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# Paleogene floral assemblages around epicontinental seas and straits in Northern Central Eurasia: proxies for climatic and paleogeographic evolution

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## ABSTRACT

Paleogene connection of Tethyan and Paleoarctic water masses and biotas was largely enhanced by a N-S trending epicontinental seaway in northern Central Eurasia, which extended from the Aral Sea to the Amerasian deep basin of the Paleoarctic. This seaway enabled warm waters to impinge into polar latitudes, being a kind of "radiator" for the Arctic. Its closure had immediate effect on climatic conditions and terrestrial flora in the Arctic and entire North Eurasia. The Kara and West Siberian epicontinental seas, which were the major components of this N-S trending seaway, were connected to adjacent oceanic basins by a system of straits. Opening, closure, narrowing and widening of these straits in the Early Cenozoic determined the evolution of the marine ecosystems and current development, as well as the related depositional processes and biota (especially flora). The evolution of these straits also influenced on the Northern Hemisphere climatic fluctuations that took place during the Paleogene transition from a warm to a colder paleoclimatic state of the Earth system.

*KEYWORDS* | **Paleogene. North Central Asia. Sea straits. Flora. Climate.**

## INTRODUCTION

The relevance of the Paleogene flora from Northern Central Eurasia was put forward during the 80–90's of the past century, when the Turgai Strait area was studied in detail in the frame of the IGCP Projects 174 (Terminal Eocene Events) and 326 (Oligocene–Miocene Transition in the North Hemisphere). These studies showed that the Cenozoic floral record of this area is more complete than that of West and Central Europe. However, many other localities from Northern Central Eurasia that are equally important remain less poorly known, although field work and collection of plant fossils have continually been carried out since the late seventies in a vast area that comprises the Volga River and Aral Sea areas, the Turgai Trough, the South and East Transuralian, the Western Siberian Plate, the Zaisan Lake Basin and other parts of Kazakhstan and Middle Asia (Fig. 1). In addition, private collections from many reference sections and localities, such as Taizhuzgen, Kara-Biryuk and Kiin-Kerish (Zaisan Lake Basin), Romankol and Baky (South Ural and South East Transuralian), Zhaman-Kaindy and Tortmolla (Turgai Through), the Amur River area (many localities of Tsagayan–type Flora), the Volgograd district

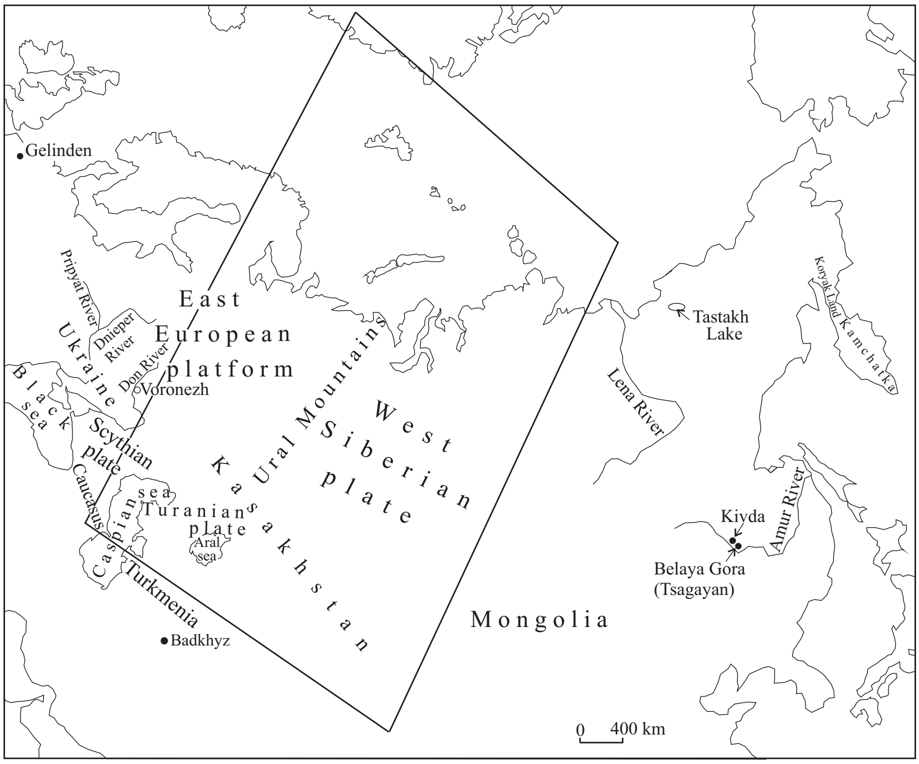


FIGURE 1 | **General map of North Eurasia showing geographic and tectonic elements mentioned in the text. Boxed area is that of Figures 2 to 4. Main localities of Paleogene flora are shown: Gelinden, Badkhyz, Belaya Gora, Kivda and Tastakh Lake.**

(Kamyshin) and some North Siberian localities have also been studied (Figs. 1 and 2). On the basis of this information, Paleogene stratigraphic schemes of the Central and South Russian Plate, the West Siberian Plate and the Transuralian area were established between 1997 and 2002, and the correlation of their main stratigraphic subdivisions was specified.

As a result of all this work, Akhmetiev (1987, 1990, 2004 and 2005) described the Paleogene flora of the Northern Central Eurasia and compared it with other analogues within the context of the Paleogene phytostratigraphy and palaeoclimatology. Unfortunately this information is not easily accessible, far less understandable, to non-Russian researchers. Therefore, this paper deals with providing a comprehensive and updated summary that might eventually prove useful to improve the knowledge of the Paleogene global climate and distribution of floras.

## PALEOGEOGRAPHIC SETTING

In the Late Cretaceous connections between Paleoarctic and Tethyan water masses and biotas were provided mostly by two N-S trending epicontinental seaways: (1) the Western Interior Basin of North America that stretched for 4,800 km along the Cordilleras from the Gulf of Mexico to the Beaufort Sea; and (2) the West Siberian–Turgai Basin in northern Central Eurasia.

