Geological Society of America Special Papers

Early Paleogene transgressions: Stratigraphical and sedimentological evidence from the northern Peri-Tethys

E. P. Radionova, Vladimir N. Beniamovski, A. I. Iakovleva, N. G. Muzylöv, Tatiana V. Oreshkina, Ekaterina A. Shcherbinina and G. E. Kozlova

Geological Society of America Special Papers 2003;369;239-261
doi: 10.1130/0-8137-2369-8.239

Geological Society of America
Special Paper 369
2003

Early Paleogene transgressions: Stratigraphical and sedimentological evidence from the northern Peri-Tethys

E.P. Radionova*
V.N. Beniamovski*
Geological Institute of the Russian Academy of Sciences, Pyzhevsky, 7, Moscow 119017, Russia
A.I. Iakovleva*
Instituto de Geologia, UNAM, Ciudad Universitaria, Del. Coyacan Mexico D.T., 04510, Mexico
N.G. Muzylöv
T.V. Oreshkina*
E.A. Shcherbinina*
Geological Institute of the Russian Academy of Sciences, Pyzhevsky, 7, Moscow 119017, Russia
G.E. Kozlova*
All-Russian Petroleum Research Exploration Institute, Liteiny prospect, 39, St. Petersburg, Russia

ABSTRACT

Our study in lithologically diverse lower Paleogene deposits of the former southern USSR and West Siberia resolves three sedimentary provinces: (i) Southern (Crimea-Caucasus and Central Asia), dominated by biogenic calcareous sediments of the deepest basinal portions; (ii) Transitional (southern Russian craton and Turan plate), displaying calcareous and siliceous clayey deposits; and (iii) Northern (central Russian craton and West Siberian plate), showing biogenic siliceous and terrigenous-siliceous sediments of basinal margin. We used standard and regional scales based on seven microfossil groups (planktonic and benthic foraminifers, nannoplankton, radiolaria, diatoms, silicoflagellates, and dinocysts) to correlate various sediment facies among ~80 reference sections across the study area. Correlation was performed for the Transitional province, where the presence of both calcareous and siliceous facies affords the use of calcareous and siliceous planktonic and dinocyst scales with varying resolutions. Besides, in the Transitional province, we established regional sedimentary cycles corresponding to the late Thanetian, Ypresian, and late Lutetian–Bartonian. These cycles are traceable into the Northern province, enabling us to determine or refine ages of the sequences, and into the Southern province.

Each sedimentary supercycle falls into three units, often with hiatus at the base, correlatable to 3rd order eustatic cycles and featured by distinctive facies. The facies succession appears to reiterate through the upper Thanetian, Ypresian, and upper Lutetian–Bartonian cycles.

The lower units of each supercycle are composed of calcareous sediments rich in nannofossils and foraminifers and are traceable from the Southern province into the Transitional province, the late Lutetian unit extending as far as the Northern province.

*E-mail: Radionova—radionova@geo.tv-sign.ru; Beniamovski—ben@geo.tv-sign.ru; Iakovleva—iakovl@yahoo.com; Oreshkina—oreshkina@geo.tv-sign.ru; Shcherbinina—shcherbinina@geo.tv-sign.ru; Kozlova—ins@vnigri.spb.su.

Radionova, E.P., Beniamovski, V.N., Iakovleva, A.I., Muzylöv, N.G., Oreshkina, T.V., Shcherbinina, E.A., and Kozlova, G.E., 2003, Early Paleogene transgressions: Stratigraphical and sedimentological evidence from the northern Peri-Tethys, *in* Wing, S.L., Gingerich, P.D., Schmitz, B., and Thomas, E., eds., Causes and Consequences of Globally Warm Climates in the Early Paleogene: Boulder, Colorado, Geological Society of America Special Paper 369, p. 239–261.

The middle unit is high in organic matter in the Southern province and passes into terrigenous-siliceous sediments rich in radiolaria, diatoms, and dinocysts in the Transitional and Northern provinces. The upper unit is terrigenous-carbonate and, in places, terrigenous-siliceous in the Southern province, becoming terrigenous-siliceous and biogenic siliceous (spongolites, diatomites) in the Transitional and Northern provinces.

Calcareous plankton (lower unit) giving way to siliceous (upper unit) might record changes in basinal circulation due to Peri-Tethys communicating with the North Atlantic and/or Arctic. The sedimentary provinces shifted southward as the Peri-Tethys shrank and climate changed between the Thanetian and Bartonian.

INTRODUCTION

In the early Paleogene, the northeastern Peri-Tethys stretched from the present-day Caucasus in the south to the Baltic Sea in the European part of Russia, and its Asian part occupied the whole of West Siberia and reached as far south as present-day western Kazakhstan, Turkmenistan, and Uzbekistan. This vast region was a shelf area dominated by biogenic sedimentation of siliceous, calcareous, and mixed types. G. Leonov (1964) divided this region into two domains, southern and northern. The southern domain was characterized by deposition of nanno- and foraminiferal oozes, not infrequently with a considerable terrigenous component. A peculiar facies was represented by sediments enriched in organic matter. The northern domain of the basin displays marine diatom oozes, whose deposition has customarily been attributed to cold water incursions. Between the two domains, an area with a mixed sedimentation type was located. This is the reason, based on prevalent sediment type, we outline three provinces: (i) Northern, gravitating to the Arctic basin and dominated by siliceous sediments (ii) Southern, adjacent to the Tethys, with calcareous sediments, and (iii) Transitional, dominated by terrigenous sediments, in places with significant amounts of biogenic carbonate or silica.

By the beginning of the Paleogene, a large back-arc basin had been separated from the Tethys by a volcanic arc stretching from what is now the Balkans via the Pontus and further on through the Lesser Caucasus, Talysh, and Iran (Zonenshain and Le Pichon, 1987). Deep-water sags of this basin have been reconstructed on the site of the present-day Black Sea and South Caspian basins and of the Greater Caucasus Range. To the north,

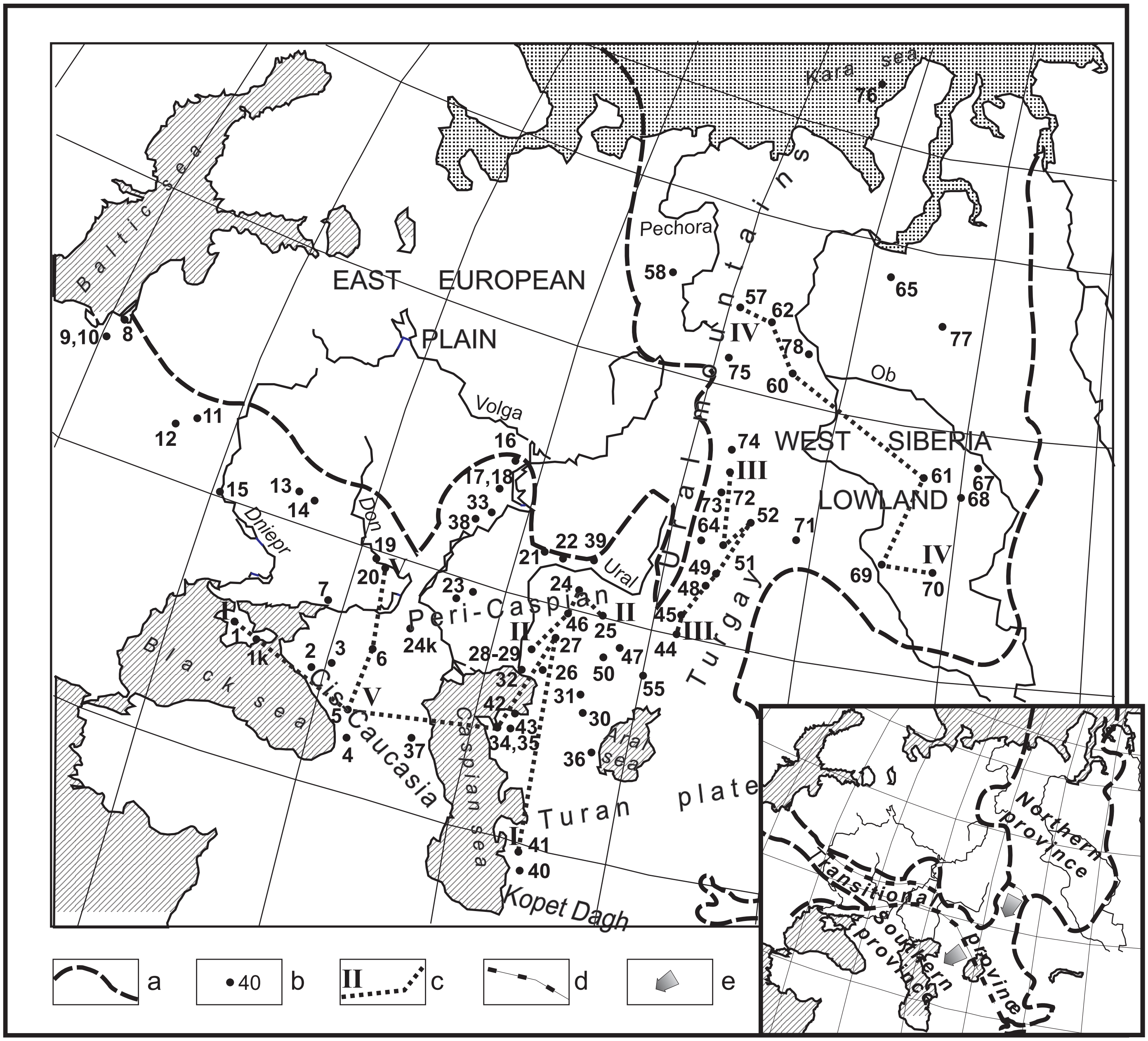
Figure 1. Study region symbols: (a) boundary of the maximum development of Paleogene marine deposits. (b) Location of sections referred to in text and in figures, by region, follows. **Crimea:** 1—Bakhchisaray* (asterisks denote lithology and stratigraphic subdivision shown on the basis of our new data); 1k—Nasypkoy (Bugrova et al., 2002). **Cis-Caucasia:** 2—the Kuban R.; 3—the Maly Zelenchuk R. and 4—Medani village (Stupin and Muzylöv, 2001); 5—the Kheu R. (Krasheninnikov and Muzylöv, 1975; Gavrilov et al., 2000; Radionova and Khokhlova, 1994, and this study); 6—Keresta valley (*); 7—Well 619, Rostov Region (T.E. Ulanovskaya's material); 37—the Rubas-Chai R., Radionova and Khokhlova, 1994. **Baltic Region:** 8—Druskiniskajte Hole and 9—Induri Hole (Fursenko and Fursenko, 1961); 10—2 Pionerskaya Well (Strelnikova et al., 1978). **Pripyat trough:** 11—Teryukha village and 12—Velavoi village (Fursenko and Fursenko, 1961). **Dnieper-Donets basin:** 13—Hole 169 (Strelnikova, 1992); 14—Hole 371, northeast slope of the basin (V.K. Ryborak's material, stratigraphy according to T.V. Oreshkina); 15—Obukhov section, Kiev (T.E. Ulanovskaya's material, stratigraphy according to E.A.Shcherbinina). **Volga region:** 16—Sengilei section (Oreshkina and Khokhlova,1999; Kozlova et al., 1998b; Oreshkina, 2000); 17—Lomovka, and 18—Dyupa Valley (Kozlova, 1999). **North Peri-Caspian:** 21—Ozinki Mountain, and 22—the Solyanka R. (Kozlova, 1999); 23—Hole 14 and Hole 29 (Grachev et al., 1971; Pechonkina and Kholodilina, 1971); 24k—Hole 85 (A.S. Zastrozhny's material, stratigraphy according to V.N. Beniamovski). **Northeast Peri-Caspian:** 24—Hole 148, Kara-Chaganak (Kozlova et al., 1998); 25—Hole SP-1, Shaidinsky basin (Kozlova et al., 1998a; Bugrova et al., 1997 [*]); 26—Hole 221 Kamyskol (Kozlova, 1999). **Central and Eastern Peri-Caspian:** 27—7 Mialy Hole (*); 28—Hole 221, Shtuttuzinsky basin (*); 29—Well Hole, Kamsaktygol basin (*); 46—Lubenka Hole (Kozlova, 1999). **Turan plate:** 30—Hole 313, North Ustyurt (*); 31—Hole 206, Predustyurtsky Plain (*); 34—Usak section (Naidin et al., 1996); 35—Kaurtykapy section (H. Oberhänsli's material [*]); 36—Aktumsuk section (Gavrilov et al., 1997; Shcherbinina, 2000). **West Kopet Dagh:** 40—Kyzyl-Cheshme section (Muzylöv et al., 1987); 41—Maly Balkhan sections (Solun, 1975). **East Trans-Caspian:** 42—Hole 1228 and 43—Hole 1338, Buzachi Peninsula (*). **South Turgay:** 44—Holes 50 and 52 (Beniamovski et al., 1991, 1993; Vasilieva, 1994; Kozlova, 1999); 45—Holes 85 and 86 (Beniamovski et al., 1989, 1991), 47—Kundyzda Mtn. (*). **North Turgay:** 48—Belinsky pit (Beniamovski et al., 1989, 1991); 49—Sokolovsky pit (Radionova et al., 2001); 50—Emba river(*). **South Trans-Uralia:** 51—Korkino pit (*); 52—Hole IG-32, Kurgan (Vasilieva et al., 1994); 55—the Sary-Oba R. (Iakovleva, 1998). **North Trans-Uralia:** 57—Hole 19-U, Ust-Manya village (Kozlova and Strelnikova, 1984). **Polar Cis-Uralia:** 58—Hole 228, the Pechora R. (Yakovleva, 2000; Yakovleva et al., 2000c); 62—Hole 29, lower reaches of the Severnaya Sosva R. (Yakovleva et al., 2000b). **West Siberia Lowland:** 60—Hole 14k, upper reaches of the Konda R. (Kozlova, 1999); 61—Hole 4, the Vasyugan R. (Yakovleva et al., 2000c); 64—Kichigino village (Amon, 1994); 65—Hole 29, lower reaches of the Pur R. (Strelnikova, 1992; Iakovleva and Kulkova, 2001); 67—Hole 2, Vasyugan and 68—Hole 29, Chuzik–Kenga interfluve (Shatsky et al., 1973); 69—Hole 011-BP (*); 70—Hole 9, Ozerny village (*), 71—Hole 9 Petukhovo (Strelnikova, 1992); 72—Hole 1-OK (Ilyina et al., 1994; Kozlova, 1999); 73—Kamyshlov pit (*); 74—Irbit pit (*); 75—the Lavdinka R. (Kozlova, 1999); 77—the Pechal-Ky R. (Strelnikova, 1992); 78—Hole K-4, Kandinskoye (Ilyina et al., 1994). **Kara Sea:** 76—Hole 157 (Gleser and Stepanova, 1994). (c) Location of section profiles shown in Figures 3–7. (d) Facial provinces boundaries. (e) Direction of facial boundaries transition during Ypresian and Lutetian. Inset—Facial provinces.

there was a more shallow-water region, here referred to as the Southern province, which is represented by carbonate shelf facies—carbonate biogenic oozes (Ph. Allen and J. Allen, 1990). In Figures 1A and 1B, most sections of the Southern province correspond to this particular facies, only the southernmost sections (Kuban, Rubas-chay), in which the content of terrigenous material (including coarse clastics) increases appreciably, apparently representing slope deposits.

