Sborník geologických věd	Antropozoikum 23	Pages 17–24	5 figs.	– tab.	– pl.	ČGÚ Praha 1999	ISBN 80-7075-272-6 ISSN 0036-5270

Late Pliocene and Pleistocene palaeoclimates in Northeastern Chukotka

STANISLAV A. LAUKHIN[1] - VLADIMIR A. KLIMANOV[2] - BERTA V. BELAYA[3]

Received October, 1996

Key words: Chukotka peninsula, Glaciations, Palaeoclimates, Palaeotemperatures, Pliocene, Pleistocene

LAUKHIN, S. A. - KLIMANOV, V. A. - BELAYA, B. V. (1999): Late Pliocene and Pleistocene palaeoclimates in Northeastern Chukotka. – Sbor. geol. Věd, Antropozoikum, 23, 17–24. Praha.

Abstract: The earliest glacial deposits in the northeastern part of Chukotka date to 3.5–3.2 and 2.5–2.4 Ma BP. Palynological data from till units, used for palaeoclimatic reconstructions, indicate mean January temperatures of the earliest and the latest glaciations close to each other, whereas mean July temperatures and precipitation were higher during the earliest glacial period. The mid-Last Glacial interval (oxygen isotope stage 3) was significantly warmer than the present climate in the area with mean July temperatures 3–6 °C higher and January temperatures 4 °C higher.

[1] *Institute of Northern Development, SD RAS, Tyumen'; Geological Institute RAS, Pyzhevsky 7, 109017 Moscow, Russia*
[2] *Institute of Geography, Russian Academy of Sciences, Staromonetny 29, 109017 Moscow, Russia*
[3] *Central Laboratory of Association "Sevvostokgeologia", Proletarsky 14, 685000 Magadan, Russia*

INTRODUCTION

The lower boundary of the Quaternary Epoch, first addressed by E. HAUG in 1903, is still a subject of debate. Several chronostratigraphical variants for the beginning of the Pleistocene were proposed at the XIth INQUA Congress in Moscow in 1982, with the Plio/Pleistocene transition at 3.5 Ma, 2.4 Ma, 1.8 Ma, 1.64 Ma and 0.8 Ma BP. The same issue was subsequently discussed at the following INQUA Congresses in Beijing (1991) and Berlin (1995).

One of the major criteria for definition of the lower boundary of Quaternary is the appearance of the first regional glaciation as an indicator of global climatic deterioration. The Chukotka peninsula is of a major significance for the study of the earliest Quaternary glaciations in the larger Beringia territory and the climatic evolution during the Pleistocene. This study summarizes recent palynological data from boreholes from several key localities in Northeast Chukotka.

SECTION, GENESIS AND AGE OF DEPOSITS

The principal site (borehole 28) is situated in the Vankarem depression (Fig. 1) where the stratigraphical section revealed several Pliocene and Pleistocene till units (LAUKHIN et al. 1989; in press). Borehole 28 was located 17.5 km south of the Vankarem lagoon (the mouth area of the Zhuravlinaya River) in the Zhuravlinaya and Okanaan Rivers interfluve 2.5 km northwest of the Okanaan Mountains. The sediments of a submeridional buried palaeovalley include 6 major depositional units spanning the transition from Pliocene to Quaternary 106.0 to 4.5 m above the Miocene sediments (Fig. 2). The following is a summary stratigraphical description of the sequence starting at the base (for details see LAUKHIN et al. in press).

Unit 1 (106.0–97.8 m) consists of interbedded pebbles and sand of lacustrine, fluvial and glaciofluvial origin (upper beds).

Unit 2 (97.8–90.4 m) is represented by pebble- to boulder-size clastic deposits in a loamy to sandy loamy matrix (diamicton) with a detached mass of Miocene lignites, representing a till with interbedded glaciofluvial sands. The till was partially deposited as a coastal-marine facies.

Unit 3 (90.4-82.4 m) is composed of interbedded glaciofluvial sand and gravel and similar superimposed fluvial deposits.

Unit 4 (82.4–75.2 m) is an interbedded grey pebbly loamy till with glaciofluvial sands and gravel beds.

Unit 5 (75.2–47.6 m) consists of a boulder-pebble deposit (diamicton) with a grey sandy loamy matrix (till).

Unit 6 (47.6–4.5 m) includes clays of glacio-marine origin, overlain by interbedded sands, sandy loams and loams.

In summary, two tills were identified in the section: the lower bluish-grey till with quartz and volcanic rocks (Zhuravlinean till-unit 2) and the ash-grey "quartzless" till referred to as "the Okanaanean" till (unit 5, LAUKHIN et al. 1990). Glacio-marine deposits are represented by unit 6.

The lower till (unit 2) is underlain by glaciofluvial deposits (upper beds of unit 1) and is interbedded by the same deposits, and possibly by coastal-marine sediments as well (unit 2 and bottom beds of unit 3). Judging by the abundant pebbles of Upper Cretaceous volcanics and the relatively rare gabbroid pebbles, as well as the detached mass of the Lower Miocene lignites occurring in the