In the Paleogene, after the Western Interior Basin was closed in the Maastrichtian, only the northern Central Eurasia epicontinental seaway remained (Figs. 1 to 3). These marine zones, which included the Kara and West Siberian seas, as well as the straits connecting them with the oceans, extended for 3,500 km from the Aral Sea in the south to the recent Franz Josef Land and the Severnaya Zemlya in the north (Fig. 1 and 2). This N-S trending seaway defines a boundary between palynologically established paleophytogeographic subdivisions (i.e., kingdoms of *Normapolles* and *Aquilapollenites*; Zaklinskaya, 1977).

The strait system also controlled the surface and bottom marine currents, as well as Arctic upwelling. The currents played a decisive role in life, dispersion and migrations of planktonic and benthic marine organisms. Water depth, shoaling and the total or partial desiccation of the seaway directly depended on differently oriented tectonic structures and paleogeographic rearrangements. Opening or closure of straits and the consequent reorientation or disappearance of currents influenced exchanges of water masses and biotas. Variations in biotic endemism determined similarities and distinctions of regional biostratigraphic zonations and zonal correlations.

When the straits became closed or transformed into gulfs, land bridges were formed and connected neighbouring areas. These bridges allowed animal and plant communities to migrate to the west and east of Eurasia (Shatsky, 1978; Akhmetiev and Beniamovski, 2006).

## Evolution of the Paleogene seaway in Northern Central Eurasia

The Paleogene history of the northern Central Eurasian system of epicontinental seas and straits and the Tethys–Arctic connections, as well as the evolution of sedimentation, flora and climate were determined by successive changes in sea and strait configuration, sea current direction, transgressive-regressive cycles and varying interaction of boreal, subboreal and subtethyan water masses and biotas. The most important moments and intervals of biospheric changes are summarized below (Fig. 3).

1. The Cretaceous–Paleogene boundary time, when most of Eurasia and adjacent areas were above the sea level (Beniamovski, 2003, 2007) (Figs. 3 and 4A).

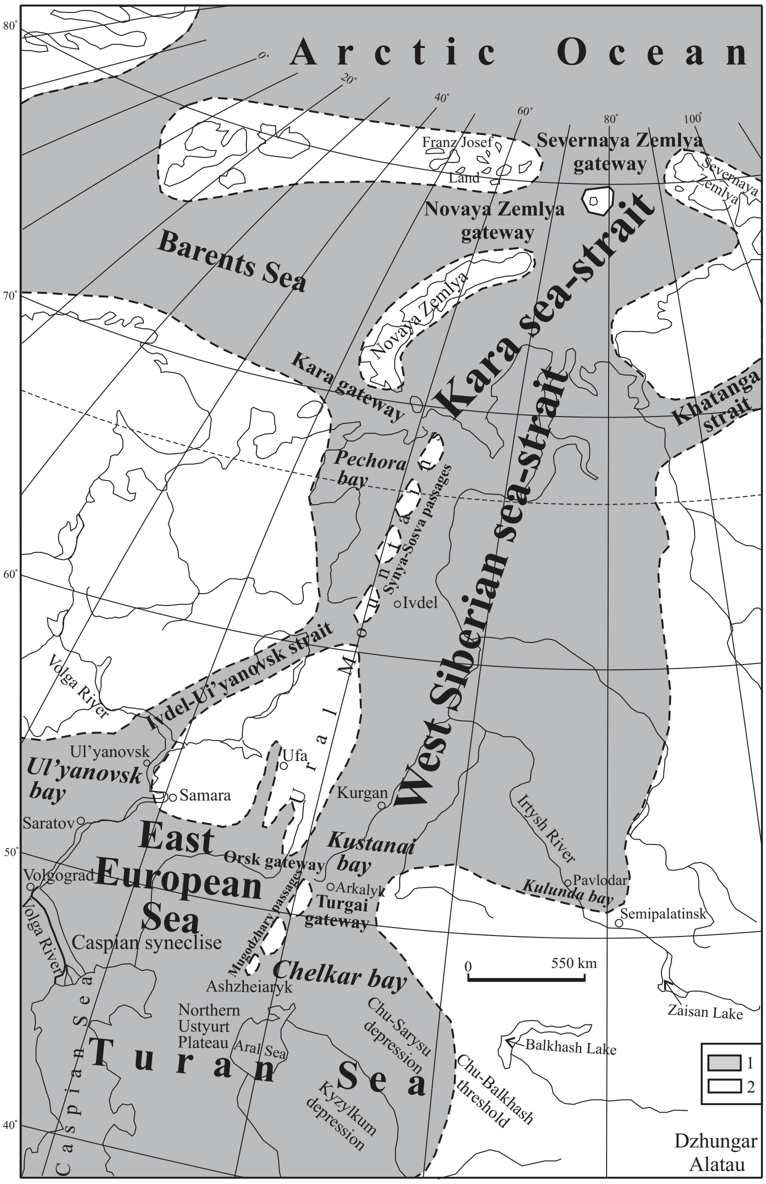


FIGURE 2 | **Paleogeographic map of the Paleogene N-S trending system of epicontinental seas and straits in Northern Eurasia (modified from Beniamovski, 2007). Location of paleogeographic features and geographic localities referred to in the text is shown. Key for Figures 2 to 4: 1 (grey): marine zones; 2 (white): emerged land.**

2. The Middle Danian transgression after the Cretaceous-Paleogene boundary regression. It resulted in a system of sea-straits and different gulfs, which formed the N-S trending epicontinental seaway connecting the Tethyan and Arctic oceans and transported low-latitude, warm water masses into northern basins (Beniamovski, 2003, 2007; Fig. 3).

