The Cenomanian-Turonian boundary in southwestern Crimea, Ukraine: Foraminifera and palaeogeographic implications

Ludmila KOPAEVICH[1], Tatyana KUZMICHEVA[2]

KOPAEVICH, L. & KUZMICHEVA, T., 2002: The Cenomanian-Turonian boundary in southwestern Crimea, Ukraine: Foraminifera and palaeogeographic implications. – In: WAGREICH, M. (Ed.): Aspects of Cretaceous Stratigraphy and Palaeobiogeography. – Österr. Akad. Wiss., Schriftenr. Erdwiss. Komm. 15: 129–149, 8 Figs., 3 Pls., Wien.

Abstract: This study compares black shale sedimentation at the Cenomanian/Turonian (C/T) boundary in five sections of southwestern Crimea, Ukraine. The study is based on the analysis of sedimentological features, comparison and biostratigraphic correlation of foraminifera with some data from nannofossils, radiolarians, and rare inoceramids as well as geochemical data. The completeness of the studied sections increases from north to south. Three planktonic foraminiferal zones are recognized around the Cenomanian-Turonian boundary: the *Rotalipora cushmani* Zone contains foraminiferal assemblages of high diversity. The *Whiteinella archaeocretacea* Zone is characterized by low diversity assemblage or a complete absence of foraminifera; this interval coincides with the black shale facies. Foraminiferal assemblages in the *Dicarinella elata* Zone (analogous to the *Helvetoglobotrucana helvetica* Zone) are again diverse and very abundant. The presence of boreal planktonic foraminiferal faunas and high radiolarian/planktonic foraminiferal ratios within the *Whiteinella archaeocretacea* Zone are interpreted as a result of relatively colder water conditions during that time. The organic-rich strata of the *W. archaeocretacea* Zone correspond to the Ocean Anoxic Event 2, widely known at the C/T boundary.
The Crimean black shales have a relatively high total organic carbon (TOC) content up to 7.2%–8%. This interval is characterized by a positive shift in δ 13C of +4–5$^0/_{00}$ Cold water conditions are interpreted as indicators of coastal upwelling of cold oceanic water along the South Crimea margin. The presence of the black shale facies, depauperation of the benthos, together with increased TOC values, indicate the existence of an oxygen-minimum zone and an increase in anaerobic bottom water conditions. The process of the accumulation of bituminous sediments in southwestern Crimea was associated with the activation of geodynamic processes. The black shales were deposited in small deep depressions in the southern part of this area. The shallower parts are characterized by the reduction of the *Whiteinella archaeocretacea* Zone or by a C/T gap resulting from the absence of this zone.

Keywords: Cenomanian-Turonian Boundary, Crimea, Black Shale, Foraminifera, Biostratigraphy, Anoxia, Palaeogeography

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[1] Moscow State University, Geological Faculty, 119899 Vorobievy Gory, Russia; E-mail: lkopaev@geol.msu.ru

[2] Institute of the Lithosphere of the Russian Academy of Sciences (Saint Petersburg department), Moika, 120, 190121, Saint Petersburg, Russia; E-mail: ienn@mail.ru

1. INTRODUCTION

Most of the information about foraminiferal changes across the Cenomanian/Turonian boundary comes from the western part of the Peri-Tethys area, from England and the North Sea in the north, to Tunisia and Marocco in the south (SCHLANGER & JENKYNS, 1976; JENKYNS, 1980; HART & BIGG, 1981; BURNHILL & RAMSAY, 1981; ARTHUR & PREMOLI SILVA, 1982; ROBASZYNSKI et al., 1994; PREMOLI SILVA et al., 1995; KUHNT et al., 1986; AMEDRO & ROBASZYNSKI, 1999). Only few data are available from the eastern part of the Peri-Tethys area. This discussion of the C/T boundary is based on new field observations in south-western Crimea, where Cenomanian and Turonian successions are widespread and well exposed. This basin had a wide connection with Tethys and the boreal seas of the Russian Platform and has great significance for the interpretation of the palaeogeography around the C/T boundary. The Upper Cretaceous strata of the Crimea were already studied in the nineteenth century (see MURATOV, 1973 for a detailed review). WEBER & MALYSHEFF (1923) gave the first biostratigraphic background, and their scheme was supplemented and/or revised in many subsequent papers (KELLER, 1951; MOSKVIN, 1959; MASLAKOVA & VOLOSHINA, 1969; MURATOV, 1973; MASLAKOVA, 1978 and many others). An extensive account of the stratigraphy of the lower part of the Upper Cretaceous in this area was presented by NAIDIN & ALEKSEEV (1981), NAIDIN et al. (1981), ALEKSEEV (1989), KOPAEVICH & WALASZCZYK (1990), NIKISHIN et al. (1993, 1998), ALEKSEEV et al. (1997), KUZMITCHEVA (2000). Data on isotope stratigraphy and sequence stratigraphy have been published by NAIDIN & KIYASHKO (1994a, b) and GALE et al. (1999).

This study compares the sedimentation and the distribution of foraminifera at the C/T boundary in five selected sections, ranging from relatively shallow marine deposits in the north to deeper environments in the south. The study area constitutes a part of the mountainous Crimea. The Crimean Mountains occupy the southern part of the Peninsula (Fig. 1A) and consist of three ranges, from south to north, as follows: the Major, the Second (Piedmont) and the Outer Ridges. They form an anticlinorium-like structure with Triassic and Jurassic deposits of the Major Ridge exposed along its axial part, and the Cretaceous and Palaeogene deposits of the Piedmont and the Outer Ridges forming its northern limb.

Upper Cretaceous deposits of the Piedmont Ridge occur in a narrow belt, stretching approximately SW-NE from the environs of Sevastopol to Feodosiya (Fig. 1A,B). These deposits dip slightly to the north and northwest, with a maximum thickness of about 450–480 m, and farther north occur in the subsurface of the Crimean Plain (Platform). The Cenomanian – Lower Turonian deposits form one mapping unit, the Belogorskaya Formation (K2bg in Fig. 1B). The C/T boundary is clearly marked by the appearance of the black shale facies or by a stratigraphic gap, marked by a hardground horizon.

2. MATERIAL AND METHODS

The study area is located in the Crimea Highland, in the Second Piedmont Ridge, 30 km south of Simferopol, between the rivers Bodrak and Kacha (Figs. 1B, 7). 90 samples were taken at 0.2 m to 1.0 m intervals from the Mender, Kyzyl-Chygyr, Selbukhra, Aksudere and Belaya sections (Figs. 2–4, 7). The foraminifera were extracted from relatively soft

