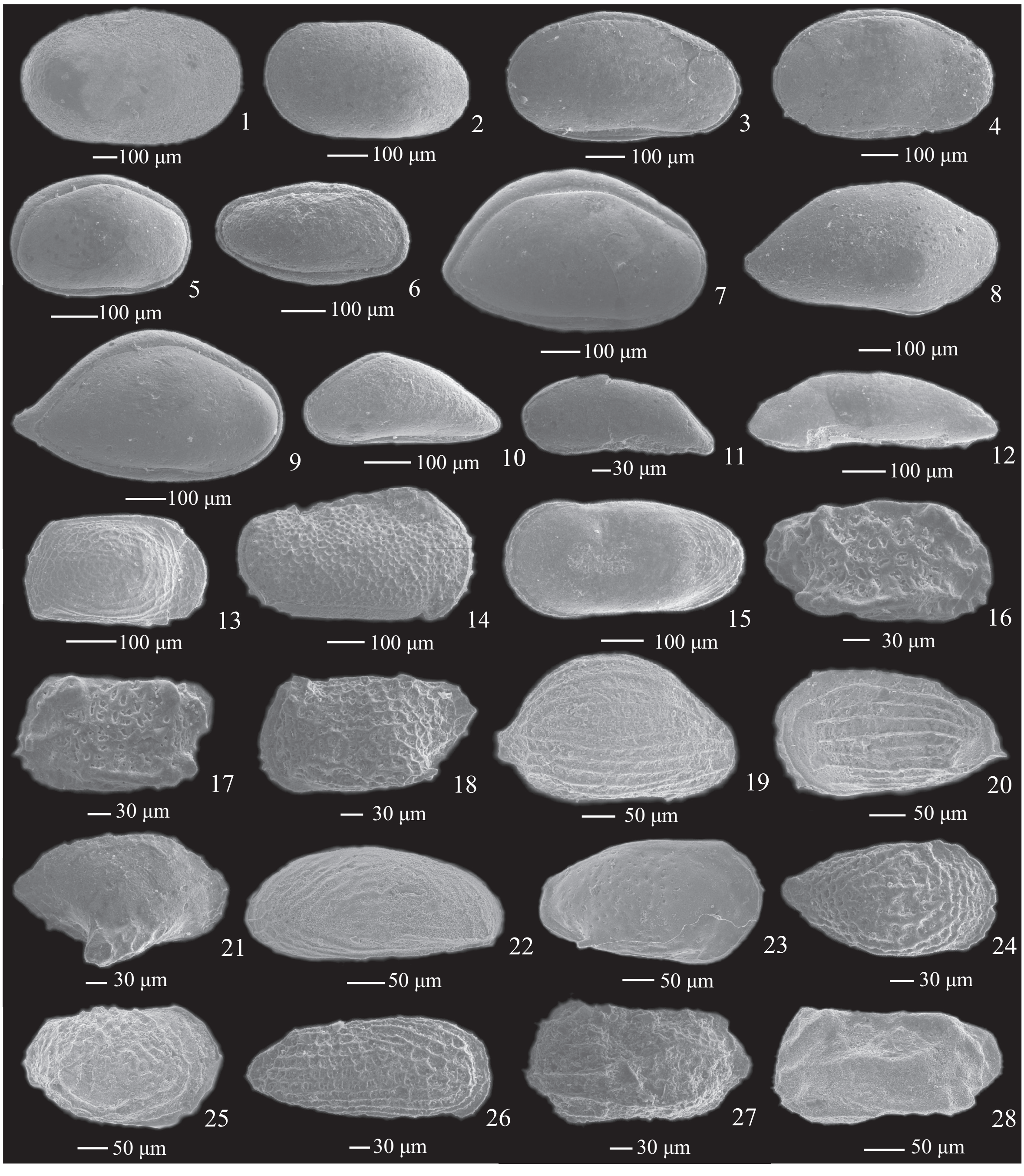

Fig. 3. Ostracods from the Zavodskaya Balka (site 3058) and Koklyuk (site 3030) sections. Berriasian: Fauriella boissieri zone: Koklyuk — 2, 3, 4, 7, 9, 11, 16, 17, 26; Zavodskaya Balka — 1, 22. Neocosmoceras euthymi subzone: Koklyuk — 6, 8, 18, 21, 23, 25. Riasanites crassicostatum subzone, Zavodskaya Balka — 20, 27. Lower Valanginian: Koklyuk — 5, 10, 12, 13, 15; Zavodskaya Balka — 14, 19, 24, 28. **1** — *Cytherella krimensis*, No. 3058-4, right valve, lateral view; **2** — *C. turgida*, No. 3030-18, left valve, lateral view; **3** — *Robsoniella longa*, No. 3030-28, carapace, right lateral view; **4** — *R. obovata*, No. 3030-31, carapace, right lateral view; **5** — *R. minima*, No. 3030-70, carapace, right lateral view; **6** — *Sigillium procerum*, No. 3030-24, carapace, right lateral view; **7** — *Bairdia* sp.1, No. 3030-14, carapace, right lateral view; **8** — B. sp.8, No. 3030-24, carapace, right lateral view; **9** — *B*. ex gr. *luminosa*, No. 3030-31, carapace, right lateral view; **10** — *Paracypris* sp.1, No. 3030-43, carapace, right lateral view; **11** — *P. caerulea*, No. 3030-20, carapace, left lateral view; **12** — *Macrocypris*? sp., No. 3030-61, carapace, left lateral view; **13** — *Cypridea* sp.2, No. 3030-46, carapace, right lateral view; **14** — *C. spinigera*, No. 3058-51, carapace, right lateral view; **15** — *Bythoceratina* sp., No. 3030-46, left valve, lateral view; **16** — *Eucytherura soror*, No. 3030-12, right valve, lateral view; **17** — *E. paula,* No. 3030-12, left valve, lateral view; **18** — *E. ardescae*, No. 3030-22, left valve, lateral view; **19** — *Hemicytherura moorei*, No. 3058-51, right valve, lateral view; **20** — *Protocytherura* sp., No. 3058-36, left valve, lateral view; **21** — *Cytheropteron* sp.4, 3030-22, right valve, lateral view; **22** — *Metacytheropteron* sp., No. 3058-4, left valve, lateral view; **23** — *Procytherura*? *baculumbajula*, No. 3058-14, right valve, lateral view; **24** — *Loxoella variealveolata*, No. 3030 - 24, right valve, lateral view; **25** — *Neocythere pyrena*, No. 3058-48, right valve, lateral view; **26** —*Vocontiana*? sp., No. 3030-2, right valve, lateral view; **27** — *Acrocythere alexandrae*, No. 3030-20, left valve, lateral view; **28** — Gen. sp. 9, No. 3058-51, left valve, lateral view.