3. In the Late Paleocene – Early Eocene interval, both the N-S and E-W trending sea connections were more widespread, and bottom and subsurface currents existed (Fig. 3). The northern system of seas and straits supplied the Kara–West Siberian Basin with boreal water masses containing siliceous and organic-walled biota from the North Sea and Danish basins, whereas the southern system provided subboreal and subtethyan water masses bearing warm-water planktonic and benthic forms. Mixing of water masses coming from different paleobiogeographic regions and of subsurface and bottom currents in upwelling areas induced the accumulation of biosiliceous

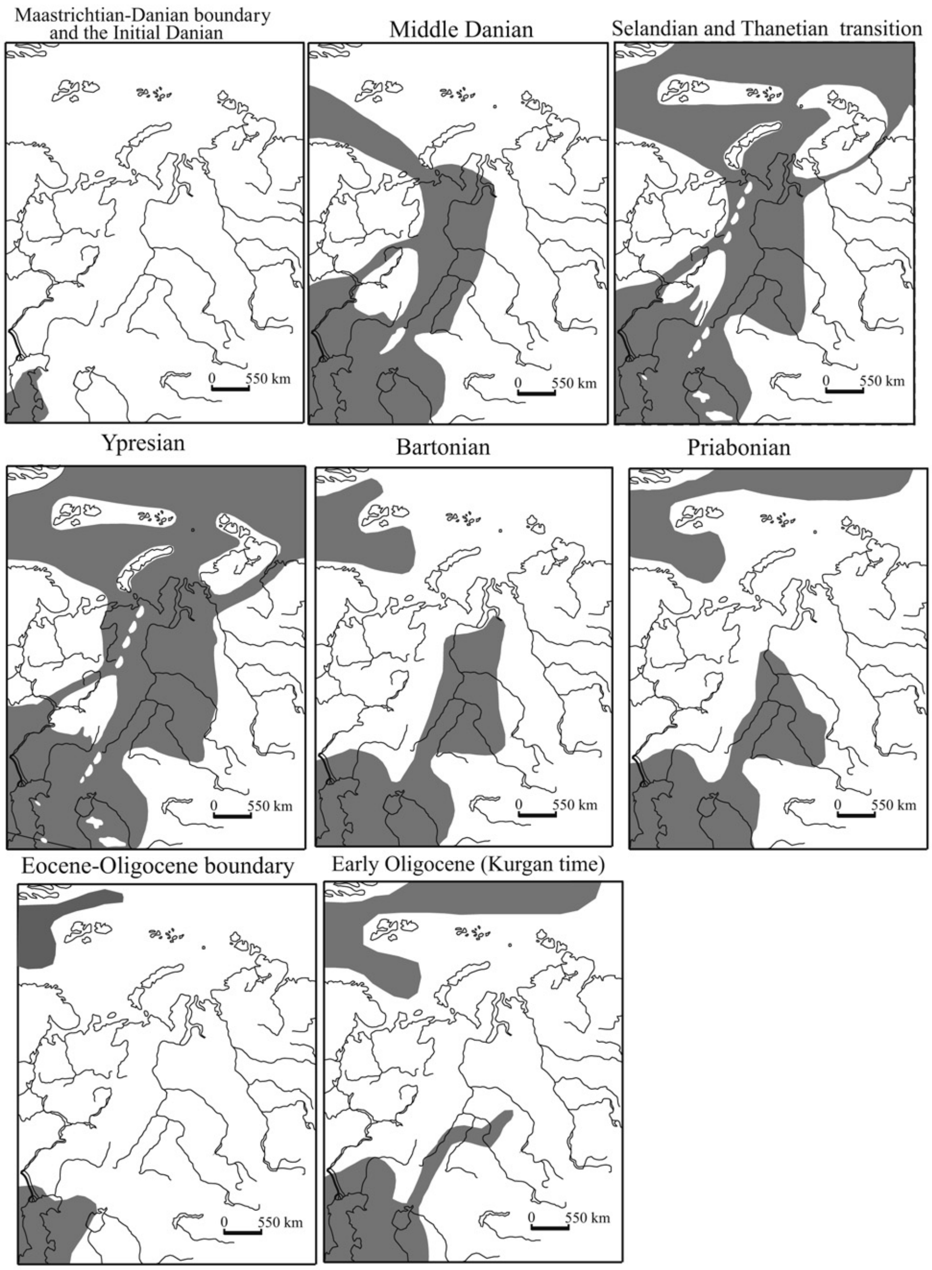


FIGURE 3 **Paleogeographic evolution of the Paleogene N-S trending system of epicontinental seas and straits in Northern Eurasia (modified from Beniamovski, 2007).**

sediments with abundant radiolarians and diatoms. This is stratigraphically reflected in uniform siliceous and organic-walled microplankton zonations for the Thanetian-Ypresian interval of the extratropical Northwestern Eurasia (Akhmetiev and Beniamovski, 2004, 2006).

4. In the Early-Middle Eocene through Bartonian the West Siberian sea-strait became separated from the Polar Basin (Figs. 3 and 4B). Tectonic activity during the first half of the middle Eocene resulted in the desiccation of the northern part of the West Siberian Plate, including the Kara epicontinental basin (Fig. 2). The West Siberian sea-strait became a semiclosed basin, which was connected to the Turanian Sea only through the Turgai Strait. This brought about radical changes in the current system, as N-S water exchanges were facilitated by a single current through the Turgai Strait. Consequently, siliceous organisms disappeared, whereas the composition of organic-walled plankton indicates episodic freshening of the Tavda Basin (Akhmetiev and Beniamovski, 2004, 2006). As a final result, the biosiliceous sedimentation of the Lyulivor cyclotheme that characterized the interval extending from the Late Paleocene to the beginning of the Middle Eocene was replaced by sandy-muddy sedimentation of the Tavda-Chegan times (Middle-Late Eocene). This situation is strikingly similar to that of the Lomonosov Ridge in the Central Arctic (Backman et al., 2006).

5. In the Eocene-Oligocene boundary time, the sea left both the West Siberian Plate and the Turgai Trough. In the Early Oligocene (the Ashzheairyk time), the sea penetrated from the Northern Ustyurt Plateau through the Turgai Trough into the West Siberian depression (Figs. 3 and 4C). This evolution is similar to the Akchagyl-Apsheron (Pliocene-Early Pleistocene) transgression of the Caspian Sea in the East European Platform and the Turanian Plate.

It is important to emphasize that in the regressive phases (pre-Middle Danian, pre-Middle Ypresian and pre-Bartonian) land bridges provided the basis for migrations of terrestrial biota. All of the sedimentation and biotic changes described above were closely connected with the evolution of climate, as demonstrated by the coeval evolution of floras.

