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GEOLOGY

Correlation of Miocene Floras of the Climatic Optimum in the Far East

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Based on interregional correlation of geological and paleogeographic events, a new approach has actively been developed in the past few decades. One such Cenozoic significant event in the Russian Far East is the Miocene Climatic Optimum, which designates a temperature increase after a prolonged climatic depression in the second half of the Oligocene–initial Miocene and reached its maximum at the Early–Middle Miocene transitional interval. This paleoclimatic event is of planetary importance [1]. It was recorded on paleoclimatic curves based on study of the isotopic composition of carbonates of marine fossils [2]. Terrestrial plants are known to be sensitive indicators of climatic changes. Therefore, they can be used not only for paleoclimatic reconstructions, but also for the stratigraphic correlation of sedimentary sequences of spatially distant regions as well. It is especially important for the southern region of the Russian Far East where Tertiary deposits are mainly represented by continental facies.

According to [1, 3, and others], the Miocene Climatic Optimum in the continental sector is reflected in floras from the so-called Engelgardia Beds studied for the first time in Korea [4]. It was revealed later [5] that analogs of these beds in the Primor'e region are underlain by Eocene coal-bearing deposits without any signs of stratigraphic hiatus, and corresponding floras include up to 10% of Eocene plants. Therefore, their association with the Miocene Climatic Optimum is debatable. Thus, the searching for floras corresponding to the Miocene Climatic Optimum in the Primor'e region is an urgent issue. We have revealed such flora only this year. Its stratigraphic position, taxonomic composition, and specific features in the context of solving correlation problems are discussed in this work.

We discovered a new (*Nezhino*) flora in the basin of lower reaches of the Razdol'naya River 3 km north of the Settlement of Nezhino (Fig. 1). The coordinates of the site (9180) are 43°29′ N and 131°47′ E. The studied section is confined to the southern edge of the Pushkin depression. Fossil plants were collected in an operating brown coal open pit. The bed-by-bed description of the section of a flora-bearing member at the depth interval of ~10–15 m is presented below. The Verkhnii coal seam of the Upper Oligocene coal-bearing sequence is overlapped with erosion by the following units:

1. Light gray, poorly cemented, medium-grained (coarse-grained at the base) sandstone with thin (up to

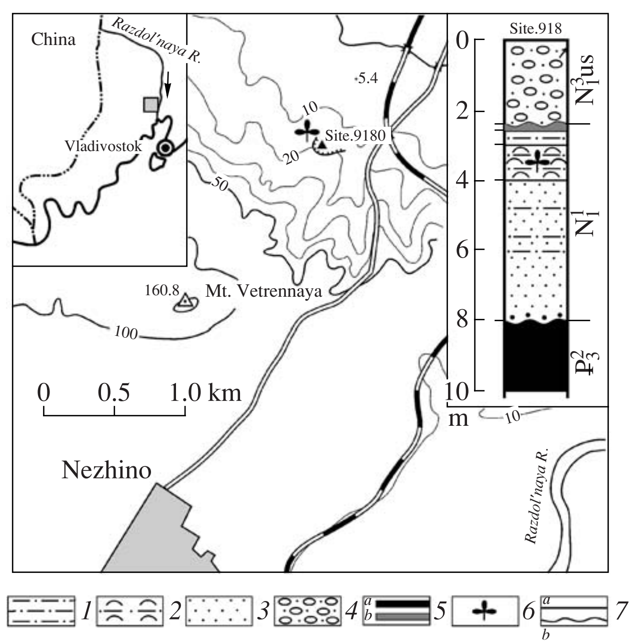

Fig. 1. Location of the Nezhino flora and a fragment of the lithological–stratigraphic column (Site 9180). (*1*) Siltstone; (*2*) tuffaceous siltstone; (*3*) medium-grained sandstone (coarse-grained at the base); (*4*) pebbles; (*5*) brown coal (*a*) and lignite (*b*); (*6*) plant remains; (*7*) boundaries: (*a*) lithological and (*b*) stratigraphic unconformities.

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5 cm) siltstone laminas and abundant lignified plant detritus. Thickness ≥4.0 m.

2. Yellowish white, laminated, firmly cemented (ferruginous and siliceous cement) tuffaceous siltstone with lenses of lapilli tuff and interlayers (up to 0.2 m) of thin-laminated gray siltstone. The bed includes numerous imprints of leaves and fruits. Thickness 1.0 m.

3. Dark olive siltstone with small-fragmental jointing. Thickness 0.2 m.

4. Strongly decayed loose lignite. Thickness 0.2 m.

The section is overlain with erosion and stratigraphic hiatus by pebbles of the Upper Miocene Ust-Suifun Formation. Its total thickness slightly exceeds 5 m in the type section (Site 9180, Fig. 1) and increases to several tens of meters northward in the central part of the depression.