France; from the basal Valanginian in the Berriasian stratotype region (France, Ardèche) — 10 genera and 5 species (Babinot et al. 1985), from the Berriasian of the North Caucasus (Kolpenskaya 2000) — 10 common genera and 3 species. On the whole, the ostracod assemblage from the Zavodskaya Balka and Koklyuk sections is of Upper Berriasian–Valanginian composition.

Palynomorphs:

Practically all the examined samples comprise spores, pollen and microphytoplankton (dinoflagellate cysts, rare acritarchs and green algae). *Classopollis* spp. pollen is dominant among palynomorphs: from 70 % in the lower parts of both sections, down to 30 % in the uppermost parts. The average number of dinoflagellate cysts makes 45 % (from 13 to 74 %).

Organic-walled dinoflagellate cysts:

50 species of organic-walled dinocysts have been found in samples from the Zavodskaya Balka section, over 90 species from the Koklyuk section (Figs. 4, 5, 6). Three beds with dinocysts have been recognized on the basis of the microphytoplankton occurrence analysis. The following are the permanent members of the assemblages from all three beds: *Phoberocysta neocomica*, *Hystrichodinium pulchrum*, *Circulodinium distinctum*, *Ctenidodinium elegantulum*, *Downiesphaeridium iaculigerum*, *Scriniodinium campanula*, *Kleithriasphaeridium eoinodes*, *Prolixosphaeridium* spp., *Wrevittia helicoidea*, *Dapsilidinium warrenii*.

Beds with ***Phoberocysta neocomica*** have been established in the Koklyuk (sample 3030-4–sample 3030-31) and Zavodskaya Balka sections (sample 3058-4–sample 3058-11). The lower boundary of the beds is recorded from the appearance of a characteristic assemblage with *Phoberocysta neocomica*. The upper boundary in the Koklyuk section corresponds to the bottom of the overlying beds with *Pseudoceratium pelliferum*, and in the Zavodskaya Balka section the boundary is marked from the last occurrence of *Egmontodinium torynum* and *Tehamadinium* aff. *daveyi*. The beds complex is peculiar for domination of *Cometodinium habibii* and *Systematophora areolata*. Beside these taxa, the following ones have been determined: *Amphorula* spp. (*A. expirata*, *A. dodekovae*, *A. metaelliptica*), *Achomosphaera neptunii*, *Chytroeisphaeridia chytroeides*, *Egmontodinium torynum*, *Tubotuberella* spp., *Muderongia* spp. (*M. simplex*, *M. longicorna*, *M. tomaszowensis*, *M. endovata*, *Muderongia simplex* subsp. *microperforata*), *Systematophora* spp. (*S. palmula*, *S.*? *daveyi*, *S. palmula/daveyi*), *Wallodinium cylindricum*. Among the solitary or rare ones: *Dichadogonyaulax culmula*, *Hystrichodinium voigtii*, *Hystrichosphaerina*? *orbifera*, *Valensiella ovulum*, *Atopodinium haromense*, *Chlamydophorella* sp., *Dissiliodinium* sp., *Tanyosphaeridium* spp., *Tehamadinium* aff. *daveyi*. Species of *Spiniferites* ex gr. *ramosus* appear and become a permanent species in the terminal part of the beds in the Koklyuk section.

The last occurrence of *A. expirata* in the Koklyuk section coincides with finds of the *Neocosmoceras euthymi* ammonites, designating the homonymous subzone that correlates with the Paramimounum subzone of the Mediterranean region (Reboulet et al. 2014). This level corresponds to the *A. expirata* species disappearance from the Boreal regions, as well (the boundary of the Runctoni and Kochi ammonite zones) (Costa & Davey 1992). Disappearance of *A. metaelliptica*, as well as reduced number and permanent presence of *M. longicorna* are known from the Late Berriasian in the Boreal region (the lowermost of the Icenii ammonite zone) (Ogg et al. 2008). In the Tethys, this level corresponds to the Picteti subzone (Ogg et al. 2008). On the whole, in terms of its composition, the assemblage of the beds is similar to the complex of the C and D subzones from the dinocyst *Gochteodinia villosa* zone, specified in the Upper Berriasian from the Volga basin (Kashpir section) (beds without ammonite characteristics from the lowermost part of the Upper Berriasian in the R. rjasanensis/S. spasskensis zone and the lowermost part of the S. tzikwinianus zone) (Harding et al. 2011).

The earlier specified beds have been determined while studying the Berriasian throughout Mountainous Crimea (Arkadiev et al. 2012; 2015b; Savelieva et al. 2014). In summary, the beds correspond to the Tauricum subzone of the Occitanica zone (central and south-western Crimea) and to the Boissieri zone (eastern, central and south-western Crimea) (Shurekova 2016).

Beds with ***Pseudoceratium pelliferum*** were established in the Koklyuk section (sample 3030-34–sample 3030-40). The lower boundary is drawn from the appearance of *Ps. pelliferum*, *Dingodinium* spp. and *Cymososphaeridium vallidum*. The upper boundary corresponds to the bottom of the overlying beds with *Oligosphaeridium* spp. Besides *Ps. pelliferum*, *Dingodinium* spp. (*D. cerviculum*, *D.*? *spinosum*, *D.* sp.) and *C. vallidum,* the following species appear here: *Occisucysta tentoria*, *Cassiculosphaeridia magna*, *Cassiculosphaeridia reticulata*, *Muderongia tetracantha*, *M. mcwhaei* forma B, *Bourkidinium granulatum*, *Pluriarvalium osmingtonense* and *Wallodinium krutzschii*. Disappearing: *A. expirata*, *E. torynum*, *M. simplex*, *D. culmula*, *H.*? *orbifera*, *V. ovulum*, *T.* aff. *daveyi*. Dominant: *S. areolata* and *Spiniferites* spp. (*Sp.* sp. and *Sp.* ex gr. *ramosus*). The number of representatives of the *C. habibii* species becomes insubstantial.