The Transitional province, apparently, can be viewed as inner shelf, in places separated from the more deep-water Southern province by minor carbonate shoals, composed of nummulitic limestone and red algae.

The Northern province is here interpreted as a seaway that opened both to the north and/or northwest toward the Arctic-Atlantic basin and to the south toward the Transitional province. This type of basin and the character of its link to the ocean remain largely unclear due to paucity of stratigraphic and sedimentologic data.

The initial objective of this study was purely stratigraphic, as we intended to correlate lower Paleogene siliceous sediments of the Northern province, whose subdivision had been based entirely on local siliceous plankton scales, with calcareous deposits of the Southern province, where standard nannoplankton scales are applicable in full measure, using stratigraphic data from the



Transitional province, where all the plankton groups are represented to some extent or another. Customary stratigraphic techniques provided only a partial solution to this problem.

In addition, we made use of the cyclic and facies analysis methods. Sedimentary cycles were identified that are continuous in Thanetian-Bartonian strata throughout the region. Synchroneity of each cycle from section to section across the region was supported by stratigraphic data. It was found that distribution of each particular facies is also governed by a cyclicity that shows distinctive features in each particular province. One more objective of our integrated study was to unravel the scenario of changes in biogenic facies over the early Paleogene across the region.

DATA AND APPROACH USED

This study is based on >80 Paleogene sections across the study region (Fig. 1). The sections were correlated using an integrated zonal scale based on various microplankton groups. Principal key sections were revisited.

Stratigraphy

A comparative stratigraphic scheme for the Southern, Transitional, and Northern provinces is given in Figure 2.

Stratigraphically, the Southern province is well understood. Its deposits are subdivided reliably using the nannoplankton scales by Martini (1971) and Okada and Bukry (1980) and a regional foraminifer scale. The regional foraminiferal scale correlates well with the oceanic one (Krasheninnikov, 1982). We managed to identify beds with radiolarians or diatoms (Radionova and Khokhlova, 1994) within upper Paleocene, upper Ypresian, and Bartonian strata from a number of sections in the northern Cis-Caucasia, similar in their microfossil assemblages to correlative zones in the Transitional and Northern provinces.

Our integrated study of the Transitional province, in which both calcareous and siliceous planktonfossils are found at certain levels, permitted us to refine the stratigraphic ranges of some local zones based on siliceous plankton. The radiolarian *Petalospiris foveolata* Zone and the diatom *Coscinodiscus uralensis* Zone were found to correspond to the upper Thanetian, in the range of the nannoplankton Zone NP9b, and to the dinocyst *Apectodinium hyperocanthum–A. augustum* zones after (Radionova et al., 2001; Oreshkina and Khokhlova, 1999). The revision of the stratigraphic ranges of the Eocene radiolarian *Petalosyiris fiscella* to *Lychnocanium separatum* zones and diatom *Coscinodiscus payeri* to *Pyxilla oligocaenica* zones evoked considerable debate (Kozlova et al., 1998a; Radionova, 1998; Bugrova et al., 1997).

The Paleocene to Eocene section is incomplete. Regional hiatuses have been established at the base of the Thanetian and Ypresian, in the lower and middle Lutetian, and in the lower part of the Priabonian. To subdivide the deposits, we used five microplankton groups, which provided the mutual control. Stratigraphic correlation with the Southern province involved the use of nannoplankton zonation; in the southern part of the Transitional province both nannoplankton scales are applicable, while in the Northern, only Martini's scale can be used. In the northern part of the province, where terrigenous-calcareous deposits give way partly to terrigenous-siliceous strata, the upper Thanetian NP9, upper Ypresian NP13–NP14, or upper Bartonian NP17 Zones are not identified. Beds with planktonic foraminifers occur only in the Thanetian, lower Ypresian, upper Lutetian, and Bartonian strata.

The second group used in subdividing the deposits from the Transitional province and their correlation to the Northern one is dinocysts. The zonation shown in Figure 2 draws on Powell's (1992) scale for the Thanetian-Ypresian and on the scale by Andreeva-Grigorovich (1985) for the upper Ypresian to Bartonian strata.

In the Transitional province, on the Turan plate and in the Peri-Caspian depression, the lower Ypresian radiolarian *Petalospyris fiscella* or diatom *Coscinodiscus payeri* zones are not identified. Stratigraphic position of the radiolarian *Lychnocanium separatum,* dinocyst *Charlesdowniea coleothrypta rotundata,* and diatom *Pyxilla oligocaenica* zones remains open to discussion. The range of these zones is defined as either the upper Ypresian to lower Lutetian or lower Lutetian based on their correlation to nannoplankton Zone NP14 (Kozlova, 1999; Vasilieva, 1994) or even as the entire Lutetian (Gleser, 1996). The issue of the upper limit of all these zones is intertwined with that of the range of the hiatus within the Lutetian from the Transitional and Northern provinces, which remains debatable.

The Paleocene and Ypresian stratigraphy of the Northern province, developed from West Siberian sections, draws on siliceous microplankton groups, such as radiolarians, diatoms, silicoflagellates, and dinocysts, and stratigraphic ranges of most zonal divisions have been refined (Akhmetiev et al., 2001; Kozlova, 1999; Strelnikova, 1992). Hiatuses are recorded at the base of the Thanetian and at the Thanetian-Ypresian boundary from the lack of the dinocyst *Wetzeliella astra* Zone in the lower Lutetian.

The middle Eocene stratigraphy of the Northern province is based on sections in the Dnieper-Donets basin and north Peri-Caspian basin. Stratigraphic ranges of the radiolarian *Heliodiscus quadratus–Theocyrtis andriashevi* and the diatom *Paralia oamaruensis* regional zones in the Northern province were established as the middle Eocene based on radiolarian finds along with nannoplankton from sections in the Dnieper-Donets basin (Radionova et al., 1994; Khokhlova et al., 1999). Middle Eocene assemblages were found to be identical in the Dnieper-Donets basin and the northern Peri-Caspian region, Hole SP-1 (Radionova, 1998). The lack of reliable correlations with calcareous microplankton groups leaves it open to debate whether the upper limit of the occurrence of siliceous organisms is constrained to the middle Eocene or whether they are encountered in Upper Eocene deposits as well (Gleser, 1996; Kozlova, 1999).

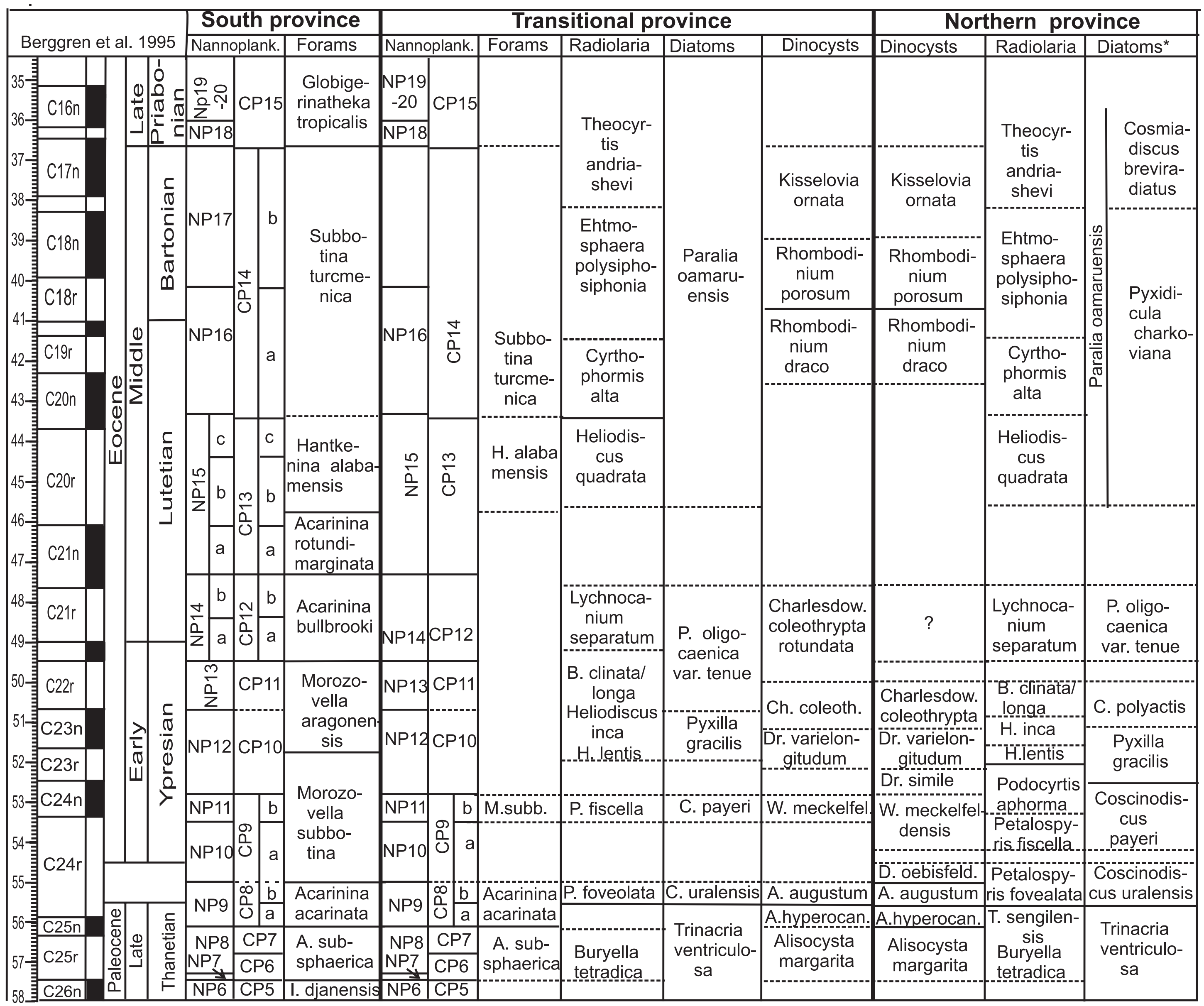


Figure 2. Zonal stratigraphic scheme correlating the Southern, Transitional, and Northern provinces. Zonal division of Paleogene deposits from the Southern province is based on standard nannoplankton scales (Martini, 1971; Okada and Bukry, 1980) and a regional foram scale (Krasheninnikov and Muzylöv, 1975; Iarkin, 1989, with 1999 amendments). To correlate the Southern and Transitional provinces, we used the standard nannoplankton scale and regional foraminiferal and radiolarian (Kozlova, 1999), diatom (Iarkin, 1989, with 1999 amendments; Kozlova et al., 1998), and dinocyst zones (Powell, 1992; Andreeva-Grigorovich, 1985). The stratigraphic range of zones whose boundaries were not documented is shown with dashed lines. To correlate the Transitional and Northern provinces, regional dinocyst and radiolarian scales were used. In subdividing Paleogene strata from the Northern province, zones are given after Akhmetiev et al. (2001) and Khokhlova et al. (1999) with minor modifications.

Cyclic analysis

In each province, the succession of lithostratigraphic units was documented by means of a series of stratigraphically correlated transects, and a certain cyclicity, reiterating in each transgressive-regressive cycle, was established. For this purpose, discontinuity surfaces, transgressive facies series, and regional stratigraphic hiatuses were established in each province.

The Southern province. To unravel cyclicity, we established the facies series from the most shallow-water nummulitic limestones, often deposited on erosion surfaces, to calcareous clays through to marls or clayey limestones of the interior basinal portions. Increase in carbonate content of the sediment in passing from calcareous clays to marls is due to increase in the calcareous plankton component of the sediment. This increase correlates to the periods of high bioproductivity of plankton, when plankton assemblages showed an increasing proportion of oceanic taxa; i.e., this marks eustatic rise of sea level in the basin.

Stratigraphic ranges of transgressive-regressive cycles in the Southern province were first proposed by Muzylöv (1996), and this study offers refined stratigraphic intervals for each cycle. The structure of the cycles from the Southern province is shown in Figure 3 through the Crimea to northern Cis-Caucasia to the southern Peri-Caspian to Mangyshlak to eastern Kopet Dagh (Transect I–I in Figure 1.)

The increase in the carbonate content upsection from the base of the transgressive Thanetian member persists across the Southern province. Thus, at the base of the lower cycle of Thanetian supercycle in the Kheu River section, one finds a clayey limestone member giving way upward to calcareous clays (Fig. 3). The same horizon displays a peak in carbonate content in the Nalchik beds, reaching 40% (Gavrilov et al., 2000). In Bakhshisaray section (Crimea), 7 Mialy Hole (Peri-Caspian), and Kyzyl-Cheshme section (western Kopet Dagh), its counterpart is marls.

A bituminous bed marks the middle cycle. We correlate the 65-cm-thick brown clay bed enclosing fish scales in the upper part of the Nalchik Formation, the Kheu section, with the pivotal event, referred to as the Initial Eocene Temperature Maximum, or IETM. The bituminous bed shows a reduced carbonate content and an increase in TOC (total organic carbon) up to 10%. Analysis of planktonic and benthic foraminifers suggests that the bituminous bed records anoxic to disoxic environments (Stupin and Muzylöv, 2001). This intercalation was first detected and reported by N.G. Muzylöv in the Southern province, from the Crimea to Central Asia, and it was addressed in rather numerous works (Muzylöv et al., 1989; Muzylöv et al., 1996; Gavrilov et al., 1997; Gavrilov et al., 2000; Gavrilov and Shcherbinina, this volume).

The upper cycle in the Kheu section is composed of alternating siliceous siltstones containing considerably recrystallized radiolarians and diatoms, and slightly calcareous argillite-like clays, with the carbonate content dropping to 10%. A considerable decrease in the carbonate content of the member overlying the bituminous layer is documented through most sections along Transect I–I

The lower cycle deposits correspond to nannoplankton Zones CP7–CP8a, the foraminifer *Acarinina subsphaerica* Zone, and the basal part of the *Acarinina acarinata* Zone. From the base of the marl member upward, planktonic foraminifers increase perceptibly in abundance and species diversity. In the eastern Kopet Dagh and Badkhyz, Thanetian deposits exhibit a facies transition, where shallow water nummulitic limestones with *Nummulites deserti* give way to the *Acarinina subsphaerica* Zone marls in deeper-water sections (Bugrova, 1991). A bed rich in organic matter occurs at the CP8a/CP8b boundary. Based on dinocysts, it was attributed to the *Apectodinium homomorphum* Zone (Akhmetiev and Zaporozhets, 1996). Alongside the index species, the bituminous bed contains other *Apectodinium* species, such as *A. augustum, A. parvum, A. quinquelatum, A. sumissum.* Currently, the appearance of *A. augustum* and *A. parvum* and the acme of the genus *Apectodinium* in the context of the Western European scale are used to identify the *Apectodinium augustum* Zone. The upper member matches nannoplankton Zone CP8b and the upper part of the foraminiferal *Acarinina acarinata* Zone. The fact that the top of the underlying Nalchik Group is lacking certain Zone CP8b nannoplankton species and the sharp lithologic boundary are interpreted to point to a minor erosional event at the base of the Ypresian deposits (Gavrilov et al., 2000)

In Mialy 7 Hole, a carbonate-free clay member, underlying the bituminous bed, yielded the *Buriella tetradica* Zone radiolarians, and further upsection, a member of alternating sand and clay yielded the *Petalospiris foveolata* Zone radiolarians (Kozlova, 1999). Correlating the span of this Zone to the foraminiferal *Acarinina acarinata* Zone in this section would help us to constrain stratigraphic position of this cycle in the Transitional and Northern provinces (Fig. 2).

