Stratigraphy and Geological Correlation, Vol. 12, No. 5, 2004, pp. 495–513. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 12, No. 5, 2004, pp. 65–86.


# New Data on the Marine Paleogene of the Southern West Siberian Plate, Paper 2

M. A. Akhmet'ev*, G. N. Aleksandrova*, V. N. Beniamovskii*, D. I. Vitukhin*, Z. I. Glezer**, Z. N. Gnibidenko***, V. D. Dergachev****, Zh. A. Dolya****, N. I. Zaporozhets*, G. E. Kozlova*****, I. A. Kul'kova***, I. A. Nikolaeva**, M. N. Ovechkina******, E. P. Radionova*, N. I. Strel'nikova*******

** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia*
*** All-Russia Research Institute of Geology, St. Petersburg, Russia*
**** Joint Institute of Geology, Geophysics and Mineralogy, Siberian Division, Russian Academy of Sciences, Novosibirsk, Russia*
***** Omsk Expedition of Geological Prospecting, Omsk, Russia*
****** All-Russia Research Institute of Oil Geological Prospecting, St. Petersburg, Russia*
******* Moscow State University, Moscow, Russia*
******** St. Petersburg University, St. Petersburg, Russia*
Received December 24, 2002

**Abstract**—Age and spatial relationships between the Gan'kino, Lyulinvor, and Tavda formations, the principal subdivisions of marine Paleogene, are clarified based on comprehensive paleontological study of marine deposits, which have been recovered by two reference boreholes in the Southern West Siberian plate. As was suggested earlier, the Talitsa Formation is missed from the sequence in a greater part of the Barabinsk lithologic-facies zone. In the study area, accumulation of the Lyulinvor Formation commenced somewhat later than in central and western areas of the plate. Breaks in sedimentation are established inside and at the top of the Lyulinvor Formation below the Tavda Formation base. Sedimentation rates are evaluated, and lithological and biostratigraphic subdivisions are correlated with geological and paleogeographic events. Principal transgressive–regressive cycles and half-cycles are outlined. It is shown for the first time that accumulation of the Tavda Formation corresponded to two cycles of this kind, the second of which is represented solely by its transgressive part corresponding to Lattorfian (late Priabonian) eustatic transgression. Directions of block movements, which controlled either the basin free connection with or partial isolation from ocean, are established. Impacts of hydrology and principal Arctic and Tethyan currents on sedimentation and climate are considered.

**Key words:** Paleogene, Eocene, Oligocene, West Siberian plate, foraminifers, dinocysts, radiolarians, diatoms, ostracodes, paleomagnetic zones, magnetostratigraphy, Gan'kino, Lyulinvor, and Tavda formations.

## INTRODUCTION

The first our paper (Akhmet'ev *et al.*, 2004) was devoted to biostratigraphic characterization of two reference boreholes, which recovered the marine Paleogene deposits of the Southern West Siberian plate. In that paper, we presented data on the sequence structure and distribution of various fossil groups (planktonic and benthic foraminifers, radiolarians, diatoms, organic-walled phytoplankton, spores and pollen) in lithostratigraphic units. Magnetostratigraphic and logging results were presented as well. In this work, we discuss the results obtained.

## AGE SUBSTANTIATION

### *Gan'kino Formation*

The Gan'kino Formation age is defined based on its nannoplankton assemblage that is characteristic of the *Nephrolithus frequens* Zone (zone CC26 corresponding to the second half of late Maastrichtian in the International standard zonation of the Upper Cretaceous). The assemblage diversity suggests a warm-water state of the Gan'kino sea basin that was of normal salinity and connected with the World Ocean. The inference is consistent with data on ostracodes and benthic foraminifers. The assemblage of the latter can be attributed to the *Spiroplectammina carinata* Zone of the upper Maastrichtian.

Earlier N.K. Lebedeva and A.F. Khlonova studied Maastrichtian dinocysts of West Siberia in the Ust-Yenisei depression only (Zakharov *et al.*, 1986; Il'ina *et al.*, 1994). Unfortunately, the host deposits have been dated then in the stage rank only, because the assemblages studied were taxonomically incomplete. Specifying age of the Gan'kino assemblage, Aleksandrova considered available data on Greenland, North Sea, West Europe, and Mangyshlak (Sharafutdinova, 1992;

Hansen, 1977, 1979; Hakånson *et al.*, 1979; Kirsh, 1991; Marheinecke, 1992; Schøler *et al.*, 1992; Brinkhuis *et al.*, 1996; Herngreen *et al.*, 1998; Slimani, 2001), as the dinocysts zonation in West Siberia is known inadequately. In the North Sea, Netherlands, and Germany, assemblages of most close composition are characteristic of the upper Maastrichtian. Based on dinocyst species in common, such as *?Phanerodinium sonciniae, P. veligerum, Cordosphaeridium fibrospinosum, Conneximura fimbriata, Cerodinium speciosum, Cerodinium diebelii, Hystrichostrogyton coninkii*, and *Trythirodinium evittii*, she identified the mid-late Maastrichtian age of the Gan'kino Formation, because *Palynodinium grallator* (the index species of the terminal Maastrichtian), *Thalassiphora pelagica* and Paleogene taxa are missed from the studied assemblage. The *Cerodinium diebelii* Beds of the formation are correlative therewith to the *Isabelidinium cooksoniae, Palaeocystodinium denticulatum*, and *Hystrichostrogylon borisii* zones of the North Sea (Schøler *et al.*, 1992), and to *Deflandrea galeata* Zone of Germany (Kirsch, 1991), Belgium (Slimani, 2001) and Dania (Fig. 2).

Two magnetic zones of normal and reversed polarity established in the Gan'kino Formation clays are of insignificant thickness and can be correlated with the boundary interval of terminal C30n and basal C29r chrons (Berggren *et al.*, 1995).

### *Lyulinvor Formation*

### Lower Lyulinvor Subformation

Characteristic of the lower Lyulinvor Subformation are the *Alisocysta margarita* and *Apectodinium homomorphum* dinocyst assemblages of the Thanetian age. The former assemblage is established between the first occurrence levels of *Deflandrea denticulate* and *Apectodinium homomorphum*, because *Alisocysta margarita* is present, though as single specimens, in the late Selandian sediments. The *A. margarita* Zone is reliably correlated with the West European biostratigraphic subdivisions Viborg4 (Heilmann-Clausen, 1985), partly with D4 (Costa *et al.*, 1988), and with *Alisocysta margarita* Zone of England (Powell, 1992). In the work by Powell, the zone is correlated with the nannoplankton zone NP8 of the lower Thanetian. In Borehole 9, the *Apectodinium homomorphum* Zone is distinguished above the first occurrence level of its index species. In West European sections, the stratotype included, it is correlated with the dinocyst zones Viborg 5 (Heilmann-Clausen, 1985), D4 (Costa *et al.*, 1988), and *Apectodinium homomorphum* of southern England (Powell, 1992), corresponding there to the nannoplankton zone NP9 of the upper Thanetian.

An impoverished assemblage of agglutinated foraminifers from basal beds of the subformation belongs to the regional *Glomospira gordialiformis* Zone. Podobina (1998) attributed this assemblage characteristic of the Talitsa–Lyulinvor transitional strata to the late Paleocene (Thanetian).

Four paleomagnetic zones of normal and reversed polarity ($N_1$ll, $R_1$ll, $N_2$ll, $R_2$ll), which are detected in the Thanetian interval, may correspond to chrons C26n, C25r, C25n, and C24r or, possibly, to their fragments. This does not exclude, however, that the subformation lower boundary is close to the Selandian–Thanetian transition. Biotic changes across the lower and upper boundaries of the lower Lyulinvor Subformation indirectly suggest breaks in sedimentation at both levels.

### Upper Lyulinvor Subformation

According to distribution pattern of siliceous sediments in the section of Borehole 9, the upper Lyulinvor Subformation is divided in two members of (a) gray diatomaceous and opoka-like shales and of (b) green mudstones.

(a) **Member of gray diatomaceous and opoka-like shales** spans the interval of the *Dracodinium varielongitudum* and *Charlesdowniea coleothrypta* s. l. dinocyst zones. In many West European stratigraphic charts, the former zone is in the middle of the Ypresian Stage. Being at the same level in the type section of Ypresian clays in Belgium, the zone is confidently correlated, based on assemblages of calcareous microplankton, with the lower part of the nannoplankton zone NP12 and with the zone P7 in zonation of planktonic foraminifers. However, Andreeva-Grigorovich (1991) correlated the *D. varielongitudum* Zone with an upper part of zone NP11. In the section of Borehole 9, the dinocyst zone in question can be directly correlated with the *Heliodiscus inca* Zone of radiolarian standard, although its basal (491–489 m) and topmost beds belong to the *Heliodiscus lentis* s. str. and *Buriella longa–B. clinata* zones, respectively. According to distribution of diatoms, the upper *Dracodinium varielongitudum* Beds are likely correlative with a lower part of the *Pyxilla gracilis* s. l. Zone of the middle Ypresian. A lower interval of the beds, which is barren of diatoms, seems to be corresponding to the upper *Coscinodiscus payeri* Beds. In sections of boreholes 011 BP, upper strata of the *Dracodinium varielongitudum* Zone yield radiolarians occurring in the terminal part of the *Heliodiscus inca* Zone.

Based on benthic foraminifers occurring in the *Dracodinium varielongitudum* Zone, basal strata of the latter can be correlated with the *Bolivinopsis spectabilis* Beds, whereas its upper part is correlative with the lower interval of the *Textularia carinatiformis* Zone. Planktonic foraminifers *Pseudohastigerina wilcoxensis* and *Subbotina eocaenica* from the depth levels of 477 and 451 m suggest a broad interval from the early to initial middle Eocene for their host deposits. The *D. varielongitudum* Zone spans paleomagnetic zones $N_3$ll, $R_3$ll, $N_4$ll, and $R_4$ll. Paleomagnetic zone $R_1$ll distinguished in Borehole 011BP near the top of the *D. vari-*