In the Zavodskaya Balka section (sample 3058-14–sample 3058-36), a dinocyst assemblage of similar composition, with *Systematophora areolata* and *Tubotuberella* spp., has been determined; but it differs in the lack of a number of stratigraphically important taxa, including the index species *Ps. pelliferum*. Nevertheless, it is common in both assemblages that the last occurrence of *Tubotuberella* spp. and *S. areolata* take place in the uppermost of the beds. We believe that irrespective of the differences, the assemblage with *S. areolata* and *Tubotuberella* spp., determined in the Zavodskaya Balka section, and the assemblage of the beds with *Ps. pelliferum* from the Koklyuk section are coeval.

The assemblage *Ps. pelliferum* is compositionally similar to the *Ps. pelliferum* complex from the Upper Berriasian in the Volga Basin (Kashpir section) (Harding et al. 2011).

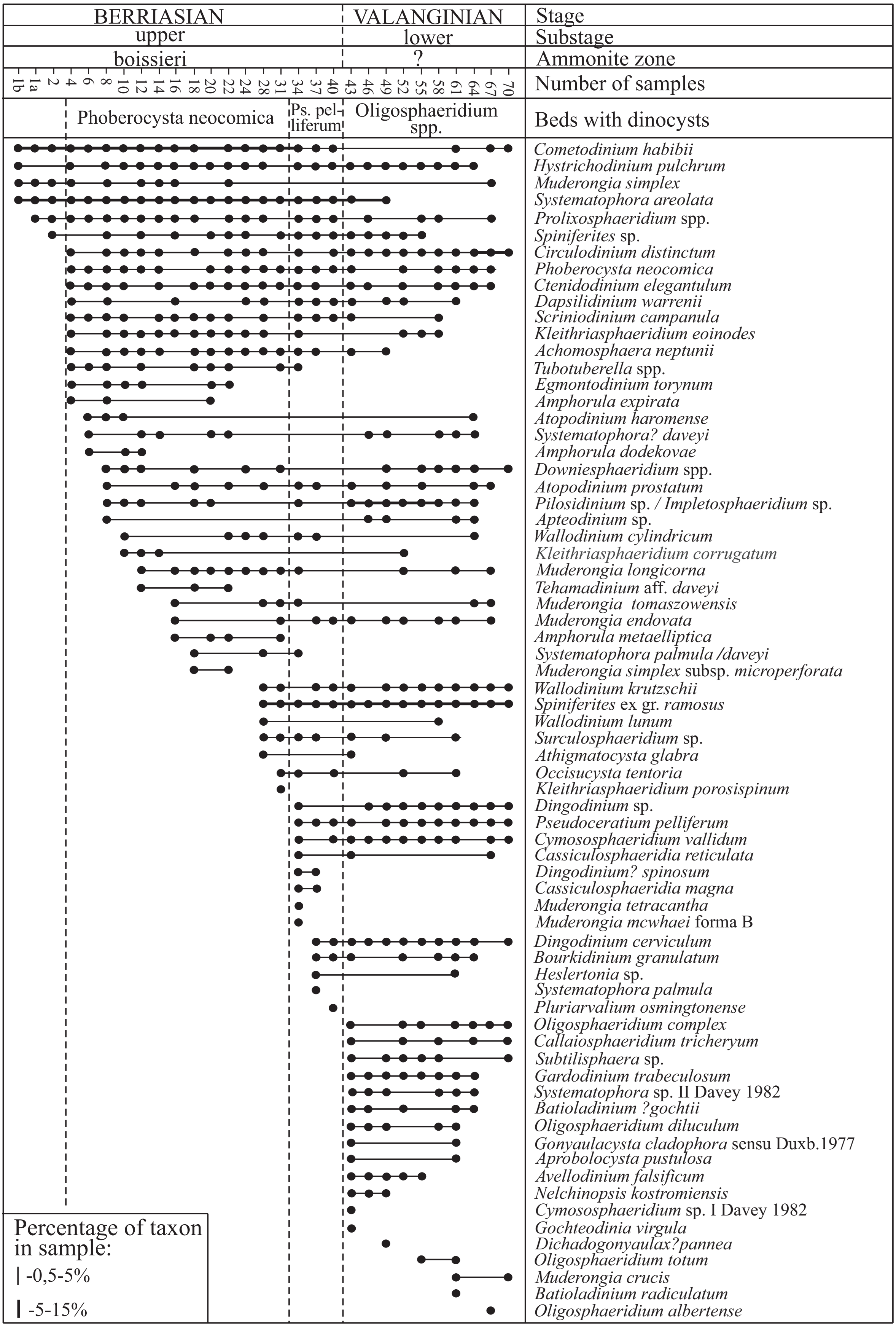

Fig. 4. Distribution of dinoflagellate cysts from the Koklyuk section.