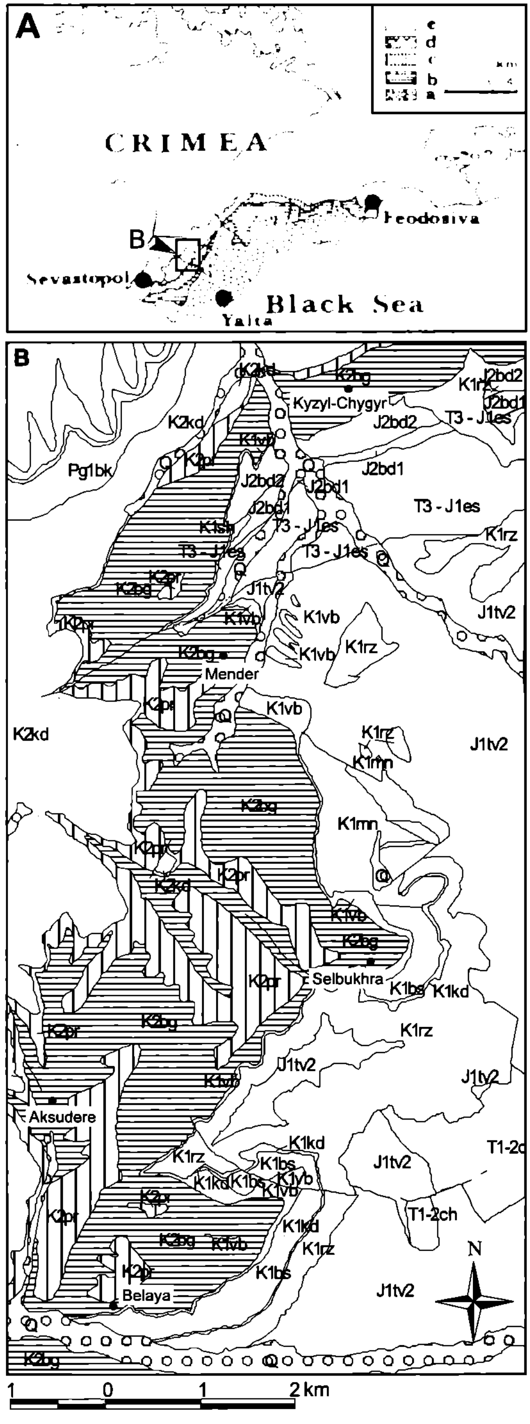

Fig. 1:
A – Geological sketch map of the Crimea Peninsula (after KOPAEVICH & WALASZCZYK, 1990); a – Upper Triassic – Jurassic; b – Lower Cretaceous; c – Upper Cretaceous; d – Palaeogene; e – Neogene;
B – geological map of the studied area and location of sections
Q – Quaternary system;
Palaeogene – Pg1bk, Pg1kc, Pg1bh, Pg2sm formations;
Upper Cretaceous: Kudrinskaia Formation (Santonian–Campanian–Maastrichtian)- K2kd; Prokhladnenskaya Formation (Upper Turonian-Lower Coniacian) – K2pr; Belogorskaya Formation (Cenomanian-Lower Turonian) – K2bg; Lower Cretaceous – K1rz, K1kd, K1bs, K1mn, K1vb formations
Triassic-Jurassic -J1tv2, J1tv1, T1-2ch – Cimmerian basement

marls with standard micropalaeontological techniques by soaking dry samples of 150 g in sodium bicarbonate and washing them through a 0.15 mm screen. Relatively hard samples were disintegrated through melting crushed rock samples with sodium sulphate.

The foraminifera were identified under a light microscope (LEICA MZ12). SEM photographs of the foraminifers were taken using an XL 30 ESEM (Philips) in the Institute Royal des Sciences Naturelles (Brussels). The planktonic foraminiferal assemblages are illustrated on plates 1–3. The preservation of the foraminifera is good in the soft chalky marls and moderate to poor in the harder rocks. Planktonic foraminiferal identifications are based on commonly used taxonomy and illustrations (Loeblich & Tappan, 1988; Pessagno, 1967; Robaszynski et al., 1979, 1984, 1994, 1995). Identification

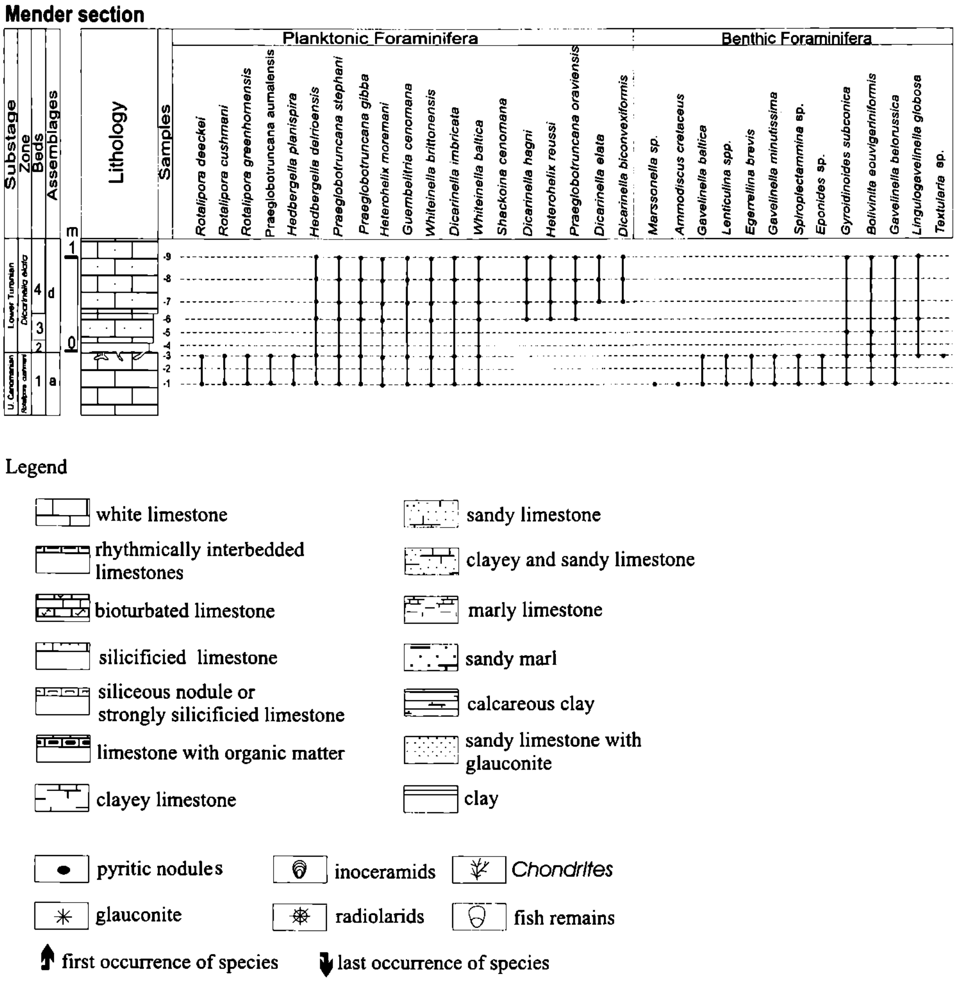

Fig. 2: Mender section and stratigraphic distribution of the most important Foraminifers.

of some benthic Foraminifera are based mainly on Vassilenko (1961), Hart (in Jarvis et al., 1988). Dr. Annie V. Dhondt (L'Institut Royal des Sciences Naturelles) and Dr. E. Yu Baraboshkin (Moscow State University) contributed the identification of an inoceramid. Radiolaria and nannofossils were studied by L.G. Bragina (Geological Institute, Russian Academy of Sciences, Moscow) and M. N. Ovechkina (Palaeontological Institute, Russian Academy of Sciences, Moscow).

3. GEOLOGICAL SETTING

The Upper Cenomanian – Lower Turonian interval in southwestern Crimea currently constitutes the best-documented carbonate succession in the whole central part of the Peri-Tethys. The Cenomanian of southwestern Crimea comprises 50–70 m of marly chalks, chalky marls and limestone, which show an overall decrease in the clay components towards the top. The boundary of the Middle and Upper Cenomanian cannot be fixed precisely. The Middle Cenomanian is represented by rhythmically bedded chalk-marl alternations; the Upper Cenomanian is composed mainly of white chalks containing a 0.5–1.0 m thick marl layer where the rhythmicity is obscured by bioturbation (bed 1 on Figures 2–4). This succession is terminated by an erosional surface in all examined sections (Alekseev et al., 1997, Gale et al., 1999).

