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GEOLOGY

Magnetochronology of the Climatic Optimum at the Early–Middle Miocene Transition in Northeast Russia

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The Miocene was characterized by sharp climatic fluctuations. Among them, the most significant (for high latitudes) fluctuations are termed climatic optimums I, II, and III [1–3]. Optimum I, which marks the Early–Middle Miocene transition, has been comprehensively studied within and beyond Northeast Russia. In the Russian literature, Optimum I is known as the "beech" horizon first defined by Kartashova [4] based on palynological data. This horizon, a reliable reference unit for the Miocene, is recognized in almost all regions of Northeast Russia with Lower–Middle Miocene sediments [5].

Characteristics of Optimum I sediments with paleomagnetic data are presented below (Fig. 1).

Eastern Yakutia. In this region, the Stadukhin Formation drilled by four parametric boreholes in the Lower Kolyma Trough is correlated with the Lower–Middle Miocene boundary sediments. The formation encloses two spore and pollen assemblages. The upper assemblage reflects the climatic optimum. The optimum is distinguished in all four boreholes [6]. In Borehole 1, the optimum is marked by prevalence of angiosperm pollen (27–83%) over gymnosperm one (9–79%) and spores (2–32%). Angiosperms are represented by the pollen of *Alnus, Betula*, and *Ericales* accompanied by scarce Sparganiaceae, Graminea, Onagraceae, and others. Gymnosperms are dominated by *Pinus.* Dark coniferous are represented by common *Picea* and *Tsuga* and rare *Abies, Cedrus, Keteleeria*, and others. Taxodiaceae constitute up to 10% of the spectra. Most abundant among spores are Polypodiaceae accompanied by less common *Sphagnum* and others. The pollen of thermophilic plants forms three peaks (20–35%), the upper one being characterized by the prevalence of Fagaceae [6].

The magnetic polarity patterns of sediments corresponding to the optimum are similar in all the boreholes [7]. The upper and lower parts of the section are characterized by the normal and reversed polarity, respectively. The sediments are correlated with chrons C5Bn–C5Br of the geomagnetic polarity time scale [8] (Fig. 2).

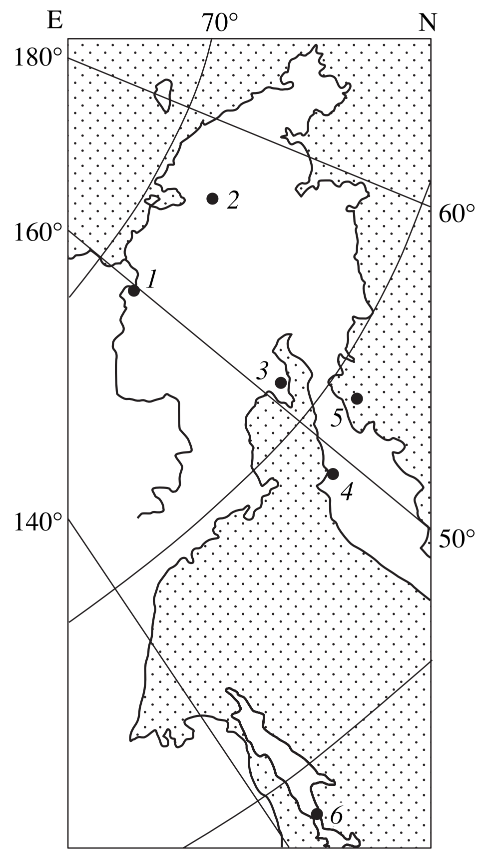

Fig. 1. Location of study sections. (*1*) Eastern Yakutia; (*2*) Chukotka; (*3*) Koryakia; (*4*, *5*) western (*4*) and eastern (*5*) Kamchatka; (*6*) southern Sakhalin.