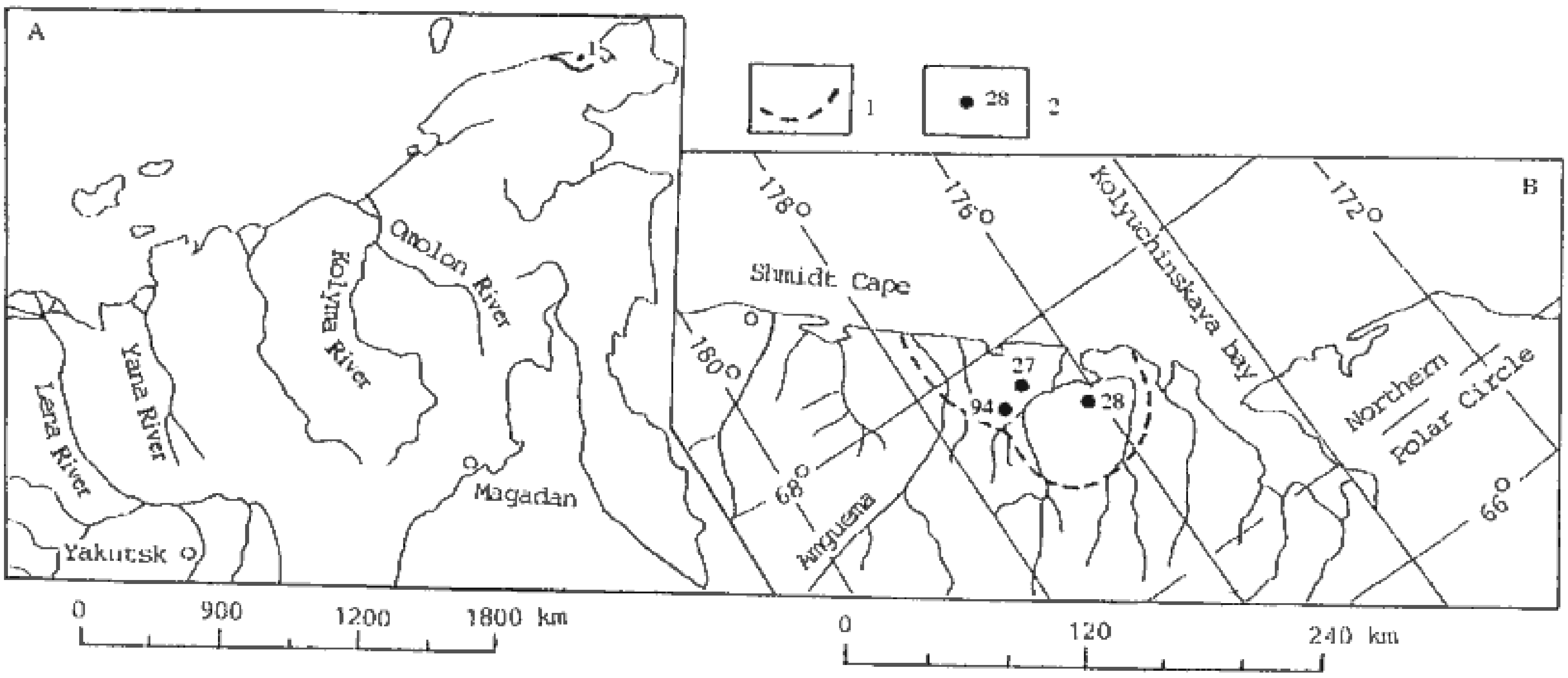

Fig. 1. A: Location of the study area in the Vankarem Depression NE Chukotka (1).
B: Detailed map of the study area. 1 – the Vankarem Depression boundary; 2 – location of the discussed sites (27, 28, 94).

Uliuveem Depression, the valley glacier was rather large and advanced from the south-east from an focus area located some 240 to 270 km from borehole 28.

The upper ash-grey Okanaanean till (unit 5) is underlain by an interbedded stratum of the same till and glaciofluvial deposits (unit 4). The glacier was advancing along the same palaeovalley and was of a valley type as well but, judging by the greater amounts of granitoids, a significantly larger proportion of gabbroids and other petrographic characteristics of the clastic material, its focus was 120–150 km to the south.

The contours of the Vankarem Depression were similar to the present ones already in the Pliocene, and the main watershed was in the area of the present-day Chukotka Range (Laukhin et al. 1989, Laukhin - Patyk-Kara 1991). The valley type of glaciation is reconstructed on the basis of pebble and boulder petrology of the till, and also by the exclusive occurrence of the till within the limits of the palaeovalley. The Quaternary block tectonics and the related denudation and multiple advances of the Pliocene and Pleistocene glaciers significantly modified former valleys, so only their fragments are preserved.

PALYNOLOGY

Detailed palynological studies of B. V. Belaya (Fig. 2) have provided significant palaeoenvironmental information. Between 106.4 and 94.5 m, the lower palynospectra (of the pre-glacial Pliocene deposits) indicate larch-dominated forests and open birch-alder woodlands with rare inclusions of broad-leaved species, yerniks and Myrica succeeded by coniferous and small-leaved species and with sphagnum yerniks. The central palynospectra (of the upper beds of unit 1 and lower beds of unit 2) are typical of the yernik vegetation with isolated small-leaved and coniferous trees with some grasses and mosses. These are succeeded (95.0–94.5 m) by tundra and Hypnum-grass moors.

The palynospectra of the glaciofluvial beds of the upper part of unit 2 show a certain areal expansion of the small-leaved and coniferous trees with related broad-leaved arboreal taxa. In the beds of unit 3, this vegetation is replaced by isolated small-leaved trees, and then by tundra vegetation characterizing spectra of both units 4 and 5.

It is not possible here to go into a detailed discussion of the complex problems of the Pliocene and Quaternary chronostratigraphy in the North of Chukotka. Dating of the till is discussed in detail by Laukhin et al. (in press). The palynospectra of the pre-glacial strata in borehole 28 are transitional from the Begunov Series to the Kutuyakh Series, which occur in Western Chukotka and in Northeastern Yakutia and are dated to 5.1–3.4 Ma BP and 3.4–1.8 Ma BP respectively (Frolov et al. 1989, Laukhin 1989). Stratigraphically more or less analogous deposits have been traced further north in Eastern Chukotka (Laukhin et al. in press) and are dated to 3.5–3.2 Ma BP (Zhuravlinean till) and 2.5–2.4 Ma BP (Okanaanean till). The overlying glacio-marine deposits of the unit 6 are estimated to be 1.8 Ma BP old and may correspond to the Middleton Glaciation.

