BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE

BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN

SCIENCES DE LA TERRE
AARDWETENSCHAPPEN
VOL. 69 – SUPPLEMENT - A

D.P. NAIDIN FESTSCHRIFT
(INTAS 94 - 1414)
edited by A. V. Dhondt and A. S. Alekseev

BRUXELLES 1999 BRUSSEL

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La rédaction remercie pour lecture critique de manuscrits:
De redactie dankt volgende reviewers voor medewerking aan dit volume:
For this volume the following reviewers are gratefully acknowledged:

A. S ALEKSEEV (Moscow), S. K. DONOVAN (London), A. S. GALE (London), R. GUIRAUD (Montpellier), J. HARDENBOL (Houston), W. HAY (Kiel), H. HESS (Binningen), Ph. HOEDEMAEKER (Leiden), Ann HOLBOURN (London), V. E. KHAIN (Moscow), J. KLEIN (Amsterdam), H. KLINGER (Cape Town), W. KUHNT (Kiel), Hedi OBERHÄNSLI (Potsdam), H. G. OWEN (London), Isabella PREMOLI SILVA (Milano), F. ROBASZYNSKI (Mons), E. STEURBAUT (Brussels)

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BULLETIN
VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN
AARDWETENSCHAPPEN

Vol. 69 - 1999 - Supplement - A ISSN 0374-6291

Publié, verschenen, *published*: 15.IX.1999

Rue Vautier 29
B-1000 Bruxelles, Belgique

Vautierstraat 29
B-1000 Brussel, België

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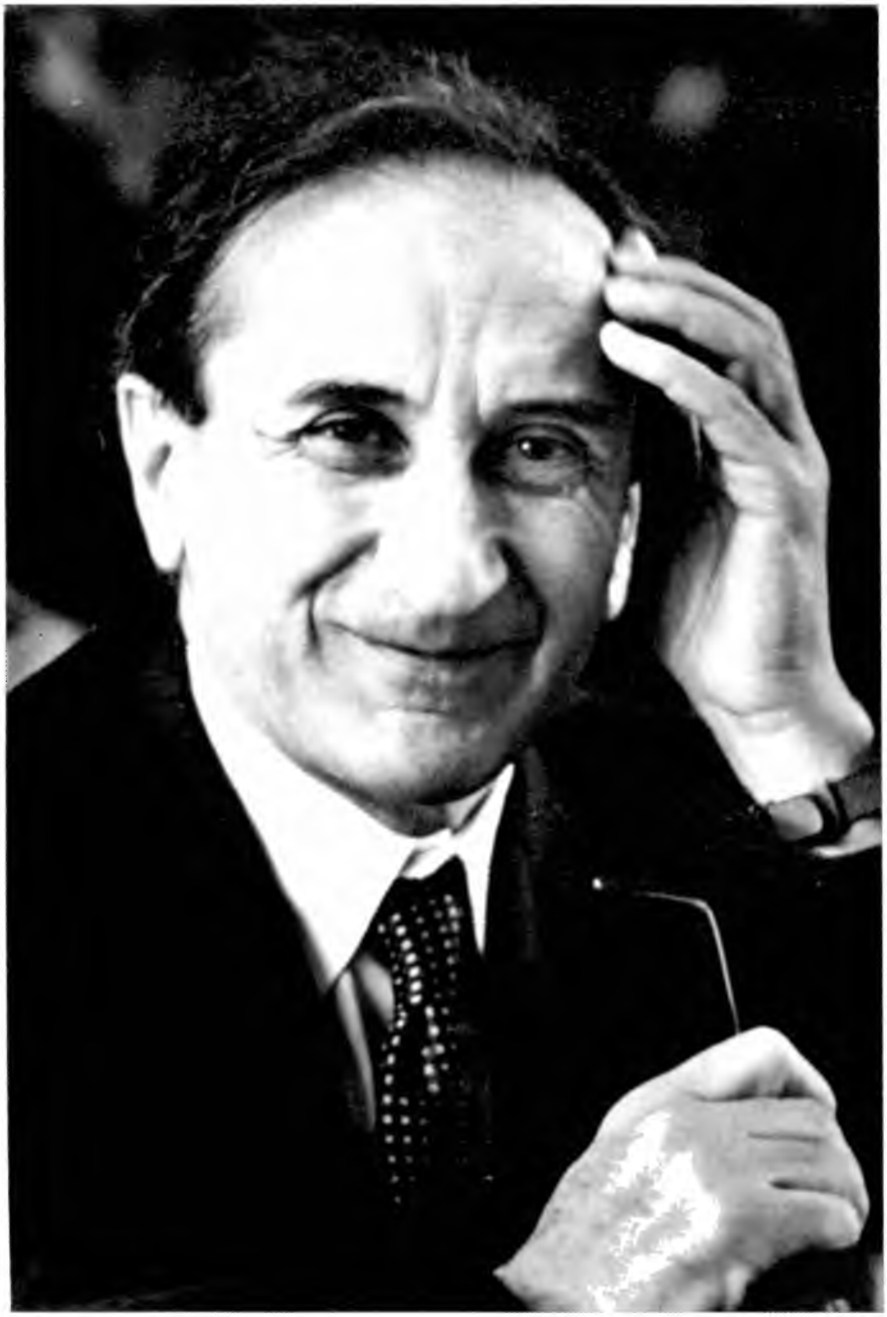

D. P. NAIDIN

Preface

It is a well known fact that geology in general, and palaeontology and stratigraphy in particular, are very international research topics. All of us, at one time or another, need to see material or sections already described by other colleagues. For research on Cretaceous strata, sections and faunas from the former USSR always were of extreme importance — directly related to the vast expanse of Cretaceous outcrops in the largest country in the world.

For many years the western scientific world considered that it was extremely difficult — not to say impossible — to make contact with colleagues, to study sections or collections in the USSR.

For western European Cretaceous workers the breakthrough came in the seventies. In 1976 a few western Cretaceous specialists met M. A. Pergament in Dresden; in 1977, in Lawrence, Kansas, similarly D. P. Naidin was introduced "in person" to some of us; in 1978 at the Münster Cretaceous meeting 10 (!) Cretaceous workers from the USSR, among them D. P. Naidin, M. A. Pergament, N. I. Shulgina and V. A. Zakharov, were present. After the Münster meeting, A. V. Dhondt decided to apply for a grant to study type collections of Cretaceous bivalves in the USSR. material. In 1980 and 1981-1982 she spent altogether 20 weeks in the USSR. From then onwards contacts with colleagues from different parts of the former USSR were self-evident, and she worked especially with specialists on Upper Cretaceous strata centred around D. P. Naidin at Moscow University.

Alexander S. Alekseev worked under D. P. Naidin's supervision from 1967 onwards. Sitting in D. P. Naidin's office at the MGU he met many foreign visitors both from eastern and western European countries — a.o. W. K. Christensen, Annie V. Dhondt, R. Marcinowski, K. A. Troeger. D. P. Naidin introduced into the Former Soviet Union many new developments in palaeontology and stratigraphy; these ideas were propagated by him through personal contacts and through numerous publications in Russian.

In 1993 between the MGU and the Belgian Institute of Natural Sciences we decided to try our luck and applied for a grant from the newly formed INTAS programme with a proposal entitled:
Bio-events at the K/T boundary on the southern margin of the white chalk sea - palaeobiology, palaeobiogeography, sequence stratigraphy, geochemistry and geochronology.

This project was conceived to include research on the uppermost Cretaceous and the K/T boundary in Mangyshlak (Kazakhstan), the Crimea (the Ukraine) and around Maastricht, by scientists from the former USSR and from western Europe. Our aim was to compare these outcrops and make the very important results obtained by D. P. Naidin and his group known to the western scientific world through publications in English. The main activities in the context of INTAS 94-1414 which officially run from November 1995 to March 1998 were:

- the first excursion with participation of western scientists to the Upper Cretaceous outcrops on Mangyshlak (May 1994);
- participation in the "Second International Symposium on Cretaceous Stage Bounndaries" in Brussels (September 1995);
- meeting at "Polygon" (geological fieldcamp of Moscow University in the Crimea) in June 1996 and June 1997;
- final scientific meeting of INTAS 94/1414 in the Geological Faculty of Moscow University (March 1998) with presentation of results;
- a LEICA-WILD MZ 12 binocular microscope was bought with our grant money, and installed in the Department of Historical and Regional Geology of the Geological Faculty of Moscow University;

We decided to conclude the project with a kind of festschrift honouring Prof. D. P. Naidin — at the occasion of his 80'th birthday. Without the extensive contribution to Cretaceous science made by D. P. Naidin our project would not have been possible. This is better explained in Jake Hancock's contribution on D. P. Naidin in this volume. The other papers and reports included in this volume, were mainly written in connection with, or as a direct result of the INTAS project. The volume includes papers on the Upper

Cretaceous and on the K/T boundary mainly in Crimea, Mangyshlak and Maastricht, but also on the Saratov region. Palaeontological aspects (on Ammonites, Bivalves, Echinoderms, Shark Teeth), biostratigraphy (on nannoplankton, Foraminifera, belemnites), sedimentology (rhythms and cycles), sequence stratigraphy, and tectonics are discussed.

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Brussels, April 15, 1999

Acknowledgements

First and foremost we would like to thank Prof. D. P. Naidin — for the continuous help he has given and still gives to Cretaceous scientists everywhere — near him in Moscow University, further afield in Russia, and wherever possible abroad. All through the years we have known him, he was always prepared to share his knowledge and experience, collections, books and time with colleagues and students near and far.

Secondly, our sincere thanks to the INTAS programme. It made possible a very interesting collaboration between scientists and our group really benefitted from it. We are especially grateful to Gerard den Ouden — for being ever ready to understand and help out when unexpected problems arose.

Many colleagues and friends participated over the years with advice and practical help in aspects of our programme. We cannot name them all, but would like to mention especially Dirk Anne, Hugo De Potter, Alexandra Egorova, Jacques Godefroid, Jake Hancock, John Jagt, Nikolay Kurdin, Anatoly Nikishin and Etienne Steurbaut.

Finally, at Moscow University, we are much indebted to Prof. B. A. Sokolov, Dean of the Geological Faculty, and to Academician Prof. E. E. Milanovsky, Head of the Department of Historical and regional Geology for making our collaboration possible; at the Royal Belgian Institute of Natural Sciences we are very grateful to Dr. D. Cahen, Director, and to Prof. P. Bultynck, Head of the Department of Palaeontology, for unstinting material and moral assistance.

Annie V. Dhondt and Aleksandr S. Alekseev

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 7-13, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 7-13, 1999

The contributions of D.P. Naidin to the study of the Cretaceous system

by Jake M. HANCOCK

Abstract

Dmitri Pavlovich Naidin has advanced our knowledge of the Upper Cretaceous in his studies of belemnites, biostratigraphy, palaeogeography, the K/T boundary, geochemistry and isotope studies. For the world at large his most important contribution has been his leadership in Russia which he has used to build and maintain geological contacts between the eastern and western political blocks.

Key-words: K/T boundary, belemnites, stratigraphy, palaeogeography, palaeotemperatures, eustasy, international relations.

Résumé

Dmitri Pavlovich Naidin a fait progresser notre connaissance du Crétacé supérieur par ses études concernant les bélemnites, la biostratigraphie, la paléogéographie, la limite K/T, la géochimie et les isotopes. A l'échelle mondiale, sa contribution la plus importante fut son leadership en Russie qu'il a mis à profit pour maintenir des contacts géologiques entre les groupes politiques de l'est et de l'ouest.

Mots-clefs: transition K/T, bélemnites, stratigraphie, paléogéographie, paléotemperatures, eustatisme, relations internationales.

Резюме

Работы Дмитрия Павловича Найдина в таких областях как белемниты, биостратиграфия, палеогеография, граница К/Т, геохимия и изотопы, способствовали усовершенствованию наших знаний о Верхнем меле. В Росиии, Дмитрий Павлович использовал свое широкое влияние в целях поддержания сотрудничества политических групп Запада и Востока в области геологии, что, несомненно, является его главным вкладом на мировом уровне.

Ключевые слова: граница К/Т, белемниты, стратиграфия, палеогеография, палеотемпературы, глобальный уровень моря.

Cretaceous sediments are spread over enormous areas of the Russian Federation and neighbouring countries (see fig. 4 in Naidin *et al.*, 1986). It is hardly surprising that a number of Russian geologists have been famous for their studies of Cretaceous rocks; Archangelsky and Bushinsky come immediately to mind. In the second half of the 20th century the most widely known name in the western countries has been Dmitri Naidin because of the exceptionally broad range of his publications which impinge on palaeontology, biostratigraphy, regional geology, sea-level changes and isotope geochemistry.

Background and early days

Dmitri Naidin was born on 28 January 1919 at Kremenchug on the Dnieper in the Ukraine, some 250 km south-east of Kiev. His father was a respected expert on fertilisers who worked at an agricultural institute in Kiev. In addition to the usual elementary education in the USSR, the young Dmitri was given private lessons in German, regarded in eastern Europe as the cultural language of science.

When Dmitri was about 12 his family moved to Moscow where his father became a senior research scientist at the All Soviet Institute of Fertilisers, Agricultural Techniques and Chemistry. Dmitri finished at secondary school in 1937 and started as a student in the Geology faculty at the Institute of Geological Prospecting in Moscow (MGRI), graduating in 1941 as an engineering geologist, specialising in geological mapping and prospecting. For a few months he worked in the Geological Survey of the Tadzhik Soviet Republic, a mountainous region to the east of Samarkand.

On 22 June 1941 Germany invaded the USSR. In March 1942 Dmitri was conscripted into the army. Until 1943 he trained at the Voronesh Military School of communications, graduating as a junior officer. He served as the commanding officer of communication sections of anti-aircraft units until being demobilised in February 1946 with the rank of "starshiy leitenant" (Senior Lieutenant).

Geological career in outline

With the end of the Great Patriotic War, Naidin became head of the Lvov section of the Carpathian expedition in

1946, under the direction of Professor A.A. Bogdanov. From 1949 to 1951 he was assistant to Bogdanov at MGRI (Moscow Geological Prospecting Institute). During this time he obtained his Ph.D. on "Upper Cretaceous deposits of the SW part of the Russian Platform".

When Bogdanov moved from MGRI to MGU (Moscow State University, also known as the Lomonosov University) in 1951, Naidin moved with him as his assistant. In 1952 Naidin published his first major paper on belemnite taxonomy and stratigraphy (see below). He became a "docent" (lecturer) at the university in 1953. He was awarded a higher doctorate in 1965, and in 1966 became a Professor at MGU where he was employed for the remainder of his career and continues to play an active role in research.

In addition to many prestigious posts in Russia, e.g. editor and member of Council of the Moscow Society of Naturalists (MOIP) which awarded him their principal prize in 1973, Naidin has been a major participant in the International Geological Correlation Programme, and from 1975-1984 was the only Voting Member from the USSR on the International Subcommission of Cretaceous Stratigraphy. These international appointments have been important vehicles for Naidin's contacts with geologists outside the USSR.

Belemnite research

Naidin's early work was on belemnites and their stratigraphy. In his 1952 monograph he attempted a comprehensive survey of all the Upper Cretaceous belemnites of the western Ukraine, and their inter-relations, largely based on the succession in the Opolie area of the Dnestr valley, north-north-west of Ivano-Frankovsk (= Stanislav). More extensive studies of the taxonomy were published 12 years later (NAIDIN, 1964a, b; 1965). *Belemnitella* and *Belemnella* were covered rather briefly at this time, and fuller accounts were given in his 1969 book and in the Atlas of the Upper Cretaceous fauna of the Donetz Basin (NAIDIN, 1974), particularly near Voroshilovgrad (= Lugansk) in the eastern Ukraine. There were also important taxonomic corrections in NAIDIN (1975).

Amongst this taxonomic work he proposed a new classification of the belemnitellids that lack a true alveolus, whose relationships had never properly been considered before. He established two new subgenera of *Actinocamax: A. (Praeactinocamax)* and *A. (Paractinocamax);* a new genus, *Belemnellocamax;* and a new subgenus of *Gonioteuthis, G. (Goniocamax).*

The studies were extended southwards to the Crimea and eastwards to the Caspian syneclise (= shallow basin) around the northern part of the Caspian Sea (summaries in NAIDIN, 1969, 1979, 1981).

As a result of this broader area of study (from western Ukraine to the Mangyshlak Hills on the north-east side of the Caspian is approximately 2,200 km, about the same distance as from the Gulf of Mexico to the Canadian border), Naidin realised that the use of belemnites for stratigraphy was much more complicated than previously realised. Not only were many regional belemnite appearances the result of immigrations rather than evolution in place - this had been realised for many years by anyone who cared to think about the sudden appearance of new taxa without evolutionary predecessors. Nor, that one genus or species might be ecologically excluded by another (NAIDIN, 1959). Far more serious was the discovery that zonal boundaries could be diachronous over a few hundred km. For example, in the Crimea one could recognise two zones in the Upper Maastrichtian: *Belemnella kazimiroviensis* above and *Belemnitella junior* below. As one goes eastwards from Crimea to the Volga Basin, the *B. junior* Zone thins and disappears and that of *B. kazimiroviensis* thickens (Fig. 1). This is not a matter of sedimentation (although there are sedimentary complications as well): other indicators for the boundary between lower and upper Upper Maastrichtian show that both subdivisions of the Upper Maastrichtian are present. Thus in Mangyshlak the whole of the Upper Maastrichtian is represented by a Zone of *Belemnella kazimiroviensis* (NAIDIN, 1973).

It is still necessary to go to the original paper (NAIDIN, 1973) for full details, although some of the taxonomy has been modified. For more recent views set in the context of the whole European - central Asian region see CHRISTENSEN (1996, 1997 a, b).

Regional studies

Alongside these studies on belemnites, Naidin has developed a broad picture of Upper Cretaceous geology. This was seen from his first papers in English (1959, 1960a), through other papers published in the west (1979, 1981b; NAIDIN & VOLKOV, 1998). Amongst those publications in Russia have been NAIDIN & PETRENKO (1961), GERASIMOV *et al.* (1962), PAPULOV & NAIDIN (1979), NAIDIN & ALEKSEEV (1980), NAIDIN *et* al. (1986); and as one of the authors of the standard work on the Cretaceous system in Russia edited by MOSKVIN, 1986-87. These studies continue, e.g. JOLKICHEV & NAIDIN (1998).

If Dmitri Naidin had done no other research, these belemnite and regional studies would still have placed him as one of the leading Russian geologists in the second half of the 20th century. In fact, he has been a leader in several other fields of Cretaceous studies.

Sea-level changes

All Naidin's accounts of regional geology and palaeogeography have been related first to transgressions and regressions, and then to eustatic changes of sea-level. Earlier work was very generalised (e.g. NAIDIN, 1971, 1972b, 1976b), but by 1980 he led a team which produced curves

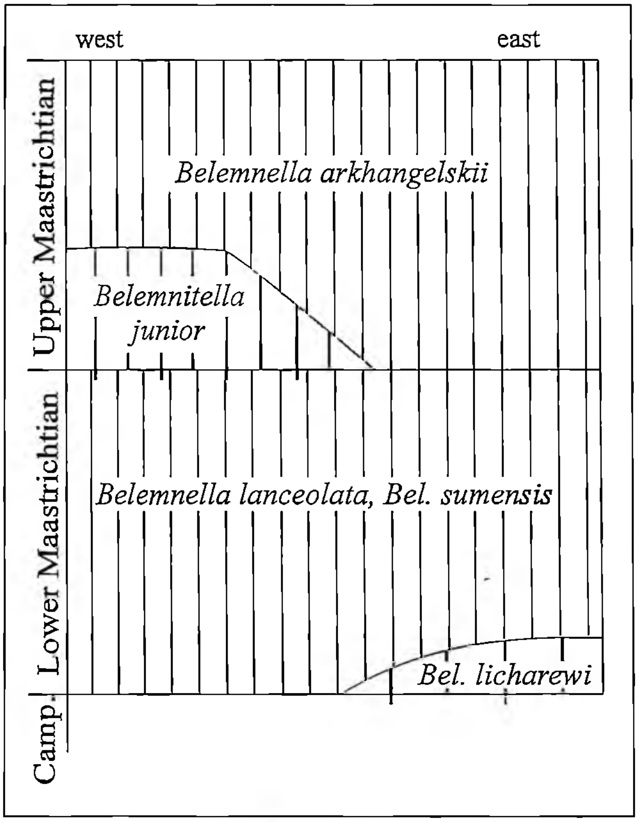

Fig. 1 — Copy of fig. 5 from NAIDIN (1973), re-drawn for this paper with anglicisation of cyrillic script. *Belemnella arkhangelskii* is now known to be a junior synonym of *Belemnella kazimiroviensis* Skolozdrowna.
This figure is one of Naidin's early diagrams to show that some belemnite species have different stratigraphical ranges in different regions. The original caption (in Russian) reads: Biozones and teilzones of Maastrichtian belemnites in the Western (western Europe, Poland, western region of the Ukraine) and the Eastern European palaeogeographical region.

on a stage-by-stage scale for eight regions of the USSR (NAIDIN *et al.*, 1980 a, b). In the 1980's he paid particular attention to Kazakhstan (NAIDIN *et al.*, 1982, 1984): this showed some startling differences from the curves for western Europe and the USA (but see MARCINOWSKI *et al.*, 1996).

In his most recent work (NAIDIN & VOLKOV, 1998) he re-affirms his belief in eustasy, which he thinks is controlled by increases and decreases in the total volume of water in the oceans. He also emphasises that many sedimentological phenomena are affected by epeirogeny and climate. In spite of the stability of the "East European Platform", (which comprises both the Russian Platform and its extension westwards through north Poland, north Germany and southern Scandinavia), there are local regions where tectonism rules over eustasy (see NAIDIN *et al.*, 1980b, fig. 10). He supports the EXXON school in their theories of coastal-onlap but does not believe that the EXXON curve is applicable to the East European Platform; and, like others before him, complains that the biostratigraphical correlations in the EXXON chart are inadequate to use their eustatic changes for correlation.

Geochemistry and general studies

Unusually in a scientific world of ever increasing specialisation, Naidin, having started as a palaeontologist, has encouraged the use of every technique to improve the overall picture of Cretaceous geology.

He has paid special attention to isotope geology for palaeotemperatures (NAIDIN, 1972a; TEIS & NAIDIN, 1973; TEIS, NAIDIN & STOYANOVA-VERGILOVA, 1975). VOLKOV & NAIDIN (1994, 1998) have attempted to reconstruct trade-winds and marine currents for much of the Late Cretaceous for the whole world. Naidin has also contributed a view on the geochronology of the Cretaceous period (NAIDIN, 1981a, 1982). He has adopted a cautious approach, not even offering his own table of dates.

Geochemistry has also been applied to his studies of the K/T boundary (see NAIDIN, 1997).

Cretaceous-Tertiary boundary

There are valuable K/T boundary sections in the Crimea, in the Kopet-Dag, straddling the border between Turkmenia and Iran, and in Mangyshlak in western Kazakhstan. The section at Koshak (44° 36.55' N; 51° 46.50' E) in particular, is accessible, free of vegetation, unlikely to be built over, contains echinoids, belemnites, ammonites, foraminifera, calcareous nannoplankton and an iridium anomaly: in many respects it would be a better global boundary stratotype and section point than El Kef, but when the international vote was taken, the Mangyshlak region was closed to non-Soviet citizens.

A valuable aspect of Naidin's research is that from the earliest papers (e.g. NAIDIN, 1960; MOSKVIN & NAIDIN, 1960) has been that he has not just concentrated on late Cretaceous extinctions but has considered the survivors into the Palaeogene, and investigated the appearance of new taxa. It was this broad view of the faunal changes that led him early in his researches to assign the Danian to the Tertiary and put the K/T boundary on the top of the Maastrichtian.

Naidin's most complete discussion of his earlier views is in his 1976a paper, but see also NAIDIN (1978). The Danian sediments of the Crimea are described in NAIDIN (1964c) and more recently by NAIDIN & BENJAMOVSKY (1994). The Maastrichtian sections in Mangyshlak are described in NAIDIN, BENJAMOVSKY & KOPAEVICH (1984).

In 1997 he distinguished two types of boundary sections in Mangyshlak: those with boundary clays, which contain Ir enrichment in the basal few mm of the clay, e.g. Koshak and Kyzylsai; and those with a hardground on top of the Maastrichtian, e.g. Aksyirtau (NAIDIN, 1997). For discussions in English, see NAIDIN (1987, 1996).

Politics

There are many innocent people, even some scientists, who believe that science is independent of politics. No discussion of Naidin's work is possible without taking politics into account. As Isaiah Berlin has written, "... despite every effort to separate them, conducted by a blind scholastic pedantry, politics has remained indissolubly intertwined with every other form of philosophical enquiry." (BERLIN, 1997, p. 192). By now there is a generation which has never known the stupid distortions of knowledge and understanding during the cold war, let alone the extremes of thought-control during and immediately after the Great Patriotic War. The isolation of Russia from western Europe and North America, and the isolation of North America and western Europe from Russia are already becoming difficult to visualise, but the differences of language merely made the separation easier: ignorance could be excused.

The degree of isolation between east and west is well illustrated by two standard works on sediments: PETTIJOHN (1957) and STRAKHOV (1962). The American work discusses the formation of clastic rocks in terms of both physics and chemistry, but it is the tectonic milieu which dominates the control on facies. ". . although sedimentation... is affected by many factors, the most fundamental is tectonics" (PETTIJOHN, 1957, p. 638). Much of this relationship between facies and tectonics is discussed in terms of "the geosynclinal cycle".

In STRAKHOV's giant work it is difficult to find a mention of geosynclines. Although he recognises a tectonic factor in the distribution of facies, the dominant control is climate. Indeed, volume 2 is on the formation of sedimentary rocks in humid climates, volume 3 on their formation in arid climates. For the Russian author the greater importance of climate was concluded after consideration of both hypotheses: American publications on tectonic controls are quoted but their conclusions are rejected.

For the American author, literature in Russian does not exist. A striking example of this is provided by the description of the Black Sea sediments. The latest and only example of Russian work which PETTIJOHN quotes is a paper in French by ANDROUSSOW published in 1897; no mention at all of the more recent Russian work, including that by STRAKHOV himself.

Naidin recognised the need to get information to geologists outside the Soviet block of research being done in the USSR and eastern Europe. And to get western geologists to visit the USSR to see what research was being done there. But this is to jump forward. At first it was a matter of developing his career inside the USSR.

If he had avoided politics until he had left the army, Dmitri could hardly have avoided them as a geologist. From 1946-49 he worked on the Upper Cretaceous stratigraphy of western Ukraine around Lwow, Drohobyoz, Stranislawow and Tarnopol. This was not just a matter of a few brief visits. He himself was concentrating on the belemnites, but he also collected the inoceramids on which Dobrov based his work, the echinoids used by Moskvin, some of the ammonites studied by Mikhailov, and the material for various authors on the foraminifera. He also worked on material in the museum at the University of Lwow. In other words, he must have spent a lot of time in western Ukraine.

During those years western Ukraine was still in a state of violent turmoil. As someone who had become a member of the Communist Party during the war yet had a Ukrainian father, Dmitri was able to move in all sections of society. Nonetheless, he must have learnt a great deal of the political skills needed to work within the Soviet system at that time.

Stalin died in 1953. Whilst he was alive any contact with foreigners would have been foolhardy. By 1955 Naidin was in an established position in Soviet society, a party member for more than ten years, working in a subject of limited political significance at the premier All Soviet university (MGU). He started sending offprints, writing letters and exchanging specimens with that most lovable of western geologists, Ehrhard Voigt (University of Hamburg), who had himself been an enterprising prisoner of war in the Soviet Union. In 1958 Naidin submitted a paper to Ivar Hessland for publication in the Stockholm Contributions in Geology (NAIDIN, 1959). We now know that the Swedish socialist government maintained very close relationships with the USSR through the cold war (Richard Reyment, personal communication). Around the same time Naidin started corresponding with Willy Wright and Jake Hancock in England.

In 1960-61 Richard Reyment was able to visit Moscow and Leningrad; in 1963 Voigt was a guest, not only in Moscow but also in the university "baza" (= field centre) near Bakhchisarai in the Crimea. Arising from these contacts came the quantitative study of *Actinocamax verus* (REYMENT & NAIDIN, 1962); and a monograph on Upper Cretaceous Bryozoa from the European part of the USSR (VOIGT, 1962); followed by a similar survey of the Bryozoa from the south Asian republics of the USSR, with the help of both Naidin and Ashot Atabekian (Leningrad) (VOIGT, 1967).

Thus Naidin gradually built up contacts between east and west. Over the years this became slightly easier, but it is difficult now to comprehend the courage which was needed during the cold war. Relationships within the eastern block were more complicated than it may have appeared. Even in the so-called free west, communication with the USSR was often regarded with suspicion and sometimes impossible if you were a government employee.

Naidin has contributed to the improvement of geological relations between east and west in a variety of ways. First, I would put the dissemination of Russian literature to western geologists.

He has sent out copies not just of his own works but of many Russian geologists, either by persuading them to write to us, or by obtaining copies of their papers and monographs to send himself. Whereas some of the atlases of fossils of the 1950's to 1970's were produced in editions of 1,400 to 2,000 copies, in the 1980's numbers went down to 600-800 copies. The number of spare copies must be very small. For some papers there is now a print-run of only 400 copies.

There was also the dissemination of ideas from the west into the USSR. He was responsible for the introduction of several developments of western research to other geologists in Russia, e.g. the concept of hardgrounds in chalk successions, and the use of quantitative measurements in palaeontology.

In the 1970's Russian geologists started to appear at Cretaceous symposia in the west. Here one must pay tribute not only to Naidin, but to Richard Reyment with his IGCP Project on MidCretaceous Events; to Tove Birkelund for the meetings she organised in Copenhagen; and to Jost Wiedmann for his International Cretaceous Symposia.

Fourthly, have been visits of western geologists to Cretaceous regions in the former Soviet Union. The craziness of the old Soviet system is nowhere better illustrated than the difficulties Naidin had in getting geologists to the Mangyshlak hills on the eastern side of the northern Caspian Sea. It has been known for many years that the hills there contain fabulous Cretaceous sections. So long as the Soviet Union existed the region was totally closed to non-Soviet citizens, even for party members from other east European countries. Dmitri tried repeatedly to get permission to take geologists there, without success. It was only with the independence of Kazakhstan that he was able to lead western geologists into Mangyshlak in 1994. On the ground there seemed to be no reason why foreigners should have been excluded.

One of my many good memories of Dmitri Naidin is at the international meeting on the K/T boundary held in Copenhagen in 1979. He explained that it was the official line in the Soviet Union that the Danian was part of the Cretaceous system, but he didn't believe that the Russians should ignore what the rest of the world had discovered and for him the boundary should be placed at the top of the Maastrichtian stage. By 1984 he had succeeded in changing the view of the Interdepartmental Stratigraphic Committee of the USSR which then came into line with international opinion.

If Dmitri Naidin's most important contribution in the history of geology has been the building of good relations between east and west, we should remember that this was only possible because of that impressive body of published research, of which the outline given above is far from a complete survey. It has been his catholic approach which has ensured the respect of a broad body of geologists.

Acknowledgements

I am indebted to a wide circle of friends for information and advice: Sasha Alekseev, Raymond Casey, Walter Christensen (particularly for his expert advice on belemnite studies), Dennis Curry, Annie Dhondt, Irene Katchourin, Ludmilla Kopaevich, Jim Kennedy, Albert Levine, Anatoly Nikishin and Richard Reyment. In view of the political sensitivities of parts of this paper, I should mention that the assessments and opinions are my own. Finally, I should like to thank Dmitri Naidin himself for all his kindnesses to me over many years.

References

BERLIN, I., 1997. The proper study of mankind. xxxvi + 667 pp. Chatto & Windus, London.

CHRISTENSEN, W. K., 1996. A review of the Upper Campanian and Maastrichtian belemnite biostratigraphy of Europe. *Cretaceous Research,* 17: 751-766.

CHRISTENSEN, W. K., 1997a. The Late Cretaceous belemnite family Belemnitellidae: taxonomy and evolutionary history. *Bulletin of the Geological Society of Denmark,* 44: 59-88.

CHRISTENSEN, W. K., 1997b. Palaeobiogeography and migration in the Late Cretaceous belemnite family Belemnitellidae. *Acta Palaeontologica Polonica,* 42: 457-495.

GERASIMOV, P. A., MIGACHEVA, E. E., NAIDIN, D. P. & STERLIN, B. P., 1962. Jurassic and Cretaceous sediments of the Russian Platform. *Ocherki Regional'noi Geologii SSSR,* 5: 196 pp. (in Russian).

JOLKICHEV, N. A., & NAIDIN, D.P., 1998. Upper Cretaceous of northern Bulgaria, Crimea and Mangyshlak: 1, Upper Cretaceous stratigraphy of northern Bulgaria. *Byulleten' Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskij,* 73: 17-28. (in Russian).

MARCINOWSKI, R., WALASZCZYK, I. & OLSZEWSKA-NEJBERT, D., 1996. Stratigraphy and regional development of the mid-Cretaceous (Upper Albian through Coniacian) of the Mangyshlak Mountains, western Kazakhstan. *Acta Geologica Polonica,* 46: 1-60.

MOSKVIN, M. M. (Editor), 1986-87. *Cretaceous System,* 2 vols, 339 + 326 pp. *Stratigraphy of the USSR* (general editor B.S. SOKOLOV). Nedra, Moscow. (in Russian).

MOSKVIN, M.M. & NAIDIN, D. P., 1960. Danian and contiguous deposits of the Crimea, Caucasus, and the Transcaspian Region and the south-eastern part of the Russian Platform. *International Geological Congress 21, Reports of Soviet Geologists, Problem 5: The Cretaceous-Tertiary boundary* 1540. Izdatelstvo Akademii Nauk SSSR, Moscow. (in Russian with English summary).

NAIDIN, D. P., 1952. Material for the biostratigraphy of the western regions of the Ukraine. Belemnites of the upper Cretaceous of the western Ukraine. *Trudy Moskovskogo Geologo-Razvedochnogo Instituta imeni S. Ordzhonikidze,* 27: 5-125. (in Russian).

NAIDIN, D. P., 1959. On the paleogeography of the Russian platform during the Upper Cretaceous epoch. *Stockholm Contributions in Geology,* **3**, 6: 127-138.

NAIDIN, D. P., 1960a. The stratigraphy of the Upper Cretaceous of the Russian Platform. *Stockholm Contributions in Geology,* 6,4: 39-61.

NAIDIN, D. P., 1960b. Concerning the boundary between the Maastrichtian and Danian stages. *International Geological Congress 21, Reports of Soviet Geologists, Problem 5: The Cretaceous-Tertiary boundary* 41-46. Izdatelsvo Akademii Nauk SSSR, Moscow. (in Russian with English summary).

NAIDIN, D. P., 1964a. Upper Cretaceous Belemnitella and Belemnella of the Russian Platform and some adjacent regions. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskij,* 39: 85-97 (in Russian).

NAIDIN, D. P., 1964b. Upper Cretaceous belemnites of the Russian Platform and adjacent regions. *Actinocamax, Gonioteuthis* and *Belemnellocamax.* Moscow University Press. 191 pp. (in Russian).

NAIDIN, D. P., 1964c. Danian and Montian sediments of the Crimea. Sbornik v Chest Akademika Jovcho Smilovicha Jovcheva, 167-184, Sofia. (in Russian).

NAIDIN, D. P., 1965. Upper Cretaceous belemnites (Family Belemnitellidae Pavlow) of the Russian Platform and adjacent regions. 41 pp. Moscow University Press. (in Russian).

NAIDIN, D. P., 1969a. Biostratigraphie und Paläogeographie der Oberen Kreide der Russischen Tafel. *Geologisches Jahrbuch,* **87**: 157-186.

NAIDIN, D. P., 1969b. Morphology and palaeobiology of the Upper Cretaceous belemnites. 303 pp. Moscow University Press (in Russian)

NAIDIN, D. P., 1971. On global sea-level changes in the Mesozoic and Caenozoic. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskij,* **46**: 10-18. (in Russian).

NAIDIN, D. P., 1972a. Isotopic palaeotemperatures and some problems in geology. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskij,* **47**: 112-124. (in Russian).

NAIDIN, D. P., 1972b. Oscillations in sea-level changes during the Mesozoic and Caenozoic. *Symposium on comprehensive studies on the nature of the ocean,* **3**: 85-103. University of Moscow. (in Russian).

NAIDIN, D. P., 1973. On the relationship between small units in biostratigraphy and those in palaeobiogeography. *Buylleten Moskovskogo Obschestva Ispitateley Prirody, otdel geologicheskij,* **48**: 50-63. (in Russian).

NAIDIN, D. P., 1974. Subclass Endocochlia-order Belemnitidae. *In:* BLANK, M. Ya., KRYMGOLTS, G. Ya. (Editor), NAIDIN, D. P. & SAVCHINSKAYA, O. V., Atlas of the Upper Cretaceous fauna of the Donbass. Nedra, Moscow, 197-240 (in Russian).

NAIDIN, D. P., 1975. Late Maastrichtian belemnitellids of Eurasia. *In:* MENNER, V. V. *et al.* (Editor), Evolution and change of the organic kingdom at the Mesozoic-Cenozoic boundary, 91-108, Publishing House Nauka, Moscow. (in Russian).

NAIDIN, D. P., 1976a. The Cretaceous-Palaeogene boundary. Boundaries of Geological Systems. To the 70th birthday of Academician V. V. Menner, 225-257. Izdatelsvo Nauka SSSR, Moscow. (in Russian).

NAIDIN, D. P., 1976b. Epeirogeny and eustasy. *Vestnik Moskovskogo Universiteta, Geologiya* **1976**, 2: 3-16 (in Russian).

NAIDIN, D. P., 1978. The stratotype stage for the top of the Cretaceous (on an example of the Maastrichtian stage). *Byulleten Moskovskogo Obshchestva Ispitateley Prirody, otdel geologicheskij,* **53**, 3: 56-77. (in Russian).

NAIDIN, D. P., 1979. Vergleichende Stratigraphie der Oberen Kreide der Russischen Tafel und West-Europa. *In*: WIEDMANN, J. (Editor), Aspekte der Kreide Europas, 497-510. International Union of Geological Sciences (A) 6.

NAIDIN, D. P., 1981a. Geochronology of the Mesozoic. *In*: KELLER, B. M. (Editor). The principles of a geochronological scale and its construction: Phanerozoic. *Itogi Nauka i Tekhniki, Series on Stratigraphy, Palaeontology,* **2**: 34-73. (in Russian).

NAIDIN, D. P., 1981b. The Russian Platform and the Crimea. *In:* REYMENT, R. A. & BENGTSON, P. (Editors). Aspects of midCretaceous regional geology, 29-68. Academic Press, London.

NAIDIN, D. P., 1982. Geochronology of the Cretaceous period. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskij,* **57**: 51-72. (in Russian).

NAIDIN, D.P., 1987. The Cretaceous-Tertiary boundary in Mangyshlak, U.S.S.R. *Geological Magazine,* **124**: 13-19.

NAIDIN, D. P., 1996. Cenomanian/Turonian and Maastrichtian/Danian events in the eastern European palaeobiogeographical region. *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg,* **77**: 369-378.

NAIDIN, D. P., 1997. On the two types of Cretaceous/Paleogene boundary. *Doklady Akademii Nauk,* **352**: 369-373. (in Russian).

NAIDIN, D. P. & ALEKSEEV, A. S., 1980. Sections of Cenomanian sediments between Kacha and Bodrak (Crimea) *Izvestiya Vysshikh Uchebnykh Zavedenii. Geologiya i Razvedka* for **1980**, 4: 11-25. (in Russian).

NAIDIN, D. P. & BENJAMOVSKY, V. N., 1994. The Suvlukaya Palaeogene Section. *Stratigraphy and Geological Correlation,* 2, 3: 272-283.

NAIDIN, D. P., BENJAMOVSKY, V. N. & KOPAEVICH, L. F., 1982. Late Cretaceous transgressions and regressions in western Kazakhstan. *Izvestiya Vysshikh Uchebnykh Zavedenii. Geologiya i Razvedka* for **1982**, 10: 3-19. (in Russian).

NAIDIN, D. P., BENJAMOVSKY, V. N. & KOPAEVICH, L. F., 1984. Methods of studying transgressions and regressions (exemplified by the Late Cretaceous basins of western Kazakhstan), 164 pp. Moscow University. (in Russian).

NAIDIN, D. P. & PETRENKO, V. S., 1961. On the Upper Cretaceous depressions in the southern part of the East European

Platform and its Palaeozoic framework. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskij,* 36: 56-75. (in Russian).

Naidin, D. P., Pokhialajnan, V. P., Kats, Yu. I. & Krassilov, V. A., 1986. The Cretaceous Period: palaeogeography and palaeoceanology, 264 pp. Akademija Nauk SSSR, Moscow. (in Russian).

Naidin, D. P., Sasonova, I. G., Pojarkova, Z. N., Djalilov, M. R., Papulov, G. N., Benjamovsky, V. N., & Kopaevich, L. F., 1980a. Cretaceous transgressions and regressions on the EastEuropean Platform, Crimea and central Asia. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskij,* 55: 27-42. (in Russian).

Naidin, D. P., Sasonova, I. G., Pojarkova, Z. N., Djalilov, M. R., Papulov, G. N., Senkovsky, Yu. M., Benjamovsky, V. N. & Kopaevich, L. F., 1980b. Cretaceous transgressions and regressions on the Russian Platform, in Crimea and central Asia. *Cretaceous Research,* 1: 375-387.

Naidin, D. P. & Volkov, Yu. V., 1998. Eustasy and Late Cretaceous seas of the East-European Platform. *Zentralblatt für Geologie und Paläontologie. Teil 1. Allgemeine, Angewandte, Regionale und Historische Geologie,* 1996: 1225-1232.

Papulov, G. N. & Naidin, D. P., 1979. The Santonian-Campanian boundary on the East European Platform. *Akademija Nauk SSSR, Uralski Nauchni Centr. Trudy Instituta Geologii i Geokhimii,* 148: 118 pp. Sverdlovsk. (in Russian).

Pettijohn, F. J., 1957. *Sedimentary Rocks,* 2nd edition, xvi + 718 pp. Harper & Brothers, New York.

Reyment, R. A. & Naidin, D. P., 1962. Biometric study of Actinocamax verus s.l. from the Upper Cretaceous of the Russian Platform. *Stockholm Contributions in Geology,* 9,4: 147-206.

Strakhov, N. M., 1962. Fundamental theory of the formation of lithologies. Akademia Nauk SSSR, Moscow (English translation published 1967-1970 by Consultants Bureau, New York; and Oliver & Boyd, Edinburgh, with the title *Principles of Lithogenesis,* 1, 431 pp).

Teis, R. V. & Naidin, D. P., 1973. Palaeothermometry and isotopics put together with oxygen and biogenic carbonates, 256 pp. , Nauka, Moscow. (in Russian).

Teis, R., Naidin, D. P. & Stoyanova-Vergilova, M., 1975. Palaeotemperatures of the Jurassic and Early Cretaceous of Bulgaria according to the isotopic oxygen composition of belemnite guards. *Geologica Balcanica,* 5: 65-80.

Voigt, E., 1962. Upper Cretaceous bryozoa from the European part of the USSR and contiguous areas. Moscow University Press. 125 pp. (in Russian). (French translation 1964. Paris, *Bureau de Recherches géologiques et minières, Traduction no. 4455*).

Voigt, E., 1967. Oberkreide-Bryozoen aus den asiatischen Gebieten der UDSSR. *Mitteilungen aus dem Geologischen Staatsinstitut in Hamburg,* 36: 5-95.

Volkov, Yu. V. & Naidin, D. P., 1994. Variation in climatic zones and surface currents in the oceans during the Cretaceous period, *Byulleten Moskovskogo Obshchestva Ispitatelei Prirody, otdel geologicheskij,* 69: 103-123. (in Russian).

Volkov, Yu. V. & Naidin, D. P. 1998. Marine currents induced by trade winds and the southerly dispersal of some marine organisms during the Late Cretaceous. *Doklady Akademii Nauk,* 358: 367-370. (in Russian). (English translation in *Doklady Earth Sciences* 358: 44-47 with the title "Tradewind currents and meridional dispersal of some marine organisms in the Late Cretaceous").

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Typescript submitted 15.10.1998
Revised typescript received 15.3.1999

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 15-45, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 15-45, 1999

Maastrichtian and Lower Palaeocene of Northern Saratov Region (Russian Platform, Volga River): Foraminifera and calcareous nannoplankton

by Alexander S. ALEKSEEV, Lyudmila F. KOPAEVICH, Mariya N. OVECHKINA &
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Abstract

From five Maastrichtian outer shelf sections of the high latitude (52°N) North Saratov Region a detailed foraminiferal and calcareous nannoplankton study has been carried out for the first time. The most important taxa are illustrated. The Maastrichtian succession contains several hiatuses, of which the most important encompasses the late early Maastrichtian (zones CC23b and CC24). On top of the Tyoplovka Uplift the uppermost Maastrichtian marls (upper part of CC26) overlie the Upper Albian. The existence of mid-Maastrichtian tectonic movements in this region is shown by detailed stratigraphic correlations. The interval with the Lower Maastrichtian *Belemnella lanceolata gracilis* belongs to Zone CC23A. During the latest Maastrichtian a transgression with invasion of warm-water and deep-water *Globotruncana* taxa was recognized in the Klyuchi 1 section and this transgressive event is an important marker in the White Chalk Sea.

Key-words: Foraminifera - calcareous nannoplankton - biostratigraphy - Maastrichtian - Lower Palaeocene - Russia

Résumé

Dans la partie septentrionale (52°N) de la région de Saratov, une étude détaillée des foraminifères et du nannoplancton calcaire a été effectuée pour la première fois dans cinq sections maastrichtiennes ayant fait partie du shelf externe situé à de hautes latitudes. Les taxa les plus importants sont figurés. La succession maastrichtienne comprend plusieurs hiatus dont le plus important coïncide avec la fin du Maastrichtien inférieur (zones CC23b et CC24). Au sommet du soulèvement de Tyoplovka, les marnes du Maastrichtien le plus supérieur (partie supérieure de CC26) recouvrent l'Albien supérieur. L'existence de mouvements tectoniques au Maastrichtien moyen dans cette région est attestée par des corrélations stratigraphiques détaillées. L'intervalle à *Belemnella lanceolata gracilis* du Maastrichtien inférieur appartient à la Zone CC23A. Au cours du Maastrichtien terminal, une transgression avec arrivée d'eaux chaudes et de taxa de *Globotruncana* d'eau profonde a été mise en évidence dans la section de Klyuchi 1; cet événement transgressif est un marqueur important dans la mer de la Craie blanche.

Mots-clefs: Foraminifères, nannoplancton calcaire, biostratigraphie, Maastrichtien, Paléocène inférieur, Russie.

Резюме

Впервые на севере Саратовской области детально изучены фораминиферы и известковый нанопланктон пяти высокоширотных (52° с.ш.) разрезов Маастрихта, приуроченных к обстановке внешнего шельфа. Наиболее важные таксоны изображены. Разрез Маастрихта в этом районе содержит несколько перерывов, главный из которых приурочен к концу раннего Маастрихта. На вершине Тепловского поднятия мергели верхней части верхнего Маастрихта (верхи зоны CC26) перекрывают верхний альб. Детальная стратиграфическая корреляция показала существование в этом регионе внутри-маастрихтских тектонических движений. Обсуждена тектоническая история Тепловского поднятия. Часть разреза нижнего Маастрихта с *Belemnella lanceolata gracilis* принадлежит зоне CC23A. В конце Маастрихта в разрезе Ключи 1 установлена трансгрессия, сопровождавшаяся проникновением в этот район тепловодных и глубоководных *Globotruncana*. Это трансгрессивное событие является важным маркирующим уровнем для моря «Писчего Мела».

Ключевые слова: Фораминиферы, наннопланктон, биостратиграфия, Маастрихт – нижний Палеоцен, Россия

Introduction

The major part of information on biotic changes across the Maastrichtian/Danian boundary comes from relatively low latitude sections, especially in the tropical and subtropical realms. Only a few sections were studied in high latitudes among which are Stevns Klint and Kjölby Gaard in N Europe (HULTBERG & MALMGREN, 1986, 1987; SCHMITZ *et al.*, 1992) and boreholes in the Antarctic, on Maud Rise and on the Kerguelen Plateau (HUBER, 1990; POSPICHAL & WISE, 1990; THIERSTEIN *et al.*, 1991). Evidence exists that sequences of biotic events and their extent during the Maastrichtian-Danian transition were quite different in tropical and high latitude basins (GARTNER, 1996). Only few data are available from the eastern part of the large, relatively shallow and cold-water marine Russian basin that covered the southern and eastern parts of the Russian Platform between 50-55°N during the Late Cretaceous and Palaeogene. This basin had connections with the Western Siberian Sea through narrow sea straits which crossed the Uralian Uplift Zone and through the wide Turgay Strait east of the Urals. The sediments of this basin contain important information for a better understanding of the terminal Cretaceous events and their appearance in dif-

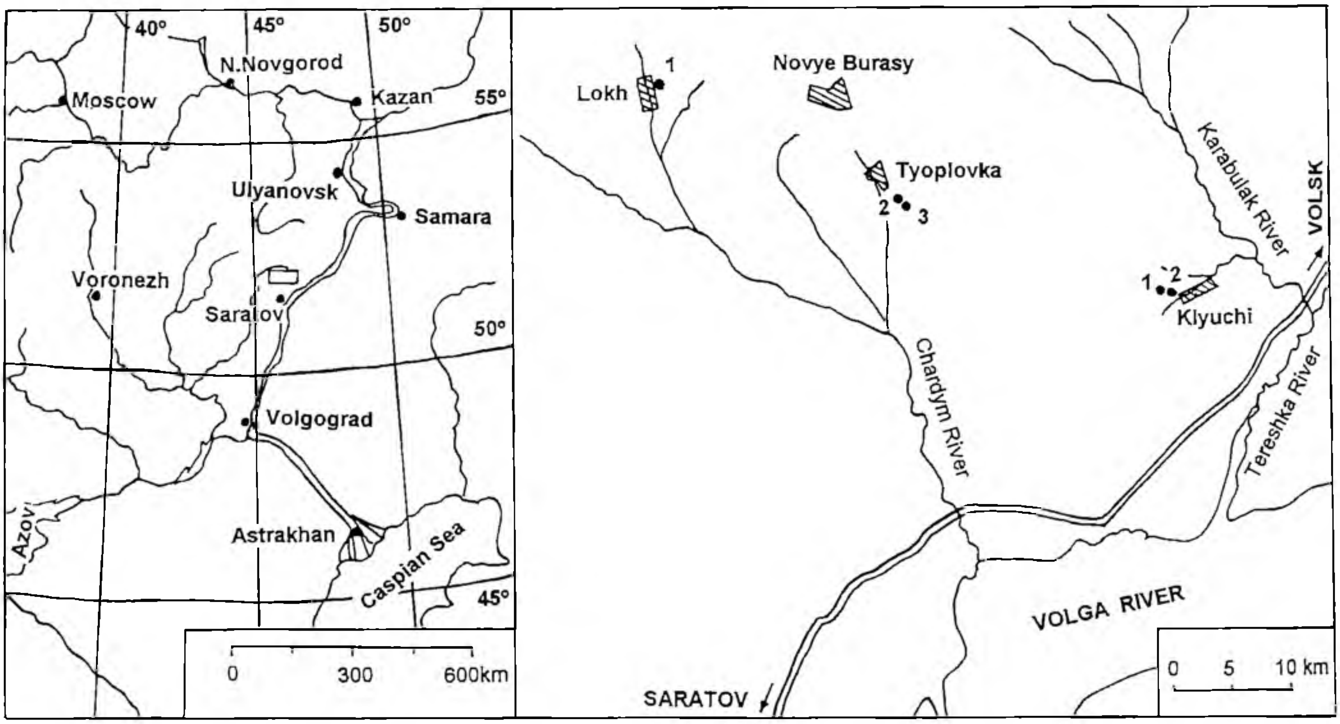


Fig 1. — Location of the area and the sections studied.

ferent climatic belts. Not only latitudinal, but also longitudinal differences exist between stratigraphic ranges of important late Maastrichtian marker species, in W Europe and in E Europe (e.g. belemnitellids), as was shown firstly by NAIDIN (1973).

The Saratov Region is situated in the N. part of the Russian Basin between 50 and 53° N along the Volga River. There is a relatively complete outer shelf Maastrichtian-Danian sequence. This sequence contains rich assemblages of planktonic Foraminifera including true deep water taxa, although never studied in detail (BARYSHNIKOVA, 1966). However, the very first illustrations of foraminiferan shells in transmitted light by EHRENBERG (1854) came from that area (Volsk chalk). Later, ARKHANGELSKY (1912) gave lists of Foraminifera from several rock samples of the *Belemnitella lanceolata* Zone (Maastrichtian) and line drawings of a few species were published by BARYSHNIKOVA *in* KAMYSHEVA-ELPATIEVSKAYA (1967). In one section the lower Upper Maastrichtian calcareous nannofossil assemblage of the *Lithraphidites quadratus* Zone was studied and illustrated (GUTSAKI *et al.*, 1975). The nannofossil *Nephrolithus frequens* Zone was recognized by MUSATOV (1995) in the topmost layers of the Maastrichtian in the Klyuchi area. All these data show the great importance of the Saratov Region for environmental reconstructions of the eastern part of the terminal Cretaceous Chalk Sea. In this paper we present preliminary results of studies of several Maastrichtian and basal Lower Palaeocene (Syzranian) sections in the N Saratov Region.

Geological Setting

The Saratov Region is part of the vast Volga River area (Povolzhie in Russian) of the East European Platform often named the Uliyanovsk-Saratov Syneclise or Depression (NAIDIN 1960, 1969; GERASIMOV *et al.* 1962), situated close to the W and NW margin of the Peri-Caspian Depression. The wide belt of the Russian craton along the Volga River was relatively mobile during Mesozoic times with several tectonic uplifts and swells were recognized (NIKISHIN *et al.*, this volume). In the vicinity of Saratov, to the west and north of the town, numerous small amplitude uplifts occur. These uplifts are known as the Saratov Dislocations and are characterized in their axial parts by Mid-Jurassic sediments overlying with an angular unconformity the Middle Carboniferous (Moscovian) limestones. Different levels of Upper Cretaceous unconformably overlie the Jurassic and Lower Cretaceous formations on the slopes of these uplifts.

The Upper Cretaceous is mainly represented by widely distributed Cenomanian sands (up to 25-30 m), Turonian-Coniacian sandy chalks and chalks (up to 25 m), Santonian and Campanian sandstones, marls and siliceous rocks (40-50 m) and Maastrichtian sands, siliceous "opokas", marls and chalks (up to 60 m). The Maastrichtian sediments are the most widely distributed Upper Cretaceous strata in the Saratov region. They are overlain by siliceous rocks of Palaeocene age known as Syzranian Stage or Syzran Formation. There are three sub-meridional facial belts of Maastrichtian age, which were first

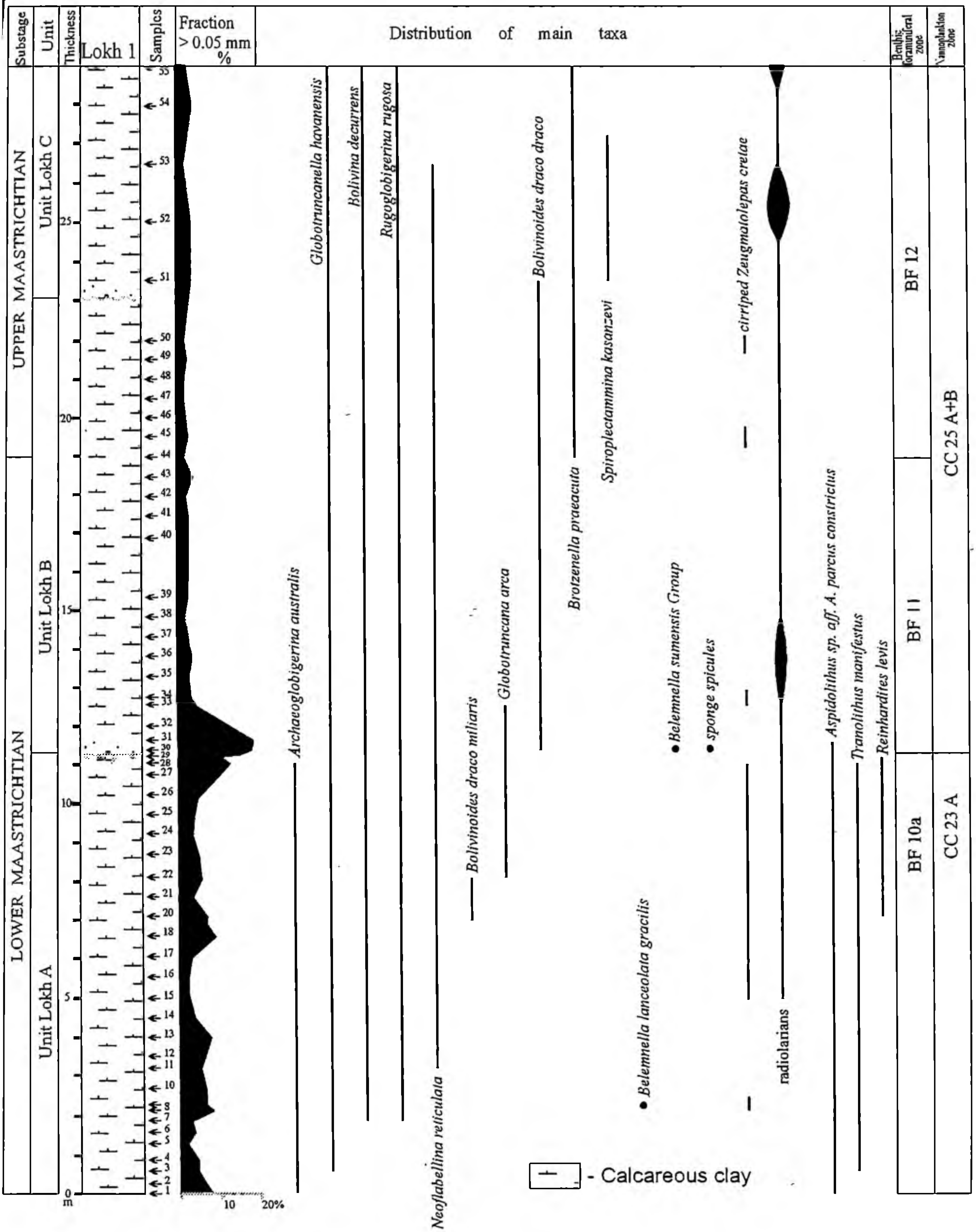


Fig 2. — Section Lokh 1 and stratigraphic distribution of the most important Foraminifera and calcareous nannoplankton taxa. Levels with most abundant radiolarians, sponge spicules, cirripeds and belemnites are also shown.

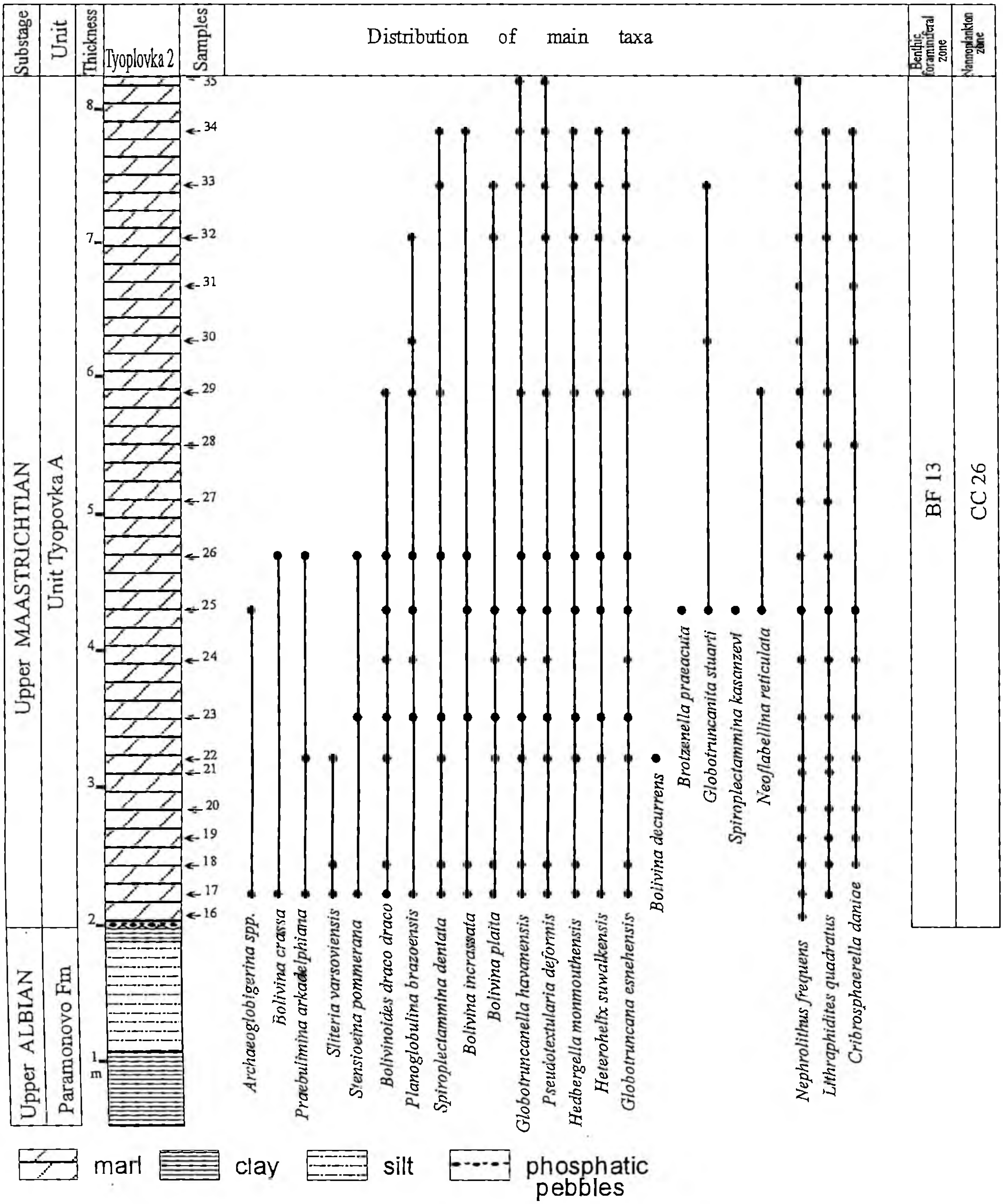


Fig 3. — Section Tyoplovka 2 and stratigraphic distribution of the most important Foraminifera and calcareous nannoplankton taxa.

documented in this region by ARKHANGELSKY (1912) and were more precisely described by FLEROVA & GUROVA (1958) and DERVIZ (1959). The first belt located in the west, consists of calcareous sands. Marls are found in the central part and chalks are present along the Volga River, north of Saratov. No formal lithostratigraphy exists for the Upper Cretaceous of the Saratov Region.

Note: "Opoka": a Polish term for siliceous rocks consisting of a mixture of amorphous silica and clay. In fresh state the opoka has a dark colour, but in weathered state it is whitish. Silica can constitute up to 90 %, but the rock is completely recrystallized under diagenesis and no clear diatom frustula are visible unlike what would have been the case in diatomite. "Opoka" occurs frequently in N. Germany, Poland, on the Russian Platform and in W. Siberia.

Material and methods

Five sections were studied and sampled 60-65 km to the NW, N and NE of Saratov (Figure 1). More than 150 samples were collected at intervals between 0.4 to 1.5 m for foraminiferal and calcareous nannofossil studies. The Foraminifera were extracted from soft marls with standard micropalaeontological techniques by soaking dry samples of 50 g in sodium bicarbonate and washing them through a 0.05 mm screen. Relatively hard Palaeocene "opokas" were disintegrated through melting crushed rock samples with sodium sulfate. For nannofossils normal smear-slides were prepared from each sample. The coccoliths were identified under the light microscope Carl Zeiss Axiolab under magnification x 1500. The SEM photographs of foraminifers and nannofossils were taken by Camscan in the Palaeontological Institute of RAS. The carbonate contents were determined in 37 samples by dissolution of 10 g rock in 20% formic acid on scales, and calculated from carbon dioxide loss with a precision of 1%. As standard in experiments chemically pure $CaCO_3$ was used.

Repository

The collections of macrofossils and Foraminifera are housed in the Paleontological Institute of the Russian Academy of Sciences (PIN) under numbers 4775 and 4776 respectively.

Locality descriptions

1. Section Lokh 1 in the Novye Burasy Area: 52° 08' N, 45° 52' E. A small abandoned quarry on the left bank of a tributary of the Chardym River, 65 km NW of Saratov and 15 km W of Novye Burasy. The quarry is on the slope of a hill covered by hard Palaeocene Syzranian "opokas". The bottom of the quarry is about 20 m above the river. The lower 2 m of the section (Figure 2) were sampled in a trench. The upper part of the section above sample LH1-49 is poorly exposed and mainly covered by grass. Samples were collected at intervals of 1.5 m up to the bottom of deep holes (up to 1 m deep) in the talus. The base of the Maastrichtian has not been reached, but the presence of abundant clastic material (up to 10%) in the lowermost sample LH1-1 supports the idea that it is close to the lower boundary of unit Lokh 1. According to previous data (BONDARENKO, 1975) the Maastrichtian marls overlie Cenomanian sands in this area. In total 28.5 m of light yellow-grey calcareous clays, siltic in their lower part and clayish marls are seen in section Lokh 1. The sequence can be subdivided into three lithological units.

Unit Lokh A. The lower 11.1 m of the sequence is represented by yellow-grey micaceous calcareous clays with 22-35% $CaCO_3$, sometimes with burrows and fissures filled with gypsum veins, often with iron oxides. The content of the fraction > 0.05 mm is 3-10%.

Unit Lokh B. The top of unit Lokh A is a prominent erosional hardground with numerous up to 60 cm deep burrows. The basal layer that overlies unit Lokh A consists of glauconitic calcareous friable sandstone (0.7 m) with rare, mainly eroded belemnite rostra and moulds of small bivalves. The calcareous sandstone is replaced up section by yellow-grey calcareous clays (28-32% carbonate) with small fragments of bivalve shells. The total thickness of this unit is 11.6 m. The content of the fraction > 0.05 mm is 1-3% only.

Unit Lokh C. In the washed residue of sample LH1-51 quite abundant large grains of glauconite occur, suggesting that this level is very probably near to another hiatus, marked by a basal glauconitic bed. This hiatus is supposed to fall in the interval between samples LH1-50 and LH1-51 that has a thickness of about 1.5 m. Unit Lokh C consists of yellow-grey calcareous clays (5.8 m thick, 23-30% of $CaCO_3$). The top of this unit and the contact with the Palaeocene are not visible in this locality.

2. Section Tyoplovka 2 in the Novye Burasy Area. 52°06' N, 46°04' E. A small ravine on the southwestern slope of a hill on the left bank of a small tributary of the Chardym River known as the Tyoplovka River and located at about 57 km N of Saratov, 10 km SE of Novye Burasy and about 1.5 km SE of Tyoplovka Village.

Below the Syzranian "opokas" which are badly exposed here, 6.3 m of light grey siltic and micaceous thinly laminated marls (41-47% of carbonate) (Figure 3) are visible in a deep and narrow ravine that first cuts the hill slope parallel to it and after that in its crest. Maastrichtian marls overlie Upper Albian black clays of the Paramonovo Formation. The top sample from these clays contains the radiolarian *Crolanium cuneatum* (Smirnova & Kh. Aliev), typical for the Paramonovo Formation, which is widely distributed in Central Russia (ALEKSEEV *et al*., 1996). A phosphoritic conglomerate lies at the base of the marls. Its thickness is up to 0.1 m. The phosphatic pebbles are generally small (1-2 cm) but occasionally can reach up to 5-7 cm across. The total thickness of the Maastrichtian marls was estimated to be 18 m (BARYSHNIKOVA, 1966). Along this ravine at a distance of 40 m the basal Maastrichtian conglomerate cuts in a westward direction progressively deeper and deeper levels of the Paramonovo Formation. This supports the existence of an angular unconformity between Albian and Maastrichtian strata.

3. Section Tyoplovka 3. A large ravine, 0.5 km south-east of section Tyoplovka 2. This ravine cuts the slope of the Tyoplovka River valley from the Palaeocene "opokas" at its top to Middle Jurassic clastics at its foot. Maastrichtian marls, the same as in section Tyoplovka 2, are situated in the relatively gentle part of the slope and are only poorly exposed. On top of the Paramonovo Formation the basal Maastrichtian phosphori-

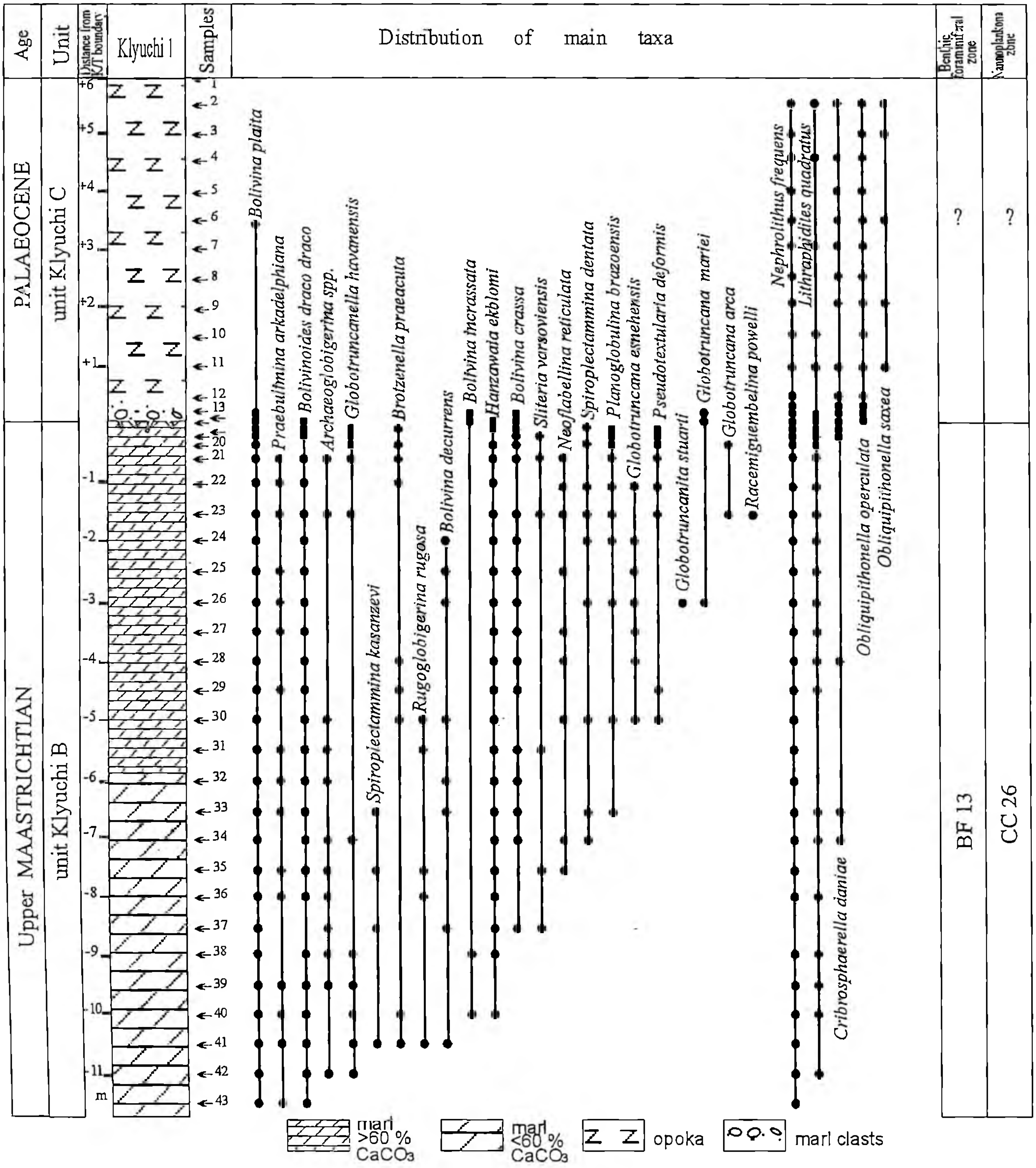


Fig 4. — Section Klyuchi 1 and stratigraphic distribution of the most important Foraminifera and calcareous nannoplankton taxa.

tic conglomerate occurs. The base of the conglomerate dips to the NE under an angle of about 30-40°. Samples TP3-17 and TP3-18 were collected at a distance of 1 m from the base of the Maastrichtian. 40 m upwards, along the ravine, in a small trench, the displaced contact of the Maastrichtian marls and Palaeocene "opoka" can be seen. 75 m upwards along the ravine, on top of a zone without exposures, green-yellow calcareous Syzranian "opoka" crops out (sample TP3-23).

4. Sections Klyuchi 1 and 2, in the Bazarny Karabulak Area: 51° 59' N, 46°30' E. Few shallow ravines cross the left gentle slope of the Malyi Klyuch River valley, about 62 km northeastern of the Saratov.

Klyuchi 1 is situated in the ravine furthest from Klyuchi Village, about 1 km beyond the last buildings of the village. The upper part of the section is located 10 m from the field margin (Figure 4). Two units can be recognized.

Unit Klyuchi C. The upper part of the section consists of 5.9 m of Lower Syzranian (Lower Palaeocene) green-grey hard calcareous "opokas" (17-20% of $CaCO_3$) with abundant moulds of small bivalves, gastropods and solitary scleractinian corals (*Trochocyathus calcitrapa* von Koenen) in its lower part (1-2.5 m above the base). The base of the "opokas" consists of a siliceous glauconitic sandstone (0.15 m) with abundant fragments of Maastrichtian marls up to 2-3 cm across. The top of the Maastrichtian is a hardground with burrows which penetrate the underlying marls up to a depth of 0.1-0.2 m. The burrows are filled with green, siliceous sandy glauconitic material which forms the base of the Palaeocene.

Unit Klyuchi B. Below the boundary hardground, a thick succession of white chalky marls (52-65% of carbonate) is seen including levels with abundant *Zoophycos* trace fossils (e.g. at 11.5 m). The lower part of unit Klyuchi B (6 m) contains more carbonate (62-65% $CaCO_3$) but in the topmost 5 m the carbonate content decreases again (55-59%). The base of unit B is covered by soil in this section. On the surface of these marls, in their middle part, a few belemnite rostra were discovered together with iron oxide pseudomorphs on small sponges.

The Klyuchi 2 section is on the same valley slope as Klyuchi 1, but 0.5 km closer to Klyuchi Village. This ravine is the last with good Cretaceous outcrops. The lower part ends in a small temporary marl quarry near the bottom of the valley. Further to the east ravines cut only Upper Pliocene (Akchagylian) or Quaternary clastics. Three unit can be recognized.

Unit Klyuchi A. Lowermost part of the section (Figure 5) consists of yellow-grey siltic calcareous clays which are very similar to the clays of unit Lokh 1, but contain slightly more carbonate (35-36% of $CaCO_3$). The thickness of this unit, although incomplete, is 3.2 m.

Unit Klyuchi Bb. Unit Klyuchi A is overlain by a bed of green-yellow clay (0.8-0.9 m) with rare dispersed glauconite grains. This bed has the lowest carbonate content (only 16-20% $CaCO_3$) of the entire studied Maastrichtian succession. The lower boundary of the clay bed is probably erosional and penetrates into the top of the calcareous clays of unit Klyuchi A, although evidence is very poor. This bed can be very easily traced along the slope as a marker horizon. On the surface of this clay rare belemnite rostra were found.

Unit Klyuchi B. More than 10 m of white chalky marls identical to those of section Klyuchi 1 are visible in this section. A bed 10 cm thick glauconite occurs at the base of the marls, overlying the erosional contact between units Klyuchi Bb and B. The top of these marls should be close to the boundary between units Klyuchi B and C, as shown by micropalaeontological data (see below).

Micropalaeontology

Maastrichtian sediments in the studied sections contain abundant planktonic and benthic Foraminifera (Plates 1 and 2). Moreover, in washed residues of many samples occur diverse, mainly smooth ostracod shells (*Krithe, Cytherella* etc), radiolarian skeletons (especially in section Tyoplovka 2) and capitular plates of the cirriped *Zeugmatolepas cretae* (Steenstrup). Also tiny echinoid spines and inoceramid prisms are constant components of the sediments. Siliceous sponge spicules occur at some levels (for example in the basal bed of unit Lokh B and in the top of the Maastrichtian).

FORAMINIFERA

Foraminiferal assemblages from all studied lithological units, except unit Klyuchi C, are very similar. The main character is the predominance of planktonic Foraminifera. The P/B ratio commonly varies between 75-92% which is typical for an outer shelf environment. Preservation is usually very good, as, quite often, shells are void and clear, and their fine sculptural elements easily visible. The planktonic assemblage has a low taxonomic diversity, resulting from the relatively high latitude position of the studied sections. The total production of planktonic foraminiferids is very high (commonly 3000 - 9000 specimens per gram of rock, and reaching up to 21000 specimens in sample KL1-28). Sedimentation rates appear to have been rather slow.

Among the planktonic Foraminifera, small heterohelicids are most frequent [mainly *Heterohelix globulosa* (Ehrenberg), up to 66-89% of the planktonic assemblage]. Common are *Globigerinelloides* (7-26%) and *Archaeoglobigerina* taxa and transitional forms between *Archaeoglobigerina* and *Rugoglobigerina* (2-15%). *Hedbergella monmouthensis* Olsson, *Rugoglobigerina rugosa* (Plummer), *Globotruncanella petaloidea* (Gandolfi) and *G. havanensis* (Voorwijk) are less frequent, but occur in most samples. The triserial *Guembelitria cretacea* Cushman is very rare. The relative abundance of these groups is characteristic for a shelf environment. The large *Archaeoglobigerina australis* Huber, first described from Antarctica (HUBER, 1990), and forms close to it, together with *Rugoglobigerina rugosa* (Plummer), are especially abundant in unit Lokh A. The taxonomy of the high spiral forms intermediate between *Archaeogloberigina* and *Rugogloberigerina* has not been studied in detail. Some authors have established new taxa, such as the genus *Helvetiella* (LONGORIA & GAMPER, 1984), but additional research is necessary to clarify their taxonomy. *Globigerinelloides multispinus* (Lalicker) occurs at some levels, but in the Upper Maastrichtian *G. volutus* (White) is more frequent.

Representatives of more warm-water and deep-water genera such as *Pseudotextularia*, *Planoglobulina, Globotruncanita* and *Globotruncana* occur sporadically as single specimens and are mainly confined to the late Maastrichtian units Tyoplovka A and Klyuchi B. *Globotruncana arca* (Cushman), *G. mariei* Banner & Blow, *G.*

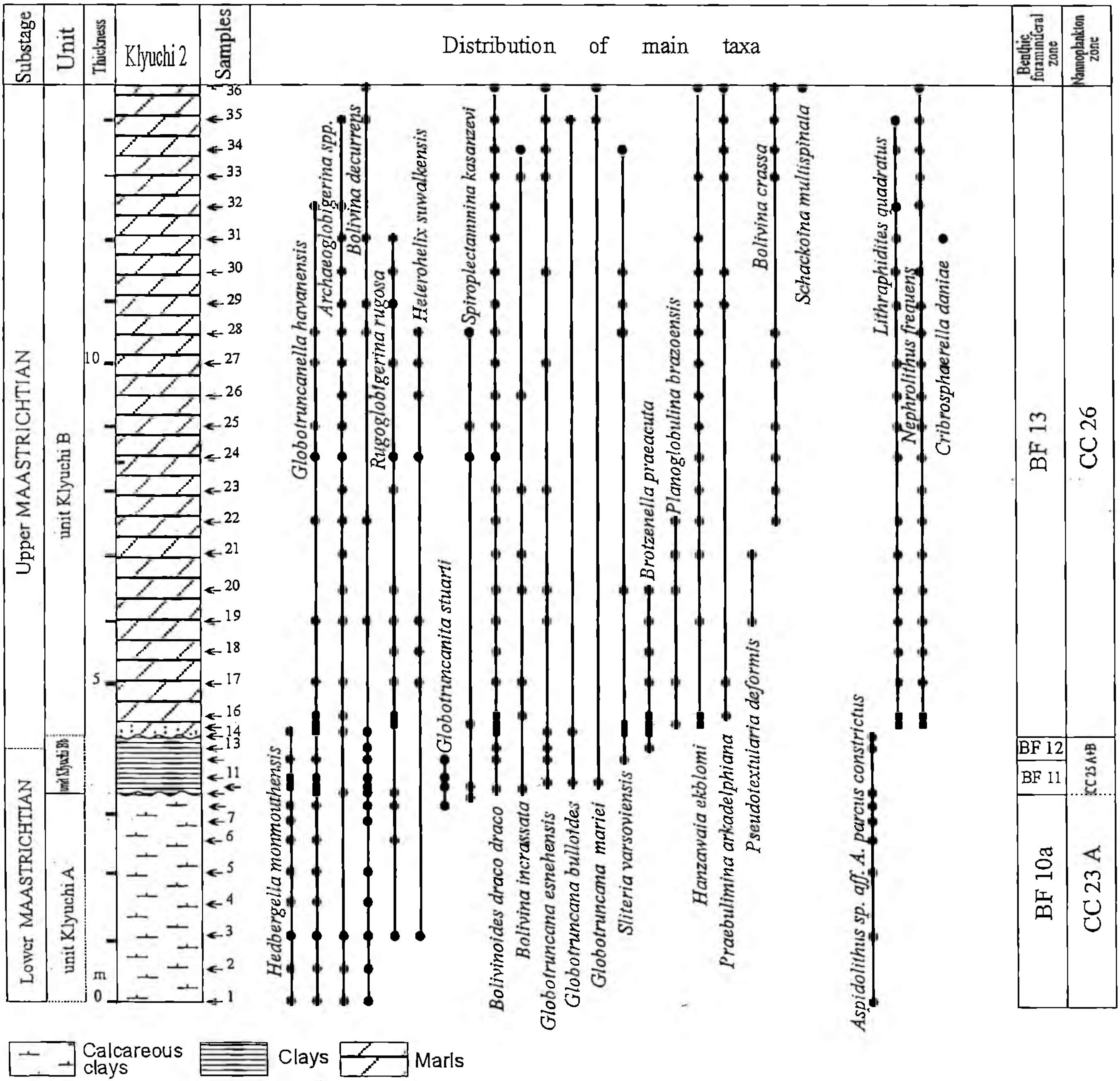


Fig 5. — Section Klyuchi 2 and stratigraphic distribution of the most important Foraminifera and calcareous nannoplankton taxa.

esnehensis Nakkady, *Pseudotextularia deformis* (Kikoine), *Planoglobulina brazoensis* Martin and *Racemiguembelina powelli* Smith & Pessagno occur in the upper 5 m of unit Klyuchi B in section Klyuchi 1.

Pseudotextularia elegans (Rzehak) (= *P. deformis* Kikoine, in this paper) has long been recognised in Europe as an index species of uppermost Maastrichtian at high latitudes (WICHER, 1953; MALMGREN, 1982; HULTBERG & MALMGREN, 1987). The level of first appearance of this species occurs in the upper part of the *Nephrolithus frequens* Zone of northern Europe (Denmark, Sweden) (MALMGREN, 1982).

In this interval (samples KL1-25 and KL2-36) also few specimens of the cosmopolitan but mainly high latitude taxon *Schackoina multispinata* Cushman & Wickenden were found (KRASHENINNIKOV & BASOV, 1985; HUBER, 1990).

Benthic Foraminifera are nicely preserved and relatively abundant (250-1700 specimens per gram of rock). The general taxonomic composition is close to that of the Polish Vistula Basin (GAWOR-BIEDOWA, 1992) and clearly differs from these in the Crimea (ALEKSEEV & KOPAEVICH, 1997). The benthic assemblages are completely dominated by calcareous forms. The agglutinated

Foraminifera (mainly *Spiroplectammina, Bolivinopsis, Arenobulimina, Ataxophragmium* and *Heterostomella*) represent no more than 1-2% of the assemblage. Among the calcareous taxa the most abundant are the infaunal species of *Bolivina, Praebulimina, Bolivinoides, Stilostomella* and *Pseudouvigerina* and some nodosariids. The epifaunal taxa belonging to *Cibicidoides, Gavelinella, Anomalinoides* and *Brotzenella*, as well as *Hanzawaia ekblomi* (Brotzen), *Stensioenia pommerana* Brotzen, *Gyromorphina allomorphinoides* (Reuss) and large *Lenticulina* species constitute a subordinate part of the assemblages.

For age determination we used the benthic foraminiferal zonation of the European palaeobiogeographic province (BENIAMOVSKIJ & KOPAEVICH, 1998). The oldest Lower Maastrichtian benthic assemblage occurs in units Lokh A and Klyuchi A. It consists mainly of *Bolivina decurrens* (Ehrenberg), *Neoflabellina reticulata* (Reuss), *Spiroplectammina kelleri* Dain, *Bolivina incrassata* Reuss, *Cibicidoides aktulagayensis* (Vasilenko), *C. commatus* (Vasilenko) and *Stensioeina pommerana* Brotzen. In the upper part of unit Lokh A (samples LH1-19 and LH1-22) rare specimens of *Bolivinoides draco miliaris* Hiltermann & Koch occur. These and other forms are characteristic for Subzone BF10a (*Neoflabellina reticulata-Bolivina decurrens* Subzone).

The lower part of Unit Lokh B (7 m, up to sample LH1-43) contains the assemblage of Zone BF11 (*Bolivinoides draco draco* Zone). The marker subspecies *Bolivinoides draco draco* (Marsson) has its first appearance datum in the basal glauconitic sandstone bed of this unit (sample LH1-30). The upper part of unit Lokh B and unit Lokh C belong to Zone BF12 (*Brotzenella praeacuta* Zone) of the lower Upper Maastrichtian. The benthic assemblage of unit Klyuchi Bb is very different from that of the underlying unit and appears to consist of both the BF11 and BF12 zones. *Bolivinoides draco draco* (Marsson) and *Spiroplectammina kasanzevi* Dain have their first appearance at the base of this unit, but *Brotzenella praeacuta* (Vasilenko) was found in sample KL2-13, 0.6 m higher up the section. Unit Klyuchi B belongs to Zone BF13 (*Hanzawaia ekblomi* Zone). This species has its first appearance in sample KL2-15 and 3 m higher up it is joined by the first *Bolivina crassa* Vasilenko.

Unit Tyoplovka A in sections Tyoplovka 2 and Tyoplovka 3 does not contain the marker species of Zone BF13, but the presence of *Bolivinoides draco draco* (Marsson) and sparse *Bolivina crassa* Vasilenko in samples TP2-18 and TP2-26 give a clear indication of their age. Units Klyuchi B and Tyoplovka A are characterized by the presence of a few specimens of *Sliteria varsoviensis* Gawor-Biedowa, although consistently represented. This taxon is considered as an indicator of late Maastrichtian upwelling sites (WIDMARK & SPEIJER, 1997).

CALCAREOUS NANNOPLANKTON

The calcareous nannofossils are abundant in all studied sections and have generally moderate or poor preservation (Plate 3). In some intervals the signatures of dissolution and overgrowth are evident. The dominance in assemblages of resistant species such as *Micula decussata* Vekshina, *Arkhangelskiella cymbiformis* Vekshina, *Prediscosphaera grandis* Perch-Nielsen, *Cribrosphaerella ehrenbergii* (Arkhangelsky) and several others in most assemblages, confirm the influence of dissolution on the taxonomic composition of the nannoflora. The distribution of the identified taxa in the studied sections is shown in Tables 1-4.

In section Lokh 1 the dominant species throughout the succession are *Arkhangelskiella cymbiformis* Vekshina, *Cribrosphaerella ehrenbergii* (Arkhangelsky), *Watznaueria barnesae* (Black *in* Black & Barnes) Perch-Nielsen, *Eiffellithus turriseiffeli* (Deflandre *in* Deflandre & Fert) Reinhardt, *E. parallelus* Perch-Nielsen, *Kamptnerius magnificus* Deflandre, *Prediscosphaera grandis* Perch-Nielsen and *Micula decussata* Vekshina. Also frequent are *Microrhabdulus decoratus* Deflandre, *Lithraphidites carniolensis* Deflandre, *Arkhangelskiella specillata* Vekshina, *Chiastozygus literarius* (Górka) Manivit and *Cretarhabdus conicus* Bramlette & Martini.

The nannofossil assemblage of unit Lokh A is characterized by *Aspidolithus* sp. aff. *Aspidolithus parcus constrictus* (Hattner *et al.*) Perch-Nielsen and *Tranolithus manifestus* Stover which do not cross the boundary between units Lokh A and B. The last specimens of the first species occur in the basal bed of unit Lokh B just above the hiatus, in LH1-31 and LH-32, probably, as a result of reworking. These *Aspidolithus* specimens differ from the typical *A. parcus constrictus* by a wider central field (Plate 3, Figure 13). *Reinhardites levis* Prins & Sissingh *in* Sissingh is rare and was found only in samples LH1-20, LH1-21 and LH1-29 and this is not the real first appearance of this species. The presence of these nannofossil taxa indicates that unit Lokh A belongs to Subzone CC23a.

The nannofossil assemblage of units Lokh B and C indicates subzone CC25a and the lower part of subzone CC25b, because of the absence of *Lithraphidites quadratus* Bramlette & Martini, which according to PERCH-NIELSEN (1985) has its first appearance in the middle of CC25b. In unit Lokh C the nannoplankton assemblage becomes less diverse, but this is due to the disappearance of rare species such as *Braarudosphaera bigelowii* (Gran & Braarud) Deflandre, *Chiastozygus fessus* (Stover) Shafik, *Rhombolithion speetonensis* Rood & Barnard and *Markalius perforatus* Perch-Nielsen.

In the sections Klyuchi 1 and Klyuchi 2 calcareous nannofossils are abundant, but have mainly moderate or poor preservation. The dominant species are the same as in the section Lokh 1. The most ancient assemblage which is identical to the assemblage of unit Lokh A is characteristic for unit Klyuchi A. It contains *Aspidolithus* sp. aff. *A. parcus constrictus* that has its last appearance in sample KL2-14, but no *Reinhardites levis* Prins & Sissingh *in* Sissingh. *R. levis* is probably very rare in the Saratov Region. Unit Klyuchi A belongs to subzone CC23a.

