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Late Pleistocene palaeogeography of North-west Siberia

SVETLANA S. SUKHORUKOVA[1]

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Abstract: Palaeogeographical data indicate a sharply contrasting natural environment of the Kazantsevo (Eemian) boreal palaeobasin and the subsequent Zyriansk Glaciation in North-west Siberia. The characteristics of the Kazantsevo sea shorelines, zoogeography, facies and composition of deposits are described. In the reference section at the Agapa River, five substages are recognized in the last (Kazantsevo) interglacial record (equivalent to marine Oxygen Isotope Stage 5e). Amongst them, $5e_1$, $5e_3$ and $5e_5$ are warm, whereas $5e_2$ and $5e_4$ are cold with indications of an increased humidity.It is assumed that the interglacial environment dynamics, shown by short periodical changes of climate, biogeocenoses and sedimentary conditions, is controlled by geoplanetary cycles of 4–5 ka duration. The climatic phenomenon of the Kazantsevo Sea is explained by a positive phase coincidence of astro- and geoplanetary factors of climate regulations, glacioisostatics and a tectonic fall of northern lowlands. The succeeding early Ermakovo Glaciation (Lower Weichselian, OIS 4) is evidenced by tills with a lithological provenance from the Ob, Yamal, Gydan and Yenisey mountainous glacial centres found in the ice sheet in the Kara shelf area. During the late Ermakovo Glaciation (OIS 2), as well as during the postglacial, buried ice blocks covered by flow tills or surrounded by shallow lake deposits were widely distributed.

[1] *United Institute of Geology, Geophysics and Mineralogy, Siberian Branch of the Russian Academy of Sciences (UIGGM SB RAS), Universitetsky prospekt 3, 630090 Novosibirsk, Russia*

THE KAZANTSEVO (EEMIAN, OIS 5) INTERGLACIAL

Presently, a sufficient amount of data is available on stratigraphy and correlation of marine Kazantsevo interglacial deposits (TROITSKIY 1979, GUDINA 1976, LEVCHUK 1984, SKABITSCHEWSKAYA 1984, ARKHIPOV 1987). Chronology of this time interval in Siberia, however, is still rather obscure. It is largerly based on ESR dates on marine mollusc shells from sections of the Kazantsevo deposits in the lower Yenisey River area and on the Taimyr peninsula (KATZENBERGER - GRUN 1986). Zoogeography and conditions of sedimentation are summarized on the schematic sketch of the Kazantsevo sea facies (Fig. 1).

In the West Siberia and Taimyr Basins, temperate-boreal and boreal molluscs were common during the last interglacial. In terms of the number of species, the North Siberian Kazantsevo fauna was as diverse as the Danish Eemian fauna, but had another zoogeographical structure. The following complexes of species have been identified: boreal – 14 %, mainly boreal – 6 %, arctic-boreal – 37 %, arctic – 43 %. The fauna can be regarded as a peculiar interglacial fauna of a marginal part of a northern province having no complete analogy in modern seas. The area of Kazantsevo Sea beyond the Urals (the Siberian boreal province) is specific in its unique range of boreal fauna penetration into arctic seas mainly from the west and less from the east.

Migration series of specific marine molluscs have been identified for the optimum conditions of the Kazantsevo Interglacial. In the Beloe paleosea, in the area of the Onega and North Dvina watershed (63–64° N, 40° E), *Nassa reticulfata* was widely distributed. *Spisulia ellectica* lived in the Pechora Sea along the western coast of the Iugor Peninsula (67–69° N, 60° E), and *Astarte sulcata* inhabited the area around the Yamal Peninsula (70° N, 70° E). Further east and north, there were mollusc semiconcentric habitat zones open to the west. On the Tanam River (69° N, 80° E), was *Cardium edule*, in the Yenisey Bay (70° N, 80° E), *Zirphaea crispata* and on the Agape River in the western part of the Taimyr Lowland (72° N, 90° E), *Macoma baltica* (TROITSKIY 1974).

The migrational assemblage of the Kazantsevo marine molluscan fauna shows a gradual decrease of the sea water temperatures from west to east from +12 °C at Danemark to + 8 °C/+ 5 °C at Gydan. In general, the Kazantsevo seawater temperature was 3 °C to 6 °C higher than the present temperatures in North and West Siberia. The boreal temperatures increased by twice as much as on the coasts of Western Europe.