Selbukhra section

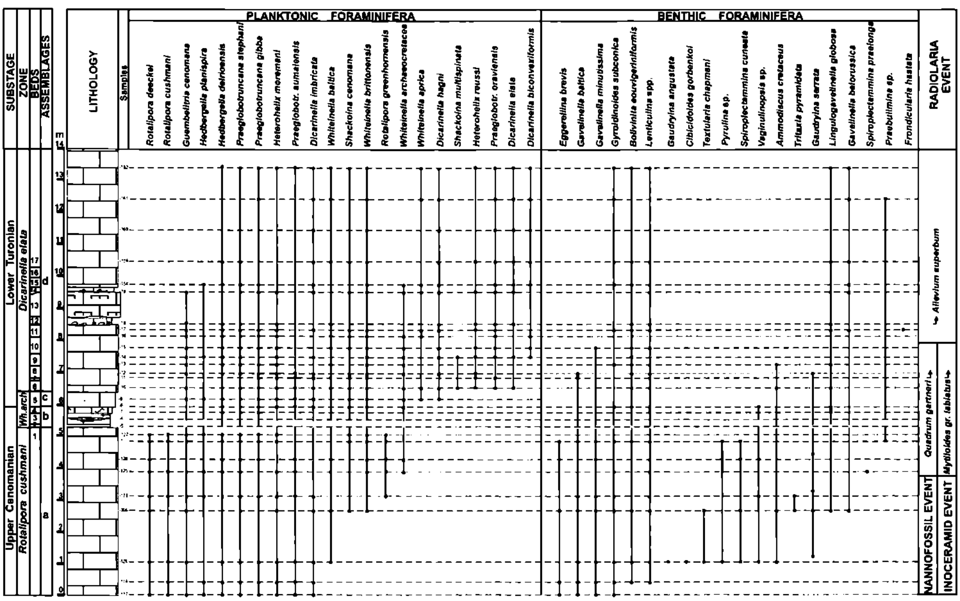

Fig. 3: Selbukhra section and stratigraphic distribution of the most important Foraminifers. Legend see Fig. 2.

3.1. Mender and Kyzyl-Chygyr sections

There is considerable lateral variation in the succession immediately overlying the Late Cenomanian erosion surface in Crimea. In the Mender and Kyzyl-Chygyr sections, a highly condensed glauconitic marl rests directly on the erosion surface and is overlain by flaggy chalks containing siliceous nodules (Fig 2).

3.2. Selbukhra section

The erosion surface is overlain here by 1 m of sandy and silty chalks with intraclasts and chalk conglomerates, debris flows, glauconites and dark-grey organic-rich lenses (beds 2–5 on Fig.3). This interval includes several levels of microfaults (GALE et al., 1999, p. 76).

3.3. Aksudere and Belaya sections

At Aksudere section the erosion surface is overlain by 0.6 m of brown clays and 1.5 m of organic-rich, brown and dark-grey variably laminated marls with silt-grade quartz, glauconite and volcanic material. These marls contain fish scales and *Chondrites*. Aksudere is analogous to the Belaya Mountain section, where brown and dark-grey clays and marls (4 m) are also represented (beds 2–8 on Fig.4). This interval is a black shale facies and a local representation of the Late Cenomanian Oceanic Anoxic Event (JENKYNS, 1980).

The black shale is overlain by a succession of thinly bedded, grey marls passing gradually upwards into light grey marls and marly limestone of Early Turonian age (Fig. 2–4). Pale and dark coloured flints start to occur in the upper half of this succession. The lower part of the marls contains two discontinuous surfaces in the Aksudere section (KOPAEVICH & WALASZCZYK, 1990). The succession contains two layers of strongly siliceous marls in the Selbukhra Mountain section (Fig.3).

4. MACROFOSSILS

The whole Upper Cenomanian interval contains only a few remains of macrofauna. A single specimen of the inoceramid bivalve *Mytiloides* cf. *labiatus* (SCHLOTHEIM) was found in a sandy chalk in the Selbukhra section (bed 5 on Fig. 3). This occurrence is used here to define the base of the Turonian in this area. The marls and marls with flint units belong to the *Mytiloides labiatus* Zone (s.l.) and the *Mytiloides hercynicus* Zone (NAIDIN et al., 1981; ALEKSEEV, 1989; KOPAEVICH & WALASZCZYK, 1990). Almost all of the inoceramid species of the Crimea belong to the North European faunal Province (*sensu* KAUFFMAN, 1976; TRÖGER, 1989) or to the European Palaeobiogeographical Area (sensu NAIDIN, 1969).

5. FORAMINIFERA

Detailed analysis of published foraminiferal records from C/T boundary successions at other localities showed no major differences between our records from the Crimea and, for example, those presented for similar sequences in the Anglo-Paris Basin, other sections of the North European Province and the European – Mediterranean area.

Assemblage "**a**" (bed 1 in Figs. 2–4) includes *Rotalipora cushmani* (MORROW), *R. deeckei* (FRANKE), *Praeglobotruncana aumalensis* (SIGAL), *P. gibba* KLAUS, *P. stephani* (GANDOLFI), *Whiteinella brittonensis* (LOEBLICH & TAPPAN), *Hedbergella planispira* (TAPPAN), *H. delrioensis* (CARSEY), *Globigerinelloides bentonensis* (MORROW), *Heterohelix moremani* (CUSHMAN), *Shackoina cenomana* (SHACKO) and *Guembelitria cenomana* (KELLER). Relatively good preservation of all species, high taxonomic diversity and a high number of specimens of every taxon characterize this assemblage. This interval is situated in the lower part of all of the five sections.

Assemblage "**b**" is present in beds 2–4 of the Selbukhra section and in beds 2–8 of the Aksudere and Belaya sections (Figs. 3, 4). The genus *Rotalipora* disappears here and the diversity of all of the foraminiferal species decreases sharply. The main part of this assemblage is made up only of small-size planktonic species, namely *Hedbergella planispira, H. delrioensis, Heterohelix moremani, Guembelitria cenomana, Globigerinelloides bentonensis,* and partly *Shackoina cenomana*. Foraminifera are completely absent in several samples of the black shale sediments (see Fig. 4). Assemblage "b" is absent in the Mender and Kyzyl-Chygyr sections. The preservation of species is poor and the number of specimens is very low.

Assemblage "**c**" is present in the Selbukhra, Aksudere and Belaya sections. It consists of more diversified associations of planktonic foraminifera with *Praeglobotruncana aumalensis, P. gibba, Dicarinella imbricata* (MORNOD), *Hedbergella planispira, H. delrioensis, Guembilitria cenomana, Globigerinelloides bentonensis* and *Shackoina cenom-*

Belaya section

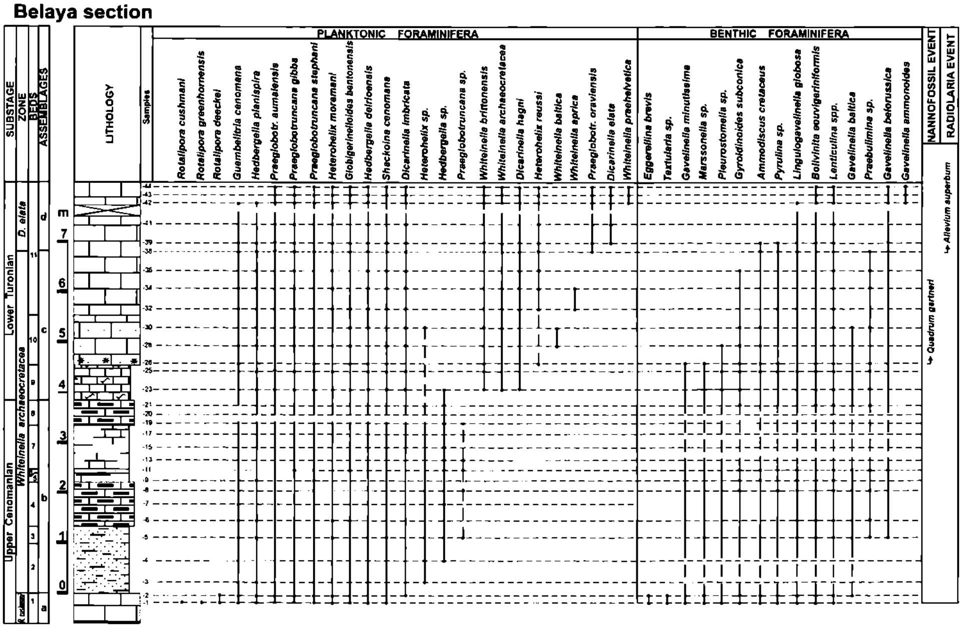

Fig. 4: Belaya section and stratigraphic distribution of the most important Foraminifers. Legend see Fig. 2.