All Ypresian cycles replicate the facies traits documented from the Thanetian supercycle.

In the Kheu section, Ypresian deposits are represented by the Cherkessk Formation, composed of soft, light greenish gray marls ~40 m thick.

The middle part of this sequence comprises green calcareous clays and contains a 15-m-thick interval (Zone CP10) with eight sapropel-like intercalations 10–25 cm thick each. Organic matter content of these intercalations is as high as 2%–3.5% (Gavrilov and Muzylöv, 1992). Foraminifers from these intercalations point to disoxic depositional environments (Oberhänsli and Beniamovski, 2000). Ypresian phase deposits terminate in a bluish marl member of Zone CP12, which again shows siliceous plankton, radiolaria and sparse diatoms (Radionova and Khokhlova, 1994).

The Cherkessk Formation displays a complete succession of nannoplankton zones CP9–CP12 and the foraminifer *Morozovella subbotinae* and *M. aragonensis* Zones.

In the Kheu section, the cyclic architecture of the Ypresian unit can be revealed only based on lithologic variations, although

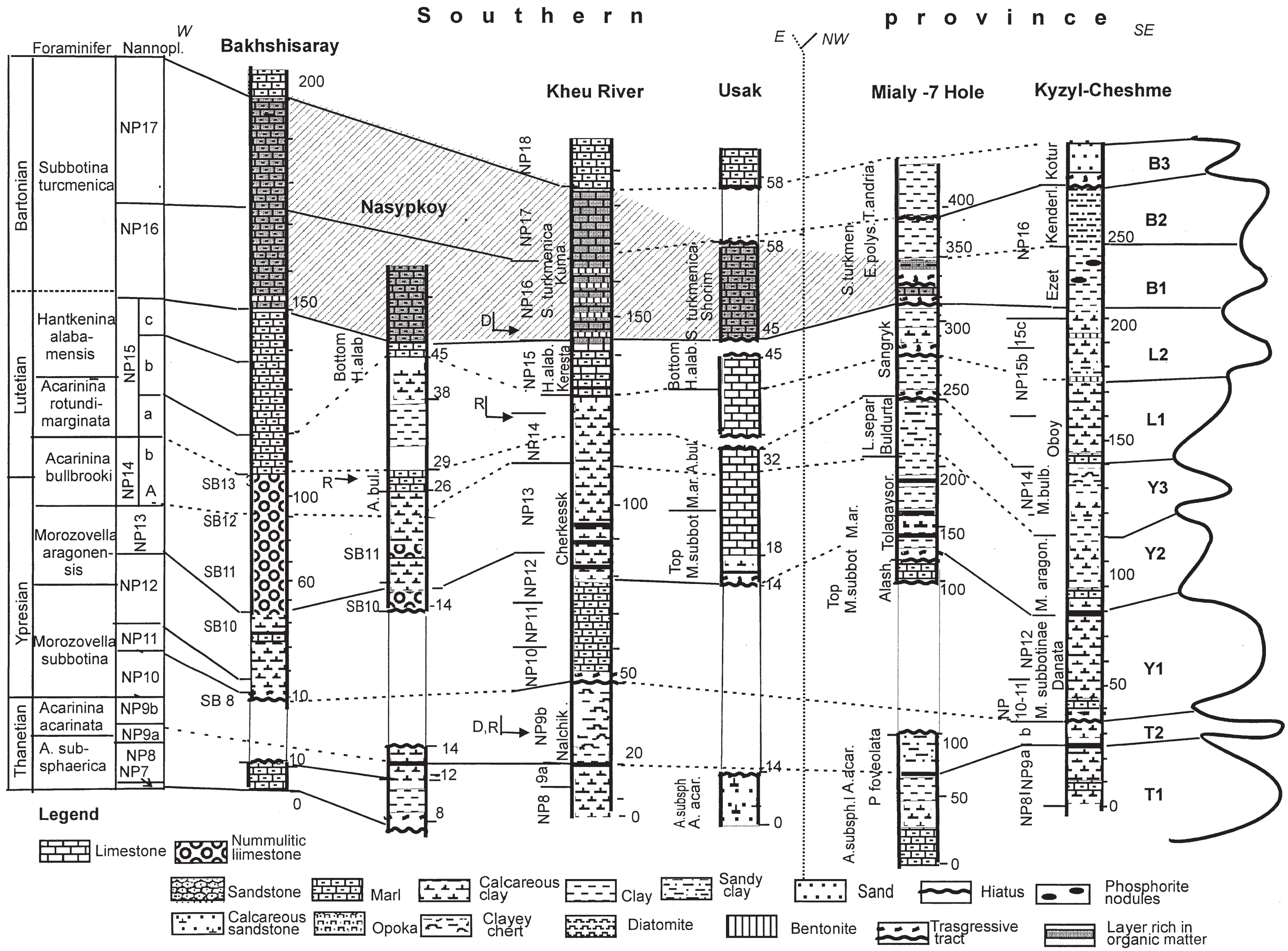


Figure 3. Correlation of key sections from the Southern province: Profile I–I in Figure 1. Zonal subdivision based on nannoplankton and foraminifers is shown in Figure 2 for the Southern province. Zonal subdivision from 7 Mialy Well based on foraminifers, carried out by V.N. Beniamovski, and based on radiolarians, by G.E. Kozlova, 1999. In lithologic columns, gray coloring depicts the "Kuma Facies" of middle Eocene age. Diagonal-striped shading shows "Kuma Facies" "distribution from section to section. T1, T2—Thanetian to initial Ypresian cycles; Y1, Y2, Y3—Ypresian to initial Lutetian (?) cycles; L, L1, L2—Lutetian cycles; B1, B2—Bartonian to initial Priabonian (?) cycles. R, D—radiolaria, diatoms in microplankton assemblage. SB8–SB13—Mediterranean Nummulitic assemblages in Bakhchisaray section according to E.Yu. Zakrevskaya (2002, personal commun. Legend is used for Fig. 3–7.

the transgressive character of the calcareous lower Ypresian sequence of the Southern province, corresponding to the *Morozovella subbotinae* Zone, was noted by many researchers (Shutskaya, 1970; Solun, 1975; Bugrova, 1991; Naidin and Beniamovski, 1994; and others). In Transect I–I, the full ranges of zones (as inferred from nannoplankton) across the Paleocene-Eocene transition are to be found only in the Kheu and Kyzyl-Cheshme sections, this cycle being in both cases represented by the most deep-water facies of multicolored marl. In the rest of the sections along this Transect, on the periphery of the Southern province, deposits of the lower cycle have an erosional base.

The same sections exhibit a distinct unconformity at the base of second cycles. In the Crimean sections, the second and third Ypresian cycles contain extensive nummulitic limestones. In the Nasypkoy section (Fig. 3), these have been encountered in a transgressive unit at the base of the middle cycle and are represented by an assemblage of Zone SB10 from the Mediterranean nummulitic scale (according to Bugrova et al., 2002). These same deposits in more deep-water Ypresian beds, represented by a sequence of calcareous clays with bituminous intercalations with fish scales at the level of Zone CP10, have been recorded from most sections along Transect I–I. A single bed of dark-colored clay with fish scales >0.5 m thick was documented at this stratigraphic level from western Kopet Dagh sections (see the Kyzyl-Cheshme section); this is the so-called "second fish bed" (Solun, 1975; Muzylöv et al., 1989). The upper part of the Ypresian strata and, apparently, the lower part of the Lutetian beds consist of terrigenous-calcareous and, occasionally, terrigenous-siliceous sediments with an abundant radiolarian assemblage. Up to 37% of radiolarians are recorded within the foraminiferal assemblage of the *Acarinina bulbrokii* Zone in this cycle in the Nasypkoy section. In 7 Mialy Hole, the upper cycle Buldurta Formation conformably overlies the Tolagaisor Formation and consists of noncalcareous gray and greenish gray clays with thin intercalations of siliceous silts. Here, the *Lichnocanium separatum* Zone radiolarians are abundant (Kozlova, 1999). This level is used for reference in correlations between provinces.

Cycles of the middle Eocene transgressive-regressive phase in the western areas of the Southern province largely mimic the structure of the Ypresian cycles. Along the Kheu River, the Keresta Formation conformably overlies the Cherkessk Formation. It is represented by rhythmically alternating compact limestone and soft greenish marl. The transgressive character for the Keresta Formation is suggested by its increased carbonate content and flysch-like rhythmicity, possibly pointing to the basin's deepening. In the Bakhchisaray section, the Keresta Formation replaces shallow-water nummulitic limestones of Ypresian–early Lutetian age. In western Cis-Caucasian sections, the Keresta Formation erosionally overlies the Cherkessk Formation (Grossheim, 1960). Unconformity at the base of the Keresta deposits is clearly traceable into the Peri-Caspian region and southern Turgay (Kurgalimova and Moksyakova, 1970; Naidin et al., 1994) and the Kyzyl-Cheshme section (Fig. 3), the western Kopet Dagh (Muzylöv et al., 1989)

Keresta Formation is correlatable to nannoplankton Zone CP13 and to the foraminifer *Acarinina rotundimarginata* and *Hantkenina alabamensis* zones and Kuma Formation corresponds to nannoplankton Zone CP14 and the foraminifer *Subbotina turkmenica* Zone, the lower and upper parts of the sequence yielding poorly preserved radiolarians and diatoms of the *Paralia oamaruensis* Zone (Radionova and Khokhlova, 1994).

In the Kheu River section, the Kuma Formation conformably overlies the Keresta Formation, but it is composed of a totally different type of deposits, thinly rhythmic soft clayey coffee-colored limestone. The rhythmicity of the formation is due to light colored clayey limestone intercalations alternating with dark colored ones, rich in organic matter and with fish scales. In the lower half, total organic carbon content is 2%–9% and in the upper half, it drops to 2.5%–4.5%. The $CaCO_3$ contents in light-colored intercalations are 20% greater than in dark-colored ones (Gavrilov et al., 2000). Kuma Formation is virtually barren of benthic foraminifers, which suggests a disoxic or anoxic environment (Beniamovski et al., 1999).

In both sequences, from the base of the Keresta Formation upwards, bentonite horizons are encountered.

In the western and central part of the Southern province, a somewhat distinctive structure is displayed by Bartonian deposits, represented along Transect I–I in the Bakhchisaray, Kheu, and Usak sections by the Kuma or Shorym Fms. Further east, in Mangyshlak and then in western and central Turkmenistan, considerable changes occur in the structure of the middle Eocene section (Korovina, 1970; Rodionova, 1963). In 7 Mialy Hole (Fig. 3), the Saurbay Formation has an erosional base and is composed of light brown marly clays with inclusions of light gray (ash?) material and contains a planktonic foraminifer assemblage of the *Subbotina turcmenica* Zone, which, nevertheless, exhibits some benthic forms, *Bifarina* ex gr. *adelae* and *Uvigerina castelata.* The upper half of the sequence can be envisaged as being an independent cycle. It is composed of greenish gray slightly sandy, low-calcareous to noncalcareous clays. This part of the sequence is dominated by agglutinated foraminifers and radiolarians of the *Ethmosphaera polysiphonia* Zone. Keguinkol Formation, overlying erosionally the Saurbay Formation and consisting of clays with radiolarians of the *Theocyrtis andriashevi* Zone, can be regarded as an independent third cycle.

In the western Kopet Dagh and on the Greater Balkhan (Solun, 1975), Bartonian deposits are represented by three lithologic units: The lower, Ezetsky Formation (Fig. 3, the Kyzyl-Cheshme section) is composed of dark greenish gray clays with phosphorite lenses and contains only planktic foraminifers. The Kenderlit Formation is transgressive and consists of calcareous silty clays with intercalations of Fe-dolomite concretions; the formation's lower horizons are barren of microfossils, and further upsection only benthic foraminifers occurr. The upper, Kotur Formation shows ample evidence of its regressive character. The formation is composed of brownish olive-colored clays intercalated by siltstone and sandstone. Clay intercalations contain abundant benthic foraminifers, including agglutinated ones, radiolarians, and diatoms. The siltstone intercalations often contain mollusks.

Therefore, in eastern region of Southern province, Bartonian deposits fall into two or three cycles. The "Kuma"-type disoxic facies are maintained only in the lower cycle of the Bartonian transgression. Deposits of both upper cycles have elevated silica contents due to abundant radiolarians and, to a lesser extent, diatoms. Although deposits of these cycles are also high in organic matter, the appearance of diversified benthos, such as foraminifers, mollusks, and nummulitic beds in the eastern Kopet Dagh and Badkhyz (Bugrova, 1991), suggests deposition in an oxic shallow-water basin. These facial types of middle Eocene deposits are close to those of the Transitional province.

The Transitional province. Although deciphering cyclicity, we established a transgressive series from the most shallow-water facies of calcareous sands with minor bioherms composed of *Cerripedia, Briozoa,* and large foraminifers, to calcareous clays. Regressive series are represented by transitions from silts to noncalcareous clays and clayey opokas.

Most cycles are marked by depositional breaks, established paleontologically. To study cyclicity patterns of Thanetian and Ypresian deposits, we constructed two roughly S–N trending Transects, II–II and III–III, respectively, which are shown in Figure 1.

Let us consider the stratigraphic ties and cyclic structure of this interval in, e.g., the Sokolovsky pit (Fig. 5), where Thanetian deposits, unconformably overlying the Mesozoic beds, are represented by two lithologic units: The Sokolovsky terrigenous-calcareous sequence and the Banded siliceous–clay sequence with a hiatus in-between. In the Transitional province, the Thanetian calcareous clay or silt-clay deposits correspond to nannoplankton Zone NP8 and often occur with a considerable stratigraphic unconformity. A hiatus at the base of the upper, terrigenous-siliceous sequence is also found across the region.

The Sokolovsky Formation was shown to be restricted to Zone NP8 of the standard nannoplankton scale and to the foraminifer *Acarinina subshpaerica* and lower *A. acarinata* zones. (Radionova et al., 2001). The radiolarian *Petalospiris foveolata,* dinocysts *Apectodinium hyperocanthum, A. augustum, Wetzeliella meckelfeldensis* zones were established in the Banded Formation. The Banded Formation contains a hiatus spanning two dinocyst zones, *Glaphyrocysta ordinata* and *Wetzeliella astra,* which correspond to nannoplankton Zone NP10.

Such architecture of the section is characteristic of the northern Turgay and the northern Peri-Caspian region alike, reflecting the transgressive-regressive cyclicity in the Thanetian to initial Ypresian, common to the entire region.

The architecture of Ypresian cycles from the Southern to Transitional province is portrayed by Peri-Caspian Transect II–II (Fig. 4). The lower cycle of Ypresian deposits is represented by marls in Kamyskol Hole 221, giving way to calcareous clays in Holes 148 and SP-1. Upsection, the Tolagaisor Formation in the Kamyskol Hole 221 has erosional base and is represented by calcareous clays with the bituminous intercalations. Further north, intercalations of beige colored slightly bituminous clays were recorded only in the Lubenka Hole 12. This interval in Hole 148 is composed of clays exhibiting erosion at the base, and in Hole SP 1, of opokas.