Distribution of fossil molluscs is rather demonstrative (Fig. 1). Well preserved massive burials of marine organisms (black dots) prevail in the regions of the Baydaratshay Inlet coast, on the southern Yamal, Gydan and Taname River, in the Yenisey Bay and in the basins of the Bolshaya and Malaya Kheta Rivers. Single remains of molluscs are linked with palaeobays along northern beaches of the Putoran Plateau, in some regions of Bolshaya and Malaya Kheta and Turukhan riverheads (white dots). Multiple burials of shell casts (black-white dots) are clearly concentrated in two regions: in the northern part of the Juribey Ridge on the Gydan River and on the eastern coast of the Yenisey Bay and foothills of the Taimyr Peninsula.

Routes of distribution and points of inhabitancy of molluscs, shown by arrows, indicate mainly eastern flow directions, beginning with the Baydaratskaya Inlet, through the Ob and Tazovo Inlets, along the latitudally stretched Gydan-Tanam Highlands into the Ust-Port region and through palaeoislands of the Taimyr Lowland and the Khatanga River mouth.

The southern boundary of the Kazantsevo Sea goes through a number of bays deeply penetrating through mouths of both small and large rivers. The lower Ob and Nadym Bays were protruding up to 65° N. The Pur-Tasovo-Turukhan Bay seems to have been the largest bay extending along Yenisey beyond the mouth of the Podkamennaya Tunguska River at 64° N and 85° E.

During the last interglacial, the greater part of the Palaeo-Yenisey waters was directed through the Turukhan River into the Tas and Pur Basins and the Ob River inlet. The immense freshwater input from the Yenisey River caused a decreased salinity in the northwestern part of the Kazantsevo Sea and impoverishment of marine fauna.The boundary of the palaeo-Yenisey Bay, reached by the Uboinaya River, where strata of deepwater clays are ESR dated to 127 ± 7 ka BP, is well marked. This date corroborates the idea that the palaeo-Yenisey River waters did not discharge to the north as today, but turned more westwards because of the tectonic uplift of the Igarka region and did not cause sea freshening and ecological changes of the Kazantsevo malacofauna in clays of the Uboinaya River.

The microfaunal assemblages indicate a sea depth of up to 45 m (Arkhipov et al. 1995). Considering the differences in the modern altitudes of these deposits, varying from –55 m to +60 m, it may be suggested that the post-Kazantsevo movements of the northern regions reached 60 m.

There are two meridian lithofacial key profiles of the Kazantsevo marine deposits: the lower Ob-Yamal and the Yenisey-Agapian profiles. In the lower Ob River Bay, the Kazantsevo Sea was shallow with a reduced salinity. At the Kasym Cape in the Salekhard region and on the Tazovskyi Peninsula, in the Khadduta River ba-