The collection of fossil plants comprises more than 500 specimens of imprints of leaves and subordinate fruits. The phytocomplex is dominated by flowering plants. Conifers (*Keteleeria, Larix, Pinus, Taxodium, Glyptostrobus*) are represented by single specimens. Fern-shaped representatives (*Osmunda, Dryopteris*) are rare. At the contacts of beds, monocotyledons form clusters of charred leaves often unidentifiable even to a genus. Dicotyledons exhibit the greatest taxonomic diversity. In total, preliminary studies of the collection made it possible to identify 92 species incorporated into 57 genera belonging to 31 families. No indisputable dominants have been revealed. The flora is polydominant, the leading part being played by representatives of valley assemblages: *Populus* (5 species), *Salix* (6 species), *Ulmus* (3 species), *Zelkova* and *Pterocarya* (4 species, leaflets and fruits), *Carya*, and *Juglans*. Plants inhabiting slopes are no less diverse. They are represented, first of all, by the Betulaceae family (*Betula, Carpinus*, and *Ostrya*), the Aceraceae family (*Acer*, 5 species, including a complex leaf type), and the Rosales order (*Sorbus*, 2 species).Of greatest importance, however, is the presence of thermophile genera, the present-day domains of which are related to subtropics and the southern part of the lukewarm realm. Here, we should note first of all diverse ligneous legumes (*Cladrastis, Desmodium, Maackia, Indigofera*, and *Spatholobus*) as one of the explicit indications of the flora thermophile nature. Moreover, we have also established *Magnolia, Liquidambar, Eucommia, Celtis, Idesia, Meliosma, Nyssa* (endocarps), *Analgium, Ilex, Paliurus* (leaves and fruits), *Cissus* (?), and *Microtropis*. Of special interest is the finding of *Davidia* leaves (Fig. 2), one of the endemic plants of mountain forests in southwestern China. It was the first finding of this monotype genus in fossil floras of the Far East. *Davidia* is represented in the collection by 17 specimens of good preservation. The presence of the Lauraceae family (*Lindera, Litsea*) needs further refinement. In terms of a series of taxons, the Nezhino flora exhibits relations to Miocene floral assemblages of the Primor'e region (Sinii Utes, Khankai, and Ust-Suifun complexes), as well as to floras of the Miocene Climatic Optimum of Japan (the Utto floras) and China (the Shangwang flora). At the same time, the flora is characterized by a clear originality. As was suggested, its thermophile degree is substantially lower than in floras of the Miocene Optimum in Japan, in which Lauraceae elements and evergreen oaks (representatives of the cyclic Balanopsidaceae family) are common.

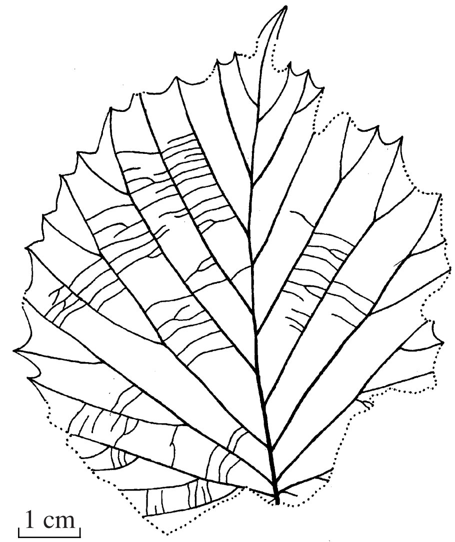

Fig. 2. *Davidia* sp. nov., collection 9180, specimen 307.

The age of the Nezhino flora is a crucial issue. Because of the lack of Eocene and Early Oligocene elements, with the exception of transit forms of the Taxodiaceae family (*Taxodium* and *Glyptostrobus*), the Nezhino flora cannot be regarded as an Eocene–Early Oligocene representative. It also has no common genera with the temperate flora of the underlying Late Oligocene coal-bearing formation. On the other hand, its composition differs radically from that of the younger (Middle Miocene) Khankai flora, which is characterized by the absolute dominance of beech (up to 50%) in all localities, as well as the abundance and diversity of conifers (more than 30 species [6]). In our opinion, the most important point for solving the issue of the Nezhino flora age is the presence of two beech species with a narrow stratigraphic range: *Fagus chankaica* T. Alexeenko characterizes the Middle Miocene of the Primor'ee region and Korea, whereas *F. evenensis* Cheleb. is known in the Primor'e region and on Sakhalin Island in the Oligocene–Early Miocene (it rises to the Middle Miocene only on the Kamchatka Peninsula). This species was found in the Primor'e region in the Sinii Utes phytocomplex of the Early Miocene. Therefore, we can consider the Nezhino flora as a transitional form between the Khankai and Sinii Utes floras. Hence, its age corresponds most likely to the second half of the Early Miocene. Paleobotanic data correlate well with the radioisotope date of 17.1 ± 1.3 Ma obtained by the tracking method for a volcanic ash interlayer from the sequence under consideration previously correlated with the Ust-Davydov Formation [7].