Table 1.
Distribution of calcareous nannofossils in the Maastrichtian of section Lokh1

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aspidolithus aff. parcus constrictus	F	F	R	F	F	R	F			F			F	R	R	F	F	
Arkhangelskiella cymbiformis	A	A	A	A	A	C	V	A	A	A	C	A	A	C	A	A	C	A
Cribrosphaerella ehrenbergii	A	C	A	C		A	C	A	A	A		A	C	A	C	A	A	A
Calculites obscurus	R	F											F	F				R
Braarudosphaera bigelowii	R										R							
Eiffellithus turriseiffelii	A	C	A	C	C	F	A	F	A	C		C			C	C	A	C
Kamptnerius magnificus	R	F	F		A	F	A	A	C	C	F	C	C	F	F	C	C	C
Micula decussata	A	A	A	A	A	C	F	A	A	A	A	A	A	A	C	A	A	A
Lithraphidites carniolensis	F	F		F	F	F		R	F		F		F	F		C	R	F
Prediscosphaera grandis	R	C	C	C	C	F	F	C	C	C	A	C	A	A	C	A		F
Microrhabdulus decoratus	F		F	F			R	R	C			F	F	F	F	F	F	
Lucianorhabdus cayeuxii	R							R			R	R		R			R	R
Watznaueria barnesae	C		C	C		F	F	F	F		F	C	C		C	F	C	F
Vekshinella angusta	F			F					R		F	F			R	F	F	
Ahmuellerella octoradiata			F		F	F	R	F	F	F						F	F	
Micula concava			F			F							R		F		F	
Tranolithus manifestus			F			R			R			F	F		F			
Zygodiscus spiralis			C				F			F	C				F		F	
Arkhangelskiella specillata				A	A				C	A		A	C	C		C	C	
Chiastozygus litterarius				C	F			A		C	F			F		C		
Rhombolithion speetonensis				R														R
Chiastozygus amphipons					F	F								C			C	
Cretarhabdus conicus					F					F				C	F			R
Prediscosphaera cretacea					F					F				C	F			R
Zygodiscus diplogrammus						R			R						R	R	F	
Prediscosphaera spinosa						F							F	F	F	R		F
Zygodiscus slaughteri						F	R											R
Markalius inversus								R		F	F		R	F				R
Microrhabdulus attenuatus									R									
Chiastozygus platyrhethus												R						
Prediscosphaera buckryi												R						
Stradneria crenulata												F			R			
Cretarhabdus angustiforatus													R					
Markalius perforatus														R				
Chiastozygus fessus																R		
Manivitella pemmatoidea																	R	
Rhagodiscus angustus																		
Obliquipithonella operculata																		
Reinhardites levis																		
Cyclagelosphaera margerelii																		
Prediscosphaera intercisa																		
Obliquipithonella saxea																		
Biscutum constans																		
Eiffellithus parallelus																		
Preservation	G	G	G	M	M	P	M	M	M	M	M	P	P	P	M	M	M	M

Note: Preservation: G - good, M - moderate, P - poor; Abundance: V - very abundant, A - abundant, C - common, F - few, R - rare, P - present

Table 1.
Continued

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
F	F					R				R		R	R							
A	C	C	A	A	A	C	A	A	C	A	V	V	A	C	C	V	A	A	A	V
A	C	A	C	C	C	A	C	A	C	A	A	A	A	C	A	V	A	A	A	A
		F	F		F			F		C		F				F			F	
F		R	R		R		R	R	R			R			R	R				
A		C		A		A	A	A	C		C	C	A	C	C	A	C	C	A	A
F	F	R	F	F	F			C		C	A	C	F	F	R		C	R		
A	C	A	C	C	A	A	C	A	A	A	V	V	V	A	A	V	C	A		V
	F	F	F		F	F	F		R		F			C		C		A		A
F	C	A	C	F	C	C	C	C	C	A	V	V	C	A	C	A	A	F		A
		F	F	F	R	F	C	C	F	C	A		A	C		A	A	C	A	C
		R					R	F		R						R			R	
		C	C	F			F	F	C	F	C	C		F	C	F	F	F		C
	C			F						F	A	A					F			F
					F		F	F		F			C			F		F	F	
C		F		R	F	F								F	R					
			R	F		R	F	C												
			F			F	C	C	F	A		A	C	C		A	C	C	F	C
		C				C		A	C		A		A			A	A	C	A	A
A			F	F			A		F	F	C	A		C		C	C		C	F
									R			R	R		R				R	
F			F	F					F						F		C			
R		F			F	F	F		C	F				F		R		R		
R		F			F	F	F		C	F				F		R		R		
F		F	F	R	R	F	F		R		C	C	F	F	R	R				F
	F					R	R				F			F	F	R	R			
				R				F		A		C					R			
			F			R			R				F	C		F		R		F
F		R	R						F											
R		F			R															
			R				F			F	R	F		R			F		R	
F			F								F	F		R		R	F		R	
R					F			C					F		R			F	F	
	F	R								R										
	R																			
						R									R					
													R		R					R
														R	F			F	F	
M	P	M	M	P	M	P	P	M	M	P	P	M	M	P	P	P	P	P	M	M

Table 1.
Continued

Species	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
Aspidolithus aff. parcus constrictus																
Arkhangelskiella cymbiformis	A	A	C	A	C	A	A	C	A	A	A	A	A	A	C	A
Cribrosphaerella ehrenbergii	A	A	A	A	A	A	A	A	A	A	A	C	C	A	A	A
Calculites obscurus	F										R	F			R	F
Braarudosphaera bigelowii			R	R		R										
Eiffellithus turriseiffelii	C	C	C		C	V	C	A	A	C	F	C	C	C	C	A
Kamptnerius magnificus	F	F	R	R		R			F	F	F		F	R	R	
Micula decussata	C	C	A	A	A	A	V	V	A	A	A	A	A	C	A	C
Lithraphidites carniolensis	C	F		F	A	F		F		F	R	F	F		C	
Prediscosphaera grandis	C	C	A	C	A	A	C	A	A	A	C	C	C	C	A	C
Microrhabdulus decoratus	C	F	C	F			F	F	F		C	F		F	F	A
Lucianorhabdus cayeuxii	R			R			R								R	
Watznaueria barnesae	C	F	C	C		F	A	C	C	F		C	A	C	F	C
Vekshinella angusta	C		C			R			F	F				F		
Ahmuellerella octoradiata			F		F	F		R	C			R	F			F
Micula concava							F	F			F	F	F		F	
Tranolithus manifestus																
Zygodiscus spiralis	C	F	C		R		F	F		C	C	R	C	F	C	C
Arkhangelskiella specillata		A	C	A	C	A	C						A	C		A
Chiastozygus litterarius			A	F	C	C	C		F	C	F	F	F	C	F	V
Rhombolithion speetonensis						R		R								
Chiastozygus amphipons				F			F		C	F		C			F	
Cretarhabdus conicus	F				F	F	F	F			R		R			F
Prediscosphaera cretacea	F				F	F	C	F	F		F	C			F	A
Zygodiscus diplogrammus	F	F		R		F						R		R	R	R
Prediscosphaera spinosa	R			F	R	R	F	R	F	F	R	F			R	F
Zygodiscus slaughteri		C			R	C		R	F		C	R		F	F	
Markalius inversus	F			R		C	F			F	F	F	F			
Microrhabdulus attenuatus		R														
Chiastozygus platyrhethus																
Prediscosphaera buckryi								R				R				
Stradneria crenulata		R														
Cretarhabdus angustiforatus																
Markalius perforatus				F			R	F	F	F						
Chiastozygus fessus				R			R									
Manivitella pemmatoidea													R			
Rhagodiscus angustus	R	F	R				F						F	F		
Obliquipithonella operculata				F									C	F	C	R
Reinhardites levis																
Cyclagelosphaera margerelii																
Prediscosphaera intercisa																
Obliquipithonella saxea		R			R											
Biscutum constans	F			F			F	F	F			F				
Eiffellithus parallelus							R	R							R	R
Preservation	M	P	P	P	P	P	P	M	P	P	P	P	M	M	P	P

Table 2.
Distribution of calcareous nannofossils in the Upper Maastrichtian and Palaeocene of section Klyuchi 1

Species	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26
Arkhangelskiella cymbiformis	A	A	A	A	A	V	C	C	A	A	C	A	A	A	A	C	A	A
Micula decussata	A	A	V	A	V	A	V	C	V	V	A	V	V	A	A	A	V	C
Prediscosphaera cretacea	F		F	F			F	C	F	C	C	F		F			C	
Watznaueria barnesae	C		C		F		C	C	A	C	C	C	A	C	A	A	C	C
Eiffellithus turriseiffeli	C	V	C	A	A			A	A	C	C	A	A	C	A	C	A	A
Lithraphidites carniolensis	F	F	F	F		C	F	C	F	F	F	F	F	F	C	F	F	F
Nephrolithus frequens	C	C	C	C	A	A	C	A	C	C	C	A	F	A	A	F	C	A
Zygodiscus spiralis	F	F	F	C	F		F		F	F		F	F	F	F	F	F	F
Prediscosphaera intercisa	R				R	R		R					R					R
Cribrosphaerella ehrenbergii	A	A	C	A	C	C	C	A	C	C	C	A		C	C	C	C	A
Arkhangelskiella specilata	A				A	A	C		A			F			C			A
Prediscosphaera grandis	A	C	C	C	A	C	C	C	C	C	C		F	C	C	C	A	C
Pr. stoveri	R										R			R		R	R	
Cretarhabdus conicus	F							F	F	F						F	F	
Ahmuerella octoradiata	F	F		R			R						F					
Calculites obscurus	F			F		F	F	R	F	F				F				
Chiastozygus litterarius	C				C		F	F	F		F	F			F			
Ch. amphipons	F			C	C		F	C			F	F			F	F		
Microrhabdulus decoratus	F	F	F		C			C			C		F	C	C			F
Lithraphidites praequadratus	R										R							
Lucianorhabdus cayeuxii	F					R	R					R					F	
Prediscosphaera spinosa		F	F	R				F	F			F	R	F	F	F	C	
Eiffellithus parralelus		R									R	R	R					
Microrhabdulus attenuatus		R	R	R				R	R		R					R	R	
Kamptnerius magnificus		F											F					
Chiastozygus fessus		R																
Micula concava		F	F	R	R	F										R		
Glaukolithus diplogrammus		F		F	F		F	R		F	F				F			
Lithraphidites quadratus		R	R		F	F	R	F		F	F		F	C	F	F	F	F
Vekschinella angusta		F	F	R				F							F			
Zygodiscus diplogrammus			R	F				F		R		R	F	R			F	F
Cretarhabdus crenulatus			F															
Stradneria crenulata			R	F		F					R			F	F			
Ceratolithus aculeus			R															
Braarudosphaera bigelowii					R													
Corollithion signum						R												
Rhagodiscus angustus						R			F	F								
Chiastozygus platyrhethus						R								R				
Aculeus scotus						R												
Cylindrolithus oweinae						R												
Z. slaugtheri						R	R					R						
Watznaueria biporta									R					R		R		R
Broinsonia enormis									R									
Markalius perforatus										F								R
Cribrosphaerella daniae										F	F					R		
Biscutum constrictum										F								
Zygodiscus acanthus										R								
Rhombolithion speetonensis											R							
Manivitella pemmatoidea													R					
Lithraphidites grossopectinatus																		
Vekshinella crux																		
Obliquipithonella operculata																		
O. saxea																		
Preservation	P	P	P	P	M	P	P	M	M	M	M	M	M	M	M	M	M	M

Table 2.
Continued

25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
A	A	A	A	A	A	A	C	C	C	C	C	C	F		F	F	F	C	C	A	A	A	C	C
A	V	V	V	A	V	A	A	A	A	A	A	C	C	F	C	C	A	A	C	V	A	A	A	A
F	C	F	C	F	F	C	F	F	F	F	R				R				R		F	F	F	F
F	A	C	C	C		C	C	C	C	C	C	F	F		C	F	C	C	C	A	C	C	C	C
C	A	C	C	C	A	C	A	C	C	C	F	F				F	C	C	F	C	C		F	F
F	F	F	F	F	F		F	F	F	F	F		F			F	F				F			F
C	C	C	A	C	C	C	A	F	C	C	C	F	R	F	F	F	F	C	C	C	C	C	F	F
F	F	C	F	F			F	F	F	F			R	R	F	F	F		F	F	F	F	F	C
			R			R											R							
C	A	A	A	C		C	A	C			C	C	F	F		F	F	A	F	A	A		C	A
A		C					C	C			C	C					F				C			
F	C	C	A	C	A	A	C	F	C	C	C			F	F			C	C	C	C	C	F	C
	R																							
R	F	F	F			F	F		F	F				R										
															R		F			R			R	
					F						F			F										
	F		F		F	F	R	F	F	C	F	R	F		F	R		F		F		R	F	[illegible]
	F		F		F	F		F	C	C	F	R	F			F				F		F		
					F				R			F			F		F	F	F	F	F	F		[illegible]
R	R		R								R													
R	F	R					F	R	F	F	F								R		R		R	[illegible]
R		R															R							
R		R	R	R		R	R	R										R					R	
		F			R				R	F	R													[illegible]
	R	R				R			R		F				F	R	R		R	F	R	R	R	[illegible]
R			F		R																			
F	F	F	F	F	F	F	F	F	F		R	R		R	F			F			R			
F	F			R	F					R	F							F						
						R								R										
				F																				
				F	R					R														
															R									
										R														
	F							R													R		R	
				R		R																		
				F												R								
	F						R	F	F	F			F	F		F	F	F	F	F	F	F	F	
			F									R						F						
														R						R				
R																								
R																								
									F	V		C	A	C	C	C	C	C	C	F	C	C	A	
															R	R			R					
G	G	M	M	M	G	G	M	M	M	G	G	M	M	M	M	G	M	G	G	G	G	G	G	

Table 3.
Distribution of calcareous nannofossils in the Maastrichtian of section Klyuchi 2

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Aspidolithus aff. parcus constrictus	R		R		F	R	R	R	R				R	R			
Micula decussata	V	A	A	A	C	A	V	A	A	C	V	A	V	A	A	V	A
Cribrosphaerella ehrenbergii	A	C	C	A	A	C	C	C	C	A	C		A	C		A	A
Arkhangelskiella cymbiformis	C	A	A	C		C	V	V	A	A	C	C		A	V	C	C
Arkhangelskiella specillata	C		A	A	A		V	C		C		F				C	C
Eiffellithus turriseiffelii	A	C	A	A	C	C	A	V	V	V	V	V	A	C	V	V	A
Prediscosphaera intercisa	F	R	R	F		R							F				
Lithraphidites carniolensis	F		C	C	F	F	F	R		F			F	F		F	R
Micula concava	R	R		F			R	R		F	F	R	R	R		R	
Cretarhabdus conicus	R	F	F				F							F			R
Vekshinella angusta	R					F	F							F			
Microrhabdulus decoratus	F	F	C	C	C	C	C	F	F	F	F	C	C	F	F	F	
Microrhabdulus attenuatus	F	F	R						R	F			R				
Chiastozygus platyrhethus	R			F	F												
Markalius circumradiatus	F			R	R	F					R	R					
Prediscosphaera cretacea	R	F	F	F	F				R	R	F						
Zygodiscus spiralis	F	C	A	C	A	C	C		F	A	C	C	C	A	C	C	F
Ahmuellerella octoradiata	F	C	F		C	A	C	F		A					F		
Chiastozygus litterarius		A	A	A	A	A	A	C	C	C	A	A	A				
Prediscosphaera grandis		C	A	A	A	F	A	C	C	A	A	C	A	A	V	A	C
Zygodiscus slaughteri		F		C												C	F
Parhabdolithus embergerii		R															
Rhagodiscus splendens			R														
Prediscosphaera spinosa			F				F										F
Zygodiscus acanthus				R													
Kamptnerius magnificus					R				R			R			R		
Obliquipithonella operculata					R												
Tranolithus manifestus						R											
Chiastozygus fessus							F										F
Lucianorhabdus cayeuxii								R								F	
Obliquipithonella saxea											R		R				
Ceratolithus aculeus													R		R		R
Rhagodiscus angustus														R			
Chiastozygus amphipons														R			
Braarudosphaera bigelowii															R	R	
Parhabdolithus asper															R		
Biscutum constans															F		
Nephrolithus frequens															C	A	C
Lithraphidites quadratus															F	F	F
Calculites obscurus															F		
Cretarhabdus crenulatus																	
Rhombolithion speetonensis																	
Stradneria crenulata																	
Vekshinella crux																	
Lithraphidites praequadratus																	
Cribrosphaerella daniae																	
Cylindralithus dupeii																	
Lithraphidites grossopectinatus																	
Chiastozygus anceps																	
Preservation	M	M	M	M	M	M	G	G	M	M	G	M	M	M	M	M	M

Table 3.
Continued

18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
V	V	V	V	V	V	A	V	A	V	A	A	A	A	A	V	V	A	V
C	R	A			A	A	A	A	C	C	V	A	C	A	C	A	C	A
A	C	A	A	A	A	C	A	A	C	A	C	A	A	V	A	A	F	C
		C		A		C				A	C		C	V	C		F	C
V	V	V	V	C	C	C	C	A	A	V	A	A	C	C	A	F	C	C
				R	R		R								R	F	R	R
				F	C	F	C		F	F	C	F	F	C	C	F	C	
R	R					R		R	F	R						F	F	
F	F	F	R	F	R	R		F	F	F		F	R	F	F			
				F		F											F	
A	F	C	F	F	F	F	F		F		F		F		A			
						R		R		R	R	R			F	R		
R							R									F		
				C	F			F			R	F			F	R	F	
A	C	A	A	C	C		C	F	F	C		C	C	C	A	A		C
								F		F								
				C	C		A	C		C			C	A		A	A	A
V	F	A	V	A		A	V	A	V	V	A	A	V		V	V	V	V
F	F			F			F	F					F		R	F		
				R		R		F			R		F					
																		F
R	R				F			R		R					R		R	
		C					F	R	R	F	F	F	R	F	R	F		
							R		R						R			
	R					R		R							R			
A	C	A	A	C	A	A	A	C	A	A	C	A		A	A	A	A	A
F	F	F	F	C		F		R	F		F	F	F	F		F	C	
F		F				F	F					F	F		F			
	A																	
		R															F	
				F						R								
									R									
														R				
													F					
																	R	
M	M	M	M	M	M	M	M	M	M	M	M	M	M	P	M	M	M	M

Table 4
Distribution of calcareous nannofossils in the Upper Maastrichtian of section Tyoplovka 2

Species	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Arkhangelskiella cymbiformis	C	A	A	A	A	C	A	A	A	V	V	A	V	A	A	A	A	A	A	V
Micula decussata	A	V	A		A	C	A	V	A	V		V	A	V	V	V	V	V	A	V
Kamptnerius magnificus	F	F		F			R			R	F						R	R	R	F
Watznaueria barnesae	C	C	C	C	C	C	C	C	C	A	A	A	C	C	A	A	A		C	A
Rhagodiscus angustus	F					R	R		F	F					F	F		R		F
Lithraphidites carniolensis	R	C	F	F	F	F	C	F	C		F	C	F		F	F	F	F	F	F
Nephrolithus frequens	F	C	C	C	C	C	F	F	C	C	C	C	C	C	A	A	A	C	C	A
Zygodiscus spiralis	F	F	C	F	F	F	F			C	C	C		F	C	F	R	F		F
Z. slaugtheri	R		C						F	C	R	C	F	R		R	R	F		F
Eiffellithus turriseiffeli	F		C		C	C	C	C	C		A		C	F	C	V		C	F	
Prediscosphaera cretacea	R	C	C	F	F	F		C	F			F	C	F	C	A	C	C	F	A
Pr. grandis	F	A	F	C	C	C	A	A	A	F	V	A	V	A	V	V	A	A	A	V
Microrhabdulus decoratus	F	F	F		C	C	C		F	F	F	F	F	F	F	C	C	F	F	F
Cribrosphaerella ehrenbergii	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	F	C	A
Manivitella pemmatoidea		R														R				
Cretarhabdus conicus		F	F				R	F			F	C	R	F		F	F			F
Vekschinella angusta		F		R				F		R			R				F		F	
Lithraphidites quadratus		F	F		F	R	F	F	C	A	R	R	F	F			F	R	F	
Micula concava		R			R				F		F		F			F		R	F	
Chiastozygus litterarius		C	C	F	C	F	C	F			C	C				V	C	A		A
Ch. amphipons		C	C	F		F				C	C	C		C	A	A	C	A		A
Arkhangelskiella specilata		A		A		C		A		V	V		V	A			A	A		A
Prediscosphaera spinosa			F		F			C	F		F	R		C		F				
Eiffellithus parralelus			R											R						
Ahmuerella octoradiata			F	F					R	F			F		F	F	F	R	R	
Zygodiscus diplogrammus			F	F				F	F					R					R	F
Rhombolithion speetonensis			F									R								
Cribrosphaerella daniae			R	F	R		F	F	F	F			R		F	C	F	A	F	F
Glaukolithus diplogrammus				F	F							F								
Markalius perforatus				F	F															
M. inversus				R				F											F	F
Prediscosphaera bukryi				R											R					
Pr. stoveri				R											R				R	
Chiastozygus fessus				R											R					
Prediscosphaera intercisa					R						F									R
Microrhabdulus belgicus							R													
Obliquipithonella saxea							F													
O. operculata							F		F											F
Biscutum constans								F												
Watznaueria biporta									R	R					F					R
Microrhabdulus attenuatus									R									R		
Calculites obscurus													F							F
Cylindrolithus oweinae															R					
Preservation	M	G	M	M	M	M	M	M	M	M	G	M	G	G	G	M	G	M	M	M

Table 5
Quantitative data for terminal Maastrichtian in section Klyuchi 1

Distance from the top of Maastrichtian (m)	Number of sample	$CaCO_3$ content, %	Total counted specimens	Abundance of planktonic Foraminifera (specimens per 1 g)	Abundance of benthic Foraminifera, (specimens per 1 g)	Planktonic Foraminifera, %	Heterochelicidae, %	*Globigerinelloides*, %	*Globotruncana* (specimens per 50 g)	Other planktonic Foraminifera, %
-0.05	KL1-18	–	548	5684	621	90.1	75.7	21.3	24	2.2
-0.15	KL1-19	–	501	4989	990	83.4	76.6	14.6	30	8.4
-0.25	KL1-20	55	377	3793	376	91.0	72.0	25.1	36	2.6
-0.45	KL1-21	–	647	5509	1116	83.2	78.8	19.0	44	2.0
-0.95	KL1-22	58	972	6117	1116	84.6	81.3	17.3	136	1.4
-1.45	KL1-23	57	514	9275	1735	84.2	89.1	6.5	52	3.7
-1.95	KL1-24	57	621	5679	745	88.4	68.8	26.0	–	4.7
-2.45	KL1-25	–	427	8290	763	91.6	81.6	15.1	5	3.3
-2.95	KL1-26	59	449	2098	374	84.9	73.2	25.7	4	1.1
-3.45	KL1-27	–	516	5938	353	87.4	81.6	16.6	4	1.8
-3.95	KL1-28	58	564	21217	1884	91.8	81.7	15.8	1	2.5
-4.45	KL1-29	58	621	2760	420	86.8	75.3	22.5	4	2.0
-4.95	KL1-30	55	721	6482	1130	85.2	76.1	9.8	13	14.2
-5.45	KL1-31	65	1044	2232	440	83.5	82.3	12.8	–	4.8
-5.95	KL1-32	63	750	3348	491	87.2	89.3	8.3	–	2.4

Unit Klyuchi B from the glauconite-rich basal bed (sample KL2-15) contains a nannofossil assemblage with *Lithraphidites quadratus* Bramlette & Martini and *Nephrolithus frequens* Górka and therefore belongs to zone CC26. *Cribrosphaerella daniae* Perch-Nielsen, a characteristic taxon for the upper part of CC26 in high latitudes of the Southern Hemisphere (Pospichal & Wise, 1990), has its first appearance in sample KL1-34. The abundance of *Nephrolithus frequens* and the absence of warm-water *Micula mura* (Martini) Bukry and *M. prinsii* Perch-Nielsen are in agreement with the high latitude setting of the Saratov sections.

The nannofossil assemblage of unit Klyuchi Bb contains *Aspidolithus* sp. aff. *A. parcus constrictus* and this interval, as well as the lower unit Klyuchi A, might belong to CC23a. However this taxon could be reworked and the biozonation of this interval based on nannoplankton remains unclear.

Unit Klyuchi B in section Klyuchi 2 belongs to Zone CC26 because of the presence of *N. frequens*. *Cribrosphaerella daniae* Perch-Nielsen has been found in one level, 7.8 m above the base of unit Klyuchi B (sample KL2-31).

Nephrolithus frequens (first appearance in sample TP2-16) and *Cribrosphaerella daniae* (first appearance in sample TP2-18) are consistently represented throughout unit Tyoplovka A in section Tyoplovka 2 indicating the upper part of zone CC26.

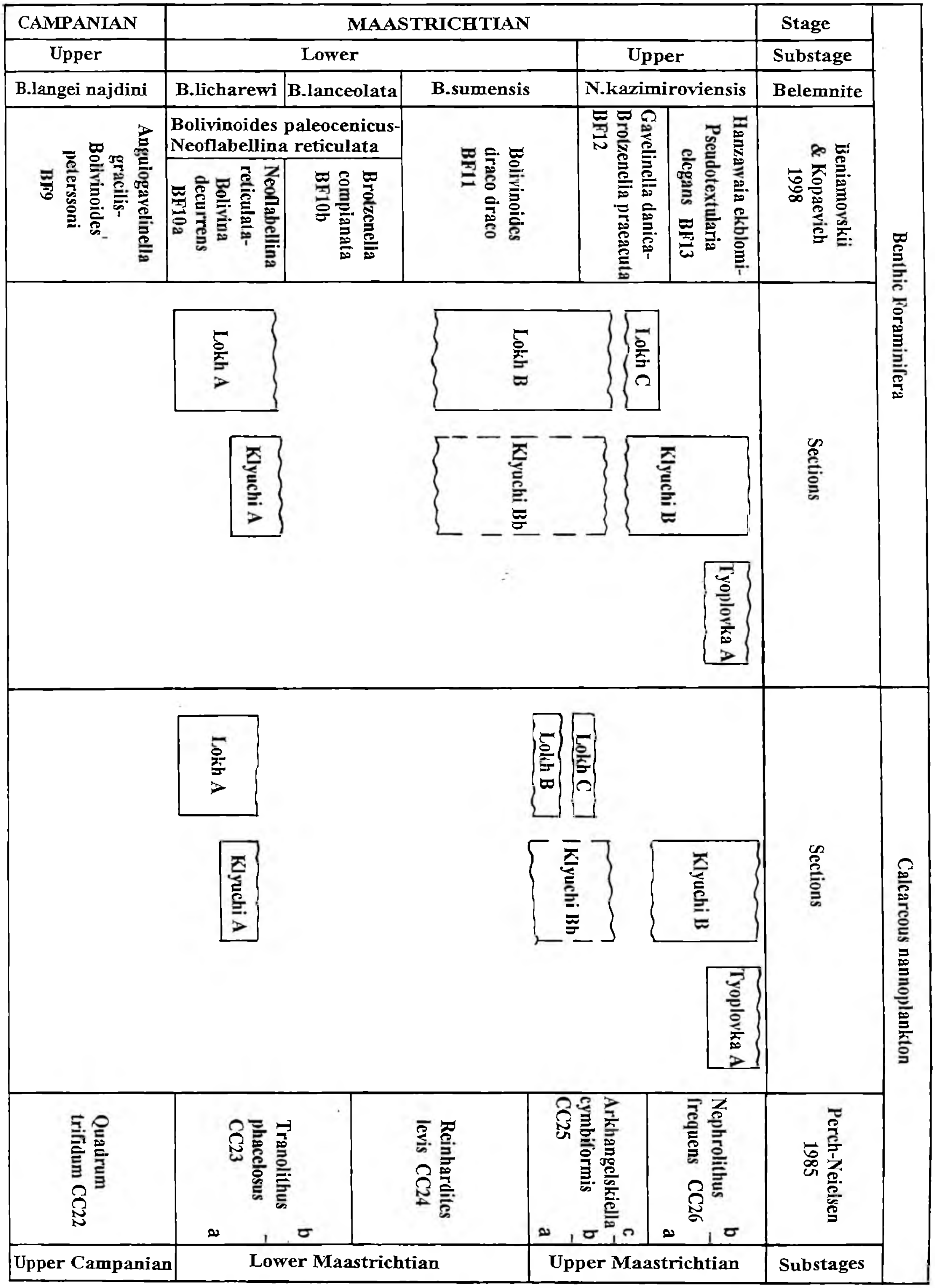
The Lower Palaeocene siliceous rocks in section Klyuchi 1, named Unit Klyuchi C, only contain reworked Cretaceous taxa indicative for CC26. Such Cretaceous species as *Lucianorhabdus cayeuxii* Deflandre, *Cretarhabdus conicus* Bramlette & Martini, *Calculites obscurus* (Deflandre) Prins & Sissingh *in* Sissingh, *Kamptnerius magnificus* Deflandre, *Stradneria crenulata* (Bramlette & Martini) Noël, *Zygodiscus diplogrammus* Deflandre *in* Deflandre & Fert occur only in the lowermost part of Palaeocene Syzran Formation (up to sample KL1-11). However, the relatively abundant *Obliquipithonella operculata* (Bramlette & Martini) and *O. saxea* (Stradner) are characteristic features of the assemblage from unit Klyuchi C and they are the only signature of Palaeocene age for this unit.

MACROFOSSILS

A single rostrum of *Belemnella lanceolata gracilis* Arkhangelsky (Plate 4, Figure 1) was found *in situ*, 1.8 m above base of unit Lokh A, together with moulds of small bivalves. The subspecies is characteristic for the lower Lower Maastrichtian in the southern part of the Russian Platform (Naidin, 1974). It was first described by Arkhangelsky (1912) from the Lower Maastrichtian of Saratov. The basal sandy bed of unit Lokh B contains rare moulds of *Hoploscaphites* sp. aff. *H. constrictus* (J. Sowerby). This species is characteristic for the Maastrichtian in Europe. Eroded rostra of the *Belemnella sumensis* Group are also common in basal bed of unit Lokh B and occur together with moulds of small unidentifiable bivalves. Belemnite rostra which were collected on clays of unit Klyuchi Bb in section Klyuchi 2 could have been washed out from these clays or from the basal bed of unit Klyuchi B (the latter is more probable). They were identified as *Belemnella sumensis praearkhangelskii* Naidin. Their rostrum surface is smooth and the length of the first visible guard is 27-28 mm (Plate 4, Figures 2 and 3). The juvenile rostra from unit Klyuchi B are more cylindrical in outline, have no recognizable first visible guard and their anterior part is ornamented with weak vascular markings. These rostra belong to *Neobe-*

→

Fig 6. — Correlation of Maastrichtian lithological units based on foraminiferal and calcareous nannoplankton evidence.


CAMPANIAN
MAASTRICHTIAN
Stage
Upper
Lower
Upper
Substage
B.langei najdini
B.licharewi
B.lanceolata
B.sumensis
N.kazimiroviensis
Belemnite
Anguiogavelinella gracilis-Bolivinoides petterssoni BF9
Bolivinoides paleocenicus-Neoflabellina reticulata
Neoflabellina reticulata-Bolivina decurrens BF10a
Brotzenella complanata BF10b
Bolivinoides draco draco BF11
Gavelinella danica-Brotzenella praeacuta BF12
Hanzawaia ekblomi-Pseudotextularia elegans BF13
Beniamovskii & Kopaevich 1998
Benthic Foraminifera
Lokh A
Lokh B
Lokh C
Klyuchi A
Klyuchi Bb
Klyuchi B
Tyoplovka A
Sections
Lokh A
Lokh B
Lokh C
Klyuchi A
Klyuchi Bb
Klyuchi B
Tyoplovka A
Sections
Calcareous nannoplankton
Quadrum trifidum CC22
Tranolithus phacelosus CC23
a
b
Reinhardtites levis CC24
Arkhangelskiella cymbiformis CC25
a
b
c
Nephrolithus frequens CC26
a
b
Perch-Nielsen 1985
Upper Campanian
Lower Maastrichtian
Upper Maastrichtian
Substages

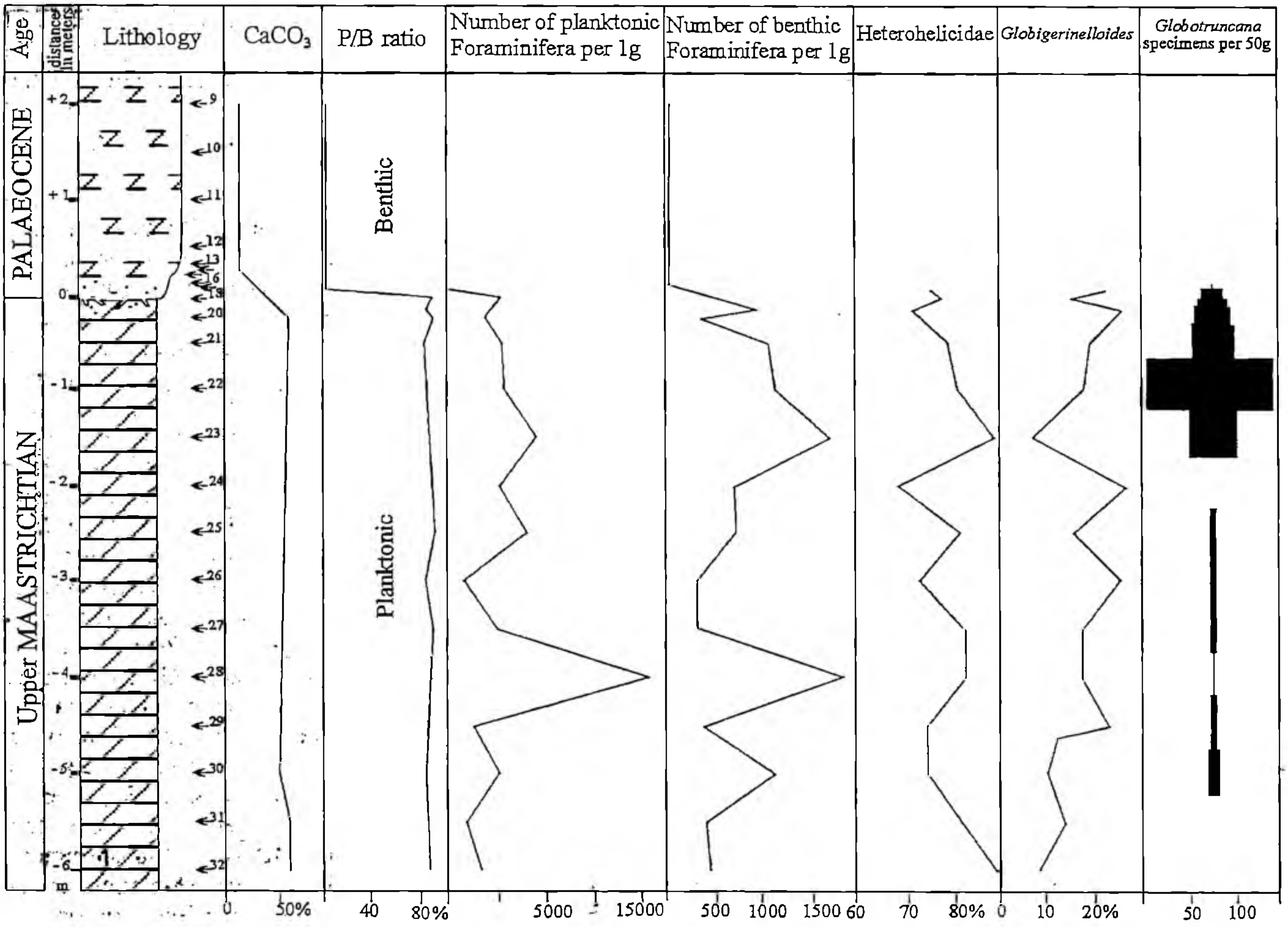


Fig 7. — Evolution of the main lithological parameters and changes in composition of the foraminiferal assemblages in the terminal Maastrichtian of section Klyuchi 1.

lemnella kazimiroviensis (Skolozdrowna). According to KOPAEVICH *et al.* (1987) *Belemnella sumensis praearkhangelskii* Naidin occurs in beds transitional from Lower to Upper Maastrichtian and *Neobelemnella kazimiroviensis* (Skolozdrowna) is distributed in Eastern Europe throughout the entire Upper Maastrichtian. Both taxa were described and figured by NAIDIN (1975) from the Saratov Region.

Thus, the belemnites support the age identifications based on benthic Foraminifera and calcareous nannofossils.

Correlations

The foraminiferal and calcareous nannofossil data certainly confirm an earliest Early Maastrichtian age for units Lokh A and Klyuchi A (Figure 6). The upper Lower Maastrichtian is not represented in the studied sections because of non-deposition or subsequent erosion. However, the correlation of Zone BF10a with the *Belemnella licharevi* Zone is not proven as *Belemnella lanceolata gracilis* Arkhangelsky, the characteristic subspecies for the younger *Belemnella lanceolata* Zone, co-occurs with foraminiferal taxa of the *B. licharevi* Zone.

Units Lokh B and Lokh C belong respectively to the uppermost Lower Maastrichtian and lower Upper Maastrichtian according to benthic foraminiferans, but have to be included in the lowermost Upper Maastrichtian on the base of calcareous nannoplankton. Unit Klyuchi Bb in section Klyuchi 2 may consist of condensed residual sediments of the same age.

Unit Klyuchi B is upper Upper Maastrichtian according to both fossil groups and belongs to CC26. The closely situated sections Klyuchi 1 and Klyuchi 2 can be correlated on the basis of first appearance of *Bolivina crassa* Vasilenko. Thus, the level of sample KL1-37 is the same as that of sample KL2-22. In this case the total thickness of unit Klyuchi B is about 12 m, and on top of section Klyuchi 2 only the uppermost 2 m of the Maastrichtian are not exposed.

According to the nannofossils unit Tyoplovka A from the Tyoplovka area also belongs to the Upper Maastrichtian. It seems to be coeval to the upper part of unit

Klyuchi B. The Maastrichtian succession in the North Saratov Region is very complete towards the top as evidenced by the presence of *Cribrosphaerella daniae* Perch-Nielsen in the upper part of unit Klyuchi B.

The age of unit Klyuchi C (lower part of the Syzranian Formation) in this locality, is uncertain, based on our data. The benthic Foraminifera are mainly represented by Maastrichtian taxa and only very few, for example, *Cibicides succedens* Brotzen, are characteristic for the Palaeocene. Nannofossils are exclusively represented by reworked Upper Cretaceous taxa. Fortunately DIGAS (1976) and KURLAEV *et al.* (1981) reported an abundant foraminiferal assemblage with about 50% of planktonic forms at the base of the Syzranian in this area, but probably from another valley. This assemblage contains according to their identifications *Globoconusa daubjergensis* (Brönnimann), *Subbotina pseudobulloides* (Plummer), *S. triloculinoides* Plummer and *S. varianta* (Subbotina), taxa which are typical for the Danĭan Zone P1c.

Unit Klyuchi C may be time equivalent of the Belogrodnya Formation - glauconitic clays and siltstones which outcrop about 40 km to the NE of Klyuchi on the right bank of the Volga River (MUSATOV & ERMOKHINA, 1998).

Cretaceous/Tertiary boundary

At section Klyuchi 1 it is possible to study the Cretaceous/Tertiary boundary in the North Saratov Region. The general opinion is that in this region the boundary between the Maastrichtian and the Palaeocene is discontinuous (ARKHANGELSKY & DOBROV, 1913; KAMYSHEVA-ELPATIEVSKAYA, 1951; DERVIZ, 1959).

Three kinds of K/T transitions exist:

(1) As a rule the top of the Maastrichtian is irregular with shallow depressions and with numerous burrows penetrating the underlying marls or chalk to different depths. These burrows are filled with siliceous material of Palaeocene Lower Syzranian "opokas". At the base of the "opoka" a thin (up to 0.5 m) conglomerate occurs with clasts of Cretaceous marls or chalks, sometimes with phosphoritic pebbles and abundant bryozoan fragments.

(2) In other sites, the K/T boundary is marked by a thin (1-5 cm) interbed of green clay with small chalk pebbles overlying the Maastrichtian.

(3) up to 2-3 m deep depressions occur at the top of Maastrichtian carbonate rocks in other localities. These depressions are filled with green-brown clay material containing few mainly agglutinated Foraminifera and Palaeocene "opokas" which often are intensively disrupted and are generally considered as ancient karst signatures.

As in other sites of the Volga River area, in Klyuchi 1 the K/T boundary coincides with a important hiatus and belongs to type (1). The basal bed of unit Klyuchi C, 15-20 cm thick, is heavily silicified and contains small (1-2 cm) clasts of Maastrichtian marls and abundant glauconite. Silification at this boundary interval is more intensive than it is in the upper part of this unit. Zones P0, P1a and P1b are probably missing in this section. However, the sequence of events can be described for the uppermost Maastrichtian in this section (Figure 7).

The planktonic Foraminifera dominate in the assemblage and their number is constant. P/B ratios change in narrow limits 83-91% and do not show a decrease towards the top of the Maastrichtian marls. The number of planktonic Foraminifera appears to increase upwards in the section up to sample KL1-23 (9275 specimens/g) and then decreases to 3700-5600 specimens/g in the interval 1.5 m below the top of Maastrichtian. The abundance of benthic Foraminifera shows a very similar trend, showing a maximum at the same level. The heterohelicids are the most abundant group among planktonic Foraminifera (68-89%), but they decrease in the last 1.5 m from 89 to 75%. The relative abundance of *Globigerinelloides* increases from 10 % at 6 m below the boundary to about 26 % in sample KL1-24, 2 m below the boundary. After a sharp minimum in sample KL1-23 (6.5%) it shows again an obvious tendency to increase. Globotruncanids (Fig. 7), the most explicit deep-water component, are absent in the lowermost part of the section (6-5 m), occur rarely (1-5 specimens per 50 g) in interval 6 - 2 m, but show a sharp increase from sample KL1-23 (52 specimens/50 g) upwards at 1.5 m below the K/T boundary with a maximum in sample KL1-22 (136 specimens/50g). In the terminal 1.5 m of the Maastrichtian the content of globotruncanids is more or less constant (44-24 specimens/50 g).

These data together with the analysis of the taxonomical composition of the planktonic Foraminifera allow to reconstruct the succession of biotic and environmental events at the end of the Maastrichtian.

1. 6-5 m. The relatively abundant large *Archaeoglobigerina* and heterohelicids are dominant components of the planktonic assemblage, reflecting outer shelf environments. The input of clastics was minor. The sediments are mostly carbonate-rich (63-65% $CaCO_3$).

2. 5-1.5 m. The appearance of rare *Globotruncana* and the increase in abundance of *Globigerinelloides* evidence the increase of water depth. This change coincides with a decrease in carbonate content from 65% in sample KL1-31 to 55% in sample KL1-30. The latter can reflect a more humid climate. The carbonate content in the remaining part of the Maastrichtian is 57-59%.

3. 1.5-0 m. The "bloom" of *Globotruncana, Globotruncanita, Planoglobulina*, *Pseudotextularia deformis* (Kikoine) and even the appearance of *Racemiguembelina powelli* Smith & Pessagno are signs of the terminal Cretaceous transgression, marked by substantial deepening and input of warmer waters in this part of the Russian marine basin.

In the Danish Trough the increase of abundance of *Pseudotextularia elegans-Racemiguembelina fructicosa* complex coincides with the interval 3-6 m below the K/T boundary in section Stevns Klint and 1-4 m in section

Kjølby Gaard (HULTBERG & MALMGREN, 1987). These two events registered in both N and E European sites could have been contemporary. The presence of this transgressive event supports the idea that in this section the youngest Maastrichtian sediments have been preserved.

Hiatuses, transgressions and climatic warming

The Maastrichtian of Saratov Region contains several hiatuses. The first is at the base of the Lower Maastrichtian that unconformably overlies older deposits. The second encompasses upper Lower Maastrichtian (zones CC23b and CC24) and it has the longest duration. The third gap coincides with an interval in the lower Upper Maastrichtian. In the nannofossil zonation the last hiatus covers Zone CC25c and lowermost CC26, but at the top of the Tyoplovka uplift its duration was even longer because the sedimentation there occurred only during the younger half of CC26.

These hiatuses separate three sequences which reflect three transgressive pulses: lower Lower Maastrichtian, lower and upper Upper Maastrichtian. These transgressions are mainly eustatic in origin. The existence of at least two Maastrichtian transgressions was documented in W. Europe by HANCOCK (1989). Two transgressive pulses (early and late Maastrichtian) separated by a short-term regressive event were mentioned for the E. European Platform by NAIDIN (1995). However, the long gap between lower Lower Maastrichtian and lower Upper Maastrichtian as well as the cutting of the Upper Albian at the top of the Tyoplovka Uplift by the uppermost Upper Maastrichtian appear to be related to tectonic activation of the Saratov dislocations in the mid-Maastrichtian.

The terminal Maastrichtian short transgressive warming episode that was registered in section Klyuchi 1 appears to be not only local, but even possibly global. The sharp increase in the abundance of *Pseudotextularia* in uppermost Maastrichtian sediments was recognised not only in N. Europe [where it is well known as ''elegans transgression'' (WICHER, 1953)], but also in the N. Atlantic (NEDERBRAGT, 1989), even though she attributed this phenomenon to differential dissolution. Recently, in the mid-latitude S. Atlantic the warm episode was shown on isotope data to have occurred during the interval 65.45 - 65.11 Ma, i.e. 100 k.y. before the end of the Cretaceous (LI & KELLER, 1998).

The recognition of a short-term warming in the uppermost Maastrichtian of the North Saratov Region could confirm the global extent of this climatic event, which be registered easily only in relatively high latitudes.

Conclusions

The integrated study of Foraminifera and calcareous nannoplankton together with a few macrofossil records shows that during the Maastrichtian the North Saratov Region was confined to the outer shelf. Correlation between local units described in sections situated 20-25 km apart is quite good. The long gap between lower Lower Maastrichtian and Upper Maastrichtian is typical for most of this area. On the top of the Tyoplovka Uplift the upper Upper Maastrichtian marls (upper part of CC26) overlie the Upper Albian clays with a weak angular unconformity. This intra-Maastrichtian event related to tectonic movements during this time interval gives a good age estimation of the terminal Cretaceous deformations in the eastern part of the Russian Platform.

The Maastrichtian foraminiferal assemblages of the Saratov Region are typical for the northern part of the Russian Basin and are very close to the contemporaneous assemblages of Poland (GAWOR-BIEDOWA, 1992) and even to those from north of the Turgay Strait, east of the Urals. The Turgay assemblages were described by AMON (1990) from the shallow-water Zhuravlevka Formation in Kustanay Region (Kazakhstan) situated at the same latitude (52-53° N) as Saratov. The nannofossil assemblages of the uppermost Maastrichtian contain abundant *Nephrolithus frequens* Górka in the Saratov Region. However, this species occurs only in a very limited interval of the Maastrichtian stratotype area (51° N) and it is absent in the uppermost part of this stage (ROMEIN *et al.*, 1996; MAI, 1999). Probably, the seawater of the Saratov part of the Russian Basin was colder than that in the Maastricht area as supported by foraminiferal and macrofossil data. We did not yet obtain arguments demonstrating that *Nephrolithus frequens* Górka appeared earlier in the Saratov Region than in lower and intermediate latitudes.

The invasion of relatively warm waters and the deepening of the basin during the latest Maastrichtian in the Saratov Region, as evidenced by the appearance of globotruncanids, *Racemiguembelina* and *Pseudotextularia* in Klyuchi 1 section, confirm the widespread terminal Maastrichtian ''elegans-transgression'' that was an even more obvious event in eastern Europe than in western Europe.

Acknowledgements

We greatly appreciated the technical assistance of Maxim S. Boiko and the help of Vitaly G. Ochev and Dmitry A. Kukhtinov from Saratov University during field work, of Raisa A. Voinova in processing of samples, of Alexey N. Reimers in SEM photography. We are very grateful to Etienne Steurbaut and Hedi Oberhänsli for having reviewed the manuscript and for having offered many useful comments and suggestions. We especially thank Annie Dhondt for editorial assistance. This study was supported by INTAS grant 94-1414 and ''Universitety Rossii''.

References

Alekseev, A. S., Gorbachik, T. N., Smirnova, S. B. & Bragin, N. Yu., 1996. Age of the Paramonovo Formation (the Albian of the Russian Platform) and global transgressive-regressive cycles of the Cretaceous. *Stratigraphy and Geological Correlation*, 4: 341-361.

Alekseev, A. S., & Kopaevich, L. F., 1997. Foraminiferal biostratigraphy of the uppermost Campanian-Maastrichtian in SW Crimea (Bakhchisaray and Chakhmakhly sections). *Bulletin Institut Royal des Sciences Naturelles de Belgique. Sciences de la Terre*, **67**: 103-118.

Amon, E. O., 1990. Foraminifera and radiolarians. *In* G. N. Papulov, V. I. Zhelezko & A. P. Levina (eds.). Verkhnemelovye otlozheniya Yuzhnogo Zauraliya (raion verkhnego Protoboliya). Sverdlovsk, pp. 9-26. [In Russian].

Arkhangelsky, A. D., 1912. Upper Cretaceous of eastern European Russia. *Materialy dlya geologii Rossii*, **25**: 1-631. [in Russian].

Arkhangelsky, A. D. & Dobrov, S.A., 1913. Geological sketch of Saratov Governement. *Materialy po izucheniyu estestvennykh uslovii Saratovskoi Gubernii*, **1**: 1-256. [in Russian].

Baryshnikova, V.I., 1966. Distribution and microfaunal characteristics of the Belemnitella americana Zone in Saratov Povolzhie. *Voprosy Geologii Yuzhnogo Urala i Povolzhiya,* **3**, 2: 274-285. [in Russian].

Beniamovskii, V. N. & Kopaevich, L. F., 1998. Benthic foraminiferal zonation in the Late Santonian-Maastrichtian of the European paleobiogeographical area (EPA). *Zentralblatt für Geologie und Paläontologie. Teil I*, **1996**, 11-12: 1149-1161.

Bondarenko, N. A., 1975. On the oscillating movements of the Earth crust in northern part of Saratov Pravoberezhie during Late Cretaceous. *Voprosy stratigrafii i paleontologii*, **1**: 97-106. [in Russian].

Derviz, T. L., 1959. Volga-Ural oil-bearing region. Jurassic and Cretaceous. *Trudy Vsesoyuznogo neftyanogo nauchno-issledovatelskogo geologorazvedochnogo instituta*, **145**: 1-367. [in Russian].

Digas, L. A., 1976. New data on the Danian of Srednee Povolzhie territory. *Voprosy Geologii Yuzhnogo Urala i Povolzhiya*, **10**: 56-63. [in Russian].

Ehrenberg, C. G., 1854. Mikrogeologie. Das Erde und Felsen schaffende wirken des unsichtbar kleinen selbstandigen Leben auf der Erde. Vol. 1: 1-374; Vol. 2: 1-88 + atlas, Leipzig.

Flerova, O. V. & Gurova, A. D., 1958. Upper Cretaceous of central region of Russian Platform. O. V. Flerova (ed.). Mezozoiskie i tretichnye otlozheniya centralnykh oblastey Russkoi Platformy. Gostoptekhizdat, Moscow, pp. 185-226. [in Russian].

Gartner, S., 1996. Calcareous nannofossils at the Cretaceous-Tertiary boundary. *In:* N. Macleod & G. Keller (eds.). Cretaceous-Tertiary mass extinctions: Biotic and environmental changes. W. W. Norton & Company, New York-London, pp. 27-47.

Gawor-Biedowa, E., 1992. Campanian and Maastrichtian Foraminifera from the Lublin Upland, Eastern Poland. *Palaeontologia polonica*, **52**: 188 pp.

Gerasimov, P. A., M , E. E., Naidin, D. P. & Sterlin, B. P., 1962. Jurassic and Cretaceous of Russian Platform. *Ocherki regionalnoi geologii SSSR*, **5**: 1-195. [in Russian].

Gutsaki, V. A., Morozov, N. S., Shumenko, S. I., 1975. The experiment of multidisciplinary studies of Maastrichtian in upper stream of Sukhaya Kazanla River (Saratov Pravoberezhie). *Voprosy stratigrafii i paleontologii*, **1**: 80-96. [in Russian].

Huber, B. T., 1990. Maestrichtian planktonic foraminifer biostratigraphy of the Maud Rise (Weddell Sea, Antarctica): ODP Leg 113 holes 689B and 690C. *Proceedings of the Ocean Drilling Program. Scientific Results*, **113**: 489-509.

Hultberg, S. U. & Malmgren, B. A., 1986. Dinoflagellate and planktonic foraminiferal paleobathymetrical indices in the Boreal uppermost Cretaceous. *Micropaleontology*, **32**: 316-323.

Hultberg, S. U. & Malmgren, B. A., 1987. Quantitative biostratigraphy based on late Maastrichtian dinoflagellates and planktonic Foraminifera from Southern Scandinavia. *Cretaceous Research*, **8**: 211-228.

Kamysheva-Elpatievskaya, V. G., 1951. On the boundary of Upper Cretaceous and Paleogene in Lower Povolzhie. *Saratovskii Gosudarstvennyi Universitet. Uchenye zapiski. Vypusk geologicheskii*, **28**: 36-44. [in Russian].

Kamysheva-Elpatievskaya, V. G. (ed.), 1967. Atlas of Mesozoic fauna and spore and pollen assemblages of Lower Povolzhie and adjacent areas. Saratov University Press, 1-257. [in Russian].

Kopaevich, L. F., Beniamovskii, V. N. & Naidin, D. P., 1987. Lower and Upper Maastrichtian boundary in the European palaeobiogeographic province. *Byulleten Moskovskogo Obshestva Ispytatelei Prirody. Otdel Geologicheskii*, 62, 5: 43-56. [in Russian].

Krashenninikov, V. A. & Basov, I. A., 1985. Cretaceous stratigraphy of Southern Ocean. *Trudy Geologicheskogo Instituta Akademii nauk SSSR*, 394: 1-174. [in Russian].

Kurlaev, V. I., Bondarenko, N. A. & Akhlestina, E. F., 1981. On the Danian of Saratov Pravoberezhie. *Voprosy Geologii Yuzhnogo Urala i Povolzhiya*, **22**: 94-102. [in Russian].

Li, L. & Keller, G., 1998. Abrupt deep-sea warming at the end of the Cretaceous. *Geology*, **26**: 995-998.

Longoria, J. F. & Gamper, M. A., 1984. Subfamily Helvetiellinae, a new group of Late Cretaceous (Maastrichtian) planktonic foraminifera. *Micropaleontology*, **30**: 171 - 179.

Mai, H., 1999. Paleocene coccoliths and coccospheres in deposits of the Maastrichtian stage at the "type locality" and type area in SE Limburg, The Netherlands. *Marine Micropaleontology*, **36**: 1 - 12.

Malmgren, B. A., 1982. Biostratigraphy of planktonic Foraminifera from the Maastrichtian white chalk of Sweden. *Geologiske Föreningens i Stockholm Förhandlingar*, **103**: 357-375.

Musatov, V. A., 1995. On the Danian Stage of the North Peri-Caspian and results of a study of calcareous nannoplankton. *In:* E. M. Bugrova (Ed.), Predely tochonosti biostratigraphicheskikh korrelyatsii. *Trudy 36 sessii Vsesoyuznogo Paleontologicheskogo Obshchestva (yanvar 1990, Syktyvkar)*. Moscow, pp. 61-66. [in Russian].

Musatov, V. A. & Ermokhina, L. I., 1998. Stratotype of the Belogrodnya Beds. *Nedra Povolzhiya i Prikaspiya*, **15**: 35 -42 [in Russian].

Naidin, D. P., 1960. The stratigraphy of the Upper Cretaceous of the Russian Platform. *Stockholm Contributions in Geology*, **6**: 39-51.

Naidin, D. P., 1969. Biostratigraphie und Paläobiogeographie der Oberen Kreide der Russischen Tafel. *Geologisches Jahrbuch*, **87**: 157-186.

NAIDIN, D. P., 1973. On the relationship of palaeobiogeographic and palaeobiogeographic subdivisions of lowest rank. *Byulleten Moskovskogo Obshestva Ispytatelei Prirody. Otdel Geologicheskii*, **48**, 6: 50-63 [in Russian].

NAIDIN, D. P., 1974. Class Cephalopoda, Superordo Belemnitida. *In:* KRYMGOLZ, G. Ya. (ed.) Atlas of the Upper Cretaceous Donbass fauna. Moscow, "Nedra", pp. 197 - 240 [in Russian].

NAIDIN, D. P., 1975. Late Maastrichtian belemnitellas of Eurasia. *In:* SHIMANSKY, V. N. (ed.). Razvitie i smena organicheskogo mira na rubezhe mezozoya i kainozoya. Novoe o faune. Publishing House "Nauka", Moscow, pp. 91-108 [in Russian].

NAIDIN, D. P., 1995. Eustacy and epicontinental seas of the East European Platform. 2. Upper Cretaceous sequences. *Byulleten Moskovskogo Obshestva Ispytatelei Prirody. Otdel Geologicheskii*, **70**, 5: 49-65 [in Russian].

NEDERBRAGT, A. J., 1989. Maastrichtian *Heterohelicidae* (planktonic Foraminifera) from the North West Atlantic. *Journal of Micropaleontology*, **8**: 183-206.

NIKISHIN, A. M., ZIEGLER, P. A., STEPHENSON, R. A. & USTINOVA, M. A., 1999. Santonian to Palaeocene Tectonics of the East-European Craton and adjacent areas. *Bulletin Institut Royal des Sciences Naturelles de Belgique. Sciences de la Terre*, **69-supplement A**: 147-159.

PERCH-NIELSEN, K., 1985. Mesozoic calcareous nannofossils. H.M. BOLLI, J.B. SAUNDERS & K. PERCH-NIELSEN (ed.). Plankton Stratigraphy. Cambridge University Press, pp. 329-426.

POSPICHAL, J. J. & WISE Jr., S. W., 1990. Calcareous nannofossils across the K/T boundary, ODP Hole 690C, Maud Rise, Weddell Sea. *Proceedings of the Ocean Drilling Program. Scientific Results*, **113**: 515-532.

ROMEIN, A. J. T., WILLEMS, H. & MAI, H., 1996. Calcareous nannoplankton of the Geulhemmerberg K/T boundary section, Maastrichtian type area, the Netherlands. *Geologie en Mijnbouw*, 75: 231-238.

SCHMITZ, B. & KELLER, O., 1992. Stable isotopic and foraminiferal changes across the Cretaceous-Tertiary boundary at Stevns Klint, Denmark; Arguments for long-term oceanic instability before and after bolide-impact event. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **96**: 233-260.

SCHULZ, M.-G., 1978. Zur Litho-und Biostratigraphie des Obercampan-Untermaastricht von Lägerdorf und Kronsmoor (SW-Holstein). *Newsletters on Stratigraphy*, 7: 73-89.

THIERSTEIN, H., ASARO , W. U., HUBER, B., MICHEL , H. & SCHMITZ, B., 1991. The Cretaceous/Tertiary boundary at Site 738, southern Kerguelen Plateau. *Proceedings of the Ocean Drilling Program. Scientific Results*, **119**: 849-861.

WICHER, C. A., 1953. Mikropaläontologische Beobachtungen in der höheren borealen Ober-Kreide, besonders im Maastricht. *Geologisches Jahrbuch*, **68**: 1-26.

WIDMARK, R. P., 1997. Benthic foraminiferal ecomarker species of the terminal Cretaceous (late Maastrichtian) deep-sea Tethys. *Marine Micropaleontology*, **31**: 135-155.

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Typescript submitted: 5.1.1999
Revised typescript received: 15.3.1999.

Explanations of Plates

PLATE 1

Benthic Foraminifera from the north Saratov Region

Figure 1 — *Arenobulimina vialovi* Woloshyna; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/1 (X 75).
Figure 2 — *Spiroplectammina kelleri* Dain; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-6, PIN 4776/2 (X 55).
Figure 3 — *Heterostomella foveolata* (Marsson); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-19, PIN 4776/3 (X 100).
Figure 4 — *Bolivina decurrens* (Ehrenberg); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-19, PIN 4776/4, (X 100).
Figure 5 — *Bolivina plaita* Carsey; section Lokh 1, unit Lokh B, Lower Maastrichtian, PIN 4776/5, sample LH1-34 (X 75).
Figure 6 — *Bolivina crassa* Vasilenko *in* Vasilenko & Myatliuk; section Klyuchi 1, unit Klyuchi C, Palaeocene, sample KL1-16a, PIN 4776/6 (X 55).
Figure 7 — *Dentalina basiplanata* Cushman; section Klyuchi 1, unit Klyuchi C, Palaeocene, sample KL1-2, PIN 4776/7 (X 30).
Figure 8 — *Neoflabellina reticulata* (Reuss); section Lokh 1, unit Lokh B, Lower Maastrichtian, sample LH1-34, PIN 4776/8 (X 100).
Figure 9 — *Nonionella communis* (d'Orbigny); section Klyuchi 1, unit Klyuchi C, Palaeocene, sample KL1-10, PIN 4776/9 (X 120).
Figure 10 — *Pullenia jarvisi* Cushman; section Klyuchi 1, unit Klyuchi C, Palaeocene, sample KL1-6, PIN 4776/10 (X 100).
Figure 11 — *Stilostomella* sp. ; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/11 (X 100).
Figure 12 — *Pseudouvigerina rugosa* (Brotzen); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/12 (X 150).
Figure 13 — *Bolivinoides draco draco* (Marsson); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/13 (X 130).
Figure 14 — *Bolivinoides draco miliaris* Hiltermann & Koch; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-19, PIN 4776/14 (X 120).
Figure 15 — *Gyromorphina allomorphinoides* (Reuss); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-6, PIN 4776/15 (X 75).
Figure 16 — *Globulina lacrima* (Reuss); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/16 (X 100).
Figure 17 — *Guttulina communis* d'Orbigny; section Klyuchi 1, unit Klyuchi C, Palaeocene, sample KL1-6, PIN 4776/17 (X 100).
Figure 18 — *Cribrebella fusiformis* (Gawor-Biedowa); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-6, PIN 4776/18 (X 100).
Figure 19 — *Gyroidinoides globosus* (von Hagenow); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/19 (X 130).
Figure 20 — *Cibicides succedens* Brotzen; section Klyuchi 1, unit Klyuchi C, Palaeocene, sample KL1-6, PIN 4776/20 (X 120).
Figure 21 — *Cibicidoides aktulagayensis* Vasilenko; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/21 (X 100).
Figure 22 — *Cibicidoides commatus* Vasilenko; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-19, PIN 4776/22 (X 120).
Figure 23 — *Stensioeina pommerana* Brotzen; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/23 (X 130).
Figure 24 — *Brotzenella taylorensis* (Carsey); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/24 (X 100).
Figure 25 — *Hanzawaia ekblomi* (Brotzen); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/25 (X 120).

PLATE 2

Planktonic Foraminifera from the north Saratov Region

Figure 1 — *Heterohelix globulosa* (Ehrenberg); section Lokh 1, unit Lokh B, Lower Maastrichtian, sample LH1-34, PIN 4776/26 (X 170).
Figure 2 — *Heterohelix globulosa* (Ehrenberg); section Lokh 1, unit Lokh B, Lower Maastrichtian, sample LH1-34, PIN 4776/27 (X 150).

Figure 3 — *Pseudotextularia deformis* (Kikoine); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/28 (X 100).

Figure 4 — *Pseudotextularia deformis* (Kikoine); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/29 (X 100).

Figure 5 — *Planoglobulina brazoensis* Martin; section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/30 (X 100).

Figure 6 — *Globigerinelloides volutus* (White); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/31 (X 200).

Figure 7 — *Globigerinelloides volutus* (White); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/32 (X 180).

Figure 8 — *Globigerinelloides volutus* (White); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/33 (X 130).

Figure 9 — *Archaeoglobigerina australis* Huber; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/34, (X 130).

Figure 10 — *Archaeoglobigerina australis* Huber; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/35, (X 130).

Figure 11 — *Archaeoglobigerina australis* Huber; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/36, (X 100).

Figure 12 — *Rugoglobigerina rugosa* (Plummer); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/37, (X 160).

Figure 13 — *Rugoglobigerina rugosa* (Plummer); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/38 (X 130).

Figure 14 — *Rugoglobigerina rugosa* (Plummer); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/39 (X 160).

Figure 15 — *Rugoglobigerina rugosa* (Plummer); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-7, PIN 4776/40 (X 150).

Figure 16 — *Globotruncanella havanensis* (Voorwijk); section Lokh 1, unit Lokh B, Lower Maastrichtian, sample LH1-34, PIN 4776/41 (X 130).

Figure 17 — *Globotruncanella havanensis* (Voorwijk); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/42 (X 120).

Figure 18 — *Globotruncanella petaloidea* (Gandolfi); section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-10, PIN 4776/43 (X 130).

Figure 19 — *Globotruncana arca* (Cushman); section Lokh 1, unit Lokh B, Lower Maastrichtian, sample LH1-34, PIN 4776/44 (X 100).

Figure 20 — *Globotruncana arca* (Cushman); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/45 (X 120).

Figure 21 — *Globotruncana mariei* Banner & Blow; section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-20, PIN 4776/46 (X 130).

PLATE 3

Calcareous nannofossils from the Maastrichtian of the north Saratov region

Figure 1 — *Cribrosphaerella ehrenbergii* (Arkhangelsky) Deflandre *in* Piveteau; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-28 (X 5000).

Figure 2 — *Cribrosphaerella daniae* Perch-Nielsen; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-28 (X 4400).

Figure 3 — *Micula decussata* Vekshina, partially dissolved; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-28, (X 5000).

Figure 4 — *Arkhangelskiella cymbiformis* Vekshina; section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL1-43 (X 6300).

Figure 5 — *Prediscosphaera stoveri* (Perch-Nielsen) Shafik & Stradner; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-18 (X 7500).

Figure 6 — *Corollithion exiguum* Stradner; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-28 (X 6300).

Figure 7 — *Kamptnerius magnificus* Deflandre; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-18 (X 6300).

Figure 8 — *Stradneria crenulata* (Bramlette & Martini) Noël; section Tyoplovka 3, unit Tyoplovka A, Upper Maastrichtian,

sample TP3-18 (X 6300).

Figure 9 — *Micula concava* (Stradner *in* Martini & Stradner) Verbeek, partially dissolved; section Lokh 1, unit Lokh C, Upper Maastrichtian, sample LH1-53 (X 5000).

Figure 10 — *Lithraphidites grossopectinatus* Bukry; section Tyoplovka 3, unit Tyoplovka A, Upper Maastrichtian, sample TP3-18 (X 6300).

Figure 11 — *Nephrolithus frequens* Górka; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-28 (X 6000).

Figure 12 — *Rhombolithion speetonensis* Rood & Barnard; section Tyoplovka 2, unit Tyoplovka A, Upper Maastrichtian, sample TP2-18 (X 6300).

Figure 13 — *Aspidolithus* sp. aff. *A. parcus constrictus* (Hattner *et al.*) Perch-Nielsen; section Klyuchi 2, unit Klyuchi A, Lower Maastrichtian, sample KL2-3 (X 5400).

Figure 14 — *Vekshinella angusta* (Stover) Verbeek; section Klyuchi 2, unit Klyuchi B, Upper Maastrichtian, sample KL2-16 (X 6300).

Figure 15 — *Lithraphidites quadratus* Bramlette & Martini; section Tyoplovka 3, unit Tyoplovka A, Upper Maastrichtian, sample TP3-18 (X 6300)

PLATE 4

Macrofossils from the Maastrichtian of the north Saratov Region

Figure 1 — *Belemnella lanceolata gracilis* (Arkhangelsky); a - ventral side, b - dorsal side; section Lokh 1, unit Lokh A, Lower Maastrichtian, sample LH1-9, PIN 4775/1 (X 1).

Figure 2 — *Belemnella sumensis praearkhangelskii* Naidin; a - ventral side; b - dorsal side; section Klyuchi 2, condensed clay bed of unit Klyuchi Bb, upper Lower and lower Upper Maastrichtian, sample KL 2, PIN 4775/2 (X 1).

Figure 3 — *Belemnella sumensis praearkhangelskii* Naidin; section Klyuchi 2, condensed clay bed of unit Klyuchi Bb, upper Lower and lower Upper Maastrichtian, sample KL 2, view of split guard showing internal characteristics, PIN 4775/3 (X 1).

Figure 4 — *Neobelemnella kazimiroviensis* (Skolozdrowna); a - ventral side; b - dorsal side; section Klyuchi 1, unit Klyuchi 2, Upper Maastrichtian, sample KL 1, PIN 4775/4 (X 1).

Figure 5 — *Neobelemnella kazimiroviensis* (Skolozdrowna); a - ventral side (X 1), b - lateral side (X 1), c - view of split guard showing internal characteristics (X 2); section Klyuchi 1, unit Klyuchi B, Upper Maastrichtian, sample KL 1, PIN 4775/5 (X 1).

Figure 6 — *Neobelemnella kazimiroviensis* (Skolozdrowna); view of split guard showing internal characteristics; section Klyuchi 1, unit Kluychi B, Upper Maastrichtian, sample KL 1, PIN 4775/6 (X 1).

Figure 7 — *Hoploscaphites* aff. *H. constrictus* (J. Sowerby); a - lateral side, b - dorsal side; section Lokh 1, base of unit Lokh B, Lower Maastrichtian, sample LH1-34, PIN 4775/7 (X 1).

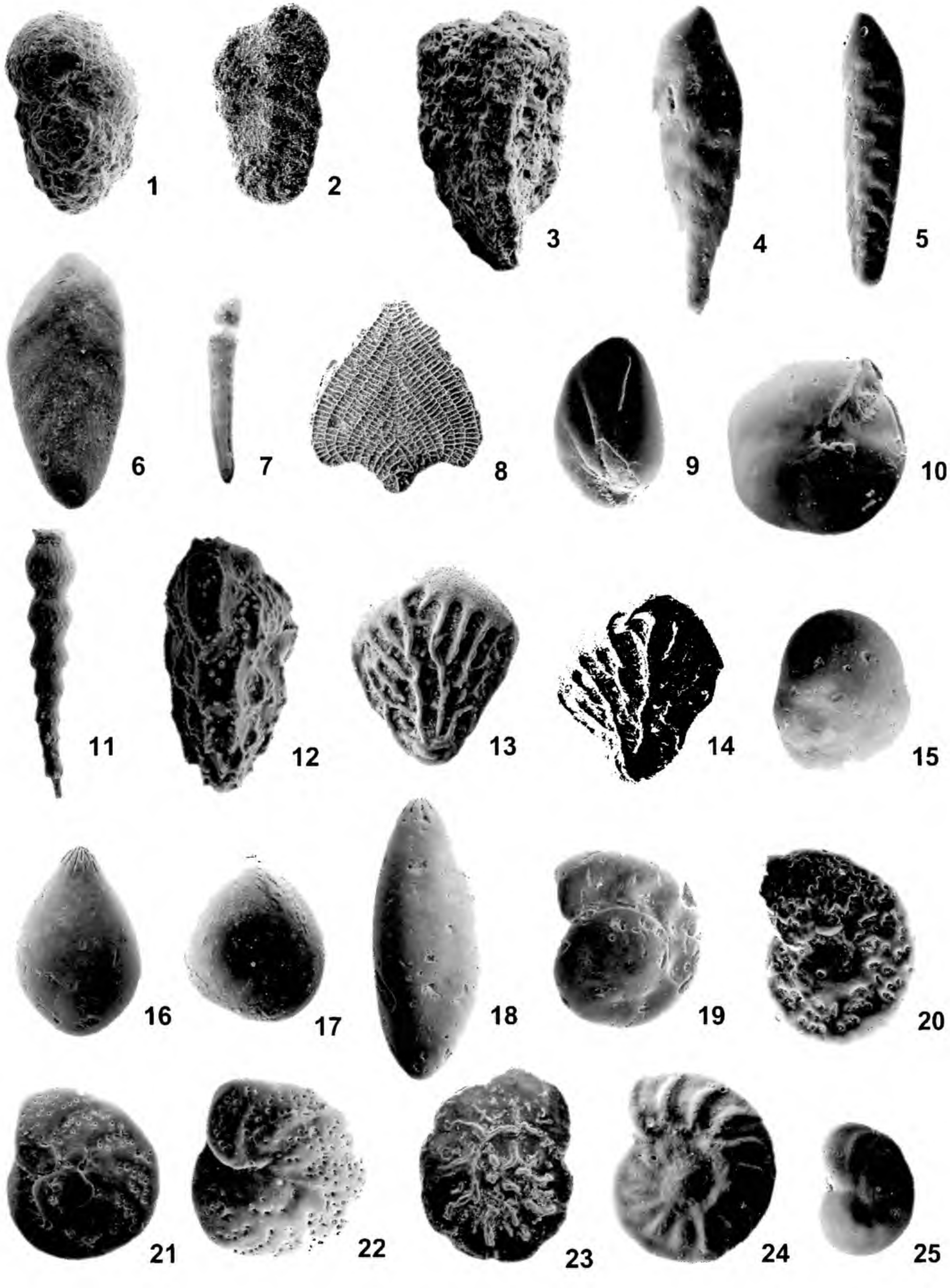

PLATE 1

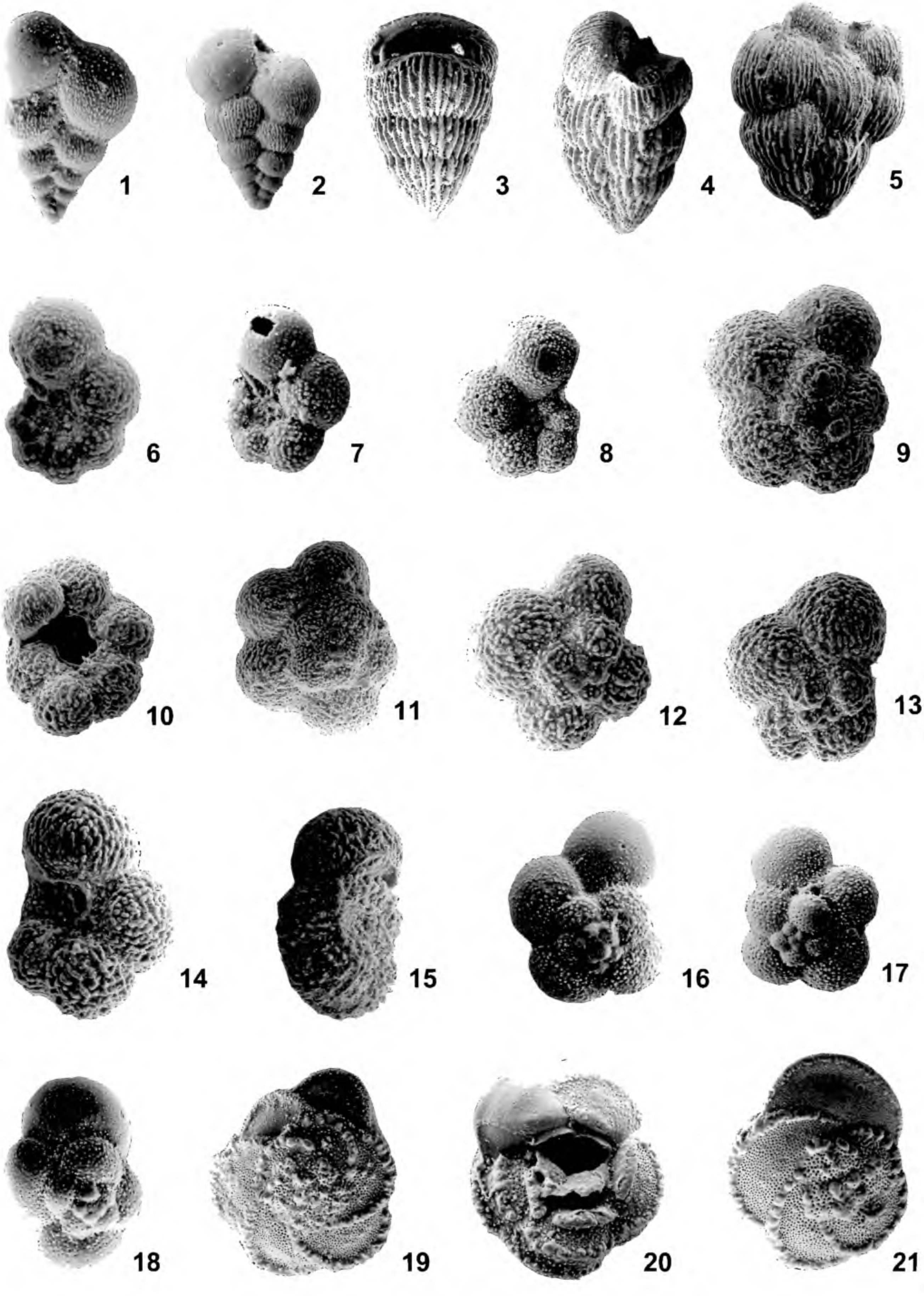

PLATE 2

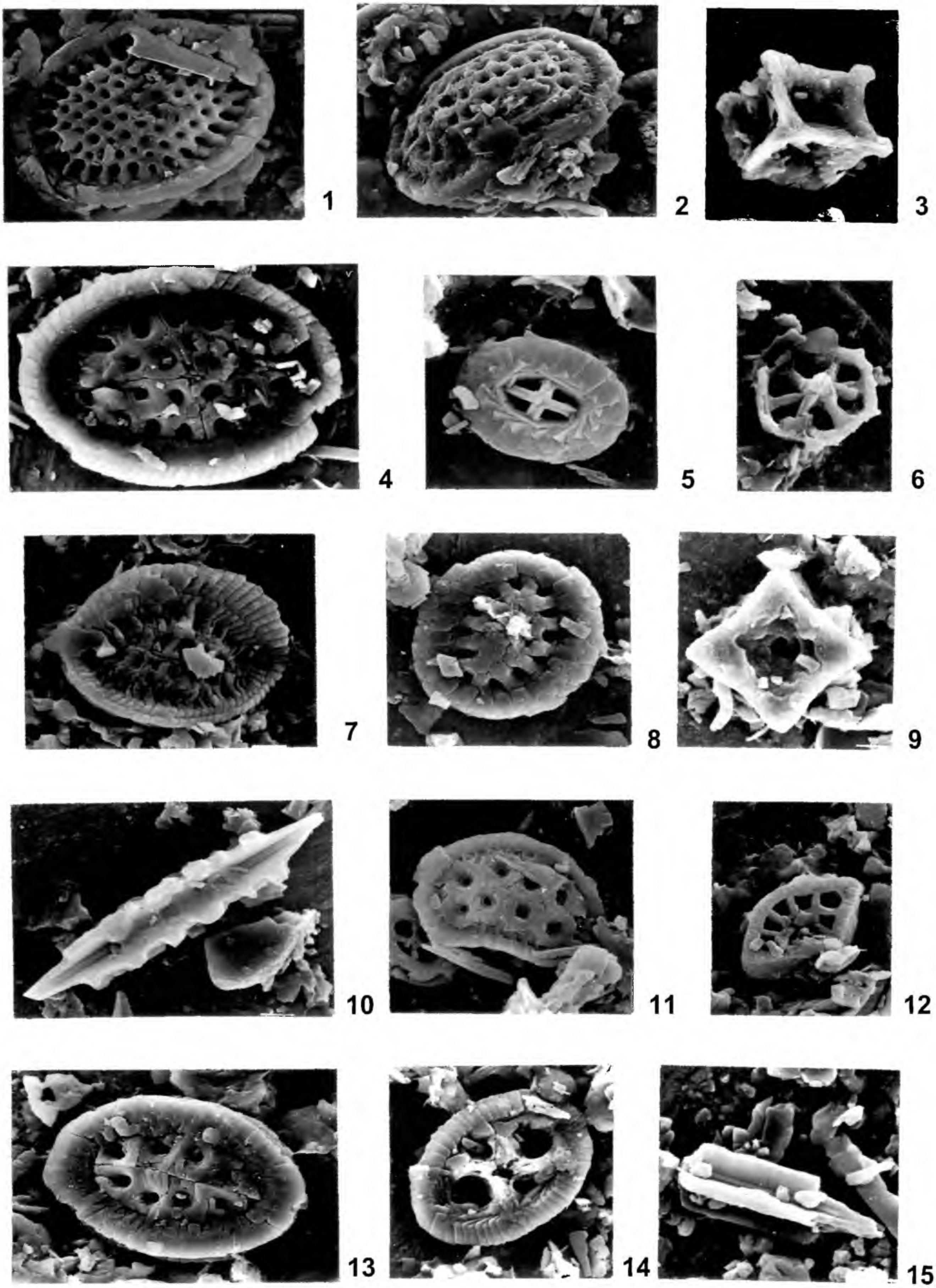

PLATE 3

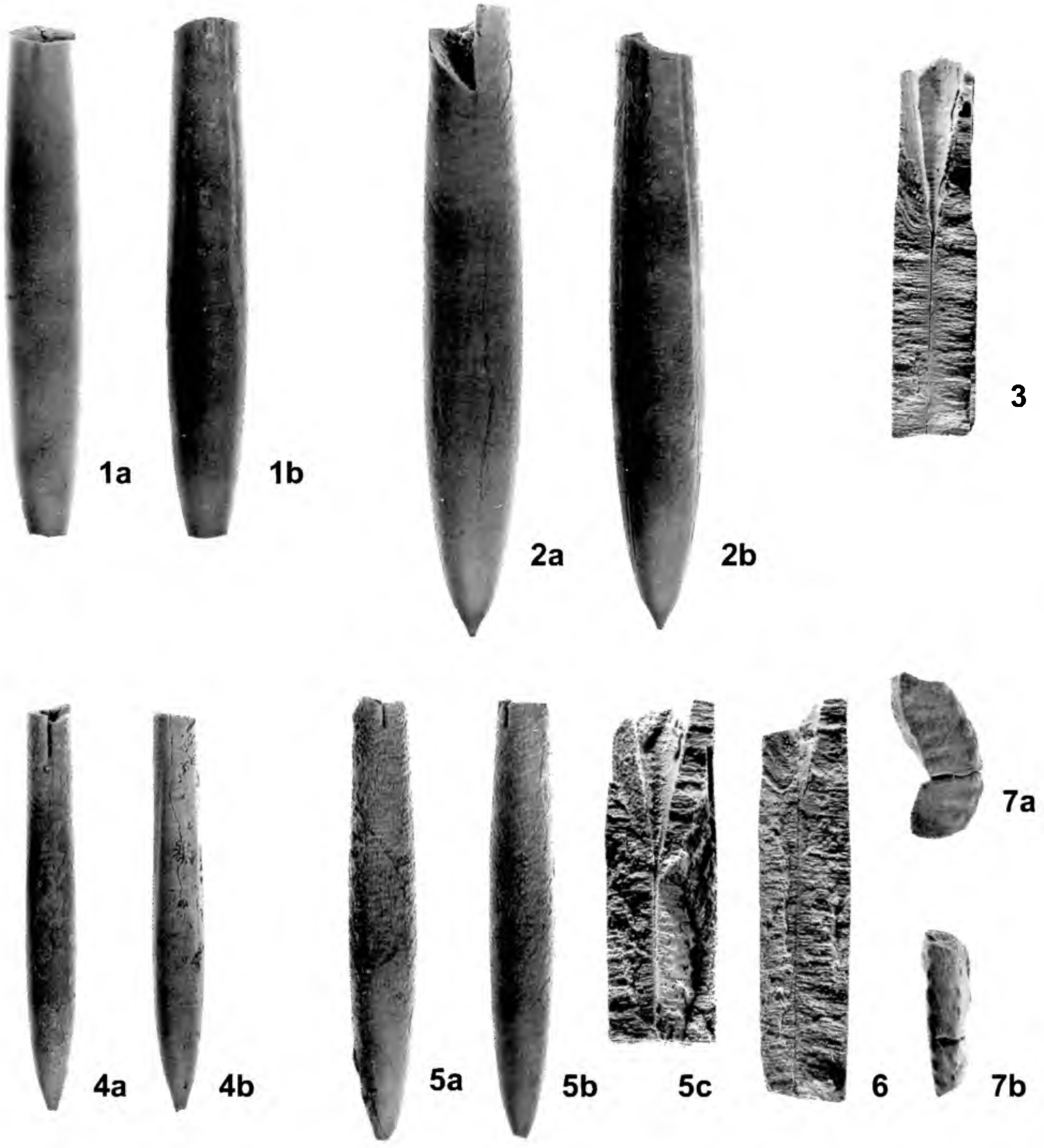

PLATE 4

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 47-54, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 47-54, 1999

Platyscaphites, a new ammonite from the Lower Campanian (Upper Cretaceous) of the United States Western Interior

by William A. COBBAN, W. James KENNEDY & Neil H. LANDMAN

Abstract

A diminutive genus of scaphite, *Platyscaphites* gen. nov., probably arose from the *Scaphites hippocrepis* (DEKAY, 1828) stock during early Campanian time in the northern part of the United States Western Interior. Three species, all new, are described; they reveal a trend towards progressive size reduction and recoiling to a planispiral shell morphology, accompanied by a possible reduction in adult size. *Platyscaphites groatensis* sp. nov., the oldest species, occurs low in the zone of *Baculites* sp. (smooth), and *P. elginensis* sp. nov., occurs high in that zone; *P. fremontensis* sp. nov., is found in the succeeding zone of *Baculites* sp. (weak flank ribs).

Key-words: Cephalopoda, Ammonoidea, *Platyscaphites*, Campanian, USA.

Résumé

Platyscaphites gen. nov., un genre de scaphite de toute petite taille, s'est vraisemblablement détaché de la lignée de *Scaphites hippocrepis* (DEKAY, 1828) au cours du Campanien inférieur, dans la partie septentrionale du "Western Interior" des Etats Unis. Trois espèces, toutes nouvelles, sont décrites; elles montrent une tendance à une réduction progressive de la taille et à un réenroulement planispiral de la coquille, accompagnée d'une réduction possible de la taille adulte. *Platyscaphites groatensis* sp. nov., l'espèce la plus ancienne, est présente dans la partie inférieure de la zone à *Baculites* sp. (lisse) et *P. elginensis* sp. nov. dans la partie supérieure de cette même zone; *P. fremontensis* se rencontre dans la zone suivante à *Baculites* sp. (avec de faibles côtes sur les flancs).

Mots-clefs: Cephalopoda, Ammonoidea, *Platyscaphites*, Campanien, USA.

Резюме

Входящий в род скафитов, *Platyscaphites* gen. nov. вероятно происходит от скопления *Scaphites hippocrepis* (DEKAY, 1928) во времена нижнего Кампана на севере «Western Interior» США. Описаны, в частности, 3 совершенно новых вида, подтверждающих общее направление развития благодаря прогрессивному сокращению размеров и возвращению к спирально-плоскостной ракушечной морфологии, с возможным сокращением взрослых размеров. *Platyscaphites groatensis* sp. nov., самый старый вид, редко встречается в зоне *Baculites* sp. (пологой), а *P. elginensis* sp.nov. встречается в ней часто; *P. fremontensis* sp.nov. найден в последующей зоне (хрупкие боковые линии нарастания).

Ключевые слова: Cephalopoda, Ammonoidea, *Platyscaphites* , Кампанский ярус, США.

Introduction

Recoiling is a widespread evolutionary trend in scaphitid heteromorph ammonites that leads ultimately to planispiral shells in which the body chamber is in contact with the phragmocone throughout ontogeny, rather than separated at maturity. The trend has been recognized in several U.S. Western Interior lineages of scaphitid ammonites that lead to taxa such as *Desmoscaphites* REESIDE, 1927a, *Clioscaphites* COBBAN, 1952, *Binneyites* REESIDE, 1927b, *Pontexites* WARREN, 1934, and *Rhaeboceras* MEEK, 1876. *Acanthoscaphites* NOWAK, 1911, and *Indoscaphites* SPATH, 1953, are recoiled genera known from western Europe, South India, and Tunisia. We describe below an additional dwarf genus of recoiled scaphite as *Platyscaphites* gen. nov., that occurs in the lower Campanian in the central and northern parts of the Western Interior in Colorado, Wyoming, South Dakota, and Manitoba. Three species are described, from oldest to youngest, *Platyscaphites groatensis* sp. nov., *P. elginensis* sp. nov., and *P. fremontensis* sp. nov., the last named being the type species. The lineage is believed to be derived from *Scaphites (Scaphites) hippocrepis* (DEKAY, 1828), which immediately predates *P. groatensis*. The lineage shows progressive recoiling; the microconchs of the two earlier species have body chambers detached from the spire, and dimorphism is obvious. In the last species, *P. fremontensis*, the whorls are in contact throughout, and macroconchs and microconchs cannot be separated. The lineage also possibly shows progressive size decrease, although the sample sizes of two of the species are too small to demonstrate this conclusively.

These ammonites were originally referred to as *Indoscaphites* sp. by COBBAN & SCOTT (1964, fig. 2), but are heterochronous homeomorphs of that genus, which is known only from the upper Maastrichtian of Pondicherry, South India, and Tunisia.

Lower Campanian Scaphite Sequence in the Western Interior

The following six ammonite zones were recognized by GILL & COBBAN (1966) in rocks of early Campanian age in the Western Interior of the United States (youngest at top):

Baculites obtusus, *Trachyscaphites praespiniger*
Baculites sp. (weak flank ribs), *Trachyscaphites praespiniger*
Baculites sp. (smooth), *"Indoscaphites"*
Haresiceras natronense, *Scaphites hippocrepis* (fine ribbed)
Haresiceras placentiforme, *Scaphites hippocrepis* (coarse ribbed)
Haresiceras montanaense, *Scaphites hippocrepis* (coarse ribbed)

The *"Indoscaphites"* is the *Platyscaphites* of the present report. Although shown only in the zone of smooth baculites by GILL & COBBAN (1966, table 2) as well as in an earlier report by COBBAN & SCOTT (1964, fig. 2), *Platyscaphites* is now known to range up into the overlying zone of baculites that have weak flank ribs.

Localities of *Platyscaphites* in the Western Interior

Localities at which *Platyscaphites* has been collected in the Western Interior of the United States are shown in Fig. 1. The USGS Mesozoic locality number, the collector(s), the year of collection, the locality, and the stratigraphic assignment are as follows (prefix D indicates Denver Mesozoic locality numbers; the others are Washington, D.C., Mesozoic locality numbers):

D3434. J.R. GILL, 1961. Elgin Creek in the N1/2 sec. 13, T. 49 N., R. 83 W., Johnson County, Wyoming. Cody Shale, 222 meters (m) below top, from a grey-weathering limestone concretion in a bed of bentonite.

D4287. J.R. GILL & R.E. BURKHOLDER, 1963. Elgin Creek in the NW1/4 sec. 13, T. 49 N., R. 83 W., Johnson County, Wyoming. Cody Shale, from yellowish-brown, calcareous sandstone concretions 7.6 m above base of Shannon Sandstone Member.

D4266. R.E. BURKHOLDER & W.A. COBBAN, 1963. Near North Fork oil field, in deep gully in the SE1/4NE1/4 sec. 26, T. 44 N., R. 82 W., Johnson County, Wyoming. Cody Shale, about 4.6 m below a 0.9 m thick bed of bentonite that underlies the Shannon Sandstone Member.

21762. J.D. LOVE & KEITH YENNE, 1949; J.R. GILL & R.C. GIVENS, 1964. Near Conant Creek, in the NE1/4 sec. 5, T. 33 N., R. 93 W., Fremont County, Wyoming. Cody Shale, from sandy, limestone concretions 60 m below top.

23116. J.B. REESIDE, Jr., and others, 1950. Near Muskrat gas field, in sec. 20, T. 34 N., R. 92 W., Fremont County, Wyoming. Cody Shale.

23121. KEITH YENNE, J.C. BELSHE, & J.B. COLLINS, 1950. Near Muskrat gas field, in the SE1/4NE1/4 sec. 27, T. 34 N., R. 92 W., Fremont County, Wyoming. Cody Shale [same bed as at 23116].

D4734. J.R. GILL & W.A. COBBAN, 1964. Near Muskrat gas field, in the NW1/4SW1/4NE1/4 sec. 27, T. 34 N., R. 92 W., Fremont County, Wyoming. Cody Shale, 53 m below top, from ridge-forming bed of brown-weathering sandy, limestone concretions [same bed as at 23116].

D4725. J.R. GILL & W.A. COBBAN, 1964. Ervay Basin, in the NW1/4SE1/4SW1/4 sec. 14, T. 34 N., R. 89 W., Natrona County, Wyoming. Cody Shale, 506 m below top, from low ridge-forming bed of brown-weathering sandy, limestone concretions.

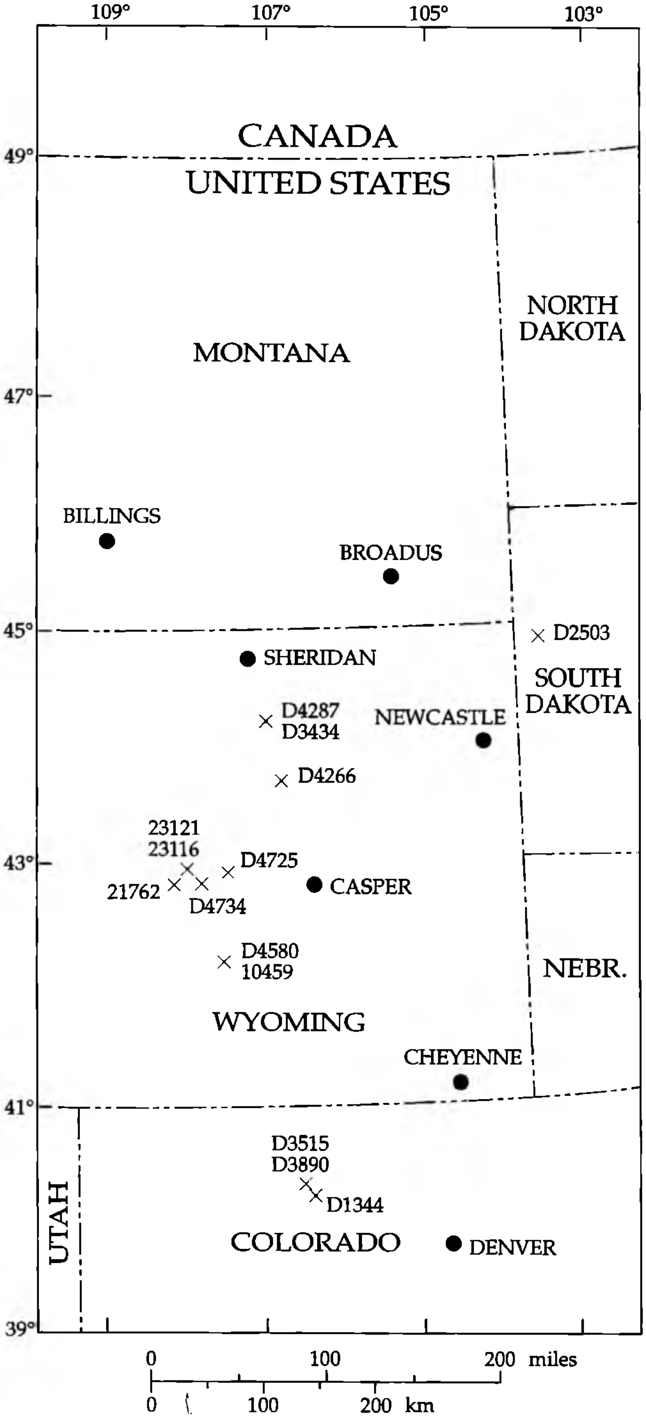

Figure 1 — Map of part of the Western Interior of the United States showing localities where *Platyscaphites* was found.

D4580. J.R. Gill, 1964. Near Lost Soldier oil field, in center of the NW1/4NE1/4 sec. 8, T. 26 N., R. 89 W., Carbon County, Wyoming. Cody Shale, from a limestone concretion in a bentonitic unit.

10459. A.E. Fath & C.Y. Hsieh, 1920. SW1/4 sec. 1, T. 26 N., R. 89 W., Carbon County, Wyoming. Steele Shale, 1,200 m above base.

D2503. G.R. Scott & W.A. Cobban, 1960. About 24 km north of Belle Fourche, in the SW1/4 sec. 27, T. 11 N., R. 2 E., Butte County, South Dakota. Pierre Shale, from sandy, limestone concretions in Groat Sandstone Bed of Gammon Ferruginous Member.

D3515. W.J. Hail, 1961. North bank of Muddy Creek about 0.6 km northwest of Haworth Ranch, in the SW1/4NW1/4 sec. 20, T. 4 N., R. 81 W., Grand County, Colorado. Pierre Shale.

D3890. W.J. Hail, 1962. SE1/4NW1/4 sec. 30, T. 4 N., R. 81 W., Grand County, Colorado. Pierre Shale, about 427 m above base.

D1344. G.R. Scott & W.A. Cobban, 1957. East side of U.S. Highway 40, 21 km north-northwest of Kremmling, in the NE1/4NE1/4 sec. 10, T. 3 N., R. 81 W., Grand County, Colorado. Pierre Shale, from iron-stained limestone concretions.

SYSTEMATIC PALAEONTOLOGY

Superfamily Scaphitaceae Gill, 1871

Family Scaphitidae Gill, 1871

Subfamily Scaphitinae Gill, 1871

Genus *Platyscaphites* gen. nov.

Type species: *Platyscaphites fremontensis* n. gen. et sp. , lower Campanian, Cody Shale, Wyoming.

Derivation of name: *Platys* (Greek), flat and *skaphe* (Greek), a type of boat.

Diagnosis

Small, weakly to strongly dimorphic scaphites, recoiled in type species (youngest), but body chambers of microconchs detached from spire in older two species. Flanks are flat and weakly ribbed on adult body chambers; small conical ventrolateral tubercles present on last part of phragmocone and body chamber.

Discussion

The type species, *P. fremontensis* n. sp. (Pl. 1, Figs. 25-61) has a planispiral shell in which the whorls are in contact throughout, such that dimorphs cannot be differentiated. The species is a homoeomorph in shell shape and coiling of *Indoscaphites* Spath, 1953 (type species *Ammonites cunliffei* Forbes, 1846, p. 109, pl. 8, fig. 2; lectotype designated by Kennedy & Henderson, 1992, p. 724) from the upper Maastrichtian of Pondicherry, South India, the two differing in the well-developed umbilical bullae of *Indoscaphites*. Similarities of juveniles is, however, striking (compare Pl. 1, Figs. 38-40 and Forbes, 1846, pl. 8, fig. 2c). Flat sides and style of ornament connect *P. fremontensis* to the slightly older *P. elginensis* n. sp. (Pl. 1, Figs. 1-6), where the hook of microconchs is clearly detached from the spire, as it is in the microconch of the oldest species, *P. groatensis* n. sp. (Pl. 1, Figs. 7-24). The origin of *Platyscaphites* seems to lie in the older *Scaphites (Scaphites) hippocrepis* (DeKay, 1828) lineage described in detail by Cobban (1969). The two genera differ in the tendency to recoil in *Platyscaphites*, which has flat sides and no umbilical and lateral tubercles. *Scaphites (S.) hippocrepis* has umbilical and ventrolateral tubercles and occasional lateral tubercles.

Occurrence

Lower Campanian of Colorado, South Dakota, and Wyoming; southern Manitoba; and possibly northeast Texas and New Jersey.

Platyscaphites groatensis n. sp.
(Pl. 1, Figs. 7-24; Fig. 2)

Derivation of name: From the Groat Sandstone Bed of the Gammon Ferruginous Member of the Pierre Shale that yielded the type material.

Types

Holotype is USNM 481620 (Pl. 1, Figs. 16-18), paratypes are USNM 481621-481626 (Pl. 1, Figs. 6-15, 19-24), from the lower Campanian zone of *Baculites* sp. (smooth). The types are from USGS Mesozoic locality D2503, about 24 km north of Belle Fourche, in the SW1/4 sec. 27, T. 11 N., R. 2 E., Butte County, South Dakota.

Diagnosis

Platyscaphites that has the body chamber of the microconch markedly detached from the spire, and the body chamber of the macroconch slightly detached from the spire. Inner whorls may have ventrolateral bullae that give rise to groups of flexuous ribs. The flanks of the early body chamber are smooth, but ribbing rejuvenates towards the aperture.

Description

The inner whorls are very involute and range from compressed (Pl. 1, Figs. 7, 8, 13-14) to depressed (Pl. 1, Figs. 9-12). The earliest growth stages seen are smooth. At a later growth stage in compressed variants, delicate prorsiradiate ribs are present on the inner flank and branch into pairs or threes on the outer flank, where additional ribs intercalate; all ribs strengthen and sweep forward to cross the venter in a broad convexity (Pl. 1, Figs. 7, 8, 22-24). Some specimens of this type may develop stronger, widely separated primaries on the inner flank (Pl. 1, Fig. 14), although this is a typical feature of depressed, robust individuals (Pl. 1, Figs. 9-12), where the ribs are prorsiradiate and slightly flexuous and terminate in well-developed ventrolateral bullae. The bullae give rise to groups of two or three ribs with others intercalated. Ribs on the depressed specimens cross the venter with less convexity than on the compressed variant.