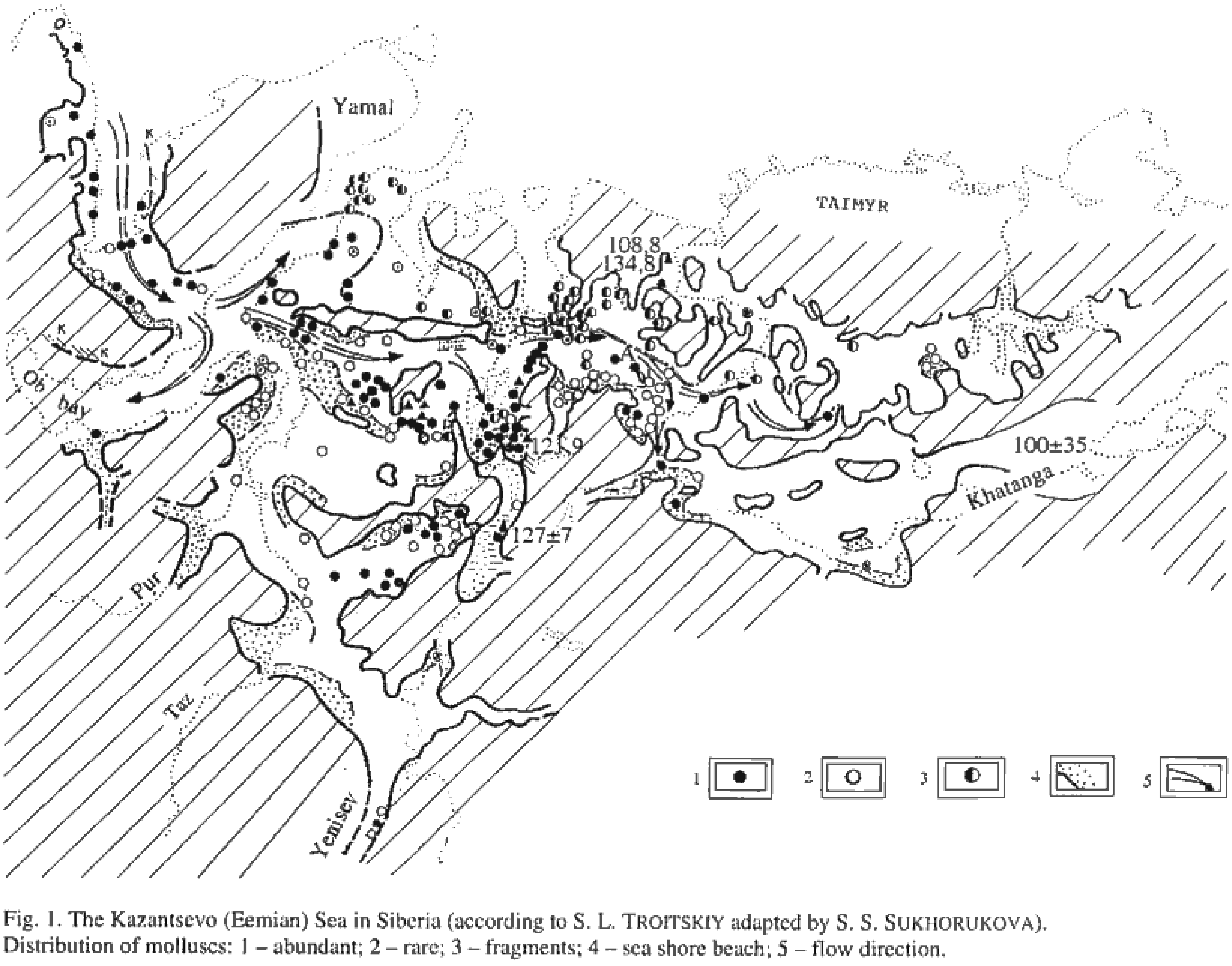

Fig. 1. The Kazantsevo (Eemian) Sea in Siberia (according to S. L. Troitskiy adapted by S. S. Sukhorukova). Distribution of molluscs: 1 – abundant; 2 – rare; 3 – fragments; 4 – sea shore beach; 5 – flow direction.

sin, sands of various grain sizes, interstratified with poor and scarce assemblages of the Kazantsevo foraminifera of shallow water facies are known –25 to –50 m below sea level. In the Yamal-Gydan region, the same sedimentary facies occurs 10 to 30 m below sea level. The top of this marine formation facies is a transition to sandy-clayey deposits of the Ob palaeodelta. It has been identified (GATTAULIN 1991) as the former Marresalian suite along the west coast of the Yamal from Mare-Sale to Cape Kharosovey. The delta deposits are dominated by clays and silty sands with a high content of pollen and plant detritus, mica, a search marine fauna, a freshwater assemblage of diatoms and various redeposited organic forms. The deposits have low palaeosalinity indices, a great thickness and high sedimentation rates. At the end of the last interglacial, the delta was actively migrating northward simultaneously with sea regression and climatic cooling.