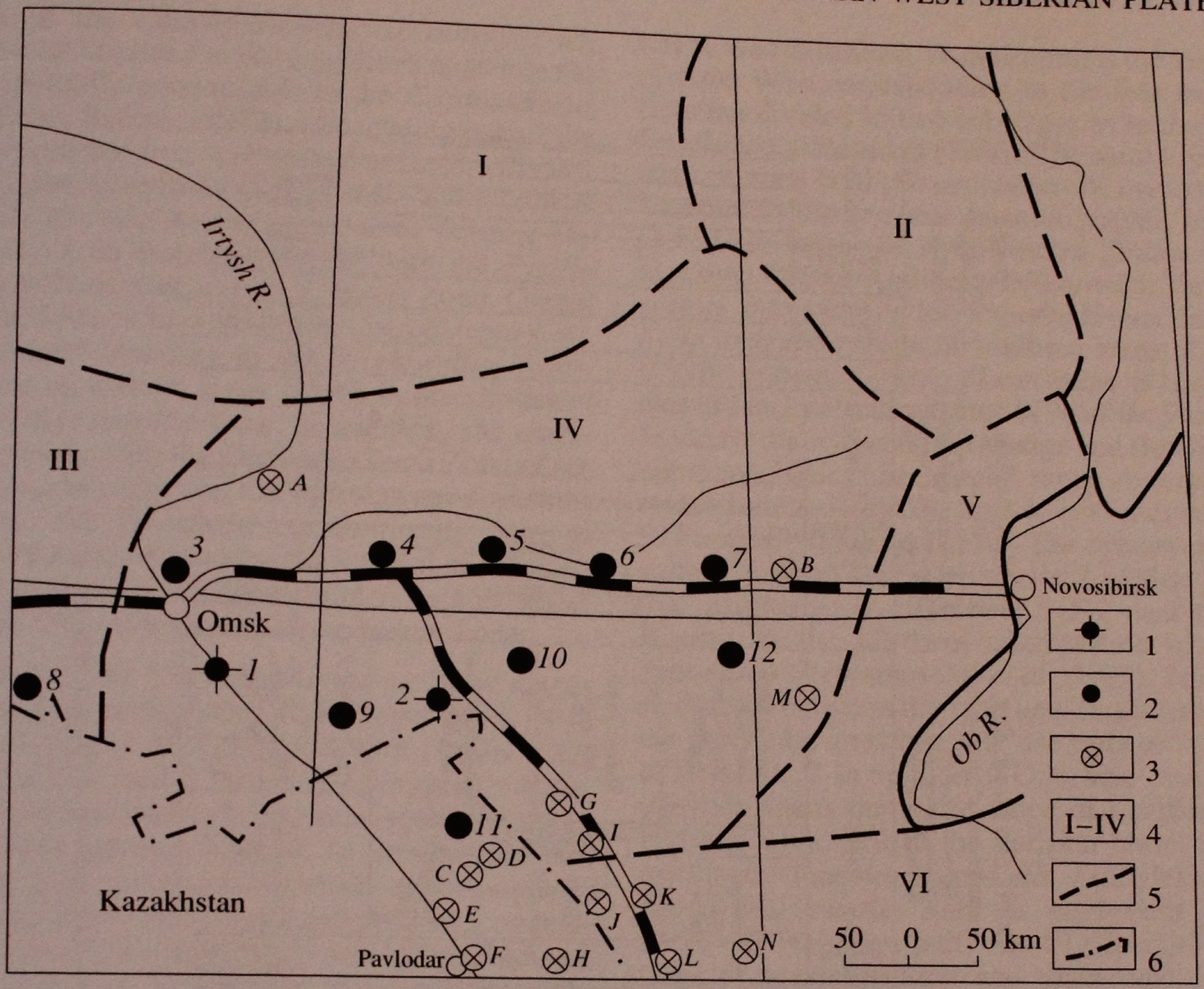


**Fig. 1.** Lithologic-facies zones and borehole localities discussed in this work (scheme is compiled based on data from *The Unified...*, 2001; Martynov, 1967, 1968, 1973; Zal'tsman, 1968): (1) boreholes 011BP of the Achair area (*1*) and 9 of the Chistoozerninskoe area (*2*) described in this work; (2) Omsk reference borehole (*3*), exploration boreholes 1R and 2R of the Tatarskoe area (*4*), exploration boreholes 1R and 1K of the Tibes area (*5*), Barabinsk reference borehole (*6*), Ubinsk borehole (*7*), Kishikaroi borehole (*8*), boreholes 69 and 2R near the village of Cherlak (*9*), exploration boreholes of the Ipatovo area (*10*), Mikhailovskaya-32 (*11*) and Yarkinskaya-35 (*12*); data on which are summarized in Table 2; (3) boreholes Bol'sherechenskaya (*A*), Kargatskaya-!2 (*B*), Trofimovskaya-30 (*C*), Trofimovskaya-3 (*D*), Kachirskaya-38 (*E*), Sychevskaya-34 (*F*), Karasukskaya 1R and 117 (*G*), Efremovskaya 185 and 48 (*H*), Burlinskaya-5K and others (*I*), Uspenskaya-35 (*J*), Slavgorodskaya-129 and others (*K*), Kulundinskaya-14 (*L*), Kochkinskaya (*M*), Blagoveshchenskaya 1R and others (*N*) discussed in brief; (4) Central (I), Narym (II), Ishim (III), Barabinsk (IV), Priobskaya (V) and Kulunda (VI) lithologic-facies zones; (5) boundaries between zones; (6) Kazakhstan state boundary.

*elongitudum* Zone is correlative with magnetozone $R_4$ll of Borehole 9. As the *D. varielongitudum* Zone corresponds to the middle Ypresian, the above paleomagnetic zones can be correlated with chrons C24n, C23r, C23n and with the lowermost interval of chron C22r. Rocks with normal polarity prevail in the indicated magnetostratigraphic interval of the upper Lyulinvor Subformation.

In both sections, the well-developed *Charlesdowniea coleothrypta* s.l. Zone of dinocysts is of the late Ypresian–early Lutetian age according to opinion of many researchers. Andreeva-Grigorovich (1991) who studied organic-walled phytoplankton and nannoplankton in southern sections of the former USSR correlated this biostratigraphic unit with standard zones NP12–NP14 and NP15 (partly). Being of the same range in regional stratigraphic charts of France and the North Sea, the unit appears to be at the level of zones P9 and P10 in zonation of planktonic foraminifers and spans zones NP15 (partly) and NP14 of the nannoplankton scale. The *Ch. Aoleothrypta* s. str. and *Ch. Aoleothrypta rotundata* subzones of the *Charlesdowniea coleothrypta* s. l. Zone correspond, respectively, to the Ypresian and terminal Ypresian–initial Lutetian intervals. In the studied sections, the latter subzone is distinguished conventionally because of unclear boundaries. It corresponds to the upper submember of gray diatomaceous clay that is 2 to 5 m thick.

The lower *Charlesdowniea coleothrypta* s.l. beds belong to the uppermost interval of the *Heliodiscus inca* Zone of the radiolarian scale, while the main part of this dinocyst zone is equivalent in range to the *Buriella clinata–B. longa* interval (though these index species have not been encountered in our samples). In Borehole 011BP, the uppermost *Ch. coleothrypta* beds yield radiolarians characteristic of interval transitional to the *Lychnocanium separatum* Zone. As for correlation with biostratigraphic units of the diatom scale, the

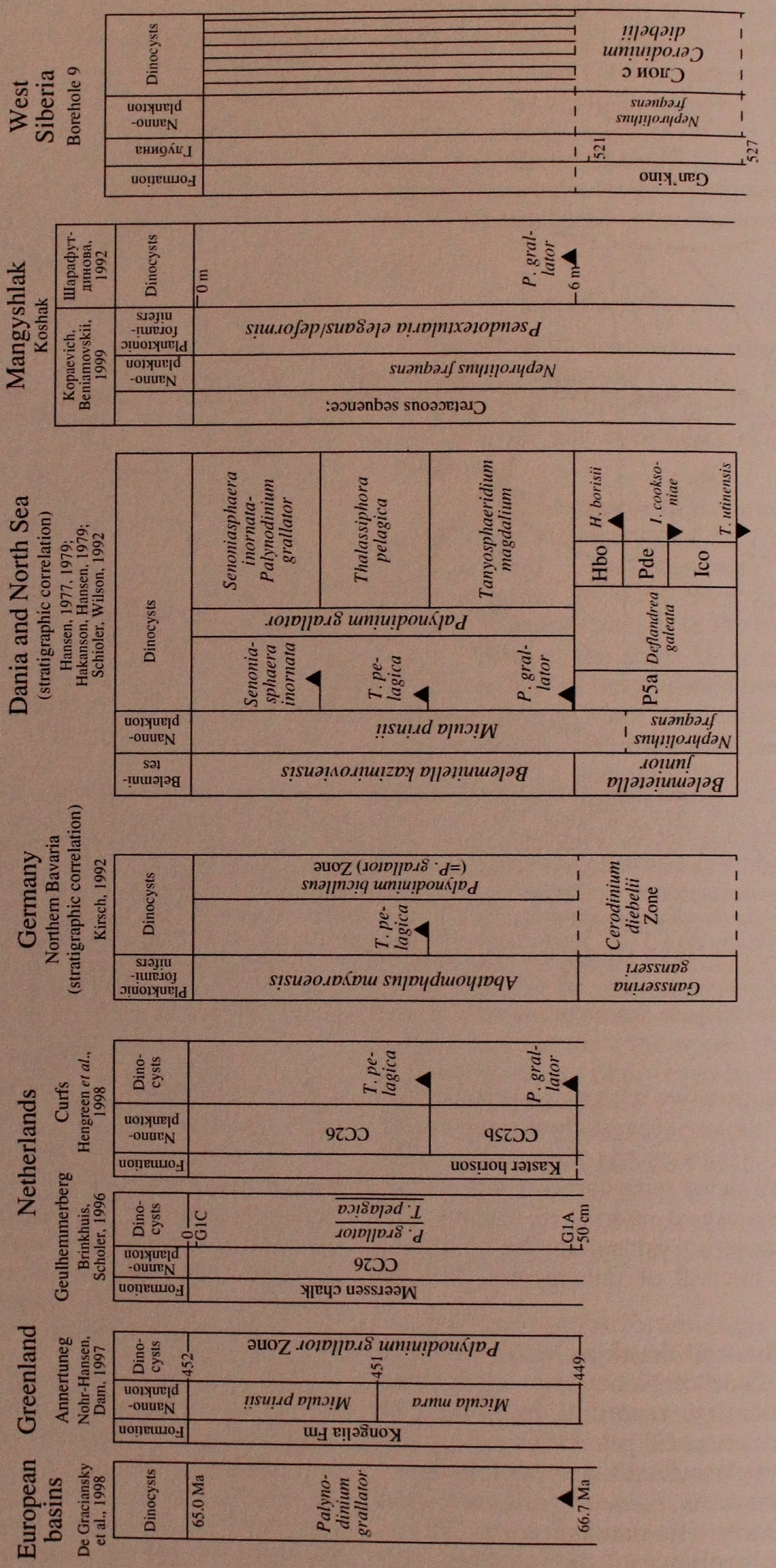


**Fig. 2.** Correlated upper Maastrichtian dinocyst zonations of different regions.

lower part of the *Charlesdowniea coleothrypta* s.l. Zone is correlative with *Pyxilla gracilis* Zone, while the upper one partially corresponds to the *Coscinodiscus poliactis* Zone. Rubina (1973) who distinguished the last zone considered it as transitional to the *Pyxilla oligocaenica* Zone. In opinion of Strel'nikova, it would be more correct to correlate the upper strata bearing *Ch. coleothrypta* s.l. in Borehole 011BP with the *Pyxilla oligocaenica–P. oligocaenica* var. *tenuis* Zone. Glezer considers the lower *Charlesdowniea coleothrypta* s. str. Subzone as corresponding to the *Brightwellia hyperborean* Zone of diatom scale, which is discriminated from the *Pyxilla gracilis* Zone. In addition, she correlated this subzone with the *Dictyocha secta* Zone of silicoflagellates and suggested the Ypresian age for all the subdivisions. The *Textularia carinatiformis* Zone of agglutinated foraminifers spans the interval of *Charlesdowniea coleothrypta* s.l. Zone coupled with an upper part of older *Dracodinium varielongitudum* Zone.

In Borehole 9, the *Ch. coleothrypta* s.l. Zone ranges through paleomagnetic zones $R_4$ll (upper part), $N_5$ll, and $R_5$ll, which can be correlated with chrons C22r (upper part),C22n, and C21r of the Berggren's scale. According to this correlation, the zone spans the upper Ypresian–lower Lutetian interval. In Borehole 011BP, the dinocyst zone under consideration corresponds to paleomagnetic zones $R_1$ll (upper part) and $N_1$ll correlative with chrons C22r (upper part) and C22n. Rocks of reversed polarity are dominant in this interval of subformation, especially in Borehole 9. Paleomagnetic zones are likely reduced here because of presumable hiatuses characteristic of the interval, which may distort the paleomagnetic records.

(b) **Member of green clays** with fish remains, the terminal one in the upper Lyulinvor Subformation, is most complete in section of Borehole 9, being of a special interest in terms of age determination. The Lyulinvor sedimentation cycle ended with deposition of this member. At this stage of evolution, the West Siberian sea basin under discussion was of a maximum size and occupied about 70% of West Siberia (Shatskii, 1978). Sedimentation rates decreased at that time, although it is difficult to estimate them correctly because of hiatuses distinguished in the section. The reduced thickness of the member definitely reflects a restricted silica influx into the basin, as it follows from sedimentation rates evaluated for lithostratigraphic units of Borehole 9. According to our estimates, consolidated sediments accumulated in a period of 1000 years are 10–12 mm thick in the lower Lyulinvor Subformation, about 10 mm thick in the member of gray opoka-like clay of the upper Lyulinvor Subformation, and only 4 mm thick in the green clay member.