The upper part of Ypresian strata, the Buldurta Formation, composed of silty clay with erosional base, yields Zone NP14 nannoplankton at the bottom of some sections, giving way upsection to the *Lychnocanium separatum* Zone radiolarians. In northern sections, penetrated by Holes 148 and SP-1, the formation is represented by siliceous clays. The upper stratigraphic limit of this sequence is unclear.

The same structural peculiarities of the Ypresian cycles persist into the northern periphery of the Transitional province. As can be seen from Transect III–III through the north part of the Transitional province in the Turgay basin (Fig. 5), the lower, Ypresian, cycle—the Taup Formation—is represented by calcareous clays and yields nannoplankton Zone NP11 to the lower part of Zone NP12 from the Belinsky quarry and from Holes 48–50 (Beniamovski et al., 1989, 1991). The second cycle—the Tasaran Formation, erosionally overlying the Taup Formation—is represented by clays and contains Zone NP12 nannoplankton in its lower part and radiolarians of the *Heliodiscus inca* and *Buriella clinata–B. longa* Zone (Kozlova, 1999). The upper cycle of the Tasaran Formation has a clay-sand composition and bears the *Charlesdowniea coleothrypta–Ch. coleothrypta angulosa* Zone dinocysts (Vasilieva, 1994; Vasilieva et al., 1994).

As is seen from Figure 4, depicting Kamiskol Hole 221, Lutetian and Bartonian lithofacies become considerably more terrigenous than Ypresian facies. During the middle Eocene, geographic arrangement of all the provinces changed, facies shifting from north to south, and all the provinces becoming much more closely spaced.

Transect V–V (Fig. 7) shows how the middle Eocene lithology changes from the Southern to the Northern province. The Keresta Valley section provides an example of architecture of middle Eocene cycles in the Transitional province. Here, as in all other sections of the Peri-Caucasian region, the Keresta Formation rests on carbonate-free clays of late Ypresian to early Lutetian age (Shutskaya, 1970) and has the same structure, lithology, and stratigraphic range as in the Kheu section. The upper part of the section, the Solonskaya Formation, is bipartite. Its lower member is composed of Kuma-type coffee-colored clayey limestone, which yielded Zone CP14a nannoplankton and the *Subbotina turcmenica* Zone foraminifers. The upper member consists of carbonate-free clay with an abundant radiolarian assemblage of the *Ethmosphaera polysiphonia* Zone.

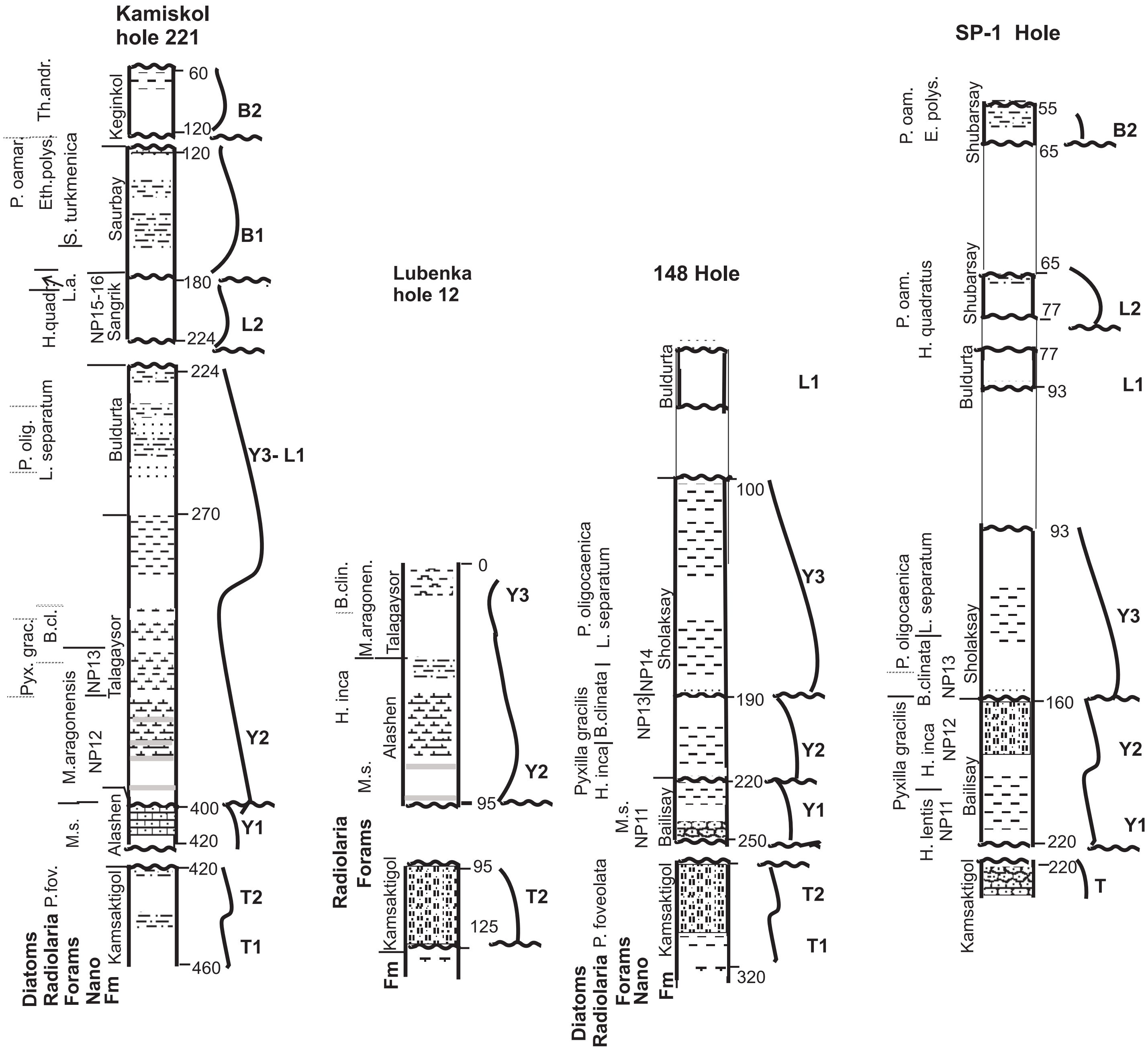


Figure 4. Correlation of Thanetian to Bartonian key sections in the Peri-Caspian basin, Transitional province. Transect II–II in Figure 1. Stratigraphic scheme, as in Figure 2 for Transitional province. In the 221 Kamyskol Hole, zonal subdivision is given after N.P. Tabachnikova (personal communication, 2001) based on nannoplankton, after V.N. Beniamovski based on foraminifers, after G.E. Kozlova based on radiolarians, and after Z.I. Gleser (personal communication, 2001) based on diatoms. Diagonal-striped shading shows facies boundary shift of the Transitional province to south in Lutetian.

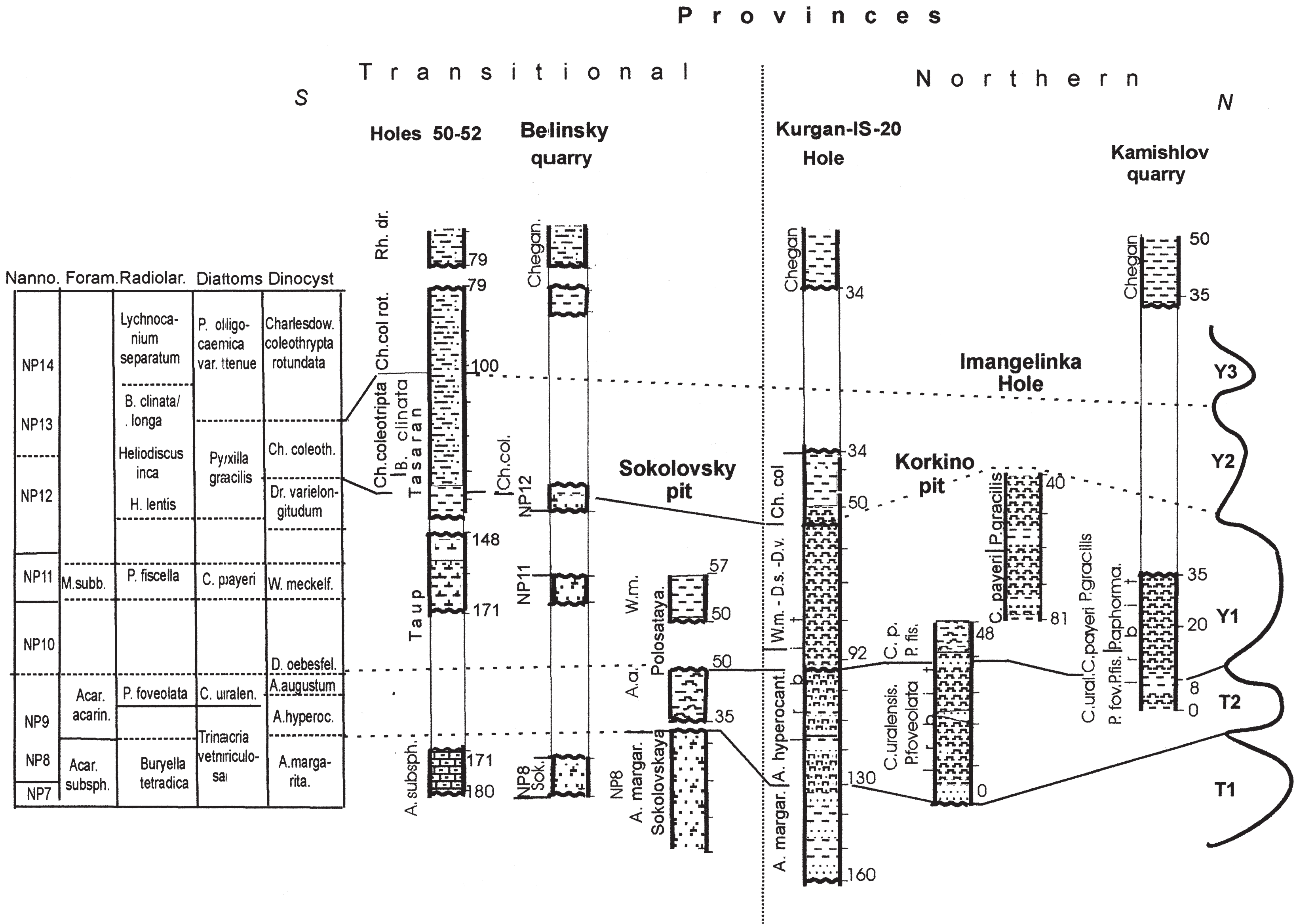


Figure 5. Correlation of key sections of Thanetian to Ypresian strata from the Transitional and Northern provinces along the S–N Transect through southern West Siberia and the north and central Turgay basin. Transect III–III in Figure 1. Stratigraphic scheme, as in Figure 2 for Transitional province. Transition from carbonate-terrigenous and siliceous-terrigenous strata of the Transitional province to the dominantly siliceous deposits of the Northern province. Breaks increase in magnitude where provinces adjoin each other, in the Turgay basin and the Sokolovsky pit and Belinsky quarry.

Comparison of the structures of the middle Eocene deposits from Mialy Hole 7, Kyzyl-Cheshme section (Fig. 3), 221 Kamiskol Hole (Fig. 4), and the Keresta Valley (Fig. 7) reveals identical regularities: (i) deposits of the lower, "Keresta," cycle in all three sections are represented by calcareous clays, (ii) Bartonian deposits are subdivided distinctly into at least two cycles, the lower being dominated by typical "Kuma" coffee-colored clays deposited in a disoxic basin, and the upper part of carbonate-free, siliceous-terrigenous strata. A zone with such structure stretches from North Cis-Caucasus Region via southern Peri-Caspian basin into the Kopet Dagh. Northwest and northeast of this zone, deposits of the northern facies type occur.

The Northern province. In this province, the transgressive depositional series is represented by transition from glauconitic sands to diatomites or diatomaceous clays, and the regressive succession by diatomaceous clays giving way to sandy siliceous strata (opokas), in turn grading into clayey sands, not infrequently with minor banks with *Bivalvia* and *Gastropoda.* Cyclicity of the Thanetian and Ypresian deposits can be studied along the transects through West Siberia, one trending N–S from central areas adjacent to the Urals to the Turgay passage (Fig. 5) and the other trending W–E from areas adjacent to the eastern Urals in the west to Omsk Region in the east (Fig. 6).

In the west of the West Siberian Lowland, Thanetian deposits are represented by Serov Formation composed of gray opoka-like clays and by diatomite customarily attributed to the Irbit Formation, exposed in a wide strip along the Urals' eastern slope, whereas further east, in the central West Siberian Lowland, these strata are essentially terrigenous, giving way to gaizes only in their upper part.

In Ust-Manya Hole 19 (Fig. 6), the Serov Formation, composed of opoka and opoka-like clays, unconformably overlies the clay-dominated Ivdel Formation. Within the formation, the radiolarian *Tripodiscinus sengilensis* Zone and the diatom *Trinacria ventriculosa* Zone are identified. We interpret this sequence as representing the lower Thanetian cycle. Transition to the Irbit Formation is identified by a considerable increase in biogenic silica content. The Irbit Formation exhibits the radiolarian *Petalospiris foveolata* Zone and the diatom *Coscinodiscus uralensis* Zone. Although the transition to the Irbit Formation diatomite is gradual throughout the zone east of the Urals, we documented the transgressive character of the Irbit strata in the Korkino section, where they rest on Triassic continental deposits (Fig. 5).

In Thanetian-Ypresian transitional strata, a change occurs in the lithology of the Irbit Formation in Ust-Manya Hole 19 and in some other holes. In the Kamyshlov section (Fig. 6), the radiolarian *foveolata-fiscella* transition and the diatom *uralensis-payeri* transition are restricted to a 0.5 m dark gray clay member with a considerable proportion of terrigenous material. Customarily, the changes in diatom, silicoflagellate, and radiolarian assemblages in these sections have been viewed as continuous. In this particular section, however, the upper part of the dinocyst *Deflandrea eobisfeldensis* Zone yields a mixed assemblage with reworked Cretaceous forms and two units of the dinocysts scale, *G. ordinata* and *W. astra,* lacking; upsection, the *Wetzelliela meckelfeldensis* Zone is identified. As appears from both transects, the absence of these dinocyst Zones is recorded from all the sections.

Ypresian deposits of the West Siberian Lowland, represented by the upper part of the Irbit Formation, Middle Lulinvor, Upper Lulinvor, and Nurolka formations, exhibit the maximum development of siliceous facies, although structural dissimilarities between the basin's western and eastern regions persist.

In the zone east of the Urals (Fig. 5), the middle and upper parts of the Irbit Formation are represented by diatomite, diatom clays, and gaize-like clays. Upsection, the proportion of terrigenous material increases, but both in the western and central parts of the basin siliceous lithologies with terrigenous admixture remain dominant. In its stratigraphic range, the lower Ypresian cycle corresponds to the radiolarian *Petalospyris fiscella–Heliodiscus lentis,* the diatom *Coscinodiscus payeri–Pyxilla gracilis* (bottom), and the dinocyst *Wetzelliela meckelfeldensis–Dracodinium varienlongitudum* (bottom) Zones, roughly correlative to nannoplankton Zones NP10 (top) to NP12 (bottom).