## FLORA AND CLIMATE OF ADJACENT LAND AREAS

Records of Paleogene floras of the Northern Central Eurasia are far less incomplete than those of West and Central Europe. Most of the studied floras were found to the south of the latitude of Voronezh, Samara, Ufa and Kurgan (Figs. 1 and 2) (Kryshtofovich, 1955; Makulbekov, 1972, 1977; Baikovskaya, 1984; Akhmetiev, 1993, 2000, 2004; Akhmetiev et al., 2005; Akhmetiev and Kvaček, 2001; Akhmetiev and Beniamovski, 2006). Additional information on coastal vegetation from the marginal Tethyan seas is available from the area between Ukraine and the Southern Urals, the Turanian plate and the Zaisan depression (Figs. 1 and 2). The latter was separated from the Kulunda gulf of the West Siberian sea-strait by a short portion, less than 300 km long, of the Upper Irtysh River valley. Plant megafossils are mostly restricted to lacustrine and fluvial sediments of coastal lowlands and, less frequently, to intermontane coal-bearing sedimentary basins (Akhmetiev, 1985, 1993; Akhmetiev et al., 2005; Akhmetiev and Shevyreva, 1989).

The development of the flora and vegetation cover was greatly affected by two marine sea-way systems. On one hand by the N-S trending Tethys-Arctic system of seas and straits that existed until Middle Eocene times. On the other hand, by the E-W trending system composed of the Dnieper-Donets Sea and the straits located to the west of it, which connected the marginal seas of the North-Eastern Tethyan periphery to the Atlantic Ocean. This situation led to a marked Paleogene climatic asymmetry of Eurasia, with distinct latitudinal temperature gradients in both the western and eastern parts of the continent.

Several phases can be distinguished in the evolution of vegetation and climate of land areas adjacent to the N-S trending seaway (Akhmetiev and Beniamovski, 2004, 2006; Fig. 5).

### Early Danian temperate climate phase

The Cretaceous-Paleogene interruption in sedimentation, which affected all marginal and inner seas of the Eastern Peritethys (Beniamovski et al., 2002) and the central part (Lomonosov Ridge) of the Arctic basin (Backman et al., 2006), allowed a transient exchange of boreal terrestrial floras between East Europe and the Siberian Platform (Figs. 3 and 4A). Desiccation of the epiplatform seas and adjacent part of the Paleoarctic Basin coincided with the Maastrichtian-Danian boundary cooling event (Olsson et al., 2001; Pardo et al., 1999). These phenomena allowed the westward migrations of thermophylic flora of the Tsagayan ecotype (with *Ginkgo*, Pinaceae, Taxodiaceae, *Trochodendroides*, Platanaceae and Hamamelidaceae; i.e., the typical warm temperate plants from the Middle Amur Area, East Asia; Akhmetiev and Shevyreva, 1989; Akhmetiev et al., 2002). Similar flora existed in the Maastrichtian-Danian boundary time in the Northeastern Koryak Land and Kamchatka (Fig. 1).

In high latitudes, boreal humid deciduous flora migrated from the east to the west along the northern margins of the Siberian Platform and along the desiccated West Siberian Plate, reaching the North and Middle Urals in the Danian (the so-called Lozva Flora of the Easthern Ural; Fig. 4A). In middle latitudes, a southern boreal flora spread from the Amur Area and Northeastern China into Mongolia, Ili River area (Ulken-Kalkan) and Semipalatinsk district (Figs. 1 and 2). The same type of flora was found in Spitsbergen (Barentsburg locality; Fig. 4A).

In riparian facies the main floral components are typical Tsagayan forms (the Danian warm temperate deciduous mesophyllic flora on the Amur River Area; Akhmetiev et al., 2002), which include *Ginkgo*, Taxodiaceae and *Trochodendroides* (Fig. 4A). Very characteristic is the presence of *Taxites olrikii*, *Trochodendroides arctica*, *Nyssa bureica*, *Platanus raynoldsii* and *Porosia* sp. in the Danian (Kara-Biryuk) flora of the Zaisan Area (Akhmetiev and Shevyreva, 1989). In the Far East, three evolutionary phases of the Tsagayan Flora were recorded in the coal-bearing strata in Amur River Area (the Middle Tsagayan–Kivda times = Danian-?Selandian). An analogous pattern is observed in the Zaisan depression, where