Lower beds of the latter (depth interval of 449.6–444 m) belong to the *Wetzeliella articulata* (acme)–*Systematophora placacantha* Zone of dinocysts. In the biostratigraphic chart of the Parisian basin (Chateaneuf and Gruas-Cavagnetto, 1978), where the Lutetian stratotype was described, *W. articulata* is the index species of zone W9a corresponding to the first half of early Lutetian divided in two substages as in the scheme of Cavellier and Pomerol (1986). The same taxon is indicative of zone D10 (*W. articulata–W. ovalis*) of the late Lutetian in the regional biostratigraphic scheme suggested for basins of northwestern Europe (Costa and Manum, 1988). Andreeva-Grigorovich included that species into name of the *Rhombodinium draco–Wetzeliella articulata* Zone of southern areas of the former USSR. *Systematophora placacantha* is the index species of late Lutetian subzone W9b of the Parisian basin. In the North Sea sections (Mudge and Bujak, 1994), the upper age limit of the species range corresponds to terminal Lutetian (middle and lower intervals of zones P12 and NP16, respectively). The *Systematophora placacantha* Zone characterizes the Lutetian Iset Formation penetrated by Borehole SG32 near the town of Kurgan in the northern continuation of the Turgai depression (Beniamovskii *et al.*, 1995). This formation is situated between the Irbit and Tavda formations like the green clay member with fish remains in the section of Borehole 9. In opinion of O.N. Vasil'eva, the zone in question spans the entire range of Lutetian Stage and zones W8 and W9 of the Parisian basin. It should be mentioned that the *Wetzeliella articulata–Systematophora placacantha* Zone is equivalent to intervals NP15–NP16 (lower part) and P11 (part)–P12 in zonations of nannoplankton and planktonic foraminifers, respectively. In Borehole 9, the green clay member is attributed to the *Pyxilla oligocaenica* Zone of diatoms, the range of later var. *tenuis* included. Simultaneously, it corresponds to the radiolarian *Lychnocanium separatum* Zone and possibly spans an interval of transition to the next *Heliodiscus quadratus* Zone. Kozlova, Strel'nikova, and Radionova suggest the late Ypresian–early Lutetian age of the *W. articulata–S. placacantha* Zone, while Glezer attributes it to the Lutetian Stage. Kozlova (1999) described the *L. separatum* radiolarian assemblage from the Kresty Formation of the Turan pate, where its post-Ypresian (likely late Lutetian) age is out of doubts. Like dinocysts, the *Acarinina rotundimarginata* assemblage of planktonic foraminifers from the lower interval of green clay member (depth level of 449 m in Borehole 9), which are characteristic of the Kuberle Horizon in the Crimea–Caucasus region, is of the Lutetian age as well. Planktonic foraminifers of the *Hantkenina alabamensis* assemblage (depth level of 445 m) elucidates age of middle strata of the green clay member (late Lutetian or, possibly, Lutetian–Bartonian transition period).

Based on planktonic assemblages, primarily on planktonic foraminifers and dinocysts, one can assume the growing influence of Tethyan waters on sedimentation environments in the basin. Taxa of different ages concentrated in the section interval of insignificant thickness suggest a general environmental reorganization during the Lutetian and transgression in the first half of that age, which is inferable from appearance of planktonic foraminifers and diversification of dinocysts. The event was responsible for recurrent partial erosion of sediments, which were at the early diagenetic stage of consolidation. Signs of erosion are established at the depth levels of 451 m (the base of sandy layer below the clay member) and 446–444 m. Above the depth interval of 445 to 444 m, there are recorded signs of progressing regression and basin shoaling. They are consistent with compositional changes in diatom assemblages (data of Radionova) and with growing abundance of prasinophytes and acritarchs among the organic-walled phytoplankton (data of Zaporozhets). Simultaneously, dinocyst species became twice less diverse than before, and abundance of spores and pollen increased considerably, up to several times.

(c) *Terminal beds of the upper Lyulinvor Subformation* characterizing transition to overlying Tavda Formation are distinguished in the depth interval of 444–435 m. Dinocyst taxa characteristic of the initial middle Eocene (*Areosphaeridium diktyoplokum, Kisselovia ornata* f. *reticulata* and others) appear beginning from the depth of 445–444 m. Because of mass abundance of acritarchs and prasinophytes in the upper interval of the green clay member, it is difficult to define here the organic-walled phytoplankton zonation, and the interval is attributed to the *Paucilobimorpha–Micrhystridium* Beds. The beds are of ecological rather than biostratigraphic significance, because dinocyst assemblages from this level consist of euryhaline taxa of broad stratigraphic ranges. The same situation is typical of transitional beds between the Kresty and Kuma formations of the northern Caucasus, in which percentage of prasinophytes and acritarchs is as high as 70–80%. The event of shoaling in the West Siberian basin caused appearance of endemic forms among dinocysts (species *Kisselovia ornata* and *Thalassiphora elongata* unknown in western regions of Eurasia).

The basin shoaling that progressed toward commencement of the Tavda epoch influenced composition of the clay member that becomes enriched in silty and sandy components. Spores and pollen of the green clay member belong to the regional *Castanopsis pseudocingulum–Castanea crenataeformis* Zone established in upper Lutetian deposits of southern areas of the East European platform and Turan plate (Panova *et al.*, 1990). Thus, palynological data and microplankton suggest concordant ages of the green clay member.

The uncertainty of the Lutetian–Bartonian boundary and inconsistent zonations of nannoplankton and planktonic foraminifers within the transitional interval provoked controversial opinions with respect to that boundary position in the general scale. Berggren *et al.* (1995) believe that being 41.2 Ma old it should be at the base of chron C18r inside zones P12 (*Morozovella lehneri*) of planktonic foraminifers and NP16 of nannoplankton zonation. In the stratigraphic scale project recommended by J. Remane with colleagues at the International Geological Congress of 2000 in Brazil, the boundary is 2 m.y. older than in the scale of Berggren. Russian experts are of different opinions as well. In the scale of Interdepartmental Stratigraphic Committee (*Resolutions…*, 1989), it is placed at the base of the zones *Hantkenina alabamensis* (this is advocated by V.A. Krasheninnikov) and NP16. In the stratigraphic scheme authorized for the East European platform in 2000, the *Hantkenina alabamensis* Zone is placed into the Lutetian Stage, and the boundary is recommended to be defined based on nannoplankton.

In Borehole 9, the *Paucilobimorpha–Micrhystridium* Beds likely correspond to the terminal Lutetian. The inference is conventional however, as the Lutetian–Bartonian boundary position remains problematic until the competent decision of the International Subcommission of the Paleogene System. At present, it is reasonable to place this boundary at the base of the lower sandy member of the Tavda Formation (depth levels of 435 m in Borehole 9 and 456–455 m in Borehole 011BP). Being placed at the member base, the boundary appears to be well identifiable in logging diagrams and traceable over the plate.

The paleomagnetic zone $N_6ll$ established in the dinocyst zone *W. articulata–S. placacantha* of Borehole 9 can be correlated with the chron C20n only. In Borehole 011BP, a thin (3 m) subzone of reversed polarity at the top of zone $N_1ll$ may correspond to a part of chron C19r.

## *Tavda Formation*

### Lower Tavda Subformation

At the base of the lowermost sandy member of the Tavda Formation, there are recorded signs of erosion especially distinct in section of Borehole 011BP. The hiatus is insignificant however, as respective palynological spectra and dinocyst assemblages show characters inherited from underlying biostratigraphic units of the upper Lyulinvor Subformation.

The basal interval of the lower Tavda Subformation (depth range of 435–408 m in Borehole 9) corresponds to the *Areosphaeridium diktyoplokum*(*Rhombodinium draco* Zone of the early Bartonian. In the Bartonian Stage stratotype, the Elume Bay of White Island, southern England, the second index species occurs in association with nannoplankton of zone NP16 and with foraminifers of zone P13 at the level of 8 m above the stage base. Andreeva-Grigorovich and Zaporozhets (see in *Geological and Biotic…*, 1998) established the same situation in sections of southern Russia. In Borehole 9, the species range is controlled based on planktonic foraminifers found at the depth levels of 445 and 404–400 m. In the first case, species of the *Hantkenina alabamensis* assemblage, its index species included, define the lower limit (late Lutetian or Lutetian–Bartonian boundary interval), while *Acarinina rotundimarginata* present at the second level implies the Bartonian but not younger age of the regional zone in question, which is conventionally attributed to the early Bartonian. Kul'kova who studied pollen and spores from the same interval attributed them to the *Quercus gracilis–Rhoipites granulatus–Castanea crenataeformis* palynozone. At the same time, Zaporozhets who found here *Castanopsis pseudocingulum* characteristic of the middle Eocene distinguished the studied interval as the *Quercus graciliformis–Castanopsis pseudocingulum* Beds.

Upper strata of the lower Tavda Subformation (depth range of 408–388 m) yield dinocysts of the *Rhombodinium porosum* Zone. In many regional dinocyst zonations of Boreal realm, this indicative zone is dated back to the late Bartonian. In the aforementioned stratotype of the Bartonian Stage, the zone has a concrete position being situated between the *Rhombodinium draco* and *Rhombodinium perforatum* zones. In England, but not in France, Germany, Belgium and Russia, the last zone is attributed to the late Eocene. As for correlation with biostratigraphic subdivisions of calcareous plankton, it corresponds in range to zones NP16 and P14 (incompletely as we think). In the dinocyst scale of Western Europe (Costa and Manum, 1988), it is at the level of zone D11. In the Russian and Turan plates, the *Rhombodinium porosum* assemblage is characteristic of the Saksaul'skii Formation of the late middle Eocene in the Aral and Turgai regions. In a sample from the depth level of 406.5 m (Borehole 9), Nikolaeva detected accumulation of ostracodes *Cyamocytheridea* aff. *corruguta* resembling *C. corrugata* characteristic of the Saksaul'skii Formation in the Manual'e section of the Irgyz area. Thus, the last group of fossils also points to the middle Eocene age of the lower Tavda Subformation. In the Voronezh anteclise, platform areas of Ukraine, and the northern Caucasus, the *Rhombodinium porosum* assemblage is confined to upper strata of the Kiev and Kuma formation, which are undoubtedly of the middle Eocene age. *Acarinina* and *Catapsydrax* forms found in the upper half of the lower Tavda Subformation suggest the same age, although the assemblage of planktonic foraminifers includes some species commonly occurring in transitional Bartonian–Priabonian strata. Like dinocysts, the foraminiferal assemblage originated in a relatively cooled basin of subtropical belt.

Two paleomagnetic zones of reversed ($R_1$tg) and normal ($N_1$tg) polarity distinguished in the lower Tavda Subformation of Borehole 9 can be correlated with chrons C18r and C18n. Characteristic of them are the *A. diktyoplokum–R. draco* and *R. porosum* dinocyst assemblages. In Borehole 011BP, paleomagnetic zones $N_1$tg, $R_1$tg, $N_1$tg yield the same assemblages and may correspond to chrons C19n, C18r, and C18n. In both sections, rocks with normal polarity prevail in the lower Tavda Subformation like in the correlative interval of the Berggren's scale.

### Upper Tavda Subformation

Bearing dinocysts of the *Charlesdowniea clathrata angulosa* Zone, the upper Tavda Subformation, especially its upper half, can be directly correlated with the Priabonian of northern Europe and the Crimea–Caucasus region (zone D12 after Andreeva-Grigorovich in the last case). In sections of the Belaya, Kuban, and Kheu rivers (Zaporozhets, 1993, 1998, 2001), this dinocyst zone is correlated with zones of nannoplankton (NP18–NP20) and planktonic foraminifers (P15–P17). The same position of the zone is established in the Parisian basin, where it was originally established and dated back to the late Eocene. The dinocyst assemblage characteristic of the upper subformation facies deposited far seaward (depth interval of 295–277 m) is very diverse. It demonstrates a combination of "recurrent" taxa (*Areosphaeridium diktyoplokum, Enneadocysta arcuata, Phthanoperidinium eocenicum*, and others), which appeared in the middle Eocene and became extinct at the stage end, and transit taxa, which radiated widely in the Oligocene. Some cold-water species, e.g., *Phthanoperidinium amoenum*, probably appeared earlier in the West Siberian sea and then migrated in central and western areas of the Peri-Tethys during the early Oligocene cooling.

Ostracodes from middle and upper parts of the subformation (depth range of 343–291.8 m) also suggest the Priabonian age of host deposits. In addition to endemic *Cytherura placida*, the ostracod assemblage includes species known from the Chegan Formation of the Aral–Turgai region. Species *Clithrocytheridea innae* is widespread in the Khanabad and Sumsar sequences of Central Asia. The young transit form *Clytheridea* existed in the Oligocene as well. Older transit forms are *Paracypris contracta* (early–middle Eocene of the East European platform), *Cytheromorpha brabantica* (Lutetian–Bartonian of Belgium), and *Bythoceratina* ex gr. *impressa* (late Paleocene of Ukraine). Some of the listed taxa were found earlier in the Tavda Formation of West Siberia (Lipman and Nikolaeva, 1964).