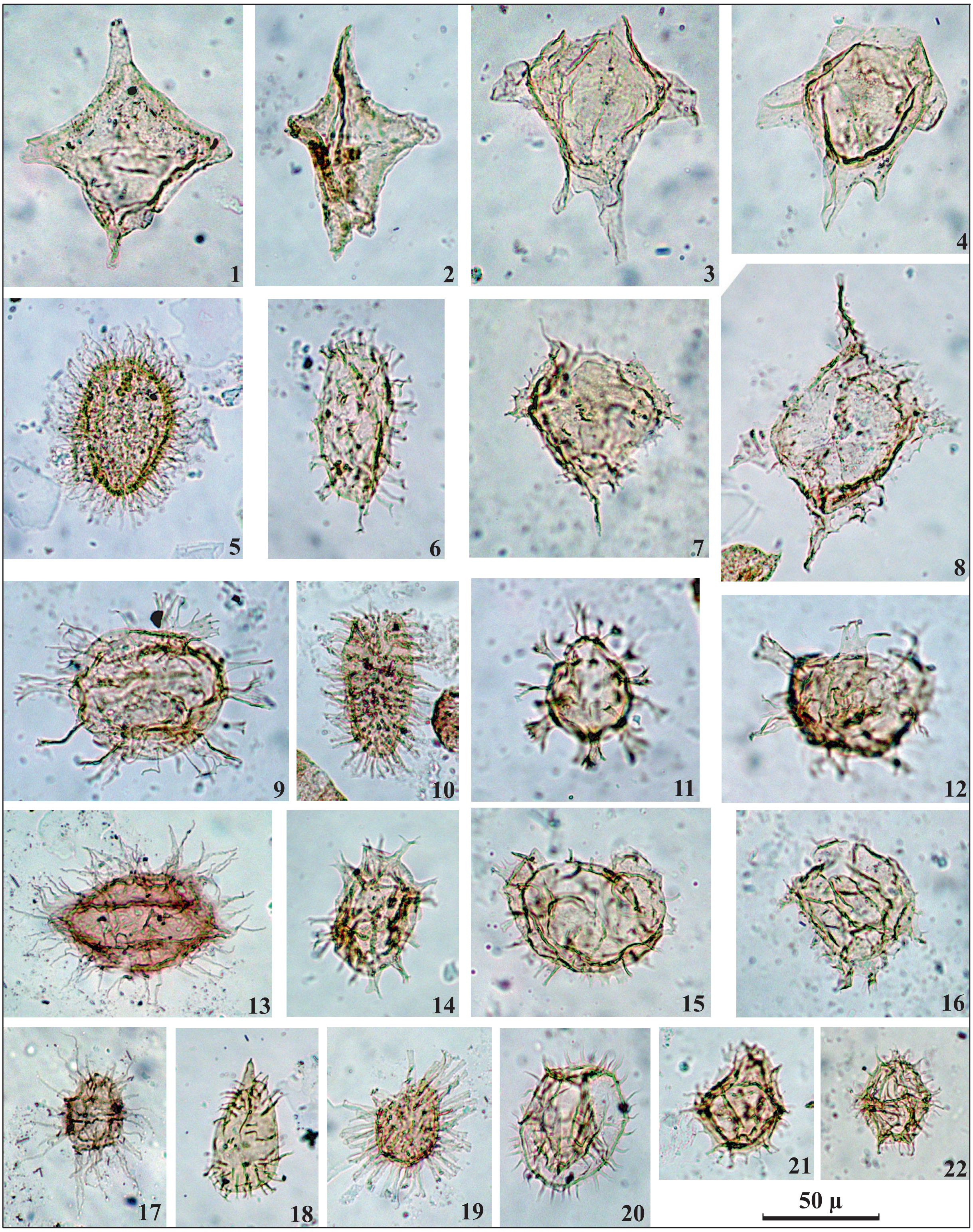

Fig. 5. Dinoflagellate cysts from the Zavodskaya Balka section (site 3058). Berriasian: Fauriella boissieri zone: Neocosmoceras euthymi subzone — 1–6, 8, 13, 16, 18, 20; Riasanites crassicostatum subzone — 7, 10, 11, 14, 15, 17, 22; Berriasella callisto subzone — 12, 21. Lower Valanginian — 9, 19. **1, 2** — *Muderongia simplex*; **3, 4** — *Muderongia longicorna*; **5** — *Cometodinium habibii*; **6** — *Egmontodinium torynum*; **7, 8** — *Phoberocysta neocomica*; **9, 12** — *Systematophora palmula*; **10** — *Prolixosphaeridium parvispinum*; **11** — *Kleithriasphaeridium eoinodes*; **13, 17** — *Hystrichodinium pulchrum*; **14** — *Achomosphaera neptunii*; **15** — *Amphorula metaelliptica*; **16** — *Phoberocysta lowryi*; **18** — *Gochteodinia villosa* subsp. *multifurcata*; **19** — *Dapsilidinium warrenii*; **20** — *Ctenidodinium elegantulum*; **21, 22** — *Spiniferites* ex gr. *ramosus*. Samples: **1** — No. 3058-8; **2–6, 8, 13, 18, 20** — No. 3058-4; **7** — No. 3058-20; **9** — No. 3058-45; **10** — No. 3058-32; **11** — No. 3058-23; **12, 21** — No. 3058-39; **14** — No. 3058-14; **15, 17, 22** — No. 3058-36; **16** — No. 3058-11; **19** — No. 3058-51.