ana. The species *Dicarinella hagni* (SCHEIBNEROVA), *Whiteinella archaeocretacea* PESSAGNO, *W. aprica* (LOEBLICH & TAPPAN) and *W. baltica* (DOUGLAS & RANKIN) first appear in this interval. The preservation of species is better than in the previous assemblage and the number of specimens is relatively high. This assemblage is absent in the Mender and Kyzyl-Chygyr sections.

The planktonic foraminiferal **assemblage "d"** consists of a very diversified association, in which keeled and large taxa predominate. *Dicarinella elata* (LAMOLDA), *Praeglobotruncana oraviensis* SCHEIBNEROVA and *Whiteinella praehelvetica* (TRUJILLO) first appear in this interval, together with *Dicarinella hagni* (SCHEIBNEROVA), *D. imbricata* (MORNOD) and all of the species of the previous assemblage. This assemblage is present in all of the studied sections.

The benthic foraminifera are represented by calcareous and agglutinated species. The abundance and specific diversity of the benthic foraminifera decrease sharply in the black shale interval and increase continuously above it. The black shale assemblages are characterized by a few dominant species – *Tritaxia pyramidata* (REUSS), *Lenticulina* spp. and *Praebulimina* sp. The first new species appear after the anoxic period in marls and marls with flints in all of the studied sections (KOPAEVICH, 1996).

6. CALCAREOUS NANNOFOSSILS, RADIOLARIA AND CALCISPHERA

The presence of *Microrhabdulus decoratus* DEFLANDRE and the appearance of *Quadrum gartneri* PRINS & PERCH-NIELSEN (calcareous nannofossils) suggest that the boundary between zones CC 10 and CC 11 lies just above the black shale level in the Selbukhra, Aksudere and Belaya sections (Fig. 3–6). The radiolaria *Alevium superbum* (SQUINQBOL) and *Crucella cachensis* PESSAGNO, which are markers of the Lower Turonian, were found higher in sample 18 of the Selbukhra section (Fig.3) and in sample 36 of the Belaya section (Fig. 4). Several beds with "blooms" of calcispheres are present in the black shale of the Aksudere section.

7. FORAMINIFERAL ZONATION

For age determination we used the planktonic foraminiferal zonation of the low and middle latitude Cretaceous area (ROBASZYNSKI & CARON, 1995). Part of this zonation – at least from uppermost Albian to Upper Turonian is also applicable in the boreal realm. We can identify the top of the *Rotalipora cushmani* Total range zone (assemblage "a"); the extinction of *Rotalipora* is the upper marker level of these biostratigraphic units. The genus *Rotalipora* disappears before the end of the Cenomanian, in the *Metoicoceras geslinianum* ammonite Zone in all of the Mediterranean area (MASLAKOVA, 1978; CARON, 1985; SLITER, 1989, PREMOLI SILVA & SLITER, 1995, ROBASZYNSKI & CARON, 1995).

The *Whiteinella archaeocretacea* Partial range Zone includes the interval from the last occurrence of *Rotalipora cushmani* to the first occurrence of *Helvetoglobotruncana helvetica* (assemblages "b" and "c" in Figs. 3,4). This zone commonly contains a low diversity assemblage related to the widespread deposition of organic-rich sediments. Assemblages in this interval typically consist only of unkeeled rare specimens of *Hed-*

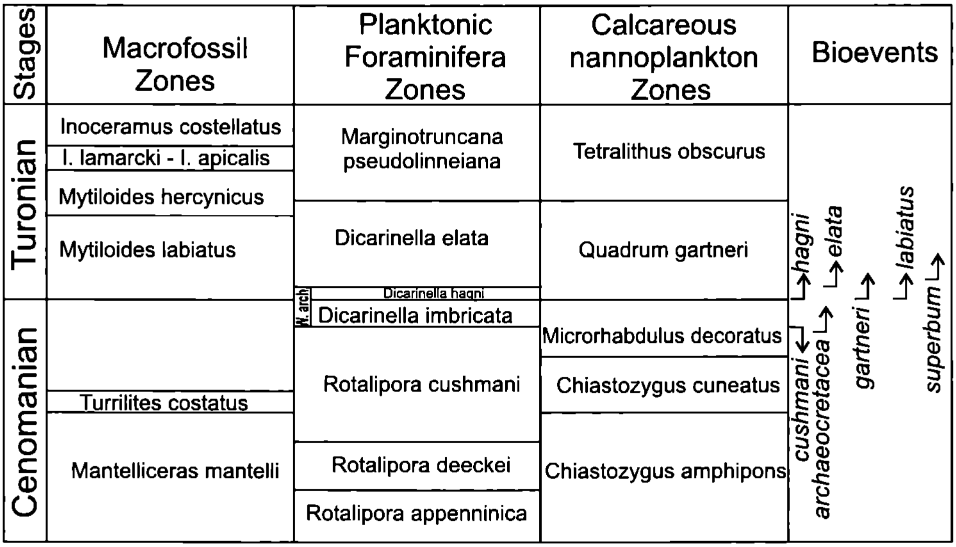

Fig. 5: Cenomanian-Turonian zonal subdivisions of south-western Crimea: macrofossils zones (KOPAEVICH & WALASZCZYK, 1990; NIKISHIN et al., 1993); calcareous nannofossil zones (NIKISHIN et al., 1993); planktonic foraminifera zones (NIKISHIN et al., 1993; C/T boundary interval according this paper); bioevents (this paper).

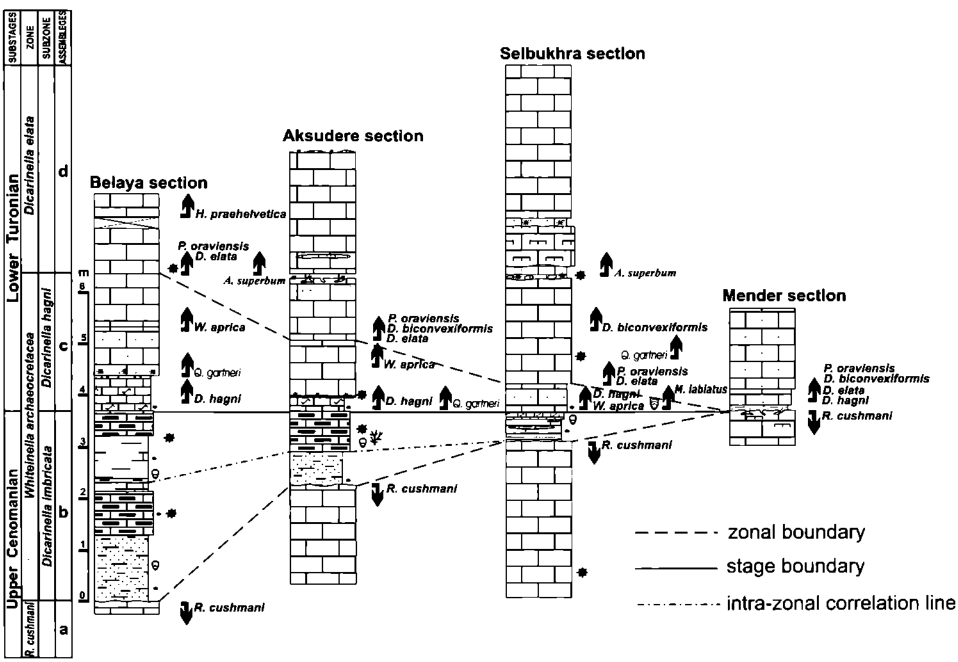

Fig. 6: Infrazonal correlation of the Upper-Cenomanian-Lower Turonian successions.

bergella, early *Whiteinella* and *Heterohelix*. The zonal species appears in the Crimea localities only in the upper half of the black shale interval, as in southeast England (see Figs. 4,5 and JARVIS et al., 1988).