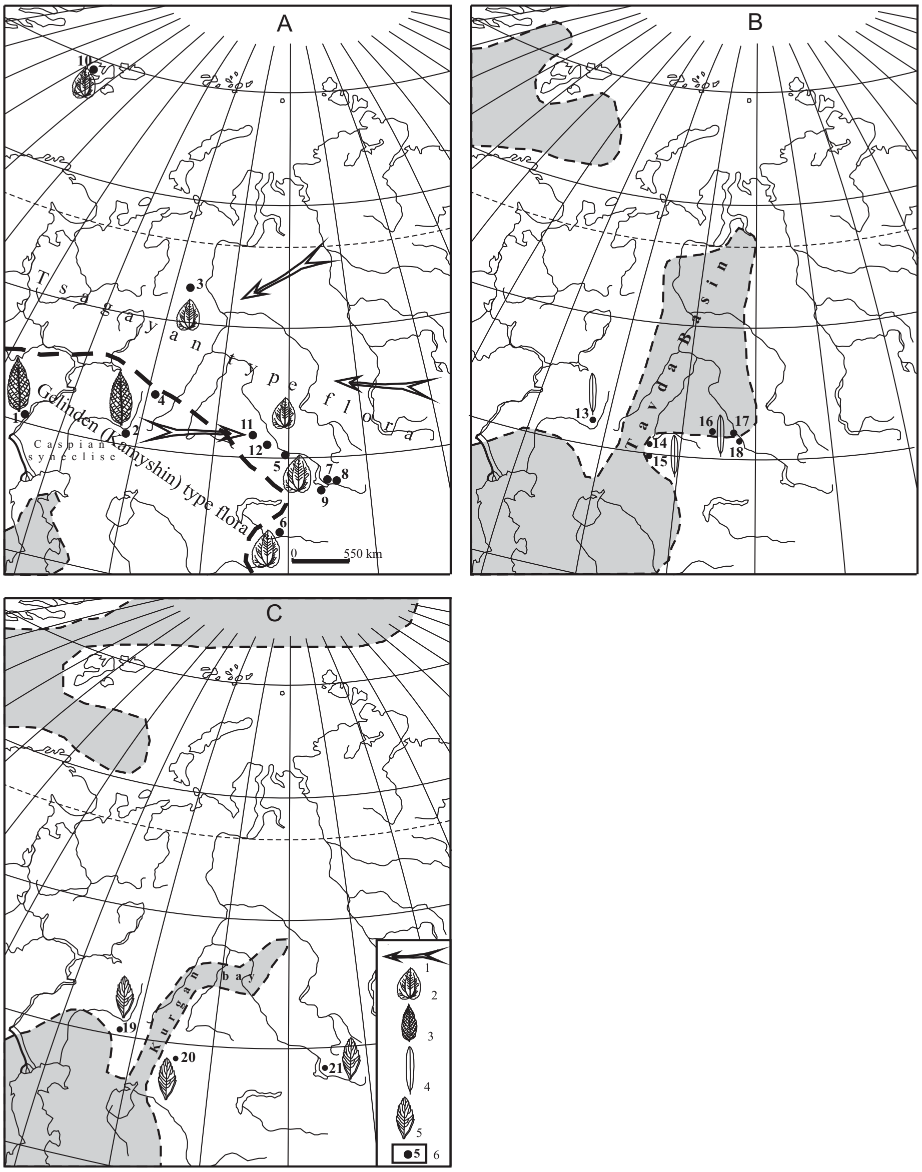


FIGURE 4 **Main types and localities of the Paleogene floras (modified from Beniamovski, 2007). Key: 1: direction of flora migration; 2: *Trochodendroides*; 3: *Ushia*; 4: *Leucothoe* (Ericaceae); 5: *Spiraea*; 6: reference sections. A) Floral types and localities (numbered) of the Danian, latest Thanetian and earliest Ypresian times: 1, Kamyshin; 2, Romancol; 3, Lozva; 4, Smolino; 5, Semipalatinsk; 6, Ulken-Kalkan; 7, Kara-Biryuk; 8, Zhuvankara; 9, Taizhuzgen; 10, Barentsburg (Spitsbergen); 11, Ekibastuz-Maisk; 12, Karasor. B) Floral types and localities (numbered) of the Bartonian: 13, Baky; 14, Zhaman-Kaindy; 15, Tortmolla; 16, Seleta; 17, Takyrsor; 18, Zhamantuz. C) Floral types and localities (numbered) of the the Early Oligocene (Turgai-type flora): 19, Kyzyltobe; 20, Mynsay; 21, Kiin-Kerish (Zaisan Lake basin).**

three successive warm temperate thermophylic humid deciduous floras (i.e., Zhuvankara, Taizhuzgen, and Kara-Biryuk; Fig. 4A) occurred (Akhmetiev, 1995, 2004; Akhmetiev and Shevyreva, 1989). Their main components were Taxodiaceae, Platanaceae and *Trochodendroides*, respectively. The oldest of these floras includes *Debeya* (Araliaceae) characteristic of the Far East Campanian floras. In West and Central Europe this form, which was previously identified as *Dewalquiea*, is abundant in both the terminal Cretaceous and Paleocene Kamyshin-Gelinden floras. We refer to them as cold-enduring Early Paleogene floras of the Zaisan depression because they existed in the southeastern flank of the inner West Siberian Basin in the Danian regressive phase (Akhmetiev, 2004; Akhmetiev et al., 2005).

## Late Danian-Early Ypresian paratropical climate phase

The onset of this phase was marked by boreal and Tethyan transgressions, which resulted in the opening of the Ivdel-Ul'yanovsk (Cis-Uralian) Strait and of the Kara, Orsk and Turgai gateways, which provided connection of the Paleoarctic Basin with marginal East European and Turanian Seas (Figs. 2 and 3). The sea barrier prevented further westward flora migrations. The climate became temperate in northern Siberia and subtropical-like in the south, as shown by the flora described below. Thus, the boundary between areas of distribution of boreal and Tethyan floras shifted northwards.

In Late Selandian times the thermophylic deciduous flora of the Zaisan depression was replaced by subtropical flora with *Dryophyllum* (Fagaceae) and Lauraceae associated with Myrtaceae, Menispermaceae and Platanaceae. In Eastern Kazakhstan the Paleocene climate was humid, subtropical, with distinct seasonal changes. In coastal areas of Southern Kazakhstan the palynospectra include mangrove pollen (Akhmetiev, 1995; Akhmetiev et al., 2005).

In Northern Siberia, the early Paleogene flora was dominated by deciduous broad-leaved trees, whereas in the southern regions to the west of the prevailing N-S seaway the Gelinden paratropical evergreen flora became widespread over the European continent. According to Kryshtofovich (1955), who defined this type of flora, its type locality was in Gelinden, Belgium (Steurbaut, 1998; Figs. 1 and 5).

In the Volga areas near Volgograd and Saratov, the typical Paleocene Gelinden paratropical flora dominated by *Chamaecyparis belgica*, *Viburnum giganteum* and including *Ushia* (form, genus Fagaceae) and *Debeya* (= *Dewalquiea*) had its first occurrence in the Late Danian. It also contains diverse evergreen forms. Main components of the Gelinden Flora (including different evergreen plants) are forms of the so-called Ushia assemblage, which consists, along with the afore listed taxa, of *Macclitockia*, *Ficus*, Lauraceae, *Ternstromiacites*, *Sabal,* and other genera (Romankol and Kamyshin Floras). This assemblage is most fully represented in the Kamyshin Horizon flora (Akhmetiev, 2004; Fig 4A). This horizon consists of marine and plant-bearing coastal-marine and lagoonal facies (see Scafati et al. this issue; Tripathi et al., this issue and cites therein where similar coastal assemblages are reported). The marine facies yielded dinocysts and diatoms related to the Late Paleocene and the Paleocene-Eocene boundary time interval, as represented by the global Paleocene-Eocene Thermal Maximum (PETM) (Oreshkina and Oberhänsli, 2003). Therefore, the plant-bearing Kamyshin Horizon corresponds to the PETM period, when coastal water temperature reached +21-22ºC (Yasamanov, 1978). The presence of *Oxicarpia* fruits (Kamyshin, Smolino) in the East European Gelinden-type flora emphasizes their endemism. Like recent tropical flora, the paratropical flora endured frost-free winter conditions (Kryshtofovich, 1955). Summer temperatures noticeably differed from those of recent tropical regions (Fig. 5). In fact, according to Mai (1995), the paratropical floras indicate that the annual temperature amplitude was less than 18°C, the average temperature of cold months was 19–11° C and their absolute minimum -2°C.