The palynospectra of the pre-glacial deposits incorporated into the 1st and most of the 2nd till, and the intertill sediments, usually have comparatively small amounts of redeposited pollen and spores that can be found by analytical techniques. Above 58.2 m, the palynospectra have abundant palynomorphs mostly well-preserved. Because it is very difficult to identify redeposited forms amongst them, especially those of different age and ecology, the palaeoclimatic regimes were not interpreted for the layers above 58.2 m.

From the geological point of view, tills produced mixed palynospectra. These include pre-glacial species

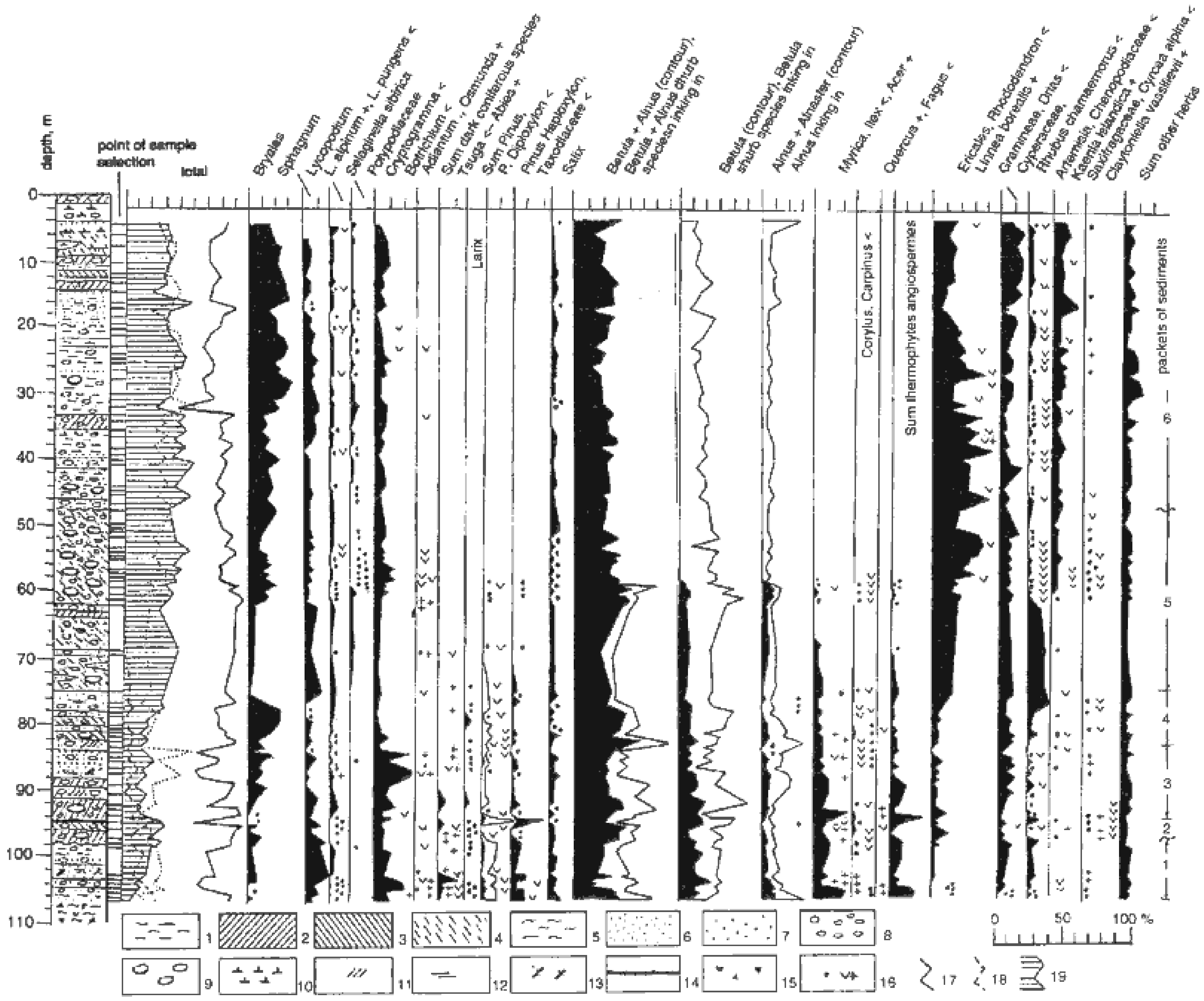

Fig. 2. Stratigraphy and palynological diagram of the bore hole 28. (Scale of all columns is identical).
1 – clay; 2 – loam; 3 – sandy loam; 4 – ligh sandy loam; 5 – silt; 6 – sand; 7 – gravel; 8 – pebble; 9 – boulders; 10 – buried ice; 11 – oblique layers; 12 – horizontal layers; 13 – fragments of wood; 14 – brown coal; 15 – quartz debris; 16 – quantity of spores and pollen less than 2 %; 17 – pollen of angiosperms; 18 – pollen of gymnosperms; 19 – pollen of grasses and shrubs.

redeposited from older pollen assemblages during the glacial advance and glacial forms existing in situ. The mixed till spectra may, therefore, suggest a higher distribution of certain plants than actually existed.