A greater part of the Tavda Formation, the facies of freshened settings and upper transgressive member included, corresponds to the *Quercus gracilis–Quercus graciliformis* palynozone. Percentages of Fagaceae and other thermophilic taxa increase upward in the section, but basal beds of the overlying Isil'kul Formation are enriched in pollen of conifers (*Picea, Abies, Tsuga*), abundance of which is negligible in the Tavda formation. Spectra of amentiferous demonstrate an opposite trend: Betulaceae turn into dominants, Juglandaceae remain indifferent, and Fagaceae decrease in abundance. Palynological data represent the only biostratigraphic indication of a significant break in sedimentation and erosion of marine deposits.

Six paleomagnetic zones of normal and reversed polarity ($R_2$tg, $N_2$tg, $R_3$tg, $N_3$tg, $R_4$tg, $N_4$tg in Borehole 9 and $R_2$tg, $N_3$tg, $R_3$tg, $N_4$tg, $R_4$tg, $N_5$tg in Borehole 011BP) span the interval of the *Ch. clathrata angulosa* and *R. porosum* (partly) dinocyst zones, which are correlative with zones P15–P17 of planktonic foraminifers (late Bartonian–Priabonian). According to this correlation, the distinguished paleomagnetic zones correspond to chrons C17r, C17n, C16r, C16n, C15r, and C15n. Rocks with normal polarity prevail in the upper Tavda Subformation.

## PRINCIPAL BIOTIC AND ABIOTIC EVENTS OF THE TAVDA TIME

Paleontological data imply that sediments of the Tavda Formation penetrated by two boreholes recorded the same succession of biotic and abiotic events, which are important for the interregional correlation. Distribution trends of acritarchs and prasinophytes, diversity peaks of dinocysts, and corresponding periods of transgression maximums define the reference levels characterizing dynamics of sedimentation. In Borehole 9, a transition from shallow-water sediments to first transgressive facies is distinguished at the depth level of 412 m, where appearance of planktonic foraminifers and reduced abundance of *Paucilobimorpha* in phytoplankton are recorded. The early Tavda transgression maximum is established in boreholes 9 and 011BP (depth intervals of 408–392 and 430–410 m, respectively) based on appearance of planktonic foraminifers, diversification of dinocysts, and decreased abundance of prasinophytes and acritarchs. In both intervals, angiosperm pollen dominates in palynological spectra (70–80%), and Hamamelidaceae pollen is a considerable component. Transition from clayey to clayey–silty and silty sediments is recognizable at the depth levels of 388 and 401 m in boreholes 9 and 011Bp, respectively, and species diversity of dinocysts is reduced above both levels. Depth ranges of 388–367 and 401–368 m in two respective sections show transition from transgressive to regressive phase of the basin evolution. Abundance and diversity of dinocysts are decreasing here, and percentage of acritarchs and prasinophytes is insignificant. Indicative of the regressive phase is the mass abundance of aquatic fern *Hydropteris indutus* and parallel appearance of freshwater algae *Pediastrum* in some samples (depth intervals of 359–337 and 360–325 m, respectively). Pollen of Fagaceae is dominant in the *Quercus gracilis–Quercus graciliformis* Zone, the index taxa of which represent over 50% of the spectrum. Termination of the regressive phase corresponds to the biotic event recorded in depth ranges of 339–334 (Borehole 9) and 333.7–330.5, 325 m (Borehole 011BP). In shallow-water sediments of these levels, massulae and fronds of aquatic fern *Azolla vera* Krysht. occur in association with benthic foraminifers *Cribroelphidium rischtanicum*, ostracodes (*Cytheridea probata, Echinocytheris spongiosa, Paracypris compacta*), and bivalves (*Muscullus* cf. *samensis, Pitar circularis, Cardiopsis* sp.). According to information from S.V. Popov and I.A. Goncharova (Paleontological Institute RAS), the first and third taxa of bivalves are known only from the Chegan deposits of Ustyurt–Aral region, whereas the second one is characteristic of these and Oligocene deposits.

The next intervals in both sections characterize a gradual transition from regressive to transgressive cycle (330–313 m in Borehole 9 and 317.3–303.5 m in Borehole 011BP). Spores of aquatic ferns, prasinophytes, and acritarchs almost disappear from sediments at these levels. By the end of intervals, diversity of dinocysts increases up to 30 species. Cooling of that time is evident from a reduced abundance of angiosperm pollen, especially of thermophilic taxa, and from a higher percentage of Juglandaceae and Betulaceae (5%) in samples 330, 326, and 313. The Tavda transgression maximum corresponds to depth intervals of 394–277 and 298.7–265 m in boreholes 9 and 011BP, respectively, where the diverse dinocyst assemblages (50 to 55 species) include recurrent forms of the lower Tavda Subformation. Representatives of the cold-water affinity from genera *Rhombodinium* and *Phthanoperidinium* become frequent here. Fagaceae dominate again in spore–pollen spectra.

Thus, the established trend of biotic and abiotic events of the Tavda time appears to be useful for interregional correlation (Table 1). The trend depicts the mass appearance and subsequent quick reduction of acritarchs and prasinophytes, fluctuations in abundance and diversity of dinocysts, and episodic simultaneous appearance of other groups of marine biota (transgressive pulses?). The most remarkable is transition from regressive to transgressive phase of the mid-Tavda time, when massulae and fronds of *Azolla vera*, benthic foraminifers of the *Cribroelphidium rischtanicum* assemblage, ostracodes (*Cytheridea probata, Echinocytheris spongiosa, Paracypris compacta*), and bivalves (*Musculus* cf. *samensis, Pitar circularis, Cardiopsis* sp.) were buried in calcareous sediments of a narrow interval (3 to 5 m thick).

The early and late Tavda transgressive episodes are contrastingly recorded in two sections. Being hardly detectable in Borehole 9, transition to the reduced half-cycle of the late Tavda time is unrecognizable in Borehole 011BP.

Sedimentation rate of the Tavda time (27 mm per 1000 years in average) was much greater than in the Lyulinvor period. It was initially relatively low (10 mm per 1000 years) and increased up to 37–39 mm per 1000 years in the late Tavda time. The plate downwarping did not compensate the intense influx of terrigenous material, and sea basin experienced a considerable shoaling in the mid-Tavda time. During the transgression peaks, the basin could be 100 and more meters deep in accumulation settings of fine clayey sediments only.

Gray kaolinic silty clays of the Isil'kul Formation (age equivalent of the Atlym Formation in the Central lithologic-facies zone) rest on uneven eroded surface of underlying green clays of the Tavda Formation. Small, flattened pebbles of green clay are widespread in basal

**Table 1.** Main stages of the Tavda basin evolution

| Main stages of the basin evolution | Principal indications of biotic and abiotic events | Depth interval (m); Borehole 9 | Depth interval (m); Borehole 011BP | Additional information |
|---|---|---|---|---|
| Termination of regressive stage that antedated the early Tavda transgression | Gradual replacement of sandy–silty deposits by clay; reducing abundance of *Paucilobimorpha* and other acritarchs and prasinophytes | 435–412 | 455–430 (?) | Offshore distance coefficient 10 to 15% |
| Transgressive phase of the early Tavda time | Accumulation of clayey sediments; appearance of planktonic foraminifers and ostracodes, growing abundance and diversity of dinocysts | 408–392 | 430–410 | Offshore distance coefficient up to 25%; warming |
| Transition from transgressive to regressive phase | Replacement of clayey sediments by silty deposits; decreasing content and diversity of dinocysts and growing abundance of acritarchs and prasinophytes | 388–367 | 401–367 | Drop of offshore distance coefficient down to 15–18% |
| Regressive phase of the mid-Tavda time | Prevalence of silty sediments; further decrease of dinocyst diversity and mass abundance of *Hydropteris, Pediastrum*, and thin-walled dinocysts *Hysrtichokolpoma* and others | 359–337 | 360–325 | Further decrease of offshore distance coefficient down to 10–12% |
| Biotic episode of the incipient transition from regression to transgression | Higher carbonate content in sediments; mass abundance of *Azolla* and *Hydropteris*, accumulations of foraminifers, ostracodes, and mollusks | 339–334 | 333.7–330.5, 325 | Resumed growth of offshore distance coefficient |
| Transition from regressive to transgressive phase | Alternating clay, sand, and silt interlayers, siderite lenses; gradual diversification of dinocysts and higher content of coniferous pollen with parallel reduction of thermophilic angiosperms in palynological spectra | 330–313 | 317.3–303.5 | Slow increase of offshore distance coefficient; cooling |
| Transgressive phase of the late Tavda time | Prevailing clay beds intercalated with sand, silt, and siderite interlayers and lenses; abundance growth and diversification of dinocysts (up to 60 species); palynospectra with thermophilic taxa and dominant gymnosperms | 304–277 | 298.7–265 | Offshore distance coefficient up to 25–30% |

Isil'kul beds. Palynological assemblages below and above the erosion surface are very different, implying a considerable break in sedimentation. Dominant Fagaceae and Taxodiaceae occurring in association with thermophilic *Engelhardtia, Corylopsis, Hamamelis, Ilex*, and *Palmae* are taxa characteristic of pollen spectrum from the depth level of 277 m, whereas Pinaceae and Betulaceae dominate in pollen at the depth of 274 m.

Paleomagnetic data also suggest a considerable hiatus between the Tavda and Isil'kul formations. The equivalent of chron C13r of the Berggren's scale is missed from the studied sections of Paleogene deposits. Magnetostratigraphic records near the Eocene–Oligocene boundary, which is established in most complete sections of Mediterranean and Crimea–Caucasus regions based on calcareous nannoplankton, are complicated, consisting of normal and reversed polarity chrons of variable durations and succession. In such a situation, it is difficult to correlate the general and regional magnetostratigraphic scales. In the general scale, the reversed polarity chrons 13r and 12r are separated by interval of normal polarity (13n) between 34.6 and 30.9 Ma, which spans about one third of the Priabonian and the greater part of the Rupelian. In boreholes 011BP and 9, the upper transgressive beds of the Tavda Formation correspond, in opinion of Gnibidenko, to the respective normal-polarity chron in the regional magnetostratigraphic scale of West Siberia. In the general scale, they may span the interval of paleomagnetic chrons C16 and C15.

## ONCE MORE ABOUT THE TAVDA FORMATION AGE

Despite the diverse viewpoints on the Tavda Formation age, there is a number of undisputable observation results.

First, nobody argues now against the two-member structure of the Tavda Formation composed of two transgressive–regressive sedimentary cycles in most complete sections of central West Siberia and its peripheral zone. Transgressive facies of the cycles correspond to clayey members, the principal ones in structure of the lower and upper Tavda subformations.

Second, the lower Tavda Subformation is naturally limited by sand or sandstone members detectable in logs as regional logging markers "T" and "B." In those cases, when sandy character of sediments in the Tavda Formation middle is not obvious, like for instance in boreholes 9 and 011BP, paleontologists detect the corresponding level based on appearance of brackish-water mollusks, abundant acritarchs and prasinophytes, aquatic fern spores. It is also important that in latitudinal profiles, which cross Paleogene deposits along and on both sides of the Omsk–Novosibirsk railway, continental coaliferous facies replace marine sediments beginning exactly from the logging marker "B."