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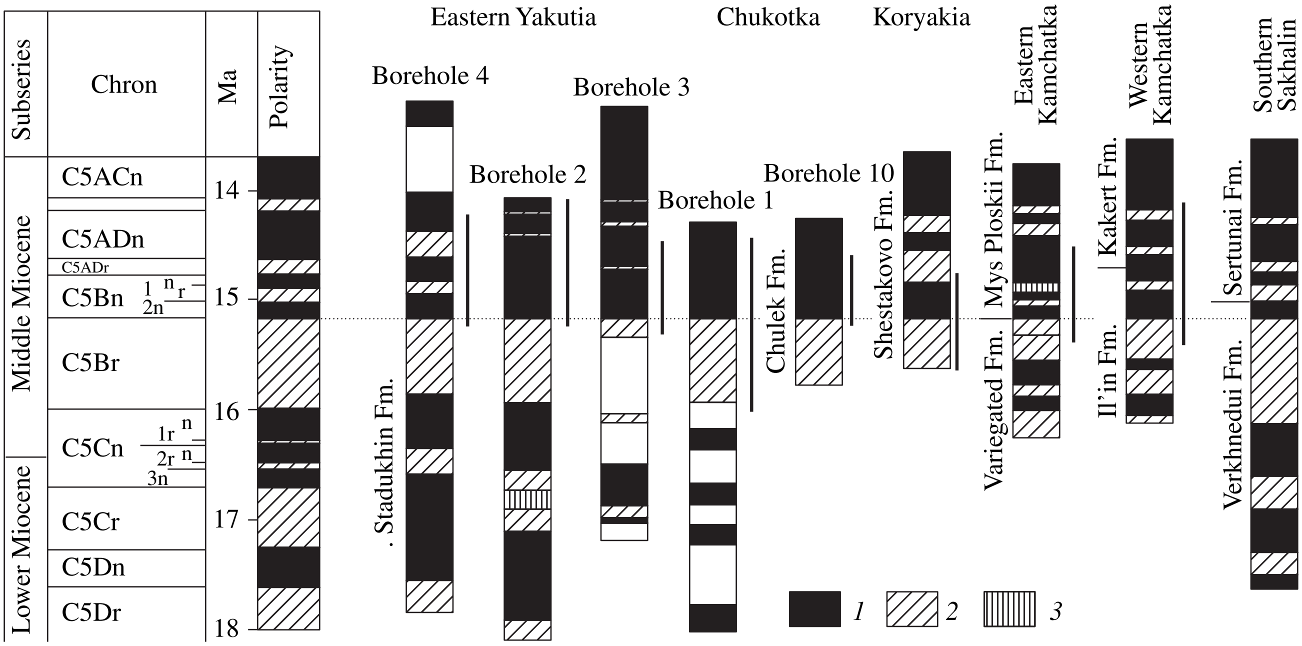

Fig. 2. Position of sediments corresponding to the climatic optimum (solid line) in Lower–Middle Miocene sections of eastern Russia. Polarity: (*1*) normal, (*2*) reversed, (*3*) anomalous. The left column shows a fragment of the geomagnetic polarity time scale [8].

Chukotka Sediments corresponding to the climatic optimum are studied in the Chaun Depression in the Chulek Formation section recovered by Borehole 10 in a depth interval of 77–85 m. In the palynological spectrum from this interval, angiosperm pollen (up to 71.0%) prevails over gymnosperm one (23.4–39.0%) and spores (3.5–5.8%). The pollen of *Alnus, Betula*, Fagaceae, *Myrica, Corylus, Carpinus*, Juglandaceae, and others characterize angiosperm plants. The families Pinaceae and Taxodiaceae dominate among gymnosperm pollen. Spores are represented by Polypodiaceae, Osmundaceae, and *Sphagnum.* The palynological spectrum reflects vegetation of coniferous–small-leaved and mixed broad-leaved forests with Fagaceae, Juglandaceae, and Taxodiaceae plants [5].

The upper and lower parts of the Chulek Formation are characterized by normal and reversed polarity, respectively (chrons C5Bn–C5Br) [7]. The thermophilic spectra (optimum) are confined to the boundary between these chrons.

Koryakia. Complex data were obtained for the Lower–Middle Miocene Shestakovo Formation of the Penzhina area [9]. Spore and pollen spectra from basal layers of the formation are characterized by an increased share of broad-leaved thermophilic plants (up to 35%) with the domination of Fagaceae (*Fagus, Quercus*, and *Castanea*) and Ulmaceae (*Ulmus* and *Zelkova*). The share of Juglandaceae pollen does not exceed 2%. The pollen of *Myrica, Corylus, Acer, Ilex, Tilia*, and *Diervilla* is a constant constituent of spectra. Among angiosperms, Taxodiaceae pollen (*Glyptostrobus, Taxodium*, and *Sequoia*) is up to 4%.