Therefore, the significance of pollen synchronous with the glaciation is higher, particularly if the ice-free areas are broader, the end moraine is closer, and the glaciofluvial deposits are more abundant in the glacial strata.

The diagram (Fig. 2) shows that the palynospectral pattern changes quite logically from the base: closer to the till, the palynospectra indicate the harsh periglacial vegetation with the "coolest" spectra found in the lower till strata. The "warmer" spectra of the upper till are due to intermixed fluvial and glaciofluvial sediments.

The lower till is interbedded by glaciofluvial sediments nearly troughout its thickness. The second ash-grey till (unit 5) was preceeded by the interbedded till and related glacigenic deposits (unit 4) that accumulated during the glacier advance from the mountains to the Vankarem Depression when it was close to the site. When the glacier overrode the deposits of unit 4, it assimilated at its base the materials with palynospectra formed at the glacier's edge. Judging by the thickness of the till (27.6, or 34.8 m with unit 4), it appears likely that there was an end moraine there. The above data and the absence of sudden changes within the reconstructed palaeotemperature curves and annual precipitation totals (Fig. 3) from the sub- and intertill deposits to the till indicate that, within certain reliability limits, the palaeoclimatic reconstructions based on the till palynospectra in this section are reasonably representative.

RECONSTRUCTIONS OF PALAEOCLIMATES - METHODS

To assess the quantitative characteristics of the past climates, the information-statistical method was employed (Klimanov 1976, 1981) that is widely used for palaeoclimatic reconstructions of the Holocene. This method was originally based on the statistical correlation of the subfossil palynospectra in the lowlands of the USSR and the recent climatic situations as given by the Climatic Atlas of the USSR (sine 1960). Tables of correlation of pollen percentage concentrations of individual species with climatic parameters were established for the total pollen and spore spectra and also for the boreal species spectrum (dendroflora is the most informative element of vegetation for the palaeoclimatic reconstructions). It was found that pollen of each arboreal species and its percent concentration carries certain information on the value of a particular climatic parameter. This information is summed up for all components of a given palynospectrum, and the maximum value gives the most probable assessment of climatic parameters at the time of formation of this palynospectrum. Empirical tests have shown that the errors for mean July and annual temperature estimations are ± 0.6 °C, and ± 1 °C for mean January temperature and ± 25 mm for total annual precipitation. V. P. Grichuk (in Velichko et al. 1986) demonstrated the great similarity of the Neogene and the recent flora, and the existence of some recent flora taxa that existed as early as the Miocene. The core of the Neogene flora consisted of plant species that have survived to the present. Under these conditions, the limitations of the principle of actualism exceeded the range of accuracy of this method and had practically no effect on the results. The more so, the forest-tundra vegetation was formed in the pre-glacial time (unit 1), and the tundra vegetation in glacial times. They differed from the recent vegetation exclusively by the ratios of the principal components and some relic forms.

Since the correlations of climate and arboreal pollen were explored by the information-statistical method at the generic level only, it is possible to employ this method for the palaeoclimatic reconstructions of the Pliocene and Pleistocene, even for the areas where the Pliocene vegetation was not so similar to the recent one, as it is in the north of Eastern Chukotka.

The Climatic Atlas of the USSR (sine 1960) described the area under study by the following modern climatic parameters: mean temperature of July 4–6 °C, annual –12 to –14 °C, total annual precipitation 250–300 mm. Fig. 3 shows mean July, January, and annual temperatures and total annual precipitation reconstructed by the palynological data of borehole 28 (Fig. 2). The plotted palaeoclimatic curves clearly show the dynamics of climatic change during the Pliocene/Quaternary transition in Eastern Chukotka.

The first glaciation is supposed to have occurred 3.5–3.2 Ma BP. Similarly as with the second glaciation (2.5–2.4 Ma BP), thickness of the sedimentary strata has no direct correlation with the duration of their deposition. Besides, most of the time coordinates are "erased" by numerous hiatuses and erosions in the section. Therefore, we have plotted the palaeoclimatic curves over the vertical axis ignoring the scale and stratigraphic breaks.

RESULTS AND DISCUSSION

The reconstructed palaeoclimatic curves show the following results. The fluctuations of mean July temperature were significant. There were few peaks and small amplitudes (up to 4 °C, usually 2 °C). On the contrary, fluctuations of mean January temperature were very high (with an amplitude up to 14 °C, 8–10 °C in average) and very frequent. Annual precipitation totals often show fluctuations and a stable trend of reduction before