The holotype (Pl. 1, Figs. 16-18) is an adult macroconch 16.5 mm long. Its last one-half whorl of spire has strong, bullate ventrolateral tubercles that give rise to groups of two or three relatively coarse ribs, with additional intercalated ribs crossing the venter in a broad convexity. Flat, parallel sides characterize the shaft of the body chamber; its umbilical wall follows a straight course when viewed from the side, and has a low convex wall; it is rather worn, but may have borne distant, prorsiradiate ribs. The venter is also abraded, but ornament appears to have been weak. The final hook is barely separated from the spire, and is strongly recurved. Outer flank ornament rejuvenates as long, delicate, distant bullae that weaken towards the adult aperture. Bullae on the first section of the hook give rise to single distant ventral ribs that are slightly concave on the curved sector (Pl. 1, Fig. 18). These break down into groups of weaker ribs that arise in pairs or threes from the bullae (Pl. 1, Fig. 17). The adult aperture is marked by a strong, narrow constriction and a weak ventral rostrum.

USNM 481621 (Pl. 1, Figs. 19-21) is an adult microconch 10.5 mm long. The phragmocone has weak ornament of ventrolateral bullae and ventral ribs. Its body chamber is compressed and flat-sided, but much narrower than that of the macroconch, and has a concave umbilical wall when viewed from the side. Flanks are initially distantly ribbed followed by a smooth sector preceding the final hook. Large, bullate to conical, ventrolateral tubercles give rise to pairs of coarse ventral ribs that loop across the venter to the tubercle on the opposite ventrolateral shoulder. Distant, straight, prorsiradiate flank ribbing rejuvenates on the final hook. Ribs terminate in the conical ventrolateral tubercles that weaken towards the adult aperture; the tubercles are linked over the venter by a weak rib or pair of ribs with some additional intercalated ribs. The adult aperture is not preserved. The very simple suture has a subtrifid first lateral saddle between the ventral and lateral lobes (Fig. 2).

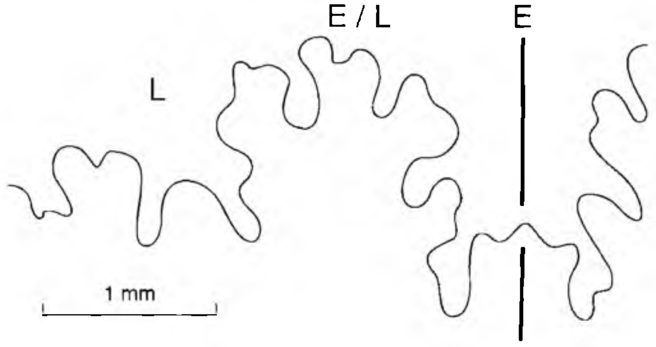

Figure 2 — Part of the external suture of *Platyscaphites groatensis* sp. nov., (Pl. 1, Figs. 19-21), from USGS Mesozoic locality D2503 (Fig. 1). E is the external lobe, L is the lateral lobe, and E/L is the saddle that separates the lobes.

Discussion

Platyscaphites groatensis sp. nov., most closely resembles *Scaphites hippocrepis* III of Cobban (1969, p. 21, pl. 3, figs. 1-25; pl. 4, figs. 35-39; pl. 5, figs. 36-40; text figs. 2, 4, 10, 11), of which it is believed to be the descendant. The two differ in the much smaller size of *P. groatensis*, the flat sides of the macroconch body chamber, and absence of umbilical and lateral tubercles on the hook.

Occurrence

Known with certainty only from USGS Mesozoic locality D2503. A single fragment of a small scaphite from the upper part of the Vermilion River Formation in southwestern Manitoba may represent this species.

Platyscaphites elginensis sp. nov.

(Pl. 1, Figs. 1-6)

Derivation of name: From the type locality on Elgin Creek, Johnson County, Wyoming.

Types

Holotype is USNM 481627 (Pl. 1, Figs. 1-3) from a limestone concretion in a bed of bentonite 222 m below the top of the Cody Shale at USGS Mesozoic locality D3434, at Elgin Creek in the N1/2 sec. 13, T. 49 N., R. 83 W., Johnson County, Wyoming. Paratype USNM 481628 (Pl. 1, figs. 4-6) is from the Cody Shale about 4.6 m below a 0.85 m-thick bed of bentonite that underlies the Shannon Sandstone Member at USGS Mesozoic locality D4266, near the North Fork oil field in a deep gully in the SE1/4NE1/4 sec. 26, T. 44 N., R. 82 W., Johnson County, Wyoming.

Diagnosis

Platyscaphites that has the body chamber of the macroconch in contact with the spire. Hook of the microconch is widely detached. Conical ventrolateral tubercles on the phragmocone and the body chamber.

Description

The holotype (Pl. 1, Figs. 1-3) is a complete macroconch 26 mm long. Its very involute phragmocone has a small, deep umbilicus and a narrowly rounded umbilical shoulder. Whorl section of the phragmocone is equidimensional and has flattened, subparallel flanks and a broadly rounded venter. Distant, relatively coarse, straight, prorsiradiate ribs, 12 per one-half whorl, arise at the umbilical shoulder and extend to well-developed conical ventrolateral tubercles. These tubercles give rise to groups of two or three ribs with an occasional intercalated rib. All ribs strengthen over the venter and cross it in a broad convexity. The body chamber is somewhat crushed but appears to have been in contact with the spire. The umbilicus is only slightly occluded, and the umbilical wall is low and concave. The body chamber is compressed and has flattened flanks and a broadly arched venter. Ornament is of delicate flank ribs that are weaker on the body chamber than on the phragmocone; some arise as mere striae at the umbilical seam. All ribs terminate in conical ventrolateral tubercles that weaken progressively towards the adult aperture. These tubercles give rise to groups of two or three narrow, convex ribs that loop between tubercles across the venter with additional intercalated single ribs.

Paratype USNM 481628 (Pl. 1, Figs. 4-6) is a large adult microconch 23 mm long. Its phragmocone is badly preserved and crushed, but appears to have been similar to that of the macroconch; ornament consists of conical ventrolateral tubercles and ventral ribs. The body chamber has a concave umbilical wall when viewed in profile; the hook is widely separated from the phragmocone. Flanks are ornamented by weak, distant, straight, prorsiradiate primary ribs. These ribs terminate in strong, conical ventrolateral tubercles that decline in strength towards the adult aperture. The ribs give rise to groups of two or three coarse, slightly convex ventral ribs that loop between tubercles; occasional intercalatory ribs are present. The imperfectly exposed suture is simple and little-incised.

DISCUSSION

The tighter coiling of the macroconch distinguishes this species from *P. groatensis* sp. nov., as does the presence of primary ribs and conical ventrolateral tubercles on the flanks of both spire and body chamber. Large size, coarseness of flank ribs, shape of tubercles, and wide separation of the later part of the body chamber from the phragmocone distinguish it from *P. fremontensis* sp. nov. The holotype (now lost) of *Scaphites similis* WHITFIELD (1892, p. 267, p. 44, figs. 1, 2) resembles *P. elginensis* but lacks tubercles on the spire.

OCCURRENCE

Platyscaphites elginensis is a rare species that has been found high in the zone of *Baculites* sp. (smooth) at localities D4266 and D4287, and in the zone of *Baculites* sp. (weak flank ribs) at locality D3434.

Platyscaphites fremontensis sp. nov.

(Pl. 1, Figs. 25-61; Fig. 3)

Derivation of name: From Fremont County, Wyoming.

TYPES:

Holotype is USNM 481629 (Pl. 1, Figs. 50-52); it and paratypes USNM 481637-481641 (Pl. 1, Figs. 44-49, 53-57) are from a sandstone bed in the Cody Shale, zone of *Baculites* sp. (weak flank ribs), at USGS Mesozoic locality 23116 in sec. 20, T. 34 N., R. 92 W., Fremont County, Wyoming. Paratypes USNM 481630-481636 (Pl. 1, Figs. 25-43) are from the Cody Shale at locality D4734 in sec. 27, T. 34 N., R. 92 W., Fremont County. Paratype USNM 481642 (Pl. 1, Figs. 58, 59) is from the Cody Shale at locality 21762 in sec. 5, T. 33 N., R. 93 W., Fremont County. Paratype USNM 481643 (Pl. 1, Figs. 60, 61) is from the Pierre Shale at locality D3890 in sec. 30, T. 4 N., R. 81 W., Grand County, Colorado.

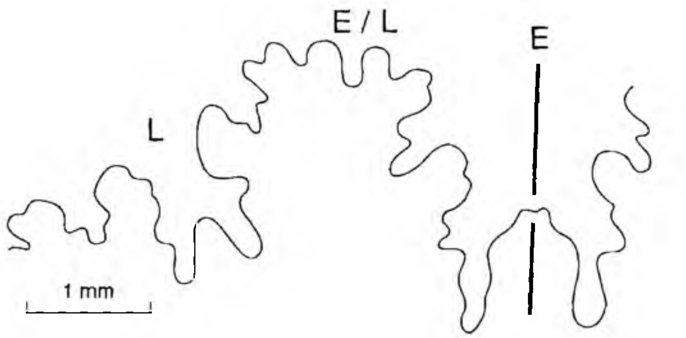

Figure 3 — Part of the external suture of *Platyscaphites fremontensis* sp. nov., (Pl. 1, Fig. 44, from USGS Mesozoic locality 10459 (Fig. 1). E is the external lobe, L is the lateral lobe, and E/L is the saddle that separates the lobes.

DIAGNOSIS

Macroconchs planispiral with whorls in contact throughout; the final section of the hook may barely detach in microconchs. Flanks ornamented by weak to strong prorsiradiate ribs and striae that terminate in very weak to strong ventrolateral tubercles. Ventral ribbing variable, generally weak.

DESCRIPTION

Dimorphism is poorly developed in this recoiled species inasmuch as both macro- and microconchs usually have their whorls in contact throughout growth. They are adult at sizes between 15.5 and 20 mm diameter. Coiling is moderately involute on the phragmocone, but becomes eccentric and progressively more evolute on the outermost whorl. The whorl section is compressed, with subparallel, flattened flanks, narrowly rounded ventrolateral shoulders, and a very broadly rounded venter. The umbilical wall is low and subvertical, and the umbilical shoulder is narrowly rounded. Ornament of the phragmocone and early body chamber is variable. Nearly smooth individuals have delicate, prorsiradiate growth lines, striae, and riblets that cross the venter in a broad convexity (Pl. 1, Figs. 47-49). Other individuals have distant, prorsiradiate primary ribs of variable strength that develop into massive, conical ventrolateral tubercles with the interspaces ornamented by delicate growth lines and striae (Pl. 1, Figs. 38-40, 55-57). Groups of two or three convex ribs loop between tubercles across the venter, and additional ventral ribs are intercalated. Ribbed and tuberculate ornament of this type may extend over much of the body chamber (Pl. 1, Figs 55-57), or the ribs may efface (Pl. 1, Figs. 58, 61). Towards the adult aperture, tubercles weaken markedly, but ribs may strengthen (Pl. 1, Figs. 53, 54). The relatively simple suture has a broad, subtrifid E/L and narrow L (Fig. 3).

DISCUSSION

Planispiral coiling that has the body chamber in contact with the phragmocone throughout growth distinguishes *P. fremontensis* sp. nov., from *P. elginensis* sp. nov., and *P. groatensis* sp. nov., *Platyscaphites fremontensis* most closely resembles *Indoscaphites cunliffei* (FORBES, 1846, p. 109, pl. 8, fig. 2) from the upper Maastrichtian of Pondicherry, South India, of which it is a heterochronous homeomorph; they differ in that the Indian species is much larger (the holotype, an adult is 34.5 mm in diameter) and has well-developed umbilical bullae.

OCCURRENCE

P. fremontensis, the most widely distributed species of *Platyscaphites*, occurs at USGS Mesozoic localities D3515, D3890, D4580, D4725, D4734, D1344, 10459, 21762, 23116, and 23121.

Acknowledgments

Photographs are by R.E. BURKHOLDER, formerly of the U.S. Geological Survey (USGS), Denver. All specimens are deposited in the U.S. National Museum of Natural History (USNM) in Washington, D.C. Casts of selected specimens are kept at the U.S. Geological Survey in Denver. KENNEDY acknowledges the financial support of the Natural Environment Research Council (U.K.), and the technical assistance of the staff of the Geological Collections, Oxford University Museum, and the Department of Earth Sciences (Oxford). The U.S. Geological Survey provided the specimens studied.

References

COBBAN, W.A., 1951 [1952]. Scaphitoid cephalopods of the Colorado Group. *U.S. Geological Survey Professional Paper,* **239**: 42 p. , 21 pls.

COBBAN, W.A., 1969. The Late Cretaceous ammonites *Scaphites leei* REESIDE and *Scaphites hippocrepis* (DEKAY) in the western interior of the United States. *U.S. Geological Survey Professional Paper,* **619**: 29 p. , 5 pls.

COBBAN, W.A. & SCOTT, G.R., 1964. Multinodose scaphitid cephalopods from the lower part of the Pierre Shale and equivalent rocks in the conterminous United States. *U.S. Geological Survey Professional Paper*, **483-E**: E1-E13, 4 pls.

DEKAY, J.E., 1828. Report on several multilocular shells from the State of Delaware; with observations of a second specimen of the new fossil genus Eurypterus. *Lyceum of Natural History of New York, Annals*, **2**: 273-279, pl. 5, figs. 2-5 (only).

FORBES, E., 1846. Report on the fossil Invertebrata from southern India, collected by Mr. Kaye and Mr. Cunliffe. *Transactions of the Geological Society of London*,(2), **7**: 97-174, pls. 7-19.

GILL, J.R. & COBBAN, W.A., 1966. The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming, with a section on A new echinoid from the Cretaceous Pierre Shale of eastern Wyoming by P.M. KIER. *U.S. Geological Survey Professional Paper*, **393-A**: A1-A73, 12 pls.

GILL, T., 1871. Arrangement of the families of mollusks. *Smithsonian Miscellaneous Collections*, **227**: 49 p.

KENNEDY, W.J. & HENDERSON, R.A., 1992. Heteromorph ammonites from the Upper Maastrichtian of Pondicherry, South India. *Palaeontology*, **35**: 693-731, 10 pls.

MEEK, F.B., 1876. A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country. *U.S. Geological Survey of the Territories Report* (Hayden), **9**: 629 p. , 45 pls.

NOWAK, J., 1911. Die Skaphiten, Pt. 2 of "Untersuchungen über die Cephalopoden der oberen Kreide in Polen". *Bulletin International de l'Acadèmie des Science de Cracovie*, **1911** (B): 547-589, pls. 32, 33.

REESIDE, J.B. Jr., 1927a. The cephalopods of the Eagle sandstone and related formations in the western interior of the United States. *U.S. Geological Survey Professional Paper*, **151**: 87 p. , 45 pls.

REESIDE, J.B. Jr., 1927b. Cephalopods from the lower part of the Cody shale of Oregon Basin, Wyoming. *U.S. Geological Survey Professional Paper*, **150-A**: 1-19, 8 pls.

SPATH, L.F., 1953. The Upper Cretaceous cephalopod fauna of Graham Land. *Falkland Islands Dependencies Survey, Scientific Reports*, **3**: 60 p., 13 pls.

WARREN, P.S., 1934. Palaeontology of the Bearpaw Formation. *Royal Society of Canada Transactions* (3), **28**, 4: 81-100.

WHITFIELD, R.P., 1892. Gasteropoda and Cephalopoda of the Raritan Clays and Greensand Marls of New Jersey. *U.S. Geological Survey Monograph*, **18**: 402 p. , 50 pls.

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Typescript submitted: 15.10.1998
Revised typescript received: 15.1.1999

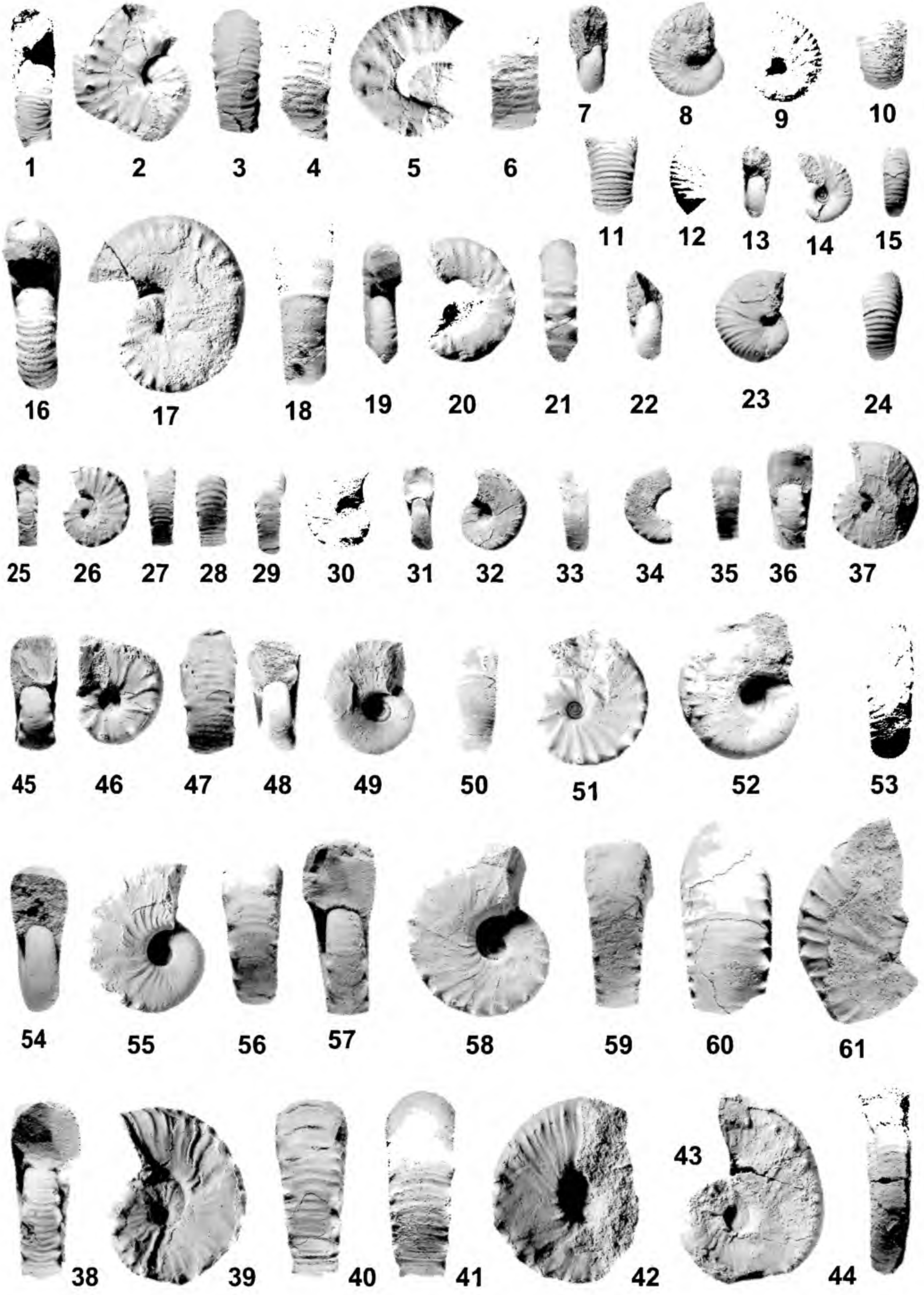
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PLATE 1

Plate 1

Figs. 1-6 — *Platyscaphites elginensis* sp. nov. 1-3, holotype USNM 481627, a macroconch, from USGS locality D3434. 4-6, paratype USNM 481628, a microconch, from USGS locality D4266.

Figs. 7-24 — *Platyscaphites groatensis* sp. nov. 7-8, paratype USNM 481622, from USGS locality D2503. 9-10, paratype USNM 481623, from USGS locality D2503. 11-12, paratype USNM 481624, from USGS locality D2503. 13-15, paratype USNM 481625, from USGS locality D2503. 16-18, holotype USNM 481620, a macroconch, from USGS locality D2503. 19-21, paratype USNM 481621, a microconch, from USGS locality D2503. For suture, see text Figure 2. 22-24, paratype USMN 481626, from USGS locality D2503.

Figs. 25-61 — *Platyscaphites fremontensis* sp. nov. 25-28, paratype USNM 481630, a microconch, from USGS locality D4734. 29, 30, paratype USNM 481631, a microconch, from USGS locality D4734. 31-33, paratype USNM 481632, a microconch, from USGS locality D4734. 34, 35, paratype USNM 481633, a microconch, from USGS locality D4734. 36, 37, paratype USNM 481634, a macroconch, from USGS locality D4734. 38-40, paratype USNM 481635, from USGS locality D4734. 41-43, paratype USNM 481636, a microconch, from USGS locality D4734. 44, paratype USNM 481638, a microconch, from USGS locality 10459. For suture, see Fig. 3. 45, 46, paratype USNM 481637, a microconch, from USGS locality 23116. 47-49, paratype USNM 481639, a microconch, from USGS locality 23116. 50-52, holotype USNM 481629, a microconch, from USGS locality 23116. 53, 54, paratype USNM 481640, a macroconch, from USGS locality 23116. 55-57, paratype USNM 481641, a microconch, from USGS locality 23116. 58, 59, paratype USNM 481642, a microconch, from USGS locality 21762. 60, 61, paratype USNM 481643, from USGS locality D3890.

Figures 1-6, 19-21, 25-37, are x 1. Figures 7-18, 22-24, 38-61 are x 2.

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 55-65, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 55-65, 1999

Upper Maastrichtian bivalve faunas from the Crimea, Maastricht and Mangyshlak

by Annie V. DHONDT

Abstract

Upper (but not uppermost) Maastrichtian bivalve faunas in the stratotypical Maastrichtian area and in the Crimea are extremely diverse and species rich, and represent a very littoral shallow and warm environment. Uppermost Maastrichtian bivalve faunas and in the Maastrichtian stratotypical area and in the Crimea indicate a somewhat deeper, cooler environment. The Upper Maastrichtian bivalves from Mangyshlak are much less diversified and indicate a cold environment, comparable with the "upper shelf" in today's seas.

Key-words: Upper Cretaceous, Bivalves, Maastricht, Crimea, Mangyshlak.

Résumé

Les faunes de bivalves du Maastrichtien supérieur (mais non terminal) dans la région stratotypique de l'étage Maastrichtien et de la Crimée sont très diversifiées et riches en espèces. Elles représentent un environnement littoral, chaud et peu profond.

Les bivalves du Maastrichtien terminal des mêmes régions indiquent un environnement plus profond et plus froid.

Les bivalves du Maastrichtien supérieur du Mangyshlak sont moins diversifiés et indiquent un environnement de "shelf", franchement plus profond.

Mots-clefs: Crétacé supérieur, Bivalves, Maastricht, Crimée, Mangyshlak.

Резюме

Фауны двухстворчатых верхнего (но не высшего) Маастрихта в статотипичной области Маастрихтского яруса и в Крыму невероятно разнообразны и богаты породами. Они представляют теплую и мелководную прибрежную фацию. Фауны двухстворчатых высшего Маастрихта в статотипичной области Маастрихтского яруса и в Крыму указывают на более глубокую и холодную фацию. Фауны двухстворчатых верхнего Маастрихта Мангъшлака менее разнообразны и указывают на холодную фацию, сравнимую с «верхним шельфом» современных морей.

Ключевые слова: Верхний мел, двухстворчатые, Маастрихт, Крым, Мангъшлак

Introduction

The Campanian represents possibly the moment of widest marine expansion in Europe (ZIEGLER, 1990). In the Lower Maastrichtian marine strata are still very widely distributed — from England to the Aral Sea in Kazakhstan — but on average they represent a somewhat shallower facies than in the Campanian. During the Upper Maastrichtian large areas, which were still marine in the Lower Maastrichtian, had become continental. This was especially true in extensive Tethyan areas of southern Europe with the development of the Garumnian facies.

In western, northern and eastern Europe, and into western Asia, the white chalk facies is found in the Campanian and Maastrichtian (Fig. 1). In this "White Chalk Sea" a fairly homogenous fauna is found. Specifically, the Upper Maastrichtian strata which were deposited by this white chalk, still represent a fairly deep marine facies.

On the southern border of this white chalk sea, well-developed, very fossiliferous Upper Maastrichtian deposits exist, sometimes overlain by Danian deposits. Across the K/T boundary sedimentation was only rarely continuous, and the Upper (uppermost) Maastrichtian sea was relatively shallow in this southern part. In three areas [(1) the Maastrichtian stratotypical area, Limburg, The Netherlands-Belgium; (2) south western Crimea, The Ukraine; (3) Mangyshlak Peninsula, W. Kazakhstan] which knew a more or less continuous sedimentation across the K/T boundary, the faunal evolution of the bivalves in the uppermost Maastrichtian and near the K/T boundary was followed.

Stratigraphy

In the Maastricht area (Limburg, Belgium-The Netherlands) the Upper Maastrichtian is mainly represented by the generally calcarenitic Maastricht Fm. (Figs. 1, 2 and map in JAGT, this volume, p. 104). Stratigraphically most of the Maastricht Fm. is part of the *junior* Zone. Only the uppermost member (Meerssen Chalk) belongs partially to the *kazimiroviensis* Zone (JAGT, 1996). At the quarry Curfs-Ankerpoort (near Geulhem, Zuid Limburg, The Netherlands) the Meerssen Chalk contains a clearly marked thin layer the "Berg en Terblijt Horizon" (formal

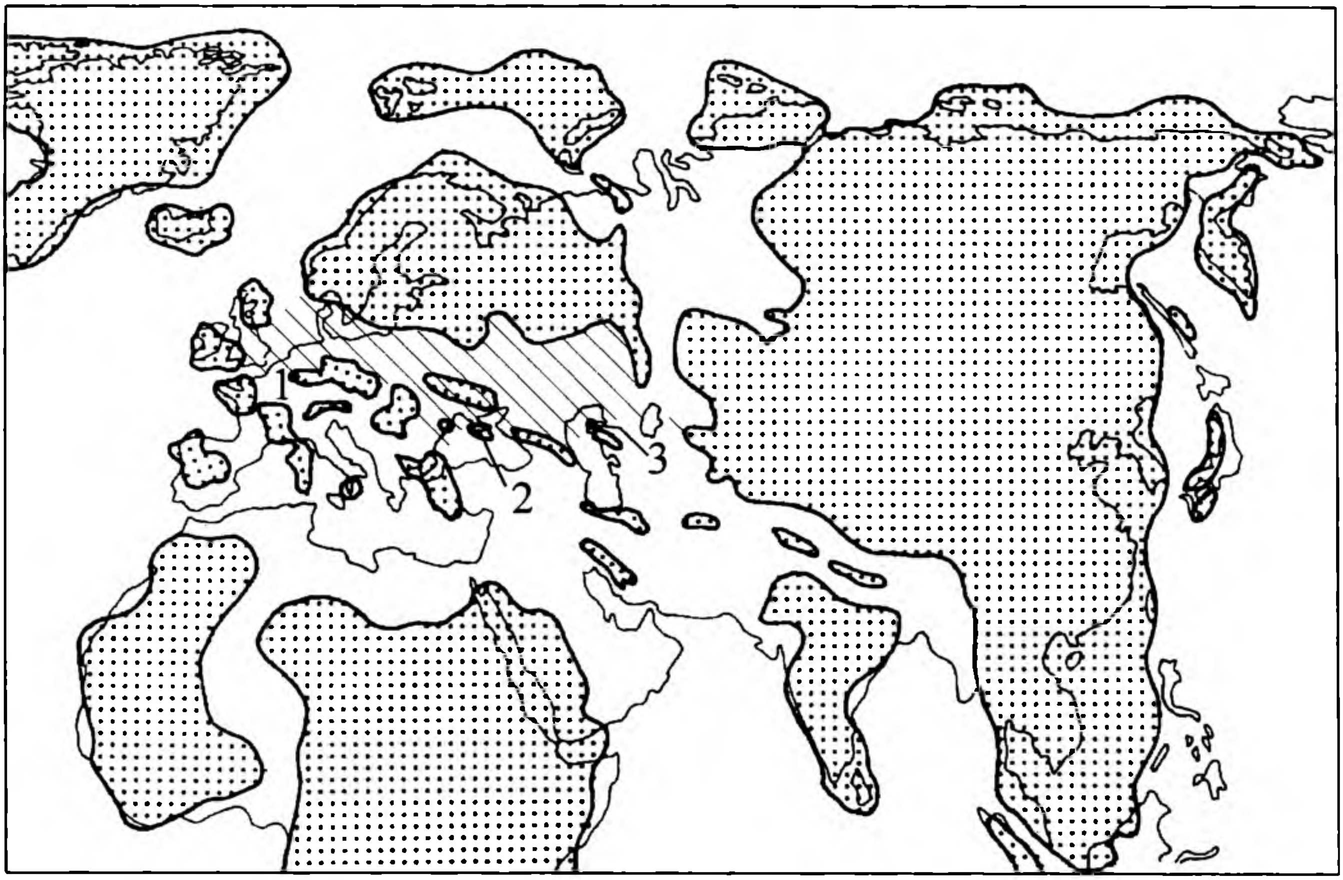

Figure 1 — Distribution of the White Chalk Sea (map from DHONDT *et al.*, 1996); the "white chalk sea" is shaded; 1: Maastrichtian stratotypical area; 2: Upper Cretaceous of Crimea; 3: Mangyshlak.

definition in FELDER & BOSCH, in press); this horizon is now considered the K/T boundary (JAGT *et al.,* 1996, Fig. 3). The upper Meerssen Chalk, above this horizon, is lowermost Danian. It is unconformably overlain by younger Palaeocene calcarenites. The Houthem Fm. of early to late Danian age (? Thanetian), is outcropping also as a calcarenite. The age of the Geulhem Member is Middle Danian (JAGT, 1996 & 1999). In the Geulhemmerberg section the K/T transition is more complete and the transitionary clay forms the Berg en Terblijt Horizon, which is a little older than the Vroenhoven Horizon at the top of the Meerssen Chalk. The Vroenhoven Horizon was previously considered to equate with the K/T boundary in that area (JAGT *et al.*, 1996).

Near Bakhchisaray and near Belogorsk (S. Crimea, the Ukraine), extensive Maastrichtian chalks (sometimes marly sandstones) are overlain generally unconformably by Palaeocene and/or Eocene limestones (sandstones) (NAIDIN *et al.*, 1984; NIKISHIN *et al.*, 1993; ALEKSEEV & KOPAEVICH, 1997; Fig. 4). Further east on the Crimean Peninsula (near Topolevka Koktebel) the Maastrichtian is present in a flysch facies, deposited in deep water.

The zonation generally used for the Maastrichtian is based on belemnites (macrofauna) and on planktonic Foraminifera and calcareous nannofossils (microfauna) (NIKISHIN *et al.*, 1993; ALEKSEEV & KOPAEVICH, 1997, p. 110, fig. 6). Also used are "units" representing faunal assemblages (ALEKSEEV, 1989).

It must be noted that the *kazimiroviensis* Zone in Crimea comprises a large part of the Upper Maastrichtian, overlying a thin *junior* Zone.

In Mangyshlak the complete Upper Maastrichtian, as was already noted by NAIDIN (1973), belongs to the *kazimiroviensis* Zone. For details on the stratigraphy see NAIDIN (1986, 1987) and NAIDIN *et al.* (1990a, b; 1996).

Faunas and environment

MATERIAL AND METHODS

The taxonomy used for bivalves herein is based on the "Treatise", but changes introduced by WALLER (1978) for the pteriomorphs and by MALCHUS (1990) for the oysters, have been taken into account. The material studied in personal or museum collections was in all three regions complemented by fieldwork.

I have studied the bivalves from the Maastrichtian

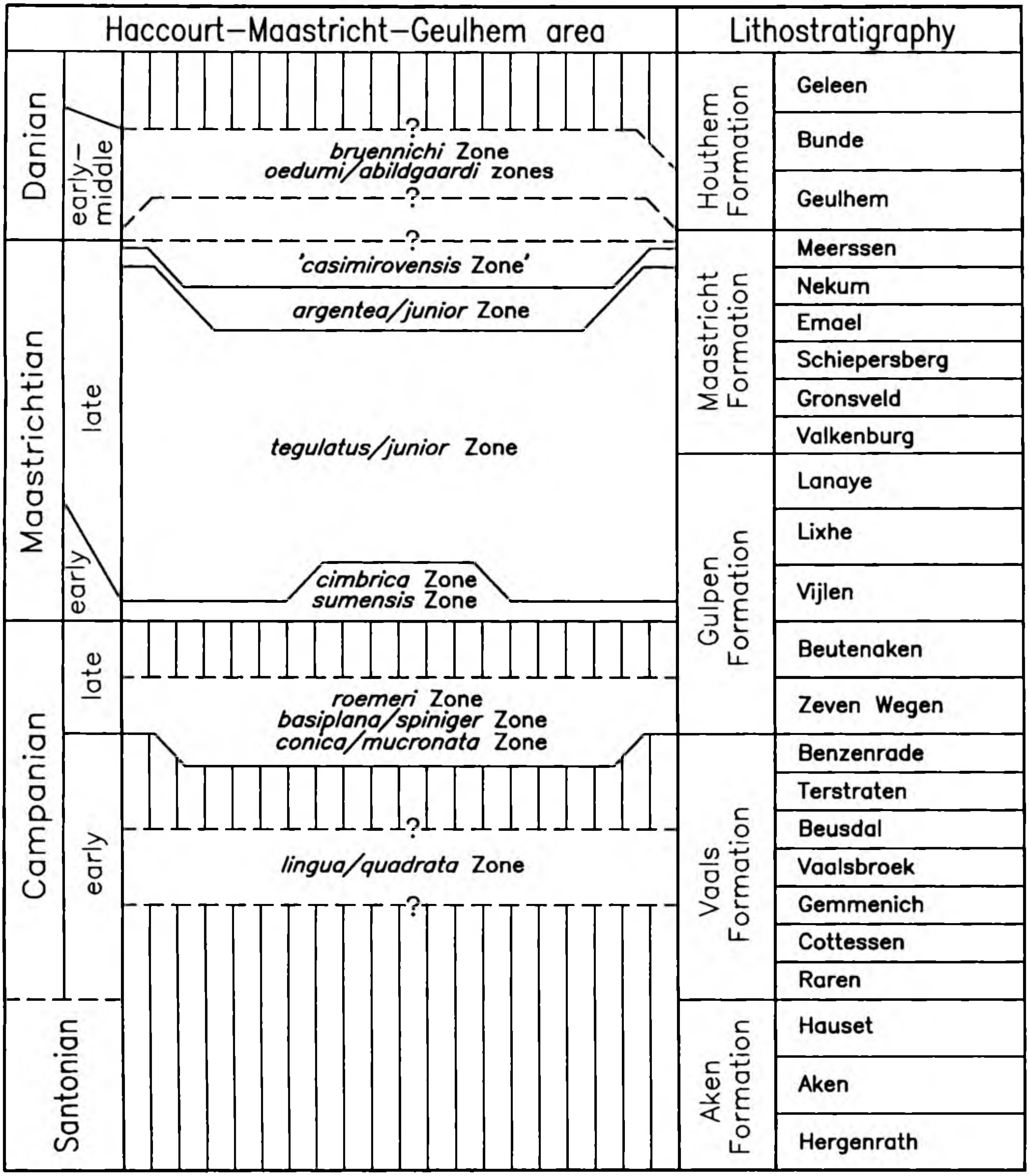

Figure 2 — Lithostratigraphy and biozonation of Campanian, Maastrichtian an Danian strata in the stratotypical region of the Maastrichtian Stage (after JAGT, this volume).

stratotypical part for the last 35 years mainly in the collections of the Royal Belgian Institute of Natural Sciences; in the list provided herein the taxa in steinkern preservation are not taken into consideration.

Bivalves from the Crimean outcrops have been mainly studied in the personal collection of Prof. D. P. Naidin at the MGU, in the collections of the late V. A. Sobetski at the PIN, and in the collections at the Baza MGU at Prokhladnoe in the Crimea.

Bivalves from Mangyshlak were studied in the collec-

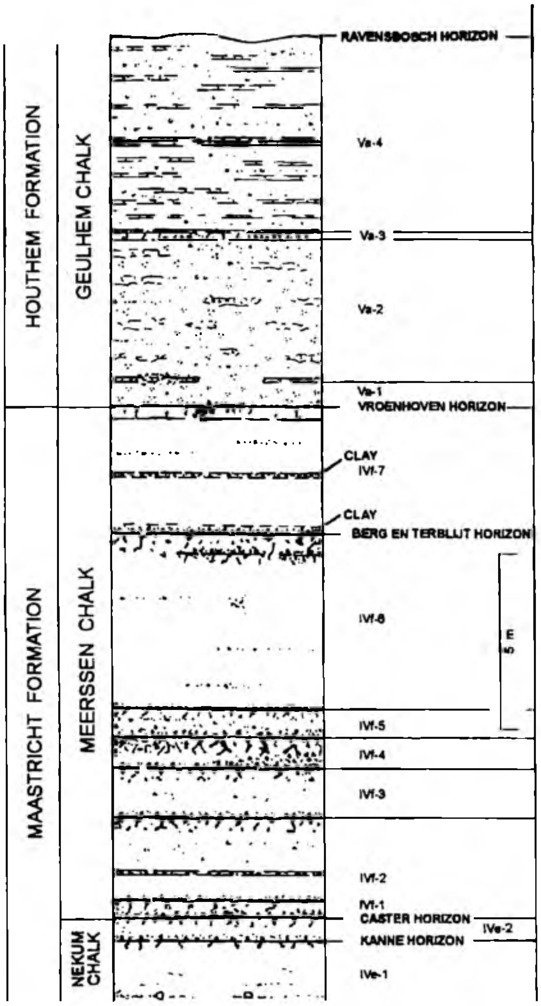

Figure 3 — Uppermost Maastrichtian section in quarry Curfs-Ankerpoort, Geulhem (after JAGT *et al.*, 1996) indicating the level of the Berg en Terblijt Horizon.

tions of Prof. D. P. Naidin at MGU. In the Mangyshlak outcrops of Maastrichtian age, bivalves are relatively rare.

MAASTRICHT

The fossils from the strata of the Maastrichtian Fm. in the stratotypical area were already described, figured and/or mentioned by FAUJAS DE SAINT FOND (1799-1802), von SCHLOTHEIM (1813, 1820), GOLDFUSS (1833-1841), d'ORBIGNY (1850). Changes throughout the faunas of the Maastricht Fm. were recognised early on (e.g. "couche à coprolithes, couche à bryozoaires"), but detailed stratigraphical occurrences of bivalves were only rarely noted.

More recent work has clearly shown that changes within the Maastricht Fm. were important. Herein we shall try to give an account of bivalve faunas within the members of the Maastricht Fm.. From the overlying Houthem Fm. bivalves are known but they have not so far been described in detail from the Maastricht region (JAGT & JANSSEN, 1988). Faunas of similar age from the colliery shafts in nearby Belgian Limburg were last revised by GLIBERT & VAN DE POEL (1973).

Among the macrofaunas from the Upper Maastrichtian Maastricht Fm. (Fig. 2) the very numerous and diverse bivalve fauna is probably one of the most species rich. Because of the limitations of the preservation in calcarenites not all taxa were preserved but only those with a mainly calcitic shell such as Pectinidae, Limidae, Spondylidae, Anomiidae, Mytilidae, modiolids, Ostreacea, Pinnidae; also recognisable are those with a very thin shell such as Pholadomyidae, and *Liopistha*. Rarely also taxa of the genus *Glycymeris*, arcids, *Nucula* s.l., *Cucullaea* sp., "*Trigonia*", crassatellids, cardiids, dosiniids are more or less identifiable as steinkerns or composite external moulds. The only "monograph" on these faunas was written by VOGEL (1895). The pectinids and some limids were revised by DHONDT (1971; 1972a & b; 1973 a & b; 1976; 1989) and *Liopistha* by DHONDT & JAGT (1988).

This Upper Maastrichtian Maastricht Fm., in the stratotypical area is characterised by a highly diversified fauna, which is fairly different from the fauna known from the underlying strata of the Gulpen Fm.

Thus, the Lower to lower Upper Maastrichtian Vijlen Chalk Member (top of the Lower Gulpen Fm.), which is a typical white chalk deposit, contains a fauna comparable to that found in the typical Schreibkreide/ Skrivekridt deposits of northern Europe (DHONDT & JAGT, 1987) (Table 1), and also further east around Lwow in the Ukraine and on the Russian Platform, onto the Precaspian Depression.

From the Lanaye Chalk Member (top of the Gulpen Fm.) upwards a strong southerly (shallower, sublittoral, subtropical) influence is visible in the faunas: e.g. the echinoid *Hemipneustes*, the bivalve *Pinna decussata*, ostracodes (BLESS, 1989), mosasaurs and cheloniid turtles (JAGT, 1995).

The Maastricht Fm. starts with the Valkenburg Chalk Member (formerly named unit Ma - UHLENBROEK, 1912), which represents a less open environment, but with the same fauna as in the underlying Lanaye Chalk Member.

The Gronsveld, Schiepersberg, and Emael Members form a virtually homogenous sediment (formerly named unit Mb - UHLENBROEK, 1912) which according to VILLAIN (1977) was deposited at a depth of 20 to 40 m, free from oceanic influences. LIEBAU (1978) considered the setting as middle sublittoral, with subtropical temperatures and with seagrass communities. These strata contain a diversified fauna in which especially the bivalves are numerous (Table 2), often largish and some typical for sea grass communities.

The Nekum Member (formerly unit Mc - UHLENBROEK, 1912) consists mainly of fairly coarse-grained biocalcarenites and contains in its lowermost part a serpulid horizon with numerous bivalves and the ammonites *Sphenodiscus binckhorsti* and *Hoploscaphites felderi*.

The upper strata of the Nekum Member contain numerous crustaceans and a coquina with tegulated inoce-

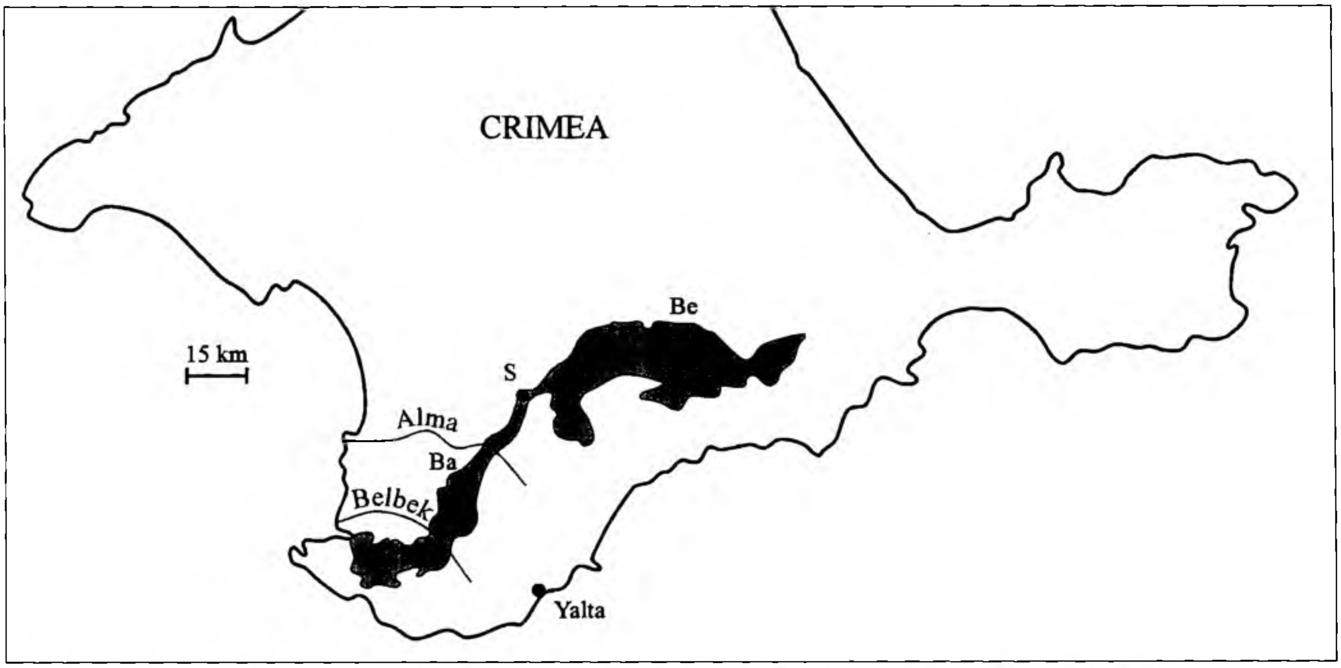

Figure 4 — Crimean Cretaceous strata. Ba: Bakhchisaray; Be: Belogorsk; S: Simferopol (from NIKISHIN *et al.*, 1993).

ramids (*Spyridoceramus tegulatus*) and *Belemnitella junior*.

The Meerssen Member (formerly unit Md - UHLENBROEK, 1912), youngest member of the Maastricht Fm., should ecologically be divided into two parts; the lower part contains a fauna similar to that of the Nekum Member and even contains rudists; the upper part (youngest Maastrichtian levels) contains a different fauna probably of cooler origin. The terminal Maastrichtian event (within the Meerssen Member of the Maastricht Fm., JAGT *et al.*, 1998) in the Maastricht area is accompanied by a cooler water fauna with rare *Neobelemnella* gr. *kazimiroviensis*, and *Tenuipteria argentea*. Among the bivalves most of the larger taxa which could live among the sea grass have gone - numerous smaller oysters and smooth pectinids remain (Table 2 and JAGT, 1996).

THE CRIMEA

The Upper Cretaceous strata from the Bakhchisaray region in the Crimea have been studied since the beginning of the 19 th century. The numerous bivalves typical for these strata immediately attracted the attention of geologists and palaeontologists. Thus FISCHER DE WALDHEIM already in 1835 described *Alectryonia deshayesi* (= *Rastellum deshayesi*) and *Pycnodonte radiata* from the Maastrichtian of "Mountain" Crimea. In 1842 ROUSSEAU *in* HUOT *in* DEMIDOFF described *Ostrea mirabilis* (*Pycnodonte mirabilis*) from the same area. These descriptions of Crimean Cretaceous taxa were widely known. Fossils from the uppermost Cretaceous strata in Bakhchisaray are present in the d'Orbigny collection (Institut de Paléontologie, Muséum National d'Histoire naturelle in Paris) and are mentioned in d'ORBIGNY (1850) e.g. and most museum collections contain specimens from "Bakhshisarai".

No monographs on these faunas were written in the 19 th century.

In the last 50 years only two papers have described Upper Cretaceous Crimean bivalves: the inoceramids were treated by DOBROV & PAVLOVA *in* MOSKVIN (1959) and many other bivalve taxa were described by SOBETSKI (1977). Danian Crimean mollusks have been studied e.g. by MAKARENKO (1961), GORBACH (1972).

Table 1 — White Chalk Sea taxa

	Vylen	Hemmoor	Crimea	Mangyshlak	Precaspia
Pseudoptera coerulescens	*		*	*	*
Limatula decussata	*	*	*		*
Pseudolimea geinitzi	*	*	*		
Microchlamys subinflexa		*	*	?	?
Mimachlamys striatissima	*	*	*		*

Table 2 — Upper Upper Maastrichtian bivalves from the Maastrichtian type area; Kunrade contains an Upper but not uppermost Maastrichtian fauna.

	Mc	Md	Kunrade
Pinna decussata	+	+	+
"Pteria" approximata	+		
Hypoxytoma danica		+	
Pseudoptera coerulescens	+	+	
Spyridoceramus tegulatus	+		
Tenuipteria argentea		+	+
Isognomon tripterus	+	+	+
Limatula decussata			+
Li. kunradensis	+	+	+
Plagiostoma hoperi		+	+
Pl. sowerbyi	+		
Pseudolimea denticulata	+	+	?
Ps. granulata	+		+
Ctenoides dunkeri	+	+	
Ct. muricata	+	+	
Ct. tecta	+	+	
Ct. vogeli	+		
Limaria ovata		+	
Pycnodonte vesicularis	+	+	+
P. vesicularis "minor"		+	
Hyotissa semiplana	+		+
Amphidonte auricularis		+	
A. decussata	+		+
Ceratostreon pliciferum	+		
Gryphaeostrea canaliculata			+
Agerostrea ungulata	+	+	
Rastellum sp.	+		
Acutostrea sp.	+	+	
Entolium membranaceum	+	+	+
Syncyclonema haeggi	+	+	
Sy. nilsoni	+	+	
Sy. semiplicata	+	+	
Camptonectes virgatus	+	+	
Microchlamys acuteplicata		+	
Mi. campaniensis	+	+	
Mi. pulchella	+		
Mi. subinflexa	+		
Lyropecten ternatus	+	+	+
Chlamys faujasi	+	+	
Mimachlamys cretosa	+	+	+
Merklinia trigeminata	+		
Me. variabilis	+	+	
Neithea quinquecostata	+		
Ne. regularis	+	+	+
Ne. sexcostata	+	+	
Ne. striatocostata	+	+	+
Spondylus dutempleanus	+	+	+
Sp. subplicatus	+		+
Liopistha aequivalvis	+	+	+

In the Crimea in several localities (near Bakhchisaray: Salachik; Skalistoe; near Belogorsk: Belaja Skala - also called Akkaja - and a few others), the assemblage unit XXIII of ALEKSEEV (1989) contains a very rich bivalve fauna (Table 3) indicating a very shallow, warm environment. As in Maastricht, mainly the taxa with calcitic shells are preserved, and others such as nuculids, lucinids, pholadomyids are only found in steinkern preservation.

The youngest Crimean Cretaceous strata, i.e. member XXIV of ALEKSEEV (1989), best visible at Belbek, with a thickness of up to 5 m, form a short transgressive impulse, resulting in marls with numerous *Neobelemnella kazimiroviensis*, and numerous bivalves (Table 3) /large smooth pectinids, and more planktonic Foraminifera than in the very shallow-water member XXIII (ALEKSEEV & KOPAEVICH, 1997) (Table 3).

MANGYSHLAK

In N. Mangyshlak the relatively deep-water chalk Maastrichtian sections at Kyzylsay and Koskak (see in KOPAEVICH & BENJAMOVSKII, this volume, p. 000) have a terminal Cretaceous chalk unit (2-2.5 m) with an assemblage of more belemnites and diverse planktonic foraminifera; bivalves are relatively rare. As in the Maastrichtian near Maastricht and in the Crimea only pteriomorphs are preserved with shells. Probably because the Mangyshlak chalks are fairly "deep water" deposits they contain a relatively poor bivalve assemblage:

Lower Maastrichtian: pteriids (*Pseudoptera coerulescens*), oysters (*Pycnodonte* sp. , *Hyotissa semiplana*,? *Amphidonte* sp.), pectinids (*Microchlamys "pulchella"*, *Neithea sexcostata*);

Upper and uppermost Maastrichtian: pteriids (*Pseudoptera coerulescens*), a few limids (*Plagiostoma* sp. , *Pseudolimea* sp.), oysters (*Pycnodonte similis*, *Hyotissa semiplana*,? *Amphidonte* sp.) almost no pectinids (a few *Microchlamys* sp. , *Merklinia* sp. and *Neithea sexcostata*), spondylids (*Spondylus dutempleanus*). Also present in the Upper Maastrichtian of Mangyshlak until just under the K/T boundary is the inoceramid *Tenuipteria argentea*.

DANIAN

In the Danian in Mangyshlak, as is also the case in some localities on the Russian platform (ARKHANGUELSKY, 1905), just above the K/T boundary level *Pycnodonte similis* is still found but none of the other bivalve taxa known from the Maastrichtian (see above) seem to cross this boundary.

The Danian, as far as present in the three areas (JAGT, 1996; NAIDIN, 1987; 1997; NAIDIN & KOPAEVICH, 1988) is often separated from the Maastrichtian by a short time hiatus. The Lower (but not lowermost) and "middle" Danian contain a not very diversified, fairly cool water molluscan fauna (GLIBERT, 1973; GLIBERT & VAN DE POEL, 1973; JAGT & JANSSEN, 1988). The climate must have warmed up progressively and the Upper Danian fauna, especially in the Crimea, is definitely a warm

Table 3 — Maastrichtian bivalve faunas from Crimea. Abbreviations: Ak: Akkaya; St: Starocelje; Sk: Skalistoe; others: i.e. Beshkosh, Glubokij Yar, Feodosia; 1: Lower Maastrichtian; 2: Upper Maastrichtian.

	Ak 1	Ak 2	St 1	St 2	Sk 1	Sk 2	oth 1	oth 2
Hypoxytoma danica				+				
Pseudoptera coerulescens								
Tenuipteria argentea				+				
Pycnodonte mirabilis		+		+		+		
P. vesicularis	+	+	+		+		+	+
Hyotissa semiplana		+		+		+		
Amphidonte auricularis		+		+				+
A. decussata	+	+	+	+		+	+	+
A. goldfussiana		+		+				
Ceratostreon pliciferum		+		+				
Gryphaeostrea canaliculata		+		+				+
Agerostrea ungulata		+				+		
Rastellum sp.		+		+		+		+
Acutostrea sp.				+				
"Ostrea" biconvexa				+				
Entolium membranaceum								+
Camptonectes virgatus			+					+
Microchlamys acuteplicata		+		+		+		+
Mi. pulchella						+		
Chlamys denticulata		+		+		+		
Lyriochlamys septemplicata						+		+
Merklinia trigeminata			+		+			+
Neithea sexcostata		+		+		+		+
Spondylus dutempleanus	+		+		+		+	
Limatula decussata	+		+					+
Li. kunradensis								+
Li. semisulcata		+						
Plagiostoma cretaceum			+					
Pl. hoperi				+				
Pl. marrotianum		+		+				+
Pl. sowerbyi	+							
Pseudolimea granulata						+		
? Ps. geinitzi		+	+			+		
Crassatella arcacea				+				
Leptosolen sp.		+						
Panope sp.		+						
Liopistha aequivalvis		+		+		+		

water fauna. A similar change in climate is also illustrated for the microfauna of Mangyshlak by Kopaevich & Beniamovskii (this volume).

Conclusions

— In the Maastricht area, Mangyshlak, and the Crimea similar trends in sedimentology [from chalk facies in uppermost Campanian (lower Maastrichtian in the Maastricht area) to shallow limestones, calcareous sandstones and siltic limestones (in Crimea) at the top Maastrichtian] and in community structures in the Maastrichtian (environments vary from deep to extremely shallow water) are seen.

— The Upper (but not uppermost) Maastrichtian bivalve faunas in the stratotypical Maastricht area (Nekum and lower Meerssen Members) and in the Crimea (assemblage XXIII of ALEKSEEV, 1989) are highly diversified and typical of a shallow, probably littoral, relatively warm environment with a Tethys influence. Near Maastricht these faunas even contain rudists.

— The uppermost Maastrichtian bivalve faunas in the stratotypical area ("middle" Meerssen Member up to the Berg en Terblijt Horizon) contain a less diverse fauna with no obvious warm water taxa. The bivalve fauna of faunal assemblage XXIV in the Crimea is also more restricted (mainly oysters and smooth pectinids).

— The Upper Maastrichtian bivalve fauna in the Mangyshlak outcrops is not diverse. It contains no real littoral taxa, and its fauna can be considered as a "white chalk" fauna, representing a deeper/colder water fauna. It does not contain all typical Lower Maastrichtian "Schreibkreide" taxa, which do occur in the Crimea and in the Vijlen Member of the Gulpen Formation in the Maastrichtian stratotypical area.

— Biostratigraphically, the uppermost Maastrichtian strata of the three regions considered contain the belemnite *Neobelemnella kazimiroviensis* and the inoceramid *Tenuipteria argentea*. However, *N. kazimiroviensis* has a different vertical extension in the three regions - in Mangyshlak it is present throughout the Upper Maastrichtian, whereas in the Maastricht area only the uppermost Maastrichtian "middle" Meerssen Member contains rare *N. kazimiroviensis*. Similarly, *Tenuipteria argentea* occurs often in the Nekum and Meerssen members of the Maastricht Fm. and also in Mangyshlak it is present throughout the Upper Maastrichtian. In the Crimea it is extremely rare: I have seen so far only two specimens - one from the Besh Kosh outcrop near Bakhchisaray and one from near Feodosia.

— Environmentally, the Crimean Maastrichtian bivalve faunas of assemblage XXIII (ALEKSEEV, 1989) probably represent the "warmest" episode, as can be assumed from the very large and thick-shelled *Rastellum* sp. [*Rastellum pectinatum* (Lamarck) and *R. deshayesi* (Fischer de Waldheim) in literature] and from the large and equally thick-shelled *Pycnodonte radiata* (Fischer de Waldheim) and *P. mirabilis* (Rousseau in Huot).

The Upper Maastrichtian faunas (Nekum and p. p. Meerssen members) in the Maastrichtian type area contain, at approximately the same level as assemblage XXIII in Crimea, small rudists indicating a Tethyan warm water influence, but the oysters (and other pteriomorph taxa) do not reach the shell thickness nor the size of the Crimean specimens. I assume that the sea grass community in which they lived was deeper/colder than the Crimean environment - possibly about 5 - 15 m depth.

As stated above, the Mangyshlak Upper Maastrichtian was even deeper and definitely colder, without littoral taxa.

— The bivalve faunas from the three areas concerned bring complementary data for the evolution and extinction of such bivalve groups as the rudists (only around Maastricht), inoceramids (*Tenuipteria* only in Maastricht and Mangyshlak in sufficient numbers), exogyrine oysters and the Neitheinae. They also illustrate that e.g. the Pycnodonteine oysters survived the K/T boundary without the slightest problem. This can be explained by their adaptation to deeper seawater.

Acknowledgements

Many colleagues and friends over the years helped in this bivalve research. For the present paper I would especially like to thank A. S. Alekseev, A. A. Atabekian, V. N. Beniamovskii, J. M. Hancock, J. W. M. Jagt, L. F. Kopaevich, D. P. Naidin, A. M. Nikishin, E. Steurbaut. I am also very grateful to the MGU students at Polygon (1996, 1997, 1998) who collected a surprising number of unexpected and interesting taxa.

At the KBIN I thank for various help in the course of this research D. Anne, R. Cremers, H. De Potter and W. Miseur.

References

ALEKSEEV, A. S., 1989. Cretaceous System. *In:* MAZAROVICH, O. A. & MILEEV, V. S., Geologic structure of the Kacha uplift of Mountain Crimea. Mesozoic Stratigraphy. pp. 123-157. Moscow University, Moscow (in Russian).

ALEKSEEV, A. S. & KOPAEVICH, L. F., 1997. Foraminiferal biostratigraphy of the uppermost Campanian-Maastrichtian in SW Crimea (Bakhchisaray and Chakhmakhly sections). *Bulletin Institut royal des Sciences naturelles de Belgique. Série Sciences de la Terre* **67:** 103-120.

ARKHANGUELSKY, A. D., 1905. Sur quelques Ostrea du Paléocène et du Crétacé supérieur de la Russie. *Annuaire géologique et minéralogique de la Russie*, **VII, 7:** 1 - 27.

BLESS, M., 1989. Event-induced changes in Late Cretaceous to Early Paleocene ostracode assemblages of the SE Netherlands and NE Belgium. *Annales de la Société géologique de Belgique*, **112**: 19 - 30.

DHONDT, A. V., 1971. Systematic revision of *Entolium, Propeamussium* (Amusiidae) and *Syncyclonema* (Pectinidae, Bivalvia, Mollusca) of the European boreal Cretaceous. *Bulletin Institut royal des Sciences naturelles de Belgique* **47**, 32: 95 pp.

DHONDT, A. V., 1972a. Systematic revision of the Chlamydinae (Pectinidae, Bivalvia, Mollusca) of the European Cretaceous. Part 1: *Camptonectes. Bulletin Institut royal des Sciences naturelles de Belgique - Sciences de la Terre,* **48**, 3: 60 pp.

DHONDT, A. V., 1972b. Systematic revision of the Chlamydinae (Pectinidae, Bivalvia, Mollusca) of the European Cretaceous. Part 2: *Lyropecten. Bulletin Institut royal des Sciences naturelles de Belgique - Sciences de la Terre,* **48**, 7: 80 pp.

DHONDT, A. V., 1973a. Systematic revision of the subfamily Neitheinae (Pectinidae, Bivalvia, Mollusca) of the European Cretaceous. *Mémoires Institut royal des Sciences naturelles de Belgique*, **176:** 101 pp.

DHONDT, A. V., 1973b. Systematic revision of the Chlamydinae (Pectinidae, Bivalvia, Mollusca) of the European Cretaceous. Part 3: *Chlamys* and *Mimachlamys. Bulletin Institut royal des*

Sciences naturelles de Belgique - Sciences de la Terre, **49,** 1: 134 pp.

DHONDT, A. V., 1976. Systematic revision of the Chlamydinae (Pectinidae, Bivalvia, Mollusca) of the European Cretaceous. Part 4: *Merklinia. Bulletin Institut royal des Sciences naturelles de Belgique - Sciences de la Terre,* **51,** 7: 38 pp.

DHONDT, A. V., 1989. Late Cretaceous *Limea* (*Pseudolimea*) species of Europe. *Bulletin Institut royal des Sciences naturelles de Belgique - Sciences de la Terre,* **59**: 105-125.

DHONDT, A. V. & JAGT, J. W. M., 1987. Bivalvia uit de Kalksteen van Vijlen in Hallembaye (België). *Grondboor en Hamer,* **41**: 78-90.

DHONDT, A. V. & JAGT, J. W. M., 1988. Upper Cretaceous *Liopistha* species in North Western Europe. *Bulletin Institut royal des Sciences naturelles de Belgique - Sciences de la Terre,* **58**: 187-197.

DHONDT, A. V., NAIDIN, D. P., LEVINA, A. P. & SIMON, E., 1996. Maastrichtian faunas from the Turgay Strait (northern Kazakhstan). *Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg,* **77**: 49-65.

DOBROV, S. A. & PAVLOVA, M. M., 1959. "Inoceramidae" *in* MOSKVIN, M. M., (Editor). Atlas of the Upper Cretaceous fauna of the Northern Caucasus and Crimea. Trudy VNIIGAZ, Moscow. pp. 130-165 (in Russian).

FAUJAS-DE-SAINT-FOND, B. 1799? 1802. Histoire naturelle de la Montagne de Saint-Pierre de Maëstricht. Paris, 263 pp.

FELDER, W. M. & BOSCH, H. W., in press. Afzettingen uit het Boven-Krijt en Danien in Zuid-Limburg en omgeving. Geologie van Nederland (Rijks Geologische Dienst).

FISCHER de WALDHEIM, G., 1835. Lettre à Monsieur le Baron de Férussac sur quelques genres de coquilles du Muséum Démidoff et en particulier sur quelques fossiles de la Crimée. *Bulletin Société impériale des Naturalistes de Moscou,* **8:** 101-119

GLIBERT, M., 1973. Revision des Gastropoda du Danien et du Montien de la Belgique. I. Les Gastropoda du Calcaire de Mons. *Mémoires Institut royal Sciences naturelles de Belgique,* **173:** 116 pp.

GLIBERT, M. & VAN DE POEL, L., 1973. Les Bivalvia du Danien et du Montien de la Belgique. *Mémoires Institut royal Sciences naturelles de Belgique,* **175**: 89 pp.

GOLDFUSS, A., 1833-1841. Petrefacta Germaniae. Arnz & Co, Düsseldorf. 312 pp.

GORBACH, L. P., 1972. Stratigrafiya i fauna molliuskov rannego Paleotsena Kryma. Izdatelstvo "Nedra", Moskva. 115 pp. (in Russian).

JAGT, J. W. M., 1995. The Maastrichtian of the Type Area (Southern Limburg, The Netherlands): recent developments. Field excursion A1. Second International Symposium on Cretaceous Stage Boundaries Brussels 8 - 16 September 1995, 15 pp.

JAGT, J. W. M., 1996. Late Maastrichtian and Early Palaeocene index macrofossils in the Maastrichtian type area (SE Netherlands, NE Belgium). *Geologie en Mijnbouw* **75,** 2-3: 153-162.

JAGT, J. W. M., 1999. An overview of Late Cretaceous and Early Palaeogene echinoderm faunas from Liège-Limburg (Belgium-The Netherlands). *Bulletin Institut royal des Sciences naturelles. Sciences de la Terre,* **69 - Supplement A:** 103-118.

JAGT, J. W. M., DONOVAN, S. K., DECKERS, M. J. M., DORTANGS, R. W., KUYPERS, M. M. M. & VELTKAMP, C. J., 1998. The Late Maastrichtian bourgueticrinid crinoid *Dunnicrinus aequalis* (d'Orbigny, 1841) from The Netherlands and Belgium. *Bulletin Institut royal des Sciences naturelles. Sciences de la Terre,* **68:** 129-154.

JAGT, J. W. M., FELDER, W. M., DORTANGS, R. W. & SEVERIJNS, J., 1996. Cretaceous-Tertiary boundary in the Maastrichtian type area (SE Netherlands, NE Belgium); a historical account. *Geologie en Mijnbouw* **75,** 2-3: 107-118.

JAGT, J. W. M. & JANSSEN, A. W., 1988. The Danian in the Maastrichtian type area (SE Netherlands, NE Belgium): past, present and future research. *Mededelingen Werkgroep Tertiair Kwartair Geologie,* **25**: 213-223.

KOPAEVICH, L. F. & BENIAMOVSKII, V. N., 1999. Foraminiferal distribution across the Maastrichtian/Danian boundary of Mangyshlak Peninsula (West Kazakhstan). *Bulletin Institut royal des Sciences de la Terre,* **69, Supplement A:** 129-145.

LIEBAU, A., 1978. Paläobathymetrische und paläoklimatische Veränderungen im Mikrofaunenbild der Maastrichtter Tuffkreide. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen,* **157**: 233-237.

MAKARENKO, D. E., 1961. Moliyuski paleotsenovikh vidkladiv Krimu. Akakemii Nauk Ukrainsjkoi RSR, Kiiv. 111 pp. (in Ukrainian).

MALCHUS, N., 1990. Revision der Kreide-Austern (Bivalvia: Pteriomorphia) Ägyptens (Biostratigraphie, Systematik). *Berliner Geowissenschaftliche Abhandlungen* **A 125**: 231 pp.

NAIDIN, D. P., 1973. On the relationship between small units in biostratigraphy and those in palaeobiogeography. *Byulletin moskovskogo Obshchestva Ispitatiley Prirody, otdel geologicheskij,* **48:** 50 - 63 (in Russian).

NAIDIN, D. P., 1986. Cretaceous/Tertiary boundary in Mangyshlak and proposed events on the limit of the Maastrichtian and Danian. *Izvestia vuzov. Geologia i razvedka,* **9:** 3-13 (in Russian).

NAIDIN, D. P., 1987. The Cretaceous-Tertiary boundary in Mangyshlak, USSR. *Geological Magazine,* **124**: 13-19.

NAIDIN, D. P., 1997. On the two types of Cretaceous/Paleogene boundary. *Doklady Akademii Nauk,* **352**: 369-373 (in Russian).

NAIDIN, D. P., BENJAMOVSKY, V. N., & KOPAEVICH, L. F., 1984. Methods of transgression and regression study (exemplified by Late Cretaceous Basins of West Kazakhstan). 164 pp. Moscow University Press (in Russian).

NAIDIN, D. P., BEN'YAMOVSKY, V. N. & KOPAEVICH, L. F., 1996. Palaeocene reference sections of Mangyshlak. *Stratigraphy and geological Correlation,* **4,** 3: 254 - 268.

NAIDIN, D. P. & KOPAEVICH, L. F., 1988. Intraformational breaks in the Upper Cretaceous of Mangyshlak. 140 pp. Moscow University Press (in Russian).

NAIDIN, D. P., KOPAEVICH, L. F., MOSKVIN, M. M., SHIMANSKAYA, N. V., KALINICHENKO, G. P. & ANDREEV, Yu. N., 1990a. Macropalaeontological data on the Maastrichtian/Danian boundary from continuous sections in Mangyshlak. *Izvestia Akademii Nauk SSSR, Serija Geologija,* **11:** 3 - 15 (in Russian).

NAIDIN, D. P., KOPAEVICH, L. F., MOSKVIN, M. M., SHIMANSKAYA, N. V., KALINICHENKO, G. P. & ANDREEV, Yu. N., 1990b. Micropalaeontological data on the Maastrichtian/Danian boundary from continuous sections in Mangyshlak. *Izvestia Akademii Nauk SSSR, Serija Geologija,* **12:** 68-82 (in Russian).

NIKISHIN, A. M., ALEKSEEV, A. S., KOPAEVICH, L. F., YANIN, B. T., BARABOSCHKIN, E. J. & V. V. YUTSIS, 1993. Crimea Field Guide Book. Cretaceous-Eocene sedimentation in the Shelf Alma Basin of the Cimmerian mobile belt (Crimea): eustatic and tectonic influences. Sequence stratigraphy workshop. Book 4. Crimea Field Guide Book. University of Amsterdam and Moscow State University. Department of Historical Geology and Centre for Marine Geology and Geophysics. 74 pp.

ORBIGNY, A. d', 1850. Prodrôme de Paléontologie stratigraphique universelle des animaux mollusques et rayonnés. II. Bivalvia cretacica: 72-84, 117-120, 135-139, 151-171, 194-198, 233-257.

ROUSSEAU, L. *in* HUOT, J.J.N. *in* DEMIDOFF, A. 1842. Description des principaux corps organiques fossiles. *in:* Voyage dans la Russie méridionale et la Crimée. Tome II.

SCHLOTHEIM, E. T. von, 1813. Beiträge zur Naturgeschichte der Versteinerungen in geognostischer Hinsicht. *Leonhard's Taschenbuch für Mineralogie*, **7**: 112-113.

SCHLOTHEIM, E. T. von, 1820 -1823. Die Petrefactenkunde und Nachträge zur Petrefactenkunde. pp. III-LXII, 1-437, Gotha.

SOBETSKI, V. A., 1977. Dvustvorchatie Mollyuski pozdnemelovikh platformennikh morej. *Trudy paleontologicheskogo instituta Akademii nauk SSSR* **159**: 256 pp. (in Russian).

SOBETSKI, V. A., NEKHRIKOVA, N. I., BALAN, T. M., PLAMADYALA, G. S., MASLENNIKOVA, L. N., SAVCHINSKAYA, O. V., KUZMICHEVA, E. I., BENIAMOVSKII, V. N., VOLCHEGURSKIJ, L. F., 1982. Atlas bespozvonochnikh pozdnemelovikh morej Prikaspijskoj vladini. *Trudy paleontologicheskogo instituta Akademii nauk SSSR*, **187**: 254 pp. (in Russian).

UHLENBROEK, G. D., 1912. Het Krijt van Zuid-Limburg. Toelichting bij eene geologische kaart van het Krijt-gebied van Zuid-Limburg. *Jaarverslag van de Rijksopsporing van Delfstoffen over 1911*: 48-57.

VILLAIN, J.-M., 1977. Le Maastrichtien dans sa région type (Limbourg, Pays-Bas). Étude stratigraphique et micropaléontologique. *Palaeontographica* **A 157**: 1-87.

VOGEL, F., 1895. Beiträge zur Kenntniss der holländischen Kreide. 66 pp. Brill, Leiden & Friedländer, Berlin.

WALLER, T. R., 1978. Morphology, morphoclines and a new classification of the Pteriomorphia (Mollusca: Bivalvia). *Philosophical Transactions of the royal Society of London*, **B 284**: 345-365.

ZIEGLER, P. A., 1990. Geological Atlas of Western and Central Europe. Second Ed. Shell Internationale Petroleum Maatschappij B. V., 239 pp., 56 enclosures, The Hague.

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Typescript submitted: 15.2.1999
Revised typescript received: 20.4.1999

Explanation of Plate

Some Maastrichtian bivalves from the Crimea

Fig. 1 — ? *Hypoxytoma danica* (Ravn): left valve, Upper Maastrichtian, Starocelje, S. side of the valley, near Bakhchisaray; Museum of MGU at Polygon, Crimea; no n°; x 4.

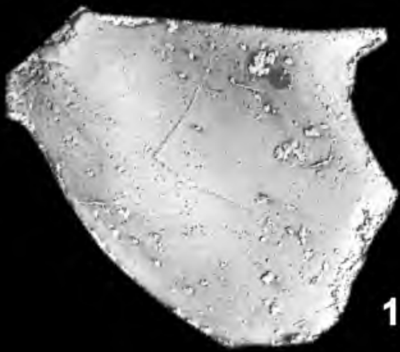
Fig. 2 — *Pseudolimea geinitzi* (von Hagenow): left valve, Upper Maastrichtian, Skalistoe, Bakhchisaray region; Museum of MGU at Polygon, Crimea; n° m 143, x 4. .

Fig. 3 — *Neithea striatocostata* (Münster *in* Goldfuss): convex valve, Upper Maastrichtian, quarry at 455.7 lower than southern side, at 150 m from the road Stavok, Bakhchisaray region; Museum of MGU at Polygon, Crimea; n° m 183, x 2.5.

Fig. 4 — *Liopistha aequivalvis* (Goldfuss): right valve, Upper Maastrichtian, near Glubokii Yar, Bakhchisaray region; Museum of MGU at Polygon, Crimea; n° m 180, x 2.

Fig. 5 — *Pseudolimea* cf. *granulata* (Nilsson): right valve, steinkern, Upper Maastrichtian, ''assemblage XXIII'' of ALEKSEEV (1989), Skalistoe, Bakhchisaray region; Museum of MGU at Polygon, Crimea; no number, x 4.5.

Fig. 6 — *Tenuipteria* cf. *argentea* (Conrad): right valve, Upper Maastrichtian, near Feodosia, E. Crimea, Museum of MGU at Polygon, Crimea; n° m 15/2, x 3.



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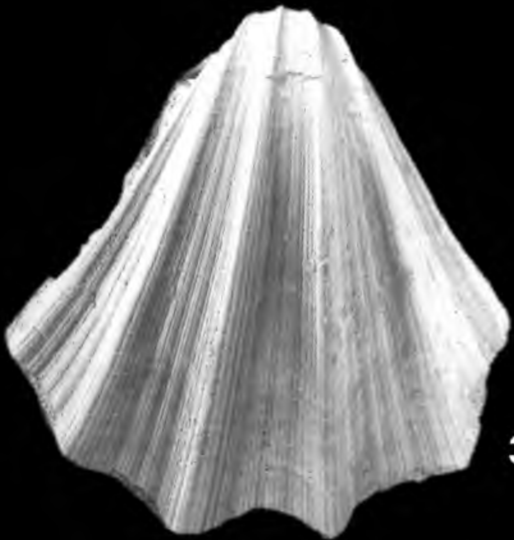

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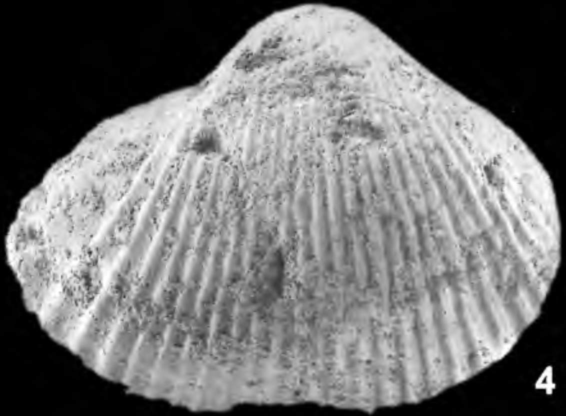

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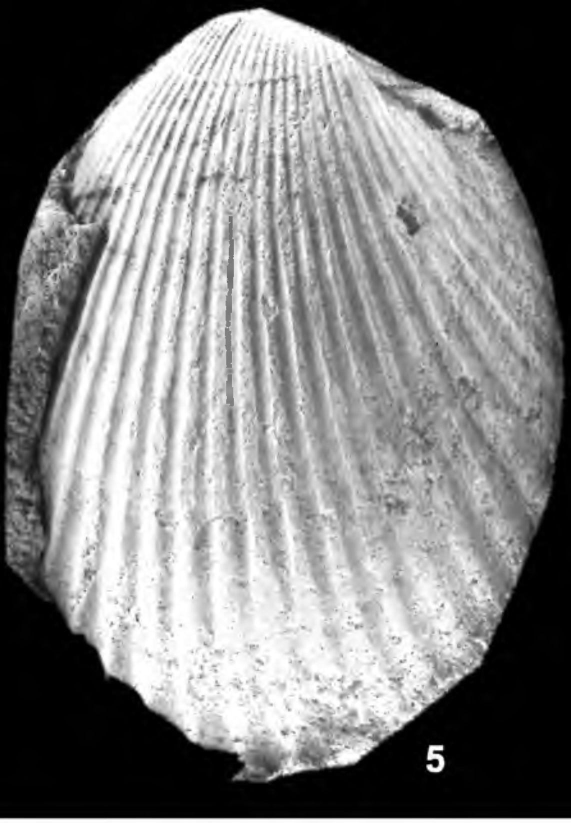

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BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 67-86, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 67-86, 1999

Biostratigraphical and sequence correlation of the Cenomanian successions in Mangyshlak (W. Kazakhstan) and Crimea (Ukraine) with those in southern England

by Andrew S. GALE, Jake M. HANCOCK & W. James KENNEDY

Abstract

Cenomanian successions in southern England (UK), Crimea (Ukraine) and Mangyshlak (Western Kazakhstan) are briefly described and the evidence for biostratigraphical correlation, based on ammonites and inoceramid bivalves is reviewed in the light of new discoveries. Our conclusions differ significantly from those of previous authors in that: i) we date the base of the Cenomanian in Crimea as early *M. dixoni* Zone age, rather than *M. mantelli* Zone age, and ii) most of the supposed Middle Cenomanian in Mangyshlak is more correctly placed within the Lower Cenomanian *M. dixoni* Zone. Sedimentological evidence from the Crimea and Mangyshlak is used to construct a sequence stratigraphical interpretation for each of these regions. The sequences thus identified are correlated by ammonite and inoceramid biostratigraphy with those described previously (1-6) from the Anglo-Paris Basin. The Crimean succession is very similar in both facies development and the distribution and extent of hiatuses to the marly chalk succession of the northern Anglo-Paris Basin, and sequences 3-6 are identified. In the shallower water sandy and marly successions in Mangyshlak sequences 1, 2, 3, 5 and 6 are identified. 4 is missing within a major hiatus which extends across Mangyshlak.

Key words: Cenomanian, Europe, Kazakhstan, biostratigraphy, sequences.

Résumé

Des successions cénomaniennes dans le sud de l'Angleterre (UK), en Crimée (Ukraine) et dans le Mangyshlak (Kazakhstan occidental) sont brièvement décrites et les critères de corrélation biostratigraphique basés sur les ammonites et les bivalves inocéramidés sont réexaminés à la lumière de nouvelles découvertes. Nos conclusions diffèrent de façon significative de celles des auteurs précédents sur les points suivants: i) l'âge de la base du Cénomanien en Crimée est celui de la Zone à *M. dixoni* inférieure plutôt que de la Zone à *M. mantelli*, et ii) la majeure partie du Cénomanien moyen supposé du Mangyshlak est placée plus exactement dans la Zone à *M. dixoni* du Cénomanien inférieur. Des critères sédimentologiques observés en Crimée et dans le Mangyshlak sont utilisés pour établir une interprétation stratigraphique séquentielle dans chacune de ces régions. Les séquences ainsi identifiées sont corrélées sur base des ammonites et des inocéramidés avec celles décrites précédemment (1-6) dans le Bassin anglo-parisien. La succession en Crimée est très semblable à la fois dans le développement des facies ainsi que la distribution et l'extension des hiatus, à la succession de craie marneuse de la partie nord du Bassin anglo-parisien; les séquences 3-6 ont été identifiées. Dans les successions gréseuses et marneuses, d'eau moins profonde du Mangyshlak, les séquences 1, 2, 3, 5 et 6 ont été reconnues. 4 est absent et se place dans un important hiatus présent dans le Mangyshlak.

Mots-clefs: Cénomanien, Europe, Kazakhstan, biostratigraphie, séquences.

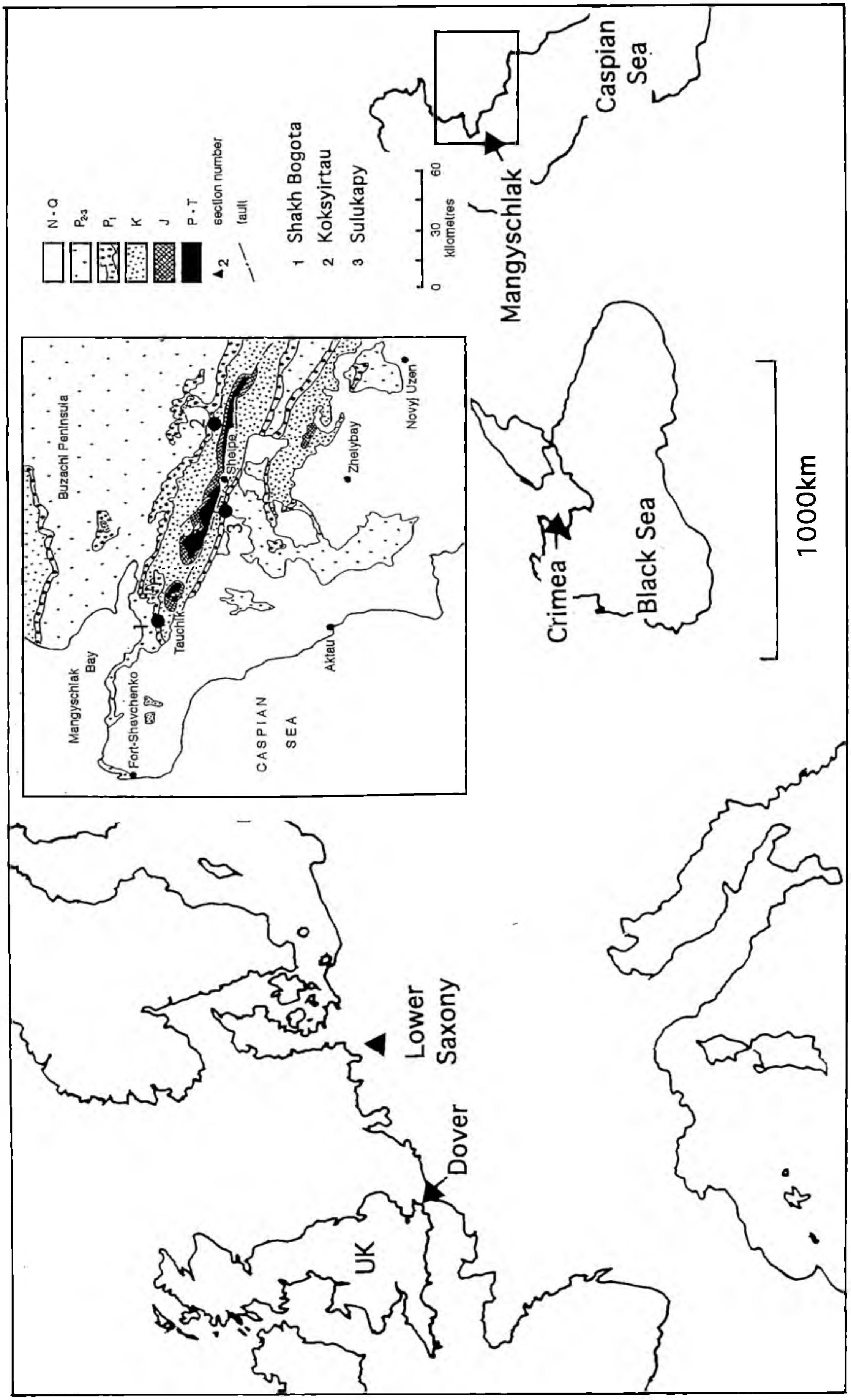
Резюме

Сеноманские отложения на юге Англии, в Крыму (Украина) и на полуострове Мангышлак (Западный Казахстан) кратко описаны, и данные биостратиграфической корреляции, опирающиеся на аммонитов и иноцерамид, заново изучены в свете новых открытий. Наши заключения значительно отличаются от заключений предыдущих авторов по следующим пунктам: i) основание Сеномана в Крыму относится к нижней части зоны *M. dixoni*, а не к зоне *M. mantelli*, и ii) большая часть предполагаемого среднего Сеномана на полуострове Мангышлак на самом деле находится в зоне *M. dixoni* нижнего Сеномана. Седиментологические признаки пород, наблюдаемых в Крыму и на полуострове Мангышлак, используются для установления стратиграфических секвенций в разрезах каждого из этих районов. Секвенции, идентифицированные таким образом, сопоставляются на основе аммонитов и иноцерамид с секвенциями, описанными ранее (1 - 6) в англо-парижском бассейне. Последовательность отложений в Крыму очень похожа на последовательность карбонатных отложений северной части англо-парижского бассейна, как с точки зрения фациальной изменчивости, так и положения и объемов перерывов. Были идентифицированы секвенции 3 - 6. В мелководных мергелистых и песчаных отложениях на Мангышлаке установлены секвенции 1, 2, 3, 5 и 6. 4 попадает внутрь главного перерыва, развитого на всем полуострове Мангышлак.

Ключевые слова: Сеноман, Европа, Казахстан, биостратиграфия, секвенции

Introduction

The Cenomanian Stage affords one of the best opportunities for development of ultra-high resolution stratigraphy in the Mesozoic, because it contains an ammonite fauna of widespread distribution which enables correlation with a resolution of nearly 0.3 Ma and displays a strong decimetre-scale rhythmicity which provides the basis for an orbitally-tuned timescale (GALE, 1989a, 1995; GALE *et al.*, in press.). Furthermore, the overall ("first order") sea-level rise which occurs throughout the Cenomanian (HAQ *et al.* 1988) is expressed in shallow marine successions as a series of progressively onlapping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Mangyschlak Bay
Fort-Shevchenko
Tauchik
Shelpe
Zhelybay
Novyj Uzen
Aktau
CASPIAN SEA
Crimea
Black Sea
1000km
Lower Saxony
Dover
UK

sequences of which 6 have been identified in western Europe (ROBASZYNSKI *et al.*, 1992, 1998; OWEN, 1996) and Tunisia, north Africa (ROBASZYNSKI *et al.*, 1993). These sequences have a mean duration of 0.8 m.y. and represent eustatic sea-level rises. A δ^{13} C curve through the Cenomanian contains a number of distinctive positive excursions which aid correlation with successions lacking a good biostratigraphical record (JENKYNS *et al.*, 1994).

In this paper, we describe in outline the lithological and faunal successions of selected Cenomanian localities in southern England, Crimea and Mangyshlak (Fig. 1). The localities are separated by very considerable distances; Crimea is 2,600 km east of southern England, and Mangyshlak is 1,300 km east of the Crimea. Our descriptions are based both on the available literature and our own observations, which provides a personal overview of the successions, although our experience of the Mangyshlak sections was limited to a week. We review the evidence for biostratigraphical correlation between the 3 regions, on the basis of material described and figured in the literature and new specimens which we have collected ourselves and figure here. Lastly, we use sedimentological data to identify the Cenomanian sequences described in western Europe by OWEN (1996) and ROBASZYNSKI *et al.* (1998) in the Crimea and the Mangyshlak Hills.

South-east England, Anglo-Paris Basin

The Anglo-Paris Basin is situated in northern France and southern England, and during the Cenomanian was surrounded by the Cornubian, Armorican and London-Brabant Massifs and the Massif Central (ROBASZYNSKI *et al.*, 1998). In these marginal areas the sea was shallow, and thin, frequently condensed clastic deposits accumulated (e.g. JUIGNET, 1974; KENNEDY, 1970). In the deeper northern part of the Anglo-Paris Basin, a more complete succession of marly chalks was deposited. Our account here is based upon the section between Dover and Folkestone, Kent, UK (JUKES-BROWNE & HILL, 1903; KENNEDY, 1969; GALE, 1989b; JENKYNS *et al.* 1994; Fig. 2 herein) with faunal and other data drawn from correlative sections in Sussex and the Isle of Wight.

LITHOLOGY AND GENERAL FEATURES

In south-east England, the Cenomanian Stage is represented by 50-70 metres of variably marly chalks (Lower Chalk Formation) and the basal 1-7 metres of the overlying White Chalk Formation (Fig. 2). At the base of the Lower Chalk a thin transgressive unit containing quartz sand and glaucony is generally present. There is an overall decrease in clay content up through the Lower Chalk succession, from 20-40% near the base to <5% in the White Chalk. The Lower Chalk is conspicuously rhythmic on a decimetre-scale in many sections, and beds of more carbonate-rich fine grained calcisphere-foraminiferal packstone or wackestone alternate with marlier wackestones. The rhythmic couplets can be correlated between sections and have been used as the basis for an orbital timescale (GALE, 1990, 1995). Ammonites are common in the Lower and Middle Cenomanian but rather scarce in the Upper Cenomanian (KENNEDY, 1969). Inoceramid bivalves are common throughout. The carbon and oxygen isotope stratigraphy of the Cenomanian has been described by JENKYNS *et al.* (1994).

←

Text-figure 1 — Map to show positions of Dover, UK, Crimea and Mangyshlak. Inset map shows locations in Mangyshlak.

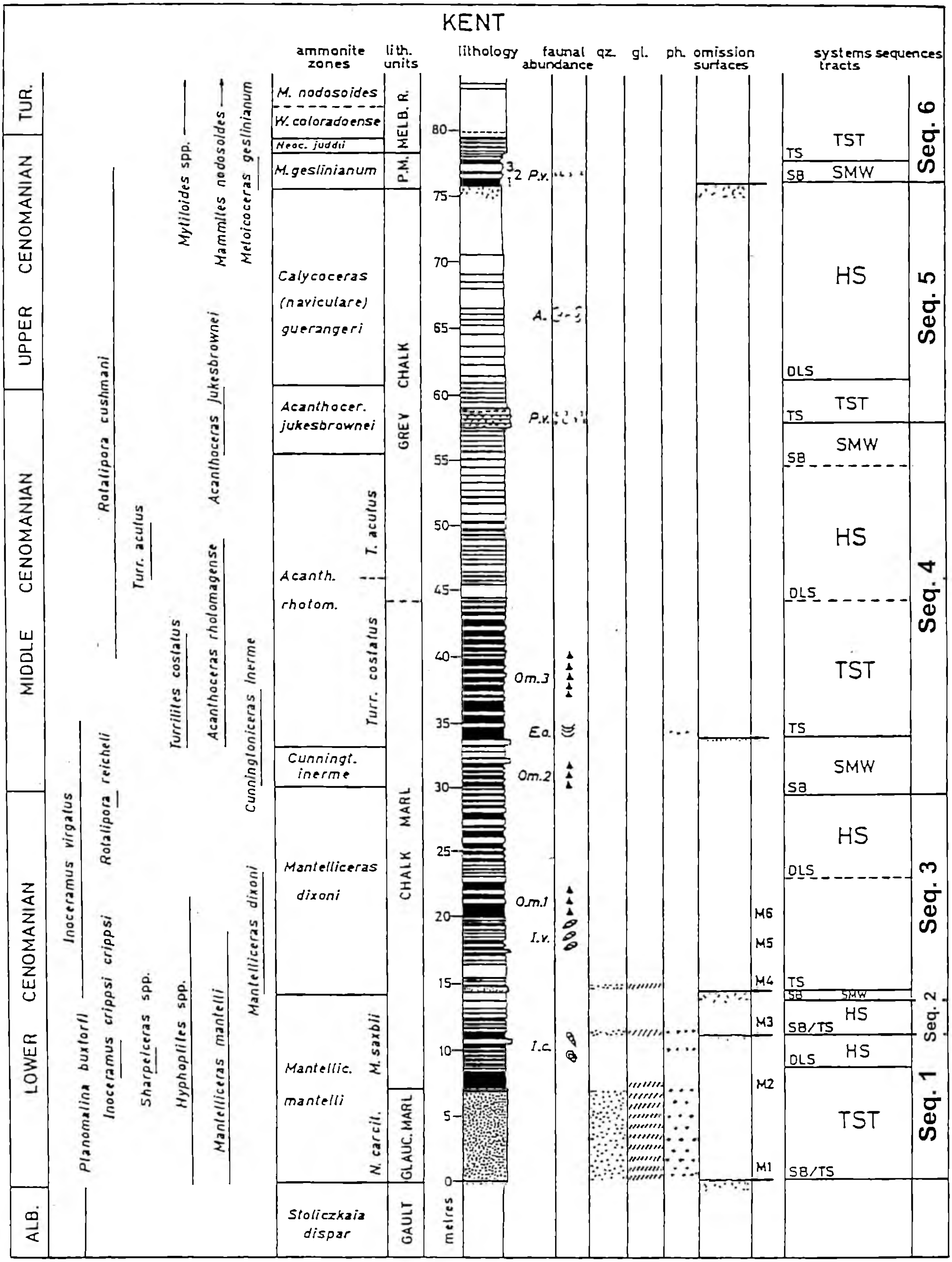
LOWER CENOMANIAN

The basal Cenomanian rests with sharp disconformity upon the Late Albian Gault Clay, the disconformity representing a gap of about 1-2 Ma (GALE *et al.*, 1996). The basal few metres comprise the **Glauconitic Marl Member,** a sandy glauconitic marl which locally (e.g. Isle of Wight; KENNEDY, 1969, 1971) yields abundant phosphatised ammonites of the *Neostlingoceras carcitanense* Subzone. The lower part of the overlying **Chalk Marl Member** (marly chalks) contains ammonites characteristic of the overlying *Sharpeiceras schlueteri* Subzone (GALE, 1995) associated with an acme of large *Inoceramus crippsi crippsi* Mantell (GALE, 1989b, 1995). In more condensed successions, like those developed at Eastbourne in Sussex and on the Isle of Wight, unphosphatised fossils of this assemblage are incorporated in the matrix of the Glauconitic Marl, which contains a rich phosphatised fauna of the *carcitanense* Subzone (KENNEDY 1969, 1971; WRIGHT *et al.*,1984). The highest part of the *M. mantelli* Zone is poorly fossiliferous at Folkestone, but to the west (Sussex, Isle of Wight) includes abundant *Mantelliceras saxbii* (Sharpe) and comprises the *M. saxbii* Subzone (KENNEDY, 1969; GALE, 1995).

The upper boundary of the *M. mantelli* Zone coincides approximately with a burrowed erosion surface at Folkestone and elsewhere in the northern Anglo-Paris Basin (GALE, 1989b; ROBASZYNSKI *et al.*, 1998). The surface is overlain by coarse chalks containing mineralised intraclasts which locally yield indigenous, unmineralised specimens of the ammonite *M. dixoni* Spath. The first appearance of this species in southern England is coincident with the first appearance of *Inoceramus virgatus* (Schlueter) which occurs in great abundance in the lower part of the *M. dixoni* Zone. Five metres above the base of the zone, there is a marked increase in carbonate, and a group of 5 closely spaced limestones (B11-15) contain an acme of *I. virgatus* and numerous ammonites. The higher part of the *M. dixoni* Zone yields few age-diagnostic ammonites in the Anglo-Paris Basin, and there is a gap of some 10 metres above the highest *Mantelliceras* and beneath the lowest *Cunningtoniceras* (GALE, 1995).