The Ushia assemblage of the Gelinden-Kamyshin ecotype occurs in the coastal zone of the East European Sea (the Cis-Uralian Area of Kazakhstan and Western Mugodzhary; Figs. 1 and 5). Here the typical flora of this ecotype was the Romancol Flora, dominated by representatives of tropical and subtropical families. Thus, Makulbekov (1977), Baikovskaya (1984) and Akhmetiev (2004) identified Moraceae (*Artocarpus*, *Ficus*), Proteaceae (*Dryandra*), Magnoliaceae, Lauraceae (six genera), Eophorbiaceae, Eleocarpaceae, Sterculiaceae, Combretaceae, Myrtaceae, Theaceae, Melostomataceae, Araliaceae, Sapotaceae (*Sideroxylon*), Symplocaceae, Apocynaceae and Rubiaceae. In the Latest Paleocene or first part of the Early Eocene, the *Ushia* assemblage extended up through Romankol to Eastern Kazakhstan.

The Arctic–Tethys connections that had developed in the Paleocene owing to the N-S trending system of epicontinental seas became widespread in the terminal Paleocene–Early Ypresian (Akhmetiev and Beniamovski, 2004, 2006). In the OPD 302 Hole 4A in the Lomonosov Ridge Backman et al. (2006) found the same Early Eocene succession of dinocysts, beginning at the *Apectodinium augustum* Zone of the PETM episode, as in West Siberia.

The early Eocene was the period of maximum warming in the Cenozoic history, characterized by the lack of frosts for a short time (Zachos et al., 2001). Temperature of polar surface water was +20ºC and palynospectra were dominated by pollen of angiosperms, which is indirect evidence of land proximity (Backman et al., 2006, p. 39-46). Climatic conditions of the northern margin of the continent were characterized by the absence of frosts or just episodic light frosts, as suggested by the occurrence of remains of thermophilic angiosperms, such as Myrtaceae (leaves and fructifications) (Ozerov et al., 2006), *Liquidambar* sp., *Craigia* sp., *Plafkeria* sp. (Laukhin et al., 1987, Kvaček et al., 2005), *Magnolia* sp. (leaves), Palmae, Loranthaceae, Moraceae and Hamamelidaceae (pollen) (Kulkova, 1971) in some localities to the north of 70ºN (the Lower Lena River area, Tastakh Lake; Fig. 1) in association with diverse deciduous broad-leaved fossils. The Paleogene flora of the northern Russian part of West Eurasia was entirely represented by broad-leaved plants, similarly to the Late Cretaceous floras that had been able to endure the deficient sunlight of polar winter.

Southwestern areas of Kazakhstan and the western part of Central Asia, which were partly occupied by marginal seas of the North-Eastern Tethyan periphery, were related to the arid tropical belt. Its boundary with the northern humid belt approximately coincided with the Chu-Balkhash threshold (Panova et al., 1990). Width of the ecotone zone was probably more than 100 km. Sedimentation type also changed. In the Chu-Sarysu and Kysylkum depressions terrigenous sediments were substituted by dolomite-anhydrite deposits and carbonate biosediments in marine areas and by red calcareous clays with sandstone interbeds in continental ones (Panova et al., 1990). Arid environments are indicated by the composition of palynospectra in marine sediments of the Kyzylkum depression, where the pollen of *Classopollis*, *Ephedra* and *Nitraria* reaches values of up to 80%. Spectra of lacustrine-marshy sediments are dominated by pollen of Myricaceae. The more humid climate of the