Third, all fossil groups used to define the Tavda Formation age (ostracodes, Elasmobranchii, benthic foraminifers, mollusks, dinocysts) include many taxa, which are characteristic of the following stratigraphic subdivisions in other regions: the Chegan Formation of Ustyurt, Aral and Turgai regions; Adaevka Formation of Mangyshlak; Rishtan, Isfara, Khanabad, and Sumsar horizons of marine Paleogene deposits in the Fergana and Tajik depressions of Central Asia. Experts on foraminifers (Subbotina, 1937; Lipman, 1955; Ushakova, 1957) and other paleontologists (Boitsova *et al.*, 1968; Khokhlova and Nikolaeva, 1964; Panova, 1967) already paid the necessary attention to this fact. Kisel'man (1978) who compared benthic foraminifers from Central Asia and Tavda Formation figured out that 9 of 16 elphidiid, nonionid, miliolid, and anomalinid species were discovered first in the Tavda Horizon, while the other seven taxa were defined in Paleogene deposits of Central Asia. "*Cribroelphidium rischtanicum* appears in the Rishtan strata and disappears at the Sumsar level; *Discorbis ferganensis* and *Nonion laevis* are detected in the Rishtan and Khanabad beds, being unknown in Fergana above the latter. The most abundant species of the *C. rischtanicum–Brotzenella munda* (N. Bykova) assemblage is simultaneously widespread in Khanabad and Sumsar strata of Fergana (Bykova, 1939). *Nonion graniferus* Terquem is also confined to the Khanabad level ... ... Since *C. rischtanicum* assemblage includes some polymorphinids, abundant miliolids, and *B. munda*, it is close to assemblage of the Khanabad regional stage" (Kisel'man, 1978; pp. 45, 46). Admitting then that *C. differensapertio* subassemblage, the upper one among three subassemblages distinguished by M.V. Ushakova in the *C. rischtanicum* Beds, may correspond as well to a higher Sumsar level of Central Asian sections, Kisel'man concluded nevertheless that this level "... can be correlated with the lower–middle interval of the Sumsar Beds in Central Asia." It is also important that Kisel'man (like Ushakova before) defined the appearance of *C. rischtanicum* assemblage at the level of 25–30 m (Tyumen borehole 1-P) and 120 m (Tar profile) above the base of Tavda Horizon. In our opinion, these data suggest, though indirectly, that lower beds of the Tavda Formation are older than the late Eocene.

Taking into account recent age determinations of the Sumsar Beds, we tried to define the Tavda Formation age based on subdivisions of the regional Paleogene scale of Central Asia. This was reasonable in view of general paleogeographic situation in Eurasia during the late Eocene, when the West Siberian sea, Tajik and Fergana basins represented eastern gulfs of the Peri-Tethys, in which eustatic movements were comparable.

It is important to compare the West Siberian and Central Asian bio- and lithostratigraphic units, because the Sumsar Beds of the Tajik and Fergana depressions bear nannoplankton (Muzylev and Salibaev, 1988; Muzylev *et al.*, 1996). In the nannoplankton assemblage from the upper Kushan (Khanabad) and Sumsar deposits of the Tajik depression, Muzylev identified single specimens of *Isthmolithus recurvus*, the index species of zone NP19/20. In the Sumsar Beds, nannoplankton of this zone is more abundant and diverse. In the Fergana depression, the other index species *Discoaster barbadiensis* was found in upper marine deposits of the Sumsar sequence stratotype near the town of Isfara. The nannoplankton assemblage characteristic of zone NP19/20 is also known from the Shor-su section of the Fergana depression. In addition to above index species, the assemblage includes *Rhabdosphaera spinula, Rh. crebra*, and *Braarudosphaera bigelowi*. Muzylev termed it the *Istmolithus recurvus–Sphenolithus pseudoradians* assemblage of undivided zones NP19/NP20 of the terminal late Eocene.

Muzylev *et al.* (1996) also reported that in the Fergana depression the Sumsar Beds transgressively overlap the eroded surface of older deposits, the Turkestan strata included, as it was first noted by Makarova and Mironova (1964) and then by Salibaev (1982). Thus, the upper Eocene of Central Asian depressions is represented by two (but not one) transgressive–regressive cycles, one of the late Rishtan–Khanabad and the other one of the Sumsar time. Transition from the lower Rishtan sands to upper Rishtan slightly calcareous clays marks the commencement of the first cycle. It was a conventional decision to regard the middle–upper Eocene boundary as coinciding with boundary between the cycles, because nannoplankton of upper Rishtan deposits is lacking index species. In opinion of Muzylev, appearance of *Crubrocentrum reticulatum* "implies that host deposits are not older than the late middle Eocene; the event does not specify stratigraphic position of the Rishtan Horizon being consistent with available viewpoints" (Muzylev *et al.*, 1996, p. 42). The regression peak of the first cycle corresponds to the pre-Sumsar hiatus. The second (Sumsar) cycle is reduced, represented by transgressive half-cycle only (calcareous clays with abundant nannoplankton), and its regressive part is consumed by the pre-Massaget hiatus. Muzylev and his colleagues correlated the mentioned half-cycle with the late Priabonian (Lattorfian) eustatic transgression. The same situation is established in the Aral–Turgai region of the Turan plate, where the regressive half-cycle of the Chegan sedimentary cycle is also reduced, and Eocene assemblages of foraminifers and dinocysts are close in composition to Central Asian and West Siberian counterparts.

In this connection, we should remind that second (late Tavda) sedimentary cycle is actually represented in studied sections of West Siberia by the lower transgressive part, while the regressive half-cycle corresponds either to the Kurgan Beds (if they are deposited during the quick shoaling of the Tavda basin) or to the pre-Atlym hiatus. Anyway, the uniform eustatic trends and great similarity between the Tavda and Rishtan–Sumsar biotas suggest definitely, as we think, the late Eocene age for the upper Tavda Subformation. In other words, the interregional correlation supports conclusions based on studied fossil groups, which are less dependent on the facies control (Elasmobranchii, dinocysts, spores, pollen, fructifications of terrestrial plants, and some ostracodes).

## REGIONAL CONSIDERATIONS AND ANALYSIS OF MARINE PALEOGENE SECTIONS IN THE BARABINSK LITHOLOGIC-FACIES ZONE (DRILLING RESULTS OF 1950–1970)

Now, after discussion of age problems, we should understand to what extent biostratigraphy of studied sections is applicable to other areas of the Barabinsk and surrounding Ishim, Central, Narym, Ob, Kulunda and Pavlodar lithologic-facies zones, where deposits of the Lyulinvor and Tavda formations are widespread (*The Unified…*, 2001). First, we should consider data on nearby boreholes, which penetrated throughout the Paleogene sequence in these zones.

In the Barabinsk zone of West Siberia, profiles and network of exploration and Craelius drilling with associated logging was in progress since the 1950s. A series of boreholes drilled in the Tatarskoe, Ipatovo–Svetlinskaya, Fedorovskaya, Burlinskii and other exploration areas elucidated the correlation potential of lithostratigraphic boundaries detectable in logs. Dozens of boreholes, which penetrated down to the top of Mesozoic sequence and deeper (Omsk, Barabinsk, and other sites), have been sampled and studied in detail (paleontological analysis included) and can be regarded as the Paleogene reference sections. Analyzing drilling results published in the 1950s and 1960s, we should bear in mind some necessary corrections. For instance, we place the bed of glauconite sand (the logging marker "T" between the Lyulinvor and Tavda formations) at the base of the Tavda Formation, as it was done by Martynov (1967, 1968, 1973), Zal'tsman (1968) and Shatskii (1978), although earlier, in 1955–1965, it was regarded as terminal bed of the Lyulinvor Formation. In general, ages of lithostratigraphic units were based at that time on a few groups of fossils, and elaboration of zonal scales for most informative groups just started. T.F. Vozzhennikova did only first steps toward a comprehensive investigation of organic-walled phytoplankton. Stratigraphic significance of planktonic foraminifers and Elasmobranchii was underestimated, and main attention was paid to benthic foraminifers, siliceous microplankton, ostracodes, and palynomorphs of terrestrial plants. Facing the undeveloped state of the general stratigraphic scale for Paleogene, where even subseries ranges were inadequately substantiated, paleontologists referred in their works to subdivisions of the regional scale authorized for the Crimea–Caucasus region. In particular, they correlated the greater part of Lyulinvor Formation with the Bodrakian regional stage and thus attributed it to the upper Eocene. As is known now, this stage corresponds to the middle Eocene, i.e., to the Bartonian and partly Lutetian stages (the Kuberle Horizon at least). Accordingly, we had to correct the

**Table 2.** Principal characteristics of the marine Paleogene sections recovered by reference boreholes in the Barabinsk lithologic-facies zone of the West Siberian plate

| Position of markers and thickness of lithostratigraphic units | Boreholes | | | |
|---|---|---|---|---|
| | 2 | 3 | 4 | 5 |
| Depth to the Tavda Formation top, m | 274 | 254 | 317 | 299 |
| Depth to the Tavda Formation base and thickness of basal sand bed (logging marker "T") | 435<br>426–435 / 9 | 443<br>436–443 / 9 | 475<br>465–475 / 10 | 434<br>432–434 / 2 |
| Thickness of the Tavda Formation, m | 162 | 189 | 158 | 165 |
| Depth to the horizon "B" between lower and upper Tavda subformations (after Gurari, Martynov, Shatskii and others) and its thickness, m | ? | 354.3–358 / 3.7 | 400–404 / 4 | 360 / ? |
| Depth to the horizon "B" and its thickness (m) in the lower part of the Tavda Formation (after Zal'tsman, 1968) | ? 388.3–388.5 / 0.5 | 406.2–410.4 / 4.2 | Not detected | Not detected |
| Depth to the base of upper Lyulinvor Subformation; presence (+) of basal horizon of glauconite sand and its thickness, m | +<br>491–492.5 / 1.5 | +<br>497–499.75 / 2.76 | 547 / ? | 480 / ? |
| Thickness of the upper Lyulinvor Subformation | 57 | 54.5 | ? 80 | 46 |
| Depth range and thickness (m) of green clay member of the upper Lyulinvor Subformation | 450.9–449.9 / 1.0 | 461–466 / 5.0 | 481–496 / 15 | ? |
| Depth range and thickness (m) of sand interlayers inside the green clay member | 447.5–448 / 0.5 | Not detected | Not detected | Not detected |
| Presence of fish remains (+) and diatoms of the *Pyxilla oligocaenica* var. *tenuis* Zone (x) in the green clay member | +<br>x | +<br>x | ?<br>? | ?<br>? |
| Depth range and thickness (m) of glauconite-sand bed at the base of lower Lyulinvor Subformation | 519–521 / 2 | 575–575.15 / 2.15 | 598 / ? | 512–522 / 1 |
| Recovery range and thickness (m) of lower Lyulinvor Subformation | 499.5–521 / 28.5 | 497.5–575.15 / 79.65 | 547–597 / 50 | 480–522 / 42 |
| Total thickness of Lyulinvor Formation, m | 86 | 132 | 130 | 88 |
| Depth range and thickness (m) of the Talitsa Formation | Unknown | 575–591 / 16 | 597–607 / 10 | Unknown |
| Depth to the top of Mesozoic Gan'kino Formation, m | 521 | 591 | 607 | 522 |

former understanding of litho- and biostratigraphic subdivisions of the Paleocene, lower and, especially, upper Eocene.

The issues we paid attention to during comparison and consideration of our results in the regional aspect were as follows:

(1) Relationships between the Cenozoic base and underlying Mesozoic deposits, the Gan'kino Formation included;

(2) Presence or absence of the Talitsa Formation in the southeast of West Siberia;

(3) Erosion marks in sediments underlying the horizon of glauconite sandstone with phosphorites, the basal one in the lower Lyulinvor Subformation;

(4) The same characters near the base of the upper Lyulinvor Subformation;

(5) Interlayers of sandy–silty glauconite-bearing sediments at the base of green clay member of the "Chegan" type (Nyurol'ka Formation s. str. after Shatskii), which are detectable in some logs (e.g., Borehole 9) and separate that member from the main upper Lyulinvor sequence composed of gray opoka-like and diatomaceous clays; their presence is significant therefore in view of hiatus at the Ypresian–Lutetian boundary level established in Borehole 9;

(6) Logging markers, which may correspond to similar interlayers inside the green clay member, and their correlation with breaks in sedimentation like the one found in section of Borehole 9;

| Boreholes | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 10 | 11 | 9 | 12 | 7 | 8 |
| 292 | 268 | 308 | 305 | 254 | 273 | 35 |
| 394 | 360 | 468 | 485 | 352 | 367 | 104.5 |
| 388–394/6 | 352–360/8 | 464–468/4 | 472–485/13 | 344–352/8 | 360–367/7 | 101.5–104/2.5 |
| 102 | 92 | 160 | 180 | 98 | 94 | 64.5 |
| 322.5–328.1/5.6 | ? | 307–309/2 | 388–390/2 | 274–285/11 | 307–309/2 | 67.5–68.5/1 |
| Not detected | 326–331/5 | 423–427/4 | ? | 313–315/2 | 333–336/3 | ? |
| | + | | | | + | + |
| ?/– | 378–380/2 | 492/? | ? | ? | 389–390/1 | 147–148.3/1.3 |
| ? 43 | 20 | 24 | ? | 35 | 23 | 43.8 |
| 409.5–414.8/5.3 | 370/? | 478–480/2 | 503–506/3 | 362.5–363/0.5 | ? | 111–112.5/1.5 |
| Not detected | Not detected | Not detected | Not detected | Not detected | Not detected | Not detected |
| + | + | ? | ? | + | ? | + |
| ? | ? | ? | ? | x | x | x |
| 464/? | 378–380/2 | 544–542/2 | 575–580/5.0 | 400–405/5 | 417–419/2 | 160.5–161/0.5 |
| 437–464/27 | 380–411/31 | 492–544/52 | Not detected | 387–400/13 | 30–419/29 | 148.3–161/12.7 |
| 70 | 51 | 76 | 95 | 53 | 52 | 56.5 |
| 464–468/4 | Unknown | 544–551/7 | Unknown | Unknown | Unknown | Unknown |
| 468 | 411 | 551 | 580 | 405 | 419 | 161a |

(7) Data on coarser grain size in topmost strata of the upper Lyulinvor Subformation, as they indirectly suggest the basin shoaling, and on beds with diatoms of the *Pyxilla gracilis* var. *oligocaenica* Zone, radiolarians of the *Lychnocanium separatum* assemblage, and dinocysts replacing taxa of the *Charlesdowniea clathrata* s.l. Zone;

(8) Fish remains and planktonic foraminifers, if they present in the green clay member and may be regarded therefore as additional correlation criterion;

(9) The lateral extent of the first sandy horizon at the Tavda Formation base (logging marker "T") and indications of hiatus below this level;

(10) The lateral extent of sandy horizon (logging marker "B") inside the Tavda Formation, which was discriminated first by F.G. Gurari and then by Martynov and Shatskii, being regarded as the boundary level between two subformations;

(11) Data clarifying age of upper Tavda horizons and indications suggesting the transgressive character of the uppermost clay member.