The Yenisey profile of the Kazantsevo marine deposits begins beyond the Polar circle with sandy facies of shallow waters near Igarka. On the Uboinaya River, there is a subzone of relatively deep water (100 m) clays, where accumulations of marine micro- and macrofauna (ESR dated to 127 ± 7 ka BP, V. A. MOLODKOV) reached a height of +8 m above the Yenisey River level. In the exposures of Dudinka in the Ust-Port region, mainly sand facies of shallow waters have been described (SUKHORUKOVA 1975). At the Karginsk Cape, sands at the level of +5 m contain a rich assemblage of marine fauna dated by ESR to 121.9 ka BP. Further north, at Ladygin Yar at the level of +30 m and +45 m, well sorted sands are traced with a rich marine fauna, with molluscs shells 1–4 cm in size, retaining a chitin layer. At the Upper Cretaceous outcrop near the Vorontsovo village, the Kazantsevo sands occur at a level of +60 to 64 m. They are coarse grained sands with intercalated beds of pebble gravel, pebbles with laminated sandy and pebble-shell layers. The molluscs occurrence is dispersed and bedded with a high concentration of cups. The faunal content and coarse-grained sand size indicate a coastal facies within the upper sublitorral temperate to warm water ice-free marine basin (TROITSKYI - SCHUMILOVA 1975). The section has a regressive structure and suggests an incomplete transgressive climatic rhythm.

The most complete geological record in the sandy-clay Kazantsevo deposits occurs in the lower Agapa River in the Pyasina River Basin (SUKHORUKOVA 1994). They resemble the clay-sandy sections of Postoye and Karepovskoe at the Yenisey River mouth. Five substages of the Kazantsevo transgression were identified in the reference section of the Agapa River by means of statistical and cluster anylysis of lithobiotic data. Amongst them, substages $5e_1$, $5e_3$ and $5e_5$ are warm and substages $5e_2$ and $5e_4$ are cool with indicators of increased freshwater input (Fig. 2).

1. Basal sands, silts and bluish clays with calcite concentrations correspond to the early substage $5e_5$. It was a time when shallow water conditions were replaced by a bay or lagoon environment in which thin clays with abundant fauna and flora were deposited. The intercalations of litho-biotic features indicate that settling and spreading of boreal organisms was caused by their migration into the Agapa region from the west together with a warm water inflow. Warming of marine waters at a latitude of 71° N was weak. A high content of the clay fraction, correlating with arctic species of macro-and microfauna, indicate a cool climate on the surrounding landscape.