The C/T boundary is situated within the *W. archaeocretacea* PRZ and its position can be recognized by the appearance of *Dicarinella hagni*. This species was recommended as index-species by several authors (SALAJ, 1996; ION, 1982; O'DOGHERTY, 1994; KOPAEVICH, 1996; TUR, 1996). This appearance correlates closely with the first appearance of *Quadrum gartneri* in the Selbukhra, Aksudere and Belaya sections (Figs 4, 5). We use *D. hagni* as the index-species of the upper subzone of the *W. archaeocretacea* Zone following ION (1982) and SALAJ (1996). The lower subzone takes the name *Dicarinella imbricata* subzone (Figs. 5, 6).

Unfortunately, the species *Helvetoglobotruncana helvetica* is absent in the Crimea localities, but *Dicarinella elata* serves as index-species for this interval. The presence of *Whiteinella praehelvetica* (TRUJILLO) and *Praeglobotruncana oraviensis* (SCHEIBNEROVA) is very typical for this assemblage.

8. GEOCHEMICAL DATA

The lower subzone of the *W. archaeocretacea* Zone – the *Dicarinella imbricata* Subzone – exactly corresponds to the Oceanic Anoxic Event 2, which is widely known at the C/T boundary (Schlanger & Jenkyns, 1976). The black shale has a relatively high TOC content up to 7.2%–8% in the Aksudere section and 2.37% in the Selbukhra section. High concentrations of biophile elements – Cu, Ni, Zn, V are found in this unit. This interval is also characterized by a positive shift in $\delta^{13}C$ of $+4^0/_{00}$ $-5^0/_{00}$ (Naidin & Kiyashko, 1994a, b). This shift coincides with global excursion of $\delta^{13}C$ at the C/T boundary (Schlanger & Jenkyns, 1976; Jenkyns, 1980; Hart & Bigg, 1981; Burnhill & Ramsay, 1981; Arthur & Premoli Silva, 1982; Kuhnt & Thurow, 1986; Kuhnt et al., 1986; Jarvis et al., 1988; Naidin & Kiyashko, 1994 a, b).

9. CORRELATIONS

The foraminiferal and calcareous nannofossil data confirm the zonal subdivisions of the C/T boundary interval (Fig. 5). The more detailed infrazonal correlations may be as following: 1 – the extinction of the genus *Rotalipora* is presented at all of the studied sections and coincides with the top of bed 1 (Fig. 6); 2 – a very poor foraminiferal assemblage exists in the lower part of the black shale with pyrite, fish scales and radiolarians; this interval is present only in the Belaya and Aksudere sections; 3 – nearly complete absence of foraminifera within the upper part of the black shale facies is associated with occurrence of *Chondrites*, a relatively high TOC content and a positive shift in $\delta^{13}C$; this interval is presented in the Belaya, Aksudere and Selbukhra sections. The interval of the *D. elata* Zone is present in all of the studied sections.

Thus the completeness of the sections increases from northeast to southwest in this area. It is well illustrated by the sections of Mender Mountain and Kyzyl-Chygyr Mountain, where the stratigraphic gap, confined to the hardground horizon, comprises

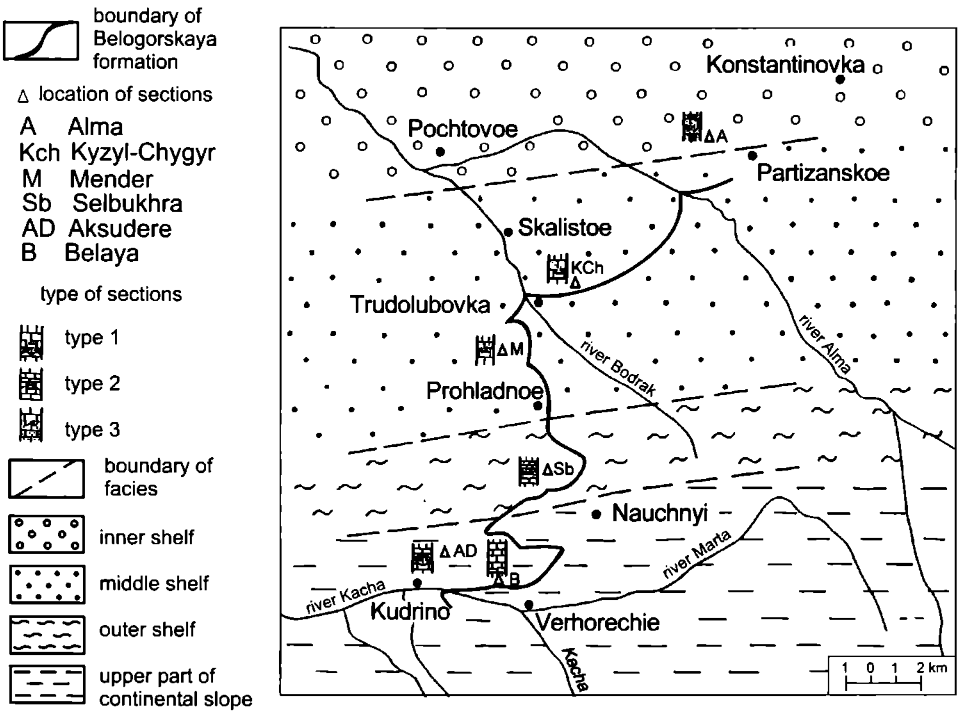

Fig. 7: Distribution of facies of Upper Cenomanian – Lower Turonian for Southwestern Crimea. Alma River area: Lower Turonian lies directly on Middle Cenomanian (shallowest part of area); Kyzyl-Chygyr and Mender mountains: interval with black shale is absent; Selbukhra section: only part of the black shale interval is present; Aksudere and Belaya sections: greatest water depth in the study area.

the whole of the *W. archaeocretacea* PRZ, including both subzones (Fig. 6, column 4). Even the more complete Aksudere and Belaya sections show a sharp erosion surface correlative with a so-called "sub-plenus erosion surface" in the Anglo-Paris Basin (see Gale et al., 1999, p. 76). The duration of the sub-plenus hiatus was longer in the Crimean sections than in the Anglo-Paris Basin (foraminiferal data). The interval of back shale facies with the presence of the last *Rotalipora* and of the first *Dicarinella hagni*, equating with beds 1–3 of the Plenus Marls Member of the Anglo-Paris Basin, is absent in all of the Crimean localities (Jarvis et al., 1988, their fig.6). Only the equivalents of beds 4–8 of the Plenus Marls Member exist in the Crimea sections.