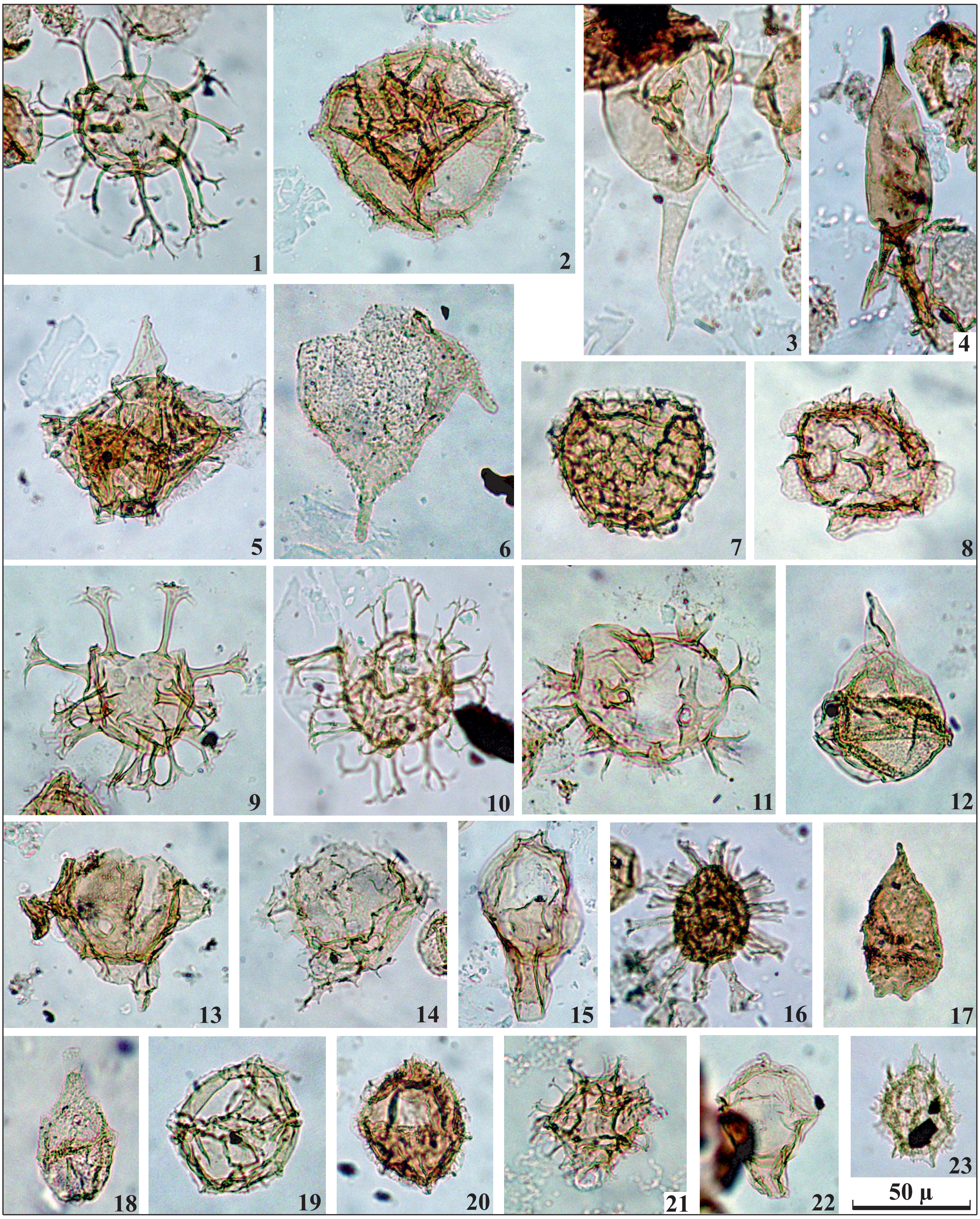

Fig 6. Dinoflagellate cysts from the Koklyuk section (site 3030). Berriasian: Fauriella boissieri zone — 4, 8, 12, 18, 20, 28, 34. Lower Valanginian — 43, 49, 52, 61, 64. **1** — *Cymososphaeridium vallidum*; **2** — *Gonyaulacysta cladophora*; **3** — *Muderongia tetracantha*; **4** — *Batioladinium radiculatum*; **5** — *Occisucysta tentoria*; **6** — *Pseudoceratium pelliferum*; **7** — *Cassiculosphaeridia reticulata*; **8** — *Amphorula metaelliptica*; **9** — *Oligosphaeridium diluculum*; **10** — *Systematophora*? *daveyi*; **11** — *Oligosphaeridium porosum*; **12** — *Dingodinium cerviculum*; **13** — *Muderongia endovata*; **14** — *Phoberocysta neocomica*; **15, 22** — *Tubotuberella apatela*; **16** — *Kleithriasphaeridium corrugatum*; **17** — *Batioladinium*? *gochtii*; **18** — *Gardodinium trabeculosum*; **19** — *Athigmatocysta glabra*; **20** — *Tehamadinium daveyi*; **21** — *Spiniferites* ex gr. *ramosus*; **22** — *Tubotuberella apatela*; **23** — *Nelchinopsis kostromiensis*. Samples: **1, 9, 11, 19, 23** — No. 3030-43; **2, 4, 5, 17** — No. 3030-61; **3, 7** — No. 34; **6, 12** — No. 3030-49; **8, 10** — No. 3030-20; **13, 16** — 52; **14** — No. 3030-8; **15** — No. 3030-4; **18** — No. 3030-64; **20** — No. 3030-12; **21** — No. 3030-28; **22** – No. 3030-18.

The appearance of *Ps. pelliferum* is a stratigraphically important event (Ogg et al. 2008). In the Boreal region, the species appears at the same level: in the Volga basin (Kashpir section) — in the middle part of the Tzikwinianus zone (Harding et al. 2011), and in north-western Europe (Costa & Davey 1992) — in the Stenomphalus zone, which in the Tethys corresponds to the basement of the Otopeta subzone (Ogg et al. 2008). The *M. mcwhaei* forma B and *C. vallidum* species, appearing in the Boreal region in the Albidum and Paratollia zones, respectively (Costa & Davey 1992; Ogg et al. 2008), are first encountered in the studied deposits synchronously with *Ps. pelliferum*.

Beds with ***Oligosphaeridium* spp**. have been established in the uppermost part of the Koklyuk section (sample 3030-43–sample 3030-67). The lower boundary is drawn according to the appearance of *Oligosphaeridium* spp., *Gonyaulacysta cladophora* sensu Duxbury 1977, *Batioladinium*? *gochtii*. The upper boundary has not been determined. The following taxa dominate here: *Sp.* ex gr. *ramosus* and *Pilosidinium/Impletosphaeridium* sp. Appear: *Oligosphaeridium* spp. (*Ol.* sp., *Ol. complex*, *Ol. diluculum*), *Callaiosphaeridium tricheryum*, *G. cladophora* sensu Duxbury 1977, *Aprobolocysta pustulosa*, *Avellodinium falsificum*, *Subtilisphaera* sp., *Cymososphaeridium* sp. I Davey 1982, *Systematophora* sp. II Davey 1982, *Gochteodinia virgula*, *B.*? *gochtii*, *Gardodinium trabeculosum*, *Nelchinopsis kostromiensis*. Species inherited from the previous assemblage occur permanently: *Wallodinium krutzschii*, *Ps. pelliferum*, *D. cerviculum*, *C. vallidum*, *Occ. tentoria*, *Bourkidinium granulatum*, *Apteodinium* sp. Disappear *Tubotuberella* spp., *D.*? *spinosum*. Appearance of the *Ol. complex*, *G. cladophora*, *B.*? *gochtii* in north-western Europe is known from the Lower Valanginian Paratollia zone; and appearance of *N. kostromiensis* — from the Polyptychites zone (Costa & Davey 1992; Ogg et al. 2008). In the Volga basin (Gorodishche and the Kashpir sections) the *Ol. complex*, *B.*? *gochtii* and *N. kostromiensis* appear in the Lower Valanginian where ammonites have not been found (Harding et al. 2011).

Comparison of the taxonomic compositions of the dinocyst assemblages reveals much greater similarity with the Boreal coeval complexes than with the Tethyan ones. This may be accounted for by considerable influence of the Boreal sea over that area during the Berriasian–Valanginian time (Baraboshkin 1999).

Conclusions

The micropalaeontological research on the continuous Berriasian–Valanginian boundary sediments within the Zavodskaya Balka and Koklyuk sections have made it possible to establish beds with characteristic foraminifer, ostracod and dinocyst assemblages (Fig. 7, 8). Analysis of foraminifers from the Zavodskaya Balka and Koklyuk sections indicate