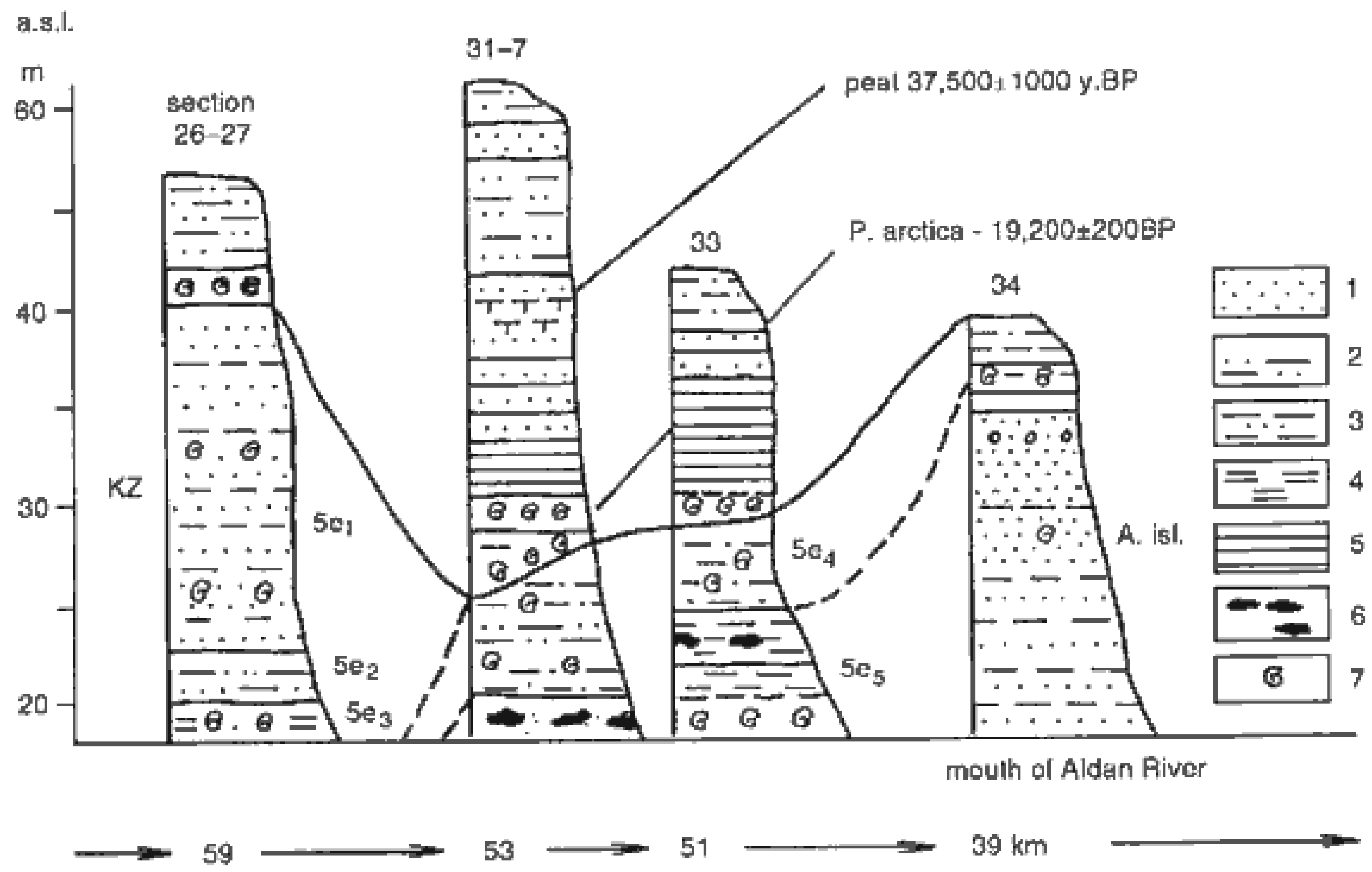

Fig. 2. Reference sections of the Agapa River for the Oxygen Isotope substage 5c.
1 – sand; 2 – silty sand; 3 – clayey silt; 4 – clayey loam; 5 – clay; 6 – carbonate concretions; 7 – fauna.

2. During the following substage $5e_4$, the marine waters became cooler due to atmospheric cooling of the land. Arctic species of molluscs dominated by up to 70 %. This interval correlates with palaeosalinity reduction. Summers became colder, winters drier and aeolian inputs increased.
3. Deposits of substage $5e_3$ contain mainly arctoboreal (70 %) and boreal (20–25 %) species of molluscs, foraminifera and a very rich boreal assemblage of diatoms. Salinity again returned to a normal level, and the water temperature increased. Winter became warmer, summers remained cool.
4. The penultimate substage ($5e_2$) shows an abrupt decrease of salinity with a simultaneous water cooling. These changes in the Kazantsevo Sea were most reflected in diatoms. The abundance of silty particles indicates cool winters, a decreased rainfall and an arid climate. The basin became shallower with freshwater due to the tectonic uplift and a temporal isolation of the palaeobasin.
5. During the final substage ($5e_1$), the Kazantsevo sea water was restored again and the water temperature increased. The boreal component of macrofauna significantly increased up to 25 %; it was even higher in the foraminifera and diatom assemblages. At the end of this stage, the local mollusc content increased and the land and sea temperatures equalised.

The record of the Kazantsevo transgression lacks a descending part to the climatic curve, implying a rapid sea regression along with a glacioeustatic sea-level drop and a tectonic uplift of the northern lowlands.