We analyzed the necessary information compiling data on well-documented reference boreholes, those of the Barabinsk and Omsk sites included, and summary of collected materials is presented in Table 2. Geographic localities of boreholes we referred to are shown in Fig. 1.

Like geologists who mapped the region, we divide the Lyulinvor Formation of the Barabinsk zone not in three, but in two subformations, and this approach is acknowledged in the Unified regional stratigraphic scheme of 2001. It was easy therefore to compare lithostratigraphic units of studied boreholes 9 and 011BP with correlative subdivisions discriminated by Martynov (1967, 1968, 1973) and Zal'tsman in the south of the West Siberian plate, as one can see from information on above issues (Table 2), especially on those numbered 1–4 and 9.

Let us consider first the problem of Talitsa Formation in the Barabinsk and adjacent zones. As is clear from Table 2, thin sequences comparable with that formation can be discriminated in sections of the Omsk, Barabinsk, and Tatarskoe reference boreholes in the northernmost area of the zone. Zal'tsman (1968, p. 14) tentatively discriminated the Talitsa Formation at the base of the Paleogene in Borehole 32, the village of Mikhailovka of the northern Kulunda area. His decision was misleading, as we think, because the corresponding 7-m-thick member (core recovery 1.2 m only) is composed of alternating shales and siltstones, which are lacking marine fauna and yield plant remains only. Similar continental deposits are widespread along periphery of the West Siberian depression, e.g., in the Zaisan basin, where they are of the same composition and yield Danian flora of the Tsagayan type. Palynological spectrum of Danian beds in that basin (*Practical Palynology*, 1990) is identical to spectra characteristic of continental terrigenous deposits penetrated by boreholes in northern and eastern flanks of the Kazakh Upland (Kopytova *et al.*, 1960; Antypko, 1962; and others). In dozens of other boreholes drilled in the Barabinsk (central and southern areas) and Kulunda zones, the Lyulinvor Formation rests directly on the eroded surface of Cretaceous deposits. It seems that the Talitsa sea occupied only a narrow boundary territory between the Barabinsk and Central zones. In southern areas of the Central zone, e.g., in the Tar reference section, the Talitsa Formation of little thickness is composed of typical marine sediments.

The limited size of the Talitsa sea predetermined transgressive onlap relations between the basal coarse-clastic horizon of glauconite-phosphorite sandstone of the lower Lyulinvor Subformation and underlying Cretaceous deposits. As one can see from Table 2, this horizon has been penetrated by all reference boreholes without exception. Even if the proper interval has not been sampled, the horizon is clearly detectable in logs. It has been penetrated everywhere in the junction area of the Barabinsk and Kulunda zones at the depths of 523 and 500 m in boreholes 3 and 23, Trofimovka area, at the depth of 510 m in Borehole 123, Berezovka area (50 km southward of Borehole 9), and in Borehole 111, Zhelezinka area, the Irtysh River right side. Boreholes of southern Pavlodar–Kulunda profile (Uspenka 35, Kulunda 14, Efremovka 185 and 48) and those situated in central and eastern Kulunda areas (Alekseevka, Acyamovo, Slavgorod and other sites) also proved presence of the basal sandy horizon under consideration. Martynov (1973) and Zal'tsman (1968) showed that the Lyulinvor Formation base overlies in places Maastrichtian or upper Campanian strata of the Gan'kino Formation and even lower Campanian horizons (Slavgorod Formation), as in central Kulunda areas, for instance. Characteristic of the Lyulinvor Formation itself is persistent alternation of dark-colored opokas, siltstones and sandstones of quartz–glauconite type, which is established everywhere.

In the Trans-Urals zone of West Siberia, the Thanetian age of the Serov Formation (age analogue of the lower Lyulinvor Subformation) is convincingly substantiated based on siliceous microplankton and dinocysts, whereas palynofloras played in contrast the prime role in correlation and age determination of host deposits in southeastern lithologic-facies zones. The studied dinocysts from Borehole 9 proved for the first time the Thanetian age of the lower Lyulinvor Subformation and showed that our colleagues rightfully regarded this subdivision as concurrent in age to the Serov Formation.

In distinction from lower subformation, discrimination of middle and upper subdivisions of the Lyulinvor Formation was always problematic. In the Barabinsk zone, where formation was divided in two subformations, its terminal green clay member was included into the upper Lyulinvor Subformation together with underlying member of gray opoka-like clay and mudstones, as it is done, for instance, in documentation of core samples from boreholes 9 and 011BP. In northerly areas, closer to the Vasyugan River basin, the upper subformation included the terminal member only, while the underlying gray beds (diatomaceous opoka-like clay, mudstones, and opokas) were attributed to the middle subformation (Kriventsov, 1984). In addition to formerly different nomenclature of the same lithostratigraphic units, we should also mention that there are coarse-grained horizons and erosion marks below them at basal levels of the upper Lyulinvor Subformation (as it is ranked in the Barabinsk zone) and its terminal member. Beds of this kind are often detectable also in borehole logs, as one can see in Table 2. Similar data are known as well in southern and northern areas of West Siberia (Martynov, 1967, 1968, 1973; Zal'tsman, 1968; Antypko, 1962; Dergachev and Lysenko, 1984). Because the green clay member penetrated by Borehole 9 yielded planktonic foraminifers, it is appropriate to mention here data elucidating the character of contact between this unit and underlying gray diatomaceous and opoka-like clays in the Vasyugan River basin, the stratotype area of the Nyurol'ka Formation distinguished by Shatskii. After geological survey in this area (Nyurol'ka and Chizhapka rivers, Ob River left tributaries upstream of the Vasyugan River mouth), Kriventsov (1984, p. 89) wrote: "The upper Lyulinvor sequence (Nyurol'ka Formation after Shatskii) is composed of clay that is greenish gray when naturally wet to greenish yellow in dry state, compact or platy, with finest laminae of silt, mica, or microscopic plant detritus. At the contact with underlying deposits, there are erosion marks, laminae of sand, separate quartz pebbles and clay pellets." He observed the same peculiarities in sections of boreholes 5k and 45p drilled in the Chuzik River basin and was first to note that the marine Paleogene sequence is of maximum thickness (over 300 m) precisely in the Nyurol'ka depression. Considering arguments in favor of hiatus below the base of green clay member, we should bear in mind as well the two points of interest. First, development of transgression usually results in erosion of basal transgressive facies and contact with underlying sediments may correspond to a cryptic hiatus, and second, sandy beds of insignificant thickness may be washed out by drilling and removed from borehole by flushing. Nevertheless, many logs show that originally they were in the sequence. Thus, the discrete age of green clay member and indications of erosion at its base may be taken for arguments in favor of rehabilitation of the Nyurol'ka Formation.

Situated at the Tavda Formation base, glauconite sand and sandstone beds with erosion marks below them (logging marker "T") are widespread in southern areas of West Siberia (see Table 2), especially in the marginal plate zone adjacent to fold structures of Kazakhstan, Altai, and the Salair Range. Borehole 3 near the village of Trofimovka (Kulunda zone) penetrated bed of this kind, which is 10 m thick, and similar beds were detected at the Kulunda, Slavgorod, and other sites (Zal'tsman, 1968). Numerous boreholes drilled in Central and Narym zones outlined distribution areas of the Tavda basal sands in the Ob–Irtysh interfluve and Vasyugan River basin (Shatskii *et al.*, 1973; Kriventsov, 1973, 1984). Deposition of these coarse-grained sediments postdated shoaling of the Lyulinvor basin, which is evident from changes in diatom and dinoflagellate assemblages and from mass abundance of acritarchs and prasinophytes (*Paucilobimorpha, Micrhystridium*) at the corresponding level. The basin remained shallow until the commencement of the early Tavda transgression. The Lyulinvor–Tavda transition is not uniform over West Siberia. In the Central zone, it is gradual, demonstrating transition from green clay beds to the so-called Taichi member (Martynov, 1973) of alternating sandstones, siltstones and shales, and then again to clay beds prevailing in the Tavda sequence. In places, break in sedimentation was insignificant, and Lutetian regressive beds (green clays) of the Lyulinvor sedimentary cycle are preserved in the sequence to a considerable extent (Borehole 9). In other cases nevertheless, these beds are eroded completely or almost completely (Borehole 011BP), and the basal sandstone bed of the Tavda Formation directly overlies the gray member of diatomaceous clays. In marginal areas of the West Siberian basin, the pre-Tavda hiatus can be larger, corresponding in range to two microplankton zones (Iakovleva, 1999).

## OCEANIC INFLUENCE ON SEDIMENTATION IN THE WEST SIBERIAN INNER SEA

Complicated relationships between the Lyulinvor and Tavda formations originated in response to changeable hydrological and sedimentation regimes in the West Siberian basin. The Ypresian period of accumulation of gray diatomaceous and opoka-like clays of the upper Lyulinvor Subformation corresponded to the time, when sedimentation was under great influence of arctic waters and the inner sea was connected with the World Ocean. This is evident from organogenic opal present in sediments depleted in the heavy mineral fraction.

During the early Lutetian, when accumulation of the green clay member commenced, biota and sedimentation in the basin experienced influence of both the northern and southern oceanic waters, as the basin was of maximum size at that time of the high sea-level stand in the World Ocean. Later on, when effect of arctic waters became weaker, influence of the Tethys increased, and planktonic foraminifers appeared in the basin. In addition, the growing impact of southern connections conditioned participation of carbonate components in sedimentation, decrease and subsequent disappearance of organogenic opal from sediments, which became enriched in glauconite, chlorite, and epidote responsible for their green coloration. The arctic influence completely ceased in the Bartonian time, especially in southern areas of the plate, as it is recorded across the Lyulinvor–Tavda boundary. Tethyan waters influenced sedimentation of this time not so intensely as well, because the late Eocene was a period of general sea-level drop in the World Ocean. Two transgressions of the Tavda period advanced however from the south, and both caused increase of sedimentation rates and higher contents of chlorite and epidote in sediments. These indications suggest a noticeable shoaling of the basin rather than crustal subsidence, and compensated sedimentation reduced the basin depth from hundreds to a few dozens of meters in average. The much lower "offshore distance coefficients" calculated for respective palynological spectra are indirect arguments in favor of this process.