Paleomagnetic studies reveal that the upper part of the section is dominated by normal polarity and the lower by reversed polarity. The polarity reversal corresponds to the C5Bn/C5Br chron boundary. Thermophilic spore and pollen spectra (optimum) are confined to the upper part of the section with the polarity reversal zone [9].

Western Kamchatka. According to palynological data, sediments corresponding to the climatic optimum in this region comprise the uppermost Il'in Formation and lower two-thirds of the Kakert Formation examined in the Tochilino section. The palynological spectra from these sediments are dominated by gymnosperm pollen: abundant *Fagus*; common *Betula, Ulmus, Juglans*, and *Pterocarya*; and rare *Corylus, Carpinus, Hamamelis*, and others. The subordinate angiosperm pollen is largely represented by Taxodiaceae (genera *Sequoia, Taxodium, Glyptostrobus, Glyptomeria*, and *Tsuga*) vegetation. The assemblage indicates the climatic optimum [10].

Based on mollusks, the warming maximum corresponds to the Il'in time marked by 61 subtropical and south Boreal species [2]. The Kakert Formation encloses thermophilic planktonic and benthic foraminifers [11].

The Il'in Formation generally characterized by normal polarity includes four polarity reversal zones, among which the second and third zones are widest. The Kakert Formation also includes four polarity reversal zones, among which two zones are located at the base of this unit. The boundary between chrons C5Bn and C5Br probably passes within sediments of the climatic optimum [10] (Fig. 2).

Eastern Kamchatka. The climatic optimum is recognized here in the Neogene section of the Mys Ploskii Formation on Karaginskii Island [12]. In the spore and pollen spectra from these sediments, angiosperms (43.9–69.5%) prevail over gymnosperms (18.2–41.5%) and spores (7.1–25.0%). Angiosperms are characterized by a high content of Taxodiaceae pollen, which accounts for up to 43% in basal layers of the formation. The pollen of *Picea, Pinus, Tsuga*, and *Abies* is common as well. *Alnus, Betula, Myrica, Corylus*, and *Juglans* pollen is dominant among gymnosperms. *Quercus, Ulmus, Pterocarya, Fagus, Acer*, and others are subordinate. The total content of thermophilic plants is 3.0–13.0%. Spores are represented by Polypodiaceae and *Sphagnum* plants. The warm paleoclimatic event in the studied section is also indicated by mollusks and foraminifers [11]. According to paleomagnetic data, the optimum comprises chrons C5ADr–C5Br [7].

Southern Sakhalin. The Lower–Middle Miocene boundary sediments in this region correspond to the Verkhnedui and Sertunai (Kurasi) formations. The flora from these sediments (climatic optimum) is attributed to the Verkhnedui floral horizon [13]. It is characterized by a significant share of Fagaceae (genera *Fagus, Quercus*, and *Castanea*) and other broad-leaved (*Liquidambar, Ulmus, Zelkova, Juglans, Cyclocarya, Pterocarya, Acer*, and others) plants. Palynological spectra of the Verkhnedui Formation are mainly composed of angiosperm pollen (32.0–85.6%) dominated by Betulaceae. The pollen of thermophilic plants (11.6–49.2% of the spectra) includes abundant *Fagus* and *Juglans* accompanied by subordinate *Ulmus*, Ulmaceae, *Tilia, Zelkova, Myrica, Carya, Carpinus, Corylus, Quercus, Castanea*, and others. The share of gymnosperm pollen assemblage (*Tsuga, Picea, Pinus*, and others) dominated by Pinaceae ranges from 7.5 to 67.2%. The content of Taxodiaceae pollen amounts to 29.2%. Spores are largely represented by Polypodiaceae and subordinate *Sphagnum, Lycopodium*, and others [14].

According to magnetostratigraphic data, the sediments under consideration correspond to the transition between chrons C5Bn and C5Br [15] (Fig. 2).

Thus, the combined paleomagnetic and biostratigraphic data on Miocene sediments of Northeast Russia suggest the synchronous nature of a climatic event at the Early–Middle Miocene transition. Judging from the examined sections, warming commenced in the region during chron C5Br and lasted through chrons C5Bn–C5ADn. The C5Br–C5Bn boundary represents an important paleomagnetic reference level for the stratigraphic interval under consideration.

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