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# Pleistocene glaciations of the eastern Sayan Mountains

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Abstract: The dynamics and morphological peculiarities of the Pleistocene glaciations of the southeastern part of the East Sayans, as the most representative part of the entire mountain system, are discussed. The existence of three independent Pleistocene glaciations has been determined on the basis of the absolute chronostratigraphical data and palynological characteristics of the local sedimentary series. The most significant glaciation dates to the early Last Glacial (Zyriansk Glaciation), the traces of which are well preserved in the present relief of East Sayans. The glacial stages were separated by warmer intervals, when glaciers disappeared completely and thermophilous biotic associations expanded over large areas.
The problems associated with past global climatic changes of our planet attract the attention of many scientific disciplines. In Siberia, geological and geomorphological investigations concerning the history of Pleistocene glaciations, which left marked traces in the geological record, have great importance for the reconstruction of the timing and extent of Quaternary glaciations in this region.

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## INTRODUCTION

The East Sayans are located in the central part of the Asian continent (Fig. 1), where the influence of humid oceanic air masses is not so significant as in the western and eastern regions of Eurasia. In this connection, a leading factor controlling the distribution of precipitation is the orientation of orographic elements relative to the dominating westerly winds.

The East Sayan mountain system consists of orographic elements oriented differently, and represents a mountain zone stretching for more than 750 km from the southern end of Baikal Lake in the northwestern direction as far as the Yenisey River. This topographic configuration predetermines an irregular distribution of atmospheric precipitation, particularly during winter. Peculiarities of the Pleistocene glaciations in the southeastern part of the East Sayan Mountains and palaeogeographical events and conditions which preceded and followed them are discussed below.

In total, six major units are distinguished in this sequence with respect to lithological differences and specific composition of palynological complexes characterizing the succession of warm and cold climatic stages. Four of them correspond to Middle Pleistocene and two younger are Late Pleistocene in age (Fig. 2, see also REZANOV - NEMCHINOV 1991).

## MIDDLE PLEISTOCENE

In the Middle Pleistocene (ca. 780–130 ka BP), processes of deposition essentially dominated in the southern part of the Okins Upland. Near the northern foot of the Munku-Sardik Ridge, coarse proluvial sequences up to 70 m thick, with lenticular intercalations of sandy silt, formed on the crystalline bedrock. Four older, from six major units, distinguished in the whole sedimentary sequence, belong to the Middle Pleistocene.

1. The formation of the sandy-silty unit at the base of the proluvial formation occurred in a rather dry and warm temperate climate of the Tobol interglacial optimum. At that time, (Oxygen isotope stage 9), *Betula-Pinus* forests were widely distributed with some *Picea* and *Alnaster* and broad-leaved species such as *Ulmus, Quercus, Juglans* and *Tsuga* in open forest-steppe areas.
2. The superimposed unit formed under a cold temperate and rather humid climate of the Samarovo Glacial (Oxygen isotope stage 8). Insular *Pine-Birch* forests spread out into open meadow-steppe areas.
3. The accumulation of the overlying proluvial unit, up to 20 m thick, occured in the period of humid temperate climate of the Messovsko-Shirta Interglacial (Oxygene isotope stage 7), characterized by *Pinus-Betula* forests with *Picea, Alnus* and *Salix*, but without broad-leaved species.
4. Formation of the following 10 m thick unit, was associated with the Tazov Glacial (oxygen isotope stage 6). Its lower part accumulated in a cold and humid climate whilst the upper was associated with cold-dry climatic conditions. This process was reflected in a