The logging marker "B" and corresponding layer of glauconite sand between the lower and upper Tavda subformations can be diachronous in different lithologic-facies zones, as the marker is at a lower stratigraphic position in southern sections. At the same time, the Tavda Formation is of a distinct three-member structure in southeastern areas of the West Siberian plate, especially in the Kulunda zone, where its lower and upper transgressive clay beds are separated by the middle member of siltstones deposited in shallow settings, as established in sections of boreholes 9 and 011BP. In the eastward direction, these shallow-water sediments grade into continental coaliferous deposits. Farther to the east, rocks of the Tavda formation are completely replaced by continental sediments of the Yurkovo Formation. In their interpretation of the above facies trend, Gurari and Shatskii suggested that after the middle member continental deposits of eastern areas replace clays of the lower Tavda Subformation and all sediments constitute here a single continental sequence. In their opinion, closer to the west the formation is of the two-members structure with a thin wedge of upper transgressive clays, which pinch out in easterly areas. The contact between clays of the upper Tavda Subformation and overlying gray sandy–silty deposits of the Isil'kul (Atlym) Formation is of a distinct transgressive type, indicative of erosion below it, and the subformation is represented in studied sections by its transgressive half-cycle only.

## CLIMATE

Paleocene and Eocene climatic fluctuations in southern areas of West Siberia depended on global and regional factors. The latter, i.e., the character of the inner epicontinental sea connections with the Arctic and Tethyan oceanic basins controlled the paleotemperature and humidity fluctuations, the annual precipitation trends included. Indicators of relatively high temperature of near-surface waters in the sea, especially during the early Eocene, are the high diversity of microplankton, foraminifers of genera *Acarinina* and *Hantkenina*, which are found in sediments and characteristic of the Earth subtropical areas, some radiolarians also typical of these areas (e.g., species of the *B. clinata–B. longa* Zone), and chorate cysts prevailing in phytoplankton. The latter dwell in seas, where temperature of the upper photic zone is up to 20°C. Terrestrial vegetation is even more sensitive to climatic changes. As is known for a long time, palyno- and macrofloras from marine or alternating marine and continental Paleogene strata of the study region include several groups of dominant taxa, which successively replace one another in the section and have been used to denote the respective zonal assemblages. For instance, Fagaceae pollen of the *Castanea crenataeformis–Castanopsis pseudocingulum* palynozone is very abundant in the late Ypresian–Lutetian strata. In Bartonian deposits, Fagaceae are of another taxonomic composition, and pollen of above palynozone occurs in association with smaller pollen of oaks of the *Quercus gracilis–Quercus graciliformis* group. The Priabonian sediments yield only pollen of the last group.

The same succession of generic taxa is characteristic of macrofloras from the Pavlodar area. Here, the Ypresian–early Lutetian Karasor flora with dominant broad-leaved *Castanopsis* and Lauraceae forms gives way upward to Bartonian Takyrsor, Zhamantuz and other xeromorphic subtropical floras, in which small-leaved sclerophyllous oaks are dominant taxa (Makulbekov, 1972, 1997; Akhmet'ev *et al.*, in press).

In the present-day vegetation cover, *Castanea* and especially *Castanopsis* forms (over 100 species in total) are widespread in tropical and subtropical areas, mainly in Southeast Asia with its monsoon climate and precipitation maximum in summer time (Burma, Vietnam, southern and southeastern China, southern Japan). Recent counterparts of sclerophyllous oaks are also characteristic of seasonal climatic areas, though of the Mediterranean type in this case, with precipitation peaks during the winter season. Besides the Mediterranean, oaks of this kind are widespread in the southwestern United States and adjacent areas of Mexico. The monsoon climate of the early Eocene developed in the study region because of through connections between the Tethys and Arctic ocean via the Turgai strait and West Siberian sea. Hindering of connections in the terminal Lutetian and earliest Bartonian gave rise to a wide development of xeromorphic sclerophyllous oaks in the vegetation cover. By the terminal Bartonian and in Priabonian, when the West Siberian sea was completely isolated from the Arctic Ocean, the Mediterranean climate replaced the former one with summer monsoons. At that time, the West Siberian basin looked like a giant gulf extending far northward from the Tethys marginal zone.

An insignificant mid-Priabonian cooling determined a higher percentage of coniferous, Betulaceae, and Juglandaceae pollen in palynological spectra. The reduced content of gymnosperm pollen in the upper 30-m-thick sequence of the Tavda Formation in Borehole 9 and concurrent abundance growth of evergreen deciduous angiosperm taxa of thermophilic affinity imply that subsequent annual temperature increase of 2–3°C was connected with transgression of the late Tavda time, when climate became more humid. The respective period of subtropical climate lasted until the end of Eocene.

## CONCLUSION

(1) Two reference boreholes drilled in the Barabinsk lithologic-facies zone penetrated through the marine Paleogene sequence of the West Siberian plate. Biostratigraphy of the recovered core sections was studied based on different fossil groups, magnetostratigraphic data, and results of electric and gamma logs. The distinguished biostratigraphic units of a high correlation potential add details to former stratigraphic schemes and characterize a series of isochronous levels traceable within and outside the West Siberian plate.

(2) Formerly, the Paleocene–Eocene sedimentation in the study region was regarded as uninterrupted, but we established several stratigraphic hiatuses, which may be related to displacements of basement blocks and eustatic fluctuations. The partial erosion of sediments took place in periods, when sedimentation regime in the West Siberian inner sea changed under influence of oceanic water masses located northward and in the south.

(3) The nannoplankton assemblage characteristic of the Gan'kino Formation upper strata is discovered for the first time in West Siberia. Planktonic foraminifers of genera *Acarinina*, *Hantkenina*, and *Turborotalia* are found at several stratigraphic levels in association with radiolarians, organic-walled phytoplankton, and palynomorphs of higher plants. Based on concurrent

assemblages of different fossil groups, we clarified and substantiated age of the green clay member with fish remains. Accumulation environments of this member crowning the upper Lyulinvor Subformation are elucidated. The Bartonian age of most typical marine facies of the lower Tavda Subformation is approved.

(4) Erosion surfaces established at the base and top of the green clay member of the upper Lyulinvor Subformation bring forward a problem of rehabilitation of the former Nyurol'ka Formation.

(5) Sea transgressions of eustatic origin and greatest amplitude took place in the Ypresian, middle Lutetian, late Bartonian, and late Priabonian. The Ypresian and Lutetian transgressions advanced in counter manner from the Tethys and Arctic Ocean. The Arctic influence on sedimentation dominated in the Ypresian and the Tethyan one in the Lutetian, as it follows from biogeographic analysis of different fossil groups. Transgressions and sea currents were interrelated. Throughout the Eocene, the southwestern part of the plate was within zone of the warm southern stream via the Turgai strait (Akhmet'ev *et al.*, 2001). That is why the most thermophilic and diverse assemblages of siliceous and organic-walled microplankton were found in association with planktonic foraminifers at several levels of the Lyulinvor and Tavda formations of the Barabinsk structural-facies zone. The basin shoaling in the early Bartonian and at the end of the Lyulinvor time antedated the commencement of sedimentation of the Tavda period.

(6) Stages of a considerable basin shoaling (terminal Thanetian, late Lutetian–early Bartonian, and Priabonian) are recorded at the levels of mass abundance of prasinophytes and acritarchs, where abundance and diversity of dinocysts is simultaneously reduced and the offshore distance coefficients are low. Shoaling of the mid-Tavda time was accompanied by freshening in the near-surface water layer. This event is evident from appearance of thin-walled *Hystrichokolpoma*, abundant spores *Hydropteris indutus* and *Azolla*, and infrequent *Pediastrum* specimens.

(7) We managed to determine age and to establish limitations of two transgressive–regressive sedimentary cycles of the Tavda Formation. The upper one is reduced and represented by the transgressive half-cycle only.

(8) In organic-walled phytoplankton of the Tavda Formation, the increase of abundance and diversity of cavate cysts is accompanied by growing content of endemic taxa. This is a consequence of climatic zoning and progressing basin isolation (in regressive phases especially) from oceans. Freshening of surface waters was also favorable for intense development of prasinophytes and acritarchs.

(9) In all transgressive members of the studied sections, there is microplankton redeposited from older strata. Cretaceous and even Jurassic radiolarians have been encountered in gray opoka-like clays of the upper Lyulinvor Subformation, Paleocene dinocysts in the green clay member of the same subformation, and Paleocene–early Eocene phytoplankton in transgressive clay member of the Tavda Formation.

(10) In southern areas of West Siberia, climatic fluctuations depended on changeable connections between the inner sea and adjacent oceans. Important in paleoclimatic aspect are palynological data on distribution of Fagaceae pollen in Ypresian–Lutetian deposits, primarily of taxa from *Castanopsis, Castanea*, and *Quercus* groups, because their geographic ranges are now under strict climatic control. According to these data, climate of the terminal Ypresian–Lutetian period in the study region was, like everywhere in middle latitudes of the former USSR except for the Far East, subtropical, of the monsoon type, with precipitation peaks in summer seasons. In the Bartonian and Priabonian, when the West Siberian sea lost connections with the Arctic Ocean, climatic conditions resembled those of the present-day Mediterranean region, where the precipitation maximum is characteristic of the winter period.

## ACKNOWLEDGMENTS

We are grateful to I.A. Goncharova and S.V. Popov (Paleontological Institute RAS) for identifications of mollusks from the Tavda Formation. The work was supported by the Russian Foundation for Basic Research, project nos. 00-05-64917, 01-05-64320, 00-15-98490 ("Leading Scientific Schools"), 02-05-65170, and 02-05-64787.

Reviewers I.A. Basov and V.S. Popov

## REFERENCES

1. M. A. Akhmet'ev, G. N. Aleksandrova, E. O. Amon, *et al.*, "Biostratigraphy of the Marine Paleogene in the West Siberian Plate," Stratigr. Geol. Korrelyatsiya **9** (2), 30–57 (2001) [Stratigr. Geol. Correlation **9**, 132–158 (2001)].
2. M. A. Akhmet'ev, G. N. Aleksandrova, V. N. Beniamovskii, *et al.*, "New Data on the Marine Paleogene of the Southwestern Siberian Plate, Paper 1," Stratigr. Geol. Korrelyatsiya **12** (1), 68–95 (2004) [Stratigr. Geol. Correlation **12**, 58–84 (2004)].
3. M. A. Akhmet'ev, N. I. Zaporozhets, and N. M. Makulbekov, "The Eocene Fossil Plants, Spores, Pollen, and Dinocysts from the Tavda Formation, the Pavlodar Area near the Irtysh River," Stratigr. Geol. Korrelyatsiya **12** (2), 64–71 (2004) [Stratigr. Geol. Correlation **12**, 167–174 (2004)].
4. A. S. Andreeva-Grigorovich, Doctoral Dissertation in Geology and Mineralogy (Kiev, 1991).
5. B. E. Antypko, "Continental Paleogene and Neogene Deposits in Petropavlovsk Area near Irtysh River," in *Collection of Works on Geology and Hydrogeology* (Gosgeoltekhizdat, Moscow, 1962), pp. 35–51 [in Russian].
6. V. N. Beniamovskii, O. N. Vasil'eva, A. P. Levina, and V. G. Pronin, "The Paleogene of Southern Trans-Urals,

Paper 2: Paleogene in Central to Northern Turgai Depression and Kurgan Area," Izv. Vyssh. Uchebn. Zaved., Geol. Razved., No. 2, 2–15 (1995).