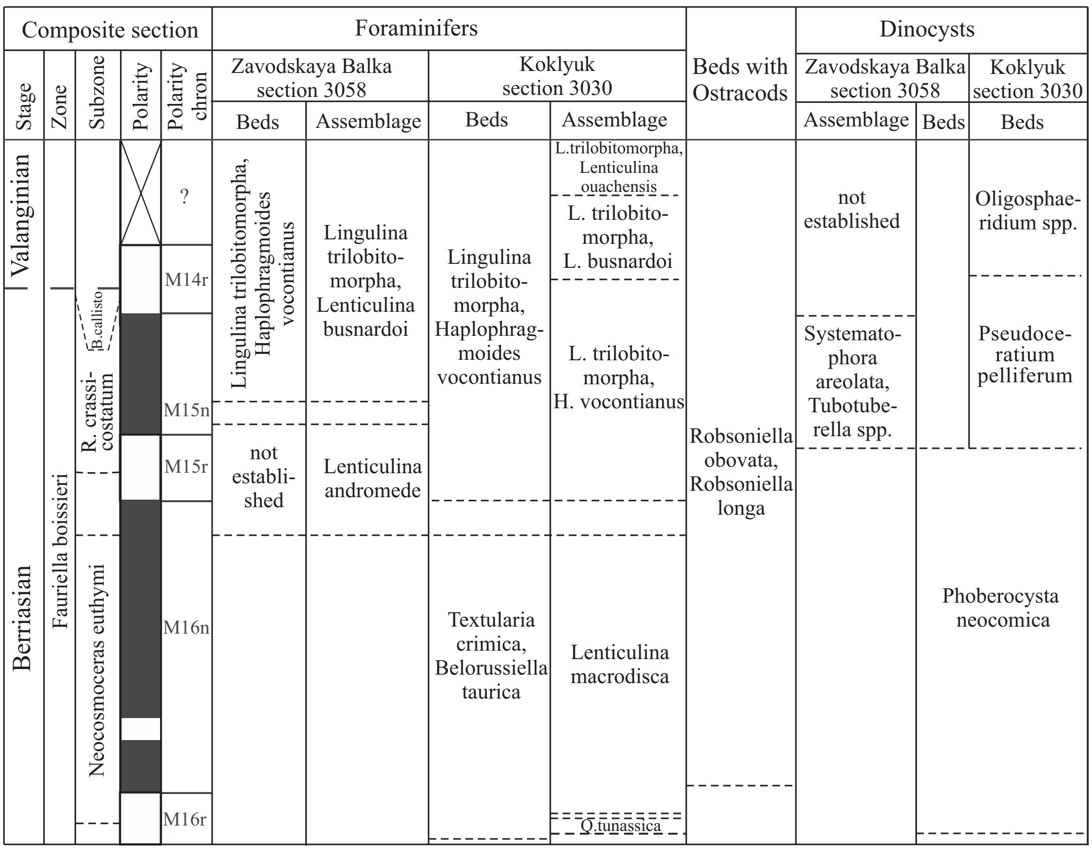

Fig. 7. Biostratigraphic correlation of the Berriasian–Valanginian boundary in the Zavodskaya Balka and Koklyuk sections.

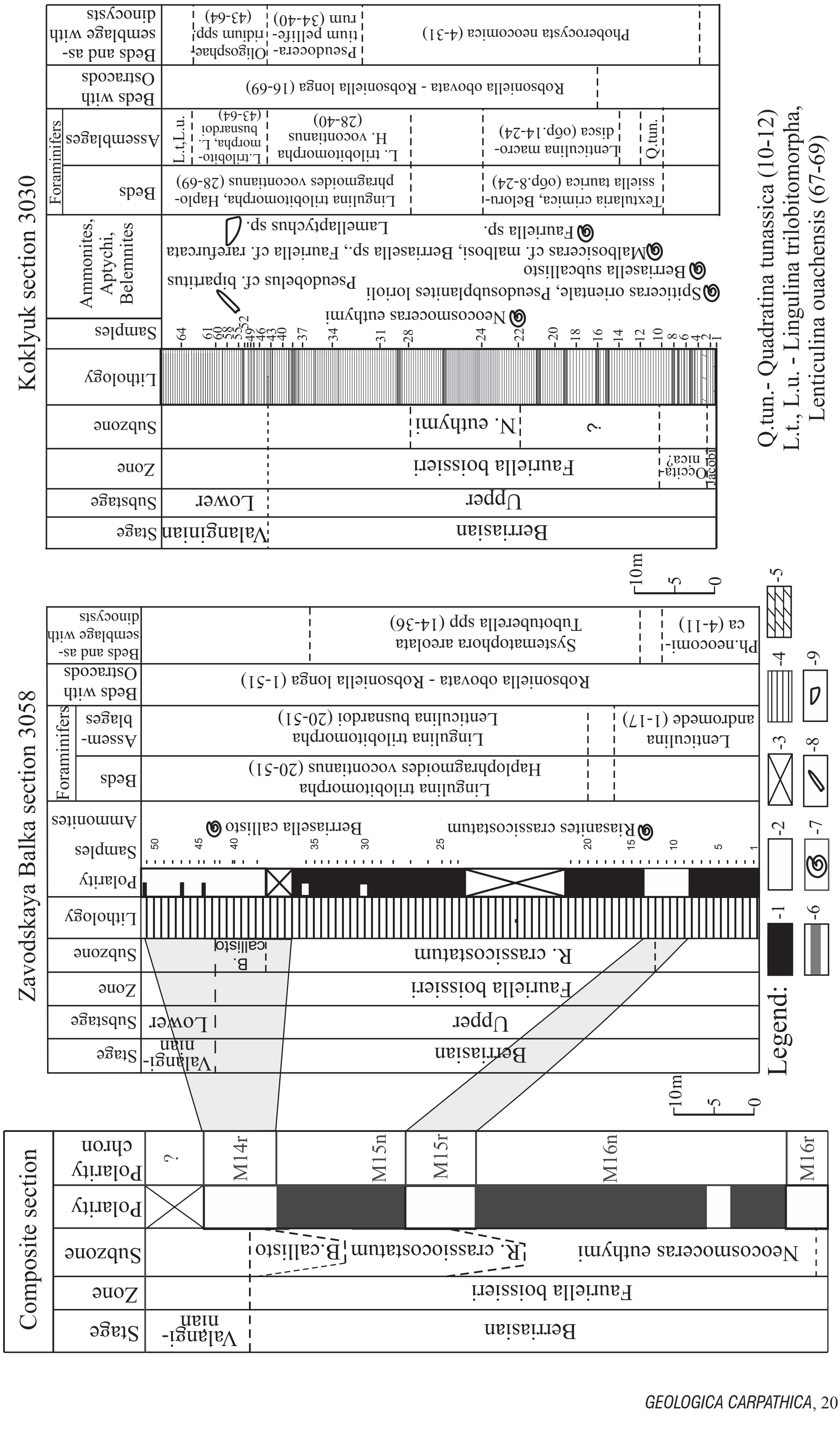

Fig. 8. Correlation of Zavodskaya Balka and Koklyuk sections on the bio- and magnetostratigraphic data. Legend: 1, 2 — normal and reverse geomagnetic polarity, respectively (in half of the column thickness – tentative determination of the polarity sign); 3 — no palaeomagnetic data available; 4 — clays; 5 — marl; 6 — ankerite and siderite intercalations; 7 — ammonite finds; 8, 9 — belemnite and aptychi finds, respectively. Q.tun. - *Quadratina tunassica* (10–12); L.t., L.u. - *Lingulina trilobitomorpha*, *Lenticulina ouachensis* (67–69); 10–12 — number of sample.