MIDDLE CENOMANIAN

The base of the Middle Cenomanian is taken at the lowest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UPPER CENOMANIAN
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LOWER CENOMANIAN
ALB.
Planomalina buxtorfi
Inoceramus virgatus
Inoceramus crippsi crippsi
Rotalipora reicheli
Rotalipora cushmani
Sharpeiceras spp.
Turr. aculus
Hyphoplites spp.
Turrilites costatus
Mytiloides spp.
Mantelliceras mantelli
Acanthoceras rhotomagense
Acanthoceras jukesbrownei
Mammites nodosoides
Mantelliceras dixoni
Cunningtoniceras inerme
Metoicoceras geslinianum
M. nodosoides
W. coloradoense
Neoc. juddii
M. geslinianum
Calycoceras (naviculare) guerangeri
Acanthocer. jukesbrownei
Acanth. rhotom.
T. acutus
Turr. costatus
Cunningt. inerme
Mantelliceras dixoni
Mantellic. mantelli
M. saxbii
N. carcil.
Stoliczkaia dispar
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GREY CHALK
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occurrence of *Cunningtoniceras inerme* (Pervinquière) which first occurs in a marly interval (Paul *et al.*, 1994; Couplet B37). This species is common at Folkestone and at Southerham in Sussex. The lowest *Acanthoceras rhotomagense* (Brongniart), marking the base of the eponymous zone, appear in a hard limestone 4 metres higher. The top of this limestone (couplet B43) is a burrowed/erosional surface, and is overlain by a dark marly bed containing abundant calcitic bivalves and brachiopods called the "Cast Bed."

The "Cast Bed", so-called because of the local abundance of composite moulds of aragonitic gastropods (Gale, 1989b), contains rare specimens of the belemnite *Actinocamax primus* (Arkhangelsky) (Paul *et al.*, 1994). Four metres above, a group of thin limestones contain abundant *Sciponoceras baculoides* (Mantell) and the rhynchonellid *Orbirhynchia mantelliana* (d'Orbigny) together with diverse ammonites of the *Turrilites costatus* Subzone (Kennedy, 1969). A correlative abundance of *Sciponoceras* and *Orbirhynchia* is present in northern Germany (Meyer, 1990) and in the Crimea (Marcinowski, 1980; see below). A basinwide increase in carbonate a short distance above the acme of *O. mantelliana* marks the base of the **Grey Chalk Member**. This boundary is approximately coincident with the base of the *Turrilites acutus* Subzone.

The marls and marly chalks of the *A. rhotomagense* Zone are very conspicuously rhythmic in southern England and the couplets (20-40 cm thick) represent the precession cycle (mode at 20 K.y.), with bundles reflecting the short eccentricity cycle (100 K.y.; Gale, 1989a). Bundles and couplets can be correlated precisely with the Selbukhra section in the Crimea (see below).

The base of the *A. jukesbrownei* Zone is taken at the first occurrence of the species. 2 metres above the base of the zone, 3 thin dark marl beds containing the oyster *Pycnodonte* are present, overlain by 2-4 metres of massive, coarse, calcisphere-rich chalk containing laminated structures (probably burrow-fills) and large *Acanthoceras jukesbrownei* (Spath) (Kennedy, 1969). The stratigraphy of these beds is constant across the northern Anglo-Paris Basin (Gale, 1995, fig. 12), and precisely correlative beds are found in northern Germany and the Crimea (see below).

←

Text-figure 2 — Succession in the Cenomanian Lower Chalk Formation between Dover and Folkestone (Kent, UK) to show main lithological horizons, biostratigraphy and sequence stratigraphy. Modified after Robaszynski *et al.* (1998, fig. 6). M1-6 refer to marker beds described by Gale (1989b). *I.c .= Inoceramus crippsi, I.v. = Inoceramus virgatus, O.m. = Orbirhynchia mantelliana, P.v. = Pycnodonte vesicularis, A. = Amphidonte* sp.

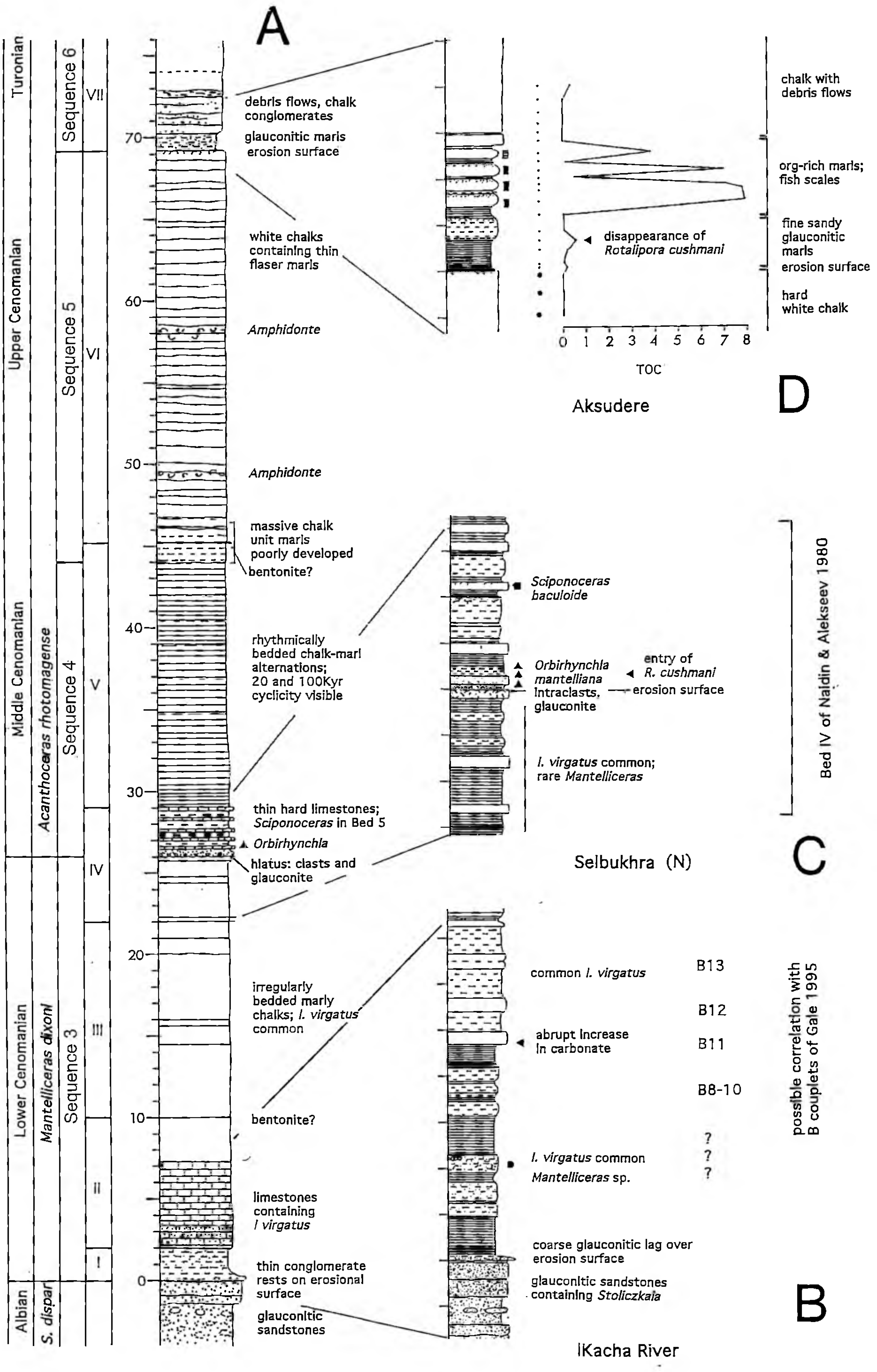
UPPER CENOMANIAN

The Upper Cenomanian contains few poorly preserved ammonites in the chalk facies of the Anglo-Paris Basin (Kennedy, 1969) and the contact between the Middle Cenomanian *A. jukesbrownei* Zone and the Upper Cenomanian *C. guerangeri* Zone cannot be accurately placed. The *C. guerangeri* Zone at Folkestone is a clay-poor, pale grey to white chalk which contains two levels containing abundant small oysters, *Amphidonte obliquatum* (Pulteney), in the middle part. The same oyster horizons are found in northern Germany (Ernst & Rehfeld, 1997; Kaplan, *in press*) and the Crimea (see below). The top of the *C. guerangeri* Zone is ubiquitously marked by the sub-plenus erosion surface (Jefferies, 1962, 1963), overlain by the rhythmically bedded marly chalks of the **Plenus Marls Member** (*M. geslinianum* Zone) which are 2-10 metres in thickness. Jefferies (1962, 1963) was able to trace each of 8 beds within the Plenus Marls throughout the expanded succession in the Anglo-Paris Basin. Features of the Plenus Marls important for correlation into eastern Europe and central Asia include the abundance of the belemnite *Actinocamax plenus* (Blainville) in Bed 4, and the presence of a $\delta^{13}C$ positive excursion in the Plenus Marls and the overlying white chalks (Gale *et al.*, 1993).

The summit of the Plenus Marls marks an important lithological boundary in the Anglo-Paris Basin; below this level, grey-hued marly chalks of the Lower Chalk Formation include up to 30% clay whereas the overlying chalks of the White Chalk Formation contain little clay (generally less than 5%). The basal **Ballard Cliff Member** comprises nodular calcisphere-rich chalks with thin flaser marls and numerous intraclasts. This unit includes rare ammonites of the *M. geslinianum* and *N. juddii* Zones, and the base of the Turonian, defined by the first appearance of rare *Watinoceras* spp. at Merstham, Kent, and Eastbourne, Sussex (Wright & Kennedy, 1981), falls close to the summit of the Ballard Cliff Member (Gale, 1996).

SEQUENCE STRATIGRAPHY

The criteria used to recognise sequences in the marly Cenomanian chalks of the Anglo-Paris Basin have been described by Owen (1996) and Robaszynski *et al.* (1992, 1998). The basal **transgressive systems tract** of each sequence typically rests upon an erosional surface (**sequence boundary**) and includes a condensed lag, commonly containing glauconite, quartz sand and mineralised (phosphatised and glauconitised) intraclasts at the base; sand and glaucony decrease above in the higher part of the transgressive systems tract. **The maximum flooding surface** is marked by an increase in carbonate content/ decrease in clay, representing the maximum distancing of clastic source. **Highstand chalks** are relatively carbonate-rich and evenly rhythmic on a decimetre scale. At the top they are truncated by the succeeding sequence boundary, marked by an increase in clay content representing the **lowstand**. In more marginal condensed suc-


A
Turonian
Upper Cenomanian
Middle Cenomanian
Lower Cenomanian
Albian
Acanthoceras rhotomagense
Mantelliceras dixoni
S. dispar
Sequence 6
Sequence 5
Sequence 4
Sequence 3
VII
VI
V
IV
III
II
I
70
60
50
40
30
20
10
0
debris flows, chalk conglomerates
glauconitic marls
erosion surface
white chalks containing thin flaser marls
Amphidonte
Amphidonte
massive chalk unit marls poorly developed
bentonite?
rhythmically bedded chalk-marl alternations; 20 and 100Kyr cyclicity visible
thin hard limestones; Sciponoceras in Bed 5
Orbirhynchia
hiatus: clasts and glauconite
irregularly bedded marly chalks; I. virgatus common
bentonite?
limestones containing I virgatus
thin conglomerate rests on erosional surface
glauconitic sandstones
chalk with debris flows
org-rich marls; fish scales
fine sandy glauconitic marls
erosion surface
hard white chalk
disappearance of Rotalipora cushmani
0 1 2 3 4 5 6 7 8
TOC
Aksudere
D
Sciponoceras baculoide
Orbirhynchia mantelliana
intraclasts, glauconite
entry of R. cushmani
erosion surface
I. virgatus common; rare Mantelliceras
Bed IV of Naidin & Alekseev 1980
Selbukhra (N)
C
common I. virgatus
abrupt increase in carbonate
I. virgatus common
Mantelliceras sp.
coarse glauconitic lag over erosion surface
glauconitic sandstones containing Stoliczkaia
B13
B12
B11
B8-10
?
?
?
possible correlation with B couplets of Gale 1995
B
Kacha River

cessions, as on the borders of the Anglo-Paris Basin, an erosional sequence boundary is commonly overlain directly by a condensed representative of the overlying transgressive systems tract. In more distal, basinal developments, there is little hiatus between successive sequences, and marly lowstand deposits are often present; neither glauconite nor intraclasts are present in the transgressive units. The 6 sequences described in outline below have been identified from the sedimentological criteria outlined above and correlated biostratigraphically between four separate regions of the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998). For a different sequence nomenclature, see HARDENBOL *et al.* (1998).

Sequence 1

At Folkestone, the Glauconitic Marl is a condensed transgressive systems tract at the base of the Cenomanian succession, resting upon a composite sequence boundary of Late Albian age (GALE *et al.*, 1996). The Glauconitic Marl at Folkestone rarely yields phosphatised ammonites of the *N. carcitanense* Subzone, but these are abundant in the southern Isle of Wight (KENNEDY, 1969, 1971). The lower part of the overlying Chalk Marl represents a maximum flooding surface which lies at the base of the *S. schlueteri* Subzone (GALE, 1995).

Sequence 2

The base of this sequence contains phosphatised intraclasts and glaucony grains representing a transgressive systems tract, and rests non-sequentially upon a hard limestone (M4 of GALE, 1989b) which is a sequence boundary. The upper part of 2 is developed as marly chalks at Folkestone. The entire sequence falls within the *M. saxbii* Subzone. Sequence 2 is not recognised widely elsewhere in northern Europe (OWEN, 1996).

Sequence 3

The marly chalks of 2 are widely surmounted by an erosional surface, which at Folkestone and elsewhere is overlain by a coarse glauconitic calcisiltite containing phosphatised intraclasts representing the basal transgressive part of 3 (Couplet B1 of GALE, 1995, fig. 4). At Southerham, this bed contains the lowest specimens of *M. dixoni*, and is taken as the base of the *M. dixoni* Zone. An increase in carbonate content several metres higher (B11/12 of GALE, 1995) represents the maximum flooding surface. The overlying marly chalks represent a highstand. An increase in clay content at the level of B34 marks the contact with the lowstand of overlying sequence 4. *C. inerme* appears a short distance above in B38. 3 therefore corresponds approximately with the *M. dixoni* Zone.

Sequence 4

The base of couplet C1 ("Cast Bed"; GALE, 1989) contains abundant calcitic fossil debris at Folkestone, and elsewhere in southern England phosphates and glauconite are present. It is the basal transgressive unit of 4. The conspicuous increase in carbonate at the base of the Grey Chalk is taken as the maximum flooding surface of this sequence and falls close to the boundary between *T. costatus* and *T. acutus* Subzones. The highstand comprises strikingly rhythmic chalks which show bundling that corresponds to the short eccentricity cycle. The base of the *A. jukesbrownei* Zone falls in the summit of the highstand.

Sequence 5

An erosional surface at the level of couplet B45 is identified as a sequence boundary. The overlying couplets B46-49 contain lenses of winnowed calcite bioclasts and constitute a lowstand deposit. The overlying massive, coarse bed (D1-8) containing laminated structures ("Jukes-Browne Bed VII"; JUKES-BROWNE & HILL, 1903) represents slight condensation and contains abundant calcispheres and locally phosphatised intraclasts (Eastbourne). It is identified as a transgressive systems tract. At the level of couplet D12 an increase in carbonate content and loss of conspicuous rhythmicity represents a maximum flooding surface. Sequence 5 falls in the upper part of the *A. jukesbrownei* Zone and includes the entire overlying *C. guerangeri* Zone.

Sequence 6

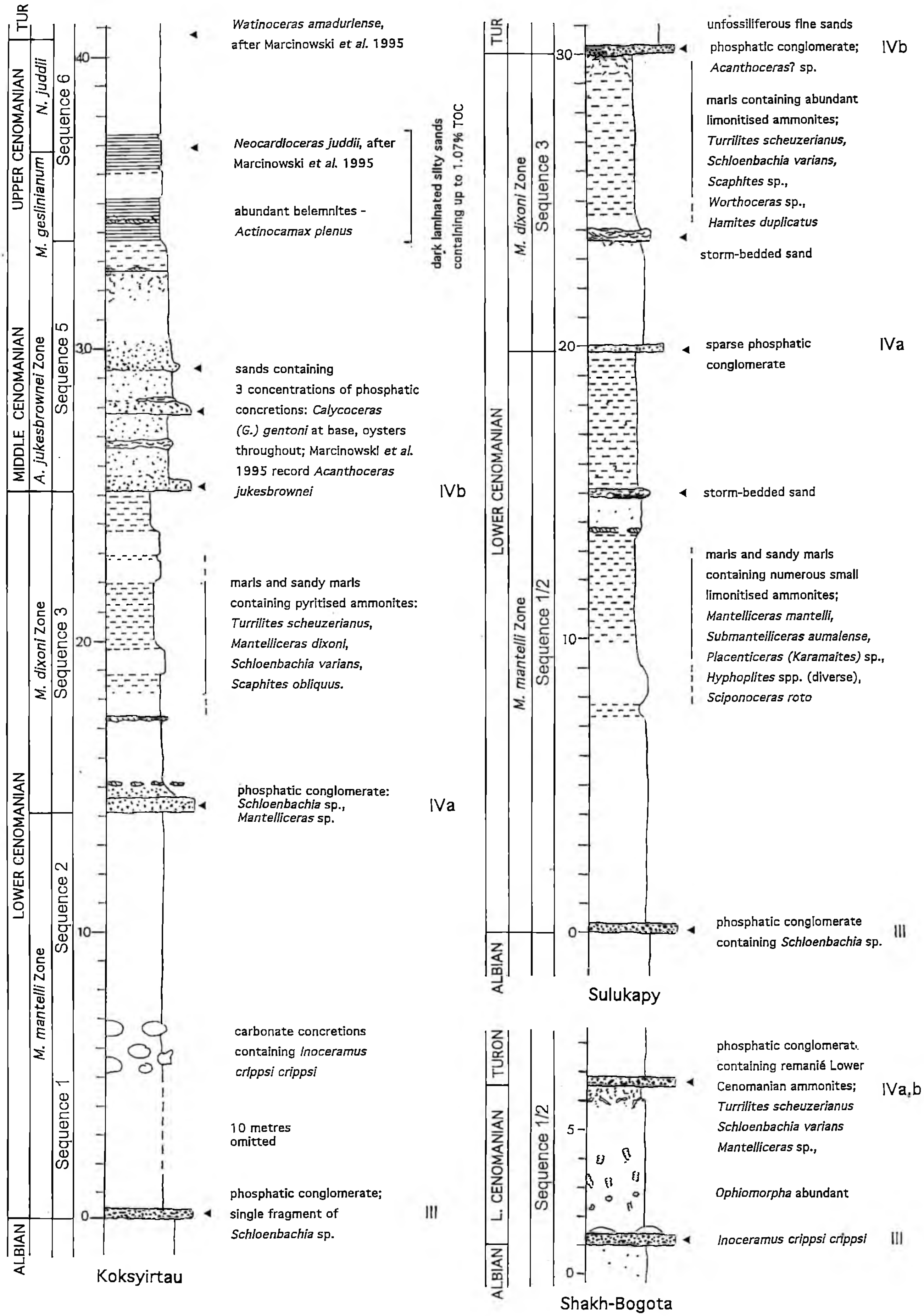
The base of the highest sequence in the Cenomanian is taken at the sub-plenus erosion surface which is ubiquitously developed in the northern Anglo-Paris Basin (sequence boundary at the limit of the *C. guerangeri* and *M. geslinianum* Zones). Beds 1-3 of the Plenus Marls comprise a lowstand, and the Bed 3-4 erosional contact represents a transgressive surface (mid - *M. geslinianum* Zone). The prominent increase in carbonate content at the top of the Ballard Cliff Member (*N. juddii* - *W. devonense* Zones) marks maximum flooding. For a slightly different interpretation of this sequence, see HANCOCK (1993).

←

Text-figure 3 — Cenomanian of the Crimea. A, general succession after NAIDIN & ALEKSEEV (1980), with their Members I-VII indicated. B, details of basal Cenomanian in Kacha River; possible correlation with precession couplets (B1-13) in western Europe, numbered after GALE (1995). C, Lower-Middle Cenomanian contact, Selbukhra. D, Late Cenomanian succession at Aksudere. The total organic carbon (TOC) data is new.

The Crimea, the Ukraine.

The Cenomanian succession in the Crimean Highland, 30 km south of Simferopol, was described by NAIDIN & ALEKSEEV (1981) and NAIDIN & KIYASHKO (1994a, b). MARCINOWSKI (1980) has described the Cenomanian ammonite faunas from the Crimea. Localities in the Crimea described by NAIDIN & ALEKSEEV (1981) were visited by ASG in the summers of 1996 and 1997 with the generous


TUR
UPPER CENOMANIAN
N. juddii
M. geslinianum
Sequence 6
MIDDLE CENOMANIAN
A. jukesbrownei Zone
Sequence 5
LOWER CENOMANIAN
M. dixoni Zone
Sequence 3
M. mantelli Zone
Sequence 2
Sequence 1
ALBIAN
40
30
20
10
0
Watinoceras amadurlense, after Marcinowski *et al.* 1995
Neocardioceras juddii, after Marcinowski *et al.* 1995
abundant belemnites - *Actinocamax plenus*
dark laminated silty sands containing up to 1.07% TOC
sands containing 3 concentrations of phosphatic concretions: *Calycoceras (G.) gentoni* at base, oysters throughout; Marcinowski *et al.* 1995 record *Acanthoceras jukesbrownei*
IVb
marls and sandy marls containing pyritised ammonites: *Turrilites scheuzerianus*, *Mantelliceras dixoni*, *Schloenbachia varians*, *Scaphites obliquus*.
phosphatic conglomerate: *Schloenbachia* sp., *Mantelliceras* sp.
IVa
carbonate concretions containing *Inoceramus crippsi crippsi*
10 metres omitted
phosphatic conglomerate; single fragment of *Schloenbachia* sp.
III
Koksyirtau
TUR
LOWER CENOMANIAN
M. dixoni Zone
Sequence 3
M. mantelli Zone
Sequence 1/2
ALBIAN
30
20
10
0
unfossiliferous fine sands
phosphatic conglomerate; *Acanthoceras*? sp.
IVb
marls containing abundant limonitised ammonites; *Turrilites scheuzerianus*, *Schloenbachia varians*, *Scaphites* sp., *Worthoceras* sp., *Hamites duplicatus*
storm-bedded sand
sparse phosphatic conglomerate
IVa
storm-bedded sand
marls and sandy marls containing numerous small limonitised ammonites; *Mantelliceras mantelli*, *Submantelliceras aumalense*, *Placenticeras (Karamaites)* sp., *Hyphoplites* spp. (diverse), *Sciponoceras roto*
phosphatic conglomerate containing *Schloenbachia* sp.
III
Sulukapy
TURON
L. CENOMANIAN
Sequence 1/2
ALBIAN
5
0
phosphatic conglomerate containing remanié Lower Cenomanian ammonites; *Turrilites scheuzerianus* *Schloenbachia varians* *Mantelliceras* sp.,
IVa,b
Ophiomorpha abundant
Inoceramus crippsi crippsi
III
Shakh-Bogota

help of A. S. Alekseev, R. R. Gabdullin, L. F. Kopaevich, T. A. Kuzmicheva and A. M. Nikishin from Moscow University. The succession is summarised in Fig. 3.

LITHOLOGY AND GENERAL FEATURES

The Cenomanian of the Crimea comprises 50-60 metres of rhythmically bedded (decimetre-scale) marly chalks, which show an overall decrease in the clay component towards the top. The succession includes several region-wide erosional surfaces. Macrofossils are not abundant throughout, and diagnostic ammonites are restricted to a few levels (MARCINOWSKI, 1980). The Middle and Upper Cenomanian were deposited in deeper water than their equivalent strata in southern England. In terms of facies, rhythmicity and some of the faunas the succession is similar to that developed in the northern Anglo-Paris Basin (GALE, 1995).

LOWER CENOMANIAN

The lowest one to several metres of the Cenomanian are sandy glauconitic marls, and a thin (<20cm) basal conglomerate includes glauconitised sandstone pebbles, gravel grade quartz and other clasts. This bed rests disconformably on glauconitic sandstones of Late Albian *S. dispar* Zone age (MARCINOWSKI & NAIDIN, 1976). The basal part of the Cenomanian succession is well exposed in the Kacha River section (Fig. 3), where a bed of silty glauconitic marl 2m above the basal erosion surface yields poorly preserved *Mantelliceras* sp. and common *Inoceramus virgatus* (Schlüter) which occurs frequently up to the highest levels accessible. *I. virgatus* first occurs in the *M. dixoni* Zone in the Anglo-Paris Basin (not in the *M. saxbii* Subzone, as recorded by TRÖGER, 1989) for the base of which it can be taken as a proxy marker (GALE, 1995). More expanded basal Cenomanian successions in the Crimea, like those in the Bodrak Valley (e.g. Kremennaya; NAIDIN & ALEKSEEV, 1981) also yield *I. virgatus* near the base of the Cenomanian. The ubiquitous presence of *I. virgatus* at or near the base of the Cenomanian successions in the Crimea is therefore taken as evidence that chalk sedimentation here commenced low in the *M. dixoni* Zone. The zonal ammonite species has however only been found near the top of the Lower Cenomanian in the Crimea (MARCINOWSKI, 1980).

The silty glauconitic beds of the basal Cenomanian pass upwards into alternating marls and marly limestones, which display a regular thickness for the lowest 5 or so metres, but above become of very variable thickness. There is a marked increase in carbonate content above 5m from the base of the Cenomanian in the Kacha River section. The entire Lower Cenomanian thickens northwards to Kremennaya Mountain (NAIDIN & ALEKSEEV, 1981). The highest few metres of the Lower Cenomanian again contains thin, evenly spaced limestones, and has yielded *Mantelliceras* cf. *dixoni* (MARCINOWSKI, 1980, pl. 2) and common *I. virgatus*; it thus falls within the *M. dixoni* Zone.

←

Text-figure 4 — Cenomanian of Mangyshlak, Kazakhstan. Sections at Sulukapy and Koksyirtau. The major nodule beds (III, IVa, IVb) of MARCINOWSKI *et al.* (1995) are marked. Stages, zones and sequences are marked.

MIDDLE CENOMANIAN

The top of the Lower Cenomanian is truncated by a conspicuous erosion surface everywhere in the Crimea (NAIDIN & ALEKSEEV, 1981); the following description is based on the Selbukhra section (Fig. 3 herein; see map in MARCINOWSKI, 1980). The erosion surface is overlain by a coarse green-grey marl containing glauconitised intraclasts, inoceramid debris, and rare exotic clasts, including Triassic or Jurassic siltstones (A. S. Alekseev, personal communication). *Thalassinoides* pipe the marl down 20 cm from the erosion surface through the underlying limestone into the marl beneath. The beds above the erosion surface comprise an alternation of marls and well-lithified limestones which contain *Sciponoceras baculoides* (Mantell); rare *Acanthoceras* sp. confirm the Middle Cenomanian *A. rhotomagense* Zone age of these beds. The basal metre yields a rich and diverse fauna of calcitic fossils including echinoids, crinoids, brachiopods, serpulids and bivalves (NAIDIN & ALEKSEEV, 1981). The brachiopods include abundant *Orbirhynchia mantelliana* (d'Orbigny) which occurs in 2 intervals within the Middle Cenomanian of southern England (KENNEDY, 1969; GALE, 1995). The co-occurrence of abundant *O. mantelliana* and *S. baculoides*, coincident with the first occurrence of *Rotalipora cushmani* (40 cm above erosion surface; L. F. Kopaevich, personal communication) establishes a firm correlation with the band of *O. mantelliana* in the *Turrilites costatus* Subzone found in northern France (AMEDRO, 1993), southern England (KENNEDY, 1969) and northern Germany (MEYER, 1990). At this horizon, the faunas and facies are closely similar in the Crimea and the northern Anglo-Paris Basin, and individual limestone-marl couplets can be correlated precisely between the two, a confirmation of the accuracy of the Milankovitch timescale proposed by GALE (1989a, 1995).

The break between the Lower and Middle Cenomanian in the Crimea can thus be demonstrated to include an unknown part of the upper *M. dixoni* Zone, the entire *C. inerme* Zone (GALE, 1995; ROBASZYNSKI *et al.*, 1998), and the basal part of the *A. rhotomagense* Zone, and probably represents more than 0.5 m.y.

The higher part of the Middle Cenomanian is strikingly rhythmic in the Kacha and Selbukhra sections and time-series analysis has provided firm evidence of orbital frequencies representing the precession cycle (mode at 20 K.y.) and bundling by both long and short eccentricity cycles (100 and 400 K.y.; GALE *et al.*, in press). This part of the succession is poorly fossiliferous, and has not yielded age-diagnostic ammonites. However, the presence of *Inoceramus* cf *atlanticus* Heinz at 25m above the basal erosion surface at Selbukhra is indicative of a late *A. rhotomagense* or early *A. jukesbrownei* Zone level, indicative of the "I. atlanticus Event" in the Lower Saxony Basin (ERNST & REHFELD, 1997). Large, poorly preserved puzosiid ammonites between 25 and 30m at Selbukhra are associated with a diverse benthic fauna, not previously recorded, which includes serpulids, calcitic bivalves, echinoids (*Poriocidaris* sp.), brachiopods, and abundant isocrinid columnals. The conspicuous thin marls at 28.5, 29.4 and 30.2m perhaps correlate with the "Pycnodonte Event" of northern Germany (ERNST, SCHMID & SEIBERTZ, 1983) and the D1-3 marls of GALE (1995). The condensed "Jukes-Browne Bed VII" of southern England (GALE, 1995) is represented in Selbukhra by seven coalesced couplets of calcisphere-rich chalk. A conspicuous 10 cm thick orange marl, possibly a weathered bentonite, is present at 32.5 m in Selbukhra (NAIDIN & ALEKSEEV, 1981). There is a sharp increase in the percentage of CaCO3 just beneath the bentonite, and the highest 25 m of Cenomanian chalks are very pure (85% carbonate) and white and contain thin flaser marls every 50-100 cm.

UPPER CENOMANIAN

Ammonites are not recorded from the higher part of the Crimean Cenomanian succession, so the boundary of the Middle and Upper Cenomanian cannot be fixed precisely. However, the oyster *Amphidonte obliquatum* (Pulteney) is common at 2 levels in the succession at Selbukhra (40 m, 58 m), which correspond with abundances of the same species in the Münster and Lower Saxony Basins in northern Germany (ERNST & REHFELD, 1997; KAPLAN, *in press*) and in southern England (GALE, 1995).

White chalks containing marls at 0.5-1.0 m intervals (Member VI of NAIDIN & ALEKSEEV, 1981) are terminated by a planar, lithified, but unbored erosional surface cut in hard white chalk in all three sections examined (Selbukhra, Mender, Aksudere). This surface, sparsely burrowed by *Planolites*, is overlain by grey or brown sandy marls (ALEKSEEV *et al.*, 1997) and represents the "sub-plenus erosion surface" (JEFFERIES, 1962, 1963) in the Anglo-Paris Basin and the "*Fazieswechsel*" (MEYER, 1990) in northern Germany. This correlation is confirmed by the highest occurrence of *Rotalipora cushmani* 50 cm above the erosion surface at Selbukhra (ALEKSEEV *et al.*, 1997). This species is last found immediately beneath the Plenus Bank in northern Germany (SCHÖNFELD *et al.*, 1991) and at the top of Bed 3 of the Plenus Marls in southern England (JARVIS *et al.*, 1988).

There is considerable lateral variation in the succession immediately overlying the Late Cenomanian erosion surface in the Crimea. At Selbukhra 1 m of marly and sandy chalks are overlain by redeposited chalks containing debris flows (conglomerates, flow lamination) and microfaults. At Mender, a highly condensed glauconitic marl resting directly upon the basal erosion surface is overlain by flaggy chalks containing marl partings. Neither locality contains diagnostic macrofossils. At Aksudere (Fig. 3), a metre of organic-rich, variably laminated marls (Member VI3) containing fish-scales is present (NAIDIN, 1993; NAIDIN & KIYASHKO, 1994a, b), representing deposition within the oxygen minimum zone. This is a local representation of the Late Cenomanian "Oceanic Anoxic Event" (JENKYNS, 1980). The base of the Turonian *H. helvetica* planktic foraminiferan Zone boundary falls 2.7 m above the base of Member VI3, according to ALEKSEEV *et al.* (1997).

SEQUENCE STRATIGRAPHY

The detailed similarity of facies between the Cenomanian of the Crimea and chalks in the northern Anglo-Paris Basin enables us to apply identical criteria for the recognition of sequences and systems tracts to those used by ROBASZYNSKI *et al.* (1998) in basinal marly chalks in southern England and northern France. In the following section, the correlation of Cenomanian sequences recognised in the Anglo-Paris Basin by ROBASZYNSKI *et al.* (1998) with those developed in the Crimea is discussed.

Sequence 3

The lowest Cenomanian sequence present in the Crimea rests directly on Upper Albian sandstones; its base can be dated as *M. dixoni* Zone from the presence of *I. virgatus* low in the succession (see above). The pronounced increase in carbonate 5 m above the base of the Cenomanian in the Kacha River is taken as the maximum flooding surface of this lowest sequence, and can probably be correlated on a bed scale with the successions in the Anglo-Paris and Saxony Basins (see GALE, 1995, fig. 4). The overlying highstand chalks are entirely of *M. dixoni* Zone age and are truncated by the erosional surface at the Lower-Middle Cenomanian contact. This sequence therefore corresponds with 3 in the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998) which falls entirely within the *M. dixoni* Zone and provides evidence of late Cenomanian onlap in the Crimean region. This is similar to the progressive onlap of successive Cenomanian zones recorded by KENNEDY (1970) across Dorset and Devon in southern England.

Sequence 4

The erosional surface at the Lower-Middle Cenomanian boundary in the Crimea is identified as a transgressive surface resting directly upon a sequence boundary. The transgressive systems tract is represented by the residual glauconitic lag at the base of the Middle Cenomanian succession and the overlying marly chalks and thin limestones mark the maximum flooding surface. An erosional break at the Lower-Middle Cenomanian boundary is widely developed in thinner successions across Europe (GALE, 1995; OWEN, 1996). The duration of the hiatus at this level in the Crimea is similar to that developed over the London Platform in eastern England, where highstand *M. dixoni* Zone Chalks are overlain with erosive contact by the condensed Totternhoe Stone (a calcarenite containing phosphatised and glauconitised intraclasts), the matrix of which contains abundant *Orbirhynchia mantelliana* from the *T. costatus* Subzone acme of the species.

Sequence 5
The highstand chalks of 4 display a very even rhythmicity, but at 30-33 m above the Lower-Middle Cenomanian erosion surface there is a slight but distinct condensation and the couplets thin and fuse as a result of the disappearance of the intervening marls. The sediment becomes coarser and contains more calcispheres. We interpret this a a weakly developed transgressive systems tract which correlates with the sequence which commences within the *A. jukesbrownei* Zone in the Anglo-Paris Basin (Robaszynski *et al.*, 1998).

Sequence 6
The sharp, planar erosion surface which is found regionally at the summit of the white coccolith chalks of Upper Cenomanian age at Mender, Selbukhra and Aksudere is lithified but apparently not bored or encrusted, and represents a sequence boundary correlative with the subplenus erosion surface in the Anglo-Paris Basin (base of sequence 6). Overlying this surface at Aksudere and Selbukhra are about 1 m of sandy and silty marls which locally contain glauconite. *Rotalipora cushmani* disappears about 0.5 m above the basal erosion surface, in a marly bed probably equivalent to Bed 3 of the Plenus Marls. Immediately overlying this bed, laminated organic rich-marls at Aksudere represent the transgressive systems tract of sequence 6.

Mangyshlak Hills, west Kazakhstan

Excellent exposures of Cretaceous rocks exist in the Mangyshlak Hills, and are present in the pericline 100 km northeast of Aktau (Naidin *et al.*, 1984). ASG and JMH visited three of these sections (Sulukapy, Shakh Bogota and Koksyirtau) in a party led by Professor D. P. Naidin and his colleagues in 1994. The lithological and faunal succession at Sulukapy has been briefly described by Marcinowski (1980) and this and other localities described in detail by Marcinowski *et al.* (1995). Our observations differ in some details from those of previous authors.

LITHOLOGY AND GENERAL FEATURES

The Cenomanian in Mangyshlak comprises 5 to 50+ metres of sands, silts, marls and thin phosphatic conglomerates that were deposited in a shallow marine setting (Marcinowski, 1980; Marcinowski *et al.*, 1995). The conglomerates comprise variably sized (1 to 10 cm) often well rounded clasts which according to Marcinowski (1980) have a complex mineralogy including silica and iron oxides as well as calcium phosphate. The conglomerates have a sandy matrix which is locally glauconitic. The sands fall into two categories; structureless, bioturbated sands which commonly contain silt and a little clay, and thin trough-cross laminated units which may represent storm events. The silty marls contain abundant limonite burrows which replace pyrite.

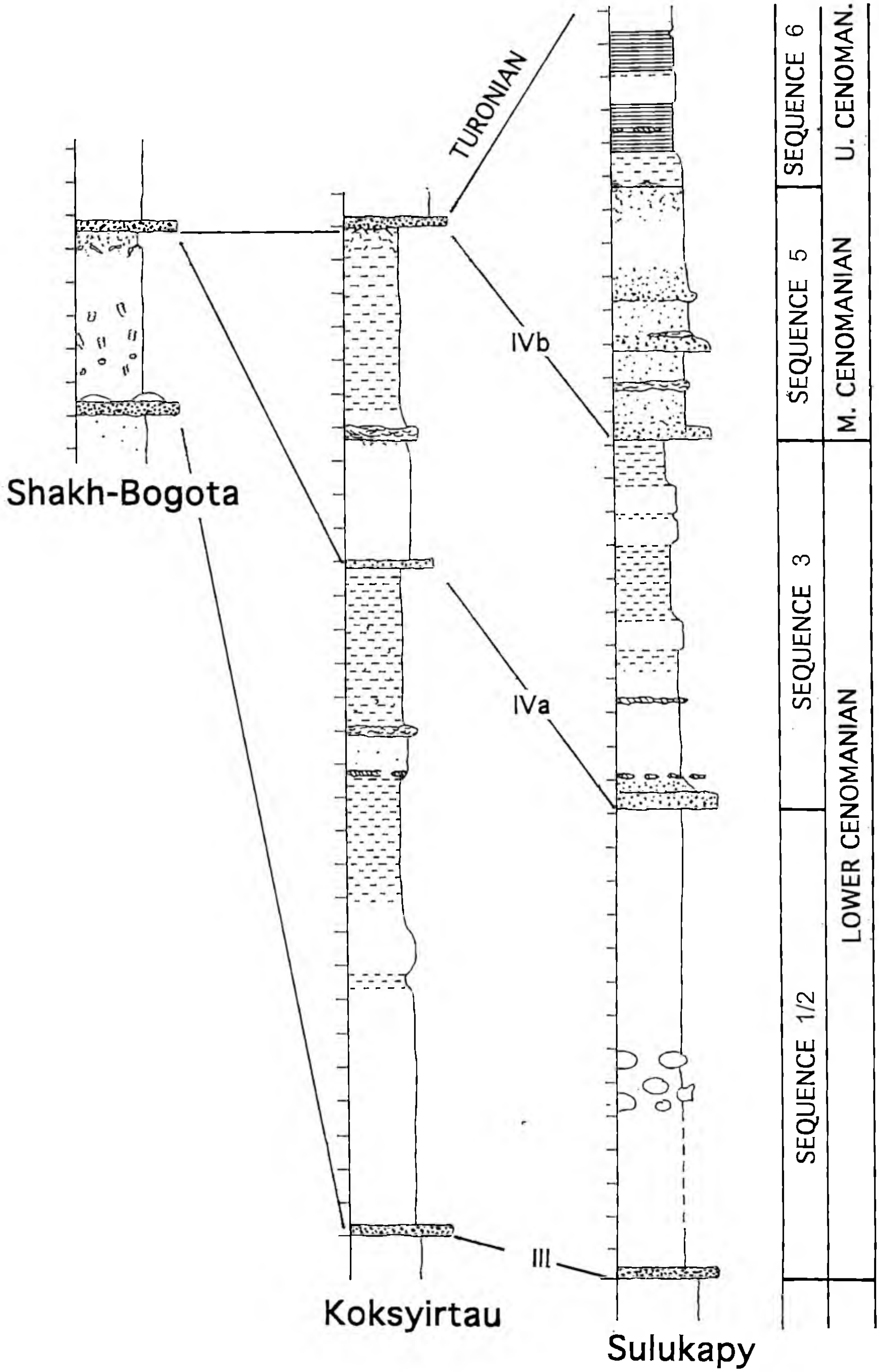
Ammonites are preserved as a) infrequent worn steinkerns among the phosphatic clasts, b) as internal moulds of limonite after pyrite which are locally very abundant in the marls, c) as calcite replacements of original shell filled with phosphate. It is quite difficult to collect material *in situ*, and many of the specimens were collected as float.

LOWER CENOMANIAN

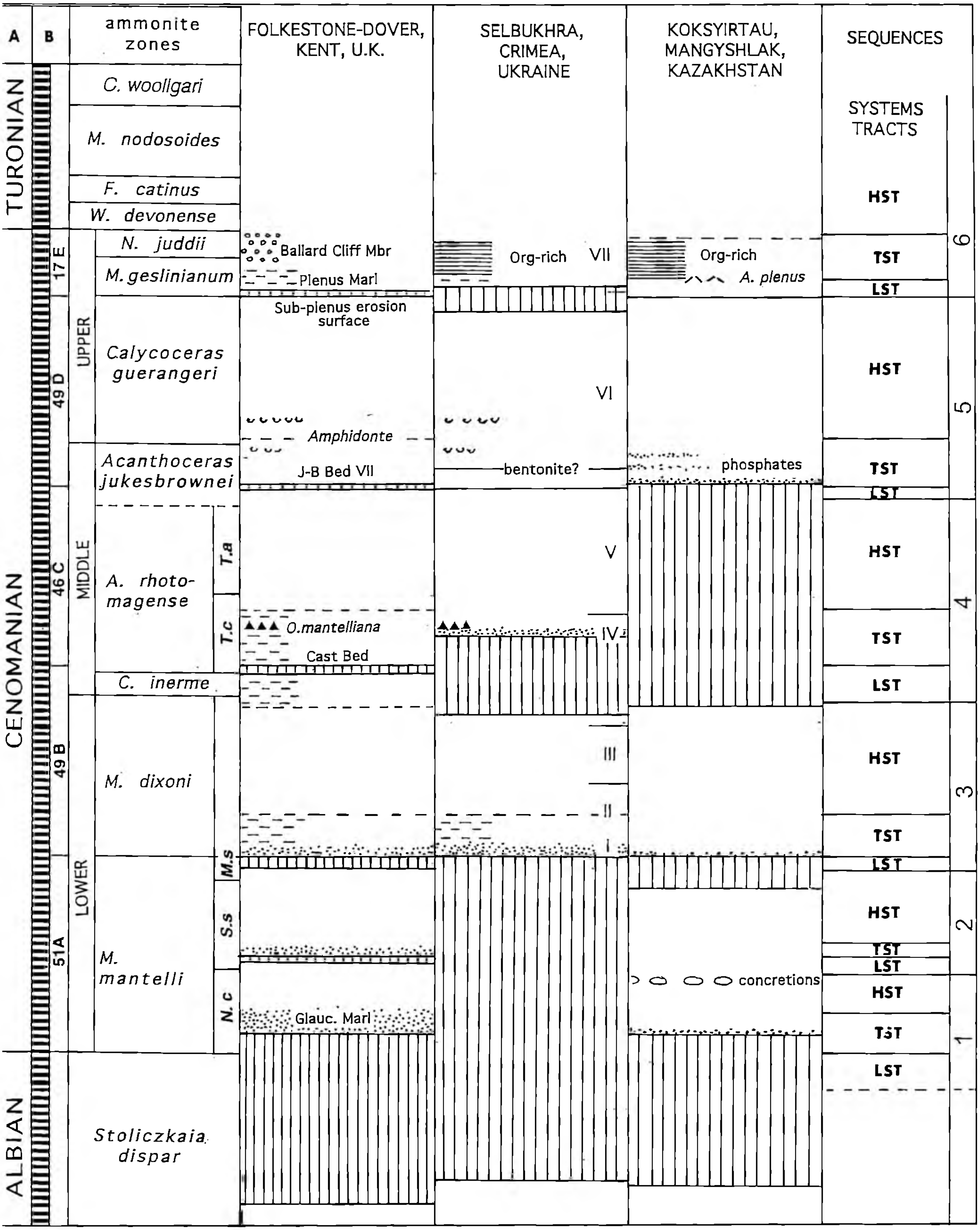
The base of the Lower Cenomanian in Mangyshlak is marked by a 0.2 m thick phosphatic conglomerate (Fig. 4) which rests upon Upper Albian sands containing *Callihoplites* spp. (Marcinowski *et al.*, 1995). The conglomerate is poorly fossiliferous, but has yielded *Schloenbachia* sp. which indicate a Cenomanian age at Sulukapy (Marcinowski *et al.*, 1995) and at Koksyirtau (personal observation). This latter record indicates that the base of the Cenomanian is 17.4 m lower than shown by Marcinowski *et al.* (1995, fig. 9). At 9-13 m above the basal conglomerate at Sulukapy, small limonitised ammonites are common, and include abundant and diverse *Hyphoplites* spp., including *H. costosus* Wright & Wright (Pl. 2, Figs. 1, 2, 18-20), *H. curvatus curvatus* (Mantell) (Pl. 2, Figs. 23, 24), *H. curvatus* (Mantell) *arausionensis* (Hébert & Munier-Chalmas) (Pl. 2, Figs. 21, 22), *H. curvatus* (Mantell) *pseudofalcatus* (Semenov) (Pl. 2, Figs. 3, 4, 16, 17), and *H. falcatus falcatus* (Mantell) (Pl. 2, Figs. 7, 8). Other taxa we have collected from this level include *Schloenbachia varians* (J. Sowerby) (Pl. 2, Figs. 5, 6, 11, 12), *Sciponoceras roto* Cieślinski (Pl. 2, Fig. 15), *Submantelliceras aumalense* (Coquand) (Pl. 2, Figs. 13, 14), and *Placenticeras (Karamaites)* sp. (Pl. 2, Figs. 9, 10). Marcinowski *et al.* (1995) record other ammonites including *Neostlingoceras morrisiformis* (Collignon), *Mantelliceras mantelli* (J. Sowerby), *Anisoceras* spp. and *Hamites* spp. from their Bed 8 at Sulukapy (8.2-10.7 m above the base of the Cenomanian). Altogether, this assemblage is indicative of a Lower Cenomanian, *Neostlingoceras carcitanense* Subzone age.

The Lower Cenomanian is well represented at Besakty, about 150 km ESE of Koksyirtau (Marcinowski *et al.*, 1995, fig. 12) where it yields diagnostic taxa of the two lower subzones of the *mantelli* Zone, the *N. carcitanense* and *S. schlueteri* assemblages (Gale, 1995). We have not seen this section, but the fauna collected and figured from Bed 25 by Marcinowski *et al.* (1995) includes *N. carcitanense* (Matheron) and *Idiohamites* spp. which are diagnostic of the *carcitanense* Subzone. From Bed 30, Marcinowski *et al.* record *Sharpeiceras schlueteri* and common *Inoceramus crippsi crippsi* Mantell, which characterise the *schlueteri* Subzone (Gale, 1995).

A conspicuous 0.2 m thick phosphatic conglomerate is present 14 m above the base of the Cenomanian succession at Koksyirtau (Marcinowski *et al.*,1995, Bed 11; herein Text-fig. 4, 14 m) and an equivalent bed is found at



Text-figure 5 — Correlation of Cenomanian sections in Mangyshlak, showing condensation of the Middle and Upper Cenomanian westwards to Shakh Bogota.



Text-figure 6 — Correlation of Cenomanian sequences and system tracts between southern England, Crimea and Mangyshlak. Column A shows Stages, B the precession timescale of GALE (1995).

Sulukapy (Fig. 4, 20 m) not marked on the MARCINOWSKI log). It does not yield zonally diagnostic ammonites. Overlying this conglomerate, the highest 10 m of the Lower Cenomanian comprises marls containing thin units of fine sand, either bioturbated or with small-scale trough cross-sets. When freshly exposed, the marls yield bivalve taxa very similar to those common in Cenomanian marly chalks of the Anglo-Paris Basin including the bivalves *Euthymipecten beaveri* (J. Sowerby) and *Plicatula inflata* (J. Sowerby). The marls at both localities contain numerous limonitised ammonites which are particularly abundant at Sulukapy (Text-fig. 4, 25-29.5 m), from which MARCINOWSKI (1980) and MARCINOWSKI *et al.* (1995, Bed 14) recorded abundant *Turrilites costatus* Lamarck (figured by MARCINOWSKI, 1980, pl. 4, figs. 1-10). These authors used this identification to assign a Middle Cenomanian age to Bed 14 at Sulukapy, but curiously, placed equivalent strata at Koksyirtau, from which they also record *T. costatus* (Beds 19-22), in the Lower Cenomanian. Because they possess interrupted ribs, but entirely lack tubercles, these ammonites are correctly identified as immature *T. scheuchzerianus* BOSC (Pl. 1, Figs. 23-25; see also WRIGHT & KENNEDY, 1996). At Koksyirtau (Text-fig. 4, 18-23 m), *T. scheuchzerianus* is associated with a single specimen of *Mantelliceras dixoni* (Pl. 1, Figs. 9-11) which confirms the Lower Cenomanian, *M. dixoni* Zone age of this assemblage. At Southerham, Sussex, UK, *T. scheuchzerianus* first appears as a rarity in the middle part of the *M. dixoni* Zone, but becomes abundant in the upper part of the zone, and persists as a rarity into the Middle Cenomanian. The *T. scheuchzerianus* at Sulukapy are associated with *Schloenbachia varians* (Pl. 1, Figs. 14, 15, 17, 18), *Hyphoplites falcatus* (Mantell), *Scaphites (Scaphites)* sp. juv. (Pl. 1, Figs. 21, 22, 28-31), *Hamites duplicatus* Pictet & Campiche (Pl. 1, Figs. 26, 27) and *Worthoceras* sp. (Pl. 1, Fig. 16). The specimens of *Schloenbachia varians* are of Lower Cenomanian rather than Middle Cenomanian aspect. At Koksyirtau, levels 18-23 m above the base of the Cenomanian yield *T. scheuzerianus, M. dixoni* and *S. varians* (Pl. 1, Figs. 1, 2, 12, 13).

MIDDLE CENOMANIAN

The marls of *M. dixoni* Zone age are disconformably overlain by a 5 m succession of sands with 3 levels of phosphatic intraclasts at Koksyirtau, the lowest of which (Text-fig. 4, 25.2 m) has yielded 3 phosphatised steinkerns of *Calycoceras (Gentoniceras) gentoni* (Brongniart) (Pl. 1, Figs. 3-8). MARCINOWSKI *et al.* (1995) record *Acanthoceras* cf. *jukesbrownei* (Spath) from their Bed 23, which is probably equivalent to the 25.2 m level on our Text-fig. 4. The beds containing numerous phosphates alternate with sandstones containing sparser gravel-grade chips of phosphate and oysters. At Sulukapy, the phosphatic conglomerate which rests disconformably upon Lower Cenomanian marls (see above) and underlies Turonian sands has yielded a single remanié *A. jukesbrownei* (MARCINOWSKI *et al.*, 1995). Thus, the Middle Cenomanian in Mangyshlak is represented only by remanié, phosphatised ammonites of *A. jukesbrownei* Zone age, which at Koksyirtau are set in a sandy matrix of which the precise age is unknown.

UPPER CENOMANIAN

The Upper Cenomanian is only identified in the succession at Koksyirtau; in the western part of the Mangyshlak inlier (Sulukapy and Shakh Bogota) it is presumably incorporated (together with the Middle Cenomanian) within the phosphatic conglomerate at the base of Turonian sands which rests upon Lower Cenomanian marls (Text-fig. 5).

The Upper Cenomanian at Koksyirtau is represented by about 8 m of fine sands, silts and clays, of which the lowest 4 m is weakly to strongly laminated and coloured dark grey by up to 5% organic matter. An abundance level of the belemnite *Actinocamax plenus* (Blainville) probably correlates with the acme occurrence of the species in the Anglo-Paris Basin in Bed 4 of the Plenus Marls (JEFFERIES, 1963) within the *Metoicoceras geslinianum* Zone (WRIGHT & KENNEDY, 1981). At a level 2.7 m above the *A. plenus* horizon at Koksyirtau, MARCINOWSKI *et al.* (1995; their Bed 26) record *Neocardioceras juddii* (Barrois & Guerne), index of the *N. juddii* Zone. 4 m higher, they record *Watinoceras amaduriense* (Arkhangelsky) indicating the Lower Turonian zone of *W. devonense*.

SEQUENCE STRATIGRAPHY

Sequences in the Cenomanian of Mangyshlak are clearly defined by sedimentological criteria. The base of each sequence comprises a thin (20-30 cm) lag of worn phosphatic concretions which rest on an erosion surface which is sometimes strongly burrowed and represents an abrupt lithological break. We interpret these surfaces as sequence boundaries which are directly overlain by transgressive surfaces. The phosphatic conglomerates are thus residual lags formed during the early stages of transgression and are very similar to other transgressive accumulations of phosphatic pebbles such as the Cambridge Greensand in the UK and the "Tourtias" of Belgium. The basal conglomerates are overlain by silty sands which formed during the latter part of transgressive systems tracts. They are overlain by silty marls representing the deepest water (most distal) facies in the succession and are interpreted as highstand deposits.

Sequence 1-2

The lowest part of the Cenomanian of Mangyshlak includes the basal phosphatic conglomerate (Shakh Bogota, Sulukapy, Koksyirtau) which is interpreted as a transgressive lag, and the overlying sands and marls which are possibly highstand deposits (Text-fig. 4). This part of the succession is dated as *M. mantelli* Zone from the ammonite faunas (MARCINOWSKI, 1980; MARCINOWSKI *et al.*, 1995). The presence of large carbonate concretions at 15-18 m above the base of the Cenomanian at Koksyirtau, and in Bed 30 at Besakty (MARCINOWSKI *et al.*, 1995), both in the middle part of the *M. mantelli*

Zone, is taken as tentative evidence of the 1-2 sequence boundary, because widespread concretion development often occurs beneath significant hiatuses (e.g. HUGGETT, 1995). However, there is no conclusive sedimentological evidence to separate the two sequences. The concretions at Besakty contain a *S. schlueteri* Subzone assemblage similar to that occurring at the summit of sequence 1 at Folkestone (GALE, 1989b). In Mangyshlak there is thus limited evidence of two separate sequences (1 and 2) within the *mantelli* Zone, as found in the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998), but these are not ubiquitously separable even within the Anglo-Paris Basin (GALE, 1995; OWEN, 1996).

Sequence 3

The summit of the *M. mantelli* Zone sequence 1-2 in Mangyshlak (Sulukapy, Koksyirtau) is truncated by an erosional surface overlain directly by a phosphatic conglomerate, interpreted as a transgressive surface overlying a sequence boundary. The marl succession above the conglomerate contains limonitic ammonites of the *M. dixoni* Zone, and represents the highstand of the same sequence. We correlate this sequence with 3 in the Anglo-Paris Basin, which is there co-eval with the *M. dixoni* Zone.

Sequences 4-5

The succession of 3 phosphatic conglomerates which rest non-sequentially upon marls of *M. dixoni* Zone age at Koksyirtau are tentatively interpreted as lag deposits formed during a transgression. The lowest conglomerate contains poorly preserved steinkerns of Middle Cenomanian ammonites indicative of the *A. jukesbrownei* Zone (MARCINOWSKI *et al.*, 1995), and the sequence is tentatively identified as the transgressive systems tract of 5 in the Anglo-Paris Basin, the lower part of which falls within the *A. jukesbrownei* Zone (ROBASZYNSKI *et al.*, 1998). Sequence 4, which includes the *C. inerme* and *A. rhotomagense* Zones, is therefore missing in Mangyshlak, within the erosional surface underlying the lowest of the Middle Cenomanian phosphatic conglomerates at Koksyirtau.

Sequence 6

At Koksyirtau, the organic-rich silts and laminated fine sands of Late Cenomanian age (*M. geslinianum* and *N. juddii* Zones, *A. plenus* near the base) are interpreted as an overall transgressive event, a local representative of the Oceanic Anoxic Event which is developed globally at this horizon (JENKYNS, 1980). This corresponds with the lower part of sequence 6 in the Anglo-Paris Basin (ROBASZYNSKI *et al.*, 1998).

Conclusions

— Facies, faunas and detailed lithological successions are remarkably similar in the Crimea, the northern Anglo-Paris Basin (southern England and northern France) and the Lower Saxony and Münster Basins, north-west Germany.

a) Beds at the base of the *M. dixoni* Zone in the Crimea show very similar development in terms of carbonate content and thickness to those in southern England. In the Crimea, we are able to tentatively identify couplet B11 (GALE, 1995 - thin prominent limestone; see Text-fig. 3 herein) and an overlying group of carbonate rich beds (B12-13).

b) The major hiatus between the Lower Cenomanian *M. dixoni* Zone and the overlying Middle Cenomanian is of very similar extent in the Crimea, over the London Platform, and in the Lower Saxony Basin, involving the uppermost *M. dixoni* Zone, the *C. inerme* Zone and the lower part of the *T. costatus* Subzone of the *A. rhotomagense* Zone.

c) The faunas of the lowest part of the Middle Cenomanian in the Crimea are closely comparable to those of the upper *T. costatus* Subzone in the Anglo-Paris Basin (KENNEDY, 1969; AMEDRO, 1993) and Lower Saxony Basins (MEYER, 1990), including abundances of the brachiopod *Orbirhynchia mantelliana* and the ammonite *Sciponoceras baculoides*.

d) Chalk-marl couplets and bundles, representing Milankovitch cycles, of Middle Cenomanian age, can be individually correlated between the Crimea, southern England and northern Germany (cf. GALE, 1995; GALE *et al.*, in press), a total distance of 3,900 km.

e) In the Middle-Upper Cenomanian of the Crimea, three thin marls (''*Pycnodonte*-Event'' in Germany, couplets D1-3 in southern England), the overlying amalgamated couplets (''Jukes-Browne Bed VII'' of GALE, 1995; ''*Pycnodonte* Limestone'' of ERNST & REHFELD, 1997) and two acme abundances of *Amphidonte* (recognised in northern Germany and southern England) can be correlated.

f) The sub-plenus erosion surface of JEFFERIES (1963) and an unfossiliferous equivalent of the Plenus Marls of the Anglo-Paris Basin are present in the Crimea.

— The ammonite biostratigraphy described in the Cenomanian of southern England by KENNEDY (1969, 1970, 1971) can be recognised in outline in the Crimea and western Kazakhstan (Mangyshlak). We modify previous work by identifying the *M. dixoni* Zone in these regions from both ammonite evidence and associated inoceramid taxa. The lower part of the ''Middle Cenomanian'' of MARCINOWSKI (1980) and MARCINOWSKI *et al.* (1995) in Mangyshlak is shown to belong to the *M. dixoni* Zone.

— The 3rd/4th order sedimentary sequences described in the Anglo-Paris Basin by ROBASZYNSKI *et al.* (1992, 1998) and OWEN (1996) can be identified in the Crimea and Mangyshlak (Text-fig. 5). In the Crimea, late onlap resulted in sequence 3 (*M. dixoni* Zone) resting directly upon Upper Albian sandstones. Sequences 4, 5, and 6 display a very similar development to that seen in the marly chalk facies of the northern Anglo-Paris Basin, and individual system tracts can be identified and correlated. In Mangyshlak, three sequences are tentatively identified in the Lower Cenomanian (1, 2, 3), but 4 is missing on an erosional surface, as in Devon, SW England, UK (Ro-

BASZYNSKI *et al.*, 1998). Sequences 5 is thin but identifiable, and 6 is present in one locality in Mangyshlak, where progressively increased condensation towards the top of the Cenomanian results in amalgamation of sequences within a phosphatic conglomerate underlying Turonian sands (Text-fig. 4).

Acknowledgements

We wish to thank especially Annie Dhondt, whose enthusiastic support made the fieldwork possible, and who has greatly increased collaboration and understanding between western European and Russian scientists. The hospitality and generous help of Russian colleagues from Moscow State University who made it possible for ASG to visit the Crimea is gratefully acknowledged; in particular, Ludmilla Kopaevich provided unpublished data on the distribution of *Rotalipora cushmani* at Selbukhra, and Ruslan Gabdullin helped greatly with the field work. We also thank Professor D. P. Naidin for leading the field excursion in Mangyshlak, and generously making known his views about Upper Cretaceous stratigraphy of the region.

A. S. Alekseev and Jan Hardenbol kindly reviewed an earlier draft of this paper.

David Ward and other members of the field party generously provided help with fossil collecting.

References.

ALEKSEEV, A. S., VENGERTSEV, V. S., KOPAEVICH, L. F. & KUZMICHAEVA, T. A., 1997. Lithology and micropalaeontology of Cenomanian-Turonian boundary interval in South-Western Crimea. Essays on the geology of the Crimea. *Transactions of the A.A. BOGDANOV Crimean geological scientific-educational center.* Moscow State University Geological Faculty Publication, **1**: 54-74. [In Russian].

AMEDRO, F., 1993. La lithostratigraphie et les biofacies: des outils de corrélation dans les craies cénomaniennes du détroit du Pas-de-Calais. *Annales de la Société géologique du Nord,* (2), **2**: 73-80.

ERNST, G. & REHFELD, U., 1997. The transgressive development in the Lower and Middle Cenomanian of the Salzgitter area (N-Germany) recorded by sea-level controlled eco- and litho-events. *Freiberger Forschungshefte,* **C 468**: 79-107.

ERNST, G., SCHMID, F. & SEIBERTZ, E., 1983. Event-Stratigraphie im Cenoman und Turon von NW-Deutschland. *Zitteliana,* **10**: 531-554.

GALE, A. S., 1989a. A Milankovitch scale for Cenomanian time, *Terra Nova,* **1**: 420-425.

GALE, A. S., 1989b. Field meeting at Folkestone Warren, 29th November, 1987. *Proceedings of the Geologists' Association,* **100**: 73-80.

GALE, A. S., 1995. Cyclostratigraphy and correlation of the Cenomanian stage in Western Europe. *In*: HOUSE, M. R. & GALE, A. S. (Editors), Orbital forcing timescales and cyclostratigraphy. *Special Publications of the Geological Society,* **85**: 177-197.

GALE, A. S., 1996. Turonian correlation and sequence stratigraphy of the Chalk in southern England. *In*: HESSELBO, S.P. & PARKINSON, D.N. (Editors), Sequence stratigraphy in British geology. *Geological Society Special Publication,* **103**: 177-195.

GALE, A. S., JENKYNS, H. C., KENNEDY, W. J. & CORFIELD, R. M., 1993. Chemostratigraphy versus biostratigraphy: data from around the Cenomanian-Turonian boundary. *Journal of the Geological Society, London,* **150**: 29-32.

GALE, A. S., KENNEDY, W. J., BURNETT, J. A., CARON, M. & KIDD, B. E., 1996. The Late Albian to Early Cenomanian succession at Mont Risou near Rosans (Drôme, SE France): an integrated study (ammonites, inoceramids, planktonic foraminifera, nannofossils, oxygen and carbon isotopes). *Cretaceous Research,* **17**: 515-606.

GALE, A. S., YOUNG, J., SHACKLETON, N. J., CROWHURST, S., WRAY, D. S. & TAZZI, M., (in press). Orbital tuning of Cenomanian marly chalk successions; towards a Milankovitch timescale for the Late Cretaceous. *Philosphical Transactions of the Royal Society, London, Series A.*

HANCOCK, J. M., 1993. Sea-level changes around the Cenomanian-Turonian boundary. *Cretaceous Research,* **14**, 553-562.

HAQ, B. U., HARDENBOL, J. & VAIL, P. R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. *In:* WILGUS, C. K., HASTINGS, B. S., KENDALL, C. G. ST. C, POSAMENTIER, H. W., ROSS, C. A. & VAN WAGONIER, J. C., (eds.), Sea-level changes: an integrated approach. *Society of Economic Paleontologists and Mineralogists, Special Publication,* **42**: 71-108.

HARDENBOL, J., THIERRY, J., FARLEY, M. B., JACQUIN, TH., de GRACIANSKY, P.-C. & VAIL, P. R. 1998. Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. *In:* de GRACIANSKY, P.-C., HARDENBOL, J., JACQUIN, TH., & VAIL, P. R. (eds.). Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. *SEPM, Special Publication,* **60**:3-13, 763-782.

HUGGETT, J.M., 1995. Carbonate concretions from the London Clay Formation (early Eocene) of southern England. *Tertiary Research,* **15**: 175-190.

JARVIS, I., CARSON, G.A., COOPER, M.K.E., HART, M.B., LEARY, P.N., TOCHER, B.A., HORNE, D. & ROSENFELD, A., 1988. Microfossil assemblages and the Cenomanian-Turonian (late Cretaceous) Oceanic Anoxic Event. *Cretaceous Research,* **9**: 3-103.

JEFFERIES, R.P.S., 1962. The palaeoecology of the *Actinocamax plenus* subzone (lowest Turonian) in the Anglo-Paris Basin. *Palaeontology,* **4**: 609-647.

JEFFERIES, R.P.S., 1963. The stratigraphy of the *Actinocamax plenus* subzone (Turonian) in the Anglo-Paris Basin. *Proceedings of the Geologists' Association,* **74**: 1-34.

JENKYNS, H.C., 1980. Cretaceous anoxic events: from continents to oceans. *Journal of the Geological Society of London,* **137**: 171-188.

JENKYNS, H.C., GALE, A.S. & CORFIELD, R.M., 1994. Carbon- and oxygen-isotope stratigraphy of the English Chalk and Italian Scaglia and its palaeoclimatic significance. *Geological Magazine,* **131**: 1-34.

JUIGNET, P., 1974. La transgression crétacée sur la bordure orientale du Massif armoricain. Aptien, Albien, Cénomanien de Normandie et du Maine. Le stratotype du Cénomanien. Thesis, University of Caen. 810 p.

JUKES-BROWNE, A.J. & HILL, W., 1903. The Cretaceous rocks of Britain. II. The Lower and Middle Chalk of England. *Memoirs of the Geological Survey of the United Kingdom,* 568pp.

KAPLAN, U., (in press). Zur Stratigraphie der tiefen Oberkreide im Teutoburgerwald (NW-Deutschland). Part IV. Neue stratigraphische Ergebnisse zum Cenoman des Raumes Halle (Westfalen). *Bericht des naturwissenschaftliches Verein Bielefeld und Umgegend.*

KENNEDY, W.J., 1969. The correlation of the Lower Chalk of south-east England. *Proceedings of the Geologists' Association*, **80**: 459-560.

KENNEDY, W.J., 1970. A correlation of the uppermost Albian and the Cenomanian of south-west England. *Proceedings of the Geologists' Association*, **81**: 613-77.

KENNEDY, W.J., 1971. Cenomanian ammonites from southern England. *Special Papers in Palaeontology*, **8**, 133 pp.

MARCINOWSKI, R., 1980. Cenomanian ammonites from the German Democratic Republic, Poland and the Soviet Union. *Acta Geologica Polonica*, **30**: 215-325.

MARCINOWSKI, R. & NAIDIN, D.P., 1976. An Upper Albian ammonite fauna from the Crimea. *Acta Geologica Polonica*, **26**: 83-119.

MARCINOWSKI, R., WALASZCZYK, I. & OLSZEWSKA-NEJBERT, D., 1995. Stratigraphy and regional development of the mid-Cretaceous (Upper Albian through Coniacian) of the Mangyshlak Mountains, Western Kazakhstan. *Acta Geologica Polonica*, **46**: 1-60.

MEYER, T., 1990. Biostratigraphische und sedimentologische Untersuchungen in der Plänerfazies des Cenoman von Nordwestdeutschland. *Mitteilungen aus dem Geologischen Institut der Universität Hannover*, **30**: 1-114.

NAIDIN, D. P., 1993. Late Cretaceous events in the east of the European palaeobiogeographic province. 2. Cenomanian/Turonian and Maastrichtian/Danian events. *Bulletin of the Moscow Society of Naturalists. Geological Series,* **68**: 33-53. [In Russian].

NAIDIN, D. P. & ALEKSEEV, A.S., 1981. Importance of ocean drilling data for interpretation of sedimentation and life of fauna in the Cenomanian of the Crimean highlands. *In*: KRASSILOV, V. (Editor), Evolution of organisms and biostratigraphy of the Mid-Cretaceous. Vladivostok. Pp. 7-21. [In Russian].

NAIDIN, D. P., BENJAMOWSKIJ, V. N. & KOPAEVICH, L. F., 1984. Methods of transgression and regression study (exemplified by Late Cretaceous basins of Western Kazakhstan). Izdatelstvo Moskovskogo Universiteta, 162 pp. Moscow. [In Russian].

NAIDIN, D. P. & KIYASHKO, S. I., 1994a. Cenomanian/Turonian boundary deposits in the Crimean highlands. 1. Lithology, organic deposits and some element contents. *Bulletin of the Moscow Society of Naturalists. Geological Series*, **69**: 28-42. [In Russian].

NAIDIN, D.P. & KIYASHKO, S.I. 1994b. Geochemistry of Cenomanian/Turonian boundary deposits in the Crimean highlands. 2. Isotopic composition of carbon and oxygen; environment of organic carbon accumulation. *Bulletin of the Moscow Society of Naturalists. Geological Series,* **69**: 59-74. [In Russian].

OWEN, D. 1996. Interbasinal correlation of the Cenomanian Stage; testing the lateral continuity of sequence boundaries. *In*: HOWELL, J.A. & AITKEN, J.F. (Editors), High resolution sequence stratigraphy: innovations and applications. *Geological Society of London Special Publications*, **104**: 269-295.

PAUL, C.R.C, MITCHELL, S.F., LEARY, P.N., GALE, A.S., DUANE, A.M. & DITCHFIELD, P.W., 1994. Palaeoceanographic events in the Middle Cenomanian of northwest Europe. *Cretaceous Research*, **15**: 707-738.

ROBASZYNSKI, F., CARON, M., AMEDRO, F., DUPUIS, C., HARDENBOL, J., GONZALES DONOSO, J.M., LINARES, D. & GARTNER, S., 1993. Le Cénomanien de la région de Kalaat Senan (Tunisie Centrale): litho-biostratigraphie et interprétation séquentielle. *Revue de Paléobiologie*, **12**: 351-505.

ROBASZYNSKI, F., JUIGNET, P., GALE, A. S., AMEDRO, F. & HARDENBOL, J., 1992. Sequence stratigraphy in the Upper Cretaceous of the Anglo-Paris Basin, exemplified by the Cenomanian Stage. Sequence stratigraphy of European Basins. CNRS - IFP, Dijon, May 18-20, 1992. Abstracts volume, pp. 79-81.

ROBASZYNSKI, F., JUIGNET, P., GALE, A.S., AMEDRO, F. & HARDENBOL, J., 1998. Sequence stratigraphy in the Upper Cretaceous Series of the Anglo-Paris Basin, Exemplified by the Cenomanian Stage. *In*: de GRACIANSKY, P-C, HARDENBOL, J., JACQUIN, TH. & VAIL, P.R., (eds), Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. *SEPM, Special Publication*, **60**: 363-386.

SCHÖNFELD, J., SCHIEBEL,R. & TIMM, S. 1991. The Rotpläner (Upper Cenomanian to Lower Turonian) of Baddeckenstedt (north-western Germany) - lithology, geochemistry, foraminifers and stratigraphic correlation. *Meyniana*, **43**: 73-95. Kiel.

TRÖGER, K.-A. 1989. Problems of Upper Cretaceous inoceramid biostratigraphy and paleobiogeography in Europe and Western Asia. *In*: WIEDMANN, J. (Editor): Cretaceous of the Western Tethys. Proceedings of the 3rd International Cretaceous Symposium, Tübingen 1987. Schweizerbart'sche, Stuttgart. 911-930.

WRIGHT, C.W. & KENNEDY, W.J. 1981. The Ammonoidea of the Plenus Marls and the Middle Chalk. *Palaeontographical Society (Monograph) London.* 148 pp.

WRIGHT, C.W. & KENNEDY, W.J. 1996. The Ammonoidea of the Lower Chalk. Part 5. *Palaeontographical Society (Monograph) London.* pp. 320-403.

WRIGHT, C.W., KENNEDY, W.J. & HANCOCK, J.M. 1984. The Ammonoidea of the Lower Chalk. Introduction. *Palaeontographical Society (Monograph).* Part 1, 1-37.

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Typescript submitted 15.12.1998
Revised typescript submitted 5.3.1999.

PLATE 1

Figs. 1-2, 12-15, 17-20	— *Schloenbachia varians* (J. Sowerby). 1,2, OUM KY2080; 12,13 OUM 2081; *Mantelliceras dixoni* Zone, Lower Cenomanian, 18-23m above base of measured section (Fig. 4), Koksyirtau. 14, 15, OUM KY2082; 17, 18 OUM KY2083; 19, 20, OUM KY2084, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section on Text-fig. 4, Sulukapy.
Figs. 3-8	— *Calycoceras (Gentoniceras) gentoni* (Brongniart). 3,4, OUM KY2094; 5,6, OUM KY2095; 7,8, OUM KY2096, Middle Cenomanian, lowest phosphate bed, 25.3m above base of measured section in Text-fig. 4, Koksyirtau.
Figs. 9-11	— *Mantelliceras dixoni* Spath. OUM KY2085, *Mantelliceras dixoni* Zone, Lower Cenomanian, 18-23m above base of measured section on Text-fig. 4, Koksyirtau.
Fig. 16	— *Worthoceras* sp. OUM KY2086, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section on Text-fig. 4, Sulukapy.
Figs. 21-22, 28-29, 30-31	— *Scaphites (Scaphites)* sp. juv. 21, 22, OUM KY2091; 28, 29, KY2092; 30, 31, OUM KY2093, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measure section on Text-fig. 4, Sulukapy.
Figs. 23-25	— *Turrilites scheuchzerianus* Bosc. 23, OUM KY2087; 24, OUM KY2088; 25, OUM KY2089, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section on Text-fig. 4, Sulukapy.
Figs. 26-27	— *Hamites duplicatus* Pictet & Campiche. OUM KY2090, *Mantelliceras dixoni* Zone, Lower Cenomanian, 25-29.5m above base of measured section in Text-fig. 4, Sulukapy.

Figures 1-8 are X1; Figures 9-13 are X2.

PLATE 2

Figs. 1-2, 18-20	— *Hyphoplites costosus* Wright & Wright. 1,2, OUM KY2097; 18,19, OUM KY2098; 20, OUM KY2099.
Figs. 3-4, 16-17	— *Hyphoplites curvatus* (Mantell) *pseudofalcatus* (Semenov). 3,4, OUM KY 2100; 16,17, OUM KY 2101.
Figs. 5-6, 11-12	— *Schloenbachia varians* (J. Sowerby). 5,6, OUM KY 2102; 11,12, OUM KY 2103.
Figs. 7-8	— *Hyphoplites falcatus falcatus* (Mantell). OUM KY2104.
Figs. 9-10	— *Placenticeras (Karamaites)* sp. OUM KY2105.
Figs. 13-14	— *Submantelliceras aumalense* (Coquand). OUM KY2106.
Fig. 15	— *Sciponoceras roto* Cieślinśki. OUM KY2107.
Figs. 21-22	— *Hyphoplites curvatus* (Mantell) *arausoniensis* (Hébert & Munier-Chalmas). OUM KY2108.
Figs. 23-24	— *Hyphoplites curvatus curvatus* (Mantell). OUM KY2109.

All specimens from *Mantelliceras mantelli* Zone, *Neostlingoceras carcitanense* Subzone, Lower Cenomanian, 9-13 m above base of section in Text-fig. 4, Sulukapy. All figures X2.

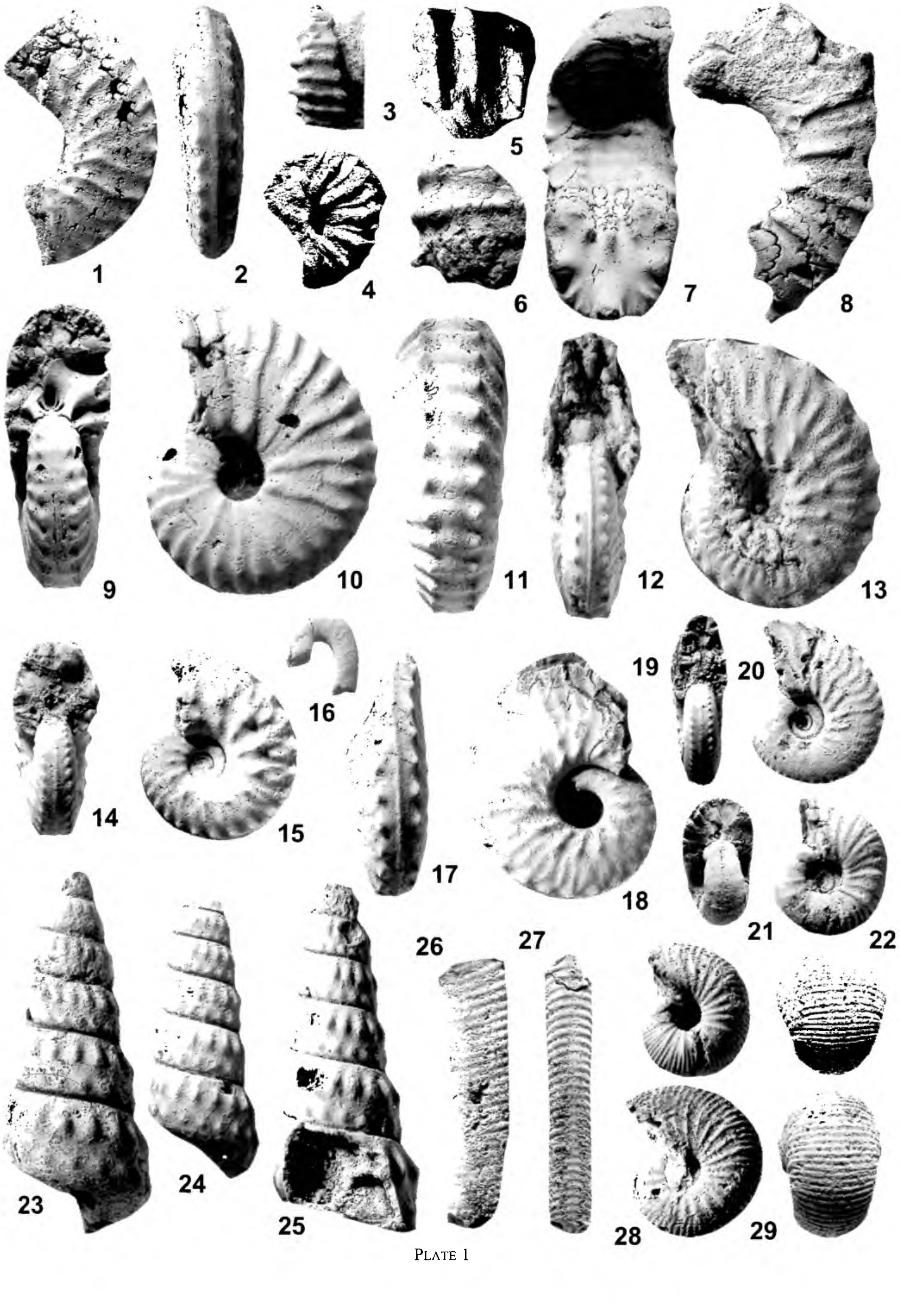


PLATE 1

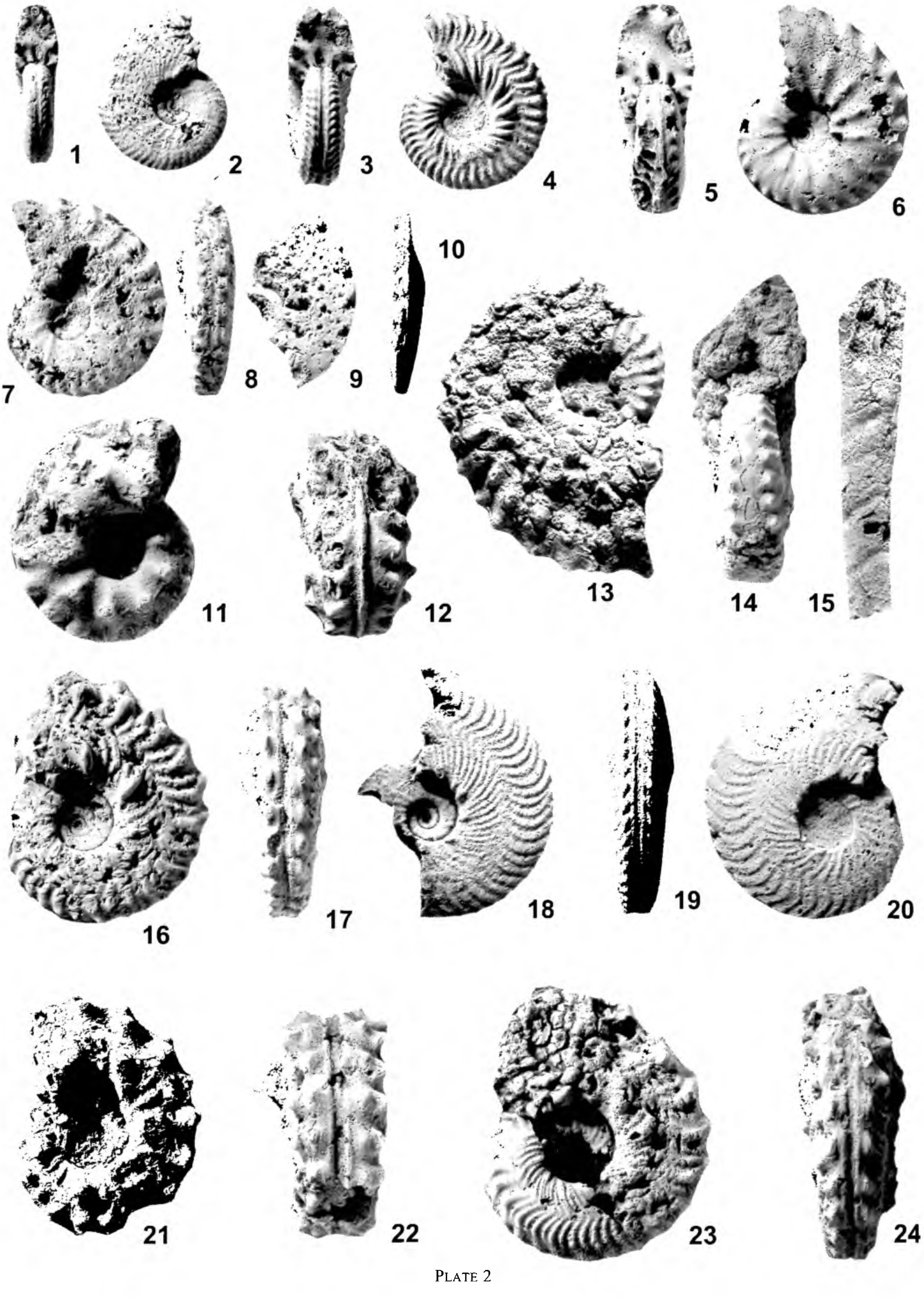


PLATE 2

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 87-101, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP.. A: 87-101, 1999

Periodites below and above the K/T boundary

by Ruslan R. GABDULLIN, Andrey Ju. GUZHIKOV, Alexey B. BOGACHKIN,
Nikolay A. BONDARENKO, Tatyana V. LUBIMOVA & Alexander B. WIDRIK

Abstract

Rhythmically bedded sedimentary rocks from the Maastrichtian and Palaeocene deposits of the Russian craton and southern adjacent areas such as SW Crimea and NW Caucasus have been analysed to determine their origin.

The carbonate content, TOC, foraminiferal, petromagnetic analyses and trace fossil distribution from five sections were studied in order to define the nature of 9 types of rhythmicity. Cycles of dilution, solution and bioproductivity are involved in producing the rhythms. Eleven palaeogeographic models are discussed and five are proposed for the studied sections. A bathymetric zonation for the types of periodites and models of their origin was established. Cyclostratigraphic correlation of the investigated sections with sections of Eurasia may be possible. The origin of rhythms can be related to Milankovich Cycles.

Key-words: Russian craton, Crimea, Caucasus, K/T boundary, Maastrichtian, Palaeocene, rhythmicity, palaeogeographic models

Résumé

Des roches sédimentaires à stratification rythmique appartenant aux dépôts maastrichtien et paléocène du craton russe et des régions méridionales voisines telles le sud-ouest de la Crimée et le nord-ouest du Caucase, ont été analysées afin d'en déterminer l'origine. Le contenu carbonaté, TOC, les foraminifères, le pétromagnétisme et la distribution des traces fossiles ont été étudiés afin de caractériser 9 types de rythmicité. Des cycles de dilution, de dissolution et de bioproduction interviennent dans la production des rythmes. Onze modèles paléogéographiques sont discutés et cinq sont proposés pour les sections étudiées. Une zonation bathymétrique pour les types de périodites et des modèles expliquant leur origine sont établis. Une corrélation par cycles sédimentaires des sections étudiées avec des sections d'Eurasie est possible. L'origine des rythmes peut être en relation avec les Cycles de Milankovitch.

Mots-clefs: Craton russe, Crimée, Caucase, limite K/T, Maastrichtien, Paléocène, rythmicité, modèles paléogéographiques

Резюме

Проанализированы ритмично построенные осадочные породы из Маастрихтских и Палеоценовых отложений Русского кратона и прилегающих южных районов таких, как ЮЗ Крым и СЗ Кавказ, с целью определения их происхождения. Изучено содержание карбоната кальция, органического углерода, петромагнитные анализы и распределение ихнофоссилий в пяти разрезах для определения природы 9 типов ритмичности. Привлечены циклы разбавления, растворения и биопродуктивности, как факторы возникновения ритмов. Обсуждены 11 палеогеографических моделей и пять предлагаются для изученных разрезов. Установлена батиметрическая зональность для типов периодитов и моделей их происхождения. Было предпринято ритмостратиграфическое сопоставление изученных разрезов с разрезами Евразии. Природа ритмичности может быть связана с циклами Миланковича.

Ключевые слова: Русский кратон, Крым, Кавказ, Мел-Палеогеновая граница, Маастрихт, Палеоцен, ритмичность, палеогеографические модели

Introduction

This study focuses on the origin of periodites outcropping on the Russian craton, SW Crimea and NW Caucasus. The K/T boundary in the investigated area was studied by GERASIMOV *et al.* (1962) and more recently by MUSATOV & ERMOKHINA (1997), but the presence, types and the nature of rhythms in these deposits were not given detailed attention. The biostratigraphic subdivision of the Maastrichtian deposits of the Besh-Kosh section was investigated by ALEKSEEV & KOPAEVICH (1997).

The presence and types of rhythmicity below and above the K/T boundary on the Russian craton were already mentioned by GERASIMOV in GERASIMOV *et al.* (1962). Carbonate turbidites on the Caucasus were studied by AFANASIEV (1993), but intervals with periodites were not observed in the succession.

During the last two years a classification of the palaeogeographic models of the origin of carbonate periodites was undertaken (GABDULLIN, 1997) and a new model was proposed (GABDULLIN & BARABOSHKIN, 1997). Space-time laws of the forming of the carbonate rhythmic successions (GABDULLIN, 1998b), the origin of rhythms in the Cretaceous of the Ulyanovsk-Saratov foredeep (GABDULLIN *et al.*, 1998 a, b) and in the Palaeocene of the Crimea and of the Ulyanovsk-Saratov foredeep (GABDULLIN & WIDRIK,1998) have been presented elsewhere.

Text-fig. 1 — Locality map. Sections: 1-Sengeley, 2-Volsk, 3-Belogrodnya, 4-Besh-Kosh, 5-Betta.

Geological setting

Examples of rhythmically bedded carbonate successions containing a K/T boundary are found (Figure 1) on the Russian platform (Sengeley, Volsk, Belogrodnya sections) and in southern adjacent areas such as the Crimea (Besh-Kosh section) and the Caucasus (Betta section). The Sengeley section (Ulyanovsk region, Russia), the Volsk and Belogrodnya sections (Saratov region, Russia) are situated inside the Ulyanovsk-Saratov foredeep. The Besh-Kosh section (Bakhchisaray region, Ukraine) was described from the slope of Besh-Kosh mountain (second chain of Crimean mountains). The Betta section is situated in the Novorossyisk foredeep on the Black Sea shore.

Materials and methods

In the field, sections were divided into rhythms based on the weathering of the profiles, their colour differences, trace fossil distribution and thickness variation.

Foraminiferal analysis (23 samples), total organic carbon content and calcium carbonate content analysis (159 samples) were used in the analysis. Petromagnetic investigations (169 samples) include measurements of magnetic susceptibility (k), natural remnant magnetization (Jr), remnant saturation magnetization (Jrs), destructive field of remnant saturation magnetization (Hcs) and magnetic susceptibility increase (dk) to determine mineral species with magnetic properties. Differential thermal magnetic analysis (DTMA) was used, JR-4 and IMB-2 machines were used for remnant magnetization and magnetic susceptibility analyses. Increasing magnetic susceptibility is connected with the thermal transformation of iron sulfides into magnetite. Thus the presence of pyrite and pyrrothine in rocks is indicated by the magnetic susceptibility increase. Petromagnetic methods can help scientists to:

- determine low concentrations of sulfide and non-sulfide Fe-magnetics of size of a dust invisible even in the thin section;
- distinguish the composition and volume of the terrestrial input;
- understand the nature of magnetic minerals.

Cyclic distribution of magnetic minerals detected by these methods can be interpreted as cycles of dilution (allotegenious Fe-magnetic minerals) or solution (authigenic sulfide Fe-magnetic minerals).

Lithostratigraphy

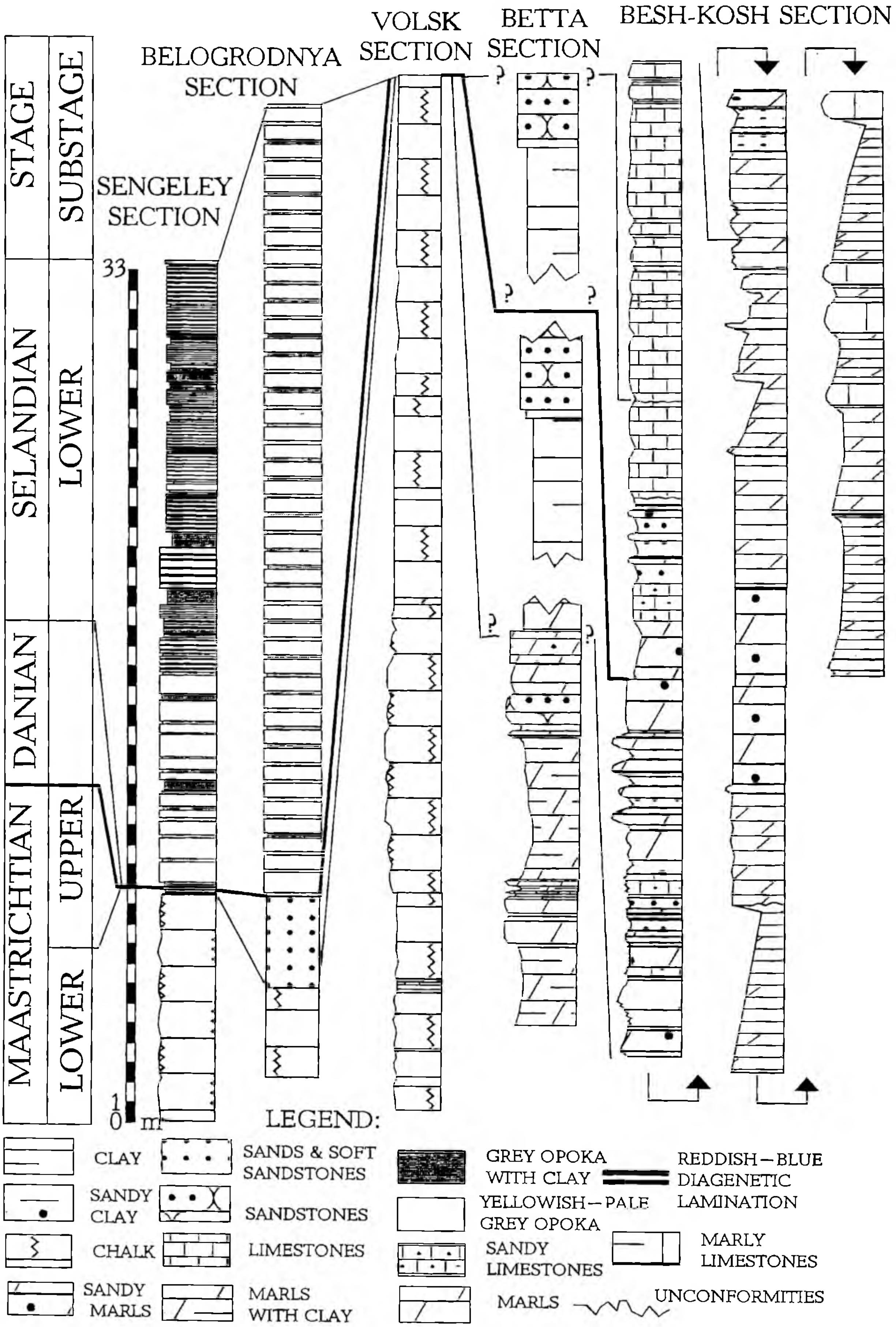
The investigation of the Maastrichtian and Palaeocene of the Russian craton and southern adjacent areas in the SW Crimea and NW Caucasus (Figure 2) resulted in the establishment of nine types of periodites in carbonate (marl-marl (1); marl-limestone (2); marl-chalk (3) and chalk-chalk (4) cycles), in terrestrial-carbonate (sandstone, sand-calcareous sandstone, sand (5); sandstone, sand-marl (6); clay-marl, limestone (7) cycles) and siliceous-carbonate successions (opoka-marl (8) cycles) and siliceous successions (sandy/marly opoka-opoka (9) cycles). Opoka is a light porous siliceous abiomorphic rock, consisting from more then 50% of opal or opal-cristabolite.