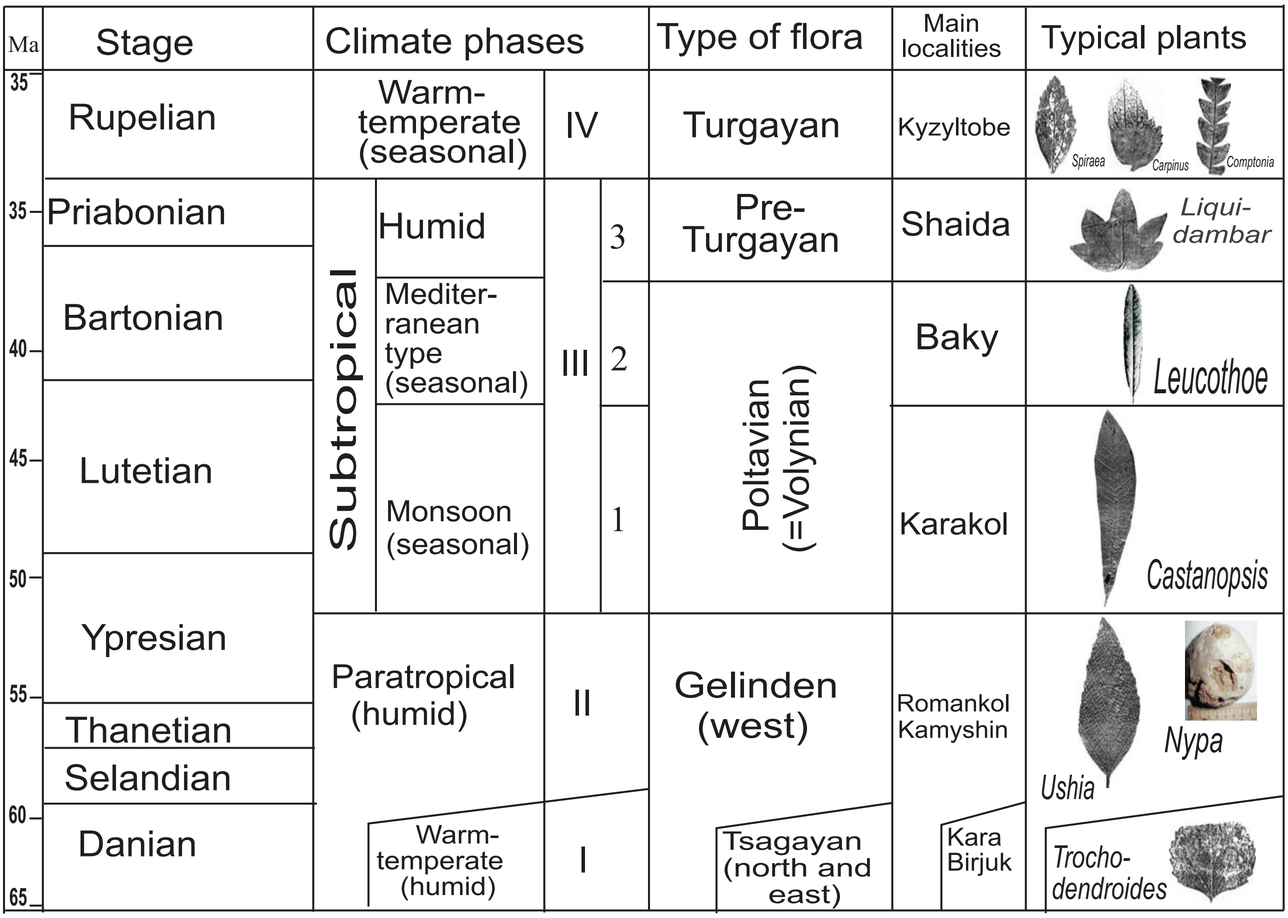


FIGURE 5 | **Paleogene phases of evolution of flora and climate in the extratropical North-Western Eurasia (after Akhmetiev, 2004; Akhmetiev and Beniamovski, 2004 and 2006, with modifications).**

neighbouring Chu-Sarysu depression is proved by its proximity to the Ulken-Kalkan (Ili River) and Semipalatinsk areas, where the Tsagayan ecotype floras with Taxodiaceae, *Trochodendroides* and Platanaceae were found (Figs. 2 and 4A). They migrated there from the east during the Early Danian cooling. The South Kazakhstan arid zone extended to West Kazakhstan and Turkmenia, as suggested by a high content of *Classopollis* and *Ephedra* pollen (Panova et al., 1990; Akhmetiev, et al., 2005).

In the terminal Paleocene, the northern boundary of the arid zone shifted southwards and the arid climate changed to a semiarid one. Indirect evidence is provided by a reduced amount of pollen of xerophytes and by discontinuous evaporite accumulation. Gypsum and dolomite deposition ceased not only in Kazakhstan but also in adjacent areas of Central Asia. To the north, in part of the Turgai trough and in its southern continuation, the Arkalyk area (Fig. 2), climate was wetter and bauxites were formed.

## Late Ypresian-Priabonian subtropical climate phase

This phase is distinguished by a change from a paratropical to a subtropical climate. Three subphases can be outlined in the evolution of floras, vegetation and climate (Figs. 2, 3 and 5).

### *Late Ypresian–Lutetian monsoon climate subphase*

In the Late Ypresian the paratropical climate started changing towards a subtropical, monsoon climate, humid in the summer period, probably because the formation of a land barrier in the Pripyat strait in the Middle Ypresian prevented connections between western and eastern basins of the Northern Tethyan periphery (Akhmetiev and Beniamovski, 2004; their fig. 15). This was combined with a reduction of the N-S trending seaway in the Ypresian-Lutetian boundary (Akhmetiev and Beniamovski, 2004, 2006). Biotas of both the seaway and bordering land areas experienced essential changes. In the absence of E-W trending connections, N-S directed exchange of warmth and water masses led to seasonal alterations in precipitation. *Castanopsis*, Lauraceae, evergreen *Quercus* became dominant among the forest vegetation. Typical representatives of the *Ushia* assemblage, such as *Ushia*, *Dewalquea* and *Oxicarpia*, disappeared. The abundant megafossils of *Castanopsis* (main components of recent monsoon zones) studied by Makulbekov (1972) are those found in the Irtysh area near Pavlodar. Pollen of *Castanopsis pseudocingulum* described by Boitsova (1972), which shows a great affinity with recent *Castanopsis* pollen, is the index-species of regional palynozones of the Middle Eocene, predominantly Lutetian, over the vast area that extends from Ukraine to southern regions of Siberia.

### *Bartonian Mediterranean type seasonal (wet winter) climate subphase*

By the second half of the Middle Eocene the West Siberian Basin became completely isolated from the Paleoarctic Basin (Figs. 3 and 4B). The OPD 302 Hole 4A in the Lomonosov Ridge shows a hiatus corresponding to the second half of the Middle Eocene–Late Eocene (Backman et al., 2006). Though indirectly, this proves the absence of sea connections between the central parts of the Arctic basin and the dwarfed West Siberian Sea (Shatsky, 1978; Akhmetiev, 1995, 1996; Akhmetiev and Beniamovski, 2006).

The end of the Tethys–Arctic connection brought about a generalized disturbance of both water and atmospheric circulation systems. The only remaining portion of the N-S trending seaway (i.e., the Turgai Strait and basin in the Southern Western Siberia; Figs. 2 and 3) represented a large warm-water Tethyan gulf penetrating far to the north. The Early Bartonian paleogeographic rearrangement of sea communications, as well as that of both water and atmospheric circulation systems, jointly induced a kind of “Mediterranean” effect. The climate of middle-latitude West Eurasia became humid in winter but arid and hot in summer. Despite still remaining seasonal, the climate experienced an inversion of the main precipitation periods. The amplitude of seasonal temperature variations increased notably mainly due to the lowering of average winter temperature. This resulted in yet weakly pronounced continental climatic conditions in middle-latitude interior regions of the Asian continent.

Dominant components of the flora and vegetation were narrow-leaved xerophilous Fagaceae, Lauraceae, Myricaceae and Ericaceae (*Leucothoe*), and the palms *Sabal* and *Trachycarpus* (the Baky flora of the South Ural and the Takyrsor, Zhamantuz and Seleta floras of the Irtych area near Pavlodar) (Usnadze-Dgebuadze, 1948; Makulbekov, 1972; Akhmetiev, 2004; Akhmetiev et al., 2005; Figs. 4B and 5). In the second half of the Middle Eocene the forest vegetation was uniform throughout the latitudinal area of distribution from Central Europe to the Irtysh Area.