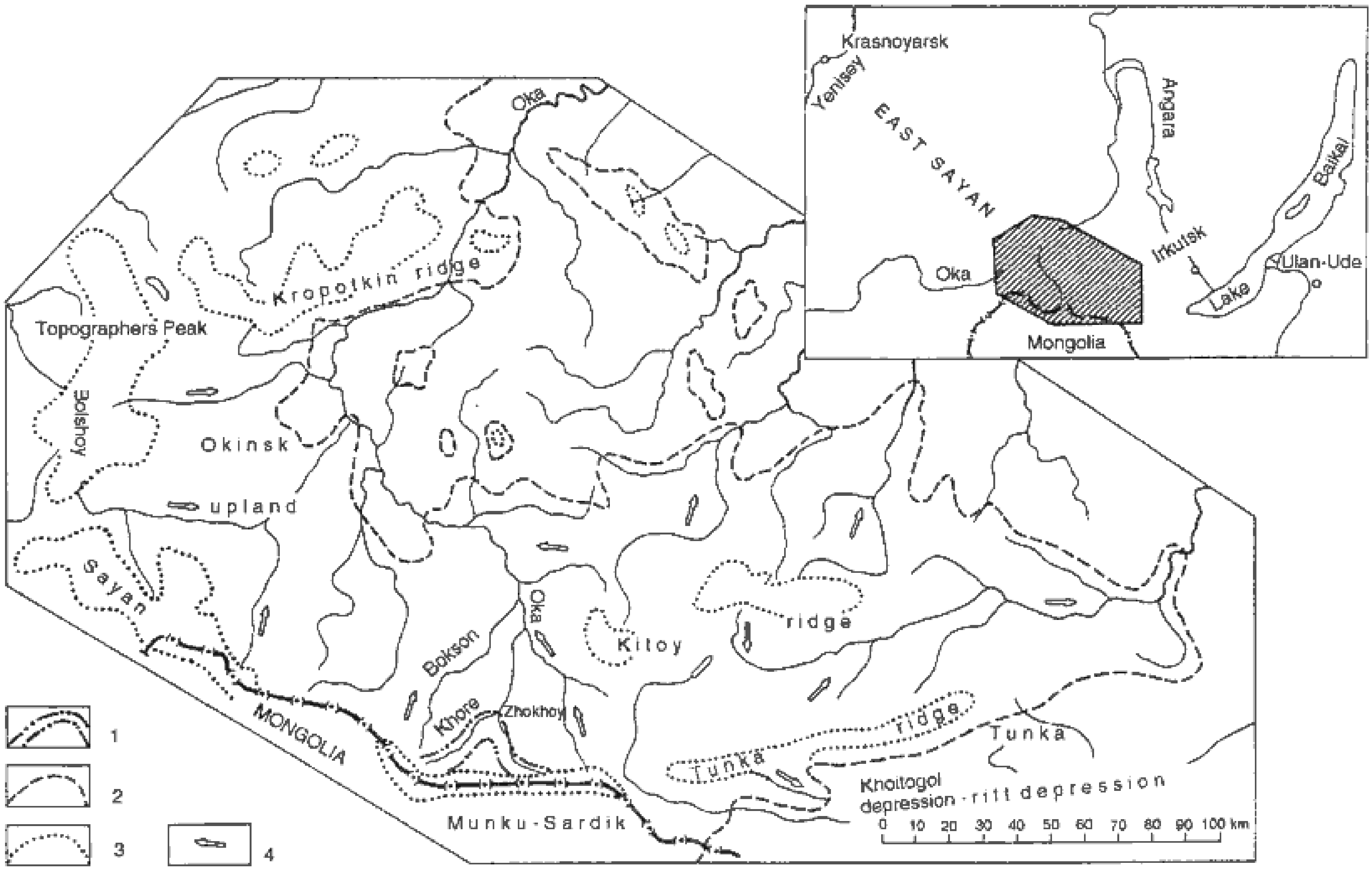


Fig. 1. Dynamics of the Eastern Sayan Pleistocene Glaciations.
1 – extension of the Middle Pleistocene ice advance; 2 – limits of the early Late Pleistocene (Zyriansk) Glaciation; 3 – location of the Last Glacial (Sartan) corrie glaciers; 4 – main directions of the glaciers movement.

successive degradation of forests and extension of open areas covered by tundra vegetation. The climatic cooling and aridization intensified from the beginning to the end of the Middle Pleistocene.