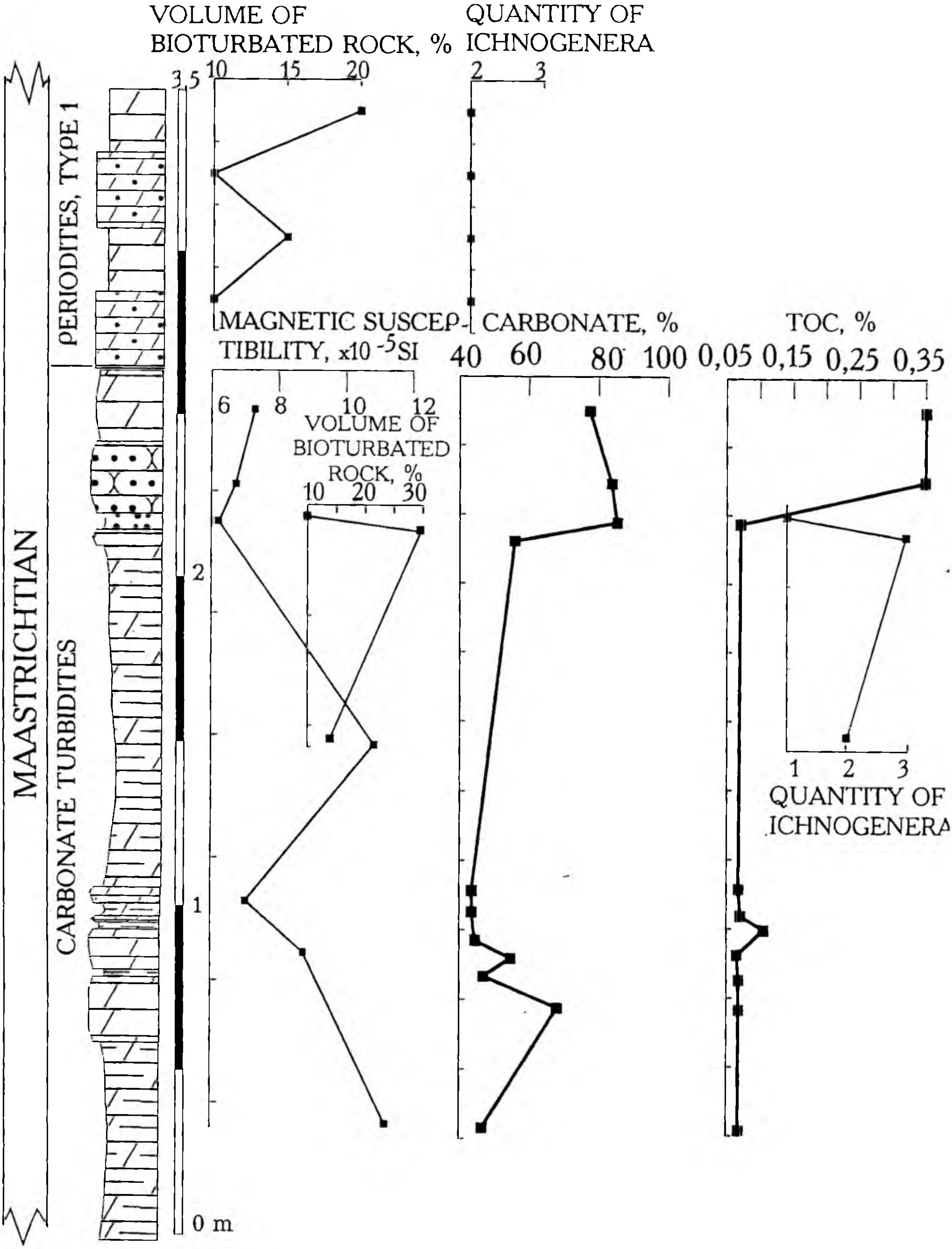
Carbonate turbidites (Caucasus), periodites (mostly Russian craton and the Crimea and Caucasus) and transitional turbidite-periodite successions (Caucasus) were observed. Most of the Maastrichtian and Palaeocene in the Caucasus contains limestone (marl)-marl-sandstone carbonate turbidites (Figure 3) or sandstone-clay, sandstone-clay-sandy clay turbidites (Figure 4). Ichnofossils are represented by *Thallassinoides* sp. , *Teichichnus* sp., *Chondrites* sp. and *Nereites* sp. Turbidites always consist of two or more rhythm elements with graded bedding. These criteria were used to separate them from the periodites. The thickness of the Maastrichtian in the Caucasus is thought to be up to 1230 m, of the Palaeocene — up to 490 m. That is why the studied parts of the succession are shown out of scale on the Figure 2. Intervals with arrhythmic, chaotic bedding were found in all investigated regions.

Studied sections of the Ulyanovsk-Saratov foredeep are characterized by the presence of Lower Maastrichtian, Danian (only in the Belogrodnya section) and Selandian. The Crimean section contains Lower and Upper Maas-

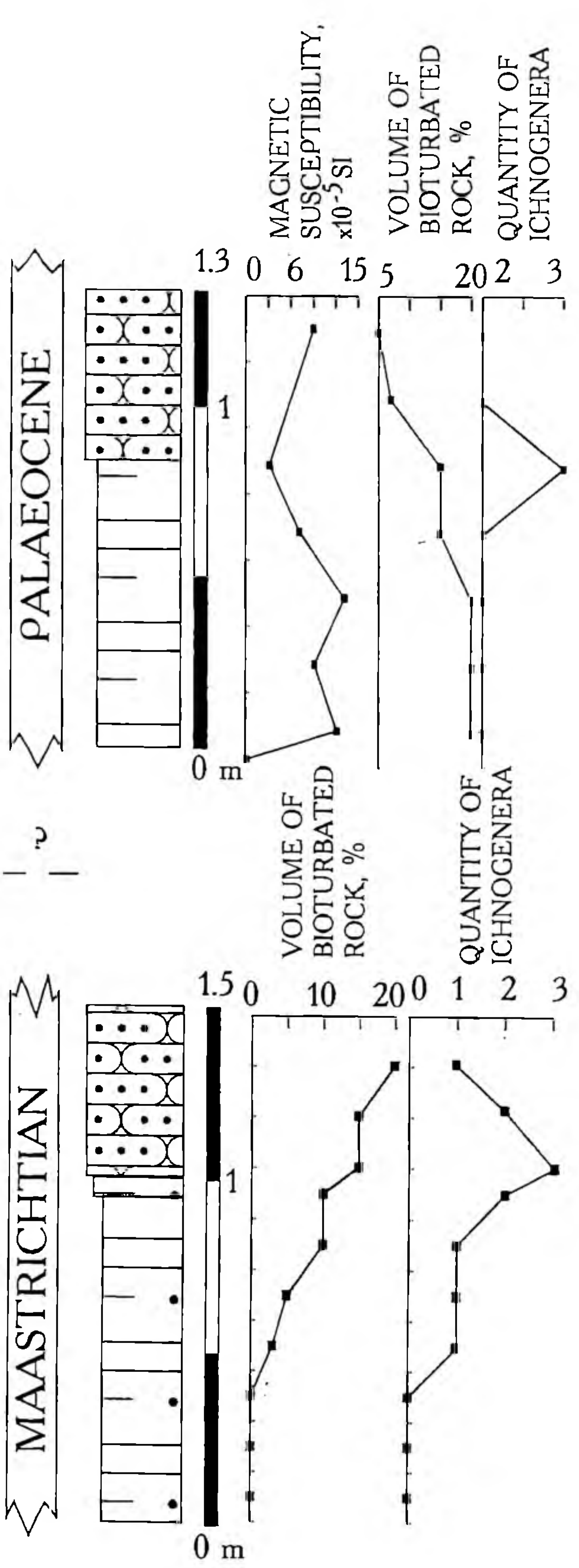
→

Text-fig. 2 — Correlation sketch of Maastrichtian, Danian and Selandian deposits of Russian craton (Sengeley, Volsk and Belogrodnya sections), SW Crimea (Besh-Kosh section) and NW Caucasus (Betta section).


STAGE
SUBSTAGE
SENGELEY SECTION
BELOGRODNYA SECTION
VOLSK SECTION
BETTA SECTION
BESH-KOSH SECTION
SELANDIAN
LOWER
DANIAN
MAASTRICHTIAN
UPPER
LOWER
33
1
0 m
?
LEGEND:
CLAY
SANDS & SOFT SANDSTONES
GREY OPOKA WITH CLAY
REDDISH-BLUE DIAGENETIC LAMINATION
SANDY CLAY
SANDSTONES
YELLOWISH-PALE GREY OPOKA
CHALK
LIMESTONES
SANDY LIMESTONES
MARLY LIMESTONES
SANDY MARLS
MARLS WITH CLAY
MARLS
UNCONFORMITIES



Text-fig. 3 — Maastrichtian transitional turbidite-periodite succession of Betta section, Caucasus. Explanation of signatures use in Text-fig. 2.



Text-fig. 4 — Two types of turbidites below and above K/T boundary (3 rhythm elements in Maastrichtian and 2 rhythm elements in Palaeocene) in Betta section, Caucasus. Explanation of signatures used, in Text-fig. 2.

trichtian, Danian and Selandian deposits. The stratigraphical position of the Betta section is not sufficiently investigated, but it is known that it consists of Maastrichtian (Figures 3 and 4) and Palaeocene (Figure 4) deposits. In the Betta section the K/T boundary does not outcrop. The Sengeley section (Figure 5) contains Lower Maastrichtian chalks (10.5 m) and Selandian opokas (more than 30 m). The Volsk section (Figure 6) consists of Lower Maastrichtian chalks (about 65 m), the Belogrodnya section (Figure 7) is composed of Lower Maastrichtian chalks (5 m), Danian sandstones (10 m) and Selandian, siliceous marls, sandy opokas (37 m) with only a few fossils. The Besh-Kosh section (Figures 8 and 9) includes Maastrichtian marls, sandy marls (total thickness — 140 m for both substages), Danian (Figure 2) bioclastic limestones and carbonate clays (26 m) and Selandian (Figure 2) reddish limestones and marly limestones (more than 6 m).

The Maastrichtian stage is characterized by the presence of periodites types 3, 4 and 8 (Russian craton); 1, 2, 5 and 6 (Crimea) and 2 (Caucasus); carbonate turbidites and transitional turbidite-periodite successions (Caucasus). The Belogrodnya section is presented by an arrhythmic interval (5 m) of chalk. It should be noted that the top of the Lower Maastrichtian in the Volsk section is rich in fossils and also arrhythmic, but other parts contain primary rhythms. In the Sengeley section, the succession is a visually arrhythmic and fossil-rich chalk, but the measured parameters demonstrate rhythmic oscillations. The thickness of the Maastrichtian rhythms usually varies from decimeters to meters.

Second order cycles can be distinguished in Maastrichtian rocks of the Russian craton and the Crimea. They contain cyclic variations of rhythmic and arrhythmic levels in the succession (type 4; Lower Maastrichtian, Volsk section) or the possibility of uniting groups of rhythms into new cycles according to their lithologic characteristics and thickness of couplets (all types, Crimea; and type 3; Lower Maastrichtian, Volsk section). This circumstance can demonstrate the connection between the investigated rhythms and Milankovich cycles.

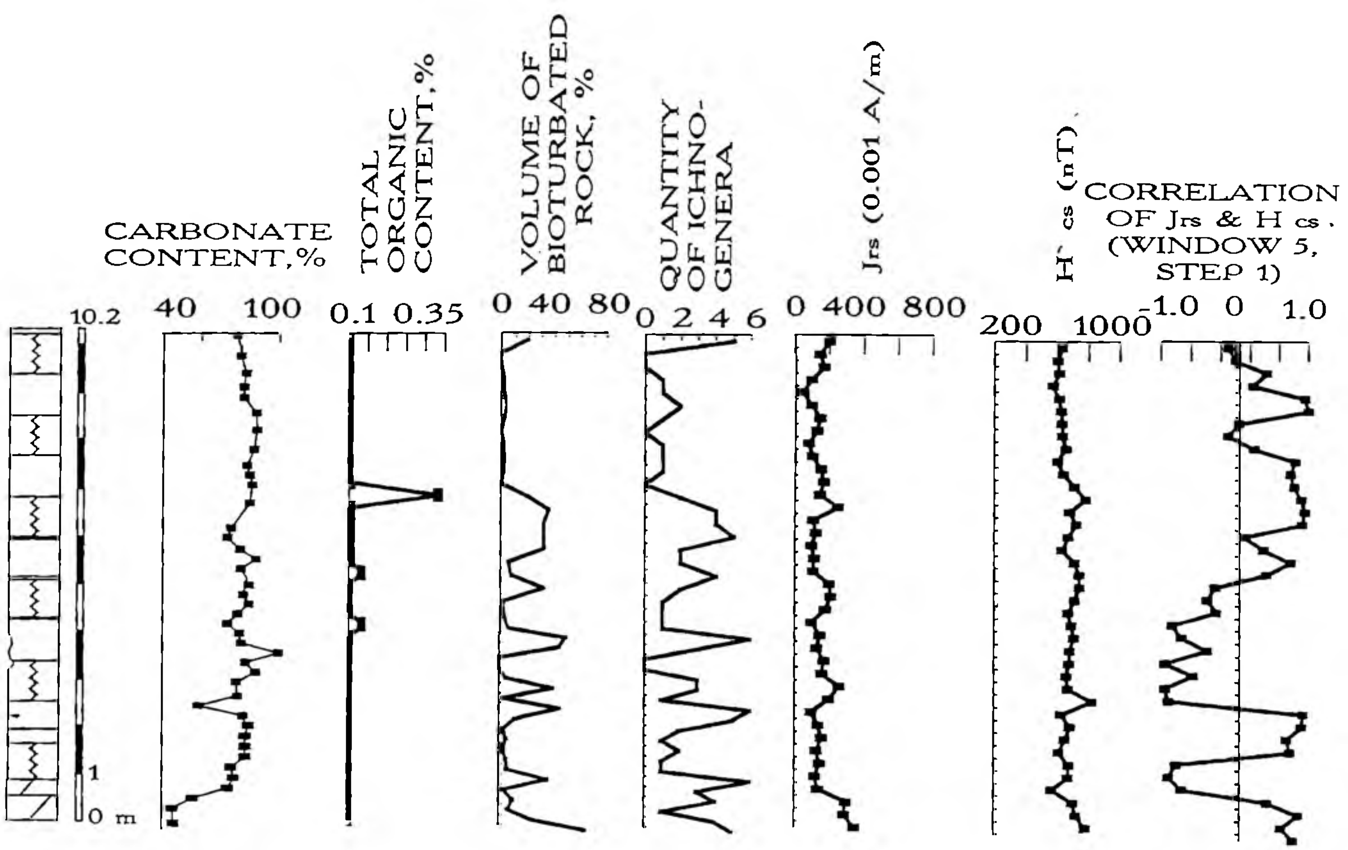
Lower Palaeocene deposits on the Russian craton and SW Crimea are represented by periodites of types 8 and 9. Palaeocene opokas were observed in all sections on the Russian craton. The Belogrodnya section contains Danian deposits presented by arrhythmic, green-blue, glauconitic sandstones. Elements of rhythms in the Besh-Kosh section usually have erosional boundaries. Thickness of Palaeocene rhythms is from a 0.10 m to a few meters.

Discussion

Questions to be answered:

(1) Which models explain the origin of the periodites in pelagic/hemipelagic sedimentary rocks?

(2) What mechanisms (cycles) are responsible for the occurrence of specific types of periodites?



Text-fig. 5 — Lower Maastrichtian of Sengeley section, Ulyanovsk-Saratov foredeep. Explanation of signatures used in Text-fig. 2.

(3) Which palaeogeographical models apply to the studied sections?

(4) What is the connection between specific types of periodites and proposed models?

(5) Is it possible to establish the bathymetrical zonality for the types of periodites and models of their origin?

(6) Is it possible to correlate by cyclostratigraphy between the investigated sections and other sections in Eurasia?

Eleven different models have been suggested for explaining the origin of the periodites. They are briefly described below:

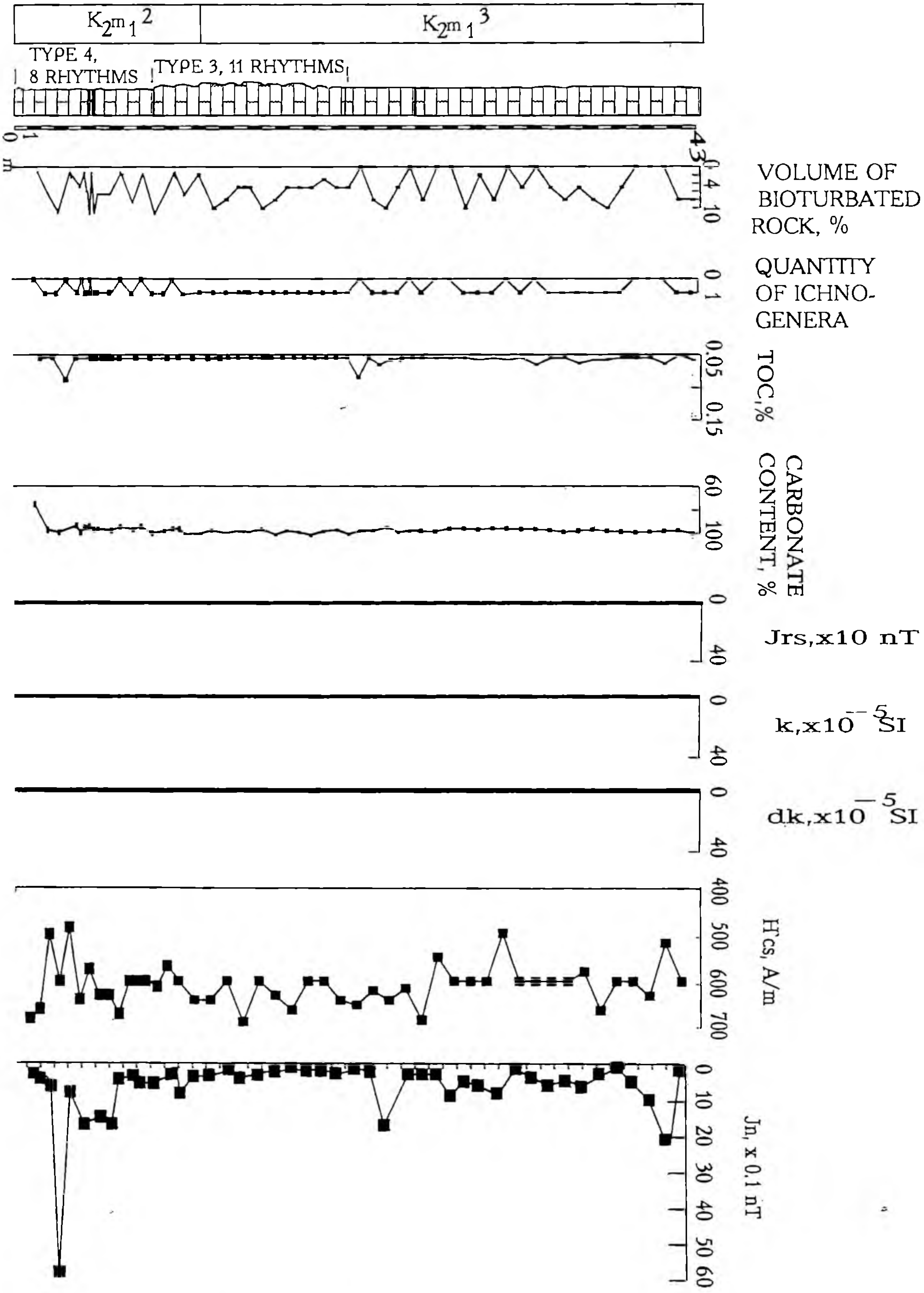
Dilution cycles. Model 1 (EINSELE, 1985). Cyclic changes of moisture, terrestrial input due to climatic variations form rhythmicity in the carbonate sediments. During times of dry climate mainly limestones are deposited. Times of wet climate produce marls, when the dilution of constant carbonate sedimentation by terrestrial material (clay), transported by rivers, takes place.

Dilution cycles. Model 2 (RUFFELL *et al.*, 1996). This model is close to the first. The difference is that in the first case cyclic climatic changes are assumed to result in the cyclic changes in the volume of run off, but here climatic fluctuations cause variations in the nature of weathering and in the composition of terrestrial material transported by rivers. Wet warm seasons are the time of marl sedimentation. Limestones occur during dry cold conditions.

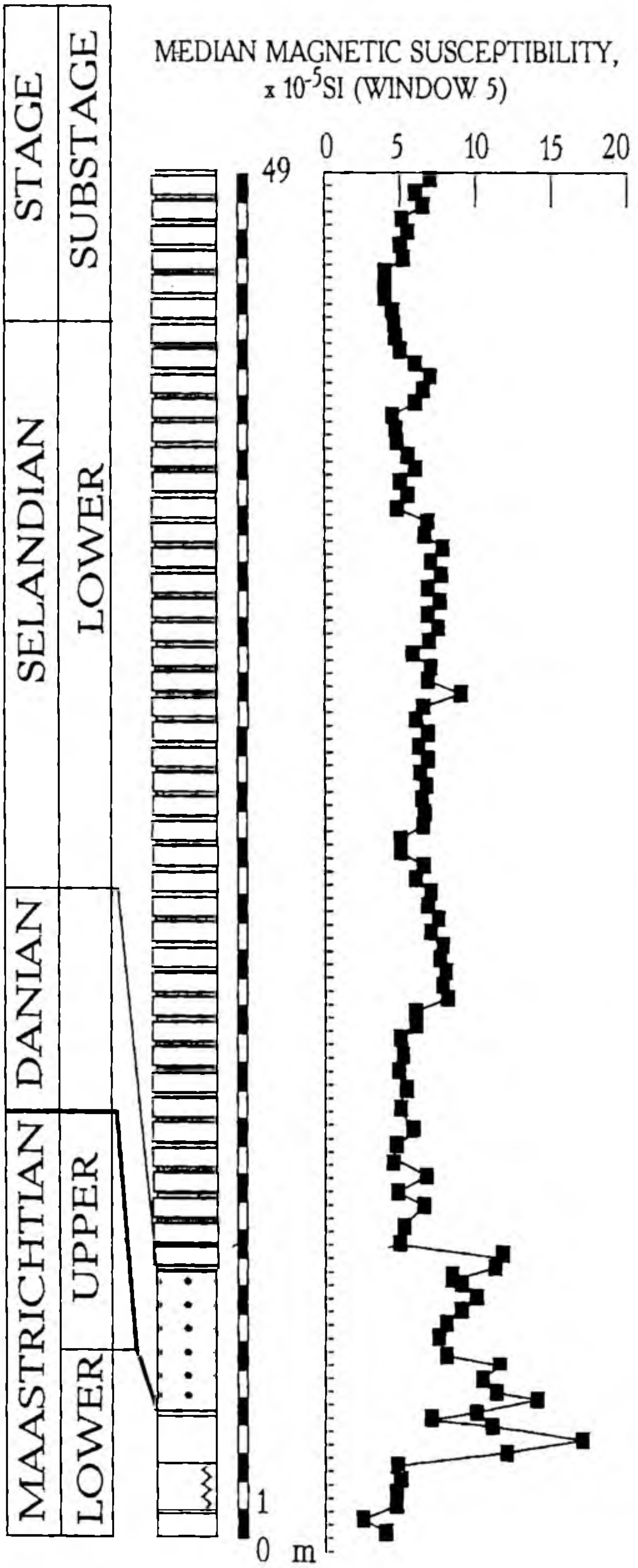
Dilution cycles. Model 3 (MOROZOV, 1952). Sea level rise is a time of transgression (ingression) which washes out accumulated terrestrial material from the shore districts into the basin. So, during transgressions relatively high terrestrial input takes place. Sea level fall is a time of regression and relatively low terrestrial input.

Dilution cycles. Model 4 (GAVRILOV & KOPAEVICH, 1996). During sea level fall coastal regions become swamps and deposition of organic rich sediments takes place. Sea level rise causes transportation of sediments into the basin, with deposition and partial dissolution, increase of bioproductivity, appearance of anaerobic conditions and occurrence of "black shales".

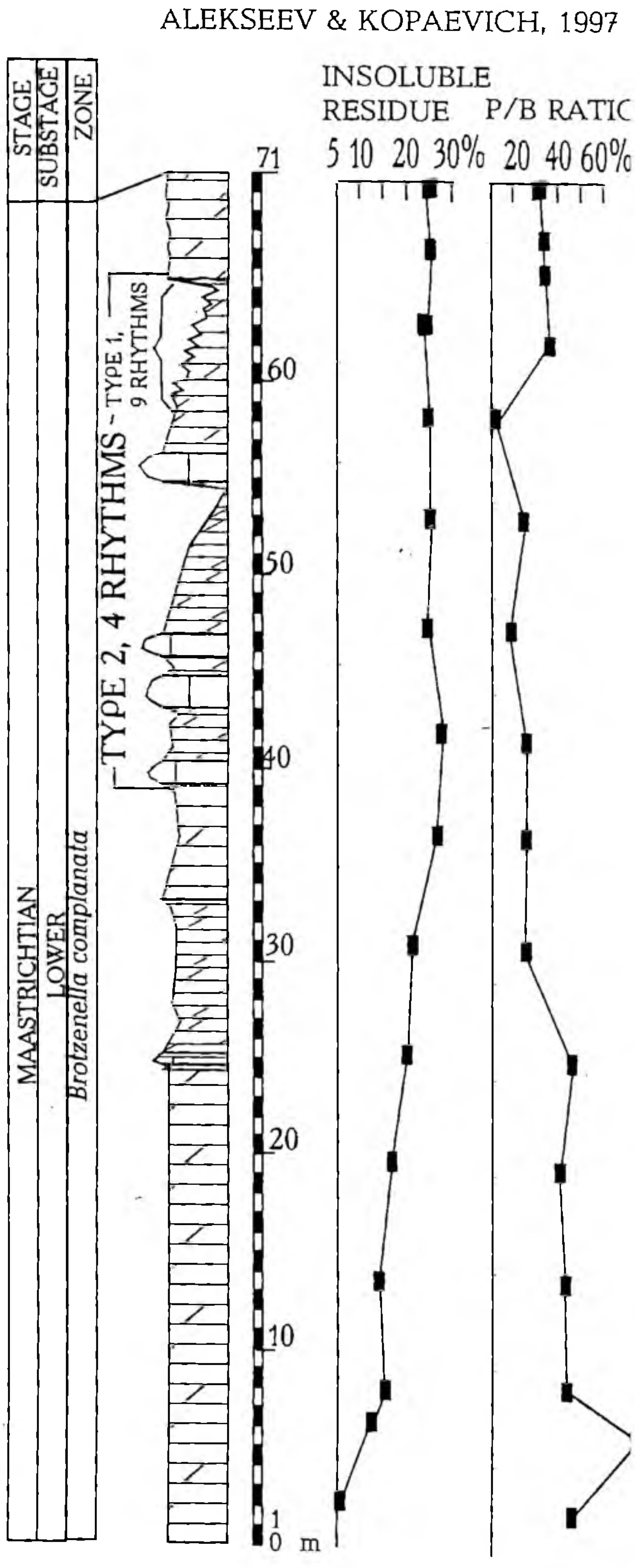
Solution cycles. Model 5 (GABDULLIN & BARABOSHKIN, 1997). Cyclic repetition of condensation and deposition result in the appearance of rhythmic limestone-carbonate clay (marl) sections. Limestones always have an erosional boundary with clays (marls). Limestones represent the sedimentation regime, condensation causes the concentration of carbonate clay, marl (result of limestone dissolution). Erosional surfaces occur due to non-depositional regimes and include soft- and hard-grounds. Con-



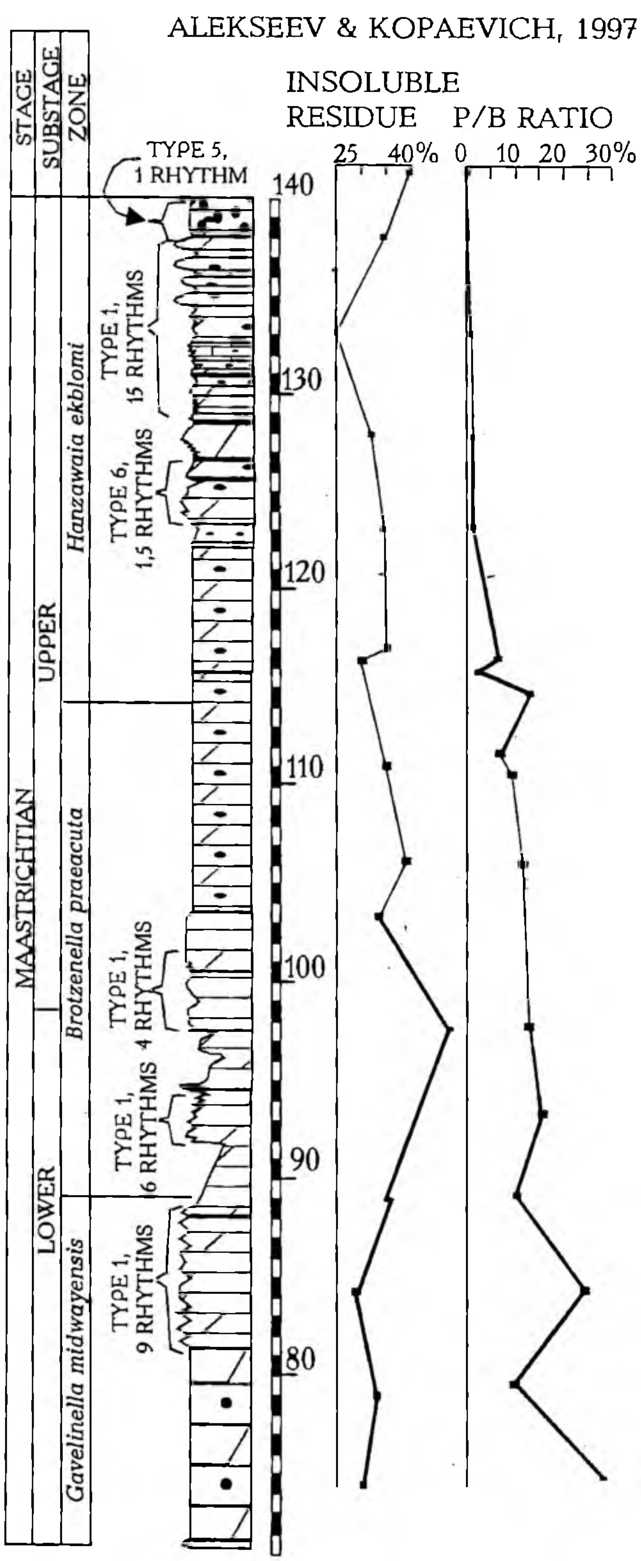
Text-fig. 6 — Lower Maastrichtian of Volsk section, Ulyanovsk-Saratov foredeep. Explanation of signatures used in Text-fig. 2.



Text-fig. 7 — Lower Maastrichtian, Danian and Selandian of Belogrodnya Volsk section, Ulyanovsk-Saratov foredeep. Explanation of signatures used in Text-fig. 2.



Text-fig. 8 — Lower Maastrichtian of Besh-Kosh, Crime
Explanation of signatures used in Text-fig. 2.



Text-fig. 9 — Lower and Upper Maastrichtian of Besh-Kosh, Crimea. Explanation of signatires used in Text-fig. 2.

densation and sedimentation are assumed to be cyclic processes.

Solution cycles. Model 6 (Einsele, 1985). SLC (sea level change) causes variation of the critical carbonate solution depth. Periodically, the volume of the constantly deposited carbonate that is dissolved changes.

Solution cycles. Model 7 (Ricken, 1994). SLC causes cyclic variation in depth of the basin. This results in periodic occurrence of stratified waters with anoxic or nearly anoxic conditions and solution of the constantly deposited carbonates. Sea level up — marl, sea level down — limestone.

Solution cycles. Model 8 (Savdrra & Bottjer, 1994). Climatic variations result in fluctuations of winds and water current direction, which cause changes in the dissolved oxygen content of the bottom waters. Because of new current directions and some specific bottom relief, stagnant, stratified water masses can occur. Cyclic changes of aerobic — dysaerobic — anaerobic conditions result in periodic solution of constantly deposited carbonates.

Dilution and solution cycles. Model 9 (Hay, 1996). Periodical volcanic input into the basin with mostly carbonate sedimentation causes cyclic appearance of bentonite couplets inside chalk or marl layers. Eruptions produce both ash clouds and acid rain. Acid rain enriches water of the basin in acids, dissolving the carbonate.

Cycles of bioproductivity, dilution, solution. Model 10 (Fischer & Arthur, 1977). The history of the organic world can be divided into polytaxic and oligotaxic intervals (Fischer-Arthur cycles), which occur due to climatic variations, SLC.

Solution cycles. Model 11 (Einsele, 1985). Global cycles of carbon are responsible for changing the carbon/oxygen relation in the atmo- and hydrospheres. This relation depends on the volume of vegetation. The greater the quantity of plants, the lower the content of carbon dioxide.

To determine the mechanisms responsible for producing the periodites and the palaeogeography implied by them established types of periodites were investigated by different analyses. The Palaeocene periodites were less thoroughly investigated. Here is the interpretation of the origin of the studied types of periodites.

A **first type** of periodites was observed in the Maastrichtian of the Besh-Kosh section (Figure 8 and 9). Periodites, consisting both of three elements (Table 1) and two elements (Tables 2 and 3) were observed. Rhythms included marls and chalky marls (Table 1), marls and sandy marls (Table 2), sandy marls and hard sandy siliceous or siliceous marls (Table 3). Rhythmicity in the Maastrichtian of the Besh-Kosh section reflects the distribution of:

- calcium carbonate, carbon dioxide and organic carbon concentration;
- volume of bioturbated rocks;
- P/B relation;
- the weathering profile;

Table 1 – The compossition of 9 marl-marl-chalky marl rhythms in the Besh-Kosh section (type 1, Lower Maastrichtian).

Lithology	Marl	Marl	Chalky marl
Thickness, m	0,05 - 0,2	0,1 - 0,35	0,15 - 0,4
Colour	greyish-yellow	greyish-green	white
Bioturbation	weak or absent	strong	weak
Planktonic forams, %[1]	4,3	0,8	4
Secretional benthic forams, %[1]	7,3	3,2	11
Agglutinated benthic forams, %[1]	88,4	96	85
Quantity of samples	9	9	9

[1] Zayeka O.V., pers. commun.

Table 2 – The composition of 15 calcareous sandstone-sandy marl rhythms in the Besh-Kosh section (type 1, Upper Maastrichtian).

Lithology	Sandy marl	Marl
Thickness, m	0,05 - 1	0,2-1
Colour	grey	yellowish-grey
$CaCO_3$, %	63,56	68,1 - 72,64
TOC, %	0,25	0,1 - 0,17
Insoluble residue, % [2]	29	35
Planktonic/Benthic forams, % [2]	5	10-13
Volume of bioturbated rocks, %	5	10
Quantity of samples	2	4

[2] ALEKSEEV & KOPAEVICH, 1997

— thickness distribution.

Origin of 9 marl-marl-chalky marl rhythms in the Lower Maastrichtian deposits of the Besh-Kosh section is connected with solution cycles and sea level change (model 7). Fluctuation of the sea level is indicated by oscillations in the relation of planktonic and benthic forams. Dark rock colour correlates with weak bioturbation and sea level rise (relatively high content of the planktonic forams).

The same criteria plus a relatively high content of TOC in the dark couplets are typical for the same model proposed for the origin of 15 calcareous sandstone-sandy marl rhythms in the Upper Maastrichtian of the Besh-Kosh section. At the same time the «sandy» lithology of the rocks is a result of dilution cycles in the basin with fluctuation of sea level (model **3**). In summary, models **3** and 7 are suggested to explain periodites of the first type. These two models and the same interpretation of the data are proposed for the appearance of the 15 sandy marl-hard sandy siliceous marl rhythms of the Lower Maastrichtian and four soft sandy marl-hard siliceous marl rhythms of the Upper Maastrichtian of the Besh-Kosh section.

Another example of periodites of this type is the Cenomanian of the Gamba Zong Shan section, Tibet (LAMOLDA & WAN, 1996).

A **second type** of periodites was found in the Betta section (NW Caucasus). Rhythmicity is represented by a limestone-marl succession with a cyclic distribution of magnetic susceptibility, volume of bioturbated rocks (Figure 3) and distinct colour differentiation (Table 4). Dilution cycles are indicated by oscillations in the terrestrial input of Fe-magnetic minerals (variations in magnetic susceptibility). Solution cycles are indicated by cyclic distribution of the volume of bioturbated rocks and the trace fossil *Chondrites* sp., which is extremely sensitive to variations of the concentration of oxygen, dissolved in the bottom waters. The presence of *Teichichnus* sp. in both rhythm elements indicates the absence of eustatic fluctuations. The origin of the second type of periodites in the Betta section is considered to be connected with models **1** and **8**.

In the Lower Maastrichtian of the Besh-Kosh section a second type of periodites is represented by thick rhythms (Figure 8). Thickness of the marl layers varies from 1 to 9,5 m. Inside one of these marl units rhythmicity of the

Table 3 – The composition of marl-marl rhythms in the Besh-Kosh section (type 1, Maastrichtian).

	K_2m_1,	K_2m_2,	K_2m_1,	K_2m_2,
Lithology	Sandy marl	Soft sandy marl	Hard sandy siliceous marl	Hard siliceous marl
Thickness, m	0,1-0,32	0,1 - 0,17	0,45 - 1,05	1 - 3,7
Colour	light grey	grey, yellowish grey	dark grey	grey
CO_2, %		25 - 27		29 - 33
$CaCO_3$, %		56,75 - 61,25		65,83 - 74,91
TOC, %		<0,08		<0,08
Volume of bioturbated rocks, %		5		10
Planktonic forams, %[1]	4		7	
Secretional benthic forams, %[1]	11		2	
Agglutinated benthic forams, %[1]	85		91	
Quantity of samples	1	5	1	4
Quantity of rhythms	15	4	15	4

first type was found. Limestones are usually 1-1,5 meters thick. Rhythmicity reflects the distribution of:

- volume of bioturbated rocks;
- insoluble residue concentration;
- P/B relation;
- the weathering profile;
- thickness distribution.

Fluctuation of the sea level is indicated by oscillations in the relation of planktonic and benthic forams, thickness distribution of the marl couplets and weak oscillations in the volume of bioturbated rock. The constant upward increase of the thickness of marls correlates with sea level fall (relatively high content of the benthic forams and relatively low volume of bioturbated rock) and corresponds to dilution cycles. The decrease of the carbonate content in the succession correlates with the shallowing of the basin. The nature of the second type of periodites in the Besh-Kosh section is considered to be explained by model 1.

It should be noted that this rhythmic succession is similar to many rhythmic Upper Cretaceous sections in Eurasia and North America (RICKEN, 1994).

The Selandian marble-marbled marl rhythms (Figure 2) of the Besh-Kosh section (GABDULLIN & WIDRIK, 1998), which are diagenetically cemented limesto and marls (Table 5) and the top of the underlying (nian) deposits of the Besh-Kosh section represented two limestone-marl rhythms (Figure 2), can be referre the second type of periodites, but there are not suffic data available to propose a comprehensive model of origin of this type of periodites.

A **third type** of periodites was found in the V section. It is represented by extremely thin greenish-w couplets inside of thick white chalk layers. In the f these layers are termed "marls", but according to lab tory analyses they are chalks (Figure 6). Rhythms characterized by oscillations of the natural remnant m netization and destructive field of remnant satura magnetization, of the volume of bioturbated rocks, cium carbonate and organic carbon content, and dif ences of colour and thickness (GABDULLIN *et al.*, 199 No periodic fluctuations in the magnetic susceptibi remnant saturation magnetization, and magnetic susc ibility increase were found in examined samples. Mod is proposed as their cause.

Other examples of periodites of this type are the C omanian and Turonian of the Anglo-Paris basin (G 1995), Campanian of the Gulf of Mexico (KAUFFM

Table 4 – The composition of 5 rhythms in the Betta section (type 2, Maastrichtian).

Lithology	Marl	Limestone
Thickness, m	0,01-1,04	0,02-0,2
Colour	dark grey	white
Ichnogenera	*Teichichnus* sp.	*Teichichnus* sp., *Chondrites* sp.

Table 5 – The composition of 3 marble-marbled marl rhythms in the Besh-Kosk section (type 2, Selandian)

Lithology	Marbled marl (transformed marl)	Marble (transformed limestone)
Thickness, m	0,1	1-6
Colour	pinky-green	pink

Table 6 – The composition of 6 sandstone-calcareous sandstone rhythms in the Besh-Kosh section (type 5, Upper Maastrichtian).

Lithology	Sandstone	Calcareous sandstone
Thickness, m	0,13 - 0,32	2,13 -0,5
Colour	dirty grey	grey
Volume of bioturbated rocks, %	5	5 - 15

Table 7 – The composition of calcareous sandstone-sandy marls rhythms in the Besh-Kosh section (type 6, Upper Maastrichtian).

Lithology	Calcareous sandstone	Sandy marl
Thickness, m	1,1-1,6	3,6
Colour	dirty grey	dirty yellow
Volume of bioturbated rocks, %	15-40	10-50
CO_2, %	26	20-28
$CaCO_3$, %	59,02	45,4 - 63,56
TOC, %	0,1	0,2 - 0,23
Quantity of samples	1	2

1985), and Campanian and Maastrichtian of the Exmouth Plateau, NW Australia (BOYD *et al.*, 1994).

Rhythmicity of the **fourth type** is presented by chalk-chalk rhythms in the Volsk section and hidden rhythmicity in the Sengeley section. The Volsk section is characterized by weak petromagnetic rhythmicity and low value of petromagnetic parameters (Figure 6). In the Sengeley section visual rhythmicity was not observed, but the distribution of the measured parameters shows periodic variations (Figure 5). Another difference between these two sections is the high value of the petromagnetic parameters in the Sengeley section. Rhythmicity in the Maastrichtian of the Sengeley section is established by distribution of: the volume of bioturbated rocks, the quantity of trace fossils, the remnant saturated magnetization (Jrs), destructive field of remnant saturated magnetization (H'cs), the Jrs-Hcs correlation, and the taxonomic diversity of macrofossils. Rhythms in the Maastrichtian of the Volsk section are defined by the same distribution of characteristics as in the Sengeley section plus cyclic oscillations in organic carbon content, colour differentiation and weathering profile.

Rhythmicity in the Maastrichtian of Sengeley section (GABDULLIN *et al.*, 1998b) was formed by solution cycles proved by the cyclic distribution of the calcium carbonate and organic carbon content, the volume of bioturbated rocks, the quantity of ichnocoenoses. Dilution cycles are indicated by cyclic fluctuations in the input of terrestrial Fe-magnetic minerals which produce oscillations in the distribution of the remnant saturated magnetization (Jrs), destructive field of remnant saturated magnetization (H'cs) and Jrs-Hcs correlation. Negative correlation we interpreted as the absence of the terrestrial input,

Table 8 – The composition of 5 clay-limestone rhythms in the Besh-Kosh section (type 7, Danian).

Lithology	Clay	Limestone
Thickness, m	0,01-0,05	1-3
Colour	greyish-green	greyish-white

Table 9 – The composition of rhythms in the Belogrodnya section (type 8, Selandian).

Lithology	Marl	Opoka
Thickness, m	0,3	0,2
Colour	yellowish pale grey	brownish grey
Magnetic susceptibility (x10^{-5} standard units)	4-6	6-10
Quantity of samples	60	56

Table 10 – The composition of rhythms in the Sengeley section (type 9, Selandian).

Lithology	Soft sandy opoka	Hard opoka
Thickness, m	0,1-1	0,2-1,5
Colour	grey	yellowish pale grey
Remnant saturation magnetization, x10^{-3} nT	670	650
Destructive field of remnant saturation magnetization, A/m	770	700
Quantity of samples	1	1

positive — as a presence of the terrestrial input. The dilution and solution cycles are described by models 1 and 8. Rhythms in the Maastrichtian of the Volsk section (GABDULLIN *et al*, 1998a) are defined by the same distribution of characteristics as in the Sengeley section plus differences in colour and in the weathering profile. The same models are proposed to explain the periodicity of the Volsk section.

A **fifth type** of periodite was studied in the Besh-Kosh section, near the K/T boundary (Figure 2). Preliminary results of the investigation are shown on Table 6. Periodite of this succession have distinct weathering profile, colour differentiation, volumes of bioturbated rock and thickness variation. The origin of this periodite is connected with dilution cycles (sandstone-calcareous sandstone succession). Model **1** is proposed for this type of rhythm.

A **sixth type** of periodite was observed in the Upper Maastrichtian of the Besh-Kosh section near the K/T boundary. Here (Table 7) the rhythmic distribution of the colour of the rocks, volume of bioturbated rocks, carbon dioxide, calcium carbonate and organic carbon content are nearly equal not direct, or sometimes inverse of those in the other parts of the section (Table 6). The lithology of the rhythms (calcareous sandstones and sandy marls) indicates that there are dilution cycles. It is interesting that the character of distribution of calcium carbonate and organic carbon content and volume of the bioturbated rocks is more complicated, than in most of the periodites studied: the TOC content in the sandy marl is higher, and the calcium carbonate content can be higher or lower than in the sandstone. At the same time the volume of the bioturbated rocks is nearly equal in both rhythm elements, but a darker colour is typical for the sandstones. Thus, the influence of the solution agent could be constant or periodic, but the duration (amplitude) of this periodicity was different (probably longer) from the duration of dilution cycles. Models **1** and **8** may account for these periodites.

Other examples of this type of periodites are the Lower Shale member of the Niobrara formation, Santonian of the Western Interior Basin, USA (RICKEN, 1994).

A **seventh type** was found in the Danian deposits of the Besh-Kosh section (Figure 2). The preliminary results of research are shown on Table 8. These periodites (GABDULLIN & WIDRIK, 1998) are distinctly identified by their weathering profiles and thickness distributions. The Danian clay couplets are thought to be the result of dissolution and condensation of limestone beds (solution cycles). The origin of the cyclic repetition of limestone beds, erosional surfaces and clay couplets with glauconite can be described by model **5**.

An **eighth type** of periodite is typical for the Selandian of the Belogrodnya section (Table 9), where rhythms can be detected by the weathering profile and fluctuations of the magnetic susceptibility (Figure 7). Dilution cycles are indicated by the variation of the petromagnetic parameters and lithology (marl-opoka) (GABDULLIN & WIDRIK, 1998). Model 1 is suggested as the cause.

A **ninth type** of periodite was observed in the Selandian of the Sengeley section (Figure 5). This type differs slightly from the previous one in the criteria of the establishment of the rhythms (Table 10). Model **1** is proposed for its origin.

From this analysis it is evident that different models could be proposed for the same types of periodites. In some cases a model can produce different types of rhythms.

It is possible to establish a bathymetric zonation for the different types of periodites and models of their origin. The shallowest periodites (littoral-sublittoral) are the terrestrial-carbonate [sandstone, sand-calcareous sandstone, sand (5); sandstone, sand-marl (6); clay-marl, limestone (7) cycles) and siliceous deposits (sandy opoka-opoka (9) cycles]. The middle position in the bathymetric zonation are sublittoral-hemipelagic carbonates [marl-marl (1); marl-limestone (2); marl-chalk (3) rhythms] and siliceous-carbonate successions [opoka-marl (8) cycles]. The deepest periodites (hemipelagic-pelagic) are the carbonate chalk-chalk (4) and siliceous-carbonate marly opoka-opoka (9) successions.

The bathymetric distribution of palaeogeographic models is more complicated than the distribution of types of periodites. It seems possible to establish a littoral-sublittoral group of models (1-5) and hemipelagic-pelagic group (6-8, 10). Models 9 and 11 reflect more global influences upon the sedimentary system, than the other models.

The Volsk, Belogrodnya and Sengeley sections are neither typically Boreal nor Tethyan; their position is transitional. The Besh-Kosh is an example of a typical Tethyan section. It is very similar to the Agost and Zumaya sections (NE Spain) (TEN KATE & SPRENGER, 1992). All of these sections have the same type of rhythms (lithology, thickness). A few groups of couplets (below and above K/T boundary) have the same thickness and the same stratigraphic position in these sections, indicating the climatic-orbital control of deposition of these rocks and probably reflect Milankovich Cycles.

The origin of periodites is a result of cycles of dilution, solution and bioproductivity described by the 10 palaeogeographic models. The climatic variations caused by Milankovich Cycles probably resulted in the appearance of different kinds of rhythmicity in Maastrichtian and Lower Palaeocene rocks of the Russian craton, SW Crimea and NW Caucasus.

Acknowledgements

This study was undertaken with the support of RBS (RFFI, no. 98-05-64196) and INTAS 94-1414. We are grateful to Philip Kochkin for help in the technical manipulations. William W. Hay and Andrew S. Gale kindly reviewed an earlier draft of the paper.

References

AFANASIEV, S. L., 1993. The flysch formation: the laws of composition and the forming conditions. pp. 55-250. Rosvuznayka, Moscow [in Russian].

ALEKSEEV, A. S. & KOPAEVICH, L. F., 1997. Foraminiferal boistratigraphy of the uppermost Campanian-Maastrichtian in SW Crimea (Bakhchisaray and Chakhmakhly sections). *Bulletin Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, **67**: 103-118.

BOYD, R., HUANG Z. & O'CONNEL, S., 1994. Milancovitch cyclicity in Late Cretaceous sediments from Exmouth Plateau of NW Australia. *In:* Orbital forcing and the Milankovich Theory. *Special Publications of the International Association of Sedimentology*. pp. 145 — 166.

EINSELE, G., 1985. General data about nature, occurrence conditions and determination of cyclic deposits (periodites). *In:* EINSELE, G. & SEILACHER, A. (Eds.): Cyclic and event stratification. Springer-Verlag, Berlin-Heidelberg-New York.

FISCHER, A. G. & ARTHUR, M. A., 1977. Secular variations in the pelagic realm. *In:* COOK, H. & ENOS, P., (Eds.): Deep-water carbonate environments, *Special Publication of the Society of economic Paleontology and Mineralogy*, **25**: 19-50.

GABDULLIN, R. R., 1997. Models of forming of the rhythmicity in the carbonate successions. Abstracts of the Jubilee session of the Russian Academy of Sciences, 28 February, 1997. pp. 103-104. Moscow [in Russian].

GABDULLIN, R. R., 1998a. Rhythmically bedded carbonates: below and above K/T boundary. Abstracts of the final Meeting of INTAS project 1994-1414. 23 — 25 March 1998, p. 13.

GABDULLIN, R. R., 1998b. Space-time laws of the forming of the carbonate rhythmic successions. Materials of the Undergraduate and Postgraduate Student International Conference on Fundamental Sciences "Lomonosov", **2**: 218 [in Russian].

GABDULLIN, R. R. & BARABOSHKIN, E. Ju., 1997. Rhythmicity in highly condensed sediments: sedimentary model of the Barremian "Cephalopod Limestones" of SW Crimea. Abstracts of 18-th IAS Regional European Meeting of Sedimentology, Heidelberg, 2-4 September 1997, *Gaea heidelbergensis*, **3**: 136.

GABDULLIN, R. R. & WIDRIK, A. B, 1998. The comparative characteristic of the rhythmical successions of the Palaeocene of the Ulyanovsk Povolgie (Sengeley) and Mountain Crimea (Besh-Kosh). Abstracts of the scientific conference "Geological sciences-98", 16-17 April 1998, p. 47. [in Russian].

GABDULLIN, R. R., GUZHIKOV, A. Ju., WIDRIK, A. B. & DUNDIN, I. A., 1998a. Forming conditions of rhythmicity in the Upper Cretaceous carbonate rocks of the Bolshevik quarry (Volsk, Saratov region). Abstracts of the international scientific conference, to the memory of V. V. Tyagshaev, 20-22 January 1998, p. 41. [in Russian].

GABDULLIN, R. R., WIDRIK, A. B., GUZHIKOV, A. & DUNDIN, I., 1998b. The nature of rhythmicity in the Upper Campanian-Lower Maastrichtian carbonate rocks of the Sengeley quarry (Ulyanovsk region). Materials of the Undergraduate and Postgraduate Student International Conference on Fundamental Sciences "Lomonosov" (in press).

GALE, A. S., 1995. Cyclostratigraphy and correlation of the Cenomanian Stage in Western Europe in: HOUSE, M. R. & GALE, A. S. (Eds.), Orbital forcing Timescales and Cyclostratigraphy, *Geological Society Special Publication*, **85**: 177 — 197.

GAVRILOV, Ju. O., & KOPAEVICH, L. F., 1996. About geochemical, biochemical and biotic evidences of eustatic fluctuations. *Stratigraphy and Geological Correlation*, 4, **4**: 3-14 [in Russian].

GERASIMOV, P. A., MIGACHEVA, E. E., NAIDIN, D. P. & STERLIN, B.P., 1962. Jurassic and Cretaceous deposits of the Russian Platform. pp. 116-155. Moscow University, Moscow [in Russian].

HAY, W. W., 1996. Tectonics and climate. *Geologische Rundschau*, **85**: 409-437.

LAMOLDA, M. & WAN, X., 1996. The response of Foraminifera to oceanic environmental changes during the Cenomanian — Turonian transition of Gamba Zong Shan section, Southern Tibet. Cretaceous stratigraphy, paleobiology and paleogeography. Abstracts of the Jost Wiedmann symposium, Germany, 7 - 10 March 1996. pp. 94 — 100, Tübingen

KAUFFMAN, E. G., 1985. Ecology and origin of the chalk-marl and limestone-clay rhythms in the Cretaceous deposits of Northern America. *In*: EINSELE, G. & SEILACHER, A. (Eds.): Cyclic and event stratigraphy. Springer-Verlag, Berlin-Heidelberg-New York .

MOROZOV, N. S., 1952. About rhythmicity of sedimentation in the Cretaceous in the region of Dono-Medveditskikh dislocations. *Doklady Sovetskoy Akademii Nauk*, **87**, 2: 265 — 268 [in Russian].

MUSATOV, V. A. & ERMOKHINA, L. I., 1997. The stratotype of Belogrodnya Formation. *Nedra Povolzhia i Prikaspiya*, **15**, February: 35-42 [in Russian].

RICKEN, W., 1994. Rhythmic sedimentation related to third order sea level variations. Upper Cretaceous, Western Interior Basin. *In:* Orbital forcing and the Milankovich Theory, *Special Publications of the International Association of Sedimentology*, 167- 193.

RUFFELL, A., SPAETH, C. & MUTTERLOSE, J., 1996. Sedimentary and biogenetic cycles in the Early Cretaceous of NW Europe. *In:* Cretaceous stratigraphy, palaeobiology and palaeogeography. Abstracts of the Jost Wiedmann symposium, Germany 7 - 10 March 1996, pp. 163-165. Tübingen.

SAVDRRA, C. & BOTTJER, D., 1994. Ichnofossils and ichnofabrics in rhythmically bedded pelagic / hemi-pelagic carbonates: recognition and evaluation of benthic redox and score cycles. *In*: Orbital forcing and the Milankovich Theory, *Special Publications of the International Association of Sedimentology*: 195 — 210.

TEN KATE, W. & SPRENGER, A., 1992. Orbital cyclicities above and below the Cretaceous/ Paleogene boundary at Zumaya (N Spain), Agost and Relleu (SE Spain) in: Rhythmicity in deep water sediments, documentation and interpretation by pattern and spectral analysis. pp 87-117. Amsterdam.

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Typescript submitted: 25. 11. 1998;
Revised typescript received: 26.3.1999.

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 103-118, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 103-118, 1999

An overview of Late Cretaceous and Early Palaeogene echinoderm faunas from Liège-Limburg (Belgium, The Netherlands)

by John W. M. JAGT

Abstract

With the exception of echinoids, echinoderm faunas from the type area of the Maastrichtian Stage still are more or less *terra incognita*. Material collected recently in the area by a group of professional and amateur palaeontologists comprises numerous new records, which have the added advantage of being well documented stratigraphically. Museum collections, and those pre-dating 1975 in particular, generally suffer from a lack of detail where stratigraphic provenance is concerned. Not only do these new collections considerably increase our knowledge of Late Cretaceous (Campanian-Maastrichtian) and Early Palaeogene (Danian) echinoderm faunas in the area, they also allow conclusions on diversification and extinction patterns prior to and across the K/T boundary to be drawn. In the present paper a brief overview is given of these echinoderm faunas, with emphasis on echinoids and asteroids.

Key words: Late Cretaceous, Early Palaeogene, echinoderms, taxonomy, stratigraphy, taphonomy.

Résumé

A l'exception des échinides, les faunes d'échinodermes de la région-type de l'Etage Maastrichtien sont encore plus ou moins *terra incognita*. Du matériel récemment récolté dans cette région par un groupe de paléontologues professionnels et amateurs comprend de nombreuses et nouvelles pièces qui ont l'avantage supplémentaire d'être bien documentées stratigraphiquement. Les collections des musées, et en particulier celles antérieures à 1975, souffrent généralement du manque de précision en ce qui concerne la position stratigraphique. Ces nouvelles collections non seulement élargissent notre connaissance des faunes d'échinodermes du Crétacé supérieur (Campanien-Maastrichtien) et Paléogène inférieur (Danien) dans la région, mais permettent également de tirer des conclusions sur les modèles de diversification et d'extinction de part et d'autre de la limite K/T. Dans cette note, ces faunes d'échinodermes sont brièvement passées en revue en mettant l'accent sur les échinides et les astéries.

Mots-clefs: Crétacé supérieur, Paléogène inférieur, échinodermes, taxinomie, stratigraphie, taphonomie.

Резюме

За исключением морских ежей, фауны иглокожих типичного района Мастрихтского яруса остаются в большей или меньшей степени *terra incognita*. Недавно представленные группой палеонтологов, профессионалов и любителей, образцы этого района стали объектом многочисленных новых наблюдений, дополнительным преимуществом которых является их стратиграфическая документированность. Музейным коллекциям, и в особенности созданным до 1975 года, не хватает, в частности, подробной информации о стратиграфическом происхождении. Новая коллекция не только значительно углубляет наши знания о фаунах иглокожих Позднего Мела (Кампанско-Мастрихтский ярусы) и Раннего Палеогена (Датский ярус) в данной области, но и позволяет подвести итоги по структуре разнообразия и вымирания, предшествовавшей границе К/Т и вкрест границе К/Т. Краткое обозрение фаун иглокожих представлено в данном очерке, особое внимание уделено морским ежам и астероидам.

Ключевые слова: Поздний Мел, Ранний Палеоген, иглокожие, таксономия, стратиграфия, тафономия.

Introduction

The calcareous, multi-element echinoderm skeleton is almost predestined to become fossilised (DONOVAN, 1991). The often gregarious occurrence of echinoderms in many types of marine strata, and the fact that, even in the case of dissociated ossicles, material is readily assigned to family, genus or species, makes them an ideal subject for palaeobiological and palaeoecological studies. All species of echinoid, asteroid, ophiuroid and crinoid from Campanian, Maastrichtian and Danian deposits in southern Limburg (The Netherlands) and contiguous areas in Belgium and Germany are currently being studied (Fig. 1). This is done within the framework of a K/T boundary diversification/ extinction project (JAGT, 1998, 1999a-d; KUTSCHER & JAGT, 1999). This has resulted in numerous new records. These include not only taxa previously described from elsewhere in northwest Europe, but also quite a lot of new genera and species, especially amongst crinoids, asteroids and ophiuroids.

The material consists mostly of dissociated ossicles or portions of skeletons at best (echinoids excepted), but rare finds of well-preserved goniasterid and astropectinid asteroids, ophiurid and ophiolepidid ophiuroids, and bourgueticrinid crinoids are also known. To date, well over 200 species are recorded from the area. The present paper provides a brief outline of studies under way as well as a selection of new records from the area. Crinoids are

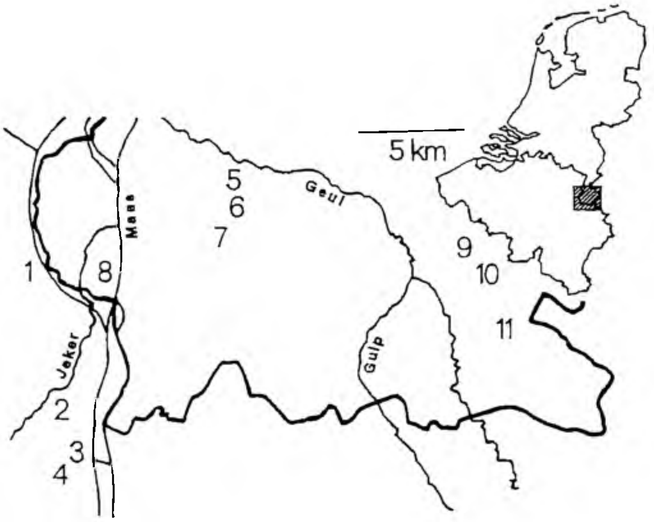


Fig. 1 — Southern Limburg (The Netherlands) and contiguous areas, showing location of outcrops and quarries referred to in the text:
1 - temporary Albertkanaal sections;
2 - CBR-Romontbos quarry;
3 - CBR-Lixhe quarry;
4 - CPL SA quarry;
5 - Ankerpoort-Curfs quarry;
6 - Blom quarry;
7 - Ankerpoort-'t Rooth quarry;
8 - ENCI-Maastricht BV quarry;
9 - Kunrade;
10 - Benzenrade;
11 - Vijlen.
The inset map of The Netherlands and Belgium shows the area of the main map (shaded).

not illustrated here, and only few figures of ophiuroids are included, since the chapters describing these echinoderms have either just come out or are about to be published (Jagt, 1999b and Kutscher & Jagt, 1999, respectively). Holothurians are not considered any further; with the exception of dissociated elements of the peristomial ring, ossicles of these echinoderms are extremely rare in the area (compare Zeleznik, 1985).

Crinoids

Known to date from the area are 36 species, in 20 genera, with all articulate (sub)orders represented. Of these, 3 genera and 6 species are new (Jagt, 1999b).

Isocrinids (genera *Austinocrinus*, *Isocrinus*?, *Isselicrinus*, *Praeisselicrinus*? and *Nielsenicrinus*) are particularly well represented in the Late Campanian (CPL SA and CBR-Lixhe quarries) and Early Maastrichtian (Vijlen/Aachen area), but do extend into the latest Maastrichtian. At least one species (possibly two) occur in the shallow-water settings represented by the Nekum and Meerssen members (Maastricht Formation; Fig. 2), where they are associated with much commoner comatulids. Of note is the absence of isocrinids in the Geulhem Member (Early Palaeocene).

Comatulids are represented by atelecrinids, pterocomids, conometrids, notocrinids and antedonids, and occur throughout the entire Late Cretaceous section. However, in the Campanian and Early Maastrichtian they are comparatively rare. Their acme is in the Nekum and Meerssen members, where *Jaekelometra* gr. *belgica* (Jaekel, 1902), *J.* gr. *concava* (Schlüter, 1878), *Semiometra lenticularis* (Schlüter, 1878) and *S. saskiae* Jagt, 1999b are very common locally (CBR-Romontbos, ENCI-Maastricht BV and Blom quarries). In addition to centrodorsals representing various ontogenetic stages, such occurrences have also yielded (proximal) brachials, cirrals and pinnules. Brachials with syzygial articulations are fairly common, suggesting these crinoids to have been able to shed arms easily, which in turn would indicate stressful conditions (?increased predation pressure; compare Messing, 1997) in shallow-water, subtropical settings. At times, species distinction is difficult, particularly of *Jaekelometra*, *Amphorometra* and *Hertha*. In this respect, they resemble extant forms (Messing, 1997).

In comparison with the underlying Meerssen Member, comatulid diversity decreases noticeably in the Geulhem Member, with only two forms represented, *Hertha* gr. *mystica* von Hagenow, 1840 (?) and *Atuatucametra annae* Jagt, 1999b.

Bourgueticrinids range through the entire section, being commonest in the Late Campanian, early Late Maastrichtian and Early Palaeocene. Of special note is the crinoid/ophiuroid lagerstätte at the base of the Gronsveld Member (ENCI-Maastricht BV quarry; see Jagt *et al.*, 1998). Newly collected slabs which preserve up to ten crinoids, as well as ophiuroids and rare asteroids, demonstrate the impact of storm activity on these crinoid "meadows". Not only do these allow the density and spatial distribution of "populations" (see Baumiller & Rome, 1998) to be determined, but also the nature of the substrate to be analysed in detail. Quite a few crowns have penetrated the substrate to depths of almost 10 cm, with arms outspread.

Bourgueticrinids disappear from the section above the base of the Emael Member, only to reappear in the Geulhem Member (Albertkanaal sections and Ankerpoort-Curfs quarry), with species that are well known from Danian strata in Denmark and southern Sweden, namely *Bourgueticrinus danicus* Brünnich Nielsen, 1913 and *Democrinus*? *maximus* Brünnich Nielsen, 1915. Håkansson *et al.* (1996) have recently suggested that an important evolutionary phase in the Bourgueticrinina took place during the earliest Palaeocene, and that numerous new dorsal cup morphologies arose through neoteny/paedomorphosis.

Of the infraorder Holopodinidia only a single representative is known, *Cyathidium vlieksi* Jagt, 1986, which is now known from the base of the Vijlen Member, the Meerssen Member and the Kunrade limestone facies (Kunrade area). There are no Danian records of this genus in the study area.

Finally, roveacrinids have been shown to range to right below the K/T boundary, with *Birgelenocrinus degraafi* JAGT, 1999b and *Applinocrinus cretaceus* (BATHER, 1924) occurring in the middle/higher Meerssen Member. Of the other species, *Veugelersia diana* JAGT, 1999b, two stratigraphically highly disjunct occurrences are known; one in the early Late Campanian (Benzenrade area) and one in the Late Maastrichtian (Ankerpoort-'t Rooth quarry).

Echinoids

To date, over 100 species are on record, but diversity is still increasing. Notable recent additions and discoveries include the following:

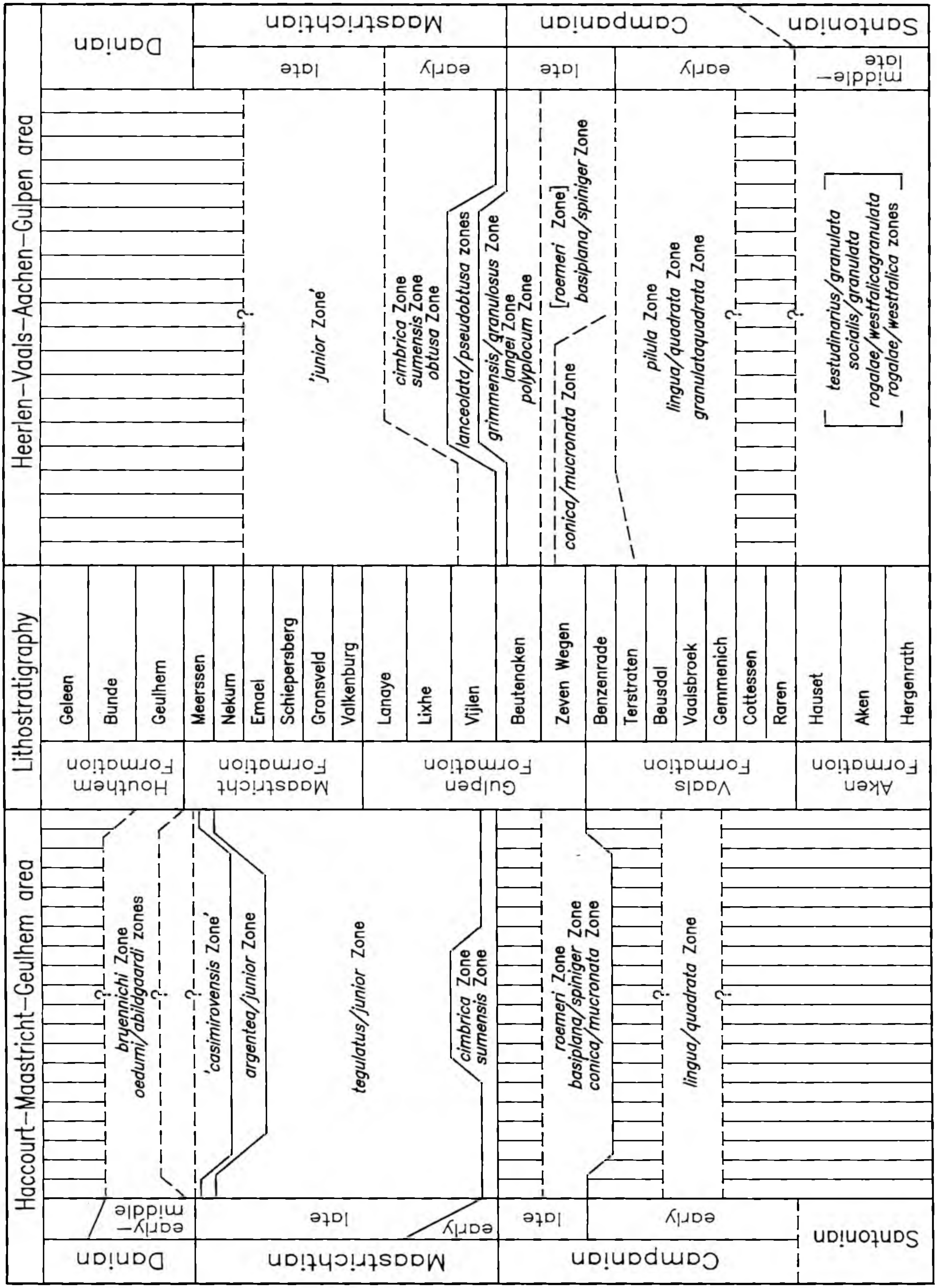
- the Zeven Wegen Member (CPL SA quarry) has yielded the highly specialised, bizarre holasteroid *Hagenowia* (Pl. 1, Figs. 11, 12), which may prove conspecific with material from Norfolk and northwest Germany, and represent a still undescribed member of the *blackmorei/elongata* lineage.
- the Benzenrade Member near Benzenrade has yielded the zeuglopleurid *Zeuglopleurus rowei* GREGORY, 1900 (Pl. 1, Fig. 4), which extends the range of this rare species, recorded mostly from white chalk settings (see SMITH & WRIGHT, 1996), to the early Late Campanian.
- from the Meerssen Member (ENCI-Maastricht BV quarry) additional spines of the psychocidarid *Tylocidaris inexspectata* JAGT & VAN DER HAM, 1995 have been collected, showing it to range to the top of that unit. This species may be a sister taxon of the Early Palaeocene *T. oedumi* BRÜNNICH NIELSEN, 1938, which in turn may prove to be a junior synonym of *T. hardouini* (DESOR, 1855).
- A small phymosomatid from the Nekum Member (ENCI-Maastricht BV quarry) preserves spines and the lantern, and shows the type of spine referred to as *Phymosoma rutoti* LAMBERT, 1898 in the literature, to belong to a genus close to *Trochalosoma* LAMBERT, 1897.
- of the locally very common Danian saleniid *Hyposalenia heliophora* (AGASSIZ & DESOR, 1846), a number of specimens with well-preserved lanterns have been collected, one of which is illustrated here in Pl. 1, Figs. 1-3.
- the Meerssen Member (ENCI-Maastricht BV quarry) has yielded the second, well-preserved specimen of an apparently new species of the plagiochasmid genus *Plagiochasma*. MEIJER (1965) noted that it appeared to differ consistently from the Palaeocene *P. cruciferum* (MORTON, 1830) [= *P. analis* (DESOR, 1857)].
- from the Zeven Wegen Member (CPL SA quarry), juveniles of the diadematid *Centrostephanus*? sp. (Pl. 1, Figs. 9, 10) are now known.
- new well-preserved material of the stomopneustid *Winkleria maastrichtensis* ENGEL, 1964 (Pl. 1, Fig. 8) allows the ambulacral structure to be described in detail, and a direct comparison with the genus *Plistophyma* (see SMITH, 1995; SMITH & JEFFERY, in press) to be carried out.
- the Meerssen Member has yielded diminutive holasteroids (Pl. 1, Figs. 5-7). These appear to be juveniles of the common holasteroid *Hemipneustes striatoradiatus* (LESKE, 1778), of which literally thousands of adult specimens have been collected in the area. The apparent absence in the area of juveniles of this species has always been a mystery; it may be that the fragile tests stood virtually no chance of being preserved in the shallow-water settings represented by the Nekum and Meerssen members.

JAGT (1998) noted that echinoid faunal composition across the K/T boundary varied considerably. Suffering heavy losses are infaunal selective deposit feeders (hemiasterids), shallow infaunal/semi-infaunal selective deposit feeders (holasteroids), infaunal bulk sediment swallowers (cassidulids), infaunal selective deposit feeders (faujasiids) and the epifaunal browser *Orthopsis*. Epifaunal diversity (cidaroids) is comparable across the boundary, with psychocidarids occurring especially in the Danian. Epifaunal generalists (saleniids) increase in diversity across the boundary, and within the Geulhem Member nearshore hardground grazers (arcopeltids, arbaciids) are confined to the upper part. That part has also yielded the highest diversity in shallow-water, more protected firm bottom species (phymosomatids, cidaroids).

Ophiuroids

Previous studies of ophiuroids from the study area (e.g., BERRY, 1938) were based almost exclusively on dissociated ossicles, which generally were poorly preserved. In recent years, especially storm-dominated deposits (Meerssen Member) have yielded many specimens with discs and (portions of) arms preserved, allowing species to be better defined. Thus, the pitfalls of combining various unrelated types of dissociated ossicles into species (see discussion in RASMUSSEN, 1950, 1952) can be evaded. In addition, preliminary observations on predation pressure, based on the number of regenerating arms (see ARONSON, 1987) are possible.

In view of the fact that most ophiuroid species, particularly those of the Late Campanian and early Late Maastrichtian, are also known from the Early Maastrichtian of Rügen (NE Germany), KUTSCHER & JAGT (1999) decided to base their descriptions mainly on material from that locality. Numerous new species, amongst the (sub)families Ophiobyrsinae, Asteronychidae, Euryalidae, Ophiomyxidae, Ophiacanthidae, Ophiuridae, Amphiuridae, Ophiothricidae, Ophiocomidae, Ophiodermatidae and Ophiolepididae. Material from the Benzenrade, Nekum, Meerssen and Geulhem members in the study area is complementary.


Haccourt–Maastricht–Geulhem area
Lithostratigraphy
Heerlen–Vaals–Aachen–Gulpen area
Danian
Maastrichtian
Campanian
Santonian
early–middle
late
early
late
early
middle–late
Houthem Formation
Maastricht Formation
Gulpen Formation
Vaals Formation
Aken Formation
Geleen
Bunde
Geulhem
Meerssen
Nekum
Emael
Schiepersberg
Gronsveld
Valkenburg
Lanaye
Lixhe
Vijlen
Beutenaken
Zeven Wegen
Benzenrade
Terstraten
Beusdal
Vaalsbroek
Gemmenich
Cottessen
Raren
Hauset
Aken
Hergenrath
bryennichi Zone
oedumi/abildgaardi zones
'casimirovensis Zone'
argentea/junior Zone
tegulatus/junior Zone
cimbrica Zone
sumensis Zone
roemeri Zone
basiplana/spiniger Zone
conica/mucronata Zone
lingua/quadrata Zone
'junior Zone'
cimbrica Zone
sumensis Zone
obtusa Zone
lanceolata/pseudobtusa zones
grimmensis/granulosus Zone
langei Zone
polyplocum Zone
[roemeri Zone]
basiplana/spiniger Zone
conica/mucronata Zone
pilula Zone
lingua/quadrata Zone
granulataquadrata Zone
testudinarius/granulata
socialis/granulata
rogalae/westfalicagranulata
rogalae/westfalica zones
?

In general, the more robust forms such as *Ophiomusium granulosum* (Pl. 1, Figs. 16, 17), are overrepresented in ophiuroid samples. Comparatively more articulated remains, such as discs and portions of arms, are known of these forms. The Geulhem Member has yielded only few species; the most interesting amongst these is a new ophiolepidid (Pl. 1, Fig. 13).

Asteroids

Starfishes are the most neglected group amongst the echinoderms of the study area, which may be explained by the fact that these animals disintegrated rather rapidly upon death and only a jumble of dissociated ossicles remained (Blake, 1989, 1996). However, although more or less complete specimens are extremely rare (see e.g., Faujas Saint Fond, 1799; Umbgrove, 1925), asteroids undoubtedly deserve better. At least 50 species have now been recognised in strata of Campanian, Maastrichtian and Danian age. More than half of these have been described previously from elsewhere in Europe, in particular from white chalk facies types. These include the following:

- representatives of the *studlandensis-alseni-peakei* lineage of *Nymphaster*, which have been shown to constitute good index fossils (Gale, 1987b, 1989; Breton, 1992) in the early and late Late Campanian (Pl. 2, Figs. 8, 19, 20).
- *Nymphaster spenceri* (Rasmussen, 1950) and *N. wrighti* (Rasmussen, 1950), well known from the Maastrichtian of northern Germany and Denmark.
- *Lophidiaster pygmaeus* Spencer, 1913 (Pl. 2, Fig. 9), which first occurs in the Zeven Wegen Member, and is a minor constituent of asteroid faunas in the remainder of the Gulpen Formation and the lower part of the Maastricht Formation. A find of associated ossicles of a single individual suggests that Müller's (1956) description of this taxon is in need of a revision.
- the sphaerasterid *Valettaster* (Pl. 2, Fig. 15), of which at least two species occur, one of them possibly new (Zeven Wegen Member), the other assignable to *V. ocellatus* (Forbes, 1848), a long-ranging taxon (see Breton, 1985).
- *Metopaster tumidus* Spencer, 1913, of which typical examples are known only from the Early Maastrichtian portion of the Vijlen Member (Pl. 2, Fig. 21); forms assignable to Schulz & Weitschat's (1975) *M. praetumidus* occur in the Zeven Wegen Member.
- Late Cretaceous species of *Crateraster* are common (Pl. 2, Fig. 22), *C. favosus* (Spencer, 1913) occurring in the Zeven Wegen Member and *C. reticulatus* (Schulz & Weitschat, 1981) in the Vijlen Member. Typically Early Palaeocene representatives such as *C. anchylus* (Brünnich Nielsen, 1943) and *C. retiformis* (Spencer, 1913) are known from the Geulhem Member, but neither is particularly common.
- "cryptozonid" (? echinasterid) forms such as the one illustrated by Müller (1953, pl. 10, fig. RA1-2) have been found associated with ambulacrals and terminal plates in the Zeven Wegen Member (Pl. 2, Figs. 1, 2, 4).
- of *Metopaster decipiens* Spencer, 1913 (Pl. 2, Fig. 3) quite a few associated remains of individuals have been collected from the Zeven Wegen Member.
- *Metopaster undulatus* Spencer, 1913 (Pl. 2, Fig. 7), which Breton (1992) placed in his new genus *Parametopaster*, is known exclusively from the Early Maastrichtian portion of the Vijlen Member; a comparable (new?) form, with a pronounced ornament of pits of varying size (Pl. 2, Fig. 10), occurs in the Zeven Wegen Member.
- the enigmatic goniasterid *Chomataster acules* Spencer, 1913, ranging from the early Late Campanian to the Middle Danian (Late Danian in Denmark; Rasmussen, 1945), of which a fairly well-preserved individual is known from the Geulhem Member of the temporary Albertkanaal sections (Vroenhoven-Riemst).
- *Ophryaster oligoplax* (Sladen, 1891) (Pl. 2, Figs. 5, 6), of which several well-preserved arm fragments and numerous dissociated marginals, some preserving granules, have been collected from the Zeven Wegen Member; in the Vijlen Member, *O. magnus* Spencer, 1913 occurs in places.

Typically Early Palaeocene species such as *Metopaster spencerii* Brünnich Nielsen, 1943 (Pl. 2, Fig. 17), *M. kagstrupensis* Brünnich Nielsen, 1943 and *Astropecten punctatus* (Brünnich Nielsen, 1943) (Pl. 2, Fig. 16) are known from the Geulhem Member, and it is in part on these forms that Rasmussen (1965) based his correlation of that unit with the lower part of the Danish Bryozoakalk (Stevns Klint).

In addition to the above-mentioned taxa, which allow interregional correlations with localities elsewhere in northwest Europe, the asteroid faunas in the study area also contain what appear to be endemic elements, although use of the term "endemic" should in fact be avoided. It may well be that the "typical Maastricht tuffaceous chalk" facies was distributed much more extensively over northwest Europe, but that these strata were eroded completely by subsequent transgressive phases. This, in fact, goes for all echinoderm groups, not only for starfish. New finds include:

←
Fig. 2 — Lithostratigraphy and biozonation of Campanian-Maastrichtian strata in the type area of the Maastrichtian Stage (from Jagt, 1999a).

Table 1 — Stratigraphic distribution (by lithostratigraphic member; see Fig. 2) of echinoderm taxa from the extended type area of the Maastrichtian Stage, known to date. Abbreviations are as follows: VF - Vaals Formation, ZW - Zeven Wegen Member, B - Beutenaken Member, Vij - Vijlen Member, Li - Lixhe 1-3 members, L - Lanaye Member, Va - Valkenburg Member, Gr - Gronsveld Member, S - Schiepersberg Member, E - Emael Member, N - Nekum Member, M - Meerssen Member, Ge - Geulhem Member.

	VF	ZW	B	Vij	Li	L	Va	Gr	S	E	N	M	Ge
Echinoids													
Tylocidaris bruennichi													x
Ty. hardouini													x
Ty. inexspectata												x	
Temnocidaris nigelliensis											x	x	
T. danica													x
T. serrata		x											
T. ubaghsi		x											
Ctenocidaris? *distincta*													x
Cidaris? *forchhammeri*													x
C.? *rosenkrantzi*													x
Goniocidaris? sp.												x	
Phyllacanthus sp.												x	
echinothuriid				x	x	x							
Centrostephanus? sp.		x		x							x	x	x
Orthopsis miliaris											x	x	
pedinoid											x		
Salenia anthophora				x									
S. belgica													x
S. bonissenti						x		x		x			
S. gr. *nutrix*											x		
S. sigillata			x	x									
S. sp. nov.													x
S. heberti		x											
S. maestrichtensis							x				x	x	
Salenocidaris minima													x
Sal. obnupta		x											
Hyposalenia heliophora													x
Codiopsis disculus											x	x	
Goniopygus minor													x
G. heberti													x
G. sp. nov.												x	
Phymosoma granulosum		x		x									x
Circopeltis maastrichtensis													x
C. sp.													x
Phymotaxis tournoueri												x	
Thylechinus sp. nov.													x
Gauthieria grossouvrei													x
G. mosae		x											
G. pseudoradiata	x			x	x	x	x	x		x	x	x	
G. maeandrina													
Gauthiosoma princeps		x		x									

	VF	ZW	B	Vij	Li	L	Va	Gr	S	E	N	M	Ge
Ga. krimica		x											
Trochalosoma? *rutoti*					x	x	x	x		x	x	x	
Micropsidia salis												x	x
Micropsis? sp. nov.										x			
Winkleria maastrichtensis											x	x	
Zeuglopleurus rowei	x												
Coenholectypus macrostomus											x	x	
Galerites stadensis				x	x								
G.? *hemisphaericus*		x											
G.? *sulcatoradiatus*				x									
Adelopneustes montainvillensis													x
A. boehmi													x
Echinogalerus belgicus													
E. muelleri													
E. pusillus				x									
E. transversus											x	x	
E.? *vetschauensis*													
Nucleopygus coravium							x	x		x	x	x	
N. scrobiculatus						x	x	x		x	x	x	
Gitolampas oblongus													x
Procassidulus lapiscancri										x	x	x	
P. elongatus													x
Rhynchopygus marmini											x	x	
Rhyncholampas macari											x	x	
Faujasia apicalis										x	x	x	
Catopygus fenestratus				x	x	x	x				x	x	
Oolopygus pyriformis						x	x	x		x	x	x	
Plagiochasma cruciferum													x
P. sp. nov.												x	
Hagenowia sp.		x											
Cardiaster granulosus					x	x	x	x	x		x	x	
C. rutoti							x		x		x		
Cardiotaxis heberti		x											
Echinocorys gr. *conica*		x											
E. gr. *conoidea*					x								
E. gr. *gibba*		x											
E. gr. *humilis*	x												
E. gr. *limburgica*				x									
E. gr. *ovata*		x											
E. gr. *subglobosa*		x											
E. gr. *pyramidata*		x		x									
Galeola papillosa basiplana		x											
Hemipneustes oculatus						x	x				x		
H. striatoradiatus						x	x	x	x		x	x	
Micraster gr. *schroederi/glyphus*		x	x										
M. stolleyi		x											
Cyclaster platornatus				x									

	VF	ZW	B	Vij	Li	L	Va	Gr	S	E	N	M	Ge
Diplodetus spp.	x	x											
D. cf. *americanus*												x	
D. parvistella				x			x	x					
D. duponti						x	x						
D. bucardium						x	x						
Hemiaster gr. *aquisgranensis*	x	x		x	x	x	x	x					
H. prunella						x	x			x		x	
H. koninckanus						x	x				x	x	
Leymeriaster eluvialis						x		x		x			
L. maestrichtensis											x	x	
L. sp. nov.	x												
Linthia? *breviuscula*													x
Li.? sp.													x
Paraster sindensis													x
Ophiuroids													
Ophiosmilax? sp. nov.		x		x									
Asteronyx? sp. nov.				x									
Trichaster? *ornatus*		x		x		x	x	x		x	x	x	
T.? sp.		x		x		x						x	
Ophiomyxa? sp. nov.				x								x	
Ophiomyxa? *jekerica*		x									x	x	
Ophioscolex? sp. nov. 1		x											
Ophioscolex? sp. nov. 2		x		x									
Ophiacantha? *danica*		x		x		x		x				x	
Ophiacantha? sp. nov. 1		x											
Ophiacantha? sp. nov. 2				x									x
Stegophiura? *hagenowi*		x		x				x					
S.? sp. nov.		x											
Ophiocten? sp. nov.												x	
Felderophiura vanderhami										x	x	x	
Ophioplinthaca? *fuerstenbergii*	x											x	
Amphiura? sp. nov.		x		x									
amphiurid gen. et sp. nov. 1												x	
amphiurid gen. et sp. nov. 2	x												
Ophiothrix? sp. nov. 1	x	x		x				x					
Ophiothrix? sp. nov. 2				x									x
Ophiactis? sp. nov.		x											
Ophiocoma? *senonensis*		x		x								x	x
Ophioderma? sp. nov.		x				x							
Ophioderma? *substriatum*		x		x		x							
Ophiarachna? sp. nov.												x	
Ophiotitanos serrata	x	x		x		x		x			x	x	x
Ophiolepis? sp. nov. 1		x											
Ophiolepis? sp. nov. 2		x		x									
Ophiolepis? sp. nov. 3													
Ophiomusium sp. nov. 1		x											
Ophiomusium granulosum		x		x	x	x	x	x		x			x

	VF	ZW	B	Vij	Li	L	Va	Gr	S	E	N	M	Ge
Ophiomusium sp. nov. 2												x	
Ophiomusium sp. nov. 3				x									
ophiolepidid gen. et sp. nov.													x
Crinoids													
Austinocrinus bicoronatus				x									
Isocrinus? sp.												x	
I.? *lanceolatus*				x									
Isselicrinus buchii				x									
Praeisselicrinus? *limburgicus*				x									
Nielsenicrinus carinatus		x											
N. agassizii				x									
N. ewaldi											x	x	
Jaekelometra gr. *belgica*											x	x	
J. gr. *concava*											x	x	
J.? *defectiva*								x		x			
Placometra gr. *laticirra*	x	x				x		x					
Atuatucametra annae													x
Amphorometra gr. *conoidea*		x									x	x	
Semiometra impressa		x											
S. lenticularis											x	x	
S. saskiae											x	x	
Loriolometra retzii	x												
Hertha gr. *plana*				x	x								
H. gr. *pygmea*				x									
H. gr. *mystica*													x
Dunnicrinus aequalis						x	x	x		x			
Bourgueticrinus aff. *baculatus*		x											
B. sp.		x	x										
B. bruennichinielseni													x
B. aff. *brydonei*				x	x								
B. constrictus				x	x								
B. danicus													x
B. hureae		x											
B.? *suedicus*		x											
Democrinus? *maximus*													x
"*Monachocrinus gallicus*"		x											
Cyathidium vlieksi				x								x	
Applinocrinus cretaceus	x	x		x	x	x				x		x	
Birgelenocrinus degraafi												x	
Veugelersia diana	x									x			
Asteroids													
astropectinid sp.												x	
Astropecten? *punctatus*													x
A.? sp. nov.													x
Aldebarania sp. nov.											x		
Lophidiaster pygmaeus		x		x	x	x	x	x		x			
Coulonia sp. nov.											x	x	

	VF	ZW	B	Vij	Li	L	Va	Gr	S	E	N	M	Ge
benthopectinid		x		x	x								
Stauranderaster miliaris													x
Aspidaster sp.												x	
Pycinaster crassus		x		x									
P. danicus													x
Valettaster granulatus													x
V. ocellatus											x	x	
V. sp. (nov.?)		x											
Metopaster sp. nov. 1												x	
M. spencerii													x
M. kagstrupensis													x
M. sp. nov. 2												x	
M. sp. nov. 3												x	
M. sp. nov. 4													x
M. decipiens		x											
M. sp. nov. 5												x	
M. sp. nov. 6												x	
M. praetumidus		x											
M. tumidus				x									
M. undulatus				x									
Ceramaster? sp.													x
Recurvaster blackmorei?							x						
R. radiatus		x											
R. sp. nov. 1				x	x								
R. sp. nov. 2												x	
Chomastaster acules		x		x		x	x	x		x	x	x	x
goniasterid sp. 1				x		x	x			x			
goniasterid sp. 2								x		x	x		
Ophryaster oligoplax		x											
O. magnus				x									
O.? *maastrichtensis*												x	
Comptoniaster sp. nov.		x											
Crateraster favosus		x											
C. reticulatus				x									
C. sp. nov.				x									
C. anchylus													x
C. retiformis													x
Nymphaster studlandensis		x											
N. alseni		x											
N. spenceri				x									
N. wrighti				x									
N.? sp.													x
asteriid(s)		x		x									
"cryptozonids"		x		x									

- apparently juvenile goniasterids, closely related to *Crateraster* (Pl. 1, Fig. 14), from the Meerssen Member (Blom quarry).
- many paxillosidans, such as possible radiasterids (Pl. 2, Fig. 13) and astropectinids, e.g. the form illustrated in Pl. 2, Fig. 12, which RASMUSSEN (1965, pl. 8, fig. 13) referred to as *Asteropecten* n. sp. aff. *cotteswoldia* [*sic*]. Cainozoic astropectinids (see e.g., RASMUSSEN, 1972; KACZMARSKA, 1987) are in need of a modern revision; only rarely have species been based on such well-preserved remains as those recently described by NOSOWSKA (1997). Forms closely related to or assignable to the genera *Tethyaster* (see e.g., HALL & MOORE, 1990; BRETON, 1995), *Dipsacaster* (see BRETON *et al.*, 1995), *Coulonia* (= *Cuneaster*; see HESS & BLAKE, 1995) and the otherwise exclusively North American *Aldebarania* (see BLAKE & STURGEON, 1995) are known from the Zeven Wegen Member and the higher Maastricht Formation (Emael, Nekum and Meerssen members; Pl. 2, Fig. 11), in particular. From flint nodules in the upper Nekum Member (CBR-Romontbos quarry), three well-preserved individuals are known of an astropectinid referable to *Aldebarania* (D.B. Blake, pers. comm.).
- stauranderasterids, especially from the Geulhem Member, appear close to *Stauranderaster miliaris* BRÜNNICH NIELSEN, 1943 (Pl. 2, Fig. 14); the Meerssen Member has yielded another form (Pl. 2, Fig. 25).
- rare benthopectinids (Pl. 1, Fig. 18), comparable to material illustrated by BLAKE (1973, 1984).
- various new species of the goniasterid *Metopaster*; this genus in particular appears to have been very successful in establishing local species, as offshoots of the *parkinsoni* lineage. GALE (1987a) erected a number of such short-lived offshoots, which are particularly typical of marginal settings, e.g., coarse-grained biocalcarenites in southern Sweden. Comparable forms have been discussed by BRETON (1992, 1997), VILLIER (1996) and VILLIER *et al.* (1997). One of the new species, *Metopaster* sp. nov. (Pl. 2, Fig. 18) is reminiscent of *M. calcar* SPENCER, 1913, from the Santonian-Early Campanian of southern Sweden (see GALE, 1987a, pl. 8, figs. 12-21) and of *M. bromleyi* GALE, 1987a (pl. 2, figs. 14-16; pl. 3, figs. 1-5) from the late Early Campanian of the same area.
- remains of at least two individuals of what appears to be a new species of *Recurvaster*, seemingly closely related to and a possible precursor of the Early Palaeocene *R. mammillatus* (GABB, 1876), are known from the uppermost Meerssen Member (Pl. 2, Figs. 23, 24) of Blom quarry.
- dissociated ossicles of asteriids (Pl. 1, Figs. 15, 19), closely comparable to material from the Cenomanian-Coniacian of France as illustrated by BRETON & FERRÉ (1995). Asteriids have rarely been recorded as fossils, and for that reason it comes as no surprise that new finds almost invariably represent new genera and/or species (see e.g., BLAKE, 1990a; BLAKE & PETERSON, 1993; BLAKE *et al.*, 1996; BLAKE & ARONSON, 1998).

Reference is made to JAGT (1999d) for more details and for a discussion of functional morphology and palaeoecology of these asteroid faunas, based on literature data (BLAKE, 1989, 1990b).

Acknowledgements

I wish to thank the following colleagues for assistance in various ways: M.J. VAN BIRGELEN, D.B. BLAKE, G.J. BOEKSCHOTEN, M.J.M. DECKERS, S.K. DONOVAN, R.W. DORTANGS, A.S. GALE, R.W.J.M. VAN DER HAM, H. HESS, J. INDEHERBERGE, Saskia M. KARS, P. VAN KNIPPENBERG, M. KUTSCHER, M.M.M. KUYPERS, J.P.H. REYNDERS and J. SNELLINGS. The managements of CPL SA-Haccourt, CBR-Lixhe, ENCI-Maastricht BV, Blom and Ankerpoort-Curfs allowed access to their quarries, which is much appreciated. This research was supported (in part) by the Geosciences Foundation (GOA) with financial aid from the Netherlands Organisation for Scientific Research (NWO).

References

AGASSIZ, L. & DESOR, E., 1846-1847. Catalogue raisonné des familles, des genres, et des espèces de la classe des Échinodermes. *Annales des Sciences naturelles*, (3. Zoologie), **6**: 305-374.

ARONSON, R.B., 1987. Predation on fossil and Recent ophiuroids. *Paleobiology*, **13**: 187-192.

BATHER, F.A., 1924. *Saccocoma cretacea* n. sp., a Senonian crinoid. *Proceedings of the Geologists' Association*, **35**: 111-121.

BAUMILLER, T.K. & ROME, E.F., 1998. The Interference Avoidance Hypothesis and the spatial distribution of *Endoxocrinus parrae* (Crinoidea, Echinodermata). *In*: MOOI, R. & TELFORD, M. (Eds), Echinoderms: San Francisco. Proceedings of the Ninth International Echinoderm Conference, San Francisco/California/USA/5-9 August 1996. Rotterdam/Brookfield, A.A. Balkema, pp. 133-137.

BERRY, C.T., 1938. Ophiurans from the Upper Senonian of South Limburg, Holland. *Journal of Paleontology*, **12**: 61-71.

BLAKE, D.B., 1973. Ossicle morphology of some Recent asteroids and description of some West American fossil asteroids. *University of California Publications in Geological Sciences*, **104**: 1-59.

BLAKE, D.B., 1984. The Benthopectinidae (Asteroidea: Echinodermata) of the Jurassic of Switzerland. *Eclogae geologicae Helvetiae*, **77**: 631-647.

BLAKE, D.B., 1989. Asteroidea: Functional morphology, classification and phylogeny. *In*: JANGOUX, M. & LAWRENCE, J.M.

(Eds), Echinoderm Studies, 3. Rotterdam/Brookfield, A.A. Balkema, pp. 179-223.

Blake, D.B., 1990a. Hettangian Asteriidae (Echinodermata: Asteroidea) from southern Germany: taxonomy, phylogeny and life habits. *Paläontologische Zeitschrift*, **64**: 103-123.

Blake, D.B., 1990b. Adaptive zones of the class Asteroidea (Echinodermata). *Bulletin of marine Science*, **46**: 701-718.

Blake, D.B., 1996. Fossils explained 18: Starfishes. *Geology Today*, **12**: 230-235.

Blake, D.B. & Aronson, R.B., 1998. Eocene stelleroids (Echinodermata) at Seymour Island, Antarctic Peninsula. *Journal of Paleontology*, **72**: 339-353.

Blake, D.B., Breton, G. & Gofas, S., 1996. A new genus and species of Asteriidae (Asteroidea; Echinodermata) from the Upper Cretaceous (Coniacian) of Angola, Africa. *Paläontologische Zeitschrift*, **70**: 181-187.

Blake, D.B. & Peterson, D.O., 1993. An unusual new asteriid (Echinodermata: Asteroidea) from the Cretaceous of California. *Journal of Paleontology*, **67**: 586-589.

Blake, D.B. & Sturgeon, K., 1995. *Aldebarania arenitea*, a new genus and species of Astropectinidae (Asteroidea; Echinodermata) from the Maastrichtian (Upper Cretaceous) Peedee Formation of North Carolina. *Journal of Paleontology*, **69**: 376-380.

Breton, G., 1985. *Valettaster* ?Sphaerasteridae mésozoïque. *Bulletin trimestriel de la Société géologique de Normandie et des Amis du Muséum du Havre*, **72**: 91-99.