The second cycle is fully documented in sections near the central part of West Siberia, from Hole 14k in the Konda River basin (Fig. 6) and from Kurgan Hole IS-20 (Fig. 5). Deposits of this cycle are essentially clayey sequences of the Upper Lulinvor Formation and correspond to the radiolarian *Heliodiscus inca–Buriella clinata* (bottom) Zone, to beds with the *Coscinodiscus polyactis* Zones diatoms (top of the *Pyxilla gracilis* Zone to bottom of the *Pyxilla oligocaenica* Zone), and to the dinocyst *Dracodinium varielongitudum* (top) to *Charlesdowniea coleothrypta* (bottom) zones, which we correlate arbitrarily to nannoplankton Zones NP12 (top) to NP13 (bottom).

The transgressive character of this cycle is especially clear in northern (Chirva, 1971; Chirva and Lyubomirova, 1973) and eastern regions of West Siberia (Shatsky et al., 1973). In Hole 4, Vasyugan River section (Fig. 6), deposits of the Upper Lulinvor Formation erosionally overlie Paleocene strata and consist of light gray opoka-like clay and, less frequently, diatomite. They have an identical stratigraphic range in Holes 011-VA and 9 (Fig. 7) in southeastern West Siberia. In an easterly direction, they decrease in thickness gradually, giving way to glauconite sands, and pinch out on the east side of the Ob River in its middle reaches (Shatsky et al., 1973). Similar replacements are documented in a southern direction, along the Chizhapka River, a southern tributary to the Vasyugan River (Kriventsov, 1973).

The upper cycle is represented by Nurolka Formation deposits, composed of yellowish green clays with gaize-like intercalations, at times with silt accumulations (Shatsky et al., 1973). In northern sections of the zone adjacent to the Urals, in the lower reaches of the Ob River and along the Pur River, the Nurolka Formation is documented by the appearance of the *Pyxilla oligocaenica* Zone diatoms (Rubina, 1973; Chirva and Lyubomirova, 1973).

Deposits of the upper cycle are presented in Figure 6 as the

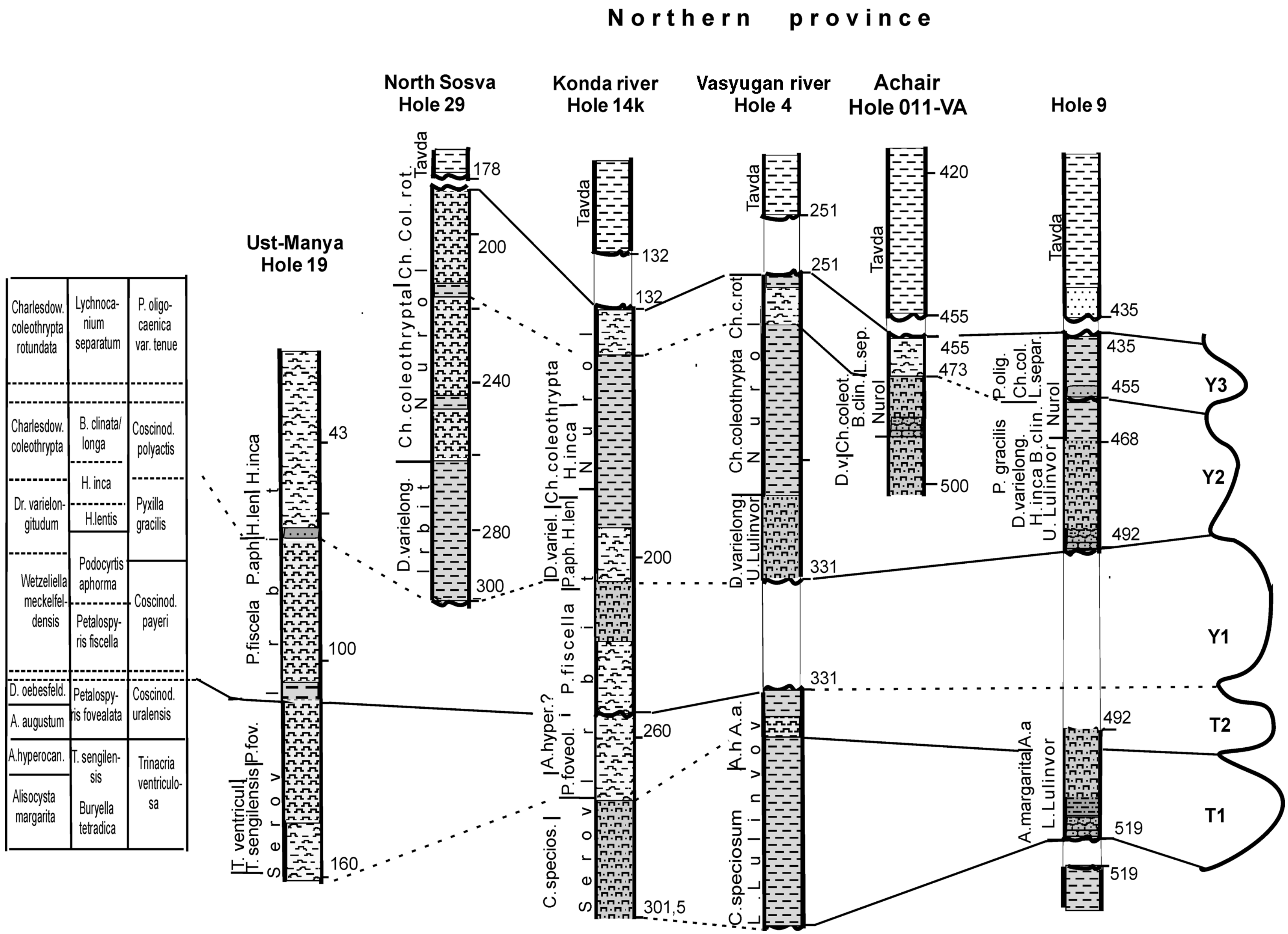


Figure 6. Correlation of Thanetian to Ypresian key sections from the Northern province along the E–W profile through the West Siberian Lowland. Transect IV–IV in Figure 1. Stratigraphic scheme, as in Figure 2 for Northern province. In western sections (Well 19, Ust-Manya) only lower and middle Ypresian strata are represented. All the eastern sections lack lower Ypresian strata, which implies gradual migration of the basin from west to east, in keeping with the cycles of Ypresian transgression (see also Figure 10).

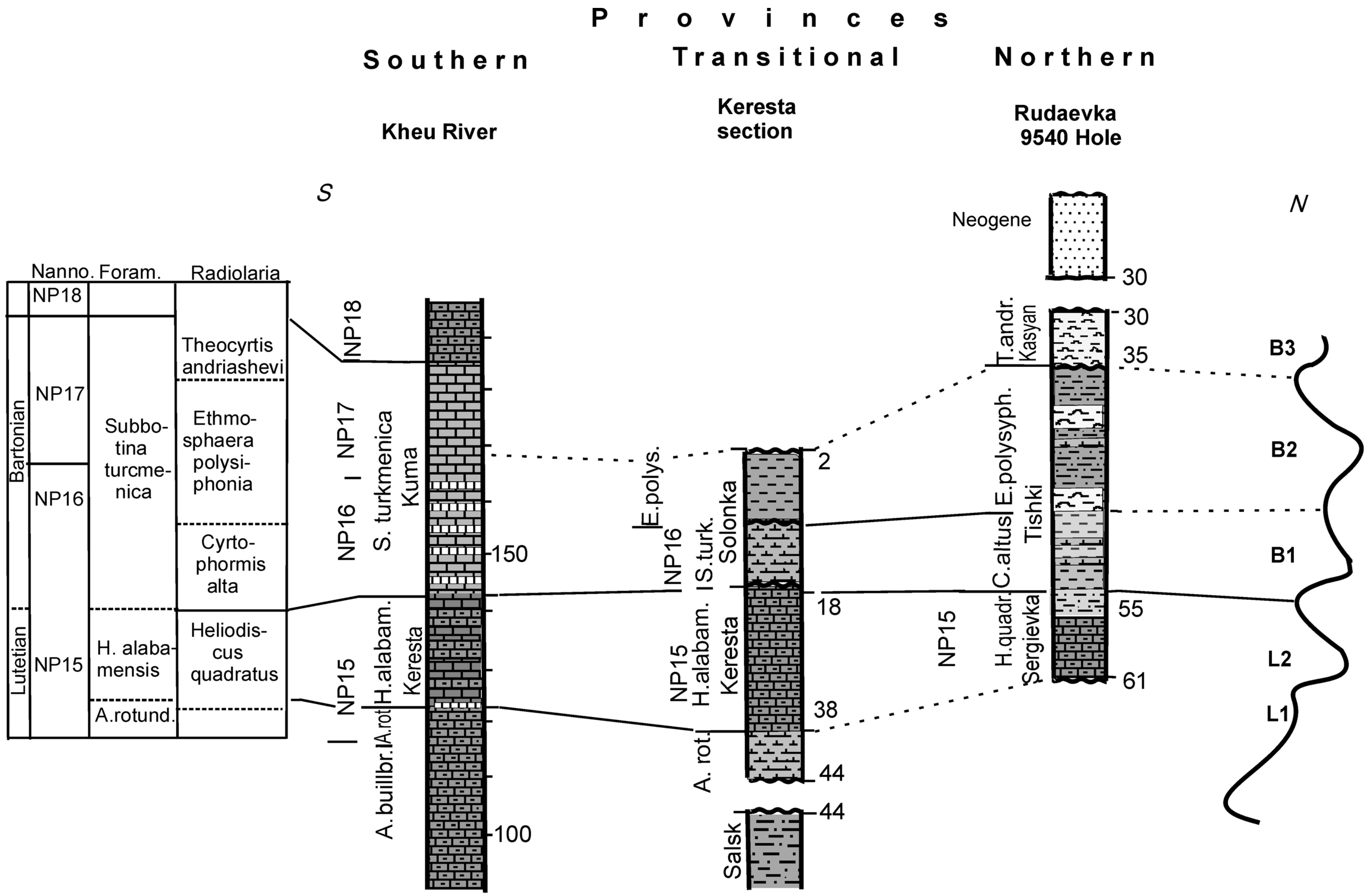


Figure 7. Correlation of Lutetian to Bartonian strata from the Southern, Transitional, and Northern provinces along the profile through the North Caucasus, Central Cis-Caucasia, Donets basin. Transect V–V in Figure 1. Stratigraphic scheme, as in Figure 2 for Transitional province.

upper strata of the Nurolka Formation, correlative to the dinocyst *Charlesdowniea coleothrypta rotundata* Zone, the radiolarian *Lychnocanium separatum* Zone, and the diatom *Pyxilla oligocaenica* Zone. In Hole 9, southeastern West Siberia, these deposits erosionally overlie those of the middle cycle.

In West Siberia, middle Eocene beds (the Tavda Formation) are represented by terrigenous deposits devoid of either calcareous or siliceous marine microplankton. These deposits belong to a basin of a different facies type and are not discussed here.

Middle Eocene deposits, represented by siliceous facies, are preserved only along the Eastern European periphery of the Peri-Tethyan basin and are addressed here in the context of Transect V–V through the north part of the Dnieper-Donets basin (Fig. 7).

DISCUSSION

Facies distribution through time

The cyclicity pattern established for each facies province persists across the study region. This pattern is illustrated on EW trending Transects I–I and IV–IV through the Southern and Northern provinces (Figs. 3, 6). N–S Transects II–II, III–III, and V–V (Figs. 4, 5, 7) show that the cycles remain laterally consistent in passing from the Southern to Transitional and from the Transitional to Northern provinces.

To summarize, we recognize in the study region three transgressive-regressive supercycles (phases): (i) Thanetian, covering nannoplankton Zones NP 8–9 (ii), Ypresian, covering Zones NP10 (top) to NP14, and (iii) upper Lutetian to Bartonian, covering Zones 15 (top) to NP17. Each supercycle had several cycles that we traced, while refining considerably the geographic pattern of various biogenic facies within the basin (Fig. 8).

In the Southern province, deposits of the lower cycle are represented in each phase by transgressive calcareous strata. More deep-water strata of this cycle are represented by marls, not infrequently multicolored, and more shallow-water strata, by limestones. Limestones become the most widespread during the late Lutetian, “Keresta” cycle. A characteristic feature of the middle part in all three phases is carbonate mud facies that are enriched in organic matter, as pointed out by Muzylöv (1994). In the Thanetian, this is a single intercalation, separating lithologically contrasting sequences; the Ypresian contains a series of bituminous layers; ultimately, the entire Bartonian sequence in the central part of the Southern province and the lower part of the Bartonian (the middle cycle) in the eastern regions become bituminous. The upper cycle of each phase exhibits a decrease in carbonate content, the appearance of clays with siliceous plankton, and, occasionally, purely siliceous facies.

In the Transitional province the deposits fall clearly into three sequences, separated by hiatuses or showing evidence of transgressive deposition: The lower, calcareous; the middle, composed of clay with intercalations rich in organic matter and replaced by a siliceous-calcareous sequence in the north of this province; and the upper, siliceous-clayey. The siliceous organisms appear in the middle cycle, the upper cycle being not infrequently represented by biogenic silica and siliciclastic deposits.

In the Northern province, during all three transgressive-regressive supercycles, the deposits maintained a similar facies aspect, and they are represented by diatomites, opoka, and clays containing siliceous plankton here. Geographic position of this province experienced considerable changes. In Thanetian time, it occupied West Siberia and the Middle Volga region; where as in Ypresian time, West Siberia and the western Arctic basin (Radionova and Khokhlova, 2000); and in middle Eocene time, it was restricted to the northern slopes of the Dnieper-Donets basin and Peri-Caspian depression.

Figure 8 shows the cycles of the Thanetian and Ypresian phases to be readily correlatable to oceanic transgressive-regressive cycles. Middle Eocene transgressions in the study region fit to oceanic ones less distinctly, biostratigraphic methods pinpointing confidently only the late Lutetian and early Bartonian transgressions. However, the boundaries of the supercycles here proposed distinctly match tectonic events at the Paleocene-Eocene transition (Kopp and Scherba, 1998), in the early and middle Lutetian (Kazmin et al., 1987), and at the Middle–upper Eocene transition (Meulenkamp and Sissingh, 2000), related to the southward jump of subduction in the Tethys and to mechanical coupling of the African-Apulian and Eurasian continental lithospheric plates since about the middle Eocene–late Eocene transition ~40–37 Ma ago.

Transgressive events through time

Time changes in facies distribution are especially spectacular if one compares the maps depicting all three transgressive-regressive phases (Figs. 9–11). In early Thanetian, Ypresian, and late Lutetian times, we restore clearly a continuous geographic distribution of carbonate shale, covering the Southern province, the distribution of this facies corresponding to the deepest part of the epeiric basin. Characteristically, the same areas were occupied by mud facies rich in organic matter. The Transitional province, composed of siliciclastic and carbonate mud, was the shallowest-water part of the basin—the inner shelf.