10. FORAMINIFERAL DYNAMICS AND PALAEOGEOGRAPHY

The Late Cenomanian in the Crimean Cenomanian succession is characterized by different planktonic and benthonic foraminiferal assemblages with high planktonic/benthonic (P/B) ratios of 60–90% (below the erosion surface). Benthic diversity decreased in the lower part of the black shale. That led to the extinction of several benthonic taxa. The extinction of specialized taxa of the planktonic genus *Rotalipora* is typical of this interval. The early repopulation or survival phase may correspond to the *Dicarinella imbricata* Subzone. It is characterized by the presence of long-ranging primitive opportunists (*Hedbergella* spp., *Heterohelix* spp. and the praeglobotruncanids with an incipient keeled structure). The keeled forms gradually begin to dominate in the *Dicarinella hagni* Subzone, where both *Praeglobotruncana* and *Dicarinella* are present. Newly appeared large double-keeled morphotypes of the *D. hagni* group inhabited vacant ecological niches and became important elements in the assemblages. The early recovery phase took place during the *D. elata* Zone, where high diversity planktonic and benthonic assemblages, both keeled and unkeeled forms, occur.

The foraminiferal assemblages generally show the following evolutionary trends in the *Whiteinella archaeocretacea* Zone: 1– decrease in diversity; 2 – absence or depauperation of benthos; 3 – quantitative decrease of keeled forms, even to pure "globigerinid" and "heterochelicid" assemblages; 4 – individual species sometimes dominate considerably; 5 – strong increase in the radiolarian/planktonic foraminiferal ratio.

The typical mid-Cretaceous Tethyan faunas are characterized by a high diversity, dominance of keeled forms, large size tests and highly variable morphologies of species. In contrast, boreal faunas are uniform and small sized, low-diversity, non-keeled morphotypes are dominant (Weiss, 1982). Thus, the "globigerinid" and "heterochelicid" morphotypes and horizons with radiolarian and calcisphere "blooms" in the *W. archaeocretacea* Zone indicate the presence of relatively cold-temperate water-masses in the Crimean area. A similar situation existed in the western part of the Tethys area just above the base of the interval of the black shale (Salaj, 1980; Butt, 1982; Kuhnt & Thurow, 1986; Kuhnt et al., 1986). Such faunas are interpreted as indicators of coastal upwelling of cold oceanic water along the south Crimea margin. The existence of the black shale facies, the absence or depauperation of benthos together with increased TOC values

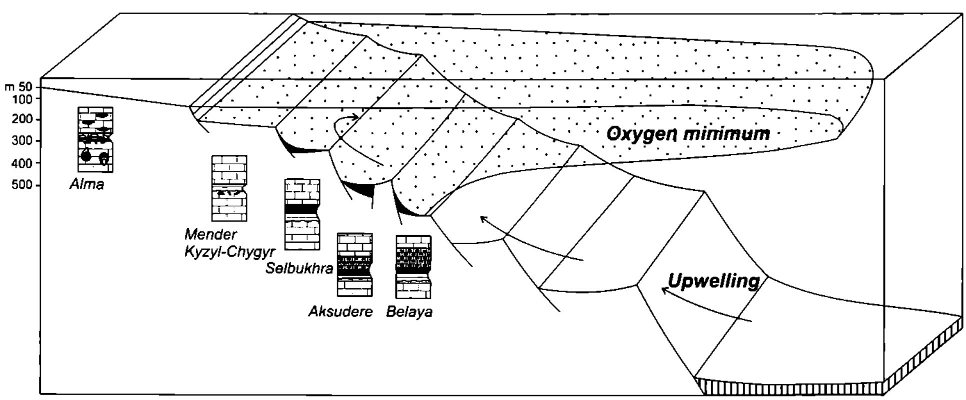

Fig. 8: Model of black shale sedimentation on the Crimea margin: there are hiatuses in the Alma, Kyzyl-Chygyr and Mender sections at the C/T boundary; the black shale were deposited in small deep depressions (small grabens or half-grabens).

suggest the existence of an oxygen-minimum zone and an increase in anaerobic bottom conditions (KUHNT et al., 1986; JARVIS et al., 1988).

11. TECTONIC HISTORY

The accumulation process of bituminous sediments in the southwestern Crimea took place simultaneously with the activation of geodynamic processes along the whole central part of the Black Sea – Great Caucasus basin margins (NIKISHIN et al., 1998; 2001). The Mid-Late Cretaceous opening of the Black Sea Basin and the formation of the continental slope of the passive margin caused significant changes in the water depth of the investigated area. The upper part of this continental margin was complicated by a series of small fault-bounded blocks on which successions with varying degrees of completeness were deposited (Fig.8). The sections of the Crimea described in this paper relate to small faults with small graben and halfgraben structures. Consequently, the distribution of Cenomanian black shale facies is lenticular without lateral continuity. Dark bituminous sediments were deposited in small deep depressions in the southern part of this area (Aksudere, Belaya). The shallower blocks are characterized by reduction of the *Whiteinella archaeocretacea* Zone (Selbukhra) or by a C/T resulting from the absence of this zone (Alma, Mender, Kyzyl-Chygyr). The hiatus increases towards the north of this area. Sediments with intensive sliding and slumping occur in the southern part (Belaya section, KUZMICHEVA, 2000), reflecting irregular tectonic subsidence.

12. CONCLUSIONS

The C/T facies distribution in the study area is shown on Fig. 7–8. The completeness of sections increases from north to south. The black shale interval and the lower part of the marls are absent in the Alma, Mender and Kyzyl-Chygyr sections and the distribution of C/T boundary facies reflects the shallowing from south to north. The local lenticular accumulations of dark bituminous sediments correlate with tectonic subsidence of the Crimea margin.

Cold-water planktonic foraminiferal faunas and high radiolarian/planktonic foraminiferal ratios can be explained by coastal upwelling (Fig. 8). The C/T boundary is accompanied by a carbone isotope signal, which is interpreted to result from the entrapment of organic matter in sediments (KUHNT et al., 1986). The concentration of some elements in sediments with high TOC and diagenetic H_2S generation, sometimes accompanied by the hydrosulphuric poisoning of bottom waters, had a negative effect on the benthic foraminifera (GAVRILOV & KOPAEVICH, 1996).

Acknowledgements: The authors are very grateful to A.S. Alekseev for numerous discussions, critical remarks and his help in the study. We are also grateful to A.M. Nikishin for stimulating discussions and his help during field work, as well as to all our colleagues from the Crimea Field Station, especially N.N. Kurdin, E.A. Voznesensky and E.N. Samarin. We greatly appreciate the help of F. Robaszynski for having given us a lot of useful comments about biostratigraphgical schemes and foraminiferal data. We would also like to thank A.V. Dhondt, Yu. O. Gavrilov, V.S. Vishnevskaia for fruitful discussions and very useful remarks. We thank Michele Caron, Sebastian

Lüning and Michael Wagreich for their insightful remarks. We thank also Julien Cilis and Wilfried Miseur from the Department of Palaeontology of the Royal Belgian Institute of Natural Sciences in Brussels for help of SEM photographs. A grant of the Belgian Academy of Science and the Moscow State University, and the «Integration» grant of the Russian Federal Program sponsored this study.