It is possible to judge the scales of the Middle Pleistocene glaciations by the relict features of the former valley glaciers in the upper reaches of the Khore River. The glacier trough was formed at the place of an ancient fragment of the river valley and was avoided by subsequent glacier advances and fluvial erosion.

Judging by the character of preserved glacial deposits, this early glaciation was not very intense. The snow line lowered to 2650 m and the total length of the Khore glacier reached 25–30 km with a maximum thickness of 350 m. The ice-movement speed 4 km from the ice-terminus did not likely exceed 2 m/year by an essentially laminar-type movement. When degrading, the glacier disintegrated into separate blocks of "dead" ice evidenced by relic-morainic fields with a great number of small free-discharge lakes. The stratigraphical situation does not allow the determination whether this glaciation was the first Middle Pleistocene (< 780 ka BP) glaciation or, the second one in succession, but it was definitely not the maximum glaciation in this region. Stratigraphically the described glaciation is correlated with the Riss glacial stage in the Alpine stratigraphical scheme (Oxygen isotope stage 6).

The appearance of the first mountain glaciation in the East Sayan Mountains could coincide with the overall development of the Middle Pleistocene climate in West Siberia and with the synchronous tectonic activity. At that time, the warping of the piedmont plain at the northern foot of the Munku-Sardik Ridge and the synchronous rise of the mountain front occurred (Grosswald 1965, Olyunin 1965). The summary amplitude of the vertical displacement reached 150–200 m which corresponds to a rate of up to 1.3 mm per year. By that time, the Angara River headshed was formed associated with the rise of the western frame of the Baikal Lake, with a rate of uplift similar to that of the Munku-Sardik Ridge.

## LATE PLEISTOCENE

At the beginning of the Late Pleistocene, differential vertical tectonic movements continued accompanied by intense erosive activity and formation of river valleys, the main part of which served as transit ways for later valley glaciers.