The greatest changes in geographic distribution are shown by siliceous facies. Note that the diatomite distribution area in Thanetian time was distinctly confined to the hypothesized basinal slope, likely suggesting either the existence of coastal upwellings or proximity of these basins to seaways. During the Ypresian, the siliceous deposition area migrated from west to east (Fig. 10). Although in the early Ypresian the entire sediment-occupied area was adjacent to the Urals, in the late Ypresian this area expanded into eastern West Siberia, i.e., this basin’s role as a passage increased.

During the middle and late Ypresian transgressions, geographic links between the Arctic and Tethyan basins were

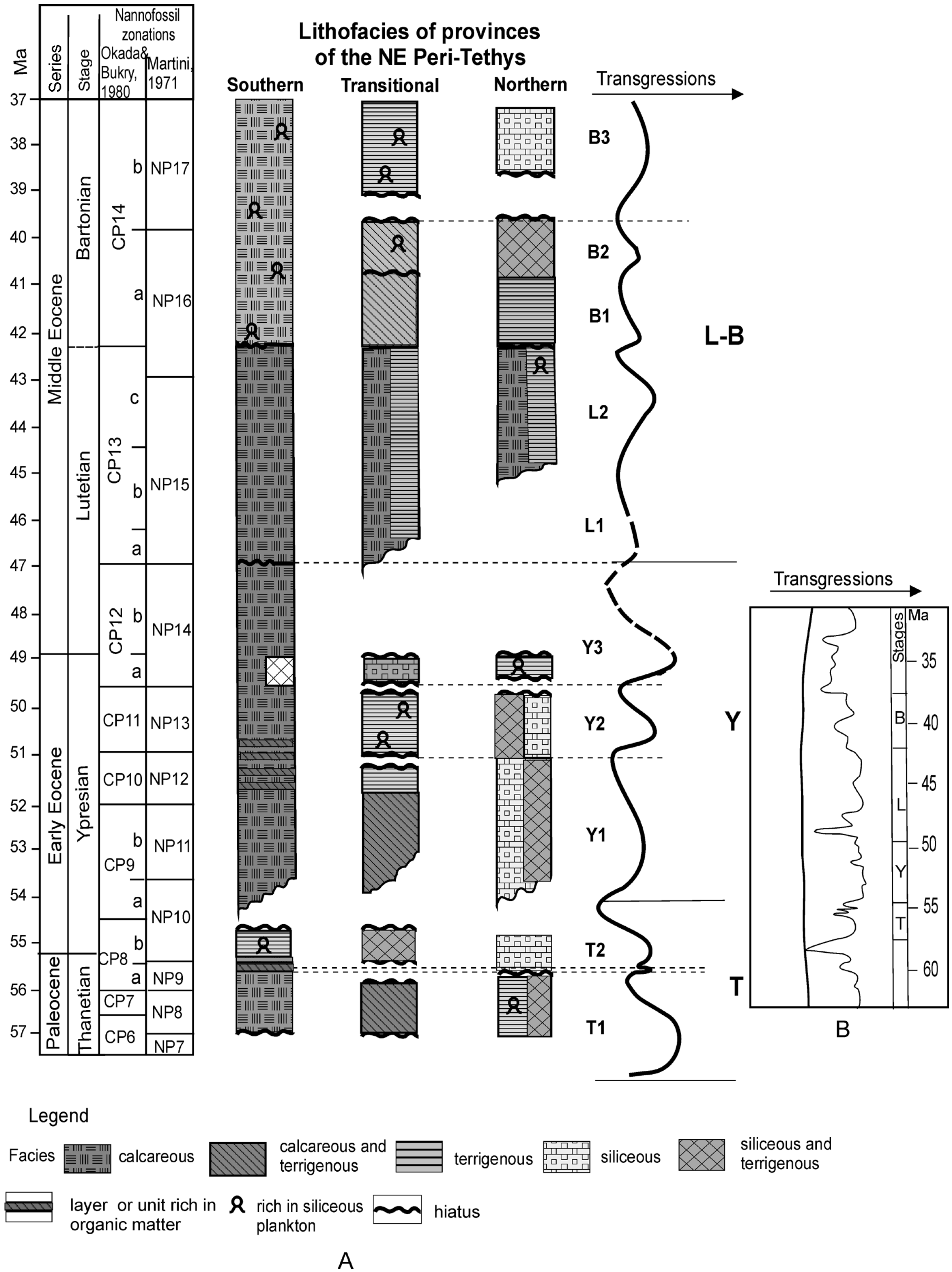
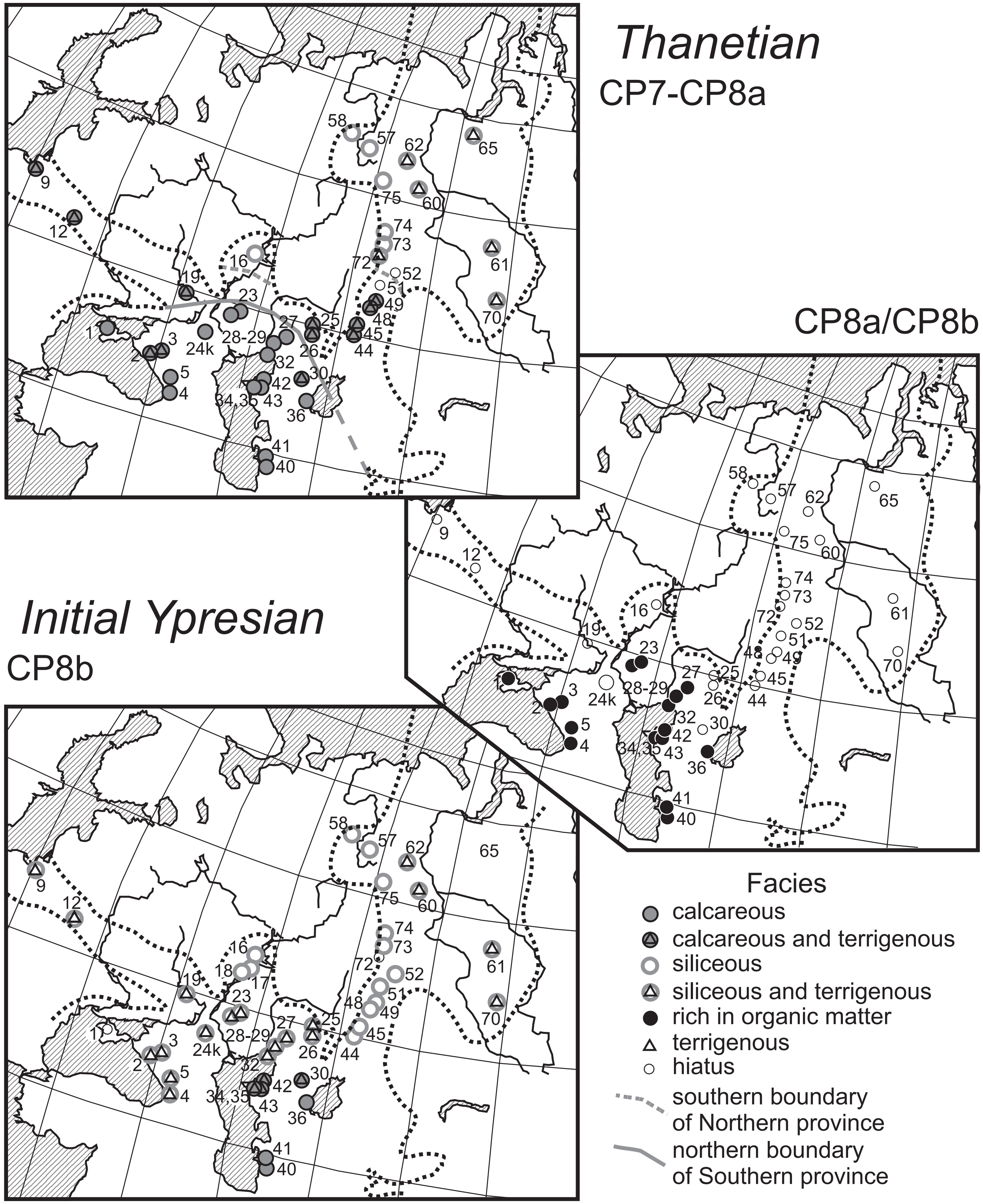


Figure 8. A: Dominant facies types of Thanetian to Bartonian strata from the Southern, Transitional, and Northern provinces and their cyclic interpretation. T, Y, L-B—Thanetian, Ypresian, Lutetian-Bartonian supercycles. In each supercycle, cycles are denoted by numbers. B: Sea-level curve for early Paleogene taken from Haq et al., 1987.



Figures 9–11 (on this and following pages). Maps showing distribution cycles of Thanetian, Ypresian, and Lutetian–Bartonian strata, constructed from the sections shown in Figure 1. Symbols are used for the dominant facies type of deposits and facial provinces boundaries.

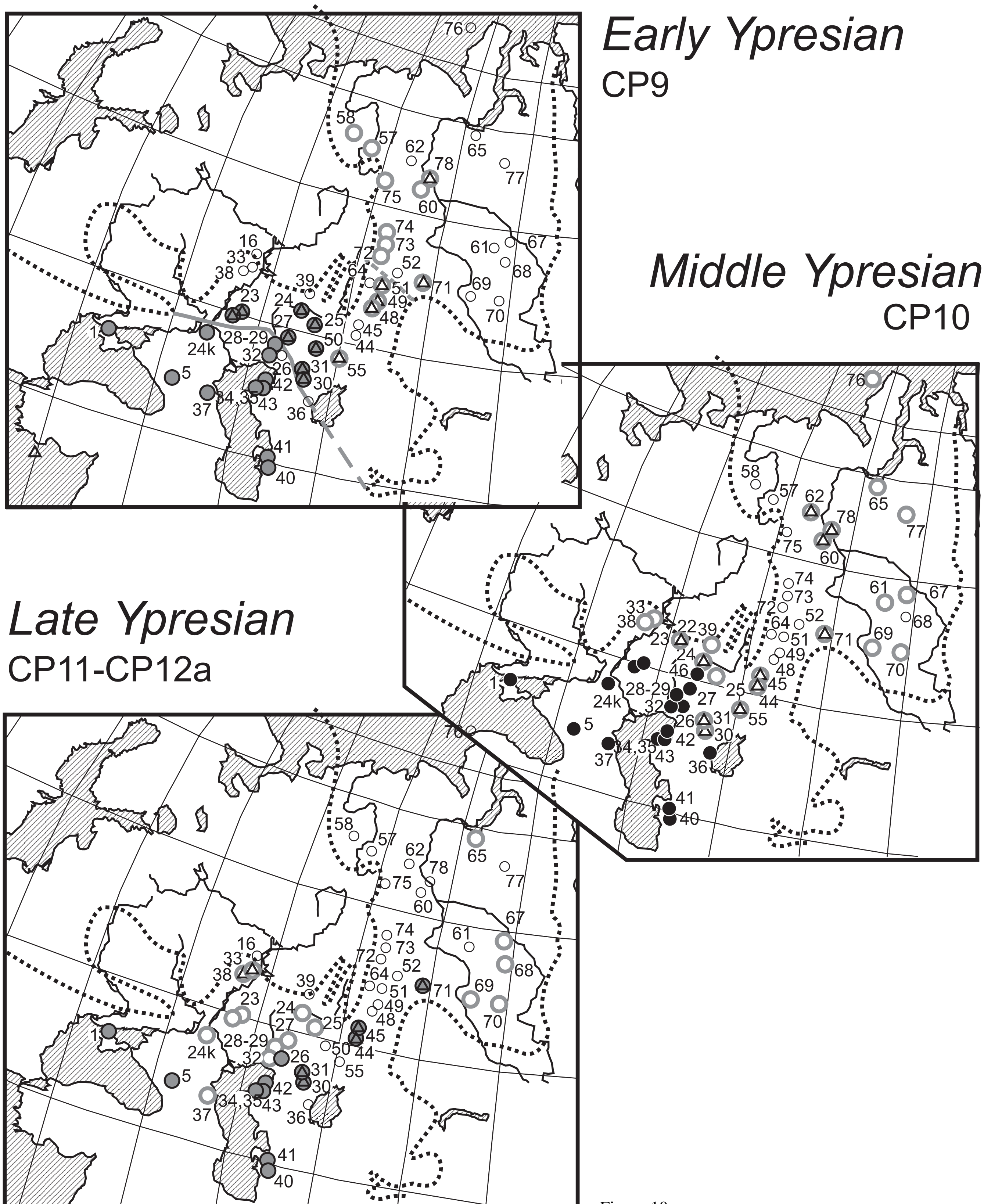

Early Ypresian
CP9
Middle Ypresian
CP10
Late Ypresian
CP11-CP12a

Figure 10

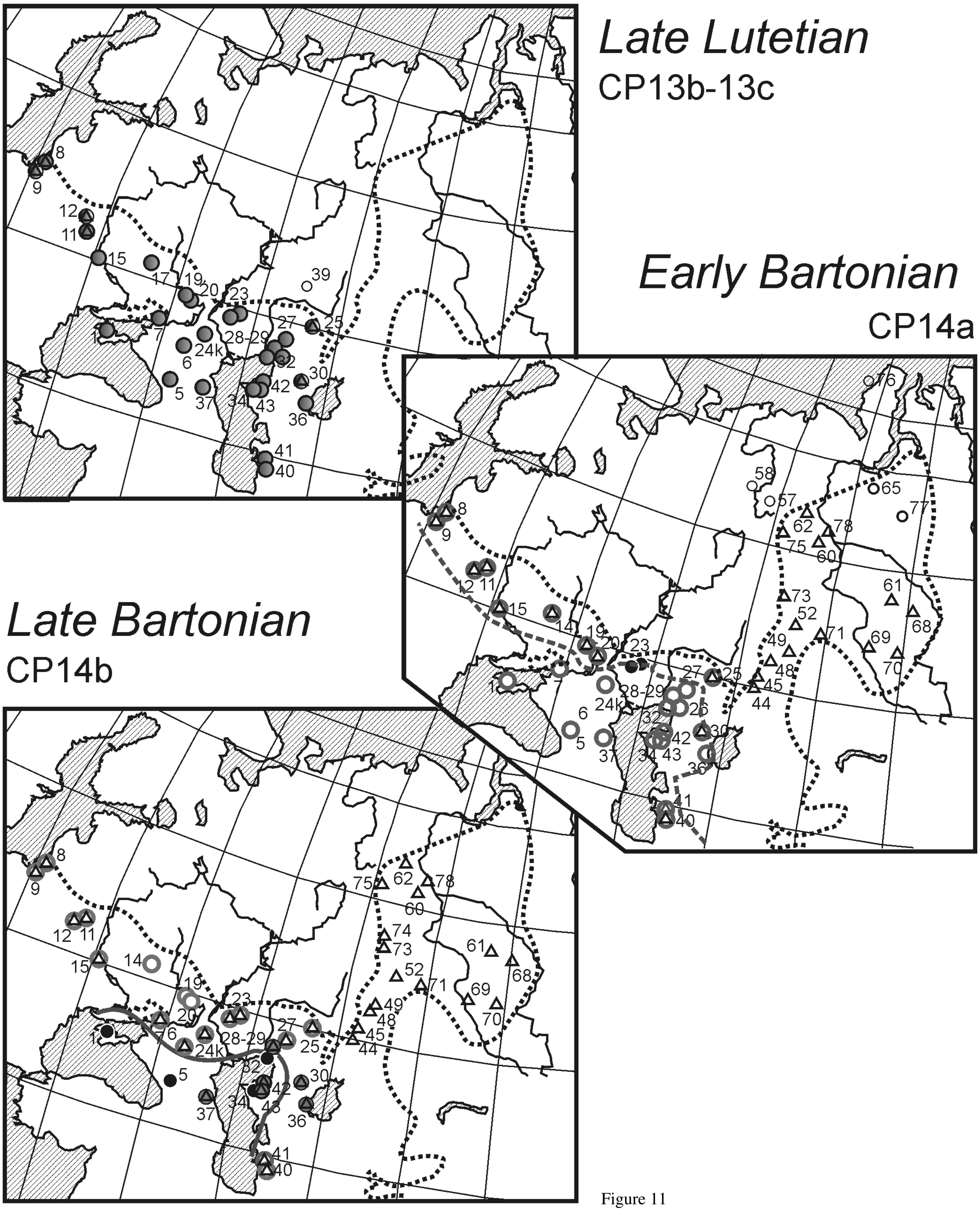

Late Lutetian
CP13b-13c
Early Bartonian
CP14a
Late Bartonian
CP14b

Figure 11

strongest, with the result that biogenic siliceous sediments then covered vast territories. Biogenic siliceous sediments penetrated into the Transitional and then into Southern provinces. Tectonic rearrangements of the early Lutetian led to a considerable regression. The link with the Arctic basin via West Siberia was cut and the geographic pattern of the late Lutetian to Bartonian transgression was essentially different.