The stratigraphic position of beds with xerophilous floras (Zhaman-Kaindy and Tortmolla) in central Turgai, which include *Palibinia* and were previously dated as Early Oligocene, remains unclear (Akhmetiev, 1993; Zhilin, 2005; Fig. 4B). They were formed in arid conditions similar to those of the Bartonian in Turkmenia (the

Badkhyz flora of Vassilevskaya, 1957, and Akhmetiev, 1993, 2004, Akhmetiev et al., 2005). If the Turgai floras with *Palibinia* were really Eocene in age, as suggested by Zhilin (2005), this would imply that the arid zone must have considerably extended towards the "blind" Turgai–West Siberian seaway during the second half of the Eocene.

### *Late Eocene humid subtropical climate subphase*

The southward sea retreat from West Siberia in the Late Eocene, especially in its second half (Figs. 3 and 5), was combined with a cooling event (Akhmetiev, 1993; Krasheninnikov and Akhmetiev, 1998). Arctic cool humid air masses penetrated into Central Siberia. Climate became humid without distinct signs of seasonal precipitation. Hard-leaved oak-laurel forests were replaced by summer-green coniferous–broad-leaved, polydominant, mesophilic vegetation including Taxodiaceae, Juglandaceae, Hamamelidaceae and deciduous Fagaceae. The riparian associations were the first to experience changes, later being followed by uplands (Akhmetiev and Reshetov, 1996). Most of the Early Paleogene angiosperm genera were already eliminated by the second half of the Eocene. Late Eocene floras were dominated by recent genera species.

## Oligocene warm temperate seasonal climate phase

The well-known global cooling at the Eocene–Oligocene transition (e.g., Zachos et al., 2001) has been the subject of many studies in the study area (Krasheninnikov and Akhmetiev, 1998). It was associated with the final desiccation of the Western Siberian Plate, the Turgai Trough and the northern part of the Turanean Plate, as well as with the confinement of water masses to deep depressions of the Cis-Caucasus, the Scythian Plate and the south-eastern part of Caspian syneclise (=North Cis-Caspian depression; Figs. 2 and 3). In the Oligocene, deciduous mesophilic coniferous–broad-leaved forests were widespread over the middle-latitude Central Eurasia (Krasheninnikov and Akhmetiev, 1998; Fig. 5).

A short-lived transgression of the Turanian Sea into the southern Western Siberian plate (Fig. 3) did not essentially affect the mesophilic deciduous flora, as the characteristics and composition of the coniferous–broad-leaved flora scarcely changed.

## CONCLUSIONS

The Paleogene evolution of Northern Central Eurasian flora and vegetation provides a reliable proxy for coeval climatic trends and phases. These were mainly determined by the paleogeographic configuration and current dynamics of the N-S trending system of epicontinental seas and straits that connected the open sea basins of the Arctic and Tethys (Fig. 3).

The global regression at the Maastrichtian-Danian transition resulted in the drainage of Northern Central Eurasia and was accompanied by the migration of deciduous mesophilic warm temperate Tsagayan ecotype flora from Eastern Asia to the East and North Kazakhstan, Siberia and North and Middle Ural (Figs. 3 and 4A). Lozva (eastern slope of the Middle Uralian Mountains), Kara-Biryuk and Taizhuzgen (Zaisan Lake Basin) are typical localities of the Tsagayan-type flora. Dominant plants were those of the genera *Trochodendroides* and Taxodiaceae, Platanaceae and Hamamelidaceae (Phase I in Fig. 5).

During the Late Paleocene and Early Eocene North Central Eurasia was included in the paratropical humid climatic zone (average annual temperature around 20°C). Kamyshin (Volga River area) and Romankol (South East Transuralian) are typical localities of the paratropical Gelinden-type flora. Dominant plants were angiosperm genera *Ushia*, *Macclintockia*, *Dewalquiea* (=*Debeya*), *Dryophyllum*, *Oxicarpia*, palms (*Nypa*, *Sabal*) and Lauraceae (*Ocotea*, *Persea*, *Daphnogene*, *Cinnamomum*). At the PETM episode and the Early-Middle Ypresian some evergreen plants probably migrated as far north as the Arctic Siberian Coast (Fig. 4A and Phase II in Fig. 5).

In the Late Ypresian and Lutetian the latitudinal straits that connected the West Siberian Sea and the Turgai Strait with the Atlantic seas were reduced (Fig. 3). As a result, the subtropical monsoon climate spread over North Central Eurasia. This is recorded by the occurrence of evergreen Fagaceae, especially *Castanopsis* like in recent monsoonal floras, *Lithocarpus*, *Dryophyllum*, different Lauraceae (*Persea*, *Cinnamomum*, *Litsea*), Sterculiaceae and palms. Typical localities are Karasor (North-Eastern Kazakhstan) and some sites in the Zaisan Lake Basin (Makulbekov, 1972; Akhmetiev, 1985; Akhmetiev et al., 2005) (Phase III-1 in Fig. 5).

By the Bartonian the West Siberian Sea became isolated from the Polar Basin, but connections with Tethys still existed (Fig. 3). This paleogeographic evolution was accompanied by a climatic change from wet summer conditions to a wet winter climate, which is similar to the recent Mediterranean subtropical climate characterized by dry and hot summers. Typical localities are Baky (Southern Ural), Takyrsor, Zhamantuz (North-West Kazakhstan) and Kiin-Kerish "white clays" (Zaisan Lake Basin). Semi-arid environments established on Northern Turgai (Zhaman Kaindy, Tortmolla Flora with *Palibinia*) (Akhmetiev et al., 1986; Akhmetiev, 1993, Akhmetiev et al., 2005; Zhilin, 2005) (Phase III-2 in Fig. 5).

The West Siberian Sea and Turgai Strait were drained in the Late Eocene-Oligocene transition (Fig. 3). The climate became cooler and wetter, warm temperate and seasonal (Phases III-3 and IV in Fig. 5). Evergreen plants disappeared. The main components of mesophyllic deciduous flora were different conifers, including Taxodiaceae (*Metasequoia*, *Sequoia*, *Glyptostrobus*), Cupressaceae and Pinaceae (*Pinus*, *Cedrus*, *Pseudolarix*), as well as a rich spectra of angiosperms (trees and shrubs), such as Juglandaceae, Myricaceae, Betulaceae, Fagaceae, Nyssaceae, Aceraceae, Ulmaceae and Rosaceae (Zhilin, 1974; Akhmetiev, 1993).

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