the presence of the upper part of the beds with *Textularia crimica–Belorussiella taurica* and beds with *Lingulina trilobitomorpha, Haplophragmoides vocontianus*, correlating with Boreal ammonite zones from the Tauricum–Verrucosum (Upper Berriasian–Valanginian). The new data on ostracods allow us to expand the volume and characteristics of the earlier recognized beds with *Robsoniella obovata–Robsoniella longa*. Although most ostracod species are endemic here, there is some similarity with Upper Berriasian–Valanginian European assemblages. Beds with *Phoberocysta neocomica* and assemblage with *Systematophora areolata, Tubotuberella* spp. have been established from dinoflagellate cysts in the Zavodskaya Balka; in Koklyuk, beds with *Phoberocysta neocomica*, beds with *Pseudoceratium pelliferum* and beds with *Oligosphaeridium* spp. have been determined. The basement of the latter beds correlates with the Lower Valanginian Paratollia zone from north-western Europe. The examined dinocyst assemblages have more similarity with the Boreal, than with the Tethyan forms, which is accounted for by the connection with the Boreal basin at that time. Notwithstanding the lack of Valanginian ammonite finds, the data on foraminifer, ostracod and dinoflagellate cyst stratigraphic occurrences, combined with macrofaunal and palaeomagnetic data, makes it possible to substantiate the occurrence of the Lower Valanginian in eastern Crimea.

Acknowledgements: The authors are grateful to: Dr. Ottilia Szives (HNH Museum), and an anonymous reviewer, Dr. Jozef Michalík and Dr. Milan Kohút (SAS) for thorough reviews, important comments and correction of the manuscript, Dr. I.A. Nikolaeva (VSEGEI) for valuable recommendation; L.A Kartseva (BIN RAN) and Dr. E.M. Tesakova (MGU) for ostracod photography; E.V. Serebryakova for the English translation.

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Supplementum

List of taxa

Foraminifers:

Ammodiscus cretaceous (Reuss), 1845;
Astacolus ambanjabensis (Espitalie et Sigal), 1963;
Astacolus calliopsis (Reuss, 1863);
Astacolus ex gr. *mutilates* Espitalie et Sigal, 1963;
Astacolus gibber Espitalie et Sigal, 1963;
Astacolus hamalilis (Reuss), 1863;
Astacolus incurvatus (Loeblich et Tappan), 1950;
Astacolus laudatus (Hoffman), 1961;
Astacolus planiusculus (Reuss), 1863;
Astacolus proprius K.Kuznetsova, 1985;
Ataxophragmiidae;
Belorussiella taurica Gorbatchik, 1971;
Citharina ex gr. *flexuosa* (Bruckmann), 1904;
Conorbina miser (Gorbatchik), 1971;
Conorboides hofkeri (Bartenstein and Brand), 1951;
Dentalina communis d'Orbigny, 1826;
Dentalina marginuloides Reuss, 1851;
Dentalina nana Reuss, 1862;
Dentalina soluta Reuss, 1851;
Discorbis crimicus Schokchina, 1960;
Dorothia aff. *zedlerae* Moullade, 1966;
Dorothia ex gr. *oxycona* (Reuss, 1860) var. *elongate* Tairov, 1956;
Dorothia ex gr. *oxycona* (Reuss, 1860);
Dorothia kummi (Zedier), 1961;
Dorothia praeoxycona Moullade, 1966;
Dorothia pseudocostata (Antonova), 1964;
Epistominidae;
Falsopalmula costata Gorbatchik, 1971;
Frondicularia complexa Pathy, 1968;
Frondicularia crimica Schokhina, 1960;
Gaudryina alternans Gorbatchik, 1985;
Gaudryina neocomica Chalilov, 1956;
Gaudryina spp.;
Globospirillina neocomina Moullade, 1966
Glomospira ex gr. *charoides* Jones & Parker, 1860;
Glomospirella ex gr. *gaultina* (Berthelin), 1880;
Haplophragmium elongatum Dain, 1973;
Haplophragmium sp.;
Haplophragmoides ustjurticus Mamaeva, 1970;
Haplophragmoides vocontianus Moullade, 1966;
Haplophragmoides spp.;
Hippocrepinidae;
Hoeglundina ex gr. *caracolla* (Roemer), 1841;
Hormosinelloides? *guttus* Vassilenko, 1980;
Lenticulina aff. *akmetchetica* Mjatliuk, 1988;
Lenticulina ambanjabensis Gorbatchik, 1985;
Lenticulina andromede Espitalie et Sigal, 1963;
Lenticulina busnardoi Moullade, 1966;
Lenticulina cf. *aquilonica* (Mjatliuk), 1939;
Lenticulina cf. *nodosa* Reuss, 1863;
Lenticulina eichenbergi Bartenstein et Brand. 1951;
Lenticulina ex gr. *andromede* Espitalie et Sigal, 1963;
Lenticulina ex gr. *guttata* (Dam), 1946;
Lenticulina ex gr. *neocomina* Romanova, 1955;
Lenticulina ex gr. *nimbifera* Espitalie et Sigal, 1963;
Lenticulina ex gr. *subalata* (Reuss), 1854;
Lenticulina lideri Romanova, 1960;
Lenticulina macra Gorbatchik, 1960;
Lenticulina macrodisca Reuss, 1862;
Lenticulina muensteri (Roemer), 1839;
Lenticulina nuda (Reuss), 1862;
Lenticulina ouachensis Sigal, 1952;
Lenticulina praegaultina Bartenstein, Bettenstaedt, Bolli 1957;
Lenticulina saxonica Bartenstein et Brand, 1951;
Lingulina trilobitomorpha Pathy, 1968;
Marginulinita pyramidalis (Kocheleva), 1851;
Nodosaria paupercula Reuss, 1845;
Orthokarstenia fenestralis Bystrova, 1983;
Planularia madagascariensis Espitalie et Sigal, 1963;
Pseudonodosaria humilis (Roemer), 1841;
Pseudosaracenaria truncata Pathy, 1968;
Quadratina (Tristix) tunassica Schokhina, 1960;
Ramulina aculeata Wright, 1886;
Ramulina spinata Cushman, 1934
Ramulina spp.;
Recurvoides ex gr. *paucus* Dubrovskaja, 1967;
Reophax spp.;
Rhizammina indiviza Brady, 1884;
Saracenaria compacta Espitalie et Sigal, 1963;
Spirillina aff. *minima* Schacko, 1892;
Spirillina kubleri Mjatliuk, 1953;
Trochammina neocomiana Mjatliuk, 1939;
Vaginulinopsis neopachynota Bartenstein et Kaever, 1973;
Vaginulinopsis spp.;
Verneuilina angularis Gorbatchik, 1971