Breton, G., 1992. Les Goniasteridae (Asteroidea, Echinodermata) jurassiques et crétacés de France. Taphonomie, systématique, biostratigraphie, paléobiogéographie, évolution. *Bulletin trimestriel de la Société géologique de Normandie et des Amis du Muséum du Havre*, h.s. Suppl., **78**: 1-590.

Breton, G., 1995. *Tethyaster guerangeri* sp. nov. (Astropectinidae, Asteroidea, Echinodermata): deux spécimens d'astérides d'une conservation exceptionelle du Cénomanien du Mans (Sarthe, France). *Bulletin trimestriel de la Société géologique de Normandie et des Amis du Muséum du Havre*, **82**: 17-29.

Breton, G., 1997. Patterns and processes of heterochrony in Mesozoic goniasterid sea-stars. *Lethaia*, **30**: 135-144.

Breton, G., Bilotte, M. & Sigro, G., 1995. *Dipsacaster jadeti* sp. nov., Astropectinidae (Asteroidea, Echinodermata) du Maastrichtien des Petites Pyrénées (France). *Bulletin trimestriel de la Société géologique de Normandie et des Amis du Muséum du Havre*, **82**: 35-42.

Breton, G. & Ferré, B., 1995. Première observation d'éléments squelettiques d'Asteriidae (Asteroidea, Echinodermata) dans les craies du Cénomanien au Coniacien du Bassin de Paris (France). *Revue de Micropaléontologie*, **38**: 299-309.

Brünnich Nielsen, K., 1913. Crinoiderne i Danmarks Kridtaflejringer. *Danmarks geologiske Undersögelse*, (2)**26**: 1-120.

Brünnich Nielsen, K., 1915. *Rhizocrinus maximus* n. sp. og nogle Bemærkninger om *Bourgueticrinus danicus* Br. N. *Meddelelser fra dansk geologiske Förening*, **4**: 391-394.

Brünnich Nielsen, K., 1938. Faunaen i Ældre Danium ved Korporalskroen. *Meddelelser fra dansk geologiske Förening*, **9** (1937): 118-126.

Brünnich Nielsen, K., 1943. The asteroids of the Senonian and Danian deposits of Denmark. *Det kongelige Danske Videnskabernes Selskab, Biologiske Skrifter*, (2)**5**: 1-68.

Desor, E., 1855-1858. Synopsis des Échinides fossiles. Paris/Wiesbaden, Ch. Reinwald/Kriedel & Niedner, lxviii + 490 pp.

Donovan, S.K., 1991. The taphonomy of echinoderms: calcareous multi-element skeletons in the marine environment. *In*: Donovan, S.K. (Ed.), The processes of fossilization. London, Belhaven Press, pp. 241-269.

Engel, H., 1964. On *Winkleria maastrichtensis* nov. gen. et nov. spec. (Echinoidea, Regularia, Stirodonta, Phymosomina, ?Phymosomatidae) from the Upper Cretaceous (Md) of Maastricht (Limburg, Netherlands). *Beaufortia*, **10**: 207-210.

Faujas Saint Fond, B., 1799. Histoire naturelle de la Montagne de Saint-Pierre de Maëstricht. H.J. Jansen, Paris, 263 pp.

Forbes, E., 1848. On the Asteridae found fossil in British strata. *Memoirs of the Geological Survey of Great Britain*, **2**(2): 457-482.

Gabb, W.M., 1876. Note on the discovery of representatives of three orders of fossils new to the Cretaceous formation of North America. *Proceedings of the Academy of Natural Sciences of Philadelphia*, **28**: 178, 179.

Gale, A.S., 1987a. Goniasteridae (Asteroidea, Echinodermata) from the Late Cretaceous of north-west Europe. 1. Introduction. The Genera *Metopaster* and *Recurvaster*. *Mesozoic Research*, **1** (1986): 1-69.

Gale, A.S., 1987b. Goniasteridae (Asteroidea, Echinodermata) from the Late Cretaceous of north-west Europe. 2. The Genera *Calliderma*, *Crateraster*, *Nymphaster* and *Chomataster*. *Mesozoic Research*, **1**: 151-186.

Gale, A.S., 1989. Migration and evolution in Late Cretaceous Goniasteridae (Asteroidea, Echinodermata) from north-west Europe. *Proceedings of the Geologists' Association*, **100**: 281-291.

Gregory, J.W., 1900. Appendix A. *Zeuglopleurus rowei*, n. sp. *In*: Rowe, A.W. The zones of the White Chalk of the English Coast. I. Kent and Sussex. *Proceedings of the Geologists' Association*, **16**: 353, 354.

Håkansson, E., Kjaer, C.R. & Thomsen, E., 1996. Benthic recovery subsequent to the Cretaceous-Tertiary boundary - the European example. *Abstracts, Sixth North American Paleontological Convention*, Washington DC, **1996**: 1 pp.

Hall, R.L. & Moore, S., 1990. ?*Tethyaster albertensis*, a Late Cretaceous (Turonian) sea star from the Cardium Formation, Alberta, Canada. *Journal of Paleontology*, **64**: 1045-1049.

Hess, H. & Blake, D.B., 1995. *Coulonia platyspina* n. sp. , a new astropectinid sea star from the Lower Cretaceous of Morocco. *Eclogae geologicae Helvetiae*, **88**: 777-788.

Jaekel, O., 1902. Über verschiedene Wege phylogenetischer Entwicklung. *Verhandlungen des fünften internationalen zoologischen Congress*, Berlin, **1901**: 1058-1117.

Jagt, J.W.M., 1986. *Cyathidium vlieksi*, a new holopodid crinoid from the Upper Maastrichtian (Late Cretaceous) of southern Limburg, The Netherlands. *Geologie en Mijnbouw*, **65**: 215-221.

Jagt, J.W.M., 1998. Late Cretaceous-Early Palaeogene echinoderm faunas and the K/T boundary in the Maastrichtian type area. *In*: Kopaevich, L.F. & Dhondt, A.V. (org.). INTAS Project 1994-1414, Bio-events at the K/T boundary on the southern margin of the white chalk sea - palaeobiology, palaeobiogeography, sequence stratigraphy, geochemistry and geochronology. Final Meeting, Moscow March 23-25, 1998: 17, 18.

Jagt, J.W.M., 1999a. Late Cretaceous-Early Palaeogene echinoderms and the K/T boundary in the southeast Netherlands and northeast Belgium - Part 1: Introduction and stratigraphy. *Scripta Geologica*, **116A**: 1-57.

Jagt, J.W.M., 1999b. Late Cretaceous-Early Palaeogene echinoderms and the K/T boundary in the southeast Netherlands and northeast Belgium - Part 2: Crinoids. *Scripta Geologica*, **116B**: 59-256, 46 pls.

Jagt, J.W.M., 1999c. Late Cretaceous-Early Palaeogene echinoderms and the K/T boundary in the southeast Netherlands and northeast Belgium - Part 4: Echinoids. *Scripta Geologica*, **122** (in press).

Jagt, J.W.M., 1999d. Late Cretaceous-Early Palaeogene echinoderms and the K/T boundary in the southeast Netherlands and northeast Belgium - Part 5: Asteroids. *Scripta Geologica*, **123** (in press).

Jagt, J.W.M., Donovan, S.K., Deckers, M.J.M., Dortangs, R.W., Kuypers, M.M.M. & Veltkamp, C.J., 1998. The Late Maastrichtian bourgueticrinid crinoid *Dunnicrinus aequalis* (d'Orbigny, 1841) from The Netherlands and Belgium. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre*, **68**: 129-154.

Jagt, J.W.M. & Van der Ham, R.W.J.M., 1995. First record of the echinoid genus *Tylocidaris* Pomel 1883 from the type Maastrichtian of the Netherlands. *Paläontologische Zeitschrift*, **69**: 233-239.

Kaczmarska, G., 1987. Asteroids from the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta geologica polonica*, **37**: 131-144.

Kutscher, M. & Jagt, J.W.M., 1999. Early Maastrichtian ophiuroids from Rügen (northeast Germany) and Møn (Denmark). *In*: Jagt, J.W.M. Late Cretaceous-Early Palaeogene echinoderms and the K/T boundary in the southeast Netherlands and northeast Belgium - Part 3: Ophiuroids. *Scripta Geologica*, **121** (in press).

Lambert, J., 1897. Note sur quelques Echinides éocènes de l'Aude, I. Endocycles. *Bulletin de la Société géologique de France*, (3) **25**: 483-517.

Lambert, J., 1898. Note sur les Échinides de la craie de Ciply. *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, **11** (1897): 141-190.

Leske, N.G., 1778. Jacobi Theodori Klein Naturalis dispositio Echinodermatum, edita et descriptionibus novisque inventis et synonymis auctorum aucta. Lipsiae, G.E. Beer, xxii + 278 pp.

Meijer, M., 1965. Sur la présence du genre *Plagiochasma* (Enchinoidea) [*sic*] dans les tuffeaux maastrichtien et danomontien aux environs de Maastricht (Pays-Bas). *Natuurhistorisch Maandblad*, **54**: 96-102.

Messing, C.G., 1997. Living comatulids. *In*: Waters, J.A. & Maples, C.G. (Eds), Geobiology of echinoderms. *Paleontological Society Papers*, **3**: 3-30.

Morton, S.G., 1830. Synopsis of the organic remains of the ferruginous sand formation of the United States, with geological remarks. *American Journal of Science*, 17: 274-295.

Müller, A.H., 1953. Die isolierten Skelettelemente der Asteroidea (Asterozoa) aus der obersenonen Schreibkreide von Rügen. *Geologie (Beiheft)*, **8**: 3-66.

Müller, A.H., 1956. Zur genaueren Kenntnis von *Lophidiaster pygmaeus* (Asterozoa) aus der Schreibkreide (Maastricht) von Rügen. *Geologie*, **5**: 642-651.

Nosowska, E., 1997. Asteroids from the Nawodzice Sands (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta geologica polonica*, **47**: 225-241.

Rasmussen, H.W., 1945. Observations on the asteroid fauna of the Danian. *Meddelelser fra danske geologiske Förening*, **10** (1944): 417-426.

Rasmussen, H.W., 1950. Cretaceous Asteroidea and Ophiuroidea with special reference to the species found in Denmark. *Danmarks geologiske Undersøgelse*, (2) **77**: 1-134.

Rasmussen, H.W., 1952. Cretaceous Ophiuroidea from Germany, Sweden, Spain and New Jersey. *Meddelelser fra dansk geologiske Förening*, **12** (1951): 47-57.

Rasmussen, H.W., 1965. The Danian affinities of the Tuffeau de Ciply in Belgium and the "Post-Maastrichtian" in the Netherlands. *Mededelingen van de Geologische Stichting*, n.s., **17**: 33-40.

Rasmussen, H.W., 1972. Lower Tertiary Crinoidea, Asteroidea and Ophiuroidea from northern Europe and Greenland. *Biologiske Skrifter fra det danske Videnskabeliges Selskab*, **19**: 1-83.

Schlüter, C., 1878. Ueber einige astylide Crinoiden. *Zeitschrift der deutschen geologischen Gesellschaft*, **30**: 28-66.

Schulz, M.-G. & Weitschat, W., 1975. Phylogenie und Stratigraphie der Asteroideen der nordwestdeutschen Schreibkreide. Teil I: *Metopaster/Recurvaster-* und *Calliderma/Chomataster-*Gruppe. *Mitteilungen aus dem geologisch-paläontologischen Institut der Universität Hamburg*, **44**: 249-284.

Schulz, M.-G. & Weitschat, W., 1981. Phylogenie und Stratigraphie der Asteroideen der nordwestdeutschen Schreibkreide. Teil II: *Crateraster/Teichaster*-Gruppe und Gattung *Ophryaster. Mitteilungen aus dem geologisch-paläontologischen Institut der Universität Hamburg*, **51**: 27-42.

Sladen, W.P., 1891-1893. A monograph of British fossil Echinodermata from the Cretaceous formations, 2. The Asteroidea and Ophiuroidea, 1-2. *Monographs of the Palaeontographical Society of London*, **1891-1893**: ii + 1-66.

Smith, A.B., 1995. Late Campanian-Maastrichtian echinoids from the United Arab Emirates-Oman border region. *Bulletin of the Natural History Museum London (Geology)*, **51**: 121-240.

Smith, A.B. & Jeffery, C.H. in press. Maastrichtian and Palaeocene echinoids: An illustrated key. *Special Papers in Palaeontology.*

Smith, A.B. & Wright, C.W., 1996. British Cretaceous echinoids. Part 4, Stirodonta 3 (Phymosomatidae, Pseudodiadematidae) and Camarodonta. *Monograph of the Palaeontographical Society London*, **150** (602): 268-341.

Spencer, W.K., 1913. The evolution of the Cretaceous Asteroidea. *Philosophical Transactions of the Royal Society of London*, **B204**: 99-177.

Umbgrove, J.H.F., 1925. Asteroidea uit het Maastrichtsche Tufkrijt. *Verhandelingen van het Geologisch-Mijnbouwkundig Genootschap voor Nederland en Koloniën*, geol. serie, 7: 207-212.

Villier, L., 1996. Les Goniasteridae (Asteroidea, Echinodermata) du Campanien d'Aquitaine; ontogenèse, évolution et paléoécologie. Université de Bourgogne, Centre des Sciences de la Terre, 50 pp. (unpublished thesis).

VILLIER, L., BRETON, G. & NÉRAUDEAU, D., 1997. Contexte paléoécologique, biodiversité et signification biostratigraphique des asteridés dans le Campanien stratotypique. *Annales de la Société Géologique du Nord*, (2) 5: 181-188.

VON HAGENOW, F., 1840. Monographie der Rügen'schen Kreideversteinerungen. Abtheilung II. Radiarien und Annulaten, nebst Nachträgen zur I. Abtheilung. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefactenkunde*, **1840**: 631-672.

ZELEZNIK, A., 1985. Analyse descriptive et quantitative des meso-et microfossiles du contact Campanien-Maastrichtien dans le Nord-Est de la Belgique et le Limbourg néerlandais. Université de Liège, Faculté des Sciences, Laboratoires de Paléontologie, 104 pp. (unpublished thesis).

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Typescript submitted: December 1, 1998.
Revised typescript received: February 2, 1999.

PLATE 1

Note — Data on provenance of material in Plates 1 and 2, as well as repository and registration numbers of specimens illustrated, are supplied by JAGT (1999b-d) and KUTSCHER & JAGT (1999), to which reference is made.

Figs. 1-3 — *Hyposalenia heliophora*, apical and lateral views of test (x 6), and associated lantern (x 23).
Fig. 4 — *Zeuglopleurus rowei*, apical view, x 9.
Figs. 5-7 — *Hemipneustes striatoradiatus* juv., apical, oral and lateral views, x 9.
Fig. 8 — *Winkleria maastrichtensis*, oblique lateral view, x 17.5.
Figs. 9, 10 — *Centrostephanus*? sp. juv., lateral and oblique apical views, x 15.
Figs. 11, 12 — *Hagenowia* sp. (?nov.), rostra, x 15 and x 12, respectively.
Fig. 13 — Ophiolepididae n. sp. , lateral arm plate, x 30.
Fig. 14 — Goniasteridae indet. juv., x 6.5.
Figs. 15, 19 — asteriid indet., x 20 and x 26, respectively.
Figs. 16, 17 — *Ophiomusium granulosum*, proximal arm portions, x 16 and x 5, respectively.
Fig. 18 — benthopectinid indet., x 21.

PLATE 2

Figs. 1, 2, 4 — indeterminate "cryptozonid" (? echinasterid), marginals, ambulacrals and terminal plate; x 13 (1), x 19 (2) and x 25 (4).
Fig. 3 — *Metopaster decipiens*, ultimate superomarginal, x 9.
Figs. 5, 6 — *Ophryaster oligoplax*, marginals preserving granules, x 10.
Fig. 7 — *Metopaster undulatus*, ultimate superomarginal, x 7.5.
Fig. 8 — *Nymphaster studlandensis*, distal marginal, x 17.
Fig. 9 — *Lophidiaster pygmaeus*, superomarginal, lateral view, x 20.
Fig. 10 — "*Parametopaster*" (sp. nov.?), oblique view of ultimate superomarginal, x 8.
Fig. 11 — astropectinid indet., superomarginal, x 18.
Fig. 12 — astropectinid (sp. nov.?), inferomarginal, x 18.
Fig. 13 — radiasterid(?) indet., superomarginal, x 20.
Fig. 14 — stauranderasterid, x 11.
Fig. 15 — *Valettaster* sp. (nov.?), x 7.
Fig. 16 — *Astropecten punctatus*, interradial superomarginal, x 18.
Fig. 17 — *Metopaster spencerii*, median superomarginal, x 4.5.
Fig. 18 — *Metopaster* sp. nov., ultimate superomarginal, x 4.
Figs. 19, 20 — *Nymphaster alseni*, interradial superomarginal, x 3.
Fig. 21 — *Metopaster tumidus*, ultimate superomarginal, x 3.
Fig. 22 — *Crateraster reticulatus*, median supero- and inferomarginal, x 3.
Figs. 23, 24 — *Recurvaster* sp. nov., median superomarginal, x 3.
Fig. 25 — stauranderasterid, x 3.5.

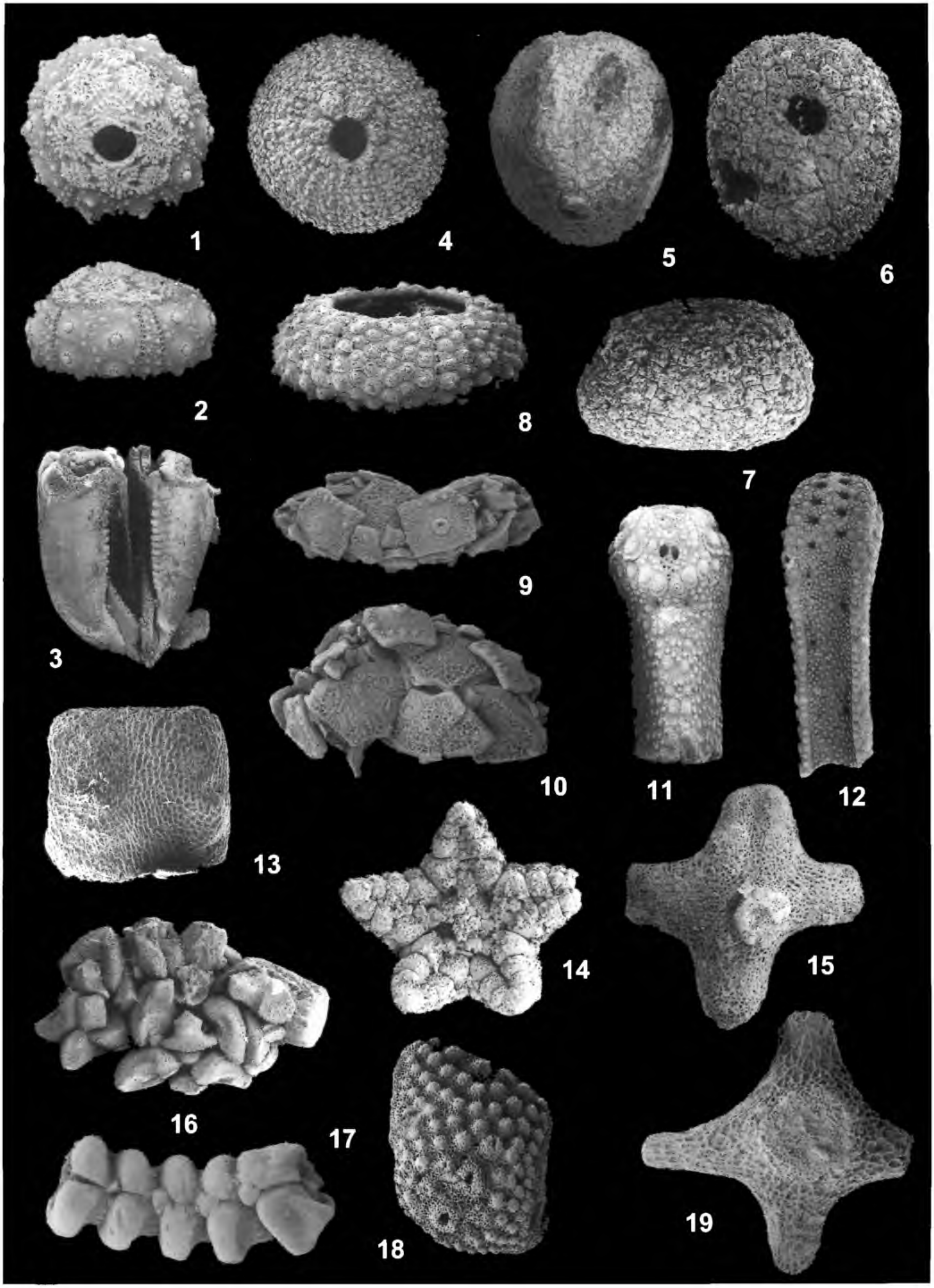

PLATE 1

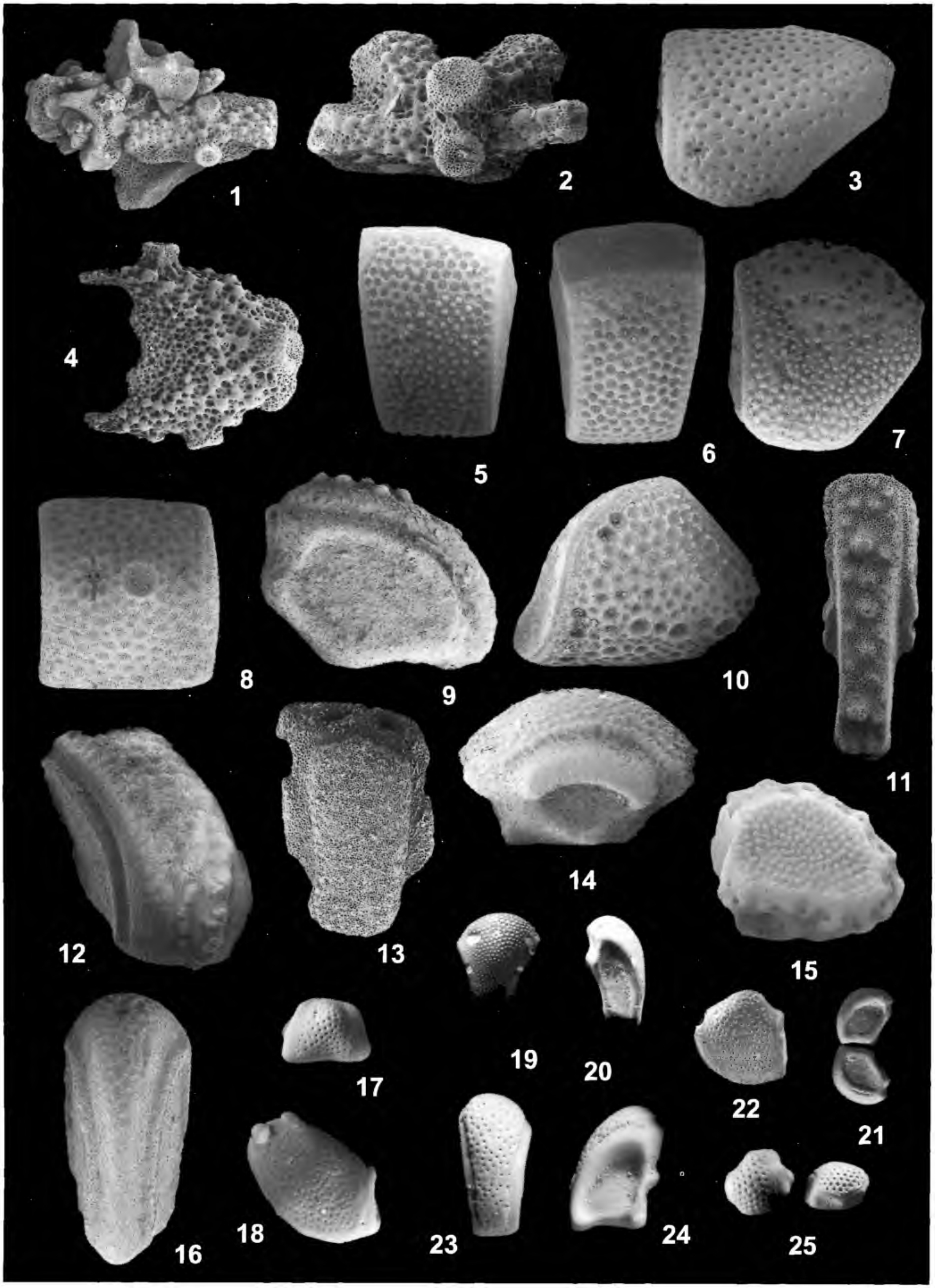

PLATE 2

Pachydiscus (Pachydiscus) hornbyense Jones, 1963, and *P. (P.) catarinae* (Anderson & Hanna, 1935) (Cretaceous, Campanian: Ammonoidea), Pacific Realm marker fossils in the Western Interior Seaway of North America

by W. James KENNEDY & William A. COBBAN

Abstract

Pachydiscus (P.) hornbyense Jones, 1963, previously known only from Hornby Island, British Columbia, occurs in the Upper Campanian *Baculites jenseni* or lowest Maastrichtian *Baculites eliasi* zone of Garfield County, Montana, the *B. compressus* or *B. cuneatus* zone of Pennington County, South Dakota, and by inference, the *B. compressus* zone of Rosebud County, Montana. *P. (P.) catarinae* (Anderson & Hanna, 1935), originally described from Lower California, Mexico, and also known from Fresno and Diabolo Counties, California, occurs in the Upper Campanian *Exiteloceras jenneyi* zone of Pueblo County, Colorado. The presence of these Pacific Realm ammonites in the United States Western Interior indicates an easterly migration route into the Interior from the Pacific Realm, complementing published evidence for westward migration of Gulf Coast and Western Interior species into the Pacific Realm.

Key-words: Biogeography, Cretaceous, Campanian, Ammonoidea, *Pachydiscus*, USA.

Résumé

Pachydiscus (P.) hornbyense Jones, 1963 qui n'était connu jusqu'à présent que dans l'île d'Hornby en Colombie Britannique (Canada), est présent dans la zone à *Baculites jensensi* du Campanien supérieur ou dans la zone à *B. eliasi* de la base du Maastrichtien, dans le comté de Garfield au Montana, dans la zone à *B. compressus* ou à *B. cuneatus* dans le comté de Pennington au Dakota du Sud, et, par induction, dans la zone à *B. compressus* dans le comté de Rosebud au Montana. *P. (P.) catarinae* (Anderson & Hanna, 1935) décrit à l'origine sur base de matériel provenant de la "Baja California" au Mexique et également signalé dans les comtés de Fresno et Diabolo en Californie se rencontre dans la zone à *Exiteloceras jenneyi* dans le comté de Pueblo au Colorado. La présence de ces ammonites du Domaine pacifique dans le "Western Interior" des Etats Unis indique une voie de migration vers l'est en direction du "Western Interior" à partir du Domaine pacifique. Cela s'ajoute aux preuves, déjà publiées, d'une migration vers l'ouest dans le Domaine pacifique, d'espèces de la "Gulf Coast" et du "Western Interior".

Mots-clefs: Biogéographie, Crétacé, Campanien, Ammonoidea, *Pachydiscus*, USA.

Резюме

Pachydiscus (P.) hornbyense JONES, 1963, ранее известный лишь на острове Хорнби, Британская Колумбия, залегает в *Baculites jenseni* Верхнего Кампана или в *Baculites eliasi* самого нижнего Мастрихта в округе Гарлфилд, Монтана, в зоне *B. compressus* или *B. cuneatus* округа Пеннингтон, Южная Дакота, и, по аналогии, в зоне *B. compressus* округа Розбуд, Монтана. *P. (P.) catarinae* (ANDERSON & HANNA, 1935) изначально описанный как происходящий из Нижней Калифорнии, Мексика, а также известный как происходящий из округов Фресно и Диаболо, Калифорния, залегает в зоне *Exiteloceras jenneyi* Верхнего Кампана, округа Пуэбло, Колорадо. Присутствие этих аммонитов тихоокеанской области в «Western Interior» США указывает на существование миграционного восточного потока внутрь материка с морского побережья. Эти данные дополняют опубликованные доказательства миграции аммонитов с побережья Мексиканского залива и из «Western Interior» на запад, в тихоокеанскую область.

Ключевые слова: биогеография, Мел, Кампанский ярус, Ammonoidea, *Pachydiscus*, США.

Introduction

The Campanian ammonite faunas of the United States Western Interior seaway are typically made up of two elements: predominantly endemic taxa, and a minority of immigrant taxa. The former have recently been recognized from scattered occurrences in the Gulf Coast and Atlantic Seaboard (e.g. Kennedy & Cobban, 1994, 1997; Cobban & Kennedy, 1994; Kennedy, Johnson & Cobban, 1995), and western Europe (Kennedy, 1993; Hancock & Kennedy, 1993; Kennedy & Jagt, 1995; Kennedy & Bilotte, 1995). We had previously assumed that immigrants into the interior seaway came via a south-easterly route through the Gulf Coast, but recent records suggest that east-west migration was also possible. These include the presence of *Didymoceras hornbyense* (Whiteaves, 1895), a species originally described from Hornby Island, British Columbia, in the Upper Campanian Coon Creek Tongue of the Ripley Formation in Tennessee (Cobban & Kennedy, 1994).

We have recently seen specimens of *Nostoceras (Nostoceras) hyatti* Stephenson, 1941, *N. (N.) helicinum* (Shumard, 1861), and *Didymoceras draconis* (Stephenson, 1941), from the San Diego area, California. These are all Upper Campanian species best known from the Atlantic Seaboard and Gulf Coast regions (Cobban,

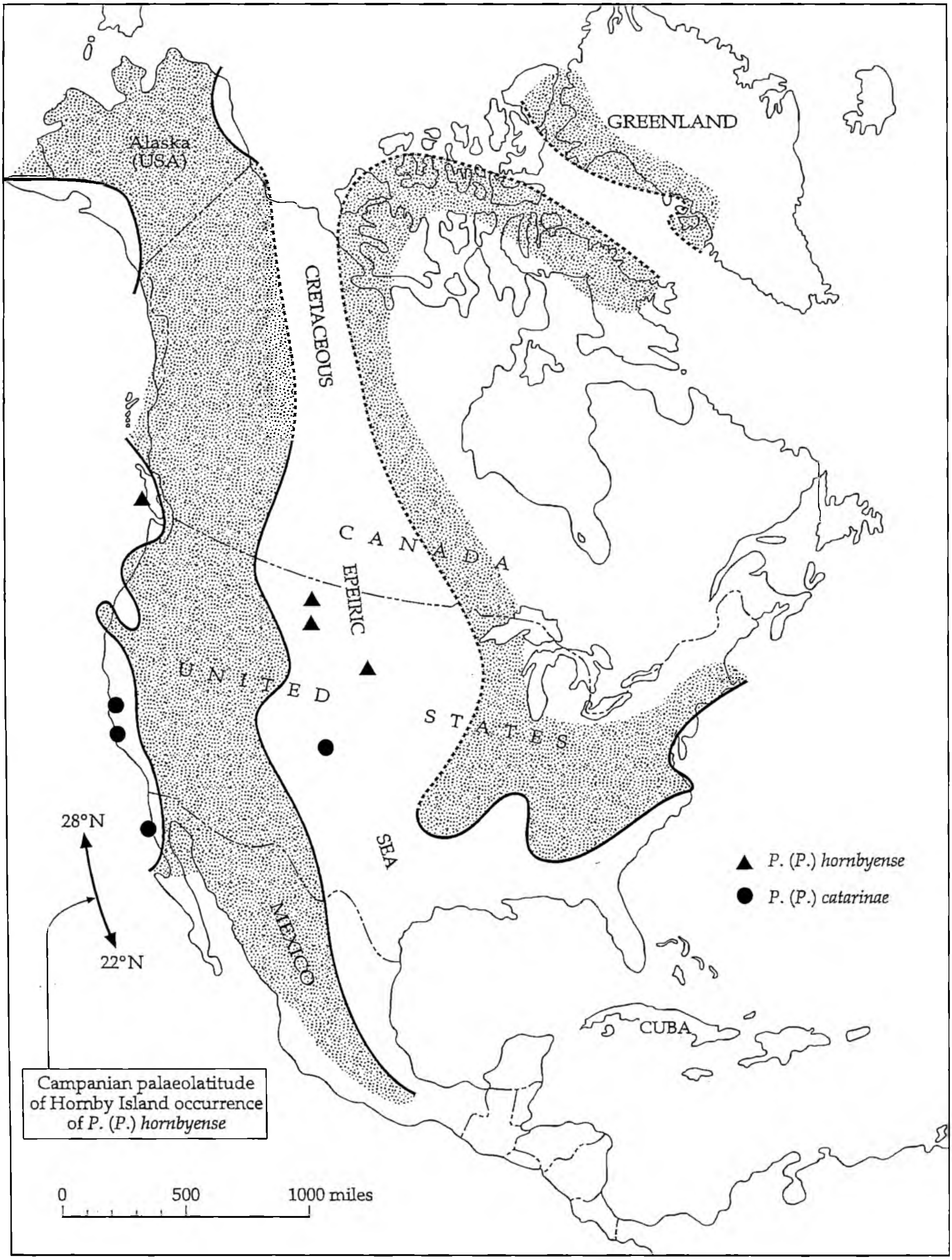

Fig. 1 — Palaeogeographic map of North America during Campanian time (modified after GILL & COBBAN, 1966).

1974; Kennedy & Cobban, 1993), with the first two also known from Western Europe (e.g. Hancock & Kennedy, 1993). *N. (N.) hyatti* occurs as a rarity in the *Baculites jenseni* zone of the Pierre Shale of Huerfano County, Colorado (Kennedy, Cobban & Scott, 1992), and *D. draconis* in the *Baculites cuneatus* zone of Middle Park, Grand County, Colorado. *Exiteloceras jenneyi* (Whitfield, 1877), best known from the northern part of the Western Interior, but also known from the New Jersey/Delaware boundary (Kennedy & Cobban, 1997) was also able to migrate southwards, and is known from Colombia in South America (Kennedy in Föllmi, Garrison, Ramirez, Zambrano-Ortiz, Ramirez, Kennedy & Lehner, 1992).

We document here the first evidence of migration of Pacific Realm ammonites into the northern part of the Western Interior Seaway (Fig. 1). This takes the form of, firstly, the occurrence of specimens of *Pachydiscus (Pachydiscus) hornbyense* Jones, 1963 (p. 38, pl. 32, figs. 2-6; pl. 33; text-fig. 10) in the Upper Campanian *Baculites jenseni* or *B. eliasi* zone (Fig. 2) of the Bearpaw Shale south of Fort Peck in Garfield County, in northeastern Montana (Pl. 1, figs. 1-3), in the *B. compressus* or *B. cuneatus* zone Pierre Shale of Pennington County, South Dakota, and in the inferred *B. compressus* zone Pierre Shale in Rosebud County, Montana (Pl. 2). *P. (P.) hornbyense* was previously known only from the Lambert Formation of the Nanaimo Group in British Columbia (Fig. 1).

The second Pacific Realm migrant is *P. (P.) catarinae* (Anderson & Hanna, 1935), a specimen of which is known from the *Exiteloceras jenneyi* zone of the Pierre Shale of Pueblo County, Colorado (Pl. 1, Figs. 3, 4). This species was originally described from near Santa, Caterina Landing, Baja, Lower California, Mexico and subsequently recorded from near Coalinga, Fresno County, and Puerto Creek in Diabolo County, California (Fig. 1).

Conventional palaeogeographic maps (e.g. Williams & Stelck, 1975; Christensen, 1993; Smith, Smith & Funnell, 1994 and references therein) also show a seaway extending north-northwest to northern Alaska. But as Jones (1963) noted, there is a lack of faunal similarity, apart from the present records. It must also be noted that the present latitude of the British Columbia records of *P. (P.) hornbyense* may be well to the north of their original site of deposition as a result of post-Cretaceous plate tectonic activity. Ward, Hurtado, Kirschvink & Verosub (1997) have shown the Campanian-(?)Maastrichtian sediments of Hornby Island to retain a stable remnant magnetism that indicates the Insular Superterrain of which they are a part originally lay at an Upper Cretaceous palaeolatitude of 25 ± 3 degrees north, equivalent to that of present-day Baja, California. Given the evidence for southerly migration out of the Gulf Coast and Western Interior into the Pacific Realm during the Upper Campanian, we take the view that this is more likely to have been the route taken by the present specimens of both *P. (P.) hornbyense* and *P. (P.) catarinae*.

Systematic palaeontology

Family Pachydiscidae Spath, 1922

Genus and Subgenus *Pachydiscus* Zittel, 1884

Type species: *Ammonites neubergicus* Hauer, 1858, p. 12, pl. 1, figs. 1-3; pl. 2, figs. 1, 2, by subsequent designation by de Grossouvre, 1894, p. 177.

Pachydiscus (Pachydiscus) hornbyense Jones, 1963

(Pl. 1, Figs. 1-3; Pl. 2)

1903 *Pachydiscus otacodensis* (Stoliczka); Whiteaves, p. 340, pl. 46, fig. 1; text-fig. 20.
1952 *Pachydiscus otacodensis* (Stoliczka); Usher, p. 85, pl. 17, figs. 1-5; pl. 18;?pls. 19, 20.
1963 *Pachydiscus (Pachydiscus) hornbyense* Jones, p. 38, pl. 32, figs. 2-6; pl. 33; text-fig. 19.
1997 *Pachydiscus* cf. *hornbyense*; Larson, Jorgensen, Farrar & Larson; unnumbered fig. on p. 61.

TYPE

Holotype is in the U.S. National Museum of Natural History (USNM n° 131209), the original of Jones, 1963, pl. 32, fig. 6, from the Lambert Formation of the Nanaimo Group, beach platform on the northwest side of Hornby Island, British Columbia.

DESCRIPTION

Black Hills Institute of Geological Research Inc. (BHI) 4140 (Pl. 1, Figs. 1-3) is a crushed phragmocone 76 mm in diameter. Involute, whorl section slightly depressed, umbilical shoulder broadly rounded. Inner flanks convex, outer flanks convergent, ventrolateral shoulders and venter broadly rounded. First half of outer whorl bears twelve narrow, distant ribs, separated by very wide interspaces. Ribs more or less regularly alternately long and short; long ribs with or without feeble bullae; shorter ribs arise low on flank. Ribs straight and prorsiradiate on flanks, projected forwards and slightly concave on ventrolateral shoulders, thickening and feebly convex over venter. Interspaces between ribs with delicate riblets and growth lines. Ribbing crowds at adapical end of specimen.

BH1 4139 (Pl. 2) is an undeformed specimen, septate to 230 mm diameter. A short section of the adapical end of the body chamber is preserved. Coiling involute, with U = 18% of the diameter, deep, with a feebly convex umbilical wall; umbilical shoulder broadly rounded. Whorl section compressed; whorl breadth to height ratio 0.88. Inner flanks broadly rounded, outer flanks convergent; venter broadly rounded. Inner flanks of inner whorls ornamented as in previous specimen. Inner flank of outer phragmocone whorl smooth. Low, broad, concave ribs strengthen across the outer flank, and cross the venter in a broad convexity on the first half of the outer whorl, but decline progressively with increasing diameter, leaving the adapertural end of phragmocone and adapical end of body chamber smooth.

Suture highly complex, with deeply incised lobes and saddles; typical for genus.

Cretaceous Stages and Western Interior informal substages		Western Interior ammonite zones	
Maastrichtian (part)	Upper (part)	*Jeletzkytes nebrascensis*	
		Hoploscaphites nicolletii	
	Lower	*Hoploscaphites birkelundi*	
		Baculites clinolobatus	
		Baculites grandis	
		Baculites baculus	
		Baculites eliasi	↑
Campanian	Upper	*Baculites jenseni*	
		Baculites reesidei	
		Baculites cuneatus	↑
		Baculites compressus	
		Didymoceras cheyennense	
		Exiteloceras jenneyi	●
		Didymoceras stevensoni	
		Didymoceras nebrascense	
	Middle	*Baculites scotti*	
		Baculites reduncus	
		Baculites gregoryensis	
		Baculites perplexus	
		Baculites sp. (smooth)	
		Baculites asperiformis	
		Baculites maclearni	
		Baculites obtusus	
	Lower	*Baculites* sp. (weak flank ribs)	
		Baculites sp. (smooth)	
		Scaphites hippocrepis III	
		Scaphites hippocrepis II	
		Scaphites hippocrepis I	
		Scaphites leei III	

● *Pachydiscus* (*P.*) *catarinae* (ANDERSON & HANNA, 1935)

↑ *Pachydiscus* (*P.*) *hornbyense* JONES, 1963

Fig. 2 — Western Interior Campanian ammonites zones.

A further unfigured fragment, USNM 499023 may belong to *P. (P.) hornbyense*; it is inferred to be from the *Baculites compressus* zone of the Pierre Shale 15 km (9 mi.) east, and 3.3 km (2 mi.) south of Ingomar, Rosebud County, Montana, in the N1/2, T.9N., R.36E. It is a wholly septate fragment with a maximum preserved whorl height of 119 mm and a whorl breadth to height ratio of 0.96. The dorsum shows impressions of sharp distant ribs, as in BHI 4140 at a comparable diameter; the outer whorl is completely smooth.

DISCUSSION

The present specimens differ in no significant respects from the holotype and topotypes from Hornby Island. Of other *Pachydiscus (Pachydiscus)* species known from the Campanian of the United States Western Interior, *P. (P.) arkansanus* (STEPHENSON, 1941) (COBBAN & KENNEDY, 1991, p. F2, pl. 1, fig. 4; pls. 2-4; text-fig. 2) is much more closely and coarsely ribbed, ribbing persisfing to a diameter where *P. (P.) hornbyense* has lost its ribbing. *P. (P.)* cf. *oldhami* (SHARPE, 1855) (COBBAN & KENNEDY, 1991, p. F1, pl. 1, figs. 1-3; text-fig. 1) is a compressed species, with crowded ribs.

OCCURRENCE

Upper Campanian, Lambert Formation of the Nanaimo Group, Hornby Island, British Columbia. In the U.S. Western Interior, there are specimens from the Bearpaw Shale, *Baculites jenseni* or *B. eliasi* zone, Garfield County, Montana; *B. compressus* or *B. cuneatus* zone of the Pierre Shale of Pennington County, South Dakota; *B. compressus* zone inferred, Rosebud County, Montana.

Pachydiscus (Pachydiscus) catarinae (ANDERSON & HANNA, 1935)

(Pl. 1, Figs. 4, 5)

1928 *Pachydiscus catarinae* ANDERSON; p. 238, pl. 9 (*nomen nudum*).
1935 *Parapachydiscus catarinae* ANDERSON & HANNA; p. 19, pls. 1, 2; pl. 3, figs. 1-3.
1958 *Parapachydiscus catarinae* (ANDERSON & HANNA); ANDERSON, p. 224, pl. 58, fig. 2.
1997 *Pachydiscus catarini* LARSON, JORGENSEN, FARRAR & LARSON; unnumbered figure on p. 61.

TYPE

Holotype is no. 4245 in the collections of the California Academy of Sciences, from the Upper Campanian near Catarina Landing, Lower California, Mexico, refigured by ANDERSON, 1958, pl. 58, fig. 2.

DESCRIPTION

USNM 486635 is a phragmocone 215 mm in diameter, with the following dimensions in millimeters: diameter: 213.0(100); whorl breadth (Wb): 92.6(43.5); whorl height (Wh): 101.0 (47.0); Wb:Wh: 0.91; umbilicus 51.9(24.4). Coiling involute, 68% of the previous whorl covered. Umbilicus small: 24.4% of the diameter, deep, with convex wall and more narrowly rounded umbilical shoulder. Whorl section compressed, with whorl breadth to height ratio 0.91, inner flanks convex, outer flanks convergent, ventrolateral shoulders and venter broadly rounded. Ornament consists of distant weak ribs, strong, straight, prorsiradiate on inner to middle flanks of outer whorl, flexing forward, concave and weakening across outer flanks and ventrolateral shoulders, weak and broadly convex across venter. Occasional shorter intercalated ribs present on outer flank and venter. Imperfectly exposed suture with deeply incised lobes and saddles, typical for genus.

DISCUSSION

Compressed whorl section and widely separated ribs distinguish *P. (P.) catarinae* from all other *Pachydiscus (Pachydiscus)* recorded from the Campanian of the U.S. Western Interior Seaway.

OCCURRENCE

Upper Campanian, Catarina Landing, Baja, Lower California, Mexico; near Coalinga, Fresno County, California; Puerto Creek, Diablo County, California. *Exiteloceras jenneyi* zone of the Pierre Shale, in the NE1/4, sec. 23, T.18S; R.64W., Pueblo County, Colorado.

Acknowledgements

We thank W. G. Camack (Pueblo, Colorado) for bringing the specimen of *Pachydiscus (P.) catarinae* to our attention, and Neal Larson (Black Hills Institute of Geological Research Inc., Hill City, S. Dakota) for loan of specimens. Kennedy acknowledges the technical support of the staff of the Geological Collections, University Museum of Natural History, Oxford, and the Department of Earth Sciences, Oxford.

References

ANDERSON, F.M., 1928. Late Cretacic fossils from Lower California. *Pan American Geologist*, **50**: 283-284.

ANDERSON, F.M., 1958. Upper Cretaceous of the Pacific Coast. *Geological Society of America Memoir*, **71**: xi + 378 p.

ANDERSON, F.M. & HANNA, G.D., 1935. Cretaceous geology of Lower California. *Proceedings of the California Academy of Sciences*, (4), **23**: 1-34.

CHRISTENSEN, W.-K., 1993. *Actinocamax cobbani* n.sp. from the Coniacian of Montana and Wyoming and the occurrence of Late Cretaceous belemnites in North America and Greenland. *Journal of Paleontology*, **67**: 434-446.

COBBAN, W.A., 1974. Ammonites from the Navesink Formation at Atlantic Highlands, New Jersey. *U.S. Geological Survey Professional Paper*, **845**: 21 p.

COBBAN, W.A. & KENNEDY, W.J., 1991. *Pachydiscus* (Ammonoidea) from Campanian (Upper Cretaceous) rocks in the Western Interior of the United States. *U.S. Geological Survey Bulletin*, **1985**: F1-F4.

Cobban, W.A. & Kennedy, W.J., 1994. Upper Cretaceous ammonites from the Coon Creek Tongue of the Ripley Formation at it's type locality in McNairy County, Tennessee. *U.S. Geological Survey Bulletin*, **2073-B**: B1-B12.

Föllmi, K.B., Garrison, R.E., Ramirez, P.C., Zambrano-Ortiz, F., Kennedy, W.J. & Lehner, B.L., 1992. Cyclic phosphate-rich sequences in the upper Cretaceous of Colombia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **93**: 151-182.

Gill, J.R. & Cobban, W.A. 1966. The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming. *U.S. Geological Survey Professional Paper*, **393-A**: 73 p.

Grossouvre, A. de, 1894. Recherches sur la craie supérieure, 2, Paléontologie. Les ammonites de la craie supérieure. *Mémoires du Service de la Carte Géologique détaillée de la France.* Imprimerie Nationale, Paris, 264 p. (misdated 1893).

Hancock, J.M. & Kennedy, W.J., 1993. The high Cretaceous ammonite fauna from Tercis, Landes, France. *Bulletin de l'Institut royal des Sciences naturelles de Belgique,* Série Sciences de la Terre, **63**: 149-209.

Hauer, F. von, 1858. Ueber die Cephalopoden aus den Gosauschichten. *Beiträge zur Paläontologie von Oesterreich*, **1**: 7-14.

Jones, D., 1963. Upper Cretaceous (Campanian and Maestrichtian) ammonites from southern Alaska. *U.S. Geological Survey Professional Paper*, **432**: 55 p.

Kennedy, W. J., 1993. Campanian and Maastrichtian ammonites from the Mons Basin (Belgium). *Bulletin de l'Institut royal des Sciences naturelles de Belgique,* Série Sciences de la Terre, **63**: 99-131.

Kennedy, W.J. & Bilotte, M., 1995. A new ammonite fauna from the sub-pyrenean Campanian (Upper Cretaceous). *Geobios*, **28**: 359-370.

Kennedy, W.J. & Cobban, W.A., 1993. Ammonites from the Saratoga Chalk (Upper Cretaceous), Arkansas. *Journal of Paleontology*, **67**: 404-434.

Kennedy, W.J. & Cobban, W.A., 1994. Upper Campanian ammonites from the Mount Laurel Sand at Biggs Farm, Delaware. *Journal of Paleontology*, **68**: 1285-1305.

Kennedy, W.J. & Cobban, W.A., 1997. Upper Campanian (Upper Cretaceous) ammonites from the Marshalltown Formation-Mount Laurel Sand boundary beds in Delaware. *Journal of Paleontology,* **71**: 62-73.

Kennedy, W.J., Cobban, W.A. & Scott, G.R., 1992. Ammonite correlation of the uppermost Campanian of Western Europe, the U.S. Gulf Coast, Atlantic Seaboard and Western Interior, and the numerical age of the base of the Maastrichtian. *Geological Magazine*, **129**: 497-500.

Kennedy, W.J. & Jagt, J.W.M., 1995. Lower Campanian heteromorph ammonites from the Vaals Formation around Aachen, Germany, and adjacent parts of Belgium and the Netherlands. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **197**: 275-294.

Kennedy, W.J., Johnson, R.O. & Cobban, W.A., 1995. Upper Cretaceous ammonite faunas of New Jersey. *Geological Association of New Jersey*, **12**: 24-55.

Larson, N.L., Jorgensen, S.D., Farrar, R.A. & Larson, P.L, 1997. Ammonites and other cephalopods of the Pierre Seaway. Geoscience Press, Tucson. xi + 148 p.

Sharpe, D., 1853-57. Description of the fossil remains of Mollusca found in the Chalk of England. I, Cephalopoda. *Palaeontographical Society Monographs*, 68 pp. , 27 pls. 1-26, pls. 1-10 (1853); 27-36, pls. 11-16 (1855); 37-68, pls. 17-27 (1857).

Shumard, B.F., 1861. Descriptions of new Cretaceous fossils from Texas. *Transactions of the Academy of Sciences of St. Louis*, **1**: 590-610.

Smith, A.G., Smith, D.G. & Funnell, B.M., 1994. Atlas of Mesozoic and Cenozoic coastlines. Cambridge University Press, Cambridge, New York and Melbourne. ix + 99 p.

Spath, L.F., 1922. On the Senonian ammonite fauna of Pondoland. *Transactions of the Royal Society of South Africa*, **10**: 113-147.

Stephenson, L.W., 1941. The larger invertebrates of the Navarro Group of Texas (exclusive of corals and crustaceans and exclusive of the fauna of the Escondido Formation). *University of Texas Bulletin*, **4101**: 641 p.

Usher, J.L., 1952. Ammonite faunas of the Upper Cretaceous of Vancouver Island, British Columbia. *Bulletin of the Geological Survey of Canada*, **21**: 1-182, pls. 1-30.

Ward, P.D., Hurtado, J.M., Kirschvink, J.L. & Verosub, K.L., 1997. Measurements of the Cretaceous paleolatitude of Vancouver Island: consistent with the Baja-British Columbia hypothesis. *Science*, **77**: 1642-1645

Whiteaves, J.F., 1895. Notes on some fossils from the Cretaceous rocks of British Columbia, with descriptions of two species that appear to be new. *Canadian Record of Science*, **6**: 313-318.

Whiteaves, J.F., 1903. On some additional fossils from the Vancouver Cretaceous, with a revised list of the species therefrom. *Geological Survey of Canada Mesozoic Fossils*, **1**: 309-409.

Whitfield, R.P., 1877. Preliminary report on the paleontology of the Black Hills, containing descriptions of new species of fossils from the Potsdam, Jurassic, and Cretaceous formations of the Black Hills of Dakota. United States Geographical and Geological Survey of the Rocky Mountain Region. 49 p.

Williams, G.D. & Stelck, C.R., 1975. Speculations on the Cretaceous palaeogeography of North America. *Geological Association of Canada Special Paper*, **13**: 1-29.

Zittel, K.A. von, 1884. Handbuch der Paläontologie, 1, Abt. 2; Lief. 3, Cephalopoda. R. Oldenbourg, München und Leipzig, p. 329-522.

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Typescript submitted: 15.10.1998
Revised typescript received: 15.1.1999

Explanation of Plates

PLATE 1

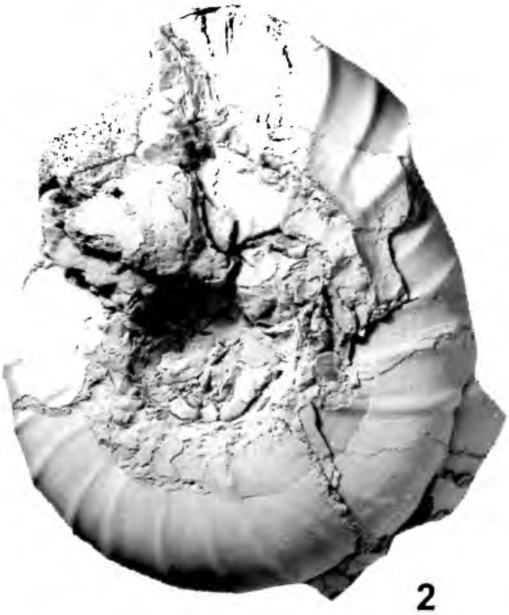
Figs. 1-3 — *Pachydiscus (Pachydiscus) hornbyense* JONES, 1963. BH1 4140, Bearpaw Shale, Upper Campanian, *Baculites jenseni* or *B. eliasi* zone, south of Fort Peck, Garfield County, Montana. Figures are x 1.

Figs. 4-5 — *Pachydiscus (Pachydiscus) catarinae* (ANDERSON & HANNA, 1935), USNM 486635, cast of a specimen from the Pierre Shale, Upper Campanian, *Exiteloceras jenneyi* zone, NE1/4 Sec. 23, T.18S, R.64W., Pueblo County, Colorado. Figures are reduced x 0.66.

PLATE 2

Figs. 1, 2 — *Pachydiscus (Pachydiscus) hornbyense* JONES, 1963. BH1 4139, Pierre Shale, Upper Campanian, *Baculites cuneatus* or *B. compressus zone*, Elk Creek, Pennington County, South Dakota. Figures are x 1.


1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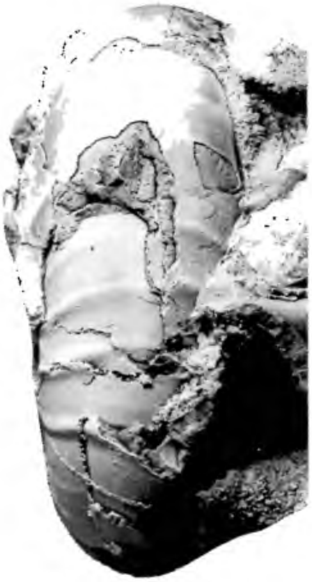
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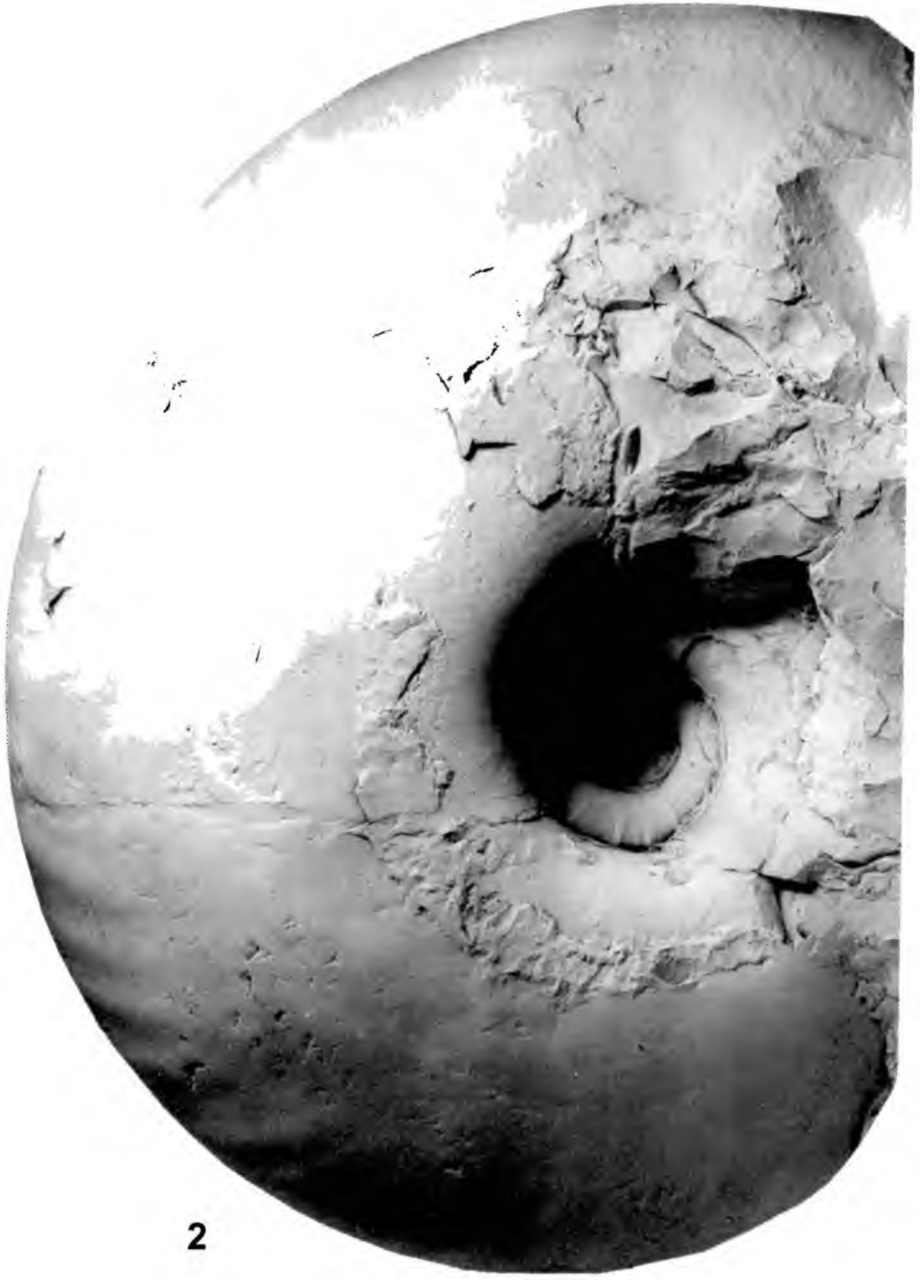
PLATE 1

PLATE 2

1



2

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 129-145, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 129-145, 1999

Foraminiferal distribution across the Maastrichtian/Danian boundary of Mangyshlak peninsula (West Kazakhstan)

by Lyudmila F. KOPAEVICH & Vladimir N. BENIAMOVSKII

Abstract

The planktonic and benthic foraminiferal distribution, resulting from bed by bed sampling across the Maastrichtian/Danian boundary was studied in detail from the Koshak and Kyzylsai sections in the Mangyshlak peninsula (West Kazakhstan). The distribution of planktonic (PF), benthic (BF) Foraminifera and nannoplankton is analysed. The stratigraphically most important species are illustrated and the biostratigraphic distribution from the Mangyshlak is compared with that from other areas of northern Europe.

Key-words: K/T boundary - Mangyshlak - Kazakhstan - Foraminifera

Résumé

Sur base d'un échantillonnage banc par banc de part et d'autre de la limite Maastrichtien/Danien, la distribution des foraminifères planctoniques et benthiques a été étudiée en détail dans les sections de Koshak et Kyzylsai situées dans la péninsule du Mangyshlak (Kazakhstan occidental). La distribution des foraminifères planctoniques (PF) et benthiques (BF) ainsi que du nannoplancton est analysée. Les espèces les plus importantes au point de vue stratigraphique sont figurées; la répartition stratigraphique des espèces dans le Mangyshlak est comparée avec celle observée dans d'autres régions d'Europe septentrionale.

Mots-clefs: Limite K/T, Mangyshlak, Kazakhstan, foraminifères

Резюме

Изучено распределение планктонных и бентосных фораминифер в послойно собранных образцах из разрезов Кызылсай и Кошак (полуостров Мангышлак, Западный Казахстан). Проанализировано стратиграфическое значение фораминиферовых и нанопланктонных комплексов и выделенные зональные подразделения сопоставлены с другими регионами. Приведены в таблицах изображения некоторых важных в стратиграфическом отношении видов.

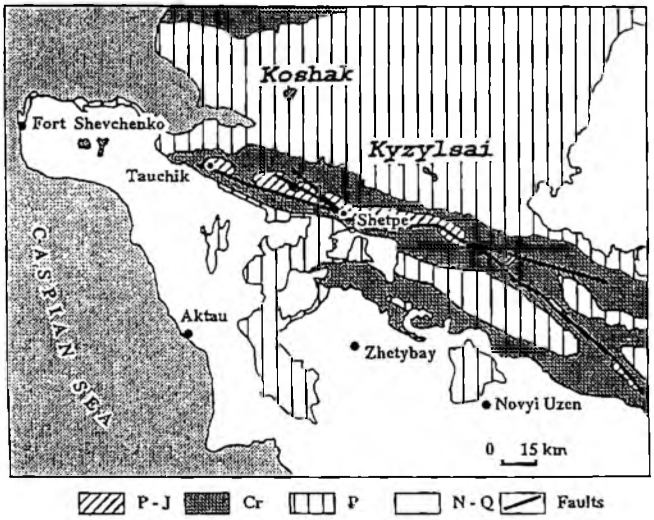
Ключевые слова: Граница мел/палеоген – Мангышлак, Казахстан, фораминиферы

Introduction

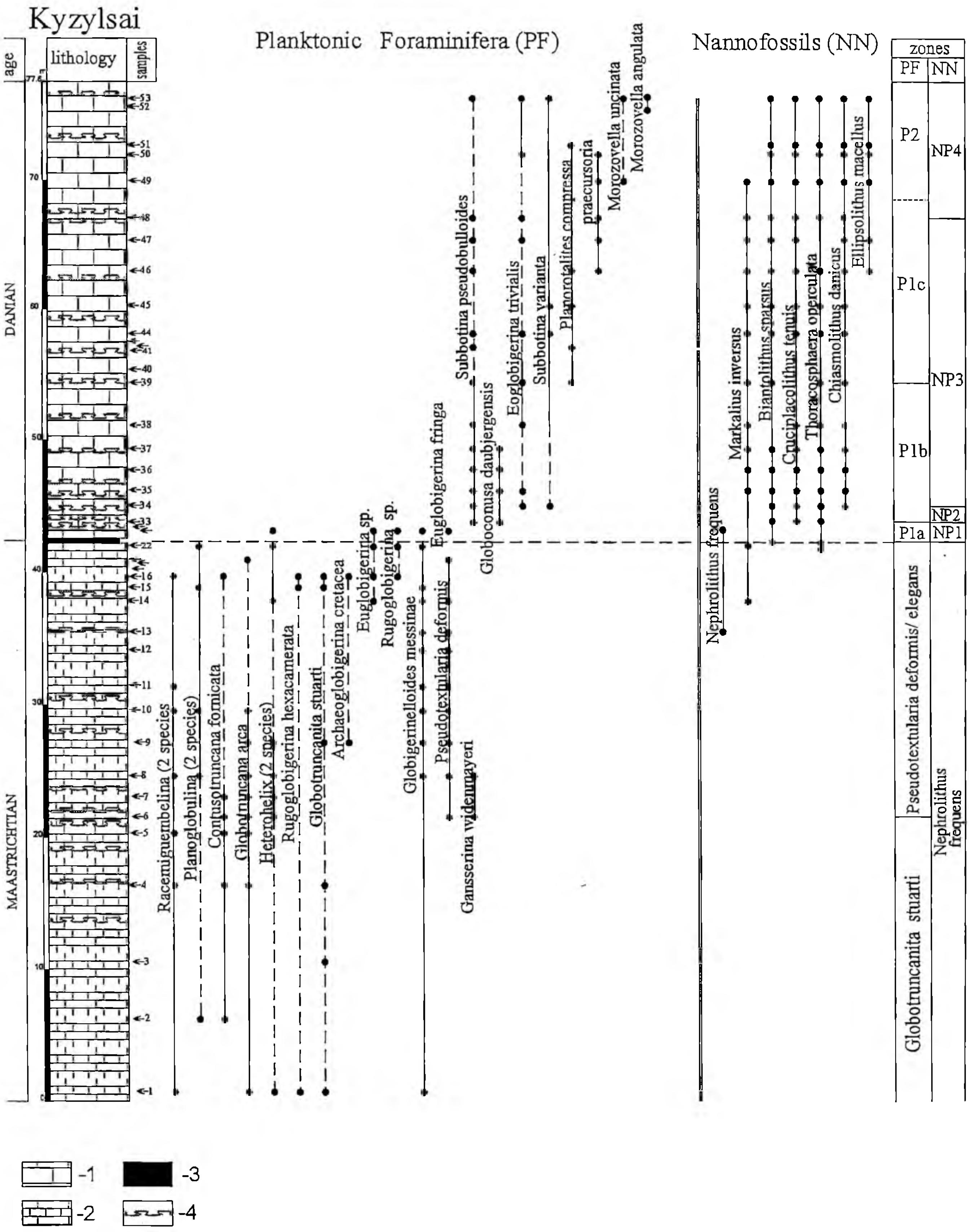
Herein the discussion on the K/T boundary is based on our field observations in western Mangyshlak, where Maastrichtian and Palaeocene are widespread and well exposed. When describing the extent of the exposures in Mangyshlak, ANDRUSOV wrote: ''If in Central Russia we should number the outcrops, here we would number the unexposed sites'' (ANDRUSOV, 1915, p. 111).

During the Late Cretaceous the Mangyshlak peninsula was covered by a relatively shallow marine basin belonging to the central part of the Tethys margin. This basin had a wide connection with the northern Tethys and with the Boreal seas of the Russian Platform. Because of the similarity in taxonomic composition of its marine fauna with fauna from northern Europe, it is generally included in the European palaeobiogeographical area — EPA (NAIDIN, 1969, Text-Fig. 1).

The Mangyshlak peninsula is a classic area for the study of the Upper Cretaceous and lower Palaeogene. The Cretaceous and Palaeogene stratigraphy in Mangyshlak were studied as early as the end of the nineteenth century (SEMENOV, 1899). Later on ANDRUSOV (1915), ALEKSEITCHIK (1941), TRIFONOV (1959), TRIFONOV & BURAGO



Text-figure 1 — Map of Mangyshlak peninsula, with location of Kyzylsai and Koshak sections. P-J: Permian to Jurassic; Cr: Cretaceous; P: Palaeogene; N-Q: Neogene to Quaternary.



Text-figure 2 — Distribution of the most important planktonic Foraminifera and the nannoflora in the Kyzylsai section around the K/T boundary. 1: limestones; 2: chalks and marls; 3: boundary clays; 4: hardground surfaces.

(1960) and BYKOVA (1960) studied this region. The most complete description of the sequences including their macro- and mainly micropalaeontological characteristics were published by VASSILENKO (1961), TRIFONOV & VASSILENKO (1963) and more recently by NAIDIN *et al.* (1984a, b, 1996). VASSILENKO proposed the first benthic foraminiferal zonation for all Upper Cretaceous of Mangyshlak.

In this paper data are presented on the distribution of the Foraminifera from two important K/T boundary sections — Koshak and Kyzylsai (see Text-Fig. 1). These sections, located on the slopes of the northern Aktau Mountains on Mangyshlak peninsula, West Kazakhstan, are continuous across the Cretaceous/Palaeogene (K/T) boundary, with only minor hardgrounds within the Upper Maastrichtian and Lower Danian. These sequences contain a rich macrofaunal assemblages composed of ammonites, belemnites, brachiopods, echinoids and bivalves. The microfossil assemblages are dominated by benthic components, typical for a rather shallow chalk facies. The first data on the K/T boundary from Mangyshlak were published by NAIDIN *et al.*, 1990a, b. These authors described the macro- and micropalaeontological assemblages; the Foraminifera from this interval, however, were not illustrated. A list of Foraminifera from the Koshak section was published by KELLER *in* OBERHÄNSLI *et al.*, (1998), without illustrations. In the present paper many taxa — planktonic and benthic — are illustrated and the correlation with other areas is discussed.

Geological setting

The detailed lithostratigraphic description of this region is published in NAIDIN (1986, 1987), HERMAN *et al.* (1988), SARKAR *et al.* (1992), OBERHÄNSLI *et al.* (1998). In these sections 140-150 m of Maastrichtian chalks and marls are overlain by 40-60 m of Danian limestones. The Maastrichtian soft chalks are composed almost exclusively of biogenic carbonates. The chalks are intercalated with yellowish-brown marls containing hardground horizons. The K/T transition is marked by a 1-4 cm thick dark layer, with remarkably sharp boundaries with the carbonates above and below. This dark layer is the boundary clay and coincides with the K/T boundary. In some exposures the clay is replaced by equally thin greenish-gray marls (75-85% $CaCO_3$), containing glauconite, plagioclase and angular quartz grains, as well as limonite and pyrite concretions. Abundant, minute fish bones and scales have also been observed; they are very similar to those in the "Fish Clay" at Stevns Klint, in Denmark (ROSENKRANTZ, 1924). The boundary clay contains illite, mixed-layer illite/smectite and chlorite (HERMAN *et al.*, 1988). Palygorskite is present throughout the Maastrichtian and Danian, reaching peak abundance in samples just above the K/T boundary (25-40 cm). Mineralogically the boundary clay is similar to the clay fraction of rocks in the K/T sections from other localities (RAMPINO & REYNOLDS, 1983). Furthermore, palygorskite is widely distributed in the Mangyshlak section and in sections from other areas (CALLEN, 1984).

In this boundary clay between Maastrichtian and Danian strata an Ir enrichment of maximum 7 ppb and 3-4 ng/g, respectively has been reported (NAZAROV *et al.*, 1983; HERMAN *et al.*, 1988). The basal Danian is an 1.5 m thick extremely hard yellowish-brown and white limestone with burrows in the Kyzylsai section. In the Koshak section the boundary clay is overlain by about 2.5 m light-yellow, coarse chalk. The basal layers grade into a white fine-grained hard limestone with irregular marly intercalations and several hardground surfaces (Text.-Fig. 2-5).

Material and methods

Eighty two samples, taken at intervals of 30 cm to 2.5 m, were collected from the Koshak and Kyzylsai sections. Samples weight varied from 150 to 200 g and they were disintegrated in water, then washed through a 63 µm sieve and dried in an oven before biostratigraphic analysis. The preservation is good to fair in the chalks of the Maastrichtian of the two sections examined. In contrast, preservation is generally poor in the coarse chalks and chalky limestones of the base of the Danian but it is better in the white fine-grained hard limestones of the upper part of the Danian. Planktonic foraminiferal identifications are based on commonly used taxonomy and illustrations including ROBASZYNSKI *et al.* (1984), MACLEOD & KELLER (1994). Identification of benthic Foraminifera are mainly based on BROTZEN (1948), VASSILENKO (1961) and GAWOR-BIEDOWA (1992).

PALAEONTOLOGY

Macrofossils

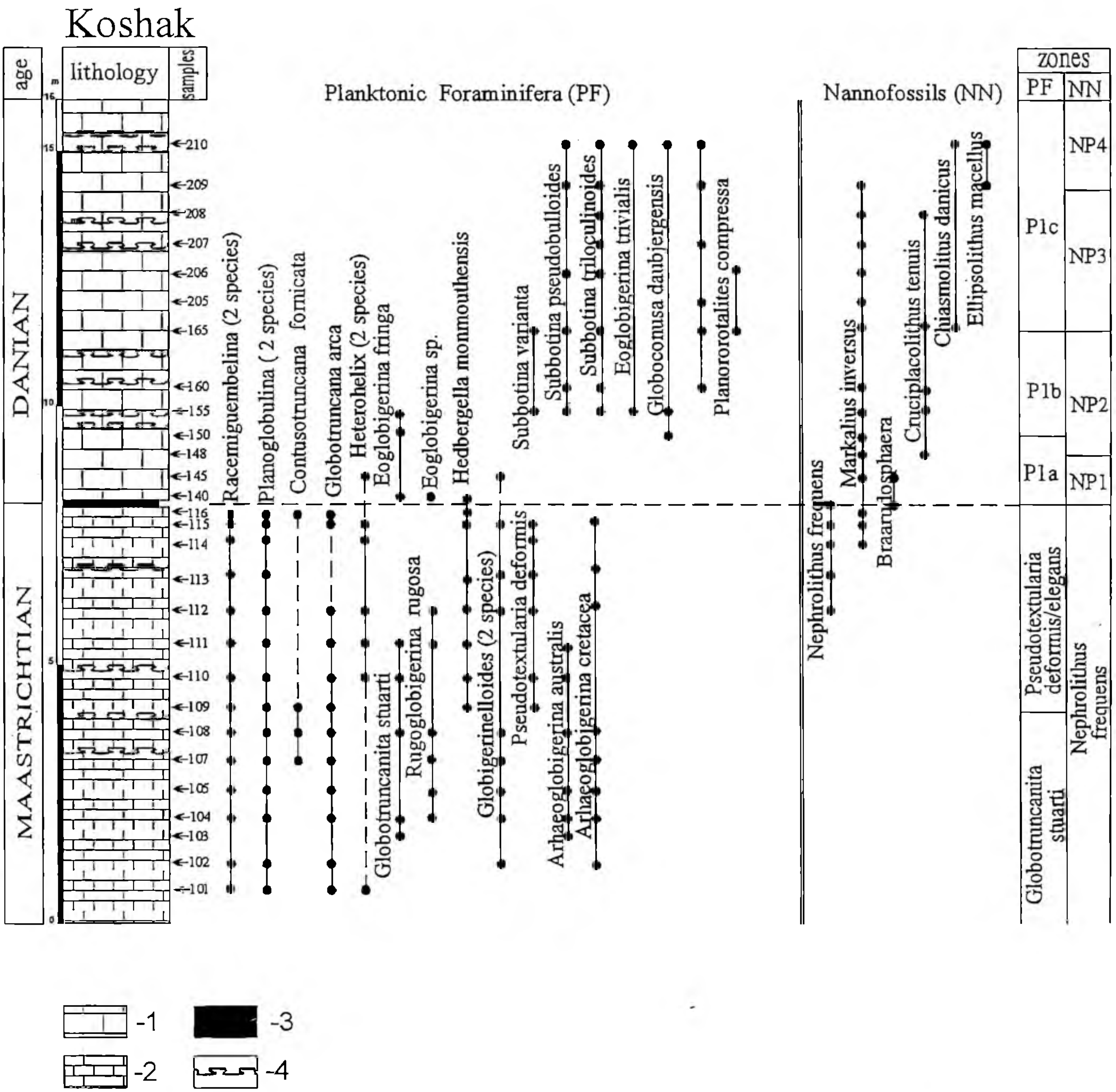
The following Upper Maastrichtian index fossils are present in the uppermost of Cretaceous of both sections: ammonites: *Hoploscaphites constrictus* (J. Sowerby), *H. constrictus crassus* (Lopuski). Abundant belemnites — *Neobelemnella kazimiroviensis* (Skolozdrowna) extend to the top of Maastrichtian. Echinoids are also common: *Cyclaster integer* Seunes, *Echinocorys ciplyensis* Lambert, *E. arnaudi* Seunes, *E. meudonensis* Lambert, *E. pyramidata* Portlock, *Gauthieria radiata broecki* Lambert and *Salenidia pygmea* (von Hagenow). Corals, bryozoans and brachiopods have also been observed.

The Danian limestones contain numerous echinoderms dominated by *Brissopneustes aturicus* Seunes, *Cyclaster danicus* Schlüter, *Echinocorys obliqua* (Ravn) and *E. pyrenaica* Seunes. Corals, bryozoans and brachiopods were also frequently encountered.

There is a marked macrofaunal change at the K/T boundary (HERMAN *et al.*, 1988; NAIDIN *et al.*, 1990a).

Foraminiferal Zonation

Planktonic Foraminifera (PF). Planktonic foraminiferal



Text-figure 3 — Distribution of the most important planktonic Foraminifera and the nannoflora in the Koshak section around the K/T boundary. 1: limestones; 2: chalks and marls; 3: boundary clay; 4: hardground surfaces.

assemblages in the Upper Maastrichtian of Mangyshlak peninsula show a low diversity. They are dominated by *Globigerinelloides*, heterohelicids and hedbergellids which comprise up to 80-90% of the planktonic part of the thanatocoenosis. Globotruncanids are very rare except in the intervals characterized by a high planktonic/benthic ratio (P/B). Among the globotruncanid assemblages, shallow-water species of the genera *Globotruncana* and *Rugoglobigerina* occur most frequently. The PF assemblage consists here of *Globotruncana arca* (Cushman), *Contusotruncana fornicata* (Plummer), *Globotruncanella petaloidea* (Gandolfi), *G. havanensis* (Voorwijk), *Globotruncanita stuarti* (de Lapparent), *Rugoglobigerina rugosa* (Plummer), *R. hexacamerata* Brönnimann, *Archaeoglobigerina cretacea* (d'Orbigny), *Globigerinelloides messinae* Brönnimann, *Gl. volutus* White, *Gl. clavatus* Brönnimann, *Hedbergella monmouthensis* (Olsson), *Heterohelix globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *Pseudotextularia deformis* (Kikoine), *Planoglobulina brazoensis* Martin, *P. carseyae* (Plummer), *Racemiguembelina fructicosa* (Egger) (Text-Fig. 2,3). *Gansserina wiedenmayeri* (Gandolfi), a typical Tethyan species was found only in two samples (6,7) of the Kyzylsai section. The higher Maastrichtian samples only contain poor assemblages of ubiquitous PF species. The first Danian forms — *Eoglobigerina* sp. - appears already in the uppermost samples of the Maastrichtian chalk in both sections.

The tropical-subtropical zonation (BOLLI, 1966; ROBASZYNSKI *et al.*, 1984; CARON, 1985) cannot be used in Mangyshlak because of the rarity or the absence of its index forms: *Globotruncana aegyptiaca* (Nakkady), *Gansserina gansseri* (Bolli) and *Abathomphalus mayaroensis* (Bolli).

Another zonation was proposed by MASLAKOVA (1978); she subdivided the Maastrichtian in two Zones. In her scale a *Globotruncanita stuarti* Zone (Lower Maastrichtian) and an *Abathomphalus mayaroensis* Zone (Upper Maastrichtian) are used. A recent study of Crimean sections showed, that the upper part of the *Globotruncanita stuarti* Zone coincides with the lower part of the Upper Maastrichtian - the beginning of *Neobelemnella kazimiroviensis* macropalaeontological Zone (ALEKSEEV & KOPAEVICH, 1997, p. 110, Text-Fig. 6) that is the standard Upper Maastrichtian zone for the eastern part of EPA (NAIDIN *et al.*, 1984). The presence of the zonal species allows to recognise the upper part of the *Globotruncanita stuarti* Zone in the Kyzylsai and Koshak sections. The next correlatable level is at the sharp increase of representatives of the genera *Pseudotextularia, Planoglobulina* and *Racemiguembelina.* This level coincides with the base of the *Pseudotextularia elegans* or *P. deformis* Zone (uppermost part of the Maastrichtian) in many sections of the EPA and of North America: Germany, Russian Platform, Mangyshlak (WICHER, 1953; KOCH, 1977) NAIDIN *et al.*, 1990 b; BENIAMOVSKII & KOPAEVICH, 1998; JONES *et al.*, 1987; KELLER, 1989). In Central Poland the equivalent of this zone is easily recognized by the presence of abundant representatives of heterohelicids, considerable numbers of *Rugoglobigerina* and *Globigerinelloides* and the absence of *Globotruncana* (PERYT, 1980). According to KELLER *in* CANUDO *et al.* (1991, p. 327) "the *Abathomphalus mayaroensis* Biozone is geographically and ecologically restricted and an alternative biozone, *Pseudotextularia deformis* was proposed for shallow water sequences".

In the boundary clay no PF were found. However, this PF "barren-interval" (KAIHO & SAITO, 1986) is the equivalent of the P0 (?) Zone of SMIT (1982) established for the K/T boundary sequence near Caravaca (Spain) and at El-Kef (Tunisia) and it coincides with the boundary clay (KELLER *et al.*, 1988 a, b).

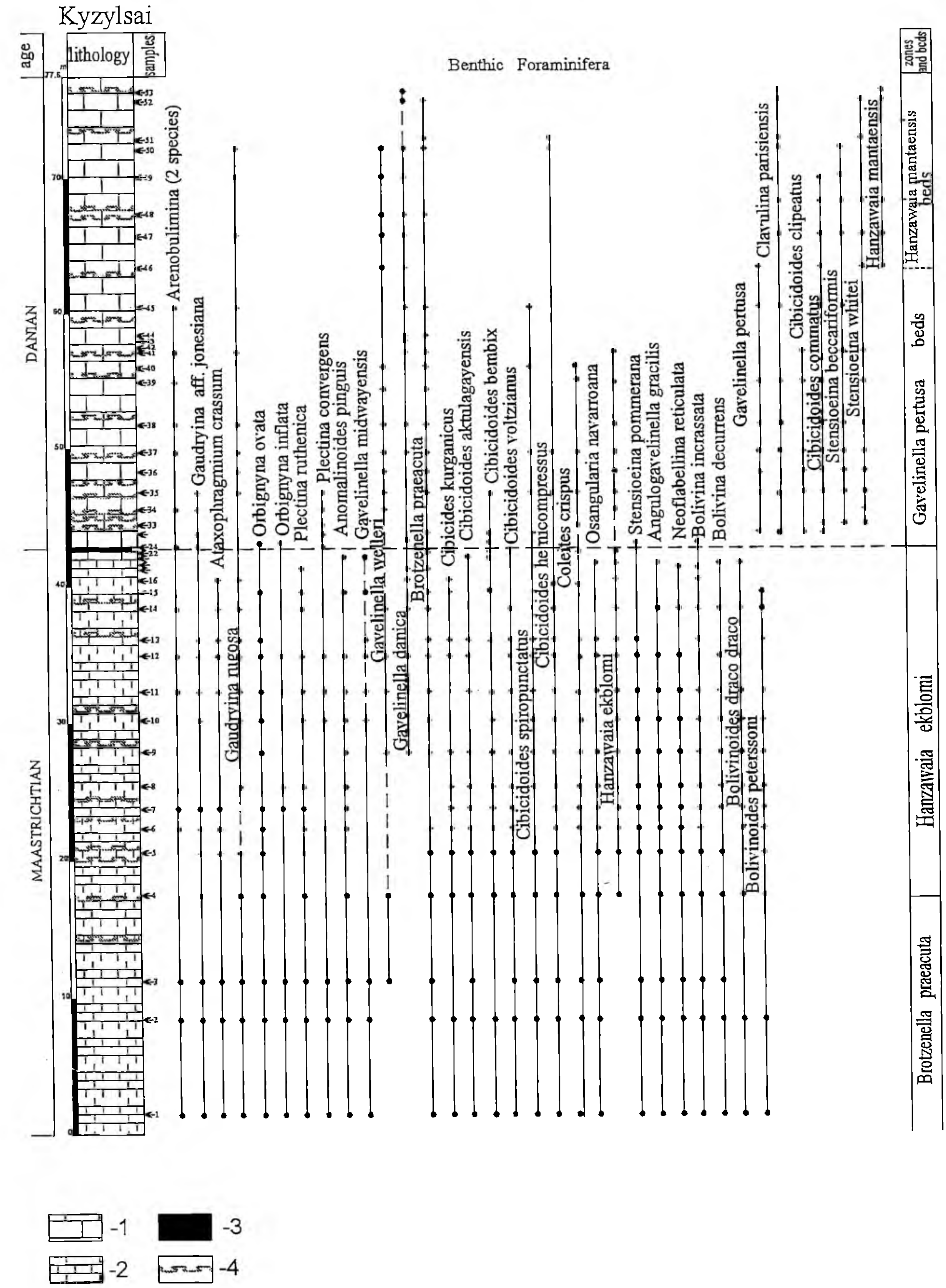
The first, very rare Tertiary species, including *Eoglobigerina fringa* (SUBBOTINA), *Eoglobigerina* sp. and rare "survivor" Maastrichtian species — small *Heterohelix-Hedbergella-Globigerinelloides* taxa — are present in the base of the Danian (Text-Fig. 2, 3). Occasionally sections of tiny (0.1-0.12 mm), compressed foraminiferal tests, similar to *Parvulorogoglobigerina eugubina* (Luterbacher & Premoli Silva) were observed in thin sections. This interval is correlated with the *Parvulorugoglobigerina eugubina* Zone (LUTERBACHER & PREMOLI SILVA, 1964; PREMOLI SILVA & BOLLI, 1973) or P1a Zone. The thickness of this Zone is about 1.5 m thick at Kyzylsai and about 2.5 m in the Koshak sections.

Higher up, in a 27 m thick interval at Kyzylsai and a 20 m thick interval at Koshak, PF become more abundant and their overall size increases. The following typical Danian taxa have been identified: *Subbotina pseudobulloides* (Bolli), *S. varianta* (Subbotina), *S. triloculinoides*, (Plummer), *Eoglobigerina trivialis* (Subbotina) and a single *Globoconusa daubjergensis* (Brönnimann). This assemblage is attributable to the *Subbotina pseudobulloides* Zone or P Ib Zone (CAVELIER & POMEROL, 1983, 1986). This zone was first described by LEONOV & ALIMARINA (1961) as *Globigerina pseudobulloides-Globigerina daubjergensis* Zone and the shortened name was introduced by BOLLI, (1966). The next zone - the *Planorotalites compressa* Zone is characterized by the FA of the index-species *Planorotalites compressa* (Plummer) and *Morozovella praecursoria* (Morozova) and also by the presence of *Subbotina pseudobulloides* (Bolli), *Globoconusa daubjergensis* (Brönnimann) (Text-Fig. 2,3). This interval is the equivalent of the *Morozovella trinidadensis* Zone - P1c (CAVELIER & POMEROL, 1983, 1986; TOUMARKINE & LUTERBACHER, 1985). The uppermost part of the Kyzylsai section (samples 49-55) is marked by the presence of *Morozovella uncinata* (Bolli) — P2 Zone (BOLLI, 1966; CAVELIER & POMEROL, 1983, 1986; TOUMARKINE & LUTERBACHER, 1985).

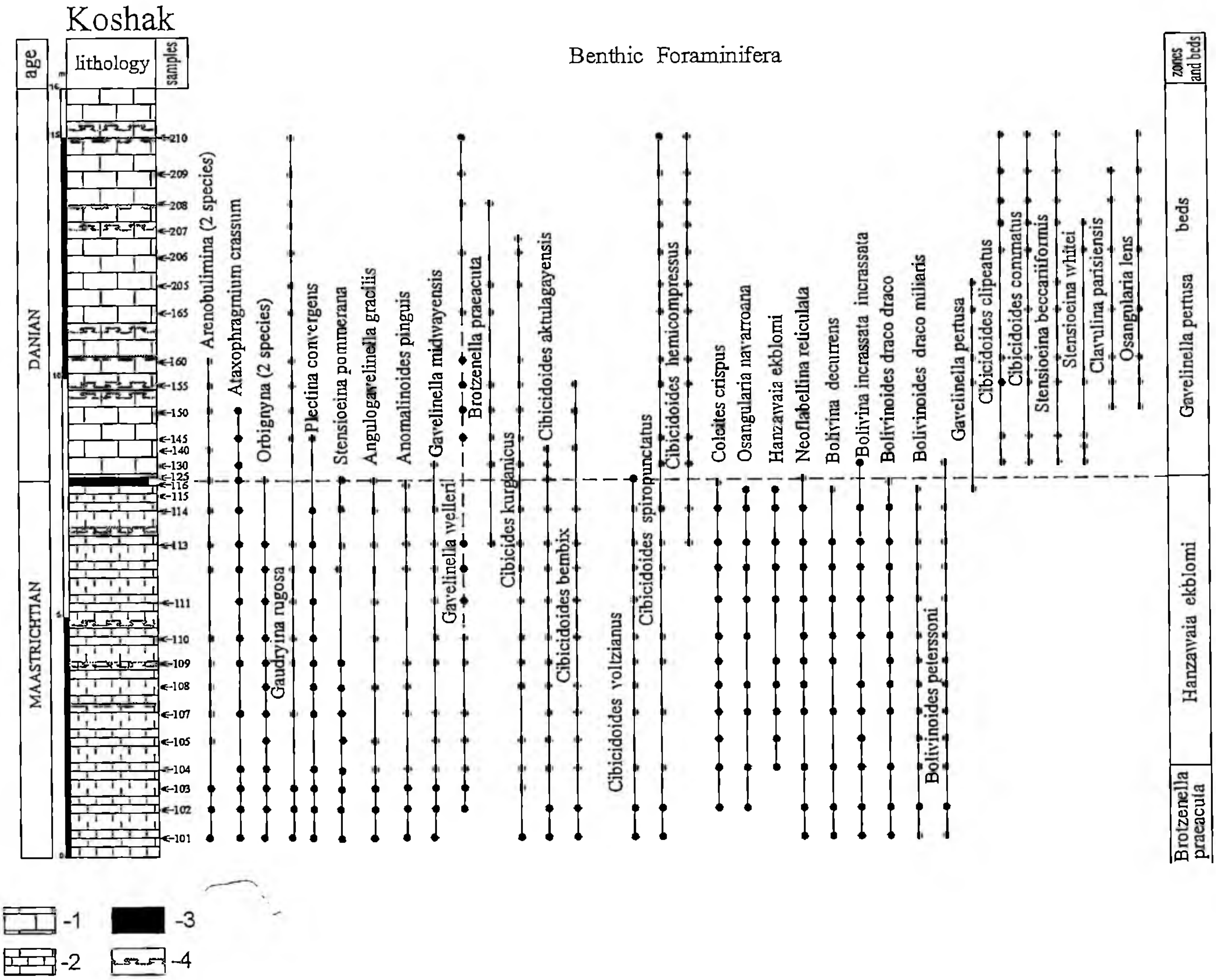
Benthic Foraminifera (BF). Maastrichtian and Danian deposits in both sections are very rich in BF. The uppermost part of the Maastrichtian contains stratigraphically important taxa of the genera *Bolivinoides, Neoflabellina, Bolivina* and other taxa of *Gavelinella, Brotzenella* and *Cibicidoides.* On the basis of the BF distribution in Mangyshlak the following zonation is presented: for the Maastrichtian the *Brotzenella praeacuta* Zone - BF12 for the lower part and the *Hanzawaia ekblomi* Zone BF13 for the upper part of both sections (NAIDIN *et al.*, 1984, a, b; BENIAMOVSKII & KOPAEVICH, 1998). This zonation was proposed for the eastern part of EPA by NAIDIN *et al.*, (1984) and was recognised without any difficulties in following regions: Peri-Caspian depression, Crimea, northern part of Turgai Straight and southern Urals (ALEKSEEV & KOPAEVICH, 1997; AMON *et al.*, 1997; BENIAMOVSKII & KOPAEVICH, 1998).

The general taxonomic composition of BF assemblages from both studied sections is very similar to those from northern Europe - Belgium (ROBASZYNSKI *et al.*, 1985; ROBASZYNSKI & CHRISTENSEN, 1989) and Northern Germany (SCHÖNFELD, 1990; SCHÖNFELD & BURNETT, 1991; BENIAMOVSKII & KOPAEVICH, 1998).

The boundary clay contains a very poor and particular BF assemblage. Only agglutinated BF show a good preservation and high diversity, whereas calcareous BF are few in number and show traces of dissolution. The limestones from the Kyzylsai and the coarse chalk from the



Text-figure 4 — Distribution of the most important benthic Foraminifera near the K/T boundary in the Kyzylsai section. 1: limestones; 2: chalks and marls; 3: boundary clay; 4: hardground surfaces.

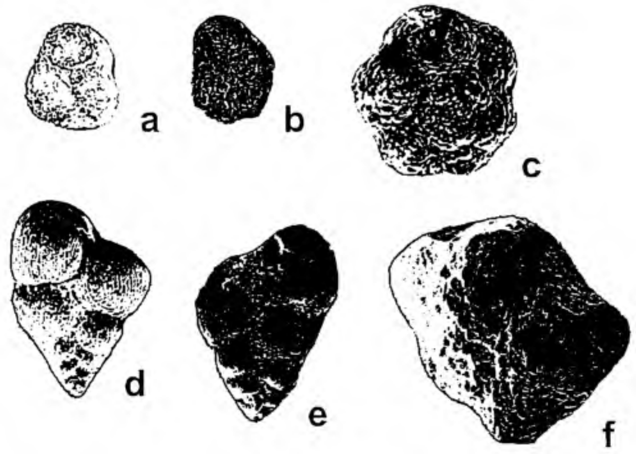


Text-figure 5 — Distribution of the most important benthic Foraminifera near the K/T boundary in the Koshak section. 1: limestones; 2: chalks and marls; 3:boundary clay; 4: hardground surfaces.

Koshak sections just above the boundary clay, also contain a poor BF assemblage, including a few Maastrichtian species. Gradually a few, new Danian species appear higher up such as *Stensioeina whitei* (Morozova), *S. beccariiformis* (White), *Osangularia lens* (Brotzen), *Cibicidoides clipeatus* (Vassilenko), *Spiroplectammina dentata* (Alth), *Clavulina parisiensis* (d'Orbigny) and *Hanzawaia mantaensis* (Galloway & Murrey) (Text-Fig. 4, 5). Several typical Maastrichtian species also still occur in the lowermost Danian. In younger Danian horizons the taxonomic diversity was restored to the same level as existing in the Upper Maastrichtian (Text-Fig. 4, 5).

Calcareous nannofossils

The calcareous nannofossils were studied by K. Perch-Nielsen (see Herman *et al.*, 1988) for the Kyzylsai section and by G. Kalinitchenko (see Naidin *et al.*,1990 b) for both sections. In all Maastrichtian samples, the calcareous nannofossils are moderately to well preserved. They include *Nephrolithus frequens* (Górka) the marker species for the Late Maastrichtian in high latitudes, and *Cribrosphaerella daniae* Perch-Nielsen, also a high latitude form restricted to the uppermost Maastrichtian in the Kyzylsai section. *Arkhangelskiella cymbiformis* Vekshina, *Cribrosphaerella ehrenbergi* (Arkhangelsky), *Lithraphidites quadratus* Bramlette & Martini, *Biscutum* sp. , also are present. *Micula mura* (Martini), the marker for low latitude Late Maastrichtian is rarely present in a few samples of the Kyzylsai section. Very rare *Obliquipithonella operculata* (Bramlette & Martini), *Braarudosphaera bigelowii* (Gran & Braarud) and *B. discula* Bramlette & Riedel were found about 2-5 cm below the K/T boundary. Very rare *Obliquipithonella cf. operculata* Bramlette & Martini fragments were found in the boundary clay itself. *Markalius inversus* (Deflandre) and *Biantholithus sparsus* Bramlette & Martini, the marker of the basal Danian in Denmark, are present here and in good preservation. The remainder of the assemblage in



Text-figure 6 — Planktonic Foraminifera from the P1a Zone.
a. *Eoglobigerina fringa* (Subbotina): umbilical side, Koshak section, sample 140 (X70)
b. *Globigerinelloides messinae* Brönnimann: Koshak section, sample 141 (X70).
c. ? *Hedbergella monmouthensis* (Olsson): Koshak section, sample 141 (X70).
d and e. *Heterohelix striata* (Ehrenberg): Koshak section, sample 141 (X70).
f. *Planoglobulina brazoensis* Martin: Koshak section, sample 140 (X80).

the boundary clay is identical to the underlying Maastrichtian assemblages, however, calcareous nannofossils are rare and poorly preserved. Just above the boundary clay the sediments contain a poor assemblage of nannofossils: *Markalius inversus* (Deflandre) (80% of all taxa), *Biantolithus sparsus* Bramlette & Martini, *Coccolithus cavus* Hay & Mohler, *Obliquipithonella operculata* Bramlette & Martini, *Braarudosphaera bigelowii* (Gran & Martini), *B. discula* Bramlette & Riedel are common and several Maastrichtian species are still present here. This interval represents the Lower Danian the NP1 (*Markalius inversus*) Zone (Text-Fig. 2, 3).