7. W. A. Berggren, D. V. Kent, C. C. Swisher, and M.-P. A. Aubry, "A Revised Cenozoic Geochronology and Chronostratigraphy," SEPM Spec. Publ. **54**, 129–212 (1995).
8. E. P. Boitsova *et al.*, "Methodical Problems of Correlating Diverse Facies in the Turgai Depression, Southwest Siberian Lowland, Ustyurt, Aral and Fergana regions," Tr. Vses Geol. Inst., Novaya Ser. **143**, 37–44 (1968).
9. H. Brinkhuis and P. Schøler, "Palynology of the Geulhemmerberg Cretaceous/Tertiary Boundary Section (Limburg, SE Netherlands)" Geol. en Mijnbouw, Netherlands, **75** (2/3), 193–213 (1996).
10. N. K. Bykova, "Foraminifers from Upper Cretaceous and Paleogene Deposits of the Fergana Valley," Tr. Neft. Geol.-Razved. Inst. **121**, 3–39 (1939).
11. C. Cavellier and Ch. Pomerol, "Echelle de correlation stratigraphique du Paleogene Stratotypes, etages standarts, biozones, chemozones et anomalies magnetiques," Geol. France, No. 3, 261–262 (1986).
12. J. J. Chateauneuf and C. Gruas-Cavagnetto, "Les zones de Wetzeleillaceae (Dinophyceae) du bassin de Paris. Comparaison et correlations aves les zones du Paleogene des bassins du Nord-Ouest de l'Europe," Bull. BRGM. Ser. 2 **IV** 59–93 (1978).
13. L. I. Costa and S. B. Manum, "The Description of the Interregional Zonation of the Paleogene (D1–D15) and the Miocene (D16–D20). The Northwest European Tertiary Basins. Results of the International Geological Correlation Program. Project 124," Geol. Jahrb. **A100**, 331–339 (1988).
14. G. Dam and H. Nohr-Hansen, "Mantle Plumes and Sequence Stratigraphy; Late Maastrichtian–Early Paleocene of West Greenland," Bull. Geol. Soc. Denmark **48**, 189–207 (2001).
15. V. A. Dargevich and A. G. Lysenko, "Eocene Paleogeography in Southeastern Areas of the West Siberian Plate," in *Environments and Life across Cenozoic Epoch Boundaries in Siberian and the Far East* (Nauka, Novosibirsk, 1984), pp. 78–81 [in Russian].
16. De Graciansky, P.-C. Handerbol, J. Jacquin, P.R. Vail, "Mesozoic and Cenozoic Sequence Stratigraphy of European Basins," SEPM Spec. Publ. **60** (1998).
17. *Geologic and Biotic Events of the Late Eocene–Early Oligocene in the Former USSR, Pt. 2: Geologic and Biotic Events* (GEOS, Moscow, 1998) [in Russian].
18. J. M. Hansen, "Dinoflagellate Stratigraphy and Echinoid Distribution in Upper Maastrichtian and Danian Deposits from Denmark," Bull. Geol. Soc. Denmark **26**, 1–26 (1977).
19. J. M. Hansen, "Dinoflagellate Zonation around the Maastrichtian–Danian Boundary," in *Cretaceous/Tertiary Boundary Events, I. The Maastrichtian and Danian of Denmark* Ed. by T. Birkelund and R.C. Bromley (Univ. of Copenhagen, Copenhagen, 1979), pp. 136–141.
20. C. Heilmann-Clausen, "Dinoflagellate Stratigraphy of the Uppermost Danian to Ypresian in the Viborg 1 Borehole, Central Jylland, Denmark," Geol. Unders., Ser. A, No. 7, 1–69 (1985).
21. G. F. W. Herngreen, H. A. H. M. Schuurman, J. W. Verbeek, *et al.*, "Biostratigraphy of Cretaceous/Tertiary Boundary Strata in the Curfs Quarry, the Netherlands," Med. Neder. Inst. Voor Toegepaste Geoweten. TNO, No. 61, 1–57 (1998).
22. A. I. Iakovleva, *Les dinoflagelles du Paleocene-Eocene de la Siberie occidentale et des regions avoisinantes: application stratigraphique, paleoecologique et palaeogeographique* (Univ. Montpellier, Montpellier, 1999).
23. V. I. Il'ina, I. A. Kul'kova, and N. K. Lebedeva, *Microfossils and Detailed Stratigraphy of Marine Mesozoic and Cenozoic in Siberia* (OIGGiM SO RAN, Novosibirsk, 1994) [in Russian].
24. K.-H. Kirsch, "Dinoflagellatenzysten aus der Obercreide des Helvetikums und Nordultrahelvetikums von Oberbayern," Munchner Geowiss. Abh. A **22**, 1–306 (1991).
25. E. N. Kisel'man, "Foraminiferal Assemblages from Paleogene Deposits in West Siberia," in *Paleogene and Neogene of Siberia (Paleontology and Stratigraphy)* (Nauka, Novosibirsk, 1978), pp. 41–51 [in Russian].
26. E. A. Kopytova *et al.*, "Stratigraphy of Jurassic, Cretaceous, and Tertiary Deposits in the Southern Irtysh Syneclise," in *Collection of Works on Geology and Hydrogeology* (Gosgeoltekhizdat, Moscow, 1960), pp. 3–66 [in Russian].
27. G. E. Kozlova, *Paleogene Radiolarians from Boreal Regions of Russia* (VNIGRI, St. Petersburg, 1999) [in Russian].
28. A. V. Kriventsov, "Marine Paleogene in the Eastern Ob–Irtysh Interfluve," in *Environments and Life across the Cenozoic Epoch Boundaries in Siberia and the Far East* (Nauka, Novosibirsk, 1984), pp. 87–92 [in Russian].
29. A. V. Kriventsov, "Paleogene Deposits in the Chipazhka River Basin," in *Marine and Continental Paleogene of Siberia* (Nauka, Novosibirsk, 1973), pp. 40–44 [in Russian].
30. R. Kh. Lipman and I. A. Nikolaeva, "Distribution of Microfauna in Some Sections of the Chegan Formation, Turgai Depression and Region North of Lake," in *The Maikop Deposits and Age Equivalents in Ukraine and Central Asia* (Naukova Dumka, Kiev, 1964), pp. 204–215 [in Russian].
31. R. Kh. Lipman and V. I. Romanova, "Stratigraphic Subdivision of Cretaceous and Paleogene Deposits Based on Microfauna from Tyumen Reference Borehole," in *Materials on geology and Mineral Deposits* (VSEGEI, Leningrad, 1955), pp. 135–140 [in Russian].
32. R. K. Makarova and L. V. Mironova, "Correlation between Marine Paleogene Deposits in Turgai, Aral Region, and Central Asia," in *General Problems of Stratigraphy and Biostratigraphy in Turgai and Central Asia* (Nedra, Leningrad, 1964), pp. 203–217 [in Russian].
33. N. M. Makulbekov, Doctoral Dissertation in Geology and Mineralogy (Moscow, 1997).
34. N. M. Makulbekov, *Eocene Flora from Northern Kazakhstan* (Nauka, Alma-Ata, 1972) [in Russian].
35. U. Marcheinecke, "Monographie der Dinozysten, Acritarcha und Chlorophyta des Maastrichtium von Hemmoor (Neidersachsen)," Palaeontographica Abt. B **227**, 1–173 (1992).

36. V. A. Martynov, "The Green Clay Horizon Corresponding to the Paleogene Transgression Maximum in the South-Southwest of West Siberian," in *Materials on Geology and Mineral Deposits in Novosibirsk Oblast* (Nauchtekhizdat, Novosibirsk, 1968), pp. 48–52 [in Russian].

37. V. A. Martynov, "Stratification of marine Paleogene Deposits in the South of West Siberian Plain," in *Marine and Continental Paleogene of Siberia* (Nauka, Novosibirsk, 1973), pp. 45–56 [in Russian].

38. V. A. Martynov, "Stratification of Paleogene Marine and Continental Deposits in the South of West Siberian Lowland," in *New Data on Geology and Mineral Deposits of West Siberia* (Tomsk Gos. Univ., Tomsk, 1967), pp. 78–88 [in Russian].

39. D. C. Mudge and J. P. Bujak, "Eocene Stratigraphy of the Northern Sea Basin," Marine Petrol. Geol **11** (2), 166–181 (1994).

40. N. G. Muzylev and G. Kh. Salibaev, "Ages of Some Paleocene and Eocene Horizons of the Tajik Section as Implied by Nannoplankton," Izv. AN TadzhSSR, Otd. Fiz.-Mat., Khim. Geol. Nauk **100**, 91–93 (1988).

41. N. G. Muzylev, U. M. Rasulov, I. E. Khokhlova, and A. R. Kushakov, "The Upper Eocene of the Fergana Depression and Adjacent Regions," Stratigr. Geol. Korrelyatsiya **4** (2), 38–45 (1996) [Stratigr. Geol. Correlation **4**, 141–147 (1996)].

42. I. A. Nikolaeva, "Changes in Ostracod Assemblages Across the Eocene–Oligocene Boundary," in *Climate and Faunas of the Cenozoic* (ZIN AN SSSR, Leningrad, 1985), pp. 74–81 [in Russian].

43. L. A. Panova, Candidate's Dissertation in Geology and Mineralogy (Leningrad, 1967).

44. L. A. Panova, N. S. Gromova, and E. Yu. Maligonova, "Palynostratigraphy of Paleogene Deposits," in *Practical Palynostratigraphy* (Nedra, Leningrad, 1990), pp. 149–179 [in Russian].

45. V. M. Podobina, *Foraminifers and Biostratigraphy of the Paleogene in West Siberia* (Nauchno-Tekh. Lit., Tomsk, 1998) [in Russian].

46. *Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions* (VSEGEI, Leningrad, 1989), No. 24 [in Russian].

47. A. J. Powell, "Dinoflagellate Cysts of the Tertiary System" in *A Stratigraphic Index of Dinoflagellate Cysts* (Chapman and Hall, London, 1992), pp. 155–252.

48. *Practical Palynology*, Ed. by L. A. Panova, M. V. Oshurkova, and G. M. Romanovskaya (Nedra, Leningrad, 1990) [in Russian].

49. N. V. Rubina, "Paleontological Substantiation of Stratigraphy of Marine and Continental Paleogene–Neogene Deposits of the West Siberian Lowland," in *Marine and Continental Paleogene of Siberia* (Nauka, Novosibirsk, 1973), pp. 87–95 [in Russian].

50. G. Kh. Salibaev, "Assemblages of Molluscan Species from the Turkestan Horizon and Age Equivalents in Central Asia," Sov. Geol., No. 3, 104–111 (1982).

51. P. Schøler and G. J. Wilson, "Maastrichtian Dinoflagellate Zonation in the Dan Field, Danish North Sea," Rev. Palaeobot. Palynol. **78**, 321–351 (1992).

52. N. G. Sharafutdinova, "Dinocysts at the Maastrichtian–Danian Boundary in the Koshak Section (Mangyshlak)," Byull. Mosk. O–va Ispyt. Prir., Otd. Geol. **67** (2), 92–98 (1992).

53. S. B. Shatskii, "Main Problems of Paleogene Stratigraphy and Paleogeography in Siberia," in *Paleogene and Neogene of Siberia (Paleontology and Stratigraphy)* (Nauka, Novosibirsk, 1978), pp. 3–21 [in Russian].

54. S. B. Shatskii, L. V. Aleksandrova, V. A. Bogdashev, *et al.*, "Paleogene of Central Areas in West Siberia," in *Marine and continental Paleogene of Siberia* (Nauka, Novosibirsk, 1973), pp. 4–38 [in Russian].

55. H. Slimani, "Les kystes dinoflagelles du Campanien au Danien dans la region de Maastricht (Belgique, Pays-Bas) et de Turnhout (Belgique): biozonation et correlation aves d'autres en Europe occidentale," Geol. Palaeontol., No. 35, 161–201 (2001).

56. *Unified Regional Stratigraphic Schemes of Neogene–Paleogene deposits in the West Siberian Plain* (OIGGiM SO RAN, Novosibirsk, 2001) [in Russian].

57. T. V. Ushakova, "The Paleogene," in *Mesozoic and Cenozoic Stratigraphy of the West Siberian Lowland* (Gostoptekhizdat, Moscow, 1957), pp. 113–132 [in Russian].

58. V. A. Zakharov, Yu. N. Zanina, K. V. Zverev, *et al.*, *Stratigraphy of Upper Cretaceous Deposits in North Siberia (Ust-Yenisei Basin)* (OIGGiM SO RAN, Novosibirsk, 1986) [in Russian].

59. I. G. Zal'tsman, *Stratigraphy of Paleogene and Neogene Deposits in the Kulunda Steppe* (SNIIGGiMS, Novosibirsk, 1968) [in Russian].

60. N. I. Zaporozhets, "Lower Oligocene Palynology and Phytoplankton of the Northern Caucasus," Stratigr. Geol. Korrelyatsiya **1** (1), 128–136 (1993) [Stratigr. Geol. Correlation **1**, 128–136 (1993)].

61. N. I. Zaporozhets, "New Data on Eocene and Oligocene Stratigraphy of Severnye Ergeni (The South of the Russian Platform)," Stratigr. Geol. Korrelyatsiya **6** (3), 56–73 (1998) (Stratigr. Geol. Correlation **6**, 262–279 (1998)].

62. N. I. Zaporozhets, "Palynological Assemblages from the Middle Eocene Kuma Horizon and Its Age Analogues in Adjacent regions," Stratigr. Geol. Korrelyatsiya **9** (6), 83–103 (2001) [Stratigr. Geol. Correlation **9**, 83–103 (2001)].