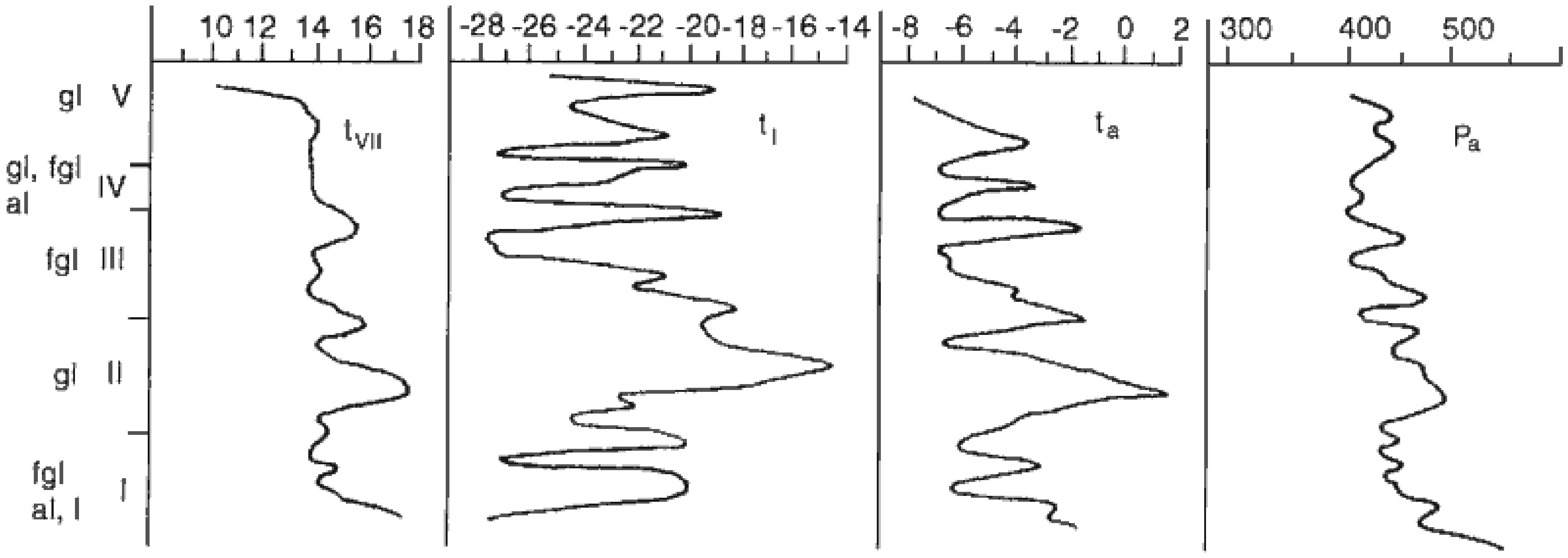

Fig. 3. Palaeoclimatic curves of the earliest glaciation on the Vankarem Depression (out of scale). Roman numbers refer to units, indexes show the genesis of sediments: l – lacustrine; al – alluvium; fgl – fluvioglacial; gl – till; palaeotemperatures (°C): t_{VII} – mean July, t_I – mean January, t_a – annual; P_a – annual precipitation (mm).

the second glaciation from 475–550 mm to 400–475 mm; since the beginning of the second glaciation it ranged between 400 and 450 mm.

Palaeoclimate of the pre-glacial period

Mean July temperature in the pre-glacial period (unit 1) was little different from that during the first glaciation. The temperatures were 15–17 °C and they ranged between 14–14.5 °C during accumulation of the glaciofluvial deposits, i.e. less than during the till deposition in the first glaciation. In the same period, precipitation was the highest (in the time interval under discussion) and ranged from 500–550 to 425–475 mm. Rather low January temperatures were typical (from –20 °C to –28 °C). These values corresponded to the growth and expansion stages of the glacier.

Palaeoclimate of the first (Zhuravlinean) glaciation

At the time of accumulation of the till in the course of degradation of the first glacier, there was the maximum July temperature 16–18 °C, and the corresponding minimum January temperature –25/–18 °C. The precipitation ranged from 425 to 500 mm. By the end of this period, the July temperature decreased to 14 °C, January temperature after a brief optimum (–14 °C) dropped to –18/–19 °C; annual precipitation was 450–475 mm.

The areas of recent mountain glaciation in the north of the Pacific rim show the closest similarity to the above climatic parameters. They are found in the south of Alaska around 60° northern latitude near the St. Elias Mountains where modern glaciers are flowing into the ocean. This region has the following characteristics: mean July temperature is 12–16 °C, mean January temperature is –4/–10 °C, annual precipitation is 500 to 1000 mm. The first glaciation in the north of Eastern Chukotka developed under lower or similar precipitation, slightly higher summer temperature compared with the modern situation in the St. Elias area.The lower precipitation values may have been compensated by very low winter temperatures. It is important to mention that the modern firn line decreases sharply near the Pacific shore both in Alaska and in the Northeast Asia: 700 to 800 m in the Kronitskiy Peninsula, 800–900 m in the north of the Sredinnyy Range of Kamchatka, 500 m and lower in the Kenai and Chugach Mountains. The firn line rises up to 1600–1700 m in Koriaksyy and the Sredinnyy Ranges even at a short distance from the ocean and at a larger distance (Brooks Range) it may extend over 2000 m.

The lower bluish-grey till was deposited in the ocean during a Beringian transgression. GLADENKOV et al. (1992) have shown that this occurred about 3.5–3.2 Ma BP. This transgression is traced all over the north of Chukotka (LAUKHIN - PATYK-KARA 1991) and suggests a correlation of the most ancient glaciation in Eastern Chukotka with the marine transgression. The more ancient Zhuravlinean glaciation in the more western areas of Chukotka probably occurred only in high-mountain areas of Koriakya close to the ocean.

Palaeoclimate of the "intertill event"

Degradation of the glacier of the first glaciation in Chukotka was possibly partly associated with the peak of high winter temperatures and decrease of precipitation at the end of the glacial period (Fig. 3) but mostly with the termination of the Beringian transgression.

During accumulation of the intertill deposits (unit 3) the palaeotemperature regime was not much more favourable than during the preceding glaciation. The intertill strata were deposited under very unstable temperatures: the amplitude of mean July temperature was gradually diminishing by the beginning of the second glaciation. Except for these climatic fluctuations, there was an overall trend towards an annual cooling with decreasing winter temperatures and annual precipitation levels (Fig. 3).