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Plate 1

Magnification x 130

a – spiral view, b – umbilical view, c – lateral view

Fig. 1a,b,c: *Rotalipora deeckei* (FRANKE), Selbukhra section, sample Sb1(1); *Rotalipora cushmani* Zone;

Fig. 2a,b,c: *Rotalipora greenhornensis* (MORROW), Selbukhra section, sample Sb126; *R. cushmani* Zone;

Fig. 3a,b,c: *Rotalipora cushmani* (MORROW), Mender section, sample M3; *R. cushmani* Zone;

Fig. 4a,b,c: *Praeglobotruncana stephani* (GANDOLFI), Selbukhra section, sample Sb12; *Dicarinella elata* Zone;

Fig. 5a,b,c: *Praeglobotruncana gibba* KLAUS, Selbukhra section, sample Sb10; *D. elata* Zone;

Fig. 6a,b,c: *Praeglobotruncana aumalensis* (SIGAL), Selbukhra section, sample Sb8; *Whiteinella archaeocretacea* Zone;

Fig. 7a,b,c: *Dicarinella* cf. *imbricata* (MORNOD), Mender section, sample M1; *R. cushmani* Zone;

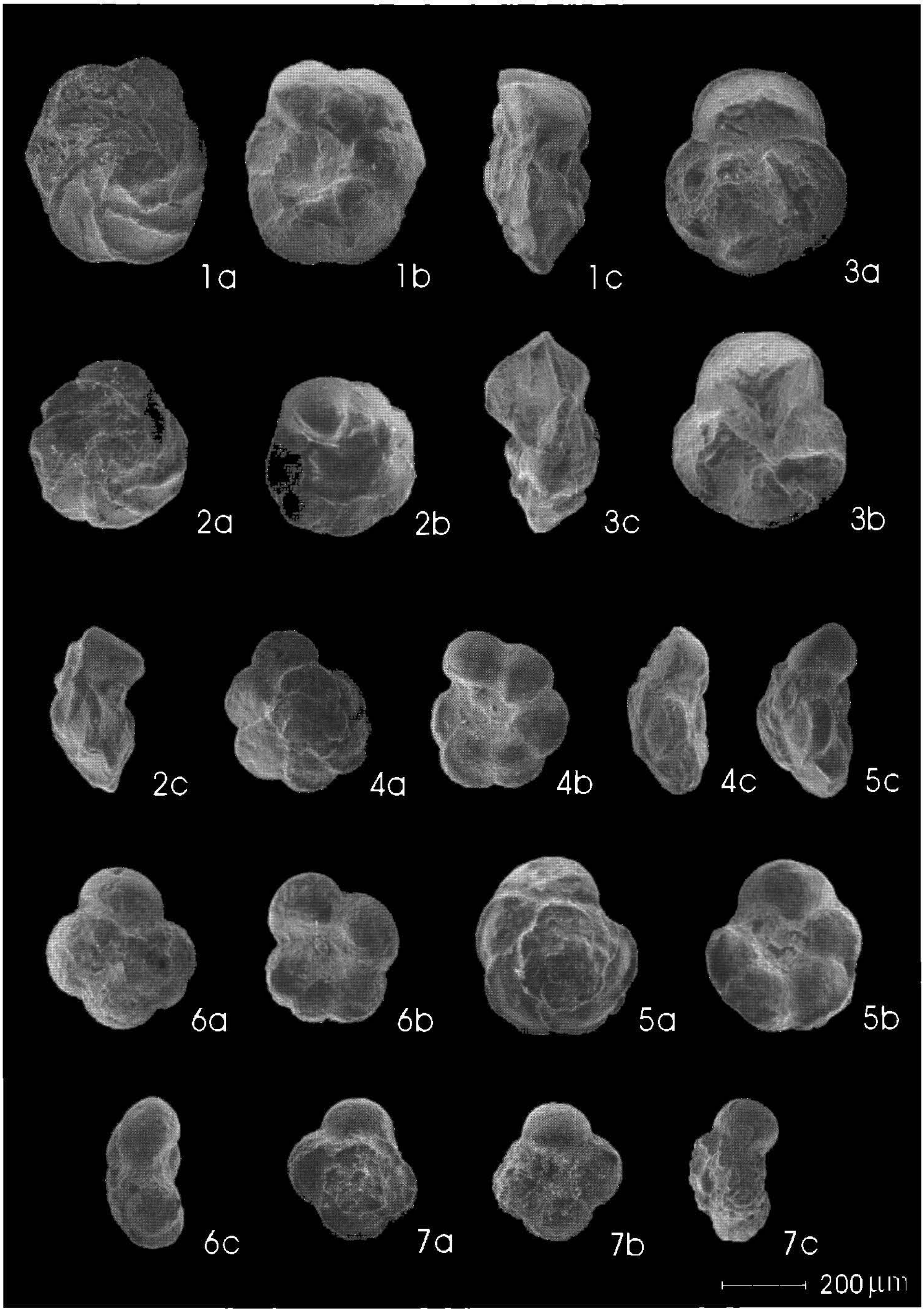
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Plate 2

Magnification x 130 for figs.1–4; x 120 for figs.5–7

a – spiral view, b – umbilical view, c – lateral view.

Fig. 1a,b,c: *Whiteinella archaeocretacea* PESSAGNO, Selbukhra section, sample Sb14; *Dicarinella elata* Zone;

Fig. 2a,b,c: *Whiteinella archaeocretacea* PESSAGNO, Selbukhra section, sample Sb16; *D. elata* Zone;

Fig. 3a,b,c: *Whiteinella brittonensis* (LOEBLICH & TAPPAN), Selbukhra section, sample Sb15; *D. elata* Zone;

Fig. 4a,b,c: *Hedbergella delrioensis* (CARSEY), Belaya section, sample B30; *Whiteinella archaeocretacea* Zone;

Fig. 5a,b,c: *Whiteinella baltica* DOUGLAS & RANKIN, Selbukhra section, sample Sb10; *D. elata* Zone;

Fig. 6a,b,c: *Whiteinella aprica* (LOEBLICH & TAPPAN), Selbukhra section, sample Sb10; *D. elata* Zone;

Fig. 7a,b,c: *Dicarinella imbricata* (MORNOD), Belaya section, sample B44; *D. elata* Zone

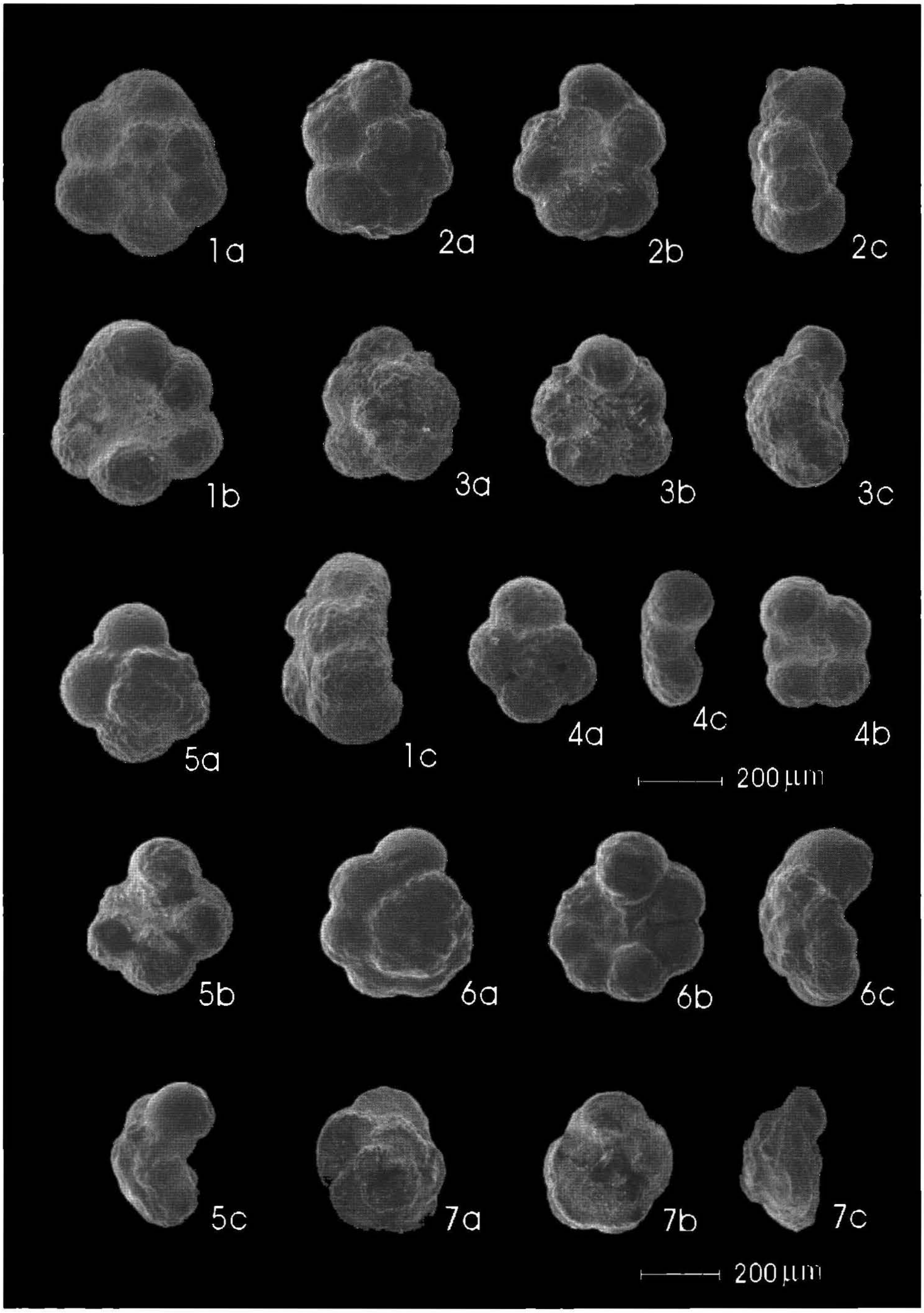
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Plate 3