Ostracods:

Acrocythere alexandrae Neale et Kolpenskaya, 2000;
Bairdia spp.;
B. ex gr. *luminosa* Kuznetsova, 1961;
Bairdia sp.1 Tesakova, Savelieva, 2005;
Cytheropteron spp.;
Cytheropteron sp. 4;
Hemicytherura moorei Neale, 1967;
Eucytherura spp.;
Eucytherura ardescae Donze, 1965;
Eucytherura paula (Luebimova, 1955);
Eucytherura soror Pokorny, 1973;
Loxoella spp.;
Loxoella variealveolata Kuznetsova, 1956;
Procytherura? *baculumbajula* (Mandelstam, 1955);
Paracypris caerulea Neale, 1962;

Paracypris sp.1;
Robsoniella spp.;
Robsoniella longa Kuznetsova, 1961;
Robsoniella obovata Kuznetsova, 1956;
Robsoniella minima Kuznetsova, 1961;
Sigillium procerum Kuznetsova, 1960;
Sigillium spp.

Organic-walled dinoflagellate cysts:

Apteodinium sp.;
Achomosphaera neptunii (Eisenack, 1958) Davey et Williams, 1966;
Amphorula dodekovae Zotto et al., 1987;
Amphorula expirata (Davey, 1982) Courtinat, 1989;
Amphorula metaelliptica Dodekova, 1969);
Aprobolocysta pustulosa Smith et Harding, 2004;
Athigmatocysta glabra Duxbury, 1977;
Atopodinium haromense Thomas et Cox, 1988;
Avellodinium falsificum Duxbury, 1977;
Batioladinium? *gochtii* (Alberty, 1961) Lentin et Williams, 1977;
Batioladinium radiculatum Davey, 1982;
Bourkidinium granulatum Morgan, 1975;
Callaiosphaeridium tricheryum Duxbury, 1980;
Cassiculosphaeridia magna Davey, 1974;
Cassiculosphaeridia reticulata Davey, 1969;
Chlamydophorella sp.;
Chytroeisphaeridia chytroeides (Sarjeant, 1962) Downie et Sarjeant, 1965;
Circulodinium distinctum (Deflandre et Cookson, 1955) Jansonius, 1986;
Cometodinium habibii Monteil, 1991;
Ctenidodinium elegantulum Millioud, 1969;
Cymososphaeridium sp. I Davey, 1982;
Cymososphaeridium vallidum Davey, 1982;
Dapsilidinium warrenii (Habib, 1976) Lentin et Williams, 1981;
Dichadogonyaulax culmula (Norris 1965) Loeblich et Loeblich, 1968;
Dichadogonyaulax? *pannea* (Norris, 1965) Sarjeant, 1969;
Dingodinium cerviculum Cookson et Eisenack, 1958;
Dingodinium? *spinosum* (Duxbury, 1977) Davey. 1979;
Dissiliodinium sp.,
Downiesphaeridium iaculigerum (Klement, 1960) Williams et al., 1998;
Egmontodinium torynum (Cookson et Eisenack, 1960) Davey, 1979;
Gardodinium trabeculosum (Gocht, 1959) Alberti, 1961;
Gochteodinia virgula Davey, 1982;
Gonyaulacysta cladophora sensu Duxbury, 1977;
Heslertonia sp.;
Hystrichodinium pulchrum Deflandre, 1935;
Hystrichodinium voigtii (Alberti, 1961) Davey, 1974;
Hystrichosphaerina? *orbifera* (Klement, 1960) Stover et Evitt, 1978;
Kleithriasphaeridium corrugatum Davey, 1974;
Kleithriasphaeridium eoinodes (Eisenack, 1958) Davey, 1974;
Kleithriasphaeridium porosispinum Davey, 1982;
Muderongia crucis Neale et Sarjeant, 1962;
Muderongia endovata Riding et al., 2000;
Muderongia longicorna Monteil, 1991;
Muderongia mcwhaei Cookson et Eisenack, 1958 forma B Monteil, 1991;
Muderongia simplex Alberti, 1961;
Muderongia simplex subsp. *microperforata* Davey, 1982;
Muderongia tetracantha (Gocht, 1957) Alberti, 1961;
Muderongia tomaszowensis Alberti, 1961;
Nelchinopsis kostromiensis (Vozzhennikova, 1967) Wiggins, 1972.
Occisucysta tentoria Duxbury, 1977;
Oligosphaeridium albertense (Pocock, 1962) Davey et Williams, 1969;
Oligosphaeridium complex (White, 1842) Davey et Williams, 1966;
Oligosphaeridium diluculum Davey, 1982;
Oligosphaeridium totum Brideaux, 1971;
Phoberocysta neocomica (Gocht, 1957) Millioud, 1969;
Pluriarvalium osmingtonense Sarjeant, 1962;
Prolixosphaeridium spp.,
Pseudoceratium pelliferum Gocht. 1957;
Scriniodinium campanula Gocht, 1959;
Spiniferites ex gr. *ramosus* (Ehrenberg, 1838) Loeblich et Loeblich, 1966;
Subtilisphaera sp.;
Surculosphaeridium sp.;
Systematophora areolata Klement, 1960;
Systematophora palmula Davey, 1982;
*Systematophora s*p. II Davey, 1982;
Systematophora? *daveyi* Riding et Thomas, 1988;
Tanyosphaeridium spp.,
Tehamadinium aff. *daveyi* Jan du Chêne et al., 1986.
Tubotuberella spp.;
Valensiella ovulum (Deflandre, 1947) Eisenack, 1963;
Wallodinium cylindricum (Habib, 1970) Duxbury, 1983;
Wallodinium krutzschii (Alberti, 1961) Habib, 1972;
Wallodinium luna (Cookson et Eisenack, 1960) Lentin and Williams, 1973;
Wrevittia helicoidea (Eisenack et Cookson, 1960) Helenes et Lucas-Clark, 1997.