Though the climatic parametres differed only slightly from those of the preceeding glaciation, the period of sedimentation of the intertill strata most probably represented an interglacial regime because the climate was milder than today, and milder than in the Pleistocene interglacials. This conclusion is supported by the facts that:

1. the second (Okanaanean) glaciation developed according to a different topographic pattern from the first one with the focus located further west from that of the first glaciation which was clearly centred towards the ocean shore;
2. the factors that produced the second glaciation were mostly of the "palaeotemperature" character, whereas the first glaciation developed under a higher precipitation and was associated with marine climates during the Beringian transgression.

Palaeoclimate of the second (Okanaanean) glaciation

With advancement of the glacier of the second glaciation, mean July temperatures stabilized around 14 °C, mean January temperatures sharply oscillated from –20 °C to –28 °C, and precipitation decreased to to 400–450 mm. Compared to the modern climatic regime in Alaska, annual precipitation was 50–100 mm lower and the January temperature was lower by 16–20 °C.

The calculated curves of the world ocean level (HARLAND et al. 1982) for the time interval between 2.5 to 2.4 Ma BP show a significant regression compared with the present sea level. The ocean shore in Chukotka was situated much further from the end moraine than now.

The Bering Strait was drained. The Okanaanean glaciation developed in the north of Chukotka under regimes that were less continental than today (precipitation was 100–200 mm higher), but most probably under a lower impact of the marine climate. The Okanaanean glaciation correlates in time with the early Quaternary glaciation in the Northern Hemisphere and was apparently associated with global cooling (ZUBAKOV 1990) when the Scandinavian ice shield closely corresponded in size to that of the last glacial. The evidence of the corresponding glaciation has been found in the Caucassus (MILANOVSKIY - KORONOVSKIY 1969), the Alps (CARRARO et al. 1975), the Pamirs (NIKONOV - PAKHOMOV 1984), the Wrangel Range (DRAWRY 1978, ARMENTRON et al. 1978), Arctic Coastal Plain of Alaska and the Seward Peninsula (HAMILTON 1994), Sierra Nevada in California (CURRY 1968), El Creek in Nevada, Nebraska, Iowa (NIKIFOROVA 1989, ZUBAKOV 1990) and other places.

Palaeoclimates of the last glaciation

The reconstruction of the Late Pleistocene glaciation in the Vankarem Depression is based on pollen and spore data from section 94 located next to the Penielkhin stream (Figs. 1, 4) which contains two basal tills. The interbedded sandy-gravelly layers produced fragments of wood and buried peats of the Karginsk age, radiocarbon dated to 39–50 ka BP. The overlying tills belong to the first and second stages of the Sartan (Late Weichselian) glaciation (LAUKHIN et al. 1989). These strata were traced from the Nadezdha Stream to the section 94 in several sections and hundreds of bore holes. Varved lacustrine silts in the upper profile of section 94 (4.0–11.4 m depth) correspond to the stationary position of the glacier in the early phase of the glaciation. They are underlain (11.4–20.0 m) by alluvial strata, corresponding to the Karginsk interstadial unit, and finally by the early Last Glacial till (21.8–23.0 m). The palynological analyses (Fig. 4) suggest that the lacustrine-glacial silts of the last glaciation were sedimented in a herbaceous and dwarf willow-sedge tundra environment with a significant contribution of *Artemisia* (4–12 % of the total grass pollen) and abundant *Selaginella sibirica* (40–50 % of total spores).

In the Karginsk (OIS 3) alluvium, ^{14}C dated to ca. 40 ka BP, the tundra palynospectra are dominated by yerniks, sphagnum and hypnum mosses. Dwarf pine with some alder are replaced by yernik with a more extensive distribution of alder indicating a much more thermophilous vegetation than the modern one (DAVIDOVICH 1979). The till of the early last glaciation (OIS 2) is characterised by pollen of the typical arctic tundras, with grasses averaging 59 % of the total assemblage (mostly *Graminae* up to 41 % and *Cyperaceae* up to 33 %), and spores (73 %) with *Selaginella sibirica* being the dominant species (up to 91.5 %).