In the younger samples, the presence of *Cruciplacolithus tenuis* Stradner, zonal species of NP 2 suggests that the base of this Zone lies at the level of sample 33 in the Kyzylsai section and of sample 146 in the Koshak section. *Chiasmolithus danicus* (Brotzen), the marker of the Danian NP3 Zone was found in sample 35 of the Kyzylsai section and in sample 165 of Koshak section. Only typical Palaeocene species characterize this zonal assemblage. The appearance of *Ellipsolithus macellus* (Bramlette & Sullivan) and other species suggest the presence of the NP4 Zone in Kyzylsai section.

Correlations

The correlation of the K/T boundary interval for the two studied sections on PF data with other regions of EPA is straightforward. The *Pseudotextularia deformis/elegans* Zone is a typical subdivision for shallow water sequences (see above). This zone is characterised by the presence of the index-species associated with that of other species of multiserial heterohelicids such as *Racemiguembelina* and *Planoglobulina*, but also by a similar very sharp increase in the P/B ratio. This change of P/B ratio is probably related to a eustatic sea-level rise and an influx of warm Tethyan water-mass into the EPA, the so-called "elegans-transgression" (Wicher, 1953; Naidin *et al.*, 1990 b; Beniamovskii & Kopaevich, 1998). The sea-level rise prior to the K/T boundary is supported by the reappearance of *Abathomphalus mayaroensis* (Bolli) in the youngest samples just below the boundary both in Zumaya (Spain) and Ain Settara (Tunisia) (Molina *et al.*, 1998). It is interesting that the presence of a short-term warming at the end of the Maastrichtian is also present in Southern hemisphere, in the South Atlantic (Li & Keller, 1998 a,b). Stable isotope analysis showed a major warm pulse between 66.45 and 65.11 Ma, which increased temperatures by 2-3° C in intermediate waters, and decreased the vertical thermal gradient to an average of 2.7°C.

Planktonic Foraminifera provide a high resolution biozonation for the K/T boundary and various zonal schemes have been proposed (Text-fig. 6). Among these, the zonal scales of Smit (1982), Keller (1988 a; 1993; also *in* Canudo *et al.*, 1991) and the scale of the present paper are very similar, but differ from that proposed by Berggren & Miller, 1988. The presence of Zone P0 marks the boundary clay and Zone P1a marks the base of the Danian. The Mangyshlak PF data show a close similarity with Danish sections (Bang, 1979; Håkansson & Hansen, 1979). In both regions towards the end of the *Pseudotextularia deformis* Zone, the genus *Globotruncana* disappeared and the *Heterohelix - Hedbergella - Globigerinelloides* assemblage became dominant and some of them can be followed into the base of the Danian. The PF assemblages of the terminal Maastrichtian, just below the boundary clay are very poorly preserved in Denmark and in Mangyshlak.

PF are practically absent within the boundary clay (P0 Zone), except for a few small survivors species of *Heterohelix, Hedbergella* and *Globigerinelloides* in Denmark and in Mangyshlak.

PF are very scarce in the base of the Danian, represented by a few Palaeocene species in Mangyshlak: *Eoglobigerina fringa* (Subbotina), *Eoglobigerina* sp. and possibly *Parvulorugoglobigerina eugubina* (Luterbacher & Premoli Silva). In the subzone P1a Cretaceous survivors disappeared. In several sections of North Jutland (Kjölby Gaard and "Dania" Quarry) just above the boundary clay PF are absent (equivalent of the "a-planktonic zone" of Hofker, 1978), but sometimes (section Nye Kløv) *Eoglobigerina danica* Zone was recognized. In addition to the genus *Eoglobigerina*, this Zone is characterized by *Chiloguembelina* spp., *Woodringia* sp. and *Guembelitria* spp. The thickness of this interval at Dania is about 2-5 m (Bang, 1979; Håkansson & Hansen, 1979), very similar with P1a Subzone of the Mangyshlak sections. The upper boundary of the *Eoglobigerina danica* Zone is defined by the first occurrence of *Globoconusa daubjergensis* (Brönnimann).

Higher Danian deposits in Mangyshlak contain typical

Palaeocene PF, among which *Subbotina pseudobulloides* (Plummer) and *Globoconusa daubjergensis* (Brönnimann) are very important. The PF zonation of Mangyshlak is closely correlatable with the standard nannofossil zonation (MARTINI, 1970; THIERSTEIN, 1976; SISSINGH, 1978; PERCH-NIELSEN, 1979; OKADA & BUKRY, 1980).

The distribution of BF in the terminal Maastrichtian and Lower Danian is practically identical all over the EPA (see BENIAMOVSKII & KOPAEVICH, 1998).

Conclusions

1. According to foraminiferal data, the zonation across the K/T boundary of Mangyshlak can be applied without any difficulty to coeval strata in western Europe and especially in the Danish sections.
2. A deepening of the basin and warmer environmental conditions are indicated in the terminal chalk of the *Pseudotextularia deformis/elegans* Zone of both Mangyshlak sections (last 2-2.5 m), by the high P/B ratio. This terminal P/B increasing coincides with the short Late Maastrichtian *elegans* - transgression (WICHER, 1953).
3. The disappearance of PF inside the boundary clay coincided with the peak of the biotic crisis, generally attributed to a "global catastrophic event." This represented the time of lowest productivity for PF (PERCIVAL & FISCHER, 1977; GERSTEL *et al.*, 1986; KELLER, 1996). Our data show that the extinction of Cretaceous species occurred throughout an interval that extends from the uppermost *Pseudotextularia deformis/elegans* Zone through the Danian P1a Zone.
4. The occurrence of typical Danian species and the coeval disappearance of "Cretaceous" species begins in the *Subbotina pseudobulloides* Zone.

Acknowledgements

We are very grateful to Isabella Premoli Silva, F. Robaszynski and W. Kuhnt for their kind comments and suggestions, on an earlier version of the paper. The theme of this paper relates to project "INTAS-94-1414" and the "Integration" of Russian Federal Program.

References

ALEKSEEV, A. S. & KOPAEVICH, L. F., 1997. Foraminiferal biostratigraphy of the uppermost Campanian-Maastrichtian in SW Crimea (Bakhchisaray and Chakhmakhly sections). *Bulletin Institut royal Sciences naturelles de Belgique, Sciences de la Terre,* 67: 103-118.

ALEKSEITCHIK, S. N. Geologicheskoe stroenie i neftenosnost poluostrova Mangyshlaka. *Trudy NIGRI,* n.s., 16: 1-235 [in Russian].

AMON, E. O., BLUEFORD, J. R., DE WEVER, P. & ZHELEZKO, V. I., 1997. An essay on regional geology and stratigraphy of the Upper Cretaceous deposits of Southern Urals territories. *Geodiversitas,* 19 (2): 293-317.

ANDRUSOV, N. I., 1915. Materials for the Transcaspian Geology: Mangyshlak (Descriptive Part). *Trudy Aralo-Kaspiiskoi Ekspeditsii,* 8: 1-458 [in Russian].

BANG, I., 1979. Foraminifera in the lowermost Danian of Denmark. *In:* BIRKELUND, T. & BROMLEY, R. (eds). Proceedings of Symposium on Cretaceous — Tertiary Boundary Events: Copenhagen, Denmark. University of Copenhagen, 1: 108-114.

BENIAMOVSKII, V. N. & KOPAEVICH, L. F., 1998. Foraminiferid Zonation in the Upper Santonian — Maastrichtian of the European Palaeobiogeographical Area (EPA). *Zentralblatt für Geologie und Paläontologie, Teil I,* 1996, 11/12: 1149-1169.

BERGGREN, W. A. & MILLER, K. G., 1988. Paleogene tropical foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology,* 34: 362-380.

BOLLI, H. M., 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. *Boletino Informativo Asociacion Venezolano de Geologia, Mineria y Petroleo.* 9: 3-32.

BYKOVA, N. K., 1960. Danian and Paleogene deposits of North Mangyshlak and South Emba area. *International Geological Congress. XXI session. Reports of soviet geologists.* Problem 5. The Cretaceous-Tertiary boundary. 148-161 [in Russian].

CANUDO, J. I., KELLER, G. & MOLINA, E., 1991. Cretaceous/Tertiary boundary extinction pattern and faunal turnover at Agost and Caravaca, S. E. Spain. *Marine Micropaleontology,* 17: 319-341.

CARON, M., 1985. Cretaceous planktonic Foraminifera. *In:* H. M. BOLLI, J. B. SAUNDERS & K. PERCH-NIELSEN, Plankton stratigraphy, pp. 17-86. Cambridge University Press.

CAVELIER, C. & POMEROL, C., 1983. Echelle de corrélation stratigraphique du Paléogène. Stratotypes, étages standards, biozones, chimiozones et anomalies magnétiques. *Géologie de la France,* 3: 261-262.

CAVELIER, C. & POMEROL, C., 1986. Stratigraphy of the Paleogene. *Bulletin Société géologique de France,* (8) 2: 255-265.

GAWOR-BIEDOWA, E., 1992. Campanian and Maastrichtian Foraminifera from the Lublin Upland, Eastern Poland. *Acta Palaeontologica Polonica,* 52: 3-187.

GERSTEL, J., THUNNEL, R., ZACHOS, J. C. & ARTHUR, M. A.. 1986. The Cretaceous/Tertiary boundary events in the North Pacific: Plankton foraminifera results from Deep Sea Drilling Project Site 577, Shatsky Rise. *Paleoceanography,* 1, 2: 97-117.

HÅKANSSON, E. & HANSEN, J. M., 1979. Guide to Maastrichtian and Danian boundary strata in Jylland. *In:* BIRKELUND, T. & BROMLEY, R. (eds.). Proceedings of Symposium on Cretaceous - Tertiary Boundary Events: Copenhagen, Denmark. University of Copenhagen, 1: 171-188.

HERMAN, Y., BHATTACHARAYA, S. K., PERCH-NIELSEN, K., KOPAEVITCH, L. F., NAIDIN, D. P., FROLOV, V. T., JEFFERS, J. D. & SARKAR, A. 1988. Cretaceous-Tertiary boundary marine extinctions: The Russian Platform record. *Revista Española de Pa-*

leontologia, Numero Extraordinario. Paleontology and evolution: Extinction events, pp. 31-40.

Hofker, J., 1978. Analysis of a large succession of samples through Upper Maastrichtian and the Lower Tertiary of drillhole 47-2 Shatsky Rise, Pacific, Deep Sea Drilling Project. *Journal of Foraminiferal Research,* **8** (1): 46-75.

Jones, D. S., Mueller, P. A., Bryan, J. R., Dobson, J. P., Channell, J. E. T., Zachos, J. C. & Arthur, M. A. 1987. Biotic, geochemical and paleomagnetic changes across the Cretaceous/Tetiary boundary at Braggs, Alabama. *Geology,* **15**: 311-315.

Kaiho, K. & Saito, T., 1986. Terminal Cretaceous Sedimentary Sequence recognized in the Northernmost Japan based on Planktonic Foraminiferal Evidence. *Proceedings of the Japan Academy,* (5) **62**: 145-148.

Keller, G., 1988 a. Extinction, survivorship and evolution of planktic foraminifers across the Cretaceous/Tertiary boundary at El-Kef, Tunisia. *Marine Micropaleontology,* **13**: 239-263.

Keller, G., 1988 b. Biotic turnover in benthic foraminifera across the Cretaceous/Tertiary boundary at El-Kef, Tunisia. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **66**: 153-171.

Keller, G., 1989. Extended period of extinctions across the Cretaceous — Tertiary boundary in planktonic foraminifers of continental shelfs sections: applications for impact and volcanism theories. *Geological Society of America Bulletin,* **101**, 11: 140-1419.

Keller, G., 1993. The Cretaceous-Tertiary boundary transition in the Antarctic Ocean and its global implications. *Marine Micropaleontology,* **21**: 1-45.

Keller, G., 1996. The Cretaceous-Tertiary mass extinction on planktic Foraminifera: Biotic constraints for catastrophe theories. *In:* Macleod, N. & Keller, G., Eds., Cretaceous-Tertiary mass extinctions. W.W.Norton & Co. New York; pp. 45-84.

Keller, G., Adatte, Th., Hollis, Ch., Ordonez, M., Zambrano, M., Jimenez, N., Stinnesbeck, W., Aleman, A. & Hale-Erlich, W. 1997. The Cretaceous/Tertiary boundary event in Ecuador: reduced biotic effects due to eastern boundary current setting. *Marine Micropaleontology,* **31**: 97-133.

Keller, G. & Macleod, N., 1995. The Cretaceous/Tertiary boundary stratotype section at El Kef, Tunisia: how catastrophic was the mass extinction? *Palaeogeography, Palaeoclimatology, Palaeoecology,* **119**: 221-254.

Koch, W., 1977. Stratigraphie der Oberkreide in Nordwestdeutschland (Pompeckjische Scholle). T. 2. Biostratigraphie in der Oberkreide und Taxonomie von Foraminifera. *Geologisches Jahrbuch,* **A 38**: 3-123.

Leonov, G. P. & Alimarina, V. P., 1961. Stratigraphy and planktonic foraminifers of the "transitional" Cretaceous to Paleogene beds of the Central Precaucasus. Sbornik Trudov Geologicheskogo Fakulteta Moskovskogo Universiteta: pp. 29-53 [in Russian].

Li, L. & Keller, G., 1998. Abrupt deep-sea warming at the end of the Cretaceous. *Geology,* **26**: 995-998.

Lutterbacher, H. P. & Premoli-Silva, I., 1964. Biostratigraphia del limite Cretaceo-Terziario nell' Appennino centrale. *Rivista Italiana Paleontologia i Stratigrafia,* **70**: 67-128.

Macleod, N. & Keller, G., 1994. Comparative biogeographic analysis of planktic foraminiferal survivorship across the Cretaceous/Tertiary boundary. *Paleobiology,* **20** (2): 143-177.

Malmgren, B. A., 1982. Biostratigraphy of planktic Foraminifera from the Maastrichtian white chalk of Sweden. *Geologiska Föreningens Stockholm Förhandlingar,* **103**: 357-375.

Martini, E., 1970. Standard Palaeogene calcareous nannoplankton zonation. *Nature,* **226**: (5245), 560-561.

Maslakova, N. I., 1978. Globotruncanids from the southern part of European USSR. Nauka, Moscow. 166 pp. [in Russian].

Molina, E., Arenillas, I. & Arz, J. A. 1998. Mass extinction in planktic foraminifera at the Cretaceous/Tertiary boundary in subtropical and temperate latitudes. *Bulletin Société géologique de France,* **169** (3): 351-363.

Naidin, D. P., 1969. Biostratigraphie und Paläogeographie der Oberen Kreide der Russischen Tafel. *Geologisches Jahrbuch,* **A 87**: 157- 186.

Naidin, D. P., 1986. Cretaceous/Tertiary boundary in Mangyshlak and proposed events on the limit of the Maastrichtian and Danian. *Izvestia vuzov. Geologia i razvedka,* 9: 3-13 [in Russian].

Naidin, D. P., 1987. The Cretaceous-Tertiary boundary in Mangyshlak. U.S.S.R. *Geological Magazine,* **124**, 1: 11-19.

Naidin, D. P., Beniamovskii, V. N. & Kopaevich, L. F., 1984. A scale for a biostratigraphic subdivision of the Upper Cretaceous of the European palaeobiogeographical area. *Vestnik Moskovskogo Universiteta. (4) Geologia,* **5**: 3-15.

Naidin, D. P., Ben'yamovskii, V. N. & Kopaevich, L. F., 1996. Paleocene reference sections of Mangyshlak. *Stratigraphy and Geological Correlation,* 4 (3): 254-268.

Naidin, D. P., Kopaevich, L. F., Moskvin, M. M., Shimanskaya, N. V., Kalinitchenko, G. P. & Andreev, Ju. N., 1990a. Macropaleontological data on the Maastrichtian/Danian boundary from continuous sections in Mangyshlak. *Izvestia Akademii Nauk SSSR, Serija Geologia,* **11**: 3-15 [in Russian].

Naidin, D. P., Kopaevich, L. F., Moskvin, M. M., Shimanskaya, N. V., Kalinitchenko, G. P. & Andreev, Ju. N., 1990 b. Micropaleontological data on the Maastrichtian/Danian boundary of continuous sections in Mangyshlak. *Izvestia Akademii Nauk SSSR, Serija Geologia,* **12**: 68-82 [in Russian].

Nazarov, M. A., Barsukova, L. D., Kolesov, G. M., Naidin, D. P. & Alekseev, A. S., 1983. Origin of the iridium anomaly at the boundary between the Maastrichtian and Danian stages. *Geokhimia,* **8**: 1160-1178 [in Russian].

Oberhänsli, H., Keller, G., Adatte, T. & Pardo, A., 1998. Diagenetically and environmentally controlled changes across the K/T transition at Koshak, Mangyshlak (Kazakhstan). *Bulletin Société géologique de France* **169**, 4: 493-501.

Okada, H. & Bukry, D., 1980. Supplementary modification and introduction of code numbers to the lowlatitude coccolith biostratigraphic zonation. *Marine Micropaleontology,* **5** (3): 321-325.

Perch-Nielsen, K., 1979. Calcareous nannofossils in Cretaceous /Tertiary boundary sections on Denmark. *In:* Birkelund, T. & Bromley, R. (eds). Proceedings of Symposium on Cretaceous — Tertiary Boundary Events: Copenhagen, Denmark. University of Copenhagen, **1**: 115-135.

Percival, S. F. & Fischer, A. G., 1977. Changes in calcareous nannoplankton in the Cretaceous-Tertiary biotic crisis at Zumaya, Spain. *Evolutionary Theory,* **2**: 1-35.

Peryt, D., Lahodynsky, R., Rocchia, R. & Boclet, D., 1993. The Cretaceous/Paleogene boundary and planktonic foraminifera in the Flyschgosau (Eastern Alps, Austria). *Palaeogeography, Palaeoclimatology, Palaeoecology,* **104**: 239-252.

PREMOLI SILVA, I., 1977. Upper Cretaceous-Paleocene magnetic stratigraphy at Gubbio, Italy. Biostratigraphy. *Geological Society of America, Bulletin*, **88**, 2: 371-374.

PREMOLI-SILVA, I. & BOLLI, H. M., 1973. Late Cretaceous to Eocene planktonic foraminifera and stratigraphy of Leg 15 sites in Caribbean Sea. *In:* N. T. EDGAR *et al.*, *Initial Report Deep Sea Drilling Project*, **15**: 449-547.

RAMPINO, M. R. & REYNOLDS, R.G., 1983. Clay mineralogy of Cretaceous/Tertiary boundary clay. *Science*, **219** (4584): 495-498.

ROBASZYNSKI, F., BLESS, M. J., FELDER, P. J., FOUCHER, J.-C., LEGOUX, O., MANIVIT, H., MEESSEN, J.P.M.Th. & VAN DER TUUK, L. A., 1985. The Campanian-Maastrichtian boundary in the chalky facies close to the type-Maastrichtian area. *Bulletin Centre de Recherche, Exploration, Production Elf-Aquitaine*, 9: 1-113.

ROBASZYNSKI, F. & CHRISTENSEN, W. K., 1989. The Upper Campanian - Lower Maastrichtian chalks of the Mons basin: a preliminary study of belemnites and foraminifera in the Harmignies and Ciply areas. *Geologie en Mijnbouw*, **68**: 391-408.

ROSENKRANTZ, A., 1924. Nye lagtagelser over Ceritiumkalken i Stevns Klint med Bemaerkninger om Graeng sen mellom Kridt og Tertiaer. *Meddedelser Danske Geologiske Foreningerne*, **6**: 28-31.

SARKAR, A., BHATTACHARYA, S. K., SHUKLA, P. N., BHANDARI, N. & NAIDIN, D. P., 1992. High resolution profile of stable isotopes and iridium across a K/T/ boundary section from Koshak Hill, Mangyshlak, Kazakhstan. *Terra Nova*, **4**: 585-590.

SCHÖNFELD, J., 1990. Zur Stratigraphie und Ökologie benthischer Foraminiferen in Schreibkreide-Richtprofil von Lägerdorf/ Holstein. *Geologisches Jahrbuch*, **A 117**: 3-151.

SCHÖNFELD, J. & BURNETT, J. A., 1991. Biostratigraphical correlation of the Campanian-Maastrichtian boundary: Lägerdorf-Hemmoor (northwestern Germany), DSDP Site 548A, 549 and 551 (eastern North Atlantic) with palaeobiogeographical and palaeoceanographical implications. *Geological Magazine*, **128**, 5: 479-503.

SEMENOV, V. P., 1899. Fauna of Cretaceous Deposits of Mangyshlak and other Areas of the Transcaspian Region. *Trudy St.-Peterburgskogo Ob-va Estestvoispytatelei Prirody. Otdelenie Geologii i Mineralogii*, **28** (5): 1-178 [in Russian].

SISSINGH, W., 1978. Microfossil biostratigraphy and stage stratotypes of the Cretaceous. *Geologie en Mijnbouw*, **57** (3): 440-443.

SMIT, J., 1977. Discovery of a planktonic foraminiferal association between the Abathomphalus mayaroensis Zone and the Globigerina eugubina Zone at the Cretaceous-Tertiary boundary in the Barranco del Gredero (Caravaca, Spain). *Proceedings of the Nederlandse Akademie der Wetenschappen*, **B 80**: 280-301.

SMIT, J., 1982. Extinction and evolution of planktonic Foraminifera after a major impact at the Cretaceous/Tertiary boundary. *Geological Society American. Special Paper*, **190**: 329-352.

STENESTAD, E., 1979. Upper Cretaceous foraminifera from Danish Basin. *In:* BIRKELUND, T. & BROMLEY, R. (eds.). Proceedings of Symposium on Cretaceous — Tertiary Boundary Events: Copenhagen, Denmark. University of Copenhagen, **1**: 101-107.

THIERSTEIN, H. R., 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Marine Micropaleontology*, **1**: 325-362.

TOUMARKINE, M. & LUTERBACHER, H., 1985. Paleocene and Eocene planktic foraminifera. *In:* H. M. BOLLI, J. B. SAUNDERS & K. PERCH-NIELSEN, Plankton stratigraphy, pp. 87-154. Cambridge University Press.

TRIFONOV, N. K., 1959. Novye dannye po stratigrafii verkhnego mela poluostrova Mangyshlaka. *Trudy Vsesoyuznogo Nauchno-Issledovatelskogo Geologo-Razvedochnogo Neftianogo Instituta (VNIGRI)*, **131**: 297-301 [in Russian].

TRIFONOV, N. K. & BURAGO, A. M., 1960. Verkhnemelovye otlozhenia Mangyshlaka. Stratigrafia i fatsii. *Trudy Vsesoyuznogo Nauchno-Issledovatelskogo Geologo-Razvedochnogo Neftianogo Instituta (VNIGRI)*, **157**: 195 pp. [in Russian].

VASSILENKO, V. P., 1961. Upper Cretaceous Foraminifera of Mangyshlak peninsula. *Trudy Vsesoyuznogo Nauchno-Issledovatelskogo Geologo-Razvedochnogo Neftianogo Instituta (VNIGRI)*, **61**: 1-487. Leningrad [in Russian].

WICHER, C. A., 1953. Micropaläontologische Beobachtungen in der höheren borealen Oberkreide, besonders im Maastricht. *Geologisches Jahrbuch*, **B 68**: 1-26.

WIDMARK, J.G.V. & SPEIJER, R.P., 1997. Benthic foraminiferal ecomarker species of the terminal Cretaceous (late Maastrichtian) deep-sea Tethys. *Marine Micropaleontology*, **31**: 135-155.

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Typescript submitted 15.12.1998
Revised typescript received 29.3.1999

Explanation of Plates

All the figured specimens are preserved in the collection of the micropaleontological unit of Palaeontology, Geological Faculty, Moscow State University

PLATE 1

Figure 1 — *Orbignyna ovata* (von Hagenow): Kyzylsai section, sample 4 (X50).
Figure 2 — *Orbignyna inflata* (Reuss): Kyzylsai section, sample 6 (X50).
Figure 3 — *Arenobulimina acuta* Woloschyna: Koshak section, sample 111 (X100).
Figure 4 — *Gaudryina* aff. *jonesiana* Wright: Koshak section, sample 107 (X80).
Figure 5 — *Gaudryina rugosa* d'Orbigny: Koshak section, sample 103 (X80).
Figure 6 — *Arenobulimina vialovi* Woloschyna: Koshak section, sample 108 (X80).
Figure 7 — *Plectina convergens* (Keller): Koshak section, sample 101 (X70).
Figure 8 — *Ataxophragmium crassum* (d'Orbigny): Kyzylsai section, sample 10 (X70).
Figure 9 — *Plectina ruthenica* (Reuss): Kyzylsai section, sample 34 (X70).
Figure 10 — *Neoflabellina reticulata* (Reuss): Koshak section, sample 104 (X60).
Figure 11 — *Angulogavelinella gracilis* (Brotzen): spiral side; Kyzylsai section, sample 6 (X80).
Figure 12 — *Angulogavelinella gracilis* (Brotzen): umbilical side; Kyzylsai section, sample 6 (X70).
Figure 13 — *Gavelinella danica* (Brotzen): spiral side; Koshak section, sample 155 (X100).
Figure 14 — *Gavelinella danica* (Brotzen): umbilical side; Koshak section, sample 145 (X100).

PLATE 2

Figure 1 — *Cibicidoides aktulagayensis* (Vassilenko): spiral side; Koshak section; sample 101 (X60).
Figure 2 — *Stensoeina pommerana* Brotzen: Kyzylsai section, sample 1 (X100).
Figure 3 — *Angulogavelinella gracilis* (Brotzen): umbilical side; Kyzylsai section, sample 6 (X100).
Figure 4 — *Cibibcides kurganicus* Neckaja: spiral side; Kyzylsai section, sample 4 (X100).
Figure 5 — *Cibibcides kurganicus* Neckaja: umbilical side; Kyzylsai section, sample 4 (X100).
Figure 6 — *Karreria fallax* Rzehak: spiral side; Kyzylsai section, sample 34 (X70).
Figure 7 — *Coleites crispus* Vassilenko: Koshak section, spiral side, sample 113 (X70).
Figure 8 — *Brotzenella praeacuta* (Vassilenko): spiral side; Kyzylsai section, sample 35 (X100).
Figure 9 — *Brotzenella praeacuta* (Vassilenko): umbilical side; Kyzylsai section, sample 35 (X100).
Figure 10 — *Cibicidoides voltzianus* (d'Orbigny): spiral side; Koshak section, sample 109 (X70).
Figure 11 — *Cibicidoides voltzianus* (d'Orbigny): umbilical side; Koshak section, sample 109 (X70).
Figure 12 — *Gyroidinoides turgidus* (d'Orbigny): spiral side; Koshak section, sample 108 (X70).
Figure 13 — *Gyroidinoides turgidus* (d'Orbigny): umbilical side; Koshak section, sample 108 (X70).
Figure 14 — *Gyroidinoides turgidus* (d'Orbigny): peripheral side; Koshak section, sample 108 (X70).
Figure 15 — *Anomalinoides pinguis* (Jennings): spiral side; Koshak section, sample 113 (X70).
Figure 16 — *Anomalinoides pinguis* (Jennings): umbilical side; Koshak section, sample 113 (X70).
Figure 17 — *Anomalinoides pinguis* (Jennings): umbilical side; Kyzylsai section, sample 3 (X100).

PLATE 3

Figure 1 — *Bolivina decurrens* (Ehrenberg): Kyzylsai section, sample 2 (X100).
Figure 2 — *Bolivina incrassata incrassata* (Reuss): Kyzylsai section, sample 6 (X70).
Figure 3 — *Bolivina incrassata crassa* (Vassilenko): Kyzylsai section, sample 13 (X70).
Figure 4 — *Bolivinoides decoratus* (Jones): Koshak section, sample 101 (X50).
Figure 5 — *Bolivinoides decoratus* (Jones): Koshak section, sample 101 (X50).
Figure 6 — *Bolivinoides peterssoni* Brotzen: Koshak section, sample 101 (X50).
Figure 7 — *Bolivinoides draco draco* Marsson: Koshak section, sample 112 (X100).
Figure 8 — *Praebulimina laevis* (Beissel): Koshak section, sample 112 (X50).
Figure 9 — *Pyramidina cimbrica* (Brotzen): Kyzylsai section; sample 6 (X140).
Figure 10 — *Pseudouvigerina cristata* (Marsson): Kyzylsai section; sample 4 (X100).
Figure 11 — *Cibicidoides commatus* (Morozova): spiral side; Koshak section, sample 155 (X100).
Figure 12 — *Hanzawaia ekblomi* (Brotzen): spiral side; Kyzylsai section, sample 37 (X100).
Figure 13 — *Hanzawaia ekblomi* (Brotzen): umbilical side; Kyzylsai section, sample 37 (X100).

Figure 14 — *Cibicidoides hemicompressus* (Morozova): spiral side; Koshak section, sample 145 (X60).
Figure 15 — *Cibicidoides hemicompressus* (Morozova): umbilical side; Koshak section, sample 145 (X80).
Figure 16 — *Anomalinoides subcarinatus* (Cushman & Deaderick): spiral side; Kyzylsai section, sample 16 (X90).
Figure 17 — *Gavelinella midwayensis* (Plummer): spiral side; Kyzylsai section, sample 2 (X60).
Figure 18 — *Gavelinella midwayensis* (Plummer): umbilical side; Kyzylsai section, sample 2 (X100).
Figure 19 — *Gavelinella pertusa* (Marsson): spiral side; Koshak section, sample 155 (X100).
Figure 20 — *Gavelinella pertusa* (Marsson): umbilical side; Koshak section, sample 155 (X100).

PLATE 4

Figure 1 — *Hedbergella monmouthensis* (Olsson): umbilical side, Kyzylsai section, sample 9 (X100).
Figure 2 — *Heterohelix striata* (Ehrenberg): Koshak section, sample 112 (X100).
Figure 3 — *Pseudotextularia deformis* (Kikoine): Koshak section, sample 112 (X100).
Figure 4 — *Globigerinellodes volutus* White: umbilical side, Koshak section; sample 108 (X100).
Figure 5 — *Globotruncana arca* (Cushman): spiral side; Koshak section, sample 112 (X70).
Figure 6 — *Globotrucana bulloides* Vogler: spiral side; Koshak section; sample 112 (X70).
Figure 7 — *Globotruncana ventricosa* White: spiral side; Kyzylsai section; sample 8 (X70).
Figure 8 — *Rugoglobigerina* sp. : spiral side; Koshak section; sample 112 (X70).
Figure 9 — *Eoglobigerina trivialis* (Subbotina): spiral side; Koshak section, sample 165 (X100).
Figure 10 — *Eoglobigerina trivialis* (Subbotina): umbilical side; Koshak section, sample 165 (X100).
Figure 11 — *Subbotina varianta* (Subbotina): spiral side; Koshak section, sample 155 (X130).
Figure 12 — *Subbotina varianta* (Subbotina): umbilical side; Koshak section, sample 155 (X130).
Figure 13 — *Subbotina pseudobulloides* (Plummer): spiral side; Kyzylsai section, sample 35 (X130).
Figure 14 — *Subbotina pseudobulloides* (Plummer): umbilical side; Kyzylsai section, sample 35 (X130).
Figure 15 — *Subbotina triloculinoides* (Plummer): spiral side; Koshak section, sample 155 (X130).
Figure 16 — *Globoconusa daubjergensis* (Brönnimann): spiral side; Koshak section, sample 150 (X130).
Figure 17 — *Globoconusa daubjergensis* (Brönnimann): umbilical side; Koshak section, sample 150 (X150).
Figure 18 — *Planorotalites compressa* (Plummer): spiral side; Kyzylsai section, sample 45 (X130).
Figure 19 — *Planorotalites compressa* (Plummer): umbilical side; Kyzylsai section, sample 45 (X160).


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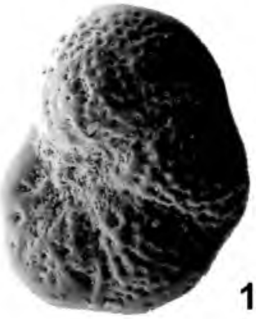
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Plate 2

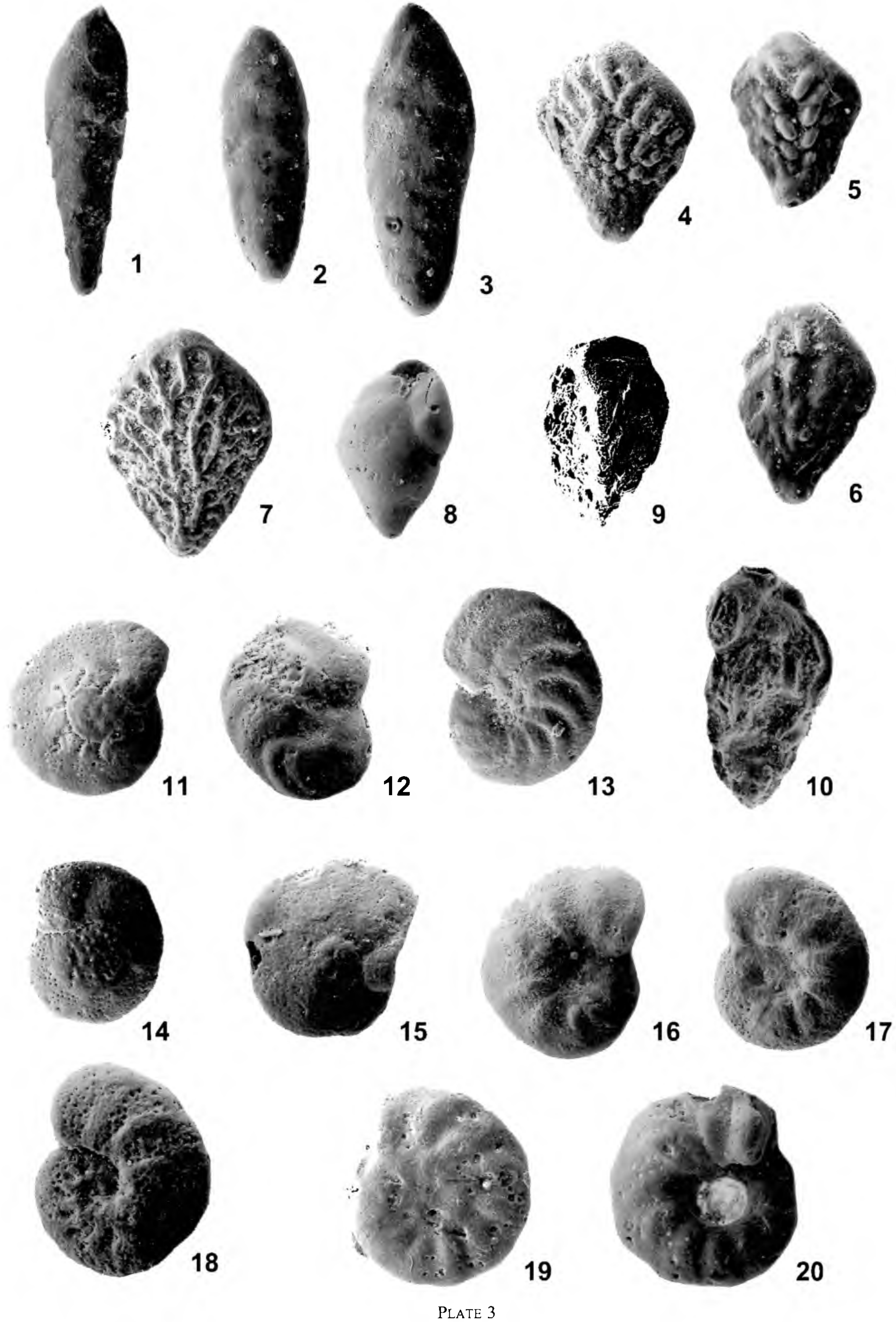

PLATE 3


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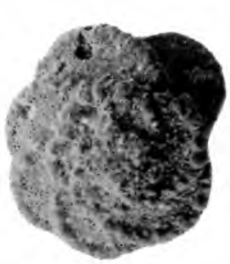
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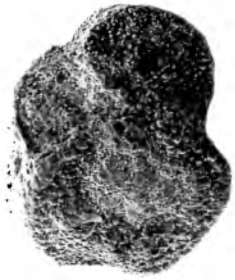
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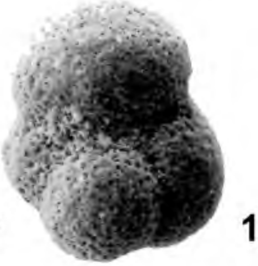
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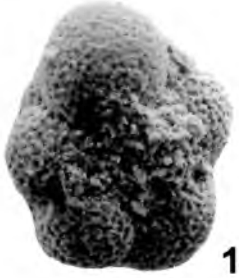
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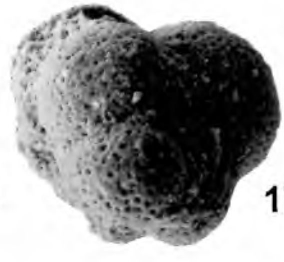
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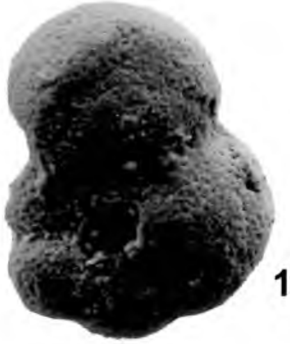
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PLATE 4

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 147-159, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 147-159, 1999

Santonian to Palaeocene tectonics of the East-European craton and adjacent areas

by Anatoly M. NIKISHIN, Peter A. ZIEGLER, Randell A. STEPHENSON & Maria A. USTINOVA

Abstract

During the Senonian to Palaeocene times the East European Craton or Platform was affected by polyphase regional compression stresses. It led to different kind intracratonic compressional tectonics including gentle lithosphere folding (buckling) with spacing close to 500-600 km, origin (or reactivation) of inversion structures mainly along former rifted basins, syn-compressional rapid subsidence of some former rifted basins like Dnieper Basin, acceleration of salt diapirism in the Peri-Caspian Basin, possible compression-related (impactogen) rifting in the Ukrainian Shield. The compression related intracratonic tectonics coincided with collision events along Tethyan belt along Pontides and other zones. The Laramide orogeny was widespread round the Earth, and it could have led to global environmental changes at the Cretaceous/Palaeogene boundary.

Key-words. East-European Craton, Cretaceous/Palaeocene boundary, inversion tectonics, Laramide orogeny, deformations, palaeotectonic reconstructions.

Résumé

Du Sénonien au Paléocène, le Craton ou Plate-forme est-européen a subi des contraintes de compression régionale polyphasée. Il en est résulté différents types de tectoniques de compression intracratoniques incluant un plissement faible de la lithosphère ("buckling") à une distance proche de 500-600 km, l'origine (ou la réactivation) de structures d'inversion principalement le long d'anciens bassins d'effondrement, une subsidence *syncompressionaire* rapide de certains bassins d'effondrement anciens comme le Bassin du Dnieper, une accélération du diapirisme lié au sel dans le Bassin de la Caspienne (Peri-Caspian Basin), un effondrement possible lié à la compression (impactogène) dans le Bassin ukrainien. La compression liée aux tectoniques intracratoniques a coïncidé avec des collisions le long de la ceinture téthysienne, des Pontides et d'autres zones. L'orogenèse Laramide s'est fait largement ressentir sur la Terre et a pu conduire à des changements globaux d'environnements à la limite Crétacé/Paléogène.

Mots-clefs: Craton est-européen, limite Crétacé/Paléocène, tectonique d'inversion (inversion tectonique?), orogenèse Laramide, déformations, reconstructions paléotectoniques.

Резюме

В сеноне-палеоцене Восточно-Европейский кратон испытал полифазное региональное сжатие. Это сжатие привело к разным типам компрессионной тектоники: к пологой литосферной складчатости с расстоянием между осями складок около 500-600 км ; к формированию или активизации инверсионных структур в основном вдоль палеорифтов ; к синкомпрессионному быстрому погружению некоторых рифтогенных бассейнов типа Днепровского ; к активизации соляного диапиризма в Прикаспийской впадине ; к вероятному импактогенному синкомпрессионному рифтогенезу на Украинском щите. Компрессионная тектоника внутри кратона была синхронна с коллизионными процессами вдоль пояса Тетис в Понтидах и других зонах. Ларамийская орогения имела глобальный характер и она могла привести к глобальным изменениям среды около мел-палеогеновой границы.

Ключевые слова: Восточно-Европейский кратон, мел/палеогеновая граница, инверсионная тектоника, ларамийская орогения, деформации, палеотектонические реконструкции.

Introduction

The Late Cretaceous to Palaeocene tectonic history of Western Europe has been described in detail by Ziegler (1990), but for Eastern Europe it was briefly discussed in Arkhangelsky (1922), Shatsky (1964), Gerasimov *et al.* (1962), E. V. Milanovsky (1940) and E. E. Milanovsky (1987), without detailed analysis of tectonic events. There is disagreement between authors on the palaeotectonic reconstruction of Europe at the Cretaceous/Palaeocene boundary (Ziegler, 1990; Dercourt *et al.*, 1993; Yilmaz *et al.*, 1997, Stampfli *et al.*, 1998). In this paper we will try to combine all available data and reconstruct the tectonic history of Eastern Europe at the Cretaceous/Palaeocene (K/T) boundary in connection with regional tectonic events.

From the Senonian to the Palaeocene, Subhercynian and Laramide inversion tectonics affected large parts of the northern Alpine and Carpathian foreland of Europe (Fig. 1; Ziegler, 1990; Ziegler *et al.*, 1995; Nikishin *et al.*, 1997a) as well as the Alpine and Taurides foreland in Africa and Arabia, respectively (Guiraud & Bosworth, 1997). Subhercynian and Laramide inversion structures on the East-European Craton and its margins were described in detail by E. V. Milanovsky (1940) and are shown on the published maps of Bogdanov & Khain


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REMNANT TETHYS OCEAN
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CARPATHIAN BASIN
RIFT BASIN
ATLANTIC OCEAN
REMNANT ALPINE TETHYS
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(1981). Classical examples of tensional basins that were inverted during the latest Cretaceous and Palaeocene are the Donets Basin [Donbass] - that formed part of the Mid-Late Devonian Dnieper-Donets-Karpinsky rift belt (E. E. Milanovsky, 1987; Stovba *et al.*, 1996), the Mid-Polish Trough (Kutek, 1994; Dadlez *et al.*, 1995), the Pre-Volga belt (e.g. Don-Medveditsa, Saratov dislocations; E. V. Milanovsky, 1940; E. E. Milanovsky, 1987), and the Pachelma aulacogen (Oka-Tsna, Kerensk-Chembar and Sura-Moksha swells; Bogdanov & Khain, 1981; E. E. Milanovsky, 1987). Additional similar features, including the Soligalich, Sukhona and Vyatka swells, have also been described (Bogdanov & Khain, 1981; E. E. Milanovsky, 1987; Nikishin *et al.*, 1997a; Ustinova *et al.*, 1998). On the East-European Craton (EEC), the main problem is to precisely date the deformation age of these intraplate compressional features, since most of them were deeply truncated during Cenozoic times, and were deformed both in pre-Cretaceous times and during the Late Cenozoic Alpine orogeny. In any case, the European continent was affected by important phases of intraplate compression during Senonian to pre-Eocene times.

Late Cretaceous to Palaeocene inversion structures of the EEC and its margins

The *Mid-Polish Trough* is located along the western margin of the EEC (Fig. 2). For the history of this basin we follow data from Ziegler (1990), Kutek (1994), Dadlez *et al.*, (1995) and E. Gazdzicka (personal communication, 1998). The basin was formed as a rift belt during the Late Permian-Early-Middle Triassic. During the Late Triassic to Early Cretaceous the rifted basin underwent postrift subsidence accompanied by stress events. The Late Cretaceous history of the basin was very complicated (Ziegler, 1990; Dadlez *et al.*, 1995; E. Gazdzicka, personal communication, 1998): during Cenomanian-Turonian times the basin underwent rapid syn-compressional subsidence which was followed by polyphase inversion of the basin. The timing of the inversion is not precisely known, but it has been suggested that the local uplift started in the Coniacian-Santonian, was more active in the Campanian, and that the main inversion phase with an amplitude of the uplift up to 2-3 km, took place in the Maastrichtian-early Palaeocene.

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Fig. 1 — Tectonic scheme of Europe for the Senonian to Palaeocene time (mainly at the time close to the K/T boundary). Map of Western Europe is prepared after Ziegler (1990), mainly. 1 - active orogen, 2 - remnant deep-water mainly flysch basin, 3 - remnant deep-water back-arc basin, 4 - oceanic basin, 5 - Palaeocene intraplate sedimentary basin, 6 - Palaeocene eroded land in stable Europe, 7 - Palaeocene subduction zone, 8 - Late Cretaceous subduction zone, 9 - thrust belt of the Great Caucasus Basin, 10 - Senonian to Palaeocene inversional swell, 11 - intracontinental topographic arch (proposed gentle lithospheric anticline), 12 - intracontinental topographic depression (proposed gentle lithospheric syncline), 13 - Late Cretaceous magmatic arc. R - Rhodope Block, KB - Kirsehir Block, H - Hellenides, MTB - Menderes-Taurus Block, SAS - Srednogorie-Strandzha Basin (hypothetical), IAB - Izmir-Ankara Basin, MPT - Mid-Polish Trough, D - Dnieper Basin, SS - Simbirsk-Saratov Basin, PC - Peri-Caspian Basin. Remnant Tethys Ocean is shown not to scale.

The Pripyat-Dnieper-Donets (PDD) Basin is located in the southern part of the EEC (Fig. 2). The history of this basin is discussed in E. E. Milanovsky (1987), Nikishin *et al.* (1996), Stovba *et al.* (1996) and Stovba & Stephenson (1999). The PDD Basin was a rift basin in the Late Devonian and underwent post-rift subsidence in the Carboniferous to Cenozoic times, complicated by numerous stress events. The PDD Basin has three segments: the Pripyat Basin, the Dnieper (or Dnieper-Donets) Basin, and the Donets Basin (or Donbass).

During the Early Cretaceous *the Dnieper Basin* in the Ukraine had a very low subsidence rate (Gerasimov *et al.*, 1962; Kaptarenko-Chernousova, 1971; Ivannikov *et al.*, 1991). During the Late Cretaceous the subsidence rate was higher; we can recognize two epochs of subsidence: Cenomanian to Coniacian (relatively low subsidence rate with up to 280 meters sediment thickness), and Santonian to Maastrichtian (relatively high subsidence rate with 700 meters sediment thickness). As we will see below the Campanian-Maastrichtian (or even Cenomanian to Maastrichtian) subsidence took place in a regional compressional tectonic environment; and we suggest that the compressional stress caused the rapid subsidence [as was discussed for the Mid-Polish Trough in Dadlez *et al.*, (1995)]. An erosional event took place in the Dnieper Basin at the Maastrichtian/Palaeocene boundary: late Maastrichtian to early Danian deposits are missing (Morroz, 1970; Ivannikov *et al.*, 1991), and late Danian(?)- Thanetian marine to continental deposits cover Maastrichtian sediments (Morroz, 1970).

The Donbass in the Ukraine and Russia underwent a few inversion events between the Permian and earliest Jurassic times (E. E. Milanovsky, 1987; Stephenson, 1997; Nikishin *et al.*, 1998b; Stovba & Stephenson, 1999). It was a relatively uplifted area mainly during the Early Cretaceous (Gerasimov *et al.*, 1962). For the Late Cretaceous history of the Donbass we used data from Gerasimov *et al.* (1962), Naidin (1960, 1969), Blank & Gorbenko (1968), Kaptarenko-Chernousova (1971), Savchinskaya (1982), E. E. Milanovsky (1987), Ivannikov *et al.* (1991) and Stovba *et al.* (1996). During the Cenomanian to Coniacian the Donbass was part of a large, shallow water to continental

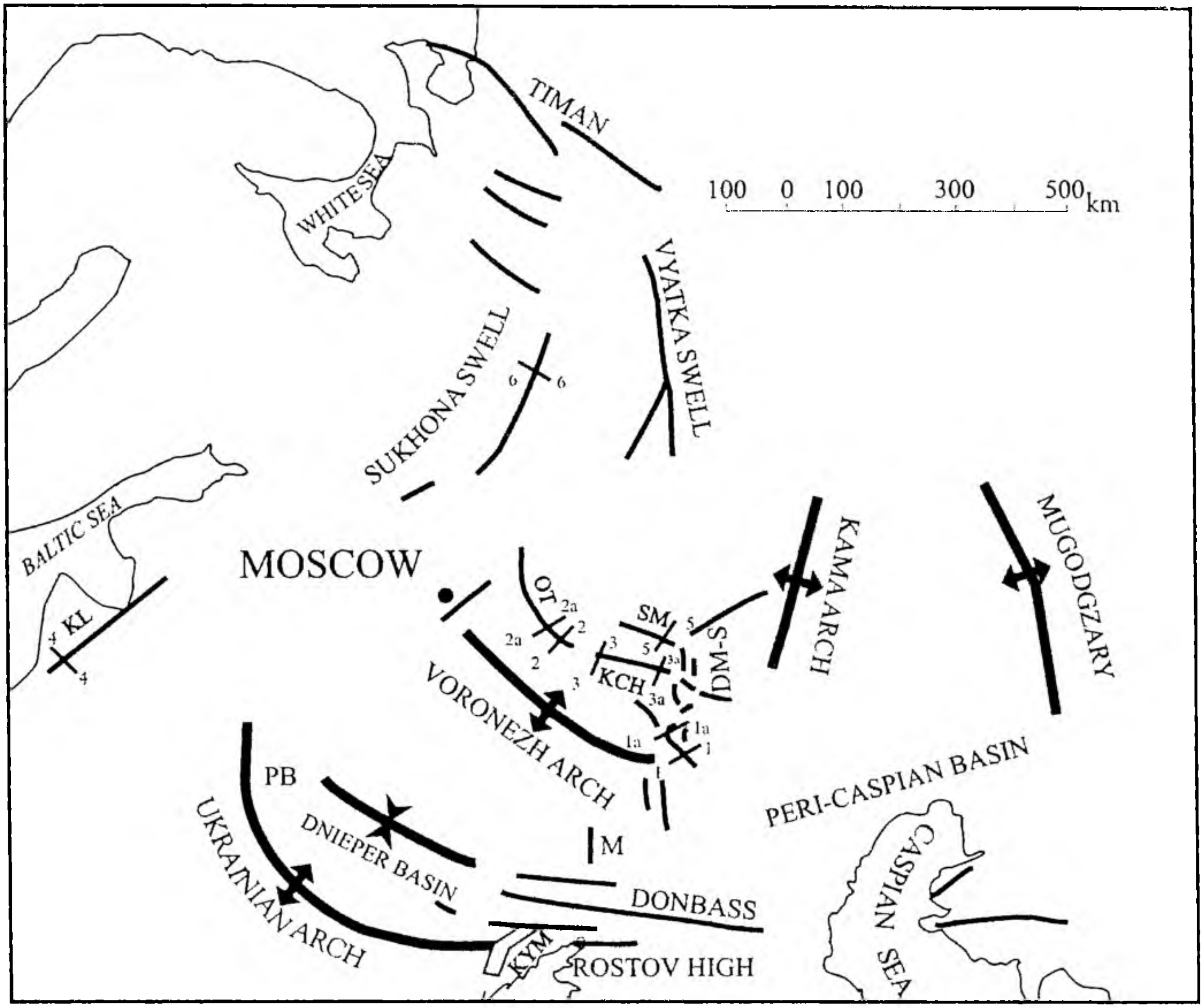

Fig. 2 — Location map for the main Late Cretaceous swells of the EEC and cross-sections for Fig. 3. 1-1 location of the cross section. KL - Klaypeda-Lokno Swell, OT - Oka-Tsna Swell, SM - Sura-Moksha Swell, KCH - Kerensk-Chembar Swell, DM-S - Don-Medveditsa-Saratov Swell belt, M - Millerovo Swell, KYM - Konka-Yaly-Molochnaya Basin, PB - Pripyat Basin.

sedimentary basin with minor evidence of local uplifting (in the Cenomanian). During the Santonian the Donbass started to uplift slowly: clastic sediments were supplied from the Donbass to the basin along the southern margin of the Donbass. An important change occurred in the Campanian (NAIDIN, 1960; GERASIMOV *et al.*, 1962; BLANK & GORBENKO, 1968; SAVCHINSKAYA, 1982; IVANNIKOV *et al.*, 1991): large scale clastic sediments were supplied by the uplifted Donbass both to the North and the South of the Donbass into the carbonate platforms. The maximum of this clastic supply was during the Late Campanian-Maastrichtian. Folding inside the Donbass and thrusting along its northern margins began at the Santonian/Campanian boundary with a maximum at the Cretaceous/Palaeocene transition; latest Maastrichtian deposits are missing along the northern margin of the Donbass (BLANK & GORBENKO, 1968; E. E. MILANOVSKY, 1987; IVANNIKOV *et al.*, 1991; STOVBA & STEPHENSON, 1999).

In the Pripyat Basin in Byelorussia only the youngest Turonian sediments are found. Post-Turonian Late Cretaceous marine sediments were eroded. Regional uplift of the Pripyat Basin region took place at the K/T boundary-Palaeocene (GERASIMOV *et al.*, 1962; Beniamovsky, personal communication, 1998). At these times, minor reverse faulting occurred along some former rift faults (R. Garetsky, personal communication, 1998).

The Konka-Yaly Basin is located inside the Ukrainian Shield in the Ukraine to the South of the Donbass (Fig. 2) (GERASIMOV *et al.*, 1962; KAPTARENKO-CHERNOUSOVA, 1971; IVANNIKOV *et al.*, 1991), and is oriented nearly orthogonally to the Donbass. *The Molochnaya* *(or Melitopol) Basin* lies directly to the South of the Konka-Yaly Basin. The Konka-Yaly and Molochnaya basins have a graben-like configuration (KAPTARENKO-CHERNOUSOVA, 1971; CHEKUNOV *et al.*, 1976); they were infilled by Cretaceous sediments (CHEKUNOV *et al.*, 1976; IVANNIKOV *et al.*, 1991). Using the data of CHEKUNOV *et al.* (1976) and IVANNIKOV *et al.* (1991) we can recognise two main minor rift events: an Albian (or Aptian-Albian) event with a subsidence close to 100 meters, and a Santonian-Maastrichtian event with a subsidence close to 200-350 meters. During these tectonic events mainly Precambrian faults were reactivated (KAPTARENKO-CHERNOUSOVA, 1971; CHEKUNOV *et al.*, 1976). The Aptian-Albian tension event could have been connected with a rifting related with the Black Sea Basin opening (NIKISHIN *et al.*, 1998b). We assume that during the Santonian-Maastrichtian times the Konka-Yaly-Molochnaya Basin was a graben-like tension structure of impactogen syn-compressional origin: it originated mainly along the axis of Late Cretaceous compressional stress, coinciding with the time of the Donbass uplift.

The Rostov High is located just to the south of the Donbass along the southern margin of the EEC. In this High the Early Eocene marine sediments cover gently folded Cretaceous strata including those of Maastrichtian age (ULANOVSKAYA, 1988). The Rostov High was part of the Donbass fold zone at the K/T boundary.

The Don-Medveditsa-Saratov Swell belt is located along the boundary between the Peri-Caspian Basin and the Russian Platform (Voronezh High), above the Devonian Don-Medveditsa rifted basin (E. V. MILANOVSKY, 1940; BOGDANOV & KHAIN, 1981; E. E. MILANOVSKY, 1987). The cross-section of this swell is shown on Figure 3. The swell underwent many inversion events since the Carboniferous. An important inversion took place during the Late Cretaceous. Data summarised in MORROZOV (1962), SENYUKOV (1949), SENCHENKO (1951) and IVANOV (1995) show that uplift inversion events took place in mid-Santonian, and at the Santonian-Campanian, Campanian/Maastrichtian, Maastrichtian/Danian boundaries. Sedimentological data show that in Campanian-Maastrichtian-Danian the Don-Medveditsa Swell was a source region for clastic sediments to the South and the East of the swell (MORROZOV, 1962), which means that the swell was an uplifted belt. Late Palaeocene deposits cover deformed Cretaceous strata (IVANOV, 1995).

The Millerovo Swell is parallel to the Don-Medveditsa Swell, 200 km to the west. It is a local anticline-like structure with an uplift of Late Cretaceous strata up to 40-50 meters (MORROZOV, 1962). It could have the same age as the Late Cretaceous deformations of the Don-Medveditsa Swell.

The Oka-Tsna Swell belt is located above the northern part and northern margin of the Riphean Pachelma aulacogen (rifted basin) in its northern prolongation (E. V. MILANOVSKY, 1940; BOGDANOV & KHAIN, 1981; E. E. MILANOVSKY, 1987) (Fig. 3). The swell had a long history, starting in the Carboniferous but its youngest deformed strata are of Santonian age (SAZONOV, 1953). An inversion phase took place possibly as early as the Santonian/Campanian transition, but it was definitely not younger than pre-Neogene.

The Kerensk-Chembar Swell is located along the northern margin of a central segment of the Riphean Pachelma rifted basin. *The Sura-Moksha Swell* is parallel to the Kerensk-Chembar Swell 70-100 km to the north, and it is not connected with a rifted basin (E. V. MILANOVSKY, 1940; BOGDANOV & KHAIN, 1981; E. E. MILANOVSKY, 1987) (Fig. 3). The swells have a polyphase deformation history. Late Cretaceous sediments are the youngest deformed strata. The available data show deformations at pre-Santonian, and also at the Santonian/Campanian and Campanian/Maastrichtian boundaries; they lasted until the Palaeocene (CHIBRIKOVA, 1951; SENCHENKO, 1951; SAZONOV, 1953; KHOKHLOV, 1955; DASHEVSKY, 1996). The main unconformity in the Sura-Moksha Swell is near the Santonian/Campanian boundary (A. Olferiev, personal communication, 1998).

The Vyatka Swell is located above the Vyatka (or Kirov, or Kazhim) Riphean and Devonian rifted basin in the eastern part of the EEC (E. V. MILANOVSKY, 1940; BOGDANOV & KHAIN, 1981; E. E. MILANOVSKY, 1987). The swell had a polyphase inversion history, but Albian strata are the youngest deformed ones. The deformations occurred in post-Albian times (ARKHIPOV & VYSOTSKY, 1996), and latest Cretaceous to Palaeocene ages are most likely. The *Sukhona Swell* is located above the Soligalich aulacogen in the Moscow Basin (BOGDANOV & KHAIN, 1981). The youngest deformed strata are of Albian age. And we assume as we did for the Vyatka Swell that the inversion occurred near the K/T boundary.

The Klaypeda - Lokno Swell belt trends in the Pre-Baltic region almost from Klaypeda (Lithuania), along the Lithuanian-Latvian boundary to the town of Pskov in Russia (BOGDANOV & KHAIN, 1981). This swell belt had a complicated inversion history. The Cretaceous strata are also deformed (Fig. 3). The swell belt is located not far from the Mid-Polish Trough and we suggest a Late Cretaceous to Palaeocene age for the inversion. New data show that compressional events took place in Lithuania at the Santonian/Campanian and Campanian/Maastrichtian boundaries at least (SLIAUPA, 1997, and personal communication, 1999).

The Timan Swell underwent many inversion events in pre-Cretaceous times (E. E. MILANOVSKY, 1987). It did not generally separate Early Cretaceous basins (E. Baraboshkin, personal communication, 1998) and was uplifted in post-early Cretaceous epochs. It is not excluded that an inversion event took place at the Cretaceous/Palaeogene boundary because some data show that compression deformations in the Polar Urals and Pay-Khoy lasted until the end of the Cretaceous (YUDIN, 1994).

The palaeogeography of *the Urals* is badly known for the time of the K/T boundary. Data for the Polar Urals show (Oreshkina *et al.*, 1998) that Coniacian to Campanian shallow-water marine deposits are located along the western margin of the recent Urals and that they were formed in the former West Siberia Basin united with the Pechora Basin. Campanian deposits are covered with mid-Palaeocene marine sediments. An uplift of the Polar Urals could be suggested for the K/T transition. Detailed facial analysis demonstrates that the southern Urals (the Mugodzhary) were an uplifted area during Santonian to Danian (Naidin & Kotelnikov, 1998): sandstones and gravelites are found between Mugodzhary and the carbonate platform of the Peri-Caspian Basin. Generally we can assume that the Uralian foldbelt underwent uplift events near the K/T boundary, but an uplift event also took place at the Santonian/Campanian boundary (Naidin & Kotelnikov, 1998).

The Peri-Caspian Basin has numerous salt diapirs containing Kungurian salts (Bogdanov & Khain, 1981; E. E. Milanovsky, 1987). Uplift of the diapirs occurred at irregular time intervals. Detailed data on the distribution of depositional thicknesses, facies and fossils show (Beniamovsky *et al.*, 1973) that a rapid uplift of the diapirs took place in the Senonian to Palaeocene, mainly during regressive phases: at the Santonian/Campanian, the Campanian /Maastrichtian, the Maastrichtian/ Danian, the Danian/Thanetian, and the Thanetian/Ypresian boundaries and also inside the Late Campanian; a maximum diapiric uplift took place at the Danian/Thanetian boundary. We can assume that the uplift events of the diapirs coincided with regional compressional events because similar compression events occur in the EEC.

Late Cretaceous to Palaeocene gentle lithosphere folds in the EEC

During the Senonian to Palaeocene times the EEC underwent long-wave deformations of its topography (Fig. 1). This can be seen mainly from palaeogeographical maps of Naidin *in* Gerasimov *et al.* (1962) and from our own more recent data. During Cenomanian to Santonian times nearly the complete southern part of the EEC was a marine sedimentary basin; on the other hand from the Campanian to the Palaeocene an arching of the topography took place. Three main arches began to rise - the Ukrainian Shield together with the Byelorussian High (the Ukrainian-Byelorussian High), the Voronezh High, and the Kama High between the Simbirsk-Saratov and Peri-Caspian basins. These highs were separated by subsidence belts: the Dnieper Basin between the Ukrainian-Byelorussian and Voronezh highs, and the Simbirsk-Saratov Basin between the Voronezh and Kama highs. The amplitude of the arching was not more than 150-300 meters (today the top of the Cenomanian deposits is at the topographical level +220 meters on the Voronezh High, but the Dnieper Basin is at -500 to - 550 meters (Blank *et al.*, 1992)). The distance between the axes of the arches (proposed lithospheric anticlines) is close to 500-600 km which is typical for intracratonic lithospheric folding (buckling) (Ziegler *et al.*, 1995; Nikishin *et al.*, 1997b)

Main types of the compression-related tectonics inside the EEC

As discussed above, the following compressional-related structures can be recognized inside the EEC from the Senonian to the Palaeocene: gentle lithosphere folding (buckling), origin of inversion structures, syn-compressional rapid subsidence of former rifted basins, acceleration of salt diapirism, compression-related (impactogen) rifting.

Late Cretaceous to Palaeocene tectonics in the Scythian Platform-Caucasus-Black Sea-Pontides-Moesian area

The Scythian Platform is located to the South of the EEC. Seismic profiling data show that minor inversion features developed on the Scythian Platform at the Cretaceous/ Palaeocene boundary (Nikishin *et al.*, 1998a, b). In the Crimea, minor unconformities are evident at an intra-Santonian level, at the Maastrichtian/Danian boundary as well as at the transition from the Thanetian to the Danian and Ypresian to Thanetian (Muratov, 1969; Mazarovich & Mileev, 1989a, b). Relatively, the pre-Ypresian unconformity is the most important. The development of these unconformities is probably related to compression phases (Nikishin *et al.*, 1998b). Field data

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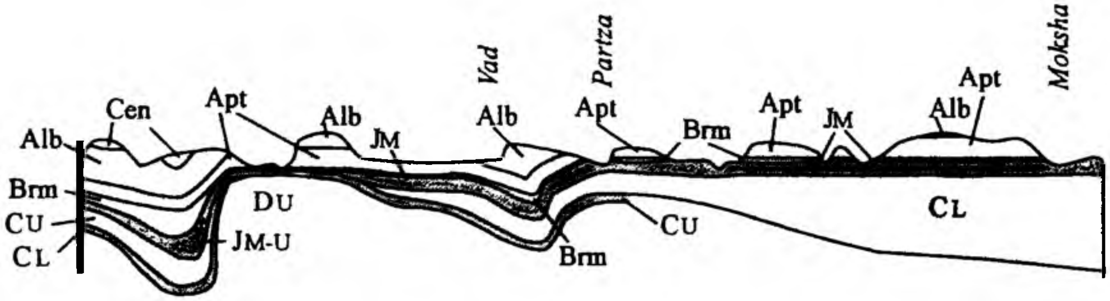
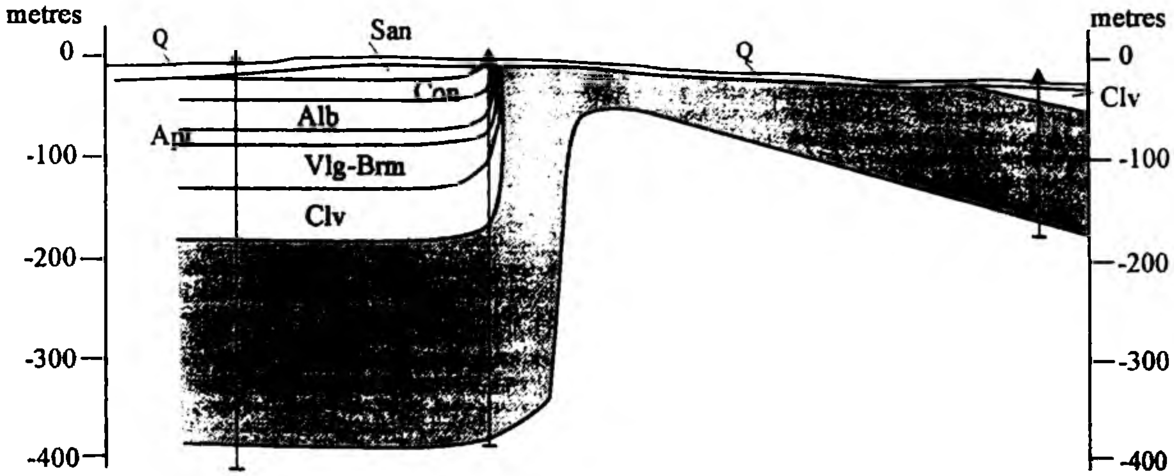
Figs 3a, 3b and 3c — Cross sections for some swells which were active during Senonian to Palaeocene times. Location of the cross-sections is shown on Fig. 2. Abbreviations: Q - Quaternary, Ne - Neogene, Pa - Palaeogene, K - Cretaceous, Ku - Upper Cretaceous, Kl - Lower Cretaceous, Cmp - Campanian, San - Santonian, Con - Coniacian, Tur - Turonian, Cen - Cenomanian, Alb - Albian, Apt - Aptian, Brm - Barremian, Nc - Neocomian, Vlg-Brm - Valanginian-Barremian, Ju - Upper Jurassic, Jm - Middle Jurassic, Jl - Lower Jurassic, Clv - Callovian, Bth - Bathonian, Baj - Bajocian, Tr - Triassic, Tl - Lower Triassic, Tat - Tatarian, P - Permian, Pu - Upper Permian, Pl - Lower Permian, C - Carboniferous, Cu - Upper Carboniferous, Cl - Lower Carboniferous, Fam - Famennian, Frs - Frasnian, Du - Upper Devonian, Dm - Middle Devonian, Ou+m - Middle and Upper Ordovician, Cmb - Cambrian, Vu - Upper Vendian, R - Riphean.

Oka-Tsna Swell (SAZONOV, 1953) (2 - 2)



Oka-Tsna swell (Nikitin S. N. , 1985, unpublished) (2a - 2a)



Sura-Mokcha Swell (AFANASIEV, 1970) (5 - 5)

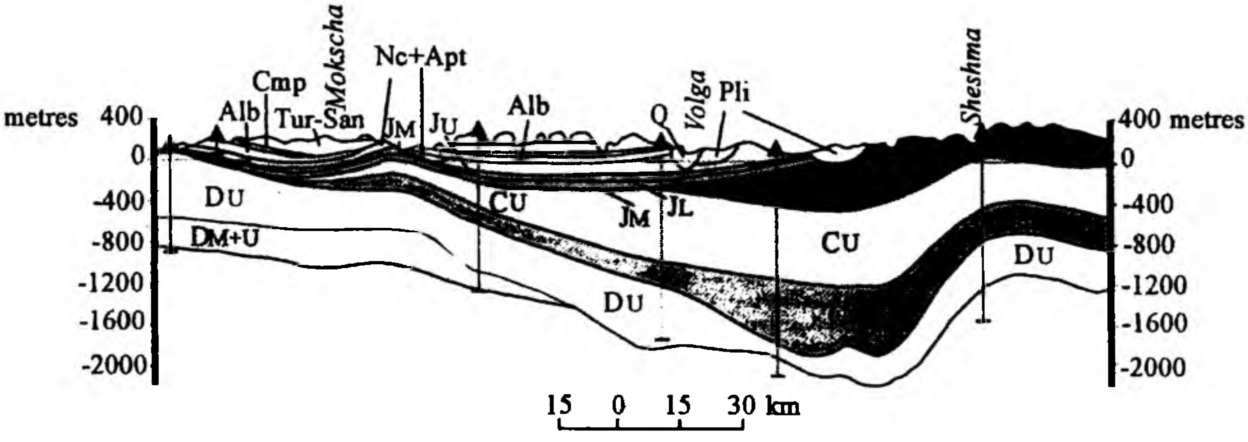
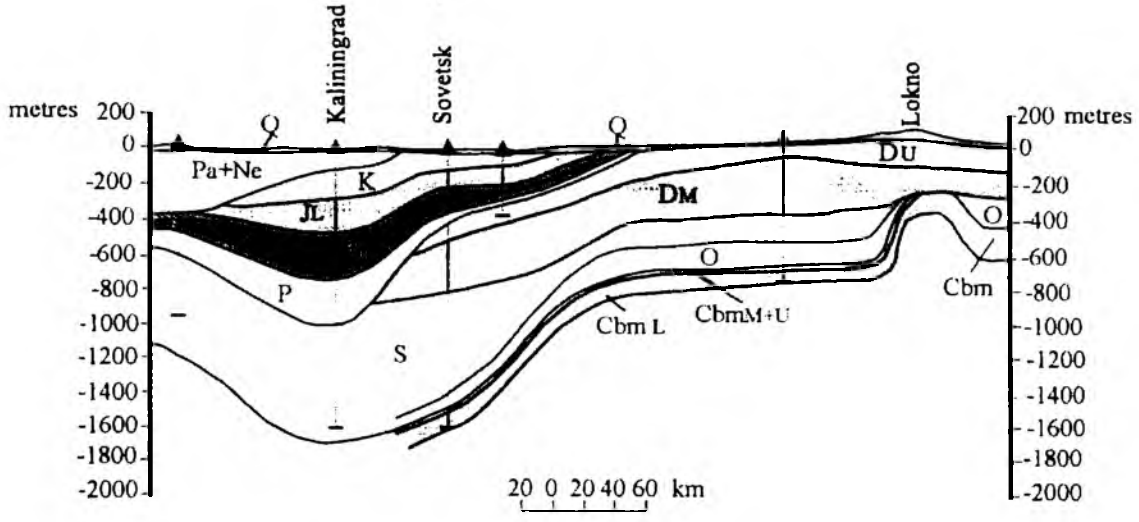
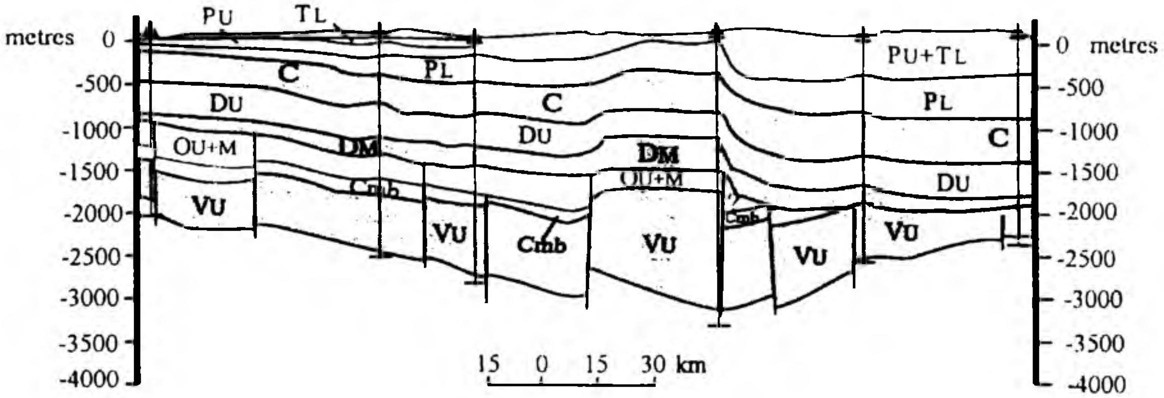


Fig. 3a

Telshay - Loknov Swell (GEISLER , 1956) (4 - 4)



Sukhona Swell (Bembinova, 1998, unpublished) (6 - 6)



Kerensk-Chembar Swell (MUCHENKO, 1963) (3 - 3)

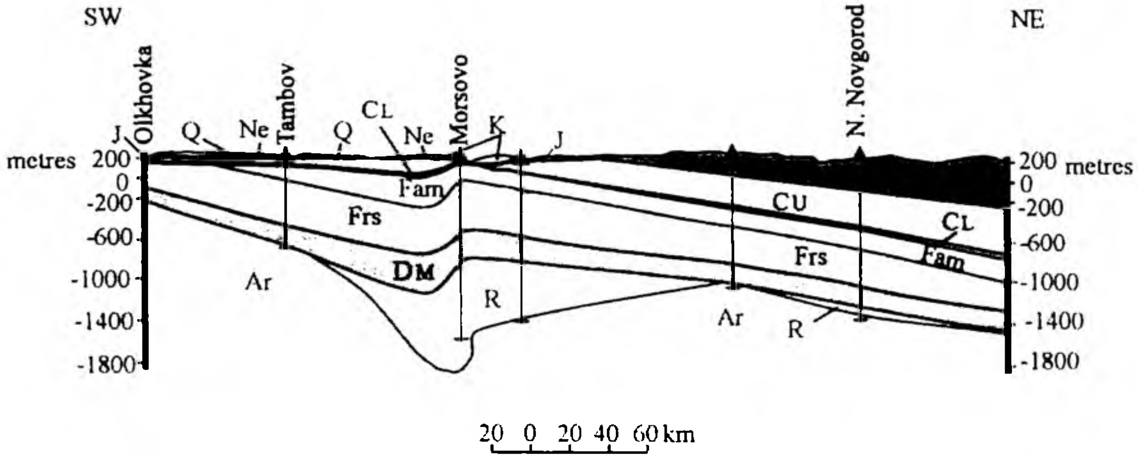
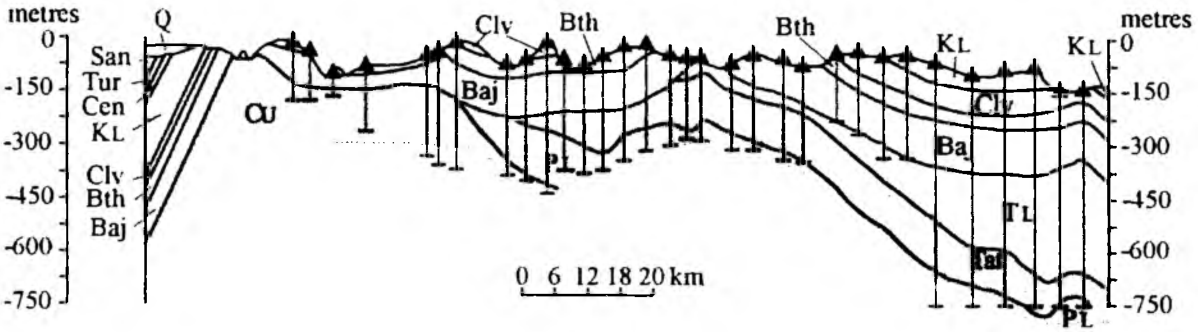
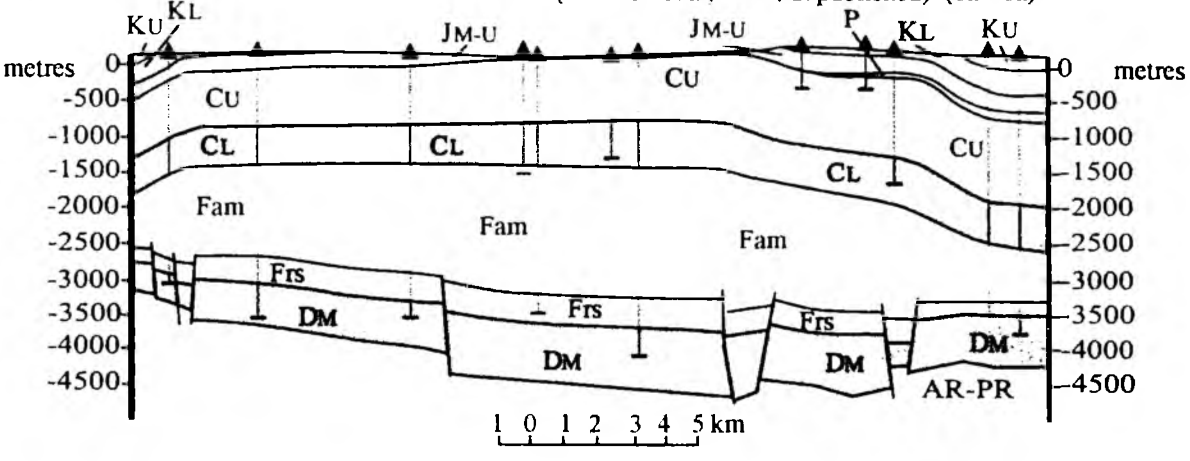


Fig. 3b

Ilovlinski height of Don-Medveditsa swell (SMIRNOV, 1962) (1 - 1)



Don-Medveditza Swell (Kolosov et al, 1973, unpublished) (1a - 1a)



Shorokopolski swell of the Kerensk-Tchembar system (Dashevskii et al. , 1996, unpublished) (3a - 3a)

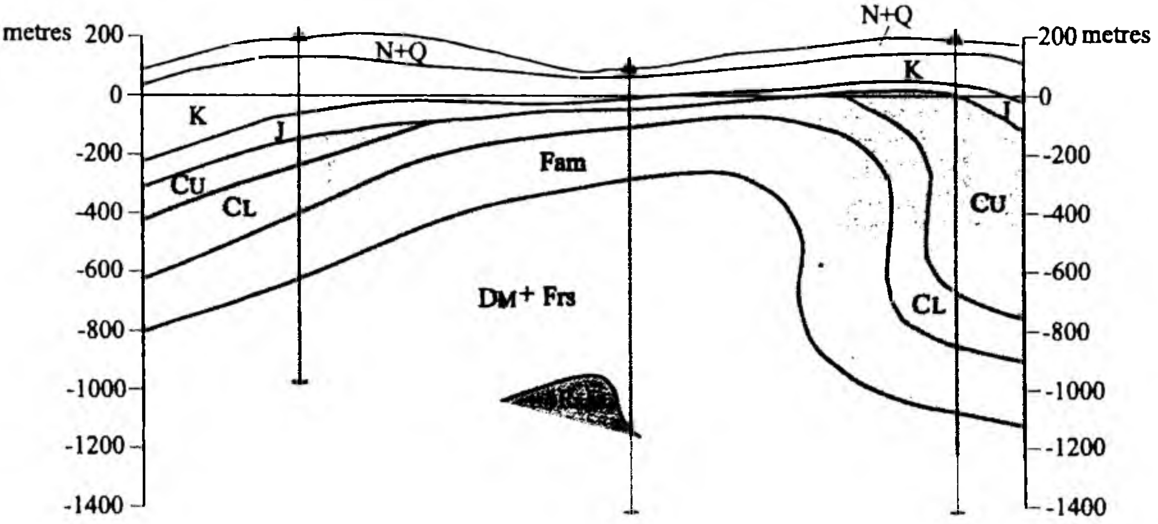


Fig. 3c

for the north-western part of the Alpine Great Caucasus (L. Rastsvetaev, 1998, personal communication) show that possible compression tectonism took place at the Maastrichtian to Palaeocene transition, because there are unconformities below the Eocene and inside(?) the Maastrichtian, and furthermore there are facial changes in the Maastrichtian deposits. In the north-eastern Caucasus in Dagestan gravitational olistostromes originated along the northern margin of the Great Caucasus Trough in Santonian to Maastrichtian times (MOSKVIN, 1962; MARKUS & SHARAFUTDINOV, 1989); their genesis could be connected with thrusting events and local inversion tectonics along the deep-water basin northern margin.

Data on the Pontides (OKAY & SAHINTURK, 1997; USTAOMER & ROBERTSON, 1997; YILMAZ *et al.*, 1997) show that collision tectonics occurred in Maastrichtian(?)-Palaeocene-pre-Lutetian times. The maximum collision took place in the Early Eocene, but the timing of these collision events is badly known. It was the collision of the Pontides and of the Gondwana-derived Kirsehir block-Menderes-Taurus Platform and the main closing of the Ankara-Erzincan suture (ophiolitic melange) (OKAY & SAHINTURK, 1997; YILMAZ *et al.*, 1997).

Data on the Lesser Caucasus region show that the Ankara-Erzincan ophiolite suture of Turkey reaches the Sevan-Akera suture in Armenia-Azerbaijan (LLORDKIPANIDZE, 1980; BOGDANOV & KHAIN, 1981; MONIN & ZONENSHAIN, 1987; E. E. MILANOVSKY, 1991). The geological structure of the region (KNIPPER & SOKOLOV, 1974; E. E. MILANOVSKY, 1991; GASANOV, 1996) shows that collision of the European continent with the South Armenian (Nakhichevan) Gondwana-derived terrane occurred in Late Cretaceous times; collision tectonics started in the Cenomanian-Coniacian and ended in mid-Santonian. A remnant flysch basin existed along the suture at the Cretaceous/Palaeocene transition.

Data on the Bulgarian shelf for the Balkan thrust wedge show (SINCLAIR *et al.*, 1997) that according to offshore seismic stratigraphy the first evidence of shortening was the reactivation of deep-level normal faults at the end of the Cretaceous. A regional uplift event took place, certainly at least in the eastern part of the Moesian Platform near the Cretaceous/Palaeogene boundary (mainly inside the Danian) (HARBURG & COHEN, 1997). It could have occurred in connection with a compression phase.

Data on the Scythian-Caucasus-Pontides-Moesian region demonstrate that Subhercynian and Laramide inversion tectonics in Europe were probably connected with collision tectonics and orogeny along the southern margins of the European continent (ZIEGLER *et al.*, 1998). We can add as further evidence that the inner Dinarides-Hellenides and Taurides started to collide with the European margin during the Senonian. With the final closure of the Vardar Ocean, this collision became important during Maastrichtian-Palaeocene times (STAMPFLI *et al.*, 1998).

Late Cretaceous to Palaeocene inversion structures in the Africa-Arabian and other areas

GUIRAUD & BOSWORTH (1997) discussed inversion structures in regions of Africa and Arabia. They recognised two main compressional events: in the Santonian (or Santonian/Campanian boundary) and at the Cretaceous/Palaeocene boundary. Close to the Santonian/Campanian boundary the inversion tectonics took place along the northern margin of the Africa-Arabia continent: Tellian Atlas, High Atlas, Tunisia, Egypt, Palmirides, Oman (start of emplacement of ophiolites); and also in rifted basins inside the continent - Benue, Termit, S. Chad, S. Sudan, Blue Nile Rift, Anza Rift, Lugh Mandera. At the Cretaceous/Palaeocene boundary, main inversion tectonics took place along the northern margin of the Africa-Arabia continent: Egypt, Palmirides, Oman (ophiolites). Generally the timing of inversion tectonic events in the Africa-Arabia continent and in Europe was very similar (ZIEGLER, 1990; GUIRAUD & BOSWORTH, 1997) but better stratigraphic control is needed for more precise conclusions. Numerous data show that inversion tectonics occurred also in the Tethys belt during the Senonian to Palaeocene (DERCOURT *et al.*, 1993; KHAIN & BALUKHOVSKY, 1993).

Recent investigations summarised in KHAIN & BALUKHOVSKY, (1993) show that near the K/T boundary orogeny affected many areas: the Laramide orogeny was very important f.i. in Northern and Southern America and in the Asian Far East.

Origin of the Late Cretaceous to Palaeocene compression stress in Eastern Europe

The origin of the Late Cretaceous to Palaeocene compression stress is a controversial problem. These important phases of intraplate compression of Senonian to Palaeocene age affected both the northern and southern Peri-Tethyan continents and were probably controlled by the accelerated counter-clockwise rotational convergence of Africa-Arabia with Eurasia (LIVERMORE & SMITH, 1985; WESTPHAL *et al.*, 1986; LE PICHON *et al.*, 1988). The Santonian/Campanian boundary coincided almost with a change of motion of Africa relative to Europe: oblique convergency was followed by more direct collision (GUIRAUD & BOSWORTH, 1997) with f.i. changes in subduction systems. We suggest three main reasons for such inversion tectonics: global plate kinematic reorganisation in the Senonian-Palaeocene, collisional tectonics along the Tethyan margins, and changes in subduction systems after accretions of new terranes.

Latest Cretaceous-Palaeocene global orogeny and biological crisis at the K/T boundary

New data show that the Laramide orogeny was very widely spread on the Earth. This led to changes in global topographical distribution of continents and oceans and f.i. also to changes in oceanic water currents and so on. In total, this could have led to a global environmental crisis. This could have been one of the main reasons for the biological crisis during the latest Cretaceous to Palaeocene with a climax at the K/T boundary.

Conclusions

1. Senonian to Palaeocene compressional polyphase regional stresses affected the East European Craton as well as the whole European palaeocontinent. This led to palaeogeographical changes and compressional tectonics inside the EEC.
2. We can recognise the following types of compressional tectonics inside the EEC: gentle lithospheric folding (buckling) with wave-length around 500-600 km; origin of inversion structures mainly above former rifted basins; syn-compressional rapid subsidence of former rifted basins; acceleration of salt diapirism; compression-related (impactogen) rifting.
3. The compression tectonics inside the EEC coincide with the orogenic epoch along the Tethyan belt.

Acknowledgements

We are very grateful to Prof. D. P. Naidin for numerous discussions and help in our research. We would also like to thank E. Milanovsky, V. Khain, A. Alekseev, Ludmila Kopaevich, E. Baraboshkin, S. Bolotov, A. Ershov, V. Beniamovsky, A. Olferiev, V. Dashevsky, L. Rastsvetaev, A. Morozov, Annie Dhondt, S. Cloetingh, R. Guiraud, Marie-Françoise Brunet, J. Dercourt, S. Stovba, S. Sliaupa and R. Garetsky for fruitful discussions and support. This work was sponsored by DWTC grant, INTAS (grant 97-0743) and Peri-Tethys Programme. The principal investigators were funded by the Russian Geological Survey and RFFI (RBFI).

This is Netherlands Research School of Sedimentary Geology Contribution No. 99-304.

References

Afanasiev, T.P. (ed.), 1970. Hydrogeology of the USSR, Nedra, Moscow, vol.13, 800 pp. (in Russian).

Arkhangelsky, A.D., 1922. A review of the geological structure of the European part of Russia, vol. 2, Central Russia. PG, Petrograd, 467 pp. (in Russian).

Arkhipov, Yu.V. , Vysotsky, K.A. & Kalinin, A.T., 1996. About deformation of platform cover of the Volga-Ural Region. *Geotektonika*, **5:** 55-66 (in Russian).

Beniamovsky, V.N., Volchegursky, L.F., Zhuravlev, V.S., Koblova, F.P., Romashev, A.A., 1973. Peculiarities of tectonic movements in the eastern part of the Peri-Caspian Basin during Late Cretaceous times. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, Geologia*, **48**, 3: 40-54. (in Russian).

Blank, M., Ya. & Gorbenko, V.F., 1968. Stratigraphy of the Upper Cretaceous deposits of the northern Donbass. *In*: Materials on the geology of the Donets Basin. Moscow, Nedra, p. 34-47. (in Russian).

Blank, M., Ya., Naidin, D.P. & Olferiev, A.G., 1992. Relief of Cenomanian root in Dniepr-Donets Trough, Voronezh Anteclyse and adjacent structures of the East-European Platform. *Byulleten Moskovskogo Obshchestva Ispytatelei Prirody, Geologia*, **67**, 6: 43-47. (in Russian).

Bogdanov, A.A. & Khain, V.E., 1981. Tectonic map of Europe and adjacent areas, 1: 2.500.000, 2nd Ed. International Geological Congress, Commission of the Geological Map of the World, Subcommission of the Tectonic Map of the World. Academy of Sciences of the USSR.

Chekunov, A.V., Veselov, A.A. & Glikman, A.I., 1976. Geological structure and history of the Peri-Black Sea basin. Kiev, Naukova Dumka, 164 pp. (in Russian).

Chibrikova, S.V., 1951. To the problem of connection of the Kerensk-Chembar and Saratov dislocations. *Scientific Notes of Saratov University, Geological Issue*, **23**; 36-46. (in Russian).

Dadlez, R., Narkiewicz, M., Stephenson, R.A., Visser, M.T.M., & Van Wees, J.-D., 1995. Tectonic evolution of the Mid-Polish Trough: modelling implications and significance for central European geology. *Tectonophysics*, **252**: 179-195.

Dercourt, J., Ricou, L.E. & Vrielynck, B. (eds.) 1993. Atlas Tethys, paleoenvironmental maps. Gauthier-Villars, Paris, 307 pp.

Gasanov, T. Ab., 1996. Geodynamics of ophiolites in the structure of the Lesser Caucasus and Iran. Baku, Elm, 454 pp. (in Russian).

Geisler, A.M., 1956. New data on stratigraphy and tectonics of the Lower Palaeozoic of the North-Western part of the Russian Platform. *In*: Data on geology of the European part of the USSR. Vsegei, Gosgeoltehizdat, Moscow, p. 174-185.

Gerasimov, P.A., Migacheva, E.E., Naidin, D.P. & Sterlin, B.P., 1962. Jurassic and Cretaceous deposits of the Russian Platform. Moscow University Press, 196 pp. (in Russian).

Guiraud, R. & Bosworth, W., 1997. Senonian basin inversion and rejuvenation of rifting in Africa and Arabia: synthesis and implications to plate-scale tectonics. *Tectonophysics*, **282**: 39-82.

Harbury, N. & Cohen, M., 1997. Sedimentary history of the Late Jurassic-Paleogene of Northeast Bulgaria and the Bulgarian Sea. *In*: A.G. Robinson (ed.), Regional and Petroleum Geology of the Black Sea and surrounding areas. *American Association of Petroleum Geologists, Memoir,* **68**: 129-168.

Ivannikov, A.V., Lipnik, E.S., Plotnikova, L.F., Blank, M. Ya., Gavrilishin, V.I., Pasternak, S.I., Nerodenko, V.M., Konashov, V.G., Matyushonok, V.A., Goncharuk, L.F., Gubkina, T.B., Rozumeyko, S.V., Karelov, M.I., & Lyulieva, S.A., 1991. Regional stratigraphical scheme of the Late Cretaceous deposits of the platform region of the Ukraine. Institute of the Geological Sciences (preprint), Kiev, 31 pp. (in Russian).

Kaptarenko-Chernousova, O.K. (ed.), 1971. Stratigraphy of the Ukraine. Vol. 8, Cretaceous. Naukova Dumka, Kiev, 320 pp. (in Ukrainian).

Khain, V.E. & Balukhovsky, A.N., 1993. Historical Geotectonics. Mesozoic and Cenozoic. INIAR, Moscow, 451 pp. (in Russian).

Khokhlov, P.S., 1955. Tectonics and history of development of the Kerensk-Chembar and Sura-Moksha dislocations. Moscow, Gostoptehizdat, 250 pp. (in Russian).

Knipper, A.L., & Sokolov, S.D., 1974. Pre-Senonian tectonic thrusts of the Lesser Caucasus. *Geotektonika*, **6**: 74-80. (in Russian).

Kutek, J., 1994. Jurassic tectonic events in south-eastern cratonic Poland. *Acta Geologica Polonica*, 44, 3-4: 167-221.

Le Pichon, X., Bergerat, F. & Roulet, M-J., 1988. Plate kinematics and tectonics leading to the Alpine belt formation: a new analysis. *Geological Society of America. Special Paper*, **218**: 11-131.

Livermore, R.A. & Smith, A.G., 1995. Some boundary conditions for the evolution of the Mediterranean Region. *In*: D.J. Stanley & F-C. Wezel (eds.), Geological Evolution of the Mediterranean Basin. Springer-Verlag, New York, Berlin, Heidelberg, Tokyo, pp. 83-98.

Llordkipanidze, M.B. 1980. Alpine volcanism and geodynamics of the central segment of the Mediterranean fold belt. Tbilisi, Metsniereba, 162 pp. (in Russian).

Markus, M.A. & Sharafutdinov, V.F., 1989. Oligocene olistostrome of the Eastern Caucasus and late Alpine tectonics. *Geotektonika*, 4: 87-98. (in Russian).

Mazarovich, O.A. & Mileev, V.S. (eds.), 1989 a. Geological structure of the Kacha Upland of Mountain Crimea. Stratigraphy of the Mesozoic. Moscow, Moscow State University Press, 168 pp. (in Russian).

Mazarovich, O.A. & Mileev, V.S. (eds.), 1989 b. Geological structure of the Kacha Upland of Mountain Crimea. Stratigraphy of the Cenozoic, magmatism and metasomatism. Moscow, Moscow State University Press. 160 pp. (in Russian).

Milanovsky, E.V., 1940. Review of the geology of the Middle and Lower Pre-Volga region. Moscow-Leningrad, State Publishing House of Oil Literature, 301 pp. (in Russian).

Milanovsky, E.E., 1987. Geology of the USSR. Part 1. Moscow University Press. 416 pp. (in Russian).

Milanovsky, E.E., 1991. Geology of the USSR. Part 3. Moscow, Moscow University Press. 272 pp. (in Russian).

Morroz, S.A., 1970. Palaeocene of the Dnieper-Donets Basin. Kiev University Press, Kiev, 190 pp. (in Russian).

Morrozov, N.S., 1962. Upper Cretaceous deposits between the Don river and the Severnyi Donets river, and southern part of the Volga-Don area. Saratov University Press, 222 pp. (in Russian).

Moskvin, M. M., 1962. Upper Cretaceous sediments of the North Caucasus and Subcaucasia. *Acta Geologica Polonica*, **12**, 2: 159-199.(in Russian).

Monin, A.S. & Zonenshain, L.P., 1987 (eds.). Geological History of the Tethys Ocean. Moscow. Academy of Sciences of the USSR, P.P. Shirshov Institute of Oceanology, 155 pp. (in Russian).

Mushenko, A.I., 1963. About some peculiarities of the development of structures of the Russian Platform. *In*: Data on tectonics of the Lower Pre-Volga Region. Nauka, Moscow, p. 147-161.

Muratov, M.V. (ed.), 1969. Geology of the USSR, Volume 8, Crimea. Part 1, Geology. Moscow, Nedra, 576 pp. (in Russian).

Naidin, D.P., 1960. The stratigraphy of the Upper Cretaceous of the Russian Platform. *Acta Universitatis Stockholmiensis. Stockholm Contributions in Geology*, 6, 4: 39-61.