The Southern province, as in the previous phase, shifted a significant distance southward. The Transitional province was restricted to the northern periphery of the Caucasus and the eastern Peri-Caspian. The Northern province was limited to within the Dneper-Donets basin, Lower Volga region, and eastern part of Turan plate (Fig. 11). Facies boundaries between the provinces were not sharp. Deposits of the lower upper Lutetian "Keresta" cycle in all three provinces have a similar facies aspect. They are characterized by green-colored calcareous facies with glauconite. At the Lutetian-Bartonian transition, the Southern province experienced a significant change in its depositional environment, and the disoxic "Kuma" basin, represented by coffee-colored bituminous marls, took shape there. Its formation is attributed to either a partial isolation from Tethys or to a considerable tectonic sagging of the basin, whose boundaries remained the same as previously.

The entire area of West Siberia turned into a gulf, and its links with normal marine basins were restricted (Shatsky, 1978). The distribution of siliceous facies and the siliceous biotic composition are suggestive of new northern links of the Peri-Tethyan basin with the Norwegian Sea via a system of seaways. The expansion of siliceous facies, in the early Bartonian, into northern Turkmenistan and, in the late Bartonian, into the Kopet Dagh and Central Asia, might point to new, southern, links with the Eastern Tethys.

Transgression scenario

Therefore, in the early Paleogene, the scenario of all three eustatic transgressions was the same in the entire northern Peri-Tethys and included several pulses. The transgression involved Tethyan water masses advancing from south to north, into the Northern province, and the development of a continuous circulation system including the Tethys, as evidenced by the appearance of numerous tropical microplankton species. During the same interval, the Northern province had a biota of its own, represented by siliceous microplankton. This phase gives no evidence of mutual penetration of the two biotas, which means that water masses of the Northern and Southern provinces did not interact. Then, a new phase in basinal evolution began, during which northern water masses transgressed to the south. This is evidenced by siliceous facies appearing in the Transitional province. Evidently, each transgression developed in several pulses, as evidenced by the hiatuses and lack of certain zonal assemblages of siliceous and organic walled organisms, observed in the uppermost Thanetian, Ypresian, and lower Bartonian strata in the Northern and Transitional provinces. Meanwhile, in the Southern province, Tethyan circulation was suffering destruction, with ensuing temporary anoxic environments.

During the terminal intervals of the Thanetian, Ypresian, and Bartonian, siliceous plankton penetrated into the Southern province, displacing considerably the calcareous plankton, with siliceous-terrigenous facies appearing in many sections of the Southern province. Therefore, during each transgression, the Arctic waters reached the Tethyan region proper, and water exchange took place between the two basins. Seaways between the Tethyan and Arctic basins changed throughout the early Paleogene. In the late Thanetian, the link was effectuated via the Baltic passage and the Dnieper-Donets basin on the one hand and via West Siberia and the Urals on the other. In the late Ypresian, the only link was via West Siberia, but it ensured an extensive exchange between the Arctic and Atlantic. In the Bartonian, the link was via the Norwegian Sea and the Dnieper-Donets basin. Evidently, the Tethyan basin communicated only with the North Atlantic.

CONCLUSIONS

The above correlation of Paleogene deposits between northern and southern areas of the eastern European craton, West Siberia, and Turan plate is as detailed as the resolving power of the methods used can afford. As discussed above, zonal stratigraphy of contrasting facies in continental sections has its limitations, due largely to transgressive-regressive cyclicity.

We are fully aware of the insufficient precision of the cyclic analysis techniques at hand. Needless to say, the use of seismostratigraphic techniques may refine considerably the cyclicity pattern for particular areas. However, across a study region as vast as ours, the use of zonal stratigraphy combined with the cyclic analysis, which draws on through-stratigraphy lithologic changes, supplemented in a number of sections by environmental analysis of microplankton assemblages, has enabled us (i) to introduce essential corrections to the synchronization of lower Paleogene deposits, (ii) to assess the ranges of hiatuses, and (iii) to propose a model for the Thanetian, Ypresian, and late Lutetian-to-Bartonian transgressions, which all followed the same scenario. This, still tentative, model requires a firm oceanologic justification, which is as yet to be elaborated.

ACKNOWLEDGMENTS

Our investigation of the links between northern and southern Paleogene domains in the northern Peri-Tethys was inspired by H. Oberhänsli, who formulated the study objective, *Climate Relevance of Sapropelite in a World Changing from a Nonglaciated to Glaciated Mode,* to our team in the context of the INTAS Project 93-2509. Our fieldwork, sample collection, and interpretation of regional geological data would hardly have been possible without the invaluable help from geoscientists and leaders of regional geological surveys, V.A. Martynov and V.D.

Dergachev (West Siberia), R.A. Segedin and T.R. Akopov (Western Kazakhstan), V.G. Pronin (Peri-Caspian Region), E.G. Sidorov, V.I. Musatov, and A.S. Zastrozhnov (Volga region), E.I. Kovalenko (Northern Caucasus), and Yu.I. Iosifova (the Dnieper-Donets basin), to all of whom we are deeply grateful. Thanks are due to E. Aleksandrova for her assistance with graphics and to I. Kravchenko-Berezhnoy for translating this paper into English. This work was supported by the Russian Foundation for Basic Research, project nos. 98-05-65060, 00-05-64917.

REFERENCES CITED

Akhmetiev, M.A., and Zaporozhets, N.I., 1996, Changes in dinocysts assemblages as reflecting in ecosystem transformations in the Russian Platform, Crimea, Caucasus, and Turan plate during Paleogene and early Miocene, *in* Kuznetsova, K.I., and Muzylöv, N.G., eds., Fossil microorganisms as the basis of the Phanerozoic stratigraphy, correlation, and paleobiogeography: Moscow, GEOS, p. 55–69 (in Russian).

Akhmetiev M.A., Alexandrova, G.N., Amon, E.O., Beniamovski, V.N., Bugrova, E.M., Vasilieva, O.N., Gleser, Z.I., Zhelezko, V.I., Zaporozhets, N.I., Kozlova G.E., Nikolaeva, I.A., Oreshkina, T.V., Panova, L.A., Radionova, E.P., Strelnikova, N.I., and Iakovleva, A.I., 2001, Biostratigraphy of the marine Paleogene of Western Siberia: Stratigraphy and Geological Correlation, v. 9, no. 2, p. 30–57.

Allen, Ph.A., and Allen, J.R., 1990, Basin analysis principles and applications: Oxford, Blackwell Scientific Publications, 451 p.

Amon, E.A., 1994, Radiolarians assocations from the Paleogene deposits of Kichigino section, South Cis-Urals, *in* Chuvashov, B.I., et al., eds., New data on Uralian upper Paleozoic and lower Cenozoic stratigraphy: Ekaterinburg, Uralian Branch of Academy of Science of Soviet Union, p. 151–162 (in Russian).

Andreeva-Grigorovich, A.S., 1985, Zonal subdivision of Paleocene–Eocene deposits of the Soviet Union based on dinocysts: Geological Journal, Kiev, v. 6, p. 112–119 (in Russian).

Beniamovski, V.N., Levina, A.P., Pronin, V.G., and Tabachnikova, I.P., 1989, The Paleogene deposits of Turgay depression: Izvestiya Vysshikh Uchebnykh Zavedeniy, Geologia i Razvedka, no. 5, p. 3–14 (in Russian).

Beniamovski, V.N., Levina, A.P., Pronin V.G., and Tabachnikova, I.P., 1991, The lower Eocene deposits of Turgay depression: Izvestiya Vysshikh Uchebnykh Zavedeniy, Geologia i Razvedka, no. 7, p. 3–16 (in Russian).

Beniamovski, V.N., Vasilieva, O.N., Levina, A.P., and Pronin, V.G., 1993, The Paleogene of south Trans-Urals, Paper 1: Paleogene deposits of the southern Turgay depression: Izvestiya Vysshikh Uchebnykh Zavedeniy, Geologia i Razvedka, no. 6, p. 22–36 (in Russian).

Beniamovski, V.N., Alekseev, A.S., Nezlina, E.Y., and Oberhänsli, H., 1999, The anoxic Kuma Formation (Bartonian) from the eastern Peri–Tethys: An environment study, *in* Schmitz, B., et al., eds., Early Paleogene warm climates and biosphere dynamics: GFF, v. 122 (abstracts).

Berggren, W.A., Kent, D.V., Swisher, C.C., III, and Aubry, M.P., 1995, A revised Cenozoic geochronology and chronostratigraphy, *in* Berggren, W.A., et al., eds., Geochronology, time scales, and global stratigraphic correlations: SEPM (Society for Sedimentary Geology) Special Publication 54, p. 129–212.

Bugrova, E.M., 1991, Paleogene Nummulites and Discocylines from eastern part of Central Asia: Izvestiya Akademii Nauk SSSR, Serya geologicheskaya, no. 1, p. 58–70 (in Russian).

Bugrova, E.M., Gleser, Z.I., Panova, L.A., Tabachnikova, I.P., Larionova, E.M., Gladkova, V.I., and Tkachenko, N.S., 1997, Biostratigraphy of the Paleogene key-section of the east Peri-Caspian region based on microfossils: All-Russian Institute of Geology (VSEGEI), St. Petersburg, Regional Geology and Metallogeny, no. 6, p. 64–76 (in Russian).

Bugrova, E.M., Zakrevskaya, E.Yu., and Tabachnikova, I.P., 2002, New Data on Paleogene biostratigraphy of the eastern Crimea: Stratigraphy and Geological Correlation, v. 10, no. 1, p. 83–93.

Chirva, S.A., 1971, Eocene sediments of the northern West Siberia and some problems of their correlation: Geology and Geophysics, no. 1, p. 44–55 (in Russian).

Chirva, S.A., and Lyubomirova, K.A., 1973, Marine and continental Paleogene correlation of the northern West Siberia, *in* Shatsky, S.B., ed. Marine and continental Paleogene of Siberia: Novosibirsk, Nauka, p. 69–77 (in Russian).

Fursenko, A.V., and Fursenko, K.B., 1961, The upper Eocene foraminifers in Belarus and their stratigraphic implications: Paleontology and Stratigraphy of the Belorusskaya Soviet Republic, sbornik 3, p. 246–361 (in Russian).

Gavrilov, Yu.O., and Muzylöv, N.G., 1992, The geochemistry of sapropelite interbeds in the Paleogene of the Central Caucasus: Lithology and Mineral Resources, v. 26, no. 6, p. 548–559.

Gavrilov, Y.O., Kodina, L.A., Lubchenko, I.Y., and Muzylöv, N.G., 1997, The Late Paleocene anoxic event in epicontinental seas of Peri-Tethys and formation of the sapropelite unit: Sedimentology and geochemistry: Lithology and Mineral Resources, v. 32, p. 427–450.

Gavrilov, Yu.O., Shcherbinina, E.A., and Muzylöv, N., 2000, A Paleogene sequence in the central North Caucasus: A response to paleoenvironmental changes, *in* Schmitz, B., et al., eds., Early Paleogene warm climates and biosphere dynamics: GFF, v. 122, p. 51–53.

Gleser, Z.I., 1996, Problems of Eocene siliceous phytoplankton zonation (exemplified by Caspian Eocene deposits): Stratigraphy and Geological Correlation, v. 4, no. 4, p. 83–92.

Gleser, Z.I., and Stepanova, G.V., 1994, Paleogene deposits of Kara sea subdivision and correlation based on diatoms and silicoflagellates: All-Russian Institute of Geology (VSEGEI), St. Petersburg, Regional Geology and Metallogeny, no. 2, p. 148–153 (in Russian).

Grachev, N.V., Zhizhchenko, B.P., Kolykhalova, L.A., and Kholodilina, T.S., 1971, The Paleogene deposits between Volga and Ural rivers, *in* Zhizhchenko, B.P., and Ivanova, V.A., eds., Cenozoic stratigraphy and paleogeogrphy of gas-bearing region of the southern Soviet Union, v. 31\39–32\40, p. 36–44 (in Russian).

Grossgeim, A.V., 1960, The Paleogene of the Northwest Caucasus: Transactions of the Krasnodar Branch of the All-Union Oil-and-Gas Research Institute, v. 4, p. 3–190.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1987, Chronology of fluctuating sea levels since the triassic: Science, v. 235, p. 1156–1167.

Iakovleva, A.I., 1998, Eocene microphytofossils from the Sari-Oba section (north Aral region): Bulletin of the Moscow Naturalist Society, Geological section, v. 73, no. 3, p. 51–55 (in Russian).

Iakovleva, A.I., 2000, Biostratigraphical and paleogeographical role of the Paleocene–Eocene dinoflagellates in Western Siberia and adjacent regions (Petchora depression and Turgay Trough), *in* Schmitz, B., et al., eds., Early Paleogene warm climates and biosphere dynamics: GFF, v. 122, p. 82–83.

Iakovleva, A.I., and Kulkova, I.A., 2001, Paleocene–Eocene dinoflagellate cysts and continental palynomorphs of the Pur Downstream Basin (Northwestern Siberia): Biostratigraphical and paleoenvironmental implication: Revista Española de Micropaleontologica, v. 33 no. 1, p. 1–33.

Iakovleva, A.I., Cavagnetto, C., and Rousseau, D.D., 2000a, Paleocene–Eocene dinoflagellate stratigraphy of the borehole No. 4 (Central Western Siberia): AASP Palynology, v. 24, p. 187–200.

Iakovleva, A.I., Kulkova, I.A., and Cavagnetto, C., 2000b, Eocene microphytofossils (dinoflagellate cysts and continental palynomorphs) of Northwestern Siberia (Severnaya Sosva Basin): Newsletters on Stratigraphy, v. 38, no. 1, p. 13–38.