Mean January and July temperatures and annual pre-

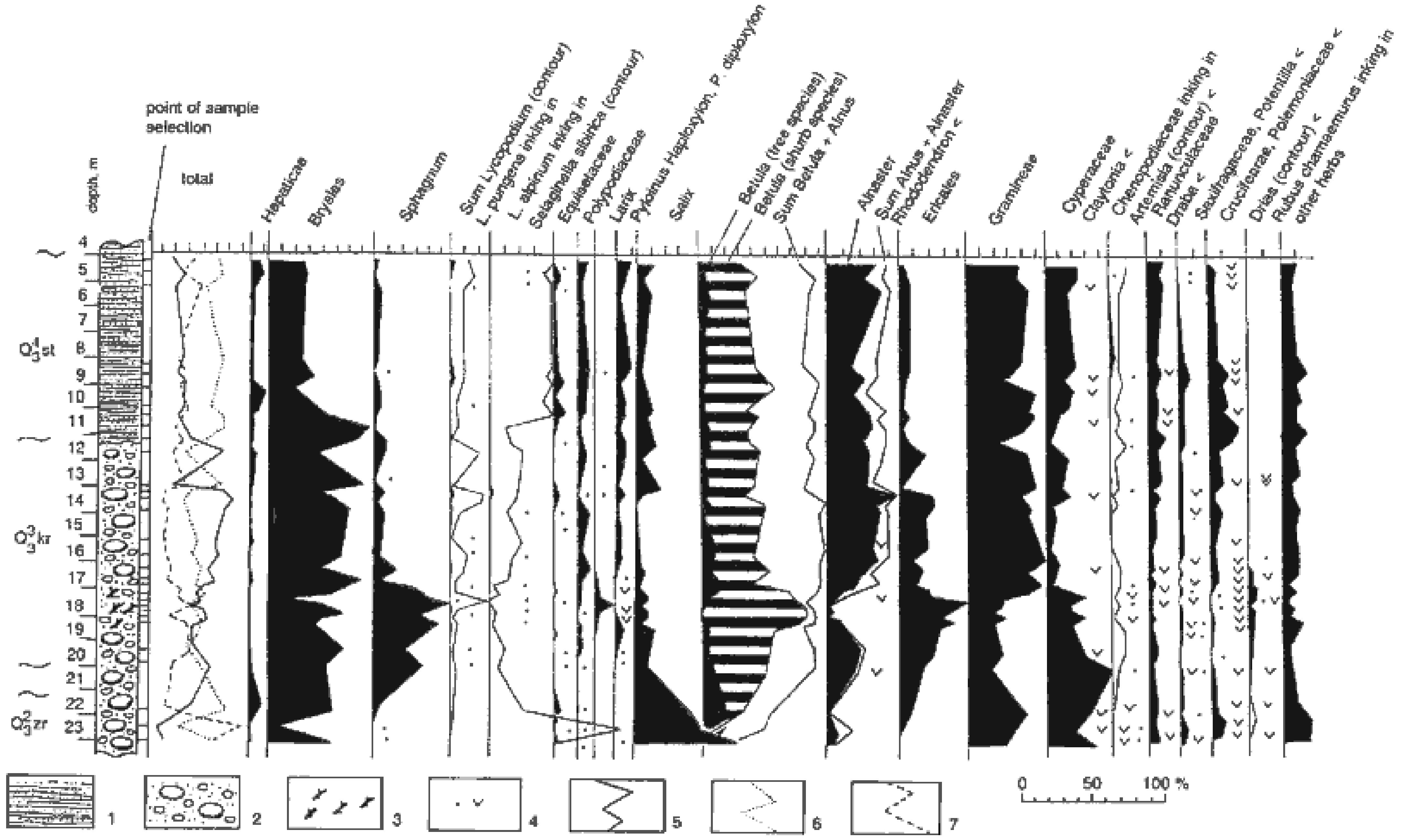

Fig. 4. Stratigraphy and palynological diagram of site 94. Scale of all columns is identical.
1 – varved silts; 2 – pebbly-bouldery deposits; 3 – fragments of wood; 4 – pollen and spores less than 2 %; 5 – arboreal pollen; 6 – non-arboreal pollen; 7 – spores. $Q^4{}_3st$ – lacustrine-glacial, varved silts of the Sartan (late Last Glacial) stage; $Q^3{}_3kr$ – fluvial deposits (pebbly to bouldery) of the Karginsk (mid-Last Glacial) stage; $Q^2{}_3zr$ – Zyriansk stage sediments (early Last Glacial). For legend see Fig. 2.