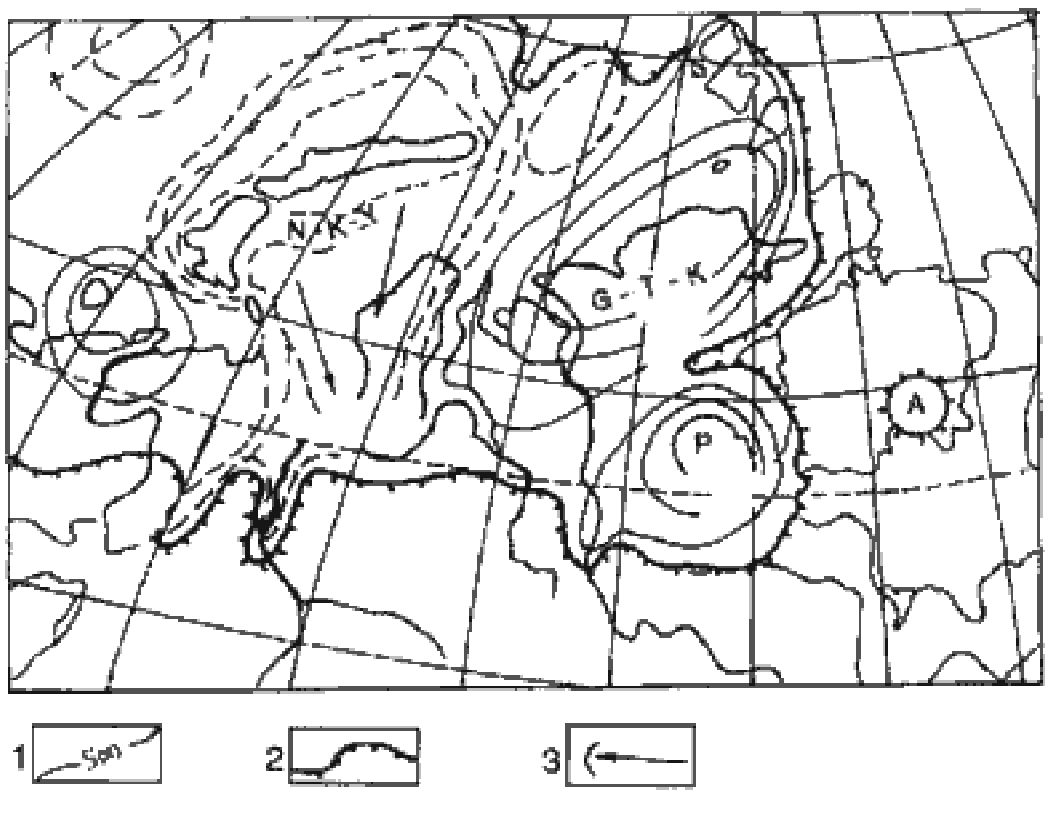

Fig. 3. The Ermakovo (Early Weichselian, OIS 4) ice-sheets in West Siberia (according to SUKHORUKOVA 1991).
Ice sheets: N-K-Y = Novaya Zemlya-Kara-Yamal; U = Ural; G-T-K = Gydan, Taimyr-Kara; P = Putoran; A = Anabar.
Contours: 1 – palaeoisohypses of glaciers; 2 – general ice-sheet limits; 3 – direction of the ice movement of the Central Siberian sheet.

THE ERMAKOVO (LOWER WEICHSELIAN, OIS 4) GLACIATION

After the Kazantsevo interglacial transgression, North and West Siberia was covered by the early Zyriansk (Ermakovo or Lower Weichselian) glaciers. Dynamic aspects of this complex three-phased glaciation are not clear, because exact chronological dates are scarce. The continental ice-sheet front extended along the Nadym belt along 65° N with separate lobes in the Ob and Yenisey River valleys. The individual glaciation centres of the Ermakovo palaeoglaciozone have been reconstructed with respect to structural and lithological composition of glacial deposits. Petrological information on the Ob and Yenisey tills (SUKHORUKOVA 1987) has been provided by new data on the poorly studied coarse tills of the West Yamal, Gydan and Nadym areas. Scarce pebbles (2 %) in the Gydan till are dominated by fragments (60 %) of rocks of the Upper Cretaceous siderite-phosphate-carbonate formation. The clasts have a different microstructure, but are similar in composition to cement and authigenic minerals that indicate a local sedimentary environment. Mineralogically, they include quartz (11 %) and some exotic rock debris from the Taimyr Peninsula trap zone – 19 %, granitoids – 4 %, shale – 6 %. In the Yamal samples (the Seyakha and Mutnaya Rivers and Marre-Saale), containing only 0.2–0.5 % debris, the majority of pebbles is composed of Palaeozoic rock fragments from the Flysh units of Novaya Zemlya. Another half is represented by pebbles of the Mesozoic sandstones with glauconite, opal cement and a corresponding microfauna. Clasts of crystalline shales and polymictic tuff-sandstones are found at top of the Marre-Saale till. This rock group in general is markedly impoverished as compared with rock associations of the Polar Ural Mountains.