Iakovleva, A.I., Oreshkina, T.V., Alekseev, A.S., and Rousseau, D.D., 2000c, A new paleontological and paleogeographical data in the Pechora depression, northeastern European Russia: Comptes Rendus de l'Académie des Sciences de France, Série II, v. 330, p. 485–491.

Iarkin, V.I., editor, 1989, Regulations of the Interdepartmental Stratigraphic Committee (ISC) and its constant commissions (decisions of the XVI Plenum of the Paleogene system): All-Russian Institute of Geology (VSEGEI) Leningrad, v. 21, p. 51–54 (in Russian).

Ilyina, V.I., Kulkova, I.A., and Lebedeva, N.K., 1994, Dinoflagellate cysts of the marine Paleogene, *in* Chlonova, A.F., ed., Microphytofossils and detailed stpatigraphy of marine Mesozoic and Cenozoic of Siberia: Russian Academy of Sciences Siberian Branch, United Institute of Geology, Geophysics and Mineralogy Transaction, v. 818, p. 98–107 (in Russian).

Kazmin, V.G., Sborschikov, I.N., Ricou, L.A., Zonenshain, L.P., Poulen, J., and Knipper, A.L., 1987, Volcanic belt as indicator of the Mesozoic–Cenozoic activity of the Eurasia edge, *in* Monin, A.S., and Zonenshain, L.P., eds., Geological history of the Tethys Ocean: P.P. Shirshov Institut of Oceanology, p. 58–74.

Khokhlova, I.E., Radionova, E.P., Beniamovsi, V.N., and Shcherbinina, E.A., 1999, Eocene stratigraphy of key sections of the Dnieper-Donetz depression based on calcareous and siliceous microplankton: Geodiversitas, v. 21, no. 3, p. 453–476.

Kopp, M.L., and Scherba, I.G., 1998, Caucasian Basin in the Paleogene: Geotectonics, v. 2, p. 29–50.

Korovina, G.M., 1970, Zonal subdivision and facies of "Kuma" Horizon of upper Eocene "Bodrak" regional stage of West Turkmenistan, *in* Shutskaya, E.K., ed., Stratigraphy and paleontology Mezosoic and Paleogene deposits of Central Asia: Transactions of All-Russian Petroleum Exploration Institute (VNIGNI), v. 49, p. 122–128 (in Russian).

Kozlova, G.E., 1999, Paleogene boreal radiolarians from the Russia: St. Petersburg, All-Russian Petroleum Research Exploration Institute (VNIGRI), v. 9, 323 p. (in Russian).

Kozlova, G.E., and Strelnikova, N.I., 1984, Significance of the section of Ust-Maninsk hole 19-V for zonal division of the West Siberian Paleogene, *in* Shatsky, S.B., ed., Environment and life at the boundaries of Cenozoic epochs in Siberia and the Far East: Novosibirsk, Nauka, p. 70–78 (in Russian).

Kozlova, G.E., Strelnikova, N.I., and Khokhlova, I.E., 1998a, Marine Paleogene of the southwestern Ural region: The siliceous microplankton stratigraphy (Holes SP-1 and 148), *in* Knipper, A.L., et al., eds., The Urals: Fundamental problems of geodynamics and stratigraphy: Moscow, Nauka, Transactions of Geological Institute, v. 500, p. 193–205 (in Russian).

Kozlova, G.E., Radionova, E.P., Scherbinina, E.A., Khokhlova, I.E., Oreshkina, T.V., Beniamovski, V.N., and Iakovleva, A.I., 1998b, Late Paleocene changes in the northeastern Peri-Tethys: Comparative study of the Sokolovsky Quarry (Turgay Passage) and Sengiley (middle reaches of the Volga) sections: Strata, série 1, v. 9, p. 72–74.

Krasheninnikov, V.A., 1982, Paleogene Stratigraphy of the northwestern part of the Pacific Ocean: Transactions of the Geological Institute, v. 389, 142 p. (in Russian).

Krasheninnikov, V.A., and Muzylöv, N.G., 1975, Relationship of zonal schemes by planktonic foraminifera and nannofossils in the Paleogene sections of the North Caucasus: Moscow, Nauka, Voprosy micropaleontologii, v. 18, p. 212–224 (in Russian).

Kriventsov, A.V., 1973, Paleogene deposits of Chizhapka river: The Paleogene of central part of West Siberia, *in* Shatsky, S.B., ed., Marine and continental Paleogene of Siberia: Novosibirsk, Nauka, p. 40–46 (in Russian).

Kurgalimova, G.G., and Moksyakova, A.M., 1970, New data on the stratigraphic range of the lower part of the Tasaran Formation in North Cis-Aralian, *in* Shutskaya, E.K., ed., Mesozoic and Paleogene deposits of Central Asia stratigraphy and paleontology: Transactions of All-Russian Petroleum Exploration Institute (VNIGNI), v. 49, p. 129–134 (in Russian).

Leonov, G.P., 1964, The main problems of Paleogene stratigraphy of the Russian plate: Moscow State University Publication, Moscow, 552 p. (in Russian).

Martini, E., 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation, *in* Farinacci, A., ed., Proceedings of the 2nd Planktonic Conference, Rome, Italy, 1970: Tecnoscienza, v. 2, p. 739–785.

Meulenkamp, J.E., and Sissingh, W., 2000, Map 17–23 Tertiary, *in* Crasquin, S., coordinator, Explanatory notes, *in* Dercourt, J., et al., eds., Atlas Peri-Tethys paleogeographical maps: Paris, Commission for the Geologic Map of the World, p. 153.

Muzylöv, N.G., 1994, Anoxic events of Paleocene–Eocene, *in* Rozanov, A.Yu., and Semikhtov, M.A., eds., Ecosystem reorganizations and the evolution of biosphere: Moscow, Nedra, v. 1, p. 160–166 (in Russian).

Muzylöv, N.G., 1996, Early Paleogene episodes of eruptive activity in the east Peri-Tethys and their possible influence on the marine microbiota, *in* Kuznetsova, K.I., and Muzylöv, N.G., eds., Fossil microorganisms as the basis of the Phanerozoic stratigraphy, correlation, and paleobiogeography: Moscow, GEOS, Voprosy mikropaleotologii, v. 31: p. 128–132 (in Russian).

Muzylöv, N.G., Pyzhonkova, E.A., and Khodzhakhmedov, K.A., 1987, The lower Paleogene nannoplankton stratigraphy of South Turkmenistan (South Kopet Dagh, Lessor Balkhan, Gyaursky Kopet Dagh): Moscow, Nauka, Voprosy mikropaleotologii, v. 29, p. 114–128 (in Russian).

Muzylöv, N.G., Benyamovskii, V.N., and Tabachnikova, I.P., 1989, Sapropel interlayers in lower Paleocene deposits of the southern Soviet Union: Izvestia Akademii Nauk SSSR, Seria Geologicheskaya, v. 11, p. 117–119 (in Russian).

Muzylöv, N.G., Beniamovski, V.N., Gavrilov, Yu.O., Shcherbinina, E.A., and Stupin, S.I., 1996, Paleontological and geochemical features of the Central Caucasian upper Paleocene sapropelite, *in* Kuznetsova, K.I., and Muzylöv, N.G., eds., Fossil microorganisms as the basis of the Phanerozoic stratigraphy, correlation, and paleobiogeography: Moscow, GEOS, Voprosy mikropaleotologii, v. 31, p. 117–127 (in Russian).

Naidin, D.P., and Beniamovski, V.N., 1994, The Suvlukaya Paleogene section (Crimea): Stratigraphy and Geological Correlation, v. 2, no. 3, p. 75–86.

Naidin, D.P., Beniamovski, V.N., and Kopaevich L.F., 1994, A paleogeographic basis for stratigraphic construction: Moscow State University Publication, Moscow, 136 p. (in Russian).

Naidin, D.P., Beniamovski, V.N., and Kopaevich L.F., 1996, Paleocene reference sections of Mangyshlak: Stratigraphy and Geological Correlation, v. 4, no. 3, p. 46–61.

Oberhänsli, H., and Beniamovski, V.N., 2000, Planktonic and benthic assemblages from the late Ypresian–early Lutetian marly and TOC-rich sediments of the Central pre-Caucasus and west coast of the Aral Sea, *in* Schmitz, B., et al., eds., Early Paleogene warm climates and biosphere dynamics: GFF, v. 122, p. 121–123.

Okada, H., and Bukry, D., 1980, Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973, 1975): Micropaleontology, v. 5, no. 3, p. 321–325.

Oreshkina, T.V., 2000, New data on early Eocene diatom succesion of the west Polar Urals margin: Paleoclimatic and paleobiogeographic implications, *in* Schmitz, B., et al., eds., Early Paleogene warm climates and biosphere dynamics: GFF, v. 122, p. 124–126.

Oreshkina, T.V., and Khokhlova, I.E., 1999, Early Paleogene siliceous microfossils of the Middle Volga region: Stratigraphy and paleogeography: Geodiversitas, v. 21, no. 3, p. 429–451.

Pechonkina, A.P., and Kholodilina, T.S., 1971, The data on Volga and Ural Paleogene deposits stratigraphy based on foraminifers, *in* Zhizhchenko, B.P., and Ivanova, V.A., eds., Cenozoic stratigraphy and paleogeogrphy of gas-bearing region of the southern Soviet Union, v. 31\39–32\40, p. 25–35 (in Russian).

Powell, A.J., 1992, Dinoflagellate cysts of the Tertiary System, *in* Powell, A.J., ed., A stratigraphic index of dinoflagellate cysts: London, Chapman and Hall, p. 155–251.

Radionova, E.P., 1998, Methods of construction of the Paleogene epicontinental zonal scales by diatoms (demonstrated with subdivision of Eocene sediments (Hole SP-1, northeastern pre-Caspian region), *in* Knipper, A.L., et al., eds., The Urals: Fundamental problems of geodynamics and stratigraphy: Moscow, Nauka, Transactions of Geological Institute, v. 500, p. 206–220 (in Russian).

Radionova, E.P., and Khokhlova, I.E., 1994, Paleogene episodes of biogenic silica accumulation in the northern Caucasus and adjacent Tethyan regions: Stratigraphy and Geological Correlation, v. 2, no. 5, p. 161–169.

Radionova, E.P., and Khokhlova, I.E., 2000, Was the North Atlantic connected via the Arctic with the Tethys in the early Eocene? Evidence from siliceous plankton, *in* Schmitz, B., et al., eds., Early Paleogene warm climates and biosphere dynamics: GFF, v. 122, p. 133–134.

Radionova, E.P., Oreshkina, T.V., Khokhlova, I.E., and Beniamovski, V.N., 1994, Eocene deposits on the northeastern slope of the Dnieper-Donets depression: Zonal stratigraphy and cyclic analysis: Stratigraphy and Geological Correlation, v. 2, no. 6, p. 85–102.

Radionova, E.P., Khokhlova, I.E., Beniamovski, V.N., Shcherbinina, E.A., Iakovleva, A.I., and Sadchikova, T.A., 2001, Paleocene–Eocene transition in the northeastern Peri-Tethys area: Sokolovskii key section of the Turgay Passage (Kazakhstan): Bulletin de la Société Géologique de France, v. 172, no. 2, p. 245–256.

Rodionova, M.K., 1963, Foraminifera from the upper Eocene deposits of West Turkmenistan, *in* Aliev, M.M., ed., Foraminifera from Cretaceous and Paleogene deposits of West Turkmenistan: Moscow, USSR Academy of Sciences, p. 58–92.

Rubina, N.V., 1973, Paleogene and Neogene stratigraphy of marine and continental deposits of West Siberia based on paleoalgology, *in* Shatsky, S.B., ed., Marine and continental Paleogene of Siberia: Novosibirsk, Nauka, p. 67–96.

Shatsky, S.B., 1978, Main problems of Paleogene stratigraphy and paleogeography of Siberia, *in* Shatsky, S.B., ed., Paleogene and Neogene of Siberia: Novosibirsk, Nauka, p. 3–21 (in Russian).

Shatsky, S.B., Aleksandrova, V.A., Bogdashev, V.A., Vasilev, I.P., Gorbovetz, A.N., Goriukhin, E.A., Kriventzov, A.V., Silvestrov, N.B., Stasov, V.I., Tolkachev, M.V., Fadeev, A.I., Freiman, E.V., and Shamakhov, A.V., 1973, The Paleogene of central part of West Siberia, *in* Shatsky, S.B., ed., Marine and continental Paleogene of Siberia: Novosibirsk, Nauka, p. 6–39 (in Russian).

Shcherbinina, E.A., 2000, Middle Eocene nannofossils and geological events of the northeastern Peri-Tethys, *in* Schmitz, B., et al., eds., Early Paleogene warm climates and biosphere dynamics: GFF, v. 122, p. 51–53.

Shutskaya, E.K., 1970, Stratigraphy, foraminifers, and paleogeography of the lower Paleogene in the Crimea, Ciscaucasus, and western part of Central Asia: Moscow, Transactions of All-Russian Petroleum Exploration Institute (VNIGNI), v. 70, 256 p. (in Russian).

Solun, V.M., editor, 1975, Paleogene of Turkmenistan (biostratigraphy and correlation): Ashkhabad, Alim, 195 p. (in Russian).

Strelnikova, N.I., 1992, Paleogene diatom algae: St. Petersburg State University Publication, St. Petersburg, 311 p. (in Russian).

Strelnikova, N.I., Kaplan, L.A., and Travina, M.A., 1978, Paleogene diatoms, silicoflagellates and ebridiea of Kaliningrad region, *in* Jouse, A.P., ed., Marine micropaleontology (diatoms, radiolarians, silicoflagellates, foraminifers, and calcareous nannoplankton): Moscow, Nauka, p. 57–65 (in Russian).

Stupin, S.I., and Muzylöv, N.G., 2001, The late Paleocene ecologic crisis in epicontinental basins of the eastern Peri-Tethys: Microbiota and accumulation conditions of sapropelitic bed: Stratigraphy and Geological Correlation, v. 9, no. 5, p. 87–93.

Vasilieva, O.N., 1994, Microphytoplankton association from the North Cis-Aralian and Usthurt regions (Kazakhstan), *in* Chuvashov, B.I., and Amon, E.A., eds., New data on Uralian late Paleozoic and lower Cenozoic stratigraphy: Ekaterinburg, Uralian Branch of Academy of Science of Soviet Union, p. 163–172 (in Russian).

Vasilieva, O.N., Zhelezko, V.I., and Lubcheko, G.N., 1994, Biostratigraphy of marine Paleogene deposits based on dinocysts and sharks in Kurgan town region, *in* Chuvashov, B.I., and Amon, E.A., eds., New data on Uralian late Paleozoic and lower Cenozoic stratigraphy: Ekaterinburg, Uralian Branch of Academy of Science of Soviet Union, p. 139–151 (in Russian).

Zonenshain, L.P., and Le Pichon, X., 1987, Deep-water basins of the Black and Caspian seas: Remnants of Mesozoic back-arc basins, *in* Monin, A.S., and Zonenshain, L.P., eds., Geological history of the Tethys Ocean: P.P. Shirshov Institute of Oceanology, p. 74–93 (in Russian).

Manuscript Accepted by the Society August 13, 2002