Naidin, D.P. & Kotelnikov, D.D., 1998. Palaeogeographical environments of deposition and clay minerals in the Lower Campanian of Aktyubinsk Pre-Mugodzhary region. *Izvestia Vysshikh Uchebnykh Zavedeniy, Geologia i Razvedka*, 4: 23-34. (in Russian).

Najdin, D.P., 1969. Biostratigraphie und Paläogeographie der Oberen Kreide der Russischen Tafel. *Geologisches Jahrbuch*, **87**: 157-186.

Nikishin, A.M., Ziegler, P.A., Cloetingh, S., Stephenson, R., Furne, A.V., Fokin, P.A., Ershov, A.V., Bolotov, S.N., Korotaev, M.V., Alekseev, A.S., Gorbachev, V.I., Shipilov, E.V., Lankreijer, A., Bembinova, E. Yu, & Shalimov, I.V. , 1996. Late Precambrian to Triassic history of the East-European Craton: dynamics of sedimentary basin evolution. *Tectonophysics*, **268**: 23-63.

Nikishin, A.M., Bolotov, S.N., Fokin, P.A., Nazarevich, B.P., Panov, D.I., Alekseev, A.S., Baraboshkin, E. Yu, Ershov, A.V., Kopaevich, L.F., Korotaev, M.V., Ustinova, M.A., Brunet, M.-F., Cloetingh, S. & Stephenson, R.A., 1997a. Devonian to Cenozoic geological history and dynamics of Scythian Platform-Donets Basin-South Russian Platform region. *In:* Intracratonic Rifting and Inversion. EUROPROBE GeoRift Workshop. ETH Zurich, October 16-19, 1997, p. 9-11.

Nikishin, A.M., Brunet, M.-F., Cloetingh, S. & Ershov, A.V., 1997b. Northern Peri-Tethyan Cenozoic intraplate deformations: influence of the Tethyan collision belt on the Eurasian continent from Paris to Tian-Shan. *Comptes-Rendus Académie Sciences Paris*, **324**, (II a): 49-57.

Nikishin, A. M., Cloetingh, S., Bolotov, S.N., Baraboshkin, E. Y., Kopaevich, L.F., Nazarevich, B.P., Panov, D.I., Brunet, M-F., Ershov, A.V., Il'Ina, V.V., Kosova S. S. & Stephenson, R.A., 1998a. Scythian platform: chronostratigraphy and polyphase stages of tectonic history. *In*: S. Crasquin-Soleau & E. Barrier (eds.), Peri-Tethys Memoir 3. Stratigraphy and Evolution of Peri-Tethyan Platforms. *Mémoires Muséum national d'Histoire naturelle*, Paris, **177**: 151-162.

Nikishin, A. M., Cloetingh, S, Brunet, M. F., Stephenson, R., Bolotov, S.N. & Ershov, A.V., 1998b. Scythian Platform and Black Sea region: Mesozoic-Cenozoic tectonic and dynamics. *In*: S. Crasquin-Soleau & E. Barrier (eds.), Peri-Tethys Memoir 3. Stratigraphy and Evolution of Peri-Tethyan Platforms. *Mémoires Muséum national d' Histoire naturelle*, Paris, **177**: 163-176.

Okay, A.I. & Sahinturk, O., 1997. Geology of the Eastern Pontides. *In*: A.G. Robinson (ed.), Regional and petroleum geology of the Black Sea and surrounding region, *American Association of Petroleum Geologists, Memoir*, 68: 291-311.

Oreshkina, T.V., Alekseev, A.S. & Smirnova, S.B., 1998. Cretaceous-Palaeogene deposits of the Polar Pre-Uralians: biostratigraphical and palaeogeographical aspects. *In*: A. Knipper, S. Kurenkov, & M. Semikhatov (eds.), Urals: fundamental problems of geodynamics and stratigraphy. Moscow, Nauka, p. 183-192. (in Russian).

Sazonov, N.T., 1951. Tectonic structure of Zhiguli and Borlinsk zons of dislocations. VNIGRI, Leningrad, vol. 2, p. 19-39. (in Russian).

Sazonov, N.T., 1953. Tectonic structure of Ryazan and Penza regions and Mordovia ASSSR. *In*: Stratigraphy and Tectonics of the Russian Platform: Geochemistry and Regional Geology. Vol. 3, p. 65-84. (in Russian).

SAVCHINSKAYA, O.V., 1982. Life conditions of the Late Cretaceous fauna of the Donets Basin. Moscow, Nauka, 132 pp. (in Russian).

SHATSKY, N.S., 1964. Selected papers. Vol.2. Nauka, Moscow, 528 pp. (in Russian).

SENCHENKO G.S., 1951. About some peculiarities in changes of composition and thicknesses of Upper Cretaceous deposits in the eastern part of the Kerensk-Chembar Dislocations. *Scientific Notes of Saratov University, Geological Issue, 23*: 55-63. (in Russian).

SENYUKOV, V.M. & BAKIROV, A.A., 1949. The tasks of the oil geology in the solving of problems of oil and gas potential of the Russian Platform. Moscow, VNIGRI, vol. 1, p. 5-31. (in Russian).

SINCLAIR, H.D., JURANOV, S.G., GEORGIEV, G., BYRNE, P. & MOUNTNEY, N.P., 1997. The Balkan thrust wedge and foreland basin of Eastern Bulgaria: structural and stratigraphic development. *In*: A.G. ROBINSON (ed.), Regional and Petroleum Geology of the Black Sea and surrounding areas. *American Association of Petroleum Geologists, Memoir,* **68**: 91-114.

SLIAUPA, S., 1997. Tectonics of South Lithuania. PhD Thesis synopsis. Vilnius, 45 pp. (in Russian).

STAMPFLI, G.M., MOSAR, J., DE BONO, A. & VAVASIS, I., 1998 (in press). Late Paleozoic, Early Mesozoic plate tectonics of the Western Tethys. *Bulletin of the Geological Society of Greece.*

STEPHENSON, R.A., 1997. GeoRift project DOBRE: Late Palaeozoic peri-cratonic basin development in Ukraine and Russia. *In*: Intracratonic Rifting and Inversion. EUROPROBE GeoRift Workshop. ETH Zurich, October 16-19, 1997, p. 1-3.

STOVBA, S. M. & STEPHENSON, R. A., 1999. The Donbass Foldbelt: its relationship with the uninverted Donets segment of the Dniepr-Donets Basin, Ukraine. *Tectonophysics*, in press.

STOVBA, S.N., STEPHENSON, R.A. & KIVSHIK, M., 1996. Structural features and evolution of the Dnieper-Donets Basin, Ukraine, from regional seismic reflection profiles. *Tectonophysics*, **268**: 127-147.

ULANOVSKAYA, T.E., 1988. Paleogeographic reconstruction based on palaeoecology and its applications to palaeotectonic analysis (on the example of the Eocene of the Azov-Kuban Depression). *Izvestiya Vysshikh Uchebnykh Zavedeniy. Geologia i razvedka*, 1:17-25. (in Russian).

USTAOMER, T., & ROBERTSON, A., 1997. Tectonic-sedimentary evolution of the North Tethyan margin in the Central Pontides of Northern Turkey. *In*: A.G. ROBINSON (ed.), Regional and petroleum geology of the Black Sea and surrounding region. *American Association Petroleum Geologists, Memoir*, **68**: 255-290.

USTINOVA, M.A., NIKISHIN, A.M., ALEKSEEV A.S., DASHEVSKY, V.V. & OLFERIEV, A.G., 1998. Deformational history of inversional structures of the Russian Platform. *In*: 6th Zonenshain Conference on Plate Tectonics (Moscow, February 17-20, 1998). Programme and Abstracts. Moscow, P.P. Shirshov Institute of Oceanology, p. 134-135.

VESELOVSKAYA, M.M., 1960. Issa deep well. VNIGRI, Leningrad, vol. 26. p. 176-226. (in Russian).

WESTPHAL, M., BAZHENOV, M.L., LAUER, J-P., PECHERSKY, D.M. & SIBUET, J.C., 1986. Paleomagnetic implications on the evolution of the Tethys Belt from the Atlantic Ocean to Pamir since Trias. *Tectonophysics*, **123**: 37-82.

YILMAZ, Y., TUYSUR, O., YIGITBAS, E., CAN GENC, S. & SENGOR, A.M.C., 1997. Geology and tectonic evolution of the Pontides. *In*: A.G. ROBINSON (ed.), Regional and petroleum geology of the Black Sea and surrounding region. *American Association Petroleum Geologists, Memoir*, **68**: 183-226.

YUDIN, V.V., 1994. Orogenes of the Northern Urals and Pay-Khoy. Ekaterinburg, Nauka, 284 pp. (in Russian).

ZIEGLER, P.A., 1990. Geological Atlas of Western and Central Europe - 2nd Ed., Shell Internationale Petroleum Maatschappij., Den Haag, Geological Society. Publishing House, Bath, 239 p.

ZIEGLER, P.A., CLOETINGH, S. & VAN WEES, J-D., 1995. Dynamics of intra-plate compressional deformations: the Alpine foreland and other examples. *Tectonophysics*, **252**: 7-59.

ZIEGLER, P.A., VAN WEES, J-D. & CLOETINGH, S., 1998. Mechanical controls on collision-related compressional intraplate deformation. *Tectonophysics*, **300**: 103-129.

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Typescript submitted: December 1, 1998.
Revised typescript received: February 1, 1999.

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 161-165, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 161-165, 1999

Cretaceous Stages Boundaries in central Tunisia: how to follow the Brussels 1995 Symposium Recommendations

by Francis ROBASZYNSKI

Abstract

At the Copenhagen (1983) and Brussels (1995) symposia, the lower boundaries of the stages were defined by a biological or physical event considered as having a global value. Following the criteria recommended at the Brussels (1995) symposium, the base of each Upper Cretaceous stage in Central Tunisia is discussed following recent publications with multibiostratigraphic charts.

Key-words: Upper Cretaceous - stage boundaries - Tunisia

Résumé

Après les Symposiums de Copenhagen en 1983 et de Bruxelles en 1995, les étages sont maintenant définis à leur base par un événement biologique ou physique considéré comme ayant une valeur mondiale. En ayant pour but de suivre au plus près les critères recommandés à Bruxelles (1995), la base de chaque étage du Crétacé supérieur de Tunisie centrale est discutée à la lumière de travaux récents portant sur des échelles multibiostratigraphiques.

Mots-clefs: Crétacé supérieur - limites d'étage - Tunisie

Резюме

На симпозиумах в Копенгагене (1983) и в Брюсселе (1995) нижние границы ярусов были определены биологическим или физическим событием, имеющим всемирную ценность. Следуя рекомендованным в Брюсселе критериям, основа каждого верхнего мелового яруса Центрального Туниса обсуждается в свете новых исследований, изучающих макробиостратиграфические масштабы.

Ключевые слова: Верхний мел, границы ярусов, Тунис

Introduction

Since 1990, the Upper Cretaceous of the Kalaat Senan region in Central Tunisia is being studied. Its succession and its palaeontological content are compared with those of Boreal regions, and especially with the type areas of the stages and "type sections" previously studied in the Paris Basin (Albian to Santonian: Robaszynski, Amédro coord. *et al.*, 1980; type Turonian: Robaszynski *et al.*, 1982; Campanian-Maastrichtian of the Maastricht area: Robaszynski *et al.*, 1983). Moreover, several sections have been studied in the Northern Tethys margin (Devalque *et al.*, 1983).

From these data, it became obvious that Tunisia was an excellent area for representing the "Southern" Tethys.

Ten years long, our aim was to find a continuous section in the Upper Cretaceous permitting a comparison between Tethys and Boreal regions. Therefore, the same biostratigraphic tools were applied to both areas, especially the study of Ammonites, Planktonic Foraminifera and Calcareous Nannoplankton. The region of Kalaat Senan seemed suitable because of its palaeogeographical position. Kalaat Senan is situated between a platform to the south and a basin to the north. Distal sedimentation took place in a very subsiding region. This resulted in a thick sedimentary lithological succession, which often contains all elements of a deposition sequence (Shelf Margin Wedge or Lowstand Systems Tract, Transgressive Systems Tract and High Stand Systems Tract). This sedimentation is largely continuous and the palaeontological assemblages are of a mixed type, containing both platform organisms (such as bivalves, including rudists and inoceramids, echinoderms but also ammonites) and basin organisms (such as planktonic and benthic foraminiferans, nannoplancton and dinoflagellates).

A few vertical faults influence the succession. The correlation between partial sections is achieved by the use of characteristic beds. The tectonics are nevertheless sufficient for a dip between 15° and 30°, which allows easy observation of the beds, good fossil collecting and sampling of non-alterated levels.

From the Albian to the Maastrichtian the succession has a thickness of almost 3700 m, distributed over several formations, from top to bottom:
El Haria Marls (700 m, of which 200 m are Cretaceous): Upper Maastrichtian.
Abiod Limestones and Marls (500 m): Upper Campanian to Lower Maastrichtian.

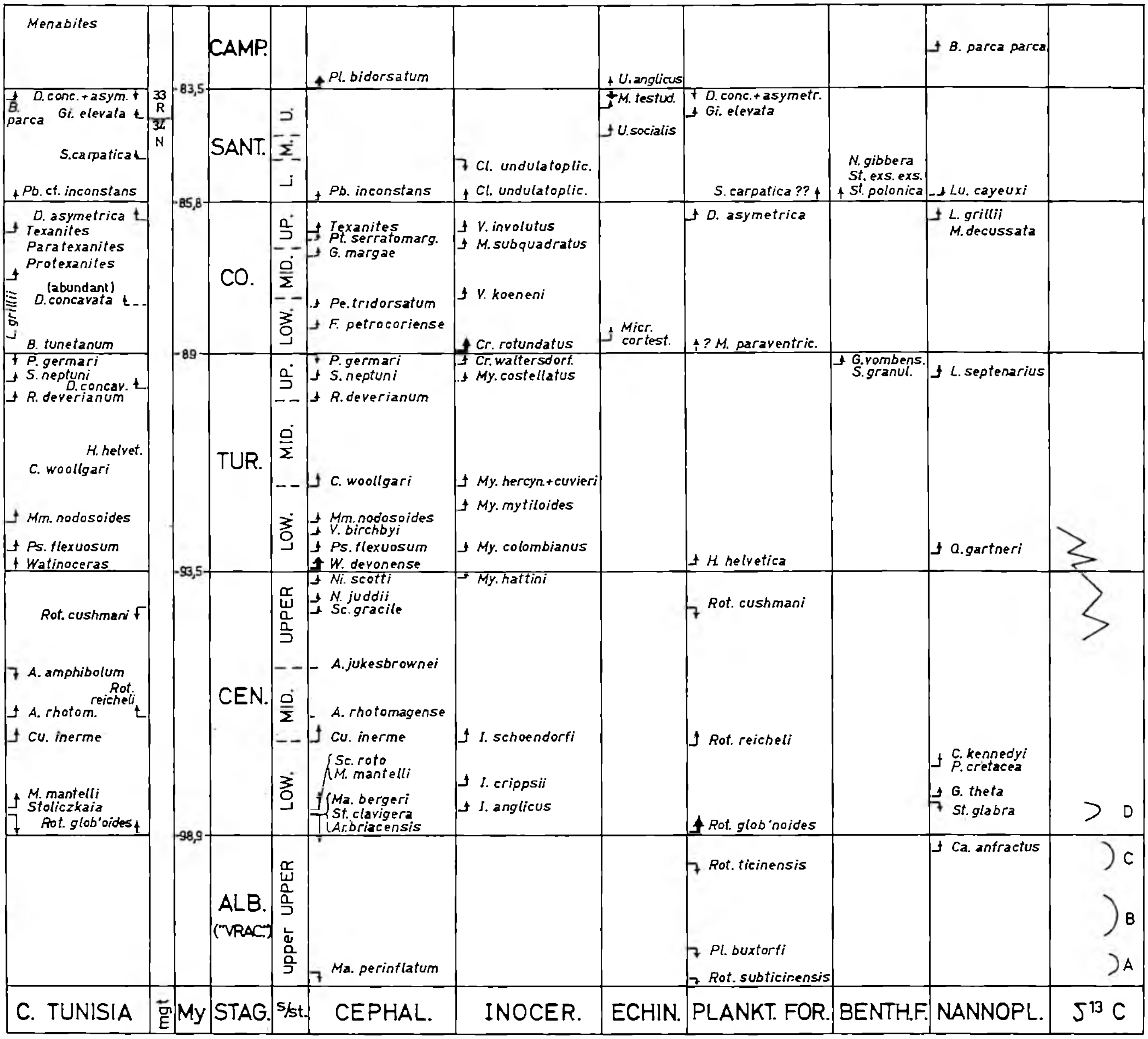

Fig. 1 — Bioevents and magnetic reversal from Upper Albian to Lower Campanian.

Abbreviations for Figs. 1 and 2. AMMONITES, A: *Acanthoceras*, Ar: *Arraphoceras*, B: *Barroisiceras*, C: *Collignoniceras*, Cu: *Cunningtoniceras*, F: *Forresteria*, G.: *Gauthiericeras*, M: *Mantelliceras*, Ma: *Mariella*, Mm: *Mammites*, Mo: *Mortoniceras*, N: *Neocardioceras*, Ni: *Nigericeras*, P: *Prionocyclus*, Pb: *Pseudoschloenbachia*, Pe: *Peroniceras*, Pl: *Placenticeras*, Ps: *Pseudaspidoceras*, Pt: *Paratexanites*, Py: *Pachydiscus*, R: *Romaniceras*, S: *Subprionocyclus*, Sc: *Sciponoceras*, St: *Stoliczkaia*, T: *Texanites*, V: *Vascoceras*, W: *Watinoceras*. INOCERAMIDS, Cl: *Cladoceramus*, Cr: *Cremnoceramus*, I: *Inoceramus*, M: *Magadiceramus*, My: *Mytiloides*, V: *Volviceramus*. ECHINODERMS, M: *Marsupites*, Micr: *Micraster*, U: *Uintacrinus*. FORAMINIFERA: A: *Abathomphalus*, C: *Contusotruncana*, D: *Dicarinella*, G: *Gavelinella*, Gi: *Globotruncanita*, Gs: *Gansserina*, H: *Helvetoglobotruncana*, M: *Marginotruncana*, N: *Neoflabellina*, Pl: *Planomalina*, Rot: *Rotalipora*, S: *Sigalia*, St: *Stensioeina*. NANNOPLANCTON, B: *Broinsonia*, Ca: *Calculites*, G: *Gartnerago*, L: *Lithastrinus*, Li: *Lithraphidites*, Lu: *Lucianorhabdus*, M: *Micula*, P: *Prediscosphaera*, Q: *Quadrum*, St: *Staurolithites*.

Aleg or Kef Marls (1250 m): middle Turonian to Campanian.

Trilogy of Bireno Limestones - Annaba - Marls Bahloul Limestones (250 m): Upper Cenomanian Lower Turonian.

Fahdène Marls (1500 m): Albian-Cenomanian.

For the lithology, from the Cenomanian to the K/T boundary, about 3000 m of marls and limestones were measured and described. Samples were taken every 2 to 6 m when possible, according to the needs of the studies on planktonic foraminifera and calcareous nannoplankton. Over the whole succession, macrofaunas were collected especially ammonites and inoceramids.

For placing stage boundaries, the first papers on the Cenomanian and the Turonian (ROBASZYNSKI *et al.*, 1990, 1993, 1994) followed the recommendations of the 1983 Copenhagen Symposium (BIRKELUND *et al.*, 1984). Some changes in these recommendations were proposed at the 1995 Brussels Symposium (RAWSON *et al.*, edit., 1996). The goal of the next paragraph is to explain how the 1996 recommendations should be followed when the type palaeontological marker is not present or not found in the succession.

Stage boundaries

Albian-Cenomanian boundary

— Before the Brussels CSB (Cretaceous Stage Boundaries) meeting (1995): appearance of the ammonite genus *Mantelliceras*.

— Since Brussels 1995: appearance of the planktonic foraminiferan *Rotalipora globotruncanoides* (= *brotzeni*) which is earlier than the appearance of *Mantelliceras*.

— In Tunisia: *R. globotruncanoides* is present together with many *Mantelliceras* and *Stoliczkaia* specimens (cf. Fig. 1).

Now *Stoliczkaia* is present in the basal Cenomanian and *Mantelliceras* in no longer the first appearing Cenomanian ammonite genus.

Note: the Cenomanian is the beginning of an important global transgressive pulse, its base is generally marked by a level with phosphates (in Tunisia, in Algeria, in the Paris Basin and also in SE France, even in the proposed boundary stratotype).

Cenomanian-Turonian boundary

— Before the Brussels CSB meeting (1995): appearance of the ammonite *Pseudaspidoceras flexuosum* (recommendation of the Copenhagen 1983 meeting).

— Since Brussels 1995: appearance of the ammonite *Watinoceras devonense*, which means a zone lower.

— In Tunisia: in 1990 the boundary was placed at *P. flexuosum*, at the top of the Bahloul Formation.

Now the boundary has to be placed within the Bahloul Fm. The presence of the planktonic foraminiferan *Helvetoglobotruncana* cf. *praehelvetica/helvetica* together with some *Watinoceras* specimens is now demonstrated below *P. flexuosum.*

Note: importance of δ13C of OAE 2 for long distance correlations (Pueblo - Dover - Menoyo Kalaat (cf. ACCARIE *et al.*, 1996).

Turonian-Coniacian boundary

— Before the Brussels CSB meeting (1995): appearance of the ammonite *Forresteria petrocoriensis*

— Since Brussels 1995: appearance of the inoceramid *Cremnoceramus rotundatus* sensu Tröger non Fiege, which means earlier.

— In Tunisia: the characteristic inoceramid species is not present and the appearance of *Globotruncana paraventricosa* is not really valid.

However, several ammonites allow to place the boundary quite correctly: the extinction of the ammonite *Prionocyclus germari* coincides in Germany with the appearance of *C. rotundatus*. Moreover, the abundance of the ammonite *Barroisiceras* cf. *tunetanum* is a good proxy for marking the basal Coniacian.

Coniacian-Santonian boundary

— Before the Brussels CSB meeting (1995): appearance of the ammonite *Texanites.*

— Since Brussels 1995: appearance of the inoceramid *Cladoceramus undulatoplicatus* (which is earlier than the appearance of *Texanites*) and which some palaeontologists consider isochronous with the appearance of the planktonic foraminiferan *Sigalia carpatica.*

— In Tunisia: no *Cladoceramus* have been collected so far, but *Texanites*, *Pseudoschloenbachia* and *Platyceramus cycloides* occur frequently.

Since the ammonite *Pseudoschloenbachia* is known in Germany and in USA just above *I. undulatoplicatus* (SUMMESBERGER, 1980; KENNEDY & COBBAN, 1991), the coexistence of *Texanites* and *Pseudoschloenbachia* is a good proxy for placing the base of the Santonian stage. However, the first *Texanites* are Coniacian. Some problems arise: the first *Sigalia carpatica* in the succession are present clearly at a higher level (+ 50 m) and the planktonic foraminiferan marker *Dicarinella asymetrica* appears clearly below (-30 m) the ''proxy'' boundary.

Santonian-Campanian boundary

— Before the Brussels CSB meeting (1995): appearance of the ammonite *Placenticeras bidorsatum* (occurs rarely).

— Since Brussels 1995: *id.*, but a preference has been expression for the extinction of the planktonic foraminifera *Dicarinella concavata* and *D. asymetrica* (cf. Fig. 2).

— In Tunisia: neither *Placenticeras bidorsatum*, nor *Marsupites testudinarius* have been found.

The extinction of *Dicarinella concavata* is clearly seen and happens after the appearance of *Globotruncanita elevata.* The appearance of *Globotruncana arca* between the first *G. elevata* and the last *D. asymetrica* is also a good proxy for the base of the Campanian.

Campanian-Maastrichtian boundary.

— Before the Brussels CSB meeting (1995): appearance of *Belemnella lanceolata.*

— Since Brussels 1995: appearance of *Pachydiscus neubergicus* (below this appearance there are two ammonite zones, the upper one is the *Nostoceras hyatti* Zone with *Pseudokossmaticeras brandti*, the lower one the *Bostrychoceras polyplocum* Zone, which was previously considered as the last Campanian zone in the Tethyan

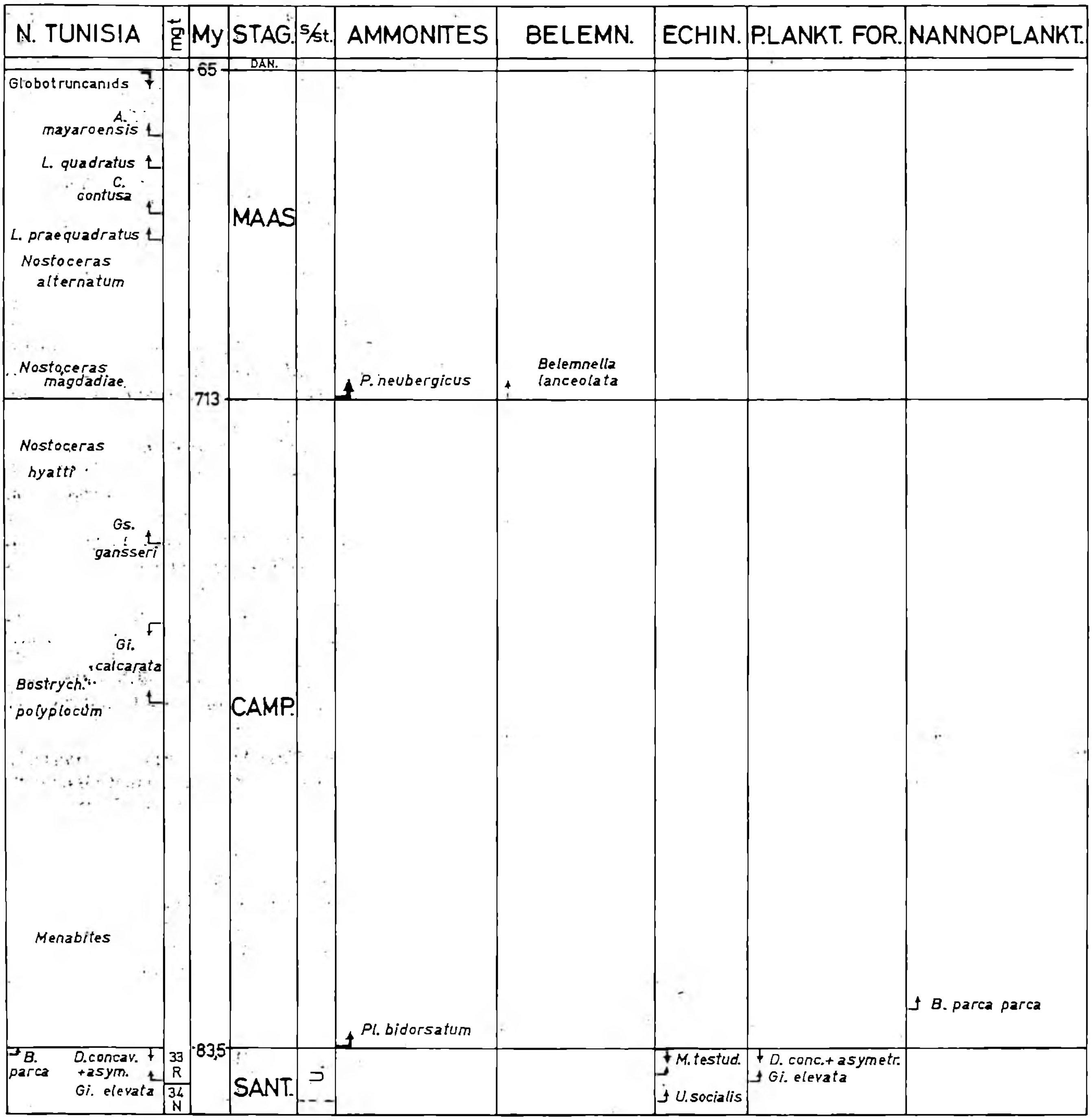

Fig. 2 — Bioevents for the Campanian-Maastrichtian. For Figs 1 and 2: time scale after GRADSTEIN *et al.* (1994); biological and physical events from RAWSON *et al.* edit (1996).

domain, cf. historic aspects *in* ROBASZYNSKI *et al.*, in press),

— In Tunisia: *Bostrychoceras polyplocum*, *Nostoceras hyatti*, *Pseudokossmaticeras brandti* are found but not *Pachydiscus neubergicus*. The extinction of *Globotruncanita calcarata* occurs after the last *B. polyplocum*, but before the first *N. hyatti*. In the absence of *P. neubergicus*, *Nostoceras (Nostoceras)*, aff. *magdadiae* is used, a species that indicates the Maastrichtian in the USA according to COBBAN & KENNEDY (1995).

Maastrichtian-Danian boundary.

— The boundary is indicated by the extinction of 45 planktonic foraminiferan taxa among which *Abathomphalus mayaroensis* and *Plummerita reicheli (= Pl. hantkeninoides)*.

The first Danian zone with a thickness of only 0.5 m, is the *Guembellita cretacea* Zone, even though this species is already present in the terminal Maastrichtian. Above this first zone, begins the *Parvularugoglobigerina eugubina* Zone.

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 167-172, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 167-172, 1999

Report 1

Upper Cretaceous Ammonites and their extinction: interpretation of data from the Caucasus and comparison with Mangyshlak, the Crimea and the Maastricht area

by Elisso KOTETISHVILI

Abstract

Comparison of Upper Cretaceous ammonite faunas from the Caucasus, the Crimea, Mangyshlak and around Maastricht.

Key words: ammonites, Upper Cretaceous, distribution, evolution.

Résumé

Comparaison des ammonites du Crétacé supérieur du Caucase, de la Crimée, du Mangyshlak, et des environs de Maastricht.

Mots-clefs: ammonites, Crétacé supérieur, répartition, évolution.

Резюме

Сравнение аммонитов верхнего мела Кавказа, Крыма, Мангышлака и окрестностей Маастрихта.

Ключевые слова: аммониты, верхний мел, распределение, развитие

INTAS project 94-1414 studies the evolution of the faunas and their environments in three stratigraphically and palaeontologically important regions. A detailed comparison of latest data from the following regions is presented: 1. Mangyshlak (West Kazakhstan), 2. Upper Crimea, 3. The Maastricht type area (Belgium-the Netherlands).

The Upper Cretaceous ammonite fauna from the Caucasus forms a link between Mangyshlak and Upper Crimea, and its characteristics shall help to define faunistic relations. Even more so as the Upper Cretaceous Caucasian basins are restricted to shallow marine basins, a kind of environment in which the Cretaceous/Tertiary boundary has rarely been studied. In Georgia some continuous sections are known which are of interest from this point view.

Let us start with the **Northern Caucasus.**

In its central part the **Campanian** stage is represented by white limestones with stylolite horizons and thin clay marl beds. These strata contain echinoids (*Micraster schroederi* Stolley, *Echinocorys turrita* Lambert, *Pseudoffaster schmidtae* Posl. & Moskvin, *Offaster pomeli* Munier-Chalmas), inoceramids (*Inoceramus azerbaydjanensis* Aliev, *I. dariensis* Dobrov & Pavlova) and rare specimens of the ammonite *Eupachydiscus launayi* de Grossouvre - (thickness 30 to 40 m).

Higher up follows an alternation of white and light-creamy limestones with clay marls of increasing thickness (from 10 to 15 up to 70 to 80 cm), containing *Hauericeras pseudogardeni* Schlüter, *Inoceramus balticus* Boehm, *I. muelleri* Petrascheck, *Micraster coravium* Posl. & Moskvin, *Seunaster gillieroni* de Loriol, *Offaster pilula* Lamarck, *Galeola senonensis* d'Orbigny, *Conulus matesovae* Posl. & Moskvin. In the upper part *Pseudoffaster caucasicus* Druschitz (70 to 80 m.).

Beside these species, in the Campanian *Pachydiscus koeneni* de Grossouvre, *Bostrychoceras polyplocum* (Roemer), *Glyptoxoceras retrorsum* (Schlüter), *Menuites auritocostatus* (Schlüter), *Baculites vertebralis* Lamarck, *Inoceramus balticus*, *Micraster brongniarti* Hébert, *Pseudoffaster caucasicus*, *Galeola gauthieri* Lambert, and rare fragments of *Belemnitella mucronata* (Schlotheim) are found.

Eastwards, the Campanian sediments extend almost unchanged up to Malchick. Further to the East in the Lower Campanian *Offaster pomeli*, *Pseudoffaster schmidtae*, *Inoceramus azerbaydjanensis* are present; in the upper part *Micraster coravium*, *Seunaster gillieroni*, *Pseudoffaster caucasicus*, *Conulus matesovae*, *Inoceramus balticus*.

In the Ardon basin the Campanian was washed out.

To the west of the Bolshoi Zelenchuk River, sediments enriched with clays are of reduced thickness (15-20 m), but both substages of the Campanian are present: in the lower part: *Micraster schroederi*, *Pseudoffaster caucasicus*, *Conulus matesovae*; in the upper part *Micraster brongniarti*, *Galeola gauthieri*, *Pseudoffaster caucasicus*.

The **Maastrichtian** stage is characterised by an abundant fauna. The Lower Maastrichtian substage consists of clayey limestones with marly ''interlayers'' with numerous inoceramids (*Inoceramus alaeformis sensu* Tsagareli *non* Zekeli, *I. pertenuis* Meek & Hayden, *I. sagensis* Owen, *I. convexus* Hall & Meek), cephalopods [*Hoploscaphites constrictus* (J. Sowerby), *Hauericeras sulcatum* (Kner), *Didymoceras schloenbachi* (Favre), *Pseudokossmaticeras galicianum* (Favre), *P. brandti* (Redtenbacher), *Baculites vertebralis*, *B. anceps* Lamarck, rarely *Belemnitella conica obesa* Naidin], echinoids (*Micraster grimmensis* Nietsch., *Orthaster ciplyensis* Lambert, *Coraster cubanicus* Posl. & Moskvin, *Galerites vulgaris* Leske) are present. Higher up these taxa occur more rarely, but we also find *Diplomoceras cylindraceum* (Defrance), *Belemnitella conica rotunda* (Naidin), *Guettaria rocardi* (Cotteau), *Stegaster chal-*

• Stage	Substage	Maastricht area Kennedy, 1986a, b Naidin, 1978	Upper Crimea Maslakova, 1986	North Caucasus Moskvin, 1986	Transcaucasus Tsagareli, 1954 Gambashidze, 1979	Mangyshlak Atabekian, 1986
Maastrichtian	Upper	*Saghalinites* sp. *Baculites anceps* *B. vertebralis* *Nostoceras* sp. *Glyptoxoceras* cf *subcompressum* *G.* cf *circulare* *Diplomoceras cylindraceum* *Hoploscaphites constrictus* *H. pungens* *H. felderi* *Acanthoscaphites* cf. *verneuilianus* *Pachydiscus gollevillensis* *P. jacquoti* *Anapachydiscus fresvillensis* *Sphenodiscus binkhorsti*	*Hypophylloceras surya* *Hoploscaphites constrictus* *Pachydiscus neubergicus* *P. gollevillensis*	*Hypophylloceras surya* *Baculites anceps* *B. vertebralis* *Neancyloceras retrorsum* *Hoploscaphites constrictus* *Pachydiscus neubergicus* *P. gollevillensis* *P. colligatus*	*Diplomoceras cylindraceum* *Hoploscaphites constrictus* *Pachydiscus neubergicus* *P. gollevillensis* *P. subrobustus orientalis*	*Baculites anceps* *Hoploscaphites constrictus crassus*
	Lower	*Diplomoceras cylindraceum* *Hoploscaphites constrictus* *H. tenuistriatus* *Acanthoscaphites tridens*	*Diplomoceras cylindraceum* *Hoploscaphites constrictus* *Acanthoscaphites tridens* *Hauericeras sulcatum* *Pseudokossmaticeras galicianum*	*Baculites vertebralis* *B. anceps* *Didymoceras schloenbachi* *Diplomoceras cylindraceum* *Hoploscaphites constrictus* *Hauericeras sulcatum* *Pseudokossmaticeras galicianum* *P. brandti*	*Diplomoceras cylindraceum* *Hoploscaphites constrictus* *Acanthoscaphites tridens* *Hauericeras sulcatum* *Pseudokossmaticeras galicianum* *P. brandti* *Pachydiscus neubergicus* *Pa.* cf. *colligatus* *Pa. perfidus* *Pa. koeneni* *Anapachydiscus fresvillensis* *Parapachydiscus icenicus*	
Campanian	Upper	*Baculites* sp. *Trachyscaphites spiniger* *Hoplitoplacenticeras marroti* *H.* cf *coesfeldiensis* *Pachydiscus colligatus*	*Baculites* ex gr. *anceps* *Hauericeras pseudogardeni* *Pachydiscus koeneni*	*Baculites vertebralis* *Bostrychoceras polyplocum* *Glyptoxoceras retrorsum* *Hauericeras pseudogardeni* *Pachydiscus koeneni* *Menuites auricostatus* *Eupachydiscus launayi*	*Bostrychoceras polyplocum schloenbachi* *Glyptoxoceras retrorsum* *Eupachydiscus levyi* *Scaphites* cf *haugi* *Hoplitoplacenticeras vari*	*Pachydiscus stobaei*
	Lower	*Scaphites hippocrepis* *Pachydiscus duelmensis*			*Glyptoxoceras wernickei* *Discoscaphites gibbus* *Eupachydiscus levyi*	

masi Seunès, *Echinocorys pyramidata* Portlock, *Galeaster bertrandi* Seunès, *Homoeaster tunetanus* Pomel. (thickness of the Lower Maastrichtian: 200 to 250 m).

The Upper Maastrichtian consists of limestones interbedded with marls, and only in the upper part with thin stylolite horizons. The lower part contains: *Pseudoffaster renngarteni* Schmidt, *Echinocorys pyramidata, Galerites vulgaris.* No inoceramids except rare *Inoceramus caucasicus* Dobrov [= *Spyridoceramus tegulatus* (Ravn)]. The upper part contains: *Pachydiscus gollevillensis* (d'Orbigny), *P. neubergicus* (Hauer), *Pseudophyllites indra* (Forbes), *Phylloceras* (*Hypophylloceras*) *surya* (Forbes), *Baculites vertebralis*, *Neancyloceras retrorsum* (Schlüter), *Neobelemnella kazimiroviensis* Skolozdrowna, *Inoceramus "tegulatus" sensu* Dobrov & Pavlova (= *Tenuipteria argentea* Conrad), *Echinocorys perconica* von Hagenow, *E. ciplyensis* Lambert, *Cyclaster integer* Seunès, *Abathomphalus mayaroensis* Bolli. *Hoploscaphites constrictus* occurs throughout the Maastrichtian (MOSKVIN, 1986).

In **Transcaucasian Georgia** Late Cretaceous ammonites were studied by TSAGARELI (1954) and GAMBASHIDZE (1979). Kotetishvili and Magalashvili provided supplementary data. Shallow marine environments dominate on the Georgian Block, and in the Artvin-Bolnisi Block and in the Adjara-Trialetian basin.

On the Georgian Block three facies types were distinguished in calcareous-marly sediments by GAMBASHIDZE (1979). In the uppermost part of the **Campanian,** in one of the blocks, *Bostrychoceras polyplocum schloenbachi* (Favre) was found. In the Transcaucasus during the **Maastrichtian** ammonites are more abundant: in the lower part of the substage *Pachydiscus neubergicus*, *Acanthoscaphites tridens* (Kner), *Hoploscaphites constrictus*, *Diplomoceras cylindraceum* were found, whereas in the upper part *Pachydiscus neubergicus*, *Hoploscaphites* cf. *constrictus* were collected. In the Dzirula type in the Lower Maastrichtian *Hauericeras sulcatum*, *Pseudokossmaticeras galicianum* and *P. brandti* were observed; in the Upper Maastrichtian only *Pachydiscus neubergicus* was noticed.

In the Ajara-Trialeti basin the Campanian is represented only by limestones and variegated marls, and it is defined only by inoceramids: *Inoceramus pseudoregularis* Sornay, *I. alaeformis sensu* Tsagareli *non* Zekeli, *I. convexus*, *I. georgicus* Tsagareli, *I.* cf. *adjakendensis* Aliev, *I. salisburgensis* Fugger & Kastner, in the lower part, and *I. balticus*, *I. alaeformis sensu* Tsagareli *non* Zekeli, *I. barabini* Morton, *I. proximus* Tuomey, *I. georgicus*, *I. colchicus* Tsagareli in the upper part.

The Maastrichtian is represented by marly limestones and in places by variegated marls. In the Lower Maastrichtian we found: *Pachydiscus neubergicus*, *P.* cf. *subrobustus* Seunès, *Hauericeras* sp. , *Inoceramus nahorianensis* Kotsyubinskij, *I. colchicus*, *I. simonovitchi* Tsagareli, *I. salisburgensis*, *I.* cf. *nebrascensis* Owen, *Echinocorys* cf. *elatus* Arnaud, and the microfossils *Arenobulimina obliqua* (d'Orbigny), *Bolivina incrassata* (Reuss), *Anomalina clementiana* (d'Orbigny), *Cyroidina caucasica* Subbotina.

In the Upper Maastrichtian *Pachydiscus neubergicus*, *P. subrobustus orientalis* Tsagereli, *Diplomoceras cylindraceum*, *Hoploscaphites constrictus*, *Coraster vilanovae* Cotteau, *Ornithaster anthulai* (Lambert), *Seunaster georgicus* Rouch., *Cardiotaxis heberti* Cotteau, *Galeaster seunesi* Lambert, *Ventilabrella carseyae* (Plummer), *Globotruncana stuarti* (de Lapparent), *Globotruncana coronata* Bolli, *Bolivinoides draco* Marsson, *Inoceramus tenuilineatus* Hayden & Meek, *I. incurvus* Meek, *I. tegulatus sensu* Tsagareli *non* von Hagenow (= *Tenuipteria argentea* (Conrad)), *I. georgicus*.

In the Somkhiti block Campanian and Maastrichtian stages are represented by limestones, in places with variegated tuffs. In the Lower Campanian we found *Glyptoxoceras retrorsum* (Schlüter) and almost the same complex of inoceramids and echinoids as in Ajara-Trialeti. In the Upper Campanian only inoceramids were found. In the Lower Maastrichtian we recognised *Pachydiscus perfidus* de Grossouvre, *P. fresvillensis* Seunès, *Parapachydiscus icenicus* (Sharpe) and *Inoceramus* cf *salisburgensis* Fugger & Kastner, *Austinocrinus erckerti* Dames, and in the Upper Maastrichtian only *Pachydiscus neubergicus*.

In the Lesser Caucasus, in the Debeda-Terter facies type, which is represented in a calcareous marly facies, and in which, according to GAMBASHIDZE (1979) the Lower and Upper Campanian are each divided into two parts.

The lower Lower Campanian is characterised by: *Inoceramus sarumensis* Woods, *I. subsarumensis* Renngarten, *I. convexus*, *I. balticus*, *I. prons* Renngarten, *I. adjakendensis* Aliev, *I.* cf. *lingua* Goldfuss, *I.* cf. *mitraikyensis* Sornay, *Pseudoffaster caucasicus*, *Caronaster cupuliformis* Airaghi, *Echinocorys ovatus* Leske, *E.* cf. *pyramidatus*, *Isomicraster fraasi* Rouch., *Galeola senonensis*.

The upper Lower Campanian contains: *Glyptoxoceras wernickei* (Wollemann), *Discoscaphites* cf. *gibbus* (Schlüter), *Inoceramus decipiens* Zittel, *I. tausensis* Aliev.

The lower Upper Campanian yielded *Hoplitoplacenticeras coesfeldiense* (Schlüter), *Scaphites* cf. *haugi* de Grossouvre, *Belemnitella mucronata* (Schlotheim), *Inoceramus balticus*.

The upper Upper Campanian *Inoceramus regularis* d'Orbigny *non* Münster (= *Selenoceramus sornayi* Dhondt).

In the Lower Maastrichtian were observed: *Pachydiscus neubergicus*, *Diplomoceras cylindraceum lvovense* Mich., *Belemnella lanceolata* (Schlotheim), *Inoceramus colchicus*, *I. nebrascensis* Owen.

In the Upper Maastrichtian *Pachydiscus gollevillensis*, *Pachydiscus colligatus* (Binkhorst), *Pachydiscus haueri haueri* Collignon, *P. egertoni jacquoti* Seunès, *Pseudokossmaticeras brandti*, *Diplomoceras cylindraceum*, *Inoceramus regularis* d'Orbigny *non* Münster, *Guettaria rocardi*, *Echinocorys duponti* Lambert, *Austinocrinus meyni* Stolley.

In **Upper Crimea** the **Campanian** stage is represented mainly by white marls, and the upper part by light grey chalky marls.

The Lower Campanian is divided into two zones: lowermost is the *Micraster schroederi* Zone and above it the *Hauericeras pseudogardeni* Zone:

– the *schroederi* Zone is characterised by the following foraminifers: *Globotruncana arca* Cushman, *Bolivinoides decoratus* Jones, *Gavelinella clementiana* (d'Orbigny), *Orbignyana inflata* (Reuss);

– the *pseudogardeni* Zone contains: rare *Hauericeras pseudogardeni*, *Belemnitella* ex gr. *mucronata* (Schlotheim), *Inoceramus balticus*, *I. azerbaydjanensis*, and the foraminifers *Globotruncanita elevata* Brotzen, *Rugoglobigerina kelleri* (Subbotina), *Cibicidoides aktulagayensis* Vassilenko; in the Lower Campanian *Inoceramus dariensis* was also observed (65 - 70 m).

The Upper Campanian is divided into two zones based on belemnites:

←

Fig. 1 — Maastrichtian and Campanian ammonites species from the Maastricht area, from Upper Crimea, from the Caucasus and from Mangyshlak.

– the lower Upper Campanian Zone contains *Belemnitella mucronata senior*
– the upper Upper Campanian Zone contains *Belemnitella langei.* The lower Upper Campanian Zone further contains *Inoceramus balticus*, rare *Pachydiscus koeneni*, *Globotruncana morozovae* Vassilenko, *G. majzoni* Sac. & Deb., *Brotzenella menneri* Keller, *B. monterelensis* Marie, *Stensioeina pommerana* Brotzen.

The upper Upper Campanian further contains *Baculites* ex gr. *anceps*, *Pachydiscus koeneni*, *Inoceramus buguntaensis* Dobrov, *I. caucasicus* Dobrov (???), *Cibicidoides voltzianus* (d'Orbigny), *Bolivina kalinini* Vassilenko, *B. incrassata* (Reuss). In the uppermost part of the section were found: *Bolivinoides miliaris* Hiltermann & Koch, *Globotruncana contusa* Cushman, *Neoflabellina praereticulata* Hiltermann.

In the **Crimean lowland** the **Campanian** is divided into two parts on foraminifers: the Lower Campanian contains *Globotruncana arca* Cushman, *Globotruncanita elevata* Brotzen, *Rugoglobigerina kelleri* Subbotina, *Bolivinoides decoratus* Jones; the Upper Campanian is characterised by *Globotruncana morozovae* Vassilenko, *Stensioeina pommerana* Brotzen, *Brotzenella menneri* Keller, *Cibicidoides voltzianus* (d'Orbigny), *Bolivina incrassata* (Reuss).

The **Maastrichtian** stage is widespread in **the Crimea**, where it is represented by grey sandy marls and sandstones.

The Lower Maastrichtian substage is characterised by the *Belemnella lanceolata - Acanthoscaphites tridens* Zone - this is the equivalent of the *Globotruncanita stuarti* Zone. Also observed in this zone are: *Belemnella sumensis* Jeletzky, *Hoploscaphites constrictus*, *Diplomoceras cylindraceum*, *Hauericeras sulcatum*, *Pseudokossmaticeras galicianum*, and foraminifers, bivalves, brachiopods and echinoids.

The Upper Maastrichtian is represented by the *Neobelemnella kazimiroviensis* Zone, or the equivalent *Abathomphalus mayaroensis* Zone. Herein occur *Hoploscaphites constrictus*, *Pachydiscus neubergicus*, *P. gollevillensis*, *Phyllopachyceras (?) surya*, inoceramids, other bivalves, gastropods, brachiopods, Bryozoa, Foraminifera.

Near Bakhchisaray remains of a dinosaur (*Orthomerus weberi* Rjab.), near Skalistoe fragments of a mosasaur (*Tylosaurus* cf. *anceps* Owen) and near Sevastopol fragments of a crocodile (*Thoracosaurus macrorhynchus* Blainville) were found.

On the Crimean lowland Maastrichtian the following foraminifers were recognised: *Raceguembelina fructuosa* Egger, *Bolivinoides draco*, *Globotruncanita stuarti* etc. (500 to 800 m on Tarkhankut peninsula).

In the **Mangyshlak** peninsula (W. Kazakhstan) the **Campanian** is represented by chalks and chalk-like limestones, which north-eastwards (in Central Usturt) become marls and clayey limestones (thickness 30 to 150 m). Four zones, recognised in the Kopet Dagh are confirmed in Mangyshlak: *Offaster pomeli* Zone, *Eupachydiscus levyi* Zone, *Hoplitoplacenticeras coesfeldiense/Stegaster gillieroni* Zone, *Bostrychoceras polyplocum* Zone. All four zones are also characterised by inoceramids, echinoids, belemnites, brachiopods and foraminifers. In the uppermost zone *Pachydiscus stobaei* Nilsson has been found.

The Mangyshlak **Maastrichtian** is represented by rocks which are similar to those of the Campanian: chalk-like limestones and chalks, in places with flint nodules and in the upper part enriched with "aleurites" (10 to 30 to 175 m). The Lower Maastrichtian contains *Belemnella lanceolata* (Schlotheim), *Inoceramus oviformis* Arzum., *I. buguntaensis* Dobrov & Pavlova, *Micraster grimmensis* Nietsch., *Echinocorys lamberti* Smiser, *E. conica* Agassiz, *E. belgica* Lambert and also foraminifers are numerous.

Sometimes an Upper Maastrichtian hardground rests on the Lower Maastrichtian. The lower Upper Maastrichtian strata correspond to the Kopet-Dagh *Diplomoceras cylindraceum* Zone and contain *Baculites anceps*, *Echinocorys ciplyensis*, *E. belgica* Lambert, *E. lamberti*, *Conulus magnificus* d'Orbigny, rare *Neobelemnella kazimiroviensis*. The *Tenuipteria argentea* Zone, besides the zonal species, contains: *Hoploscaphites constrictus crassus* Lopuski, *Oxytoma danica* (Ravn), *Echinocorys ciplyensis*, *E. pyramidata*, *Galerites sulcatus* d'Orbigny, *G. vulgaris* Leske, *Cyclaster integer* Seunès and also foraminifers: *Bolivina incrassata crassa* Vassilenko, *B. plaita* Carsey, *Karreria fallax* Rzeh.

When we compare the three main localities of the Alpine line: Upper Crimea, the Caucasus and Mangyshlak, we can see that in
– the *Campanian* the genera *Hauericeras*, *Baculites* and *Pachydiscus* occur both in the Crimea and the Caucasus; *Pachydiscus* was also found in Mangyshlak, where it is the only Campanian ammonite genus known so far.
– in the *Maastrichtian* the genera common between the Caucasus and the Crimea are: *Hoploscaphites*, *Diplomoceras*, *Hauericeras*, *Pseudokossmaticeras*. Thus the Campanian-Maastrichtian Crimean ammonite complex contains taxa also known from the Caucasus, and has no distinctive elements.

In Mangyshlak two genera were observed: *Baculites* and *Hoploscaphites*. Both are also known in the Caucasus and the Crimea.

In the **Maastricht type area** the following genera are known:
– in the **Campanian**: *Baculites*, *Scaphites*, *Trachyscaphites*, *Hoplitoplacenticeras*, *Pachydiscus*. Only *Trachyscaphites* is not known from the Caucasus.
– in the **Maastrichtian**: *Saghalinites*, *Baculites*, *Nostoceras*, *Glyptoxoceras*, *Diplomoceras*, *Hoploscaphites*, *Acanthoscaphites*, *Pachydiscus*, *Anapachydiscus*, *Sphenodiscus*. *Saghalinites*, *Nostoceras* and *Sphenodiscus* are not known from Crimea nor from the Caucasus nor from Mangyshlak.

Ammonites are a group of organisms which went extinct at the end of the Maastrichtian. The Late Cretaceous is the last epoch of their existence. How were they distributed during this time?

Usually it is accepted that the stratigraphic importance of ammonites in the Late Cretaceous is decreasing - more precisely they decrease in number and there are hiatuses in their distribution. Therefore belemnites, inoceramids, echinoids and foraminifers become stratigraphically more important.

In the Caucasus already in the Albian zonation only with ammonites is impossible.

In order to have a complete view of the distribution and extinction of the ammonites, we review them for the complete Upper Cretaceous:
CENOMANIAN
Caucasus - 19 - *Hypophylloceras, Gaudryceras, Tetragonites, Sciponoceras, Baculites, Anisoceras, Hypoturrilites, Turrilites, Bostrychoceras, Scaphites, Puzosia, Austeniceras, Latidorsella, Schloenbachia, Mantelliceras, Calycoceras, Acanthoceras, Cunningtoniceras, Couloniceras.*
Crimea - 6 - *Mesogaudryceras, Sciponoceras, Scaphites, Puzosia, Schloenbachia, Mantelliceras.*
Mangyshlak - 14 - *Sciponoceras, Anisoceras, Idiohamites, Neostlingoceras, Turrilites, Scaphites, Worthoceras, Hyphoplites, Schloenbachia, Submantelliceras, Acompsoceras, Acanthoceras, Euomphaloceras, Karamaites.*

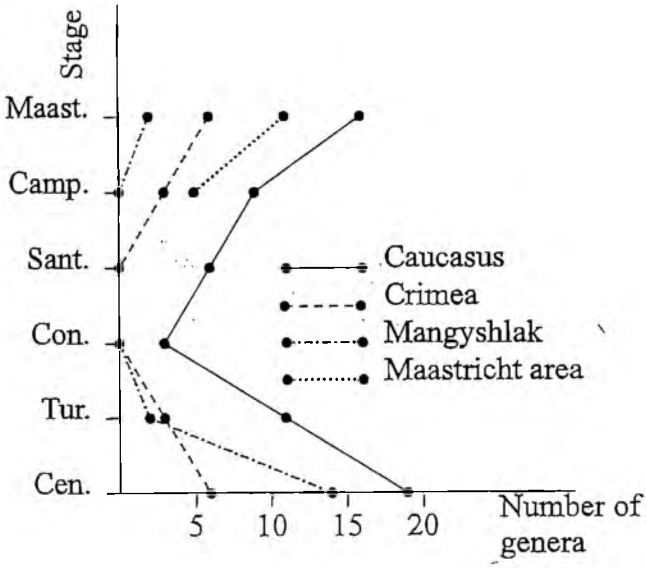

Fig. 2 — Number of ammonite genera in the Upper Cretaceous of the studied regions.

TURONIAN
Caucasus - 11 - *Neogaudryceras, Sciponoceras, Tetragonites, Scaphites, Puzosia, Lewesiceras, Romaniceras, Mammites, Collignoceras, Subprionocyclus, Arkhangelskiceras.*
Crimea - 3 - *Hypanthoceras, Scaphites, Lewesiceras.*
Mangyshlak - 6 - *Sciponoceras, Hypanthoceras, Scaphites, Lewesiceras, Metoiococeras, Collignoceras.*
CONIACIAN
Caucasus - 3 - *Baculites, Eubostrychoceras, Nowakites.*
Crimea - 0.
Mangyshlak - 0.
SANTONIAN
Caucasus - 6 - *Gaudryceras, Scaphites, Puzosia, Hauericeras, Nowakites, Eupachydiscus.*
Crimea - 0.
Mangyshlak - 0.
CAMPANIAN
Caucasus - 9 - *Baculites, Bostrychoceras, Glyptoxoceras, Discoscaphites, Hauericeras, Pachydiscus, Menuites, Eupachydiscus, Hoplitoplacenticeras.*
Crimea - 3 - *Baculites, Hauericeras, Pachydiscus.*
Mangyshlak - 1 - *Pachydiscus.*
Maastricht - 5 - *Baculites, Scaphites, Trachyscaphites, Hoplitoplacenticeras, Pachydiscus.*
MAASTRICHTIAN
Caucasus - 16 - *Hypophylloceras, Helicoceras, Baculites, Didymoceras, Diplomoceras, Neancyloceras, Hoploscaphites, Acanthoscaphites, Hauericeras, Kossmaticeras, Discoscaphites, Pachydiscus, Parapachydiscus, Pseudophyllites, Discohoplites, Pseudokossmaticeras.*
Crimea - 6 - *Phyllopachyceras, Diplomoceras, Hoploscaphites, Hauericeras, Pachydiscus, Pseudokossmaticeras.*
Mangyshlak - 2 - *Baculites, Hoploscaphites.*
Maastriocht - 11 - *Saghalinites, Baculites, Nostoceras, Glyptoxoceras, Diplomoceras, Scaphites, Hoploscaphites, Acanthoscaphites, Pachydiscus, Anapachydiscus, Sphenodiscus.*

To summarize:

	Caucasus	Crimea	Mangyshlak	Maastricht
Maastrichtian	16	6	2	11
Campanian	9	3	0	5
Santonian	6	0	0	–
Coniacian	3	0	0	–
Turonian	11	3	6	–
Cenomanian	19	6	14	–

In the Cenomanian the maximum number of genera was present; during the Turonian it decreased. In the Coniacian and Santonian (two short stages) the number of ammonite genera was minimal, and in Crimea and Mangyshlak they were not found. From the Campanian upwards the number of genera increased again and reached (except in Mangyshlak) in the Maastrichtian a level comparable to that known from the Cenomanian. Thus shortly before the complete extinction of the ammonites in the Maastrichtian they knew a last expansion.

References

Atabekjan, A. A., 1986. West of Middle Asia. Upper Series. in: Cretaceous System. Volume 1. Stratigraphy of the USSR. pp. 277-298 (in Russian).

Gambashidze, R. A., 1979. Stratigraphy of Upper Cretaceous deposits in Georgia and in adjacent areas of Azerbaidjan and Armenia. *Trudy GIN AN Gruzhinskoi SSR, N.S.* **61**, 226 pp. (in Russian).

Kennedy, W. J., 1986a. The Campanian-Maastrichtian ammonite sequence in the environs of Maastricht (Limburg, The Netherlands), Limburg and Liège provinces (Belgium). *Newsletters on Stratigraphy*, **16**, 3: 149-168.

Kennedy, W. J., 1986b. The ammonite fauna of the type Maastrichtian with a revision of *Ammonites colligatus* Binkhorst, 1861. *Bulletin Institut royal Sciences naturelles de Belgique, Sciences de la Terre*, **56**: 151 - 267

Maslakova, N. I., 1986. The Crimea. Upper Series. in: Cretaceous System. Volume 1. Stratigraphy of the USSR. pp. 136-144 (in Russian).

Moskvin, M. M., 1986. The Caucasus. Upper Series. in: Cretaceous System. Volume 1. Stratigraphy of the USSR. pp. 190-238 (in Russian).

Naidin, D. P., 1978. On stratotypes of Upper Cretaceous stages (example of the Maastrichtian stage). *Byulleten Moskovskogo Obshestva Ispytateley Prirody - Serija Geologicheskaja* **53**, 3: 56-77 (in Russian).

Tsagareli, A. L., 1954. Upper Cretaceous of Georgia.*Monographs of the Institute of Geology and Mineralogy*, **5**: 436 pp. (in Russian).

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Typescript submitted: 1.6.1998

Addendum

Stratigraphic distribution of Upper Cretaceous ammonite genera from the Caucasus, the Crimea, Mangyshlak and the Maastricht area

1. *Phyllopachyceras* Spath, 1925, br - m
2. *Hypophylloceras* Salfeld, 1924, h - m
3. *Neogaudryceras* Shimizu, 1935, tur - m (= *Gaudryceras*)
4. *Mesogaudryceras* Spath, 1927, cen
5. *Gaudryceras* de Grossouvre, 1894, tur - m
6. *Tetragonites* Kossmat, 1895, al$_2$ - cen$_3$
7. *Pseudophyllites* Kossmat, 1895, camp. -m
8. *Helicoceras* d'Orbigny, 1842, al$_2$ [= *Hamites* (*Hamitella*)]
9. *Sciponoceras* Hyatt, 1894, al$_3$ - tur$_2$
10. *Baculites* Lamarck, 1799, tur$_2$-m
11. *Anisoceras* Pictet, 1854, al$_3$ - tur$_3$
12. *Idiohamites* Spath, 1925, al$_3$ - cen
13. *Hypoturrilies* Dubourdieu, 1953, cen
14. *Neostlingoceras* Klinger & Kennedy, 1978, cen$_{1-2}$
15. *Turrilites* Lamarck, 1801, cen-tur$_1$
16. *Bostrychoceras* Hyatt, 1900, cen-m$_1$
17. *Eubostrychoceras* Matsumoto, 1967, al - sant (? camp)
18. *Hyphantoceras* Hyatt, 1900, tur-sant
19. *Didymoceras* Hyatt, 1884, camp -m (= *Ciroceras* Conrad, 1868)
20. *Nostoceras* Hyatt, 1884, camp
21. *Diplomoceras* Hyatt, 1900, camp
22. *Neancyloceras* Spath, 1926, camp$_2$-m
23. *Glyptoxoceras* Spath, 1925, sant - m
24. *Scaphites* Parkinson, 1811, al$_3$ - m
25. *Hoploscaphites* Nowak, 1911, camp - m
26. *Discoscaphites* Meek, 1870, camp - m
27. *Acanthoscaphites* Nowak, 1911, camp
28. *Trachyscaphites* Cobban, 1964, camp - m
29. *Worthoceras* Adkins, 1928, al$_3$ - tur$_2$
30. *Puzosia* Bayle, 1878, al$_1$ - tur$_2$
31. *Austiniceras* Spath, 1922, cen$_3$ - tur$_2$ (= *Parapuzosia*)
32. *Latidorsella* Jacob, 1908, al$_3$ - cen (= *Desmoceras* Zittel)
33. *Hauericeras* de Grossouvre, 1894, con - m
34. *Kossmaticeras* de Grossouvre, 1901, tur$_2$ - camp
35. *Pseudokossmaticeras* Spath, 1922, camp$_2$ - m
36. *Brahmaites* Kossmat, 1897, m
37. *Lewesiceras* Spath, 1939, cen$_3$ - con
38. *Nowakites* Spath, 1922, con-sant
39. *Pachydiscus* Zittel, 1884, camp-m
40. *Parapachydiscus* Hyatt, 1900, "Senonian"
41. *Anapachydiscus* Yabe & Shimizu, 1926, con-m
42. *Menuites* Spath, 1922, sant - camp
43. *Eupachydiscus* Spath, 1922, con - camp
44. *Pseudophyllites* Spath, 1926, con
45. *Hoplitoplacenticeras* Spath, 1922, camp$_1$ - m
46. *Discohoplites* Spath, 1925, al$_3$
47. *Hypoplites* Spath, 1922, al$_3$ - cen$_3$
48. *Schloenbachia* Neumayr, 1875, al$_3$ - cen$_3$
49. *Mantelliceras* Hyatt, 1903, cen$_1$
50. *Sharpeiceras* Hyatt, 1903, cen
51. *Submantelliceras* Spath, 1923, cen$_1$ (= *Mantelliceras*)
52. *Acompsoceras* Hyatt, 1903, cen$_1$
53. *Calycoceras* Hyatt, 1900, cen - tur$_1$ (= *Newboldiceras*)
54. *Acanthoceras* Neumayr, 1875, cen$_1$ - cen$_3$
55. *Euomphaloceras* Spath, 1923, cen$_3$
56. *Cunningtoniceras* Collignon, 1937, cen$_3$ (= *Euomphaloceras*)
57. *Romaniceras* Spath, 1923, cen$_3$ - tur$_2$
58. *Metoiococeras* Hyatt, 1903, tur$_1$
59. *Mammites* Laube & Bruder, 1886, tur
60. *Collignoniceras* Breistroffer, 1947, tur
61. *Prionotropis* Meek, 1878, tur
62. *Subprionocyclus* Shimizu, 1932, tur$_2$
63. *Barroisiceras* de Grossouvre, 1894, con
65. *Arkhangelskiceras* Iljin, 1957, cen?
66. *Couloniceras* Busnardo, 1966, cen
67. *Karamaites* Sokolov, 1961, cen

BULLETIN DE L'INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE SCIENCES DE LA TERRE, 69-SUPP. A: 173-178, 1999
BULLETIN VAN HET KONINKLIJK BELGISCH INSTITUUT VOOR NATUURWETENSCHAPPEN AARDWETENSCHAPPEN, 69-SUPP. A: 173-178, 1999

Report 2

Stratigraphic distribution of lamnoid sharks at Cretaceous and Palaeogene stage boundaries in the Eastern Peri-Tethys

by Viktor I. ZHELEZKO

Abstract

The distribution of lamnoid sharks during the Cretaceous and Palaeogene was studied in the Eastern Peri-Tethys in W. & N. Kazakhstan and in Preuralia. The Santonian/ Campanian, Cretaceous/ Palaeocene, and Palaeocene/ Eocene were given special attention.

Key-words: Cretaceous, Palaeogene, Lamnoid sharks, Eastern Peri-Tethys.

Résumé

La distribution des requins lamnoïdes pendant le Crétacé et le Paléogène a été étudié dans la Peri-Tethys orientale, dans l'ouest et le nord du Kazakhstan et dans le Préural. Les limites santono-campanienne, Crétacé-Paléocène et Paléocène-Eocène ont été particulièrement étudiées.

Mots-clefs: Crétacé, Paléogène, requins lamnoides, Péri-Tethys orientale.

Резюме

Распределение ламноидных акул в меле и палеогене было изучено в восточном Перитетисе, в западном и северном Казахстане и в Преуралье. Особое внимание было уделено изучению сантоно-кампанской, мелово-палеоценовой и палеоцено-эоценовой границам.

Ключевые слова: мел, палеоген, ламноидные акулы, восточный Перитетис

Introduction

The regions of the Eastern Peri-Tethys (mainly Mangyshlak and the NE Pericaspian, Kazakhstan) contain relatively complete sections of all stages of the Cretaceous and Palaeogene systems.

From these sediments (Mangyshlak, Aktyubinskoe Premugodzharia, Ustyurt, Preuralia, Turgay) many elasmobranch teeth were collected (GLÜCKMAN, 1964, 1980; GLÜCKMAN & ZHELEZKO, 1979; ZHELEZKO, 1994, 1995; ZHELEZKO & KOZLOV, 1999). The study of the stratigraphic distribution and of the phylogenetic development of Cretaceous and Palaeogene fishes bring information on the development of the seas and faunas of this extensive territory (Fig. 1).

The best shark teeth material was collected in sediments of Santonian/ Campanian, Cretaceous/ Palaeocene and Palaeocene/ Eocene transitions.

Santonian/ Campanian boundary

The Santonian/ Campanian boundary deposits were studied during several field conferences under the direction of D. P. Naidin and G. N. Papulov (PAPULOV & NAIDIN, 1979; AKIMETS *et al.*, 1979) in Aktyubinskoe Premugodzharia and Mangyshlak (W. Kazakhstan).

In the *Aktyubinsk - Premugodzharie* area, the Altykuduk Fm., unconformably overlying white Albian - Cenomanian sands, contains the following beds:

Kubley beds (Santonian): quartz-glauconitic sands with phosphorites are divided into three beds, from bottom to top:

- bed A: irregular granular sands, with phosphatic pebbles at the base. Fossil content: *Squalicorax santonicus* GLÜCKMANN & ZHELEZKO, 1979, *Eostriatolamia aktobensis* ZHELEZKO, 1988; *fide* NAIDIN (1979) the belemnite *Goniocamax lundgreni uilicus*. Thickness of the fossil bed: 1.5 - 3.5 m.
- bed B: sandy clays, with phosphatic concretions at the base. Fossil content: *Squalicorax papulovi* Zhelezko,1988, *Eostriatolamia aktobensis*; *fide* NAIDIN (1979) the belemnite *Goniocamax lundgreni uilicus*.
- bed C: fine-grained quartz-glauconitic sands, interbedded with clays, and with a phosphoritic bed at the base. Thickness of the bed is 3 - 4 m. Fossil content: *Squalicorax kaupi* (Agassiz, 1843), *Eostriatolamia venusta* (Leriche, 1906), *Archaeolamna macrorhiza* (Cope); *fide* NAIDIN (1979) the belemnites *Belemnitella praecursor praecursor*, *Actinocamax verus fragilis*.

The Kubley beds are characterized by the *Gavelinella infrasantonica* foraminifer complex (BENIAMOVSKII *et al.*, 1979); the higher part of the section - the Zhurun beds - are characterized by the *G. stelligera* complex for the Santonian part of the section and by the *Cibicidoides temiremsis* complex for the Campanian (ibid.).

Zhurun beds (Santonian-Campanian) - the section is described from bottom to top:

- Santonian part: quartz - siltstone sands with a few phosphatic nodules. Fossil content: *Squalicorax kaupi*, *Eostriatolamnia venusta*, *Archaeolamna macrorhiza*; *fide* NAIDIN (1979) the belemnite *Belemnitella praecursor media* and *fide* BOBKOVA (1979) the bivalve *Oxytoma tenuicostata*.

Shark teeth localities
Cretaceous: 1- Aktyubinsk
2- Mangyshlak
Palaeogene: 3- Emba River
4- Tobol River

Fig. 1 — Localities from where shark teeth were studied

- Campanian part: fine-grained sands, clayey siltstones, with phosphorites in basal part. Thickness of the bed: 4 - 6 m. Fossil content: *Squalicorax lindstroni* (Davis, 1890), *Eostriatolamia lerichei* Glückmann & Zhelezko, 1979, *Archaeolamna arcuata* (Woodward, 1874); *fide* Naidin (1979) the belemnites *Paractinocamax grossouvrei pseudoalfridi*, *Actinocamax laevigatus laevigatiformis*, *A. verus fragilis*, *Belemnitella praecursor media* and *B. praecursor mucronatiformis*.

Santonian-Campanian boundary deposits in *Mangyshlak peninsula* have been studied in the Zhalgan, Kush, Aksyrtau and Sulukapy sections. A composite section of the sections in these individual outcrops would be as follows (from bottom to top):

(1) greenish-grey marl, with *Inoceramus undulatoplicatus* (*fide* Atabekian, 1979); in the basal levels the *Stensoeina exculpta* foraminifer complex, in the top levels the *S. granulata perfecta* complex (*fide* Beniamovskii *et al.*, 1979). Thickness: over 5 m. Age: Santonian.

(2) white, coarse-grained chalk, with numerous *Osangularia*. Thickness: 3 to 5 m. Age: Santonian.

(3) white chalk, more sandy in its upper part, with the crinoids *Uintacrinus* and *Marsupites*, the *Gavelinella stelligera* foraminiferal complex (*fide* Beniamovskii *et al.*, 1979) and the shark *Squalicorax kaupi*. Thickness: 3 to 4 m. Age: Santonian.

(4) white, coarse-grained chalk, with the *Gavelinella clementiana* foraminifer complex (*fide* Beniamovskii *et al.*, 1979) in the top levels, and with the echinoid *Offaster pilula* and the shark *Squalicorax kaupi*. Thickness: 6 m. Age: Santonian.

(5) interbedded white chalk and greenish, marly chalk. Fossil content: the echinoids *Micraster schroederi* and *Offaster pilula*, the shark *Squalicorax lindstromi*; also foraminiferal complexes with *Bolivinoides decoratus/ Cibicidoides temirensis* (*fide* Beniamovskii *et al.*, 1979). Thickness: 7 to 11 m.

It is difficult to precisely place the Santonian-Campanian boundary in Mangyshlak and in the Pericaspian strata because of the absence of ammonites. The problem is complicated further because Aktyubinsk and Preuralia are part of the Temperate realm and Mangyshlak of the Tethyan realm. The classical index fossils in the Precaspian are belemnites, and in Mangyshlak for this boundary *Marsupites* is used.

Locally, stratigraphical correlation can be undertaken with taxa of the genus *Squalicorax*: bed 4 in the Mangyshlak sections contains the foram complex *Gavelinella clementiana*, the echinoid *Offaster pilula* and the shark *Squalicorax kaupi* - they indicate the Santonian. The lower boundary of the Campanian in the NE Pericaspian correlates with the base of the beds with *Belemnitella praecursor mucronatiformis*, *Paractinocamax grossouvrei pseudoalfridi* and *Squalicorax lindstromi*.

Cretaceous/ Palaeocene boundary

The faunal turnover at the K/ T boundary is extensive and occurs in many different fossil groups (Naidin, 1976; Alekseev, 1989). Also in the development of elasmobranch sharks this boundary is clearly visible (Fig. 2).

In the Cretaceous basins the main osteodont fishes belonged to the families Cretodontidae, Cretoxyrhinidae, Anacoracidae and Ptychodontidae. From their teeth it is obvious that they were large fishes (7 to 10 m, or even more). They dominated in the pelagic and in the littoral zones. Cretodontidae, Cretoxyrhinidae and Anacoracidae had teeth of the tear-cutting type. Ptychodontidae had huge chewing teeth, with a thick layer of enamel, capable of crushing animals, even those with a thick armour. The acme of the Cretodontidae, Cretoxyrhinidae and Ptychodontidae is situated in the Albian-Santonian time interval. From the Campanian onwards, distinct signs of decrease in number of taxa are seen. In the Anacoracidae the maximum development was in the Santonian-Campanian interval; during the Maastrichtian their number decreased. At the end of the Maastrichtian the last representatives of the Cretodontidae, Cretoxyrhinidae, Anacoracidae, and Ptychodontidae died out.

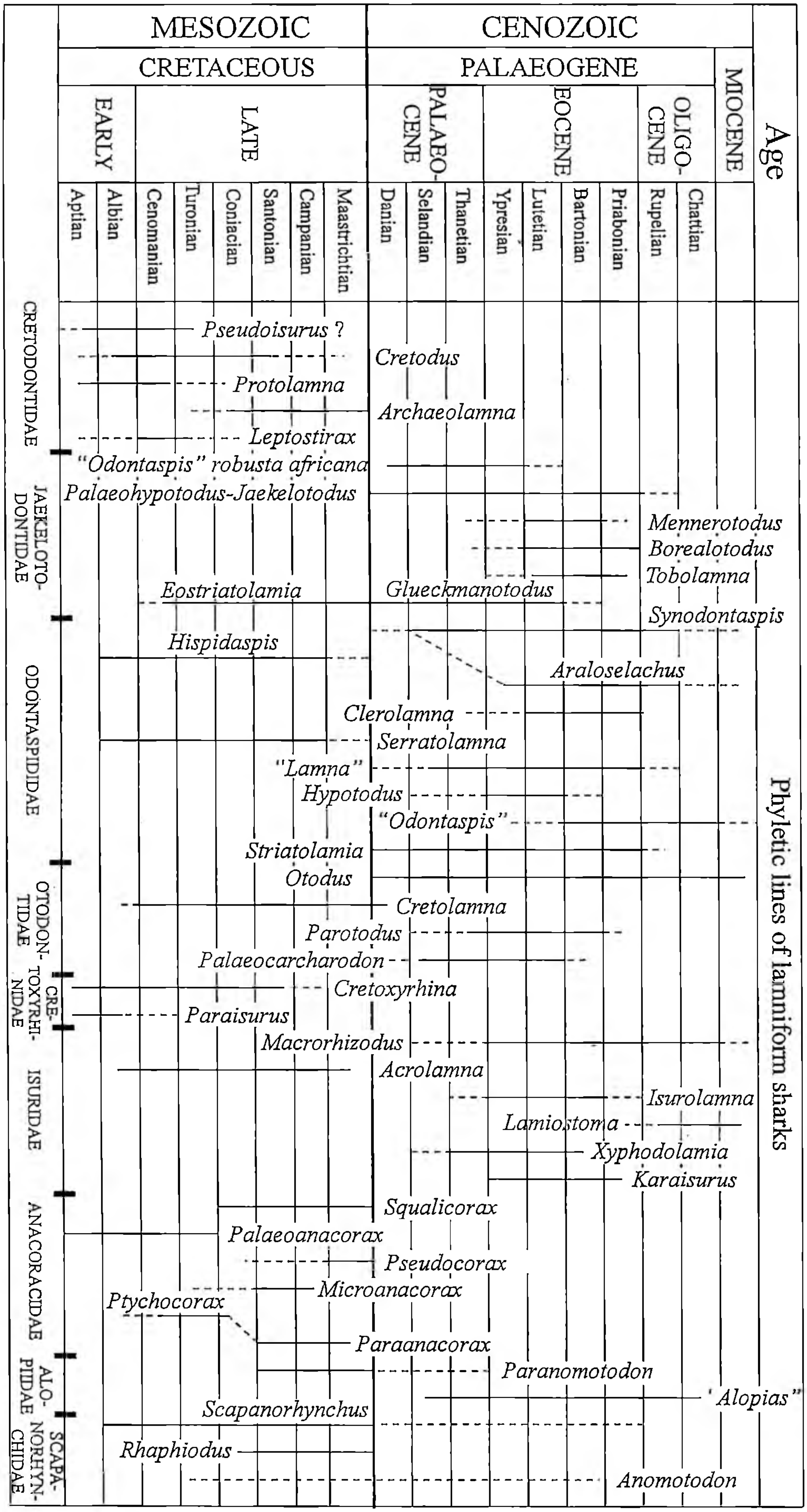
Another group of lamnoid sharks (families Jaekelodontidae, Odontaspididae, Otodontidae, Isuridae, Alopiidae, and Scapanorhynchidae) had their origin in the late Cretaceous, but the main development of this group was in the Palaeogene.

The Scapanorhynchidae had three genera in the Cretaceous: *Scapanorhynchus*, *Raphiodus* and *Anomotodon*; in the Palaeogene the family was less developed. The acme of the Jaekelodontidae was during the Palaeogene; in the Cretaceous the family was represented by the genus *Eostriatolamia*. Similarly, in the Cretaceous, the Odontaspididae were represented by the genera *Hispisdaspis* and *Serratolamna*, the Otodontidae by the genus *Cretolamna*, the Isuridae by the genus *Acrolamna*, the family Alopiidae by the genus *Paranomotodon*; in the Palaeogene the Alopiidae expanded into many taxa of the compound genus *Alopias*. New phylogenetic lines developed for the Jaekelodontidae, Odontaspididae, Otodontidae, Isuridae and Alopiidae in the Palaeogene.

The K/T boundary can be dated by the extinction of the lamnoid

→

Fig. 2 — Distribution of Cretaceous and Palaeogene lamnoid sharks


MESOZOIC
CENOZOIC
CRETACEOUS
PALAEOGENE
EARLY
LATE
PALAEO-CENE
EOCENE
OLIGO-CENE
MIOCENE
Age
Aptian
Albian
Cenomanian
Turonian
Coniacian
Santonian
Campanian
Maastrichtian
Danian
Selandian
Thanetian
Ypresian
Lutetian
Bartonian
Priabonian
Rupelian
Chattian
CRETODONTIDAE
JAEKELOTO-DONTIDAE
ODONTASPIDIDAE
OTODON-TIDAE
CRE-TOXYRHI-NIDAE
ISURIDAE
ANACORACIDAE
ALO-PIIDAE
SCAPA-NORHYN-CHIDAE
Pseudoisurus ?
Cretodus
Protolamna
Archaeolamna
Leptostirax
"Odontaspis" robusta africana
Palaeohypotodus-Jaekelotodus
Mennerotodus
Borealotodus
Tobolamna
Eostriatolamia
Glueckmanotodus
Synodontaspis
Hispidaspis
Araloselachus
Clerolamna
Serratolamna
"Lamna"
Hypotodus
"Odontaspis"
Striatolamia
Otodus
Cretolamna
Parotodus
Palaeocarcharodon
Cretoxyrhina
Paraisurus
Macrorhizodus
Acrolamna
Isurolamna
Lamiostoma
Xyphodolamia
Karaisurus
Squalicorax
Palaeoanacorax
Pseudocorax
Microanacorax
Ptychocorax
Paraanacorax
Paranomotodon
'Alopias"
Scapanorhynchus
Rhaphiodus
Anomotodon
Phyletic lines of lamniform sharks

shark families Cretodontidae, Cretoxyrhinidae and Anacoracidae.

The orthodont sharks also were influenced by the K/T boundary. More than 15 families of Cretaceous orthodont sharks are known. The most important among them are: Polyacridontidae, Hexanchidae, Heterodontidae, Squatinidae, Ginglimostomatidae, Rhinobatidae, Squalidae, Dalatiidae.

These small and medium-sized sharks and batoids were part of benthos in littoral waters. They mainly fed on small species of invertebrates and fishes. At the K/T boundary these Selachians show changes at the generic and specific level. In the Palaeogene new orthodont families such as the Myliobatidae, Torpedinidae, Echinorhinidae, Triakidae and Carcharinidae arose. They were the first representatives of the neoselachians, which in recent seas and oceans have a prevalent position.

Palaeocene - Eocene boundary

The Thanetian/ Ypresian boundary was studied in sections at Shatyrlisay (on the Emba River) and at Belinsky/ Ajat on the Tobol River in northern Kazakhstan. For comparative purposes the Marke and Egem quarries in Belgium, and the Thanetian stratotypical section at Herne Bay (England) were also sampled.

The section at Shatyrlisay (Emba River basin) contains Palaeocene and Lower Eocene deposits: clayey to sandy strata with phosphoritic concretions at the base, delimited by erosional surfaces. From bottom to top the following beds have been identified:

(1) white marls with belemnites (Maastrichtian); thickness: more than 3 m;
(2) sands with phosphatic nodules; fossil content: *Striatolamia striata* (Winkler, 1874), *Palaeohypotodus rutoti* (Winkler, 1874); age: Upper Palaeocene;
(3) quartz-glauconitic sands, with phosphatic nodules at the base; fossil content: *Striatolamia striata*, *Otodus obliquus* Agassiz, 1843; age: according to TABACHNIKOVA (1989a) nannoplankton zone UP 8 (upper part of Palaeocene); thickness: 0.6 m;
(4) clayey sands, at the base with phosphoritic concretions; fossil content: *Striatolamia elegans* (Agassiz, 1843), *Otodus obliquus*; age: lower part of the Ypresian; thickness: more than 4 m.

The Belinsky quarry (Tobol River basin) shows the following Palaeogene section, from bottom to top:

(1) conglomerate, without fauna (0.5 m);
(2) siltstone, fine grained sand, weakly carbonaceous, with flint pebbles at the base; fossil content: *Striatolamia striata*; age: Thanetian; thickness: 1.3 to 3.7 m;
(3) interbedded clays and irregularly grained gravel sands; fossil content: *Striatolamia elegans* and *Otodus obliquus*; age: according to TABACHNIKOVA (1989b) nannoplankton zone NP 12, dinoflagellate zone W 6-7 according to VASILJEVA (1990), Lower Ypresian; thickness: 2.3 m;
(4) olive-green clays with pebbles at the base; fossil content: *Striatolamia macrota* (Agassiz, 1843); age: Bartonian; thickness: 1.9 m

Between the Palaeocene and Eocene important changes occurred in the selachians; in some groups (especially the large predators) this development seems to have been progressive whereas in others it seemed more sudden. Many existing groups of smaller sharks had an explosive evolution in the early Eocene.

References

AKIMETS, V. S., BENIAMOVSKII, V. N., GLADKOVA, V. I., ZHELEZKO, V. I. & NAIDIN, D. P., 1979. Foraminifera of the Santonian/ Campanian boundary sediments (Upper Cretaceous) of Mangyshlak. *Byulleten Moskovskogo Obshchestvo Ispitateley Prirody- Serija Geologia* **54**, 6: 113-120. [in Russian].

ALEKSEEV, A. S., 1989. Global biotic crises and mass extinctions in the Phanerozoic history of the world. *In*: MENNER, V. V., Biotic events at the main Phanerozoic boundaries [in Russian].

ATABEKYAN, A. A., 1979. Inoceramids of the Santonian-Campanian boundary strata in the Aktyubinsk district. *In*: PAPULOV, G. N. & NAIDIN, D. P., Eds., The Santonian/Campanian boundary on the East European Platform. *Trudy Instituta Geologii i Geokhimii, Akademya Nauk SSSR - Uralskij nauchnij tsentr*, **148**: 42 - 65. [in Russian].

BENIAMOVSKII, V.N., GLADKOVA, V. I. & KOPAEVICH, L. F. , 1979. Foramimfera. *In*: PAPULOV, G. N. & NAIDIN, D. P. , Eds., The Santonian/Campanian boundary on the East European Platform. *Trudy Instituta Geologii i Geokhimii, Akademya Nauk SSSR - Uralskij nauchnij tsentr*, **148**: 31 - 41. [in Russian].

BOBKOVA, N. N., 1979. Oxytomas from the Santonian-Campanian interval of the Aktyubinsk district. *In*: PAPULOV, G. N. & NAIDIN, D. P. , Eds., The Santonian/ Campanian boundary on the East European Platform. *Trudy Instituta Geologii i Geokhimii, Akademya Nauk SSSR - Uralskij nauchnij tsentr*, **148**: 66 - 70. [in Russian].

GLÜCKMAN, L. S., 1964. Sharks of the Palaeogene and their stratigraphic significance. Nauka Izdatelstvo, Moscow-Leningrad, 299 pp. [in Russian].

GLÜCKMAN, L. S., 1980. Evolution of Cretaceous and Cainozoic lamnoid sharks. Akademia Nauk SSSR, Moscow, 247 pp. [in Russian].

GLÜCKMAN, L. S. & ZHELEZKO, V. I., 1979. Sharks. *In*: PAPULOV, G. N. & NAIDIN, D. P., Eds., The Santonian/ Campanian boundary on the East European Platform. *Trudy Instituta Geologii i Geokhimii, Akademya Nauk SSSR - Uralskij nauchnij tsentr*, **148**: 90-105. [in Russian].

NAIDIN, D. P., 1976. The Cretaceous/Palaeogene boundary. In: Boundaries of geological systems. For the 70 th birthday of Academician V. V. Menner. Nauka, Moscow, pp. 225 - 257. [in Russian].

NAIDIN, D. P., 1979. Belemnitellidae. *In*: PAPULOV, G. N. & NAIDIN, D. P., Eds., The Santonian/ Campanian boundary on the East European Platform. *Trudy Instituta Geologii i Geokhimii, Akademya Nauk SSSR - Uralskij nauchnij tsentr*, **148**: 75 - 89. [in Russian].

PAPULOV, G. N. & NAIDIN, D. P. , Eds., 1979. The Santonian/ Campanian boundary on the East European Platform. *Trudy Instituta Geologii i Geokhimii, Akademya Nauk SSSR - Uralskij nauchnij tsentr*, **148**: 117 pp. [in Russian].

TABACHNIKOVA, I.P., 1989a *in*: BENYAMOVSKY, V.N., LEVINA, A. P., PRONIN, V.G., TABACHNIKOVA, I. P., Palaeocene of the

Turgay depression. *Izvestiya Vysshikh Uchebnykh Zavedenii. Geologiya i Razvedka*, **1989**, 6: 47-55 [in Russian].

TABACHNIKOVA, I.P., 1989b *in*: BENYAMOVSKY, V.N., LEVINA, A. P., PRONIN, V.G., TABACHNIKOVA, I. P., 1989a. Lower Eocene of the Turgay depression. *Izvestiya Vysshikh Uchebnykh Zavedenii. Geologiya i Razvedka*, **1989**, 9: 3-16 [in Russian].

VALSILJEVA, O.N., 1990. Palynology and microphytoplancton of Palaeogene of South Trans Urals. Sverdlovsk. 54 pp. [in Russian].

ZHELEZKO, V. I., 1994. Sharks of the family Jaekelotodontidae from European and middle Asian palaeogeographic provinces. *Byulleten Moskovskogo Obshchestvo Ispitateley Prirody- Geologicheskii Seriya*, 69, 6: 47 - 62. [in Russian].

ZHELEZKO, V. I., 1995. Biostratigraphy of Palaeogene sediments of the northern Karagia depression (Mangyshlak, Kazakhstan). Akademya Nauk SSSR - Uralskij otdelenie, Ekaterinburg, pp. 6-10. [in Russian].

ZHELEZKO, V. I. & KOZLOV, V. A., 1999. Elasmobranchii and Palaeogene biostratigraphy of Trans Urals and Central Asia. *Materials on Stratigraphy and Palaeontology of the Urals*, 3. Ekaterinburg: Urals Branch of Russian Academy of Sciences Publ. House, 1999. 324 pp. [in Russian].

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Typescript submitted: 15.1.1999

APPENDIX

Stratigraphic distribution of lamnoid shark genera in Cretaceous and Palaeogene.

CRETACEOUS FAMILIES AND GENERA
Family Ptychodontidae Woodward, 1932
Ptychodus Agassiz, 1839.
Heteroptychodus Yabe et Obata, 1930.
Family Cretodontidae Zhelezko, fam. nov. , 1999
? *Pseudoisurus* Glückman, 1957
Cretodus Sokolov, 1965
Protolamna Cappetta, 1980
Archaeolamna Siverson, 1992
Leptostirax Williston, 1900
Family Cretoxyrhinidae Glückman, 1958.
Cretoxyrhina Glückman, 1958.
Paraisurus Glückman, 1957.
Family Anacoracidae Casier, 1947.
Palaeoanacorax Glückman, 1971
Squalicorax Whitley, 1939.
Pseudocorax Priem, 1897.
Microanacorax Glückman, 1979.
Ptychocorax Glückman, 1979.
Paraanacorax Glückman, 1979.
CRETACEOUS AND PALAEOGENE FAMILIES AND GENERA
Family Jaekelotodontidae, Glückman, 1964 (Cretaceous-Palaeogene).
Eostriatolamia Glückman, 1979, Cretaceous.
Palaeohypotodus Glückman, 1964, Palaeogene.
Jaekelotodus Menner, 1928, Palaeogene.
Glueckmanotodus Zhelezko, 1999, Palaeogene.
Mennerotodus Zhelezko, 1985, Palaeogene.
Borealotodus Zhelezko, 1999, Palaeogene.
Tobolamna Zhelezko, 1999, Palaeogene.
Family Odontaspididae Müller & Henle, 1839 (Cretaceous-Palaeogene).
Hispidaspis Sokolov, 1978, Cretaceous.
Serratolamna Landemaine, 1991, Cretaceous.
Synodontaspis White, 1931, Palaeogene.
Araloselachus Glückman, 1964, Palaeogene.
Clerolamna Zhelezko, 1999, Palaeogene.
Hypotodus Jaekel, 1985, Palaeogene.
Striatolamia Glückman, 1964, Palaeogene.
Family Otodontidae Glückman, 1964 (Cretaceous-Palaeogene).
Cretolamna Glückman, 1958, Cretaceous.
Otodus Agassiz, 1843, Palaeogene. (The genus *Carcharocles* is herein included into the genus *Otodus*).
Parotodus Cappetta, 1980, Palaeogene.
Palaeocarcharodon Casier, 1961, Palaeogene.
Family Isuridae Gray, 1851 (Cretaceous- Palaeogene).
Acrolamna Zhelezko, 1990, Cretaceous.
Macrorhizodus Glückman, 1964, Palaeogene.
Isurolamna Cappetta, 1976, Palaeogene.
Lamiostoma Glückman, 1964, Palaeogene.
Xiphodolamia Leidy, 1877, Palaeogene.
Family Alopiidae Gill, 1855 (Cretaceous-Recent)
Paranomotodon Herman *in* Cappetta & Case, 1975, Cretaceous-Palaeogene.
Alopias Rafinesque, 1810, Palaeogene-Recent.
Family Scapanorhynchidae Bigelow & Schroeder, 1948 (Cretaceous-Palaeogene).
Scapanorhynchus Woodward, 1889, Cretaceous-Palaeogene.
Rhaphiodus Glückman, 1980, Cretaceous.
Family Mitsukurinidae Jordan, 1898
Anomotodon Arambourg, 1952, Cretaceous-Palaeogene.
Mitsukurina Jordan, 1818, Palaeogene- recent

Recommandations aux auteurs

Le Bulletin de l'I.R.Sc.N.B. est publié annuellement en trois séries: Biologie, Entomologie, Sciences de la Terre.
Seuls seront acceptés les articles originaux. Les manuscrits doivent être rédigés en anglais, français, allemand ou néerlandais. Les articles seront soumis à un comité de lecture dont la décision est souveraine. Celle-ci sera communiquée à l'auteur dans les meilleurs délais. Les manuscrits non conformes aux présentes recommandations seront refusés.
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Le texte doit être dactylographié dans sa forme définitive en trois exemplaires sur format DIN A4, avec des marges suffisantes (4 cm côté gauche), double interligne, recto seulement. Il doit mentionner le(s) nom(s), le(s) prénom(s) du (des) auteur(s) et leur adresse professionnelle à placer après les références bibliographiques.
Il doit indiquer, outre le titre, un titre abrégé (35 caractères maximum). Il doit être accompagné d'un résumé en deux langues, dont un en anglais. Chaque résumé sera suivi de trois à six mots-clefs. Le renvoi aux références bibliographiques se fera en mentionnant dans le texte le nom de l'auteur (en petites capitales), suivi de l'année et éventuellement de la page, placées entre parenthèses.
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Les références seront classées par ordre alphabétique des auteurs et par ordre chronologique pour chaque auteur. Les titres des périodiques ne seront pas abrégés, mais écrits en toutes lettres. Les références seront présentés de la manière suivante:

BROWN, S., CASSUTO, S. & LOOS, R.W., 1985. Biomechanics of chelipeds in some decapod crustaceans. *Journal of Zoology*, 188 (2): 143-159.

GERY, J., 1977. Characoids of the World. Tropical Fish Hobbyist Publications Inc. Ltd., Neptune City, U.S.A., 672 pp.

HAQ, B.U., 1984. A synoptic review of 200 million years of ocean history. *In*: HAQ, B.U. & MILLIMAN, J.D. (Editors), Marine Geology and Oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, London, pp. 201-232.

MILLE, G.S., 1913. Revision of the Bats of the genus Glossophaga. *Proceedings of the United States National Museum*, 46: 413-429.

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Les tableaux seront présentés séparéments. Ils seront numérotés en chiffres arabes accompagnés d'une légende et porteront le nom de l'auteur.

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Les noms de genres et d'espèces et les mots latins seront soulignés.
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GERY, J., 1977. Characoids of the World. Tropical Fish Hobbyist Publications Inc. Ltd., Neptune City, U.S.A., 672 pp.

HAQ, B.U., 1984. A synoptic review of 200 million years of ocean history. *In*: HAQ, B.U. & MILLIMAN, J.D. (Editors), Marine Geology and Oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, London, pp. 201-232.

MILLE, G.S., 1913. Revision of the Bats of the genus Glossophaga. *Proceedings of the United States National Museum*, 46: 413-429.

Tabellen

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Verbeteringen worden in het rood aangebracht in de marge, door middel van de conventionele tekens. Ieder wijziging van de tekst, aangebracht in de drukproef, zal aan de auteur aangerekend worden.

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BROWN, S., CASSUTO, S. & LOOS, R.W., 1985. Biomechanics of chelipeds in some decapod crustaceans. *Journal of Zoology*, 188 (2): 143-159.

GERY, J., 1977. Characoids of the World. Tropical Fish Hobbyist Publications Inc. Ltd., Neptune City, U.S.A., 672 pp.

HAQ, B.U., 1984. A synoptic review of 200 million years of ocean history. *In*: HAQ, B.U. & MILLIMAN, J.D. (Editors), Marine Geology and Oceanography of Arabian Sea and coastal Pakistan. Van Nostrand Reinhold, London, pp. 201-232.

MILLE, G.S., 1913. Revision of the Bats of the genus Glossophaga. *Proceedings of the United States National Museum*, 46: 413-429.

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