Our finding of the new (Miocene) thermophile flora has quite certain implications for the study of the Neogene flora in the Far East. According to [1], the Miocene Climatic Optimum in the Far East region is most clearly manifested in Japan (northern Honshu) within two temporally conjugate fossil leaf floras: the Aniai lukewarm flora related to continental coal-bearing deposits and the Daijima subtropical flora confined to coastal–marine facies. The Aniai flora (its age corresponds to the first half of the early Miocene) predated the climatic optimum, whereas the Daijima flora corresponded to the climatic optimum. The paleoclimatic succession based on two above-mentioned types of Japanese floras was used by Russian paleobotanists for solving the issue of the age of Neogene floras in the Primor'e region [2, 8]. Engelgardia floras of the Primor'e region (Kraskino, Rettikhovka, Velikaya Kema, and Dembi) were used as analogs of the Daijima-type floras. However, the former floras exhibit the specific features described above, which rules out their affiliation to the Miocene. Moreover, they are characterized by the presence of correlative taxons with a narrow stratigraphic range but large geographic area. The taxons include a three-bladed fruit sheath (bract) of a nut-tree, which was previously attributed to the Engelgardia family but later transferred to another genus of this family (*Alfaropsis*) [9]. Moreover, Engelgardia floras comprise some specific species of the *Quercus* genus, including those of uncertain section affinity. The mentioned taxons were also found in Engelgardia floras of Korea and Japan, but they were not revealed in the Daijima-type floras. These taxonomic features of Engelgardia floras in the Far East together with data on other paleontological methods and radioisotope datings led to revision of their age as the Early Oligocene [10]. The author of the present communication has supported this point of view with regard to floras of this type in the Primor'e region [5, 6, 11].

The initial choice of Engelgardia floras as corresponding to the peak of the Miocene Climatic Optimum seems to be quite logical. The point is that Miocene floras known in the Primor'e region (Ust-Suifun, Khankai, and Sinii Utes) had a distinct lukewarm outlook by the early 1970s when the mentioned correlation scheme was elaborated. Only Engelgardia floras were suitable as an analog of the subtropical Daijima-type floras. Decisions taken at that time were governed by the following fact: like the Kogeonweon reference flora of Korea, Engelgardia floras are thermophilic and similar to subtropical ones. The correlation reconstructions in [3, 8, and others] led to changes in the concept of the regional stratigraphic succession of the Tertiary complex in the Primor'e and Amur regions. In our opinion, the fallaciousness of the decisions mentioned above is related to insufficient consideration of the regional climatic factors, because they ignored climatic conditions that governed the coeval continental and island floras. When translating the paleoclimatic situation in Japan to the continent, the researchers did not take into account the following fact: when applied to a specific territory, any climatic (paleoclimatic included) phenomenon shows up through the interaction of two factors: global and regional. The final result is determined by their unidirectionality or multidirectionality. Depending on this process, the factors either strengthen each other or become mutually compensated. In the study region, the East Asian winter monsoon, formed as long ago as the Early Oligocene, was such a factor [12]. It is this factor that is responsible for negative conditions (low temperatures and high air aridity at low precipitation), which complicate the wintering of plants and restrict the possibilities of growth for some of them. The territory of Japan is protected significantly against its influence by the Sea of Japan and the Tsushima warm current. It should be noted that the Aniai-type floras of Japan and their analogs in the Primor'e region (in particular, the Sinii Utes flora), which preceded the opening of the Sea of Japan estimated at the mid-Early Miocene by most geotectonists [13, 14, and others], are similar both in the thermophile degree and the taxonomic composition [6].

Later, the situation sharply changed: after the territory of present-day Japan was separated from the Asian continent, the effect of global warming was strengthened by the influence of the Tsushima warm current along the western rim of the Japanese Archipelago. Consequently, the Aniai-type lukewarm floras were replaced by the Daijima-type subtropical floras. The general increase in the temperature was compensated by an adverse influence of the winter monsoon in the continental coastal sector of the Sea of Japan and by the Primor'e cold current in the Primor'e region. Pavlyutkin [6] suggested that an analog of the Daijima-type floras can be represented in the Primor'e region by the Khankai flora, which comprise a series of thermophile elements but are significantly inferior to type floras of this level in Japan. The age of the Khankai flora corresponds to the Middle Miocene. Taking into account that floristic relationships between the Khankai flora and the Sinii Utes flora (first half of the Early Miocene) are rather weak, we suggested the existence of more thermophile intermediate flora in the Primor'e region, which should fill up the lacuna mentioned above [6]. Now there is every reason for the Nezhino flora to pretend to this role.

Thus, floras of the Miocene Climatic Optimum in the Primor'e region, Korea, and Sakhalin Island formed under the active influence of the East Asian winter monsoon and beyond the domain of the Tsushima warm current. Therefore, they are less thermophile as compared to type floras of this level in Japan.

This inference is of fundamental importance for correlations with Miocene floras of the temperate zone at the Far East margin of Asia and for elaborating regional stratigraphic scales, since it allows us to reduce the risk of serious errors.

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