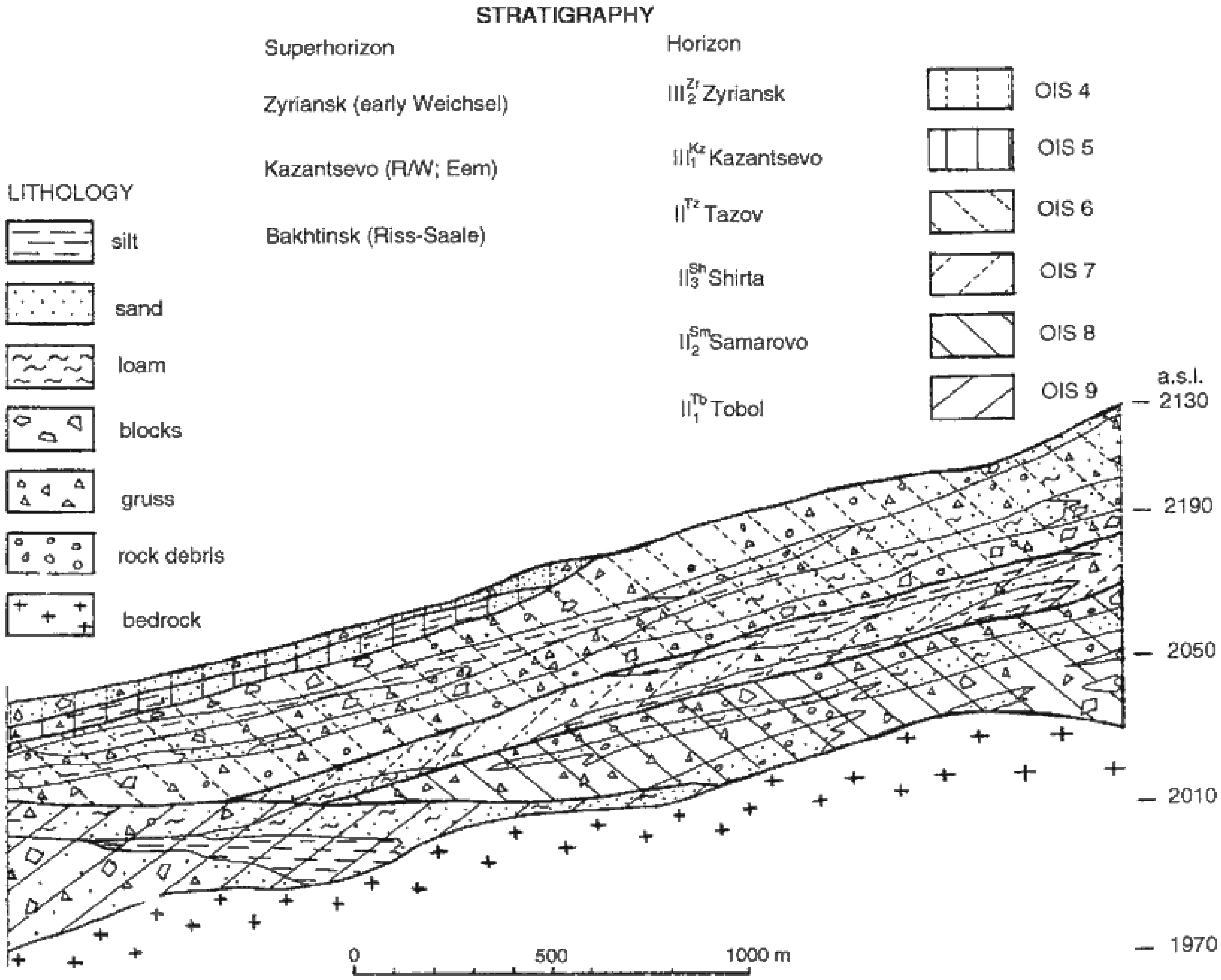


Fig. 2. Stratigraphical scheme of the Pleistocene sedimentary sequence in the Eastern Sayan Mountain region.

## The Kazantsevo Interglacial

The earliest Late Pleistocene (last interglacial) sediments are gravel and pebble beds revealed in the Kitoy River valley. The deposits lay in a 20 m section and represent a slightly lithified brownish coloured pebbly unit alternating with gravel and coarse sand with a total thickness of 2 m. According to ESR dating, their age is ca. 105 000 ± 4000 yr. BP, which corresponds to the end of the Kazantsevo Interglacial. The pebble beds are overlain by a series of rock debris with silty accumulations and the basal moraine.

The last interglacial layers are also revealed in a core near Urunge-Nur Lake. They are represented by lacustrine silty sands with some rock debris and reach up to 4 m in thickness. They are overlain by glacifluvial deposits of the early Last Glacial. At the end of the Kazantsevo Interglacial, coniferous species such as *Pinus sibirica, Picea* and in a lesser measure *Tsuga* were widely distributed. The *Betula, Larix, Salix* and *Alnaster* indicate a warm temperate and relatively humid climate.

## The Zyriansk Glacial

A gradual climatic cooling at the beginning of the last glacial resulted in the most intensive glaciation in the Eastern Sayans, encompassing most of the Late Pleistocene and including two glacial phases, the Zyriansk Glaciation (early last glacial) and the Sartan Glaciation (late last glacial) that correspond to the lower and upper Würm, respectively. The first during Oxygen isotope stage 4, was the maximum glaciation in view of dynamics of the glacier advance and the area covered by ice. The second glaciation, correlated with the Oxygen isotope stage 2, was chiefly of a corrie type with an insignificant glacier drift into the main valleys.