Magnification x 120 for figs. 1–5; x 270 for figs.6–16

a – spiral view, b – umbilical view, c – lateral view

Fig. 1a,b,c: *Dicarinella hagni* (Scheibnerova), Belaya section, sample B43; *Dicarinella elata* Zone;

Fig. 2a,b,c: *Praeglobotruncana oraviensis* Scheibnerova, Selbukhra section, sample Sb15; *D. elata* Zone;

Fig. 3a,b,c: *Whiteinella praehelvetica* (Trujillo), Belaya section, sample B43; *D. elata* Zone;

Fig. 4a,b,c: *Dicarinella elata* (Lamolda), Selbukhra section, sample Sb19; *D. elata* Zone;

Fig. 5a,b,c: *Dicarinella biconvexiformis* Maslakova, Selbukhra section, sample Sb19; *D. elata* Zone;

Fig. 6a: *Shackoina multispinata* (Cushman & Wickenden), Mender section, sample M1; *Rotalipora cushmani* Zone;

Fig. 7c: *Shackoina multispinata* (Cushman & Wickenden), Selbukhra section, sample Sb11; *D. elata* Zone;

Fig. 8b: *Shackoina multispinata* (Cushman & Wickenden), section Mender, sample M1; *R. cushmani* Zone;

Fig. 9c: *Shackoina cenomana* (Shacko), Belaya section, sample B42; *D. elata* Zone;

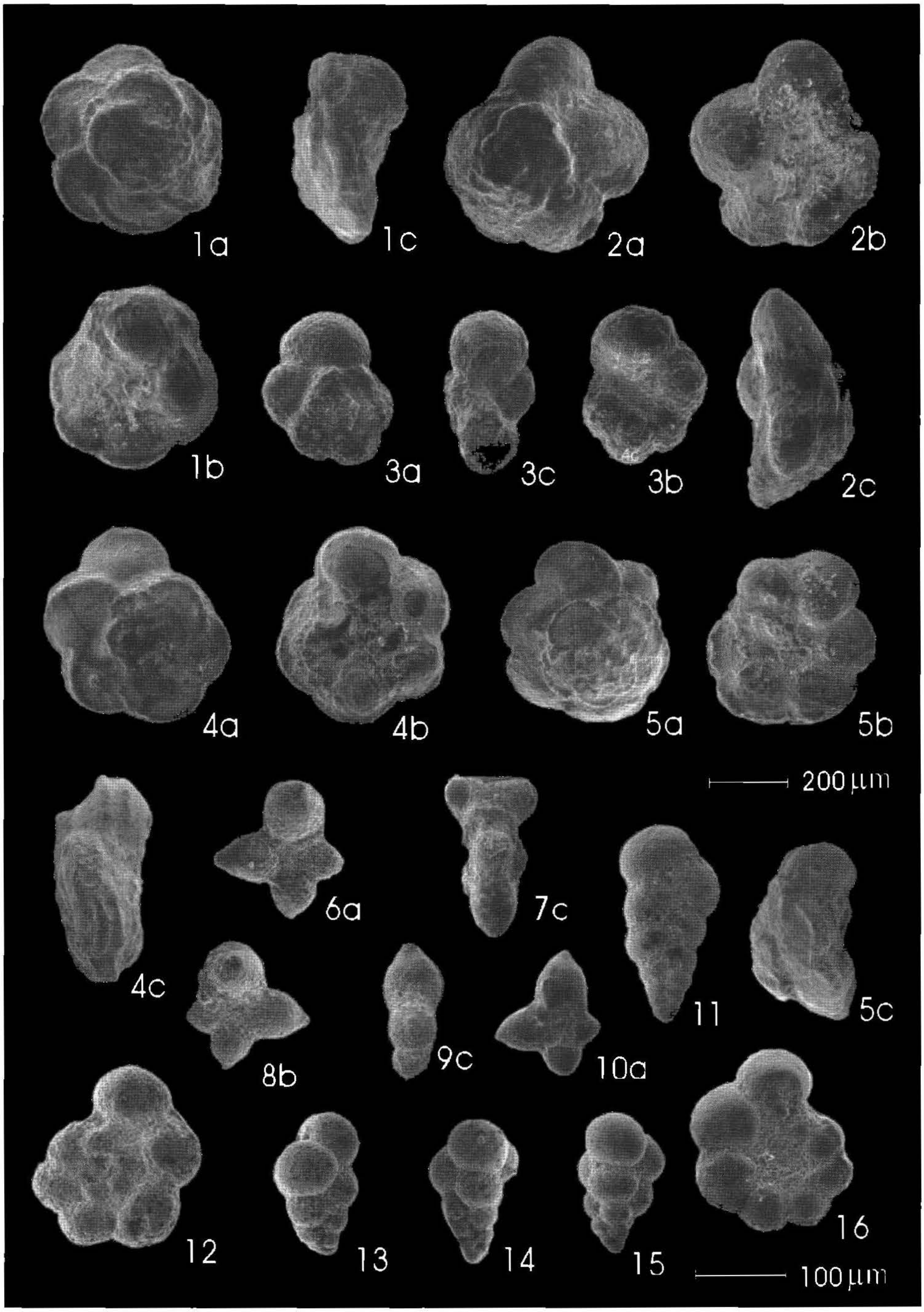
Fig. 10a: *Shackoina cenomana* (Shacko), Mender section, sample M2; *R. cushmani* Zone;

Fig. 11: *Heterohelix moremani* (Cushman), Mender section, sample M3, *R. cushmani* Zone;

Fig. 12: *Hedbergella planispira* (Tappan), Selbukhra section, sample Sb12; *D. elata* Zone;

Fig. 13, 14, 15: *Guembelitria cenomana* Keller, Mender section, sample M2; *R. cushmani* Zone;1

Fig. 16: *Globigerinelloides bentonensis*(Morrow), Mender section, sample M1; *R. cushmani* Zone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