The Nadym sample with a low content of small pebbles reveals a predominance of fragments of the Mesozoic-Cenozoic sedimentary rocks (80 %) due to exaration of the Cretaceous outcrops and the brown-coal bearing Palaeocene deposits.

In the northern Ural area, the Belogorye Kormuzhikhantsk till from the first half of the Zyriansk glaciation is also impoverished (0.2 %) in debris content. Half of the pebbles is represented by crystalline rocks of Urals, with the Ural Palaeozoic sandstone and some Palaeocene claystone debris. On the Yenisey River, the Ermakovo till is rich in trap rocks and carbonate fragments and corresponds to the rock composition of the western margin of the Siberian Platform.

In the Late Pleistocene, four major glaciation centres reappeared; on the Novaya Zemlya, northern Ural, the Taimyr Peninsula and the Putoran Plateau. They gave rise to four ice sheets with tills of different composition. From the Novaya Zemlya, the glacier flowed through the Kara shelf, crossed the Yamal and reached the

Nadym town. The Taimyr-Gydan glacier was orographically higher. A boundary between them went along the line of the Ob inlet, coinciding with the fault. At the latitude of the Polar Circle, they merged with the Ural-Ob glacier in the west and with the Putoran-Yenisey glacier in the east (Fig. 3).

A lithological analysis of glaciocomplexes has revealed variations of temperature and water supply in late- and post-glacial times in the northern territories. In the Yamal, Gydan, and Nadyn-Pur areas, deglaciation occurred under humid and swampy conditions with water filling the basin. These were the specific conditions when dead ice fields were surrounded by lake basins (Arslanov et al. 1983). Different kind of lake landscapes existed on the Yenisey. For example, at the Ledyanaya Gora section at the latitude of the Polar Circle, the termination caused a partial ice melting and mobilisation of great masses of terrigenous material (analogous to flow tills) that buried the Ermakovo glacier (Zolnikov 1991). It has remained buried until recently and now is being exposed by erosion.

CONCLUSIONS

To explain the phenomenon of the Kazantsevo transgression, it is important to stress the different mechanism of regulation of palaeotemperatures of marine basins. The temperature of marine waters was defined by a structure of currents, dependent in turn on the shelf relief of the northern seas and adjacent land. The deep penetration of warm currents to the east was due to tectonic movement and glacioisostatic depression. Input of additional heat into the Kazantsevo Sea raised the water temperatures and stimulated the climatic optimum of the surrounding land. This explains an abnormal increase in palaeotemperatures and the shift of floral palaeozones to the north.

Five substages of the Kazantsevo transgression, corresponding to the North Siberian interglacial, correlate with geoplanetary climatic changes of 2 to 4–5 ka duration. A spatial reconstruction of the early last glacial (Zyriansk) ice sheet is based on petrology and distribution of glacial deposits and index rock types with glacier centres located in the highlands.

The differentiated structure of the regional ice cover defined in the Yamal and Gydan areas does not confirm Grosswald's model (1983) of a panarctic Kara shelf super ice-sheet. The presented palaeogeographical reconstruction supports, in turn, the classic concept and stresses the fact that, in the development and deglaciation of the Siberian ice covers, tectonics played a major role in addition to climatic factors.

Peculiarities of distribution of both the Kazantsevo marine and Ermakovo glacigenic facies demonstrate the existence of relatively short and periodical climatic fluctuations. Nevertheless, they are also linked with the history and intensity of tectonic activity in the northern part of Siberia during the Upper Pleistocene.

In terms of climatic prediction for the North Siberian territory (Arkhipov et al. 1995), it can be suggested that a climatic optimum, similar to the last interglacial, may be repeated in the North of Siberia only under conditions of global warming combined with regional tectonic activity. However, it is unlikely that a future warming will be an exact analogy of the last interglacial with the abnormal increase of temperatures in the northern part of Siberia. As shown by lithology, there was no cryolithozone beyond the Polar Circle during the Kazantsevo interval. In case of a future warming, the degradation of the modern frost will prevent an increase of temperatures in high latitudes. Without additional heat, including the warm Atlantic currents, the climate in high latitudes will be cold and closer to the Karginsk interstadial of Oxygen Isotope Stage 3.

Recommended for print by V. Ložek

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