The major centers of the Zyriansk Glaciation in the Eastern Sayans were located over the ridges of Kropotkin, Munku-Sardik, Bolshoy Sayan, Kitoy and Tunka (Fig. 1). Unlike these places, the Oka Upland situated in an orographic "shadow" developed only a few small accumulations of corrie and firn fields on insular massifs, as on Sakhir-Shuluta. The only vast ice-field was located in the southern part of the Oka Upland. Mountain valley glaciers, expanding from the northern slopes of the Munku-Sardik Ridge and the northeastern slopes of the Bolshoy Sayan Ridge, formed mighty piedmont glaciers penetrating far into the extraglacial zone. Thus, the terminal moraine of the Oka glacier formed 90 km from the ice-formation source. Thickness of glaciers usually exceeded the depth of the preglacial valleys and the ice tongues often moved into interfluvial areas and merged with each other. For example, eastward of the Dibi River, the width of the entire ice sheet reached 60–70 km.

During the period of maximum expansion of the Khore glacier, a snow line reached 2300 m a.s.l. on the moisture-receiving slope of the Munku-Sardik Ridge. The maximum thickness of the Khore and Oka ice-sheet reached 700 m and down in the valley did not exceed 400 m. The average ice advance speed is estimated to have been 20 m per year at a distance of 20 km from the terminus.

The Oka glacier, with its tributaries (Zokhoy, Khore and Bokson) was one of the most significant in the region. It formed a great ice-field covering an area of several hundred square kilometres. Its thickness was about 240 m in the region of the Upper Oka River, but along the valley it increased rapidly reaching 400 m in the Zokhoy mouth and exceeding 500 m in the Khore mouth.

The largest glacier of the early last glacial stage was the Tissa glacier. It was generated on the "Topographers Peak", a massif of the Bolshoy Sayan Ridge, and expanded eastwards for 80 km into the Oka River valley. The maximum area covered by the ice exceeded 1300 km$^2$ whilst its thickness reached 700 m.

In the Kitoy Ridge, located in the inner zone of the region, the mountain glaciation occured at a somewhat limited scale. The snow line altitude was within 2400 m a.s.l. with the maximum ice thickness reached 400 m nearby. The thickness of the valley glaciers was 300 to 400 m and in the lower courses of through valleys it was only 150 m. Ice movement speed varied approximately from 20 to 40 m per year in the upper reaches and from 5 to 20 m year by their terminuses.

Interesting information on the dynamics of the Zyriansk Glaciation has been obtained by investigating the ice-terminal glacial formations in the Khoitogol Depression of the Tunka Rift system (BUDAEV - NEMCHINOV 1986). Moraines left behind by the mountain-valley glaciers from the Tunka Ridge are formed along its northern slope. The total area of the piedmont glacier, formed as a result of coalescence of several ice tongues, reached 30 km$^2$. Judging by the interrelations of morainic and glacio-fluvial relief forms, the preservation degree and their surface microrelief, several stages of glacial advance occured.

Glacial formations of the first phase of the last glacial, which corresponds to the maximum ice expansion, are represented by fragments of end moraines up to 100–200 m height. At that time the glacier descended down to elevations of 1600 m.

End moraines of the second glacial phase of the Zyriansk Glacial are distinguished by better preservation than the first and lie in the form of morainic "tongues" with an eskerine relief. Up to three ice-margin oscillation moraines can be distinguished.

In the lower reaches of the Ikhe-Ukhgun River, glacial formations of the local valley glacier cover an area of more than 30 km$^2$ and lie in the form of horse shoe-shaped ramparts occupied by small lakes and kettle-holes.

The most recent structural-neotectonic movement predetermined a specific character of the subsequent ice activity. The resulting transformation of the glacier dynamics with larger ice build-up under an ongoing orogenesis, contributed to accumulation of thick sedimentary series in sinking zones.

## The Karginsk interstadial

The following Karginsk interval (mid-last glacial, Oxygen isotope stage 3) was marked by a development of large alluvial accumulation plains. In river valleys, 5–7 m high sandy terraces and sandy terrace ridges were formed. A marked warming is reflected in the palynological spectra from the sediments. The interstadial vegetation was represented by shrub and arboreal taxa (54 to 70 %), amongst which *Pinus silvestris, P. sibirica, Abies, Picea* and *Tsuga* dominated. Apart from the coniferous species, deciduous trees (*Quercus, Ulmus, Corylus* and *Alnus*) and shrubs (*Salix, Alnaster*) were also present.

Lacustrine and proluvial series of that time are characterized by swampy facies. A radiocarbon date of 47 500 ± 1500 yr. BP was obtained on one wood fragment.

The palaeoenvironmental data indicate that former glaciers completely degraded, probably with the exception of isolated firns and passive corrie glaciers preserved within the highest mountain massifs.

## The Sartan Glaciation

The final Late Pleistocene glacial activity relates to the late-Last Glacial stage, or the Sartan Glaciation (Oxygen isotope stage 2). In the Eastern Sayans, it was less significant than the former Zyriansk Glaciation and was represented mainly by corrie glaciers with a maximum ice protrusion on the northern slopes not exceeding 3–8 km. The ridges of the Bolshoy Sayan and Munku-Sardik were characterized by active corrie glaciers and a snow line at an elevation of 2700 m. In the upper river valleys, deposits of the 3–4 m terrace, composed of coarse mountain alluvium are mixed with facies of corrie moraines. Relic lacustrine sandy series formed on the valley slopes, often filling fragments of the Zyriansk glaciofluvial channels.

In the Oka River valley, the age of such sediments have been ESR dated to 15 600 ± 3900 yr. BP.

## HOLOCENE

The climate in the Holocene optimum in the Eastern Sayan Mountains was warm temperate. At that time, coniferous forests prevailed, dominated by *Pinus silvestris* and *P. sibirica*, and followed by *Picea, Alnaster* and *Salix*. *Polypodiaceae* were also present, as well as some broad-leaved trees, such as *Quercus, Corylus* and *Alnus*. In some former glacial lakes, swamps were formed at elevations of 2000–2300 m. Two radiocarbondated samples of peat and wood from the lacustrine-swampy horizons produced dates of 6200 ± 90 yr. BP and 6500 ± 40 yr. BP, respectively.

At the present time, rigorous climatic conditions dominate over the region with an average annual temperature of –4 °C. A considerable part of the territory is occupied by tundra. *Larix* dominates the composition of coniferous species, followed by *Pinus sibirica*, whereas *Betula nana* prevails among shrub species. Different mosses and lichens are widely spread. Perenial frost is developed almost everywhere.

As to recent glaciations, for the entire Eastern Sayan Mountains, there are no more than two dozens hanging and corrie glaciers filling inherited corries of the Sartan Glaciation. They are concentrated mainly on the ridges of the Bolshoy Sayan and the Munku-Sardik where a snow line is located at 2800 m a.s.l. on the northern slope and at 3170 m on the southern slope. Glaciers on the northern slope of the "Topographers Peak" extend for up to 5 km.

## Summary

- Three definite glacial stages, separated by warmer intervals with a significantly reduced glacial activity, are evidenced in the Pleistocene climatic history of the Eastern Sayan Mountains;
- a Middle Pleistocene glaciation is less known, but was clearly less extensive than the first Late Pleistocene (Zyriansk) glaciation;
- the Zyriansk glaciation marks the maximum ice advance of mountain glaciers and was followed by several ice-front oscillations;
- the second (Sartan) Late Pleistocene glaciation was independent and separated from the previous glacial by the warm (Karginsk) interstadial. The glaciers were largely limited to corrie glaciers in high mountains;
- the Pleistocene glaciations, especially the maximum of the early Last Glacial, undoubtedly influenced the process of sedimentation in the larger area. This is evidenced by accumulation and subsequent redeposition of glacial sediments, in the changes of the hydrodynamic river regime due to restructuring of the drainage system caused by glacial supports.

*Recommended for print by T. Czudek*

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