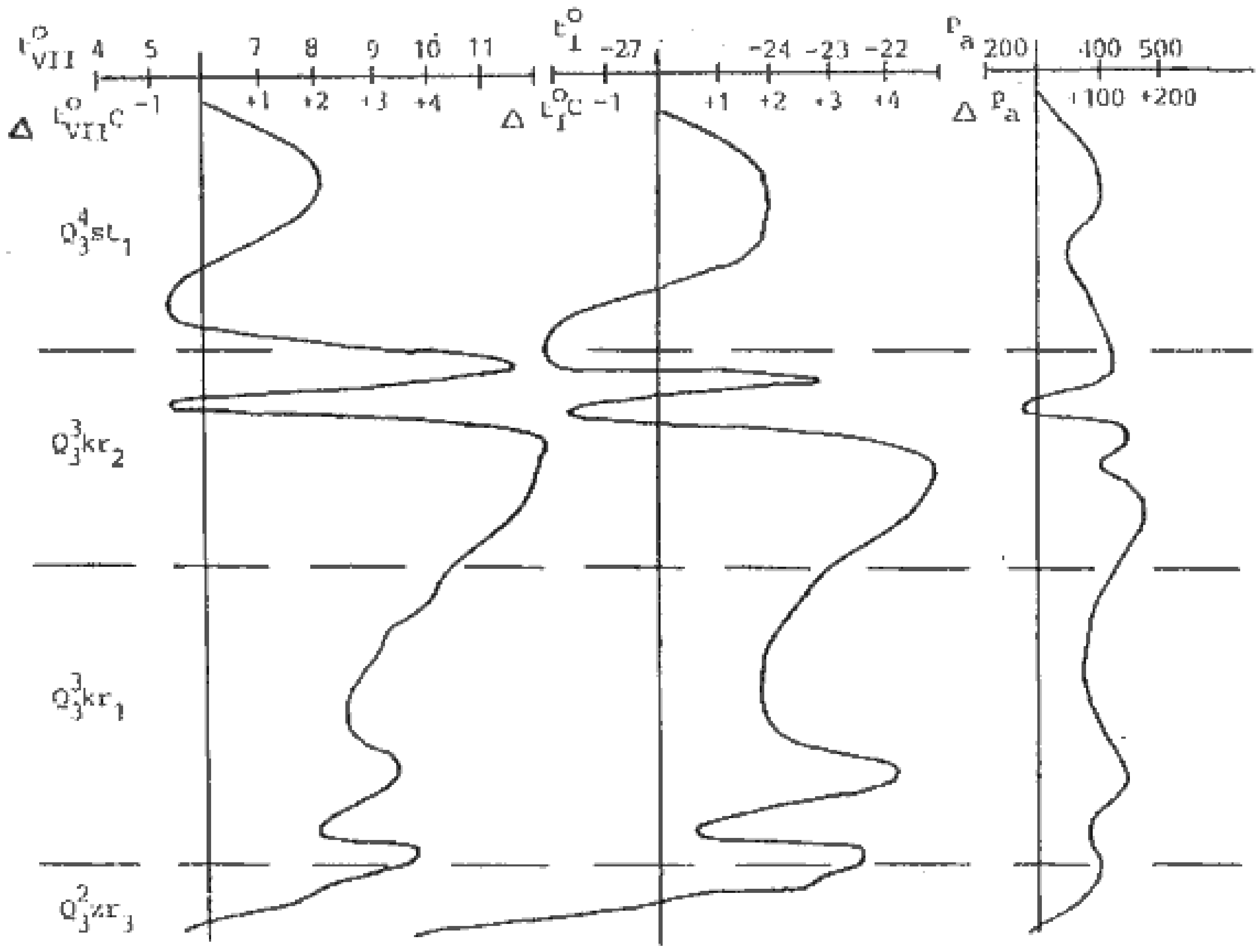

Fig. 5. Palaeoclimatic curves (out of scale) for section 94. Absolute numbers and deviations (Δ) from the present indexes. For legend see Fig. 3.

cipitation (Fig. 5) for the three stages (OIS 4–2) of the Late Pleistocene were calculated by the same technique as for the deposits of the transition period from the Pliocene to the Pleistocene.

A notable fact is that the summer palaeotemperatures at the end of the early Last Glacial (Zyriansk stage OIS 4) as well as at the beginning of the late Last Glacial (Sartan stage OIS 2) are within the range of the modern mean July temperature. During the mid-Last Glacial interstadial (oxygen isotope stage 3) they persistently exceeded the modern ones by 2–4 °C, and during the optimum by as much as 6 °C.

As for winter palaeotemperatures, their pattern was more complicated. At the end of the early Last Glacial (oxygen isotope stage 4) they dropped down below –31 °C, i.e. 5 °C lower than today. At the very beginning of the late Last Glacial (oxygen isotope stage 2) they were by 2 °C lower than at present with 100–120 mm higher precipitation. The warming that followed (1 °C of winter and 1–2 °C summer temperatures lower than modern values) apparently stopped the glacier in the foothills and resulted in sedimentation of the lacustrine-glacial varved silts at the glacier front. In this period, precipitation was reduced to 350 mm during the advance stage.

In the mid-Last Glacial, winter temperatures dropped twice below the modern level as shown by the spore-pollen diagram. The most pronounced reduction (by 2 °C) coincided with accumulation of the Upper Karginsk strata. In that period glaciation did not developed in the mountainous area because the cooling was associated with the sharp reduction of precipitation (Fig. 5). After the second drop until the early Last Glacial stage, January temperature was 1–3 °C higher and during the optimum by 4 °C higher than today.

Total annual precipitation was lower than today at the end of early Last Glacial and the brief mid-Last Glacial interval (Fig. 5). Generally in the Karginsk stage it was 50–100 mm higher than now, and during the optimum 175 mm greater. Climate was warmer and milder that at present. At the very end of the Zyriansk and the beginning of the Sartan glacial stages, annual precipitation was about 100 mm higher than now. In summary, the Karginsk interglacial with its significantly more thermophilous vegetation than now was characterised by higher temperatures, i.e. 3–6 °C higher in July, 1–4 °C higher in January and precipitation reached 350–475 mm, i.e. 1.5 more than now. A reduction of the mean January temperature by 2 °C and an increase of precipitation by 100 to 125 mm, as compared to modern conditions, was sufficient for development of the Late Würm glaciation and advancement of glaciers beyond mountains.

Comparison of the Plio/Pleistocene and Late Pleistocene climates

A direct comparison of the palynospectra of the Plio/Pleistocene and Late Pleistocene glacials (Figs. 2 and 4) is difficult because of the distribution of the Neogene taxa in the Pliocene as a result of a long evolution of vegetation that survived several Early and Middle Pleistocene glaciations. The comparison below is based on a summary of the specific palaeoclimatic characteristics discussed above (Figs. 3 and 5).

The ratios of continental and oceanic areas of mountains and lowlands were similar during the second earliest and the Late Pleistocene glaciations in Northeast Chukotka (Palaeogeographical Atlas 1991). The palaeoclimatic parameters during the Okanaanean glaciation and the late Last Glacial (Sartan glaciation) were rather similar: mean January temperature was –28 to– 25 °C and –28 to –24 °C, and annual precipitation totals were 425 and 475 mm respectively. However, the July temperature differed significantly in the T/Q transition being 5–6 °C higher and probably compensated by a somewhat higher precipitation during the Okanaanean glaciation.

The first Plio/Pleistocene interglacial that separated the Zhuravlinean (3.5–3.2 Ma BP) and Okanaanean Glacials (2.5–2.4 Ma BP) was characterised by a milder climate compared to the Karginsk "interglacial". The latter was characterised by lower mean July temperature of 2–6 °C and lower January temperature of 4–7 °C and by 50–75 mm less precipitation (Figs. 3 and 5) than the late Pliocene interglacial.

The earliest glaciation (3.5–3.2 Ma BP) was developed under significantly different climatic conditions to that of the mid-last Glacial stage: mean July temperature was 4–8 °C higher, mean January temperature was similar or possibly 4–5 °C lower; however, precipitation during the Zhuravlinean Glaciation was 100 mm higher. Higher precipitation and lower winter temperatures were the distinctive features of the Karginsk palaeoclimates as compared to those of the earliest Plio/Pleistocene glaciation. Together with the Late Pliocene (Beringian) transgression, that was more extensive than during the Karginsk, these factors were apparently the most important for the development of the earliest glaciations in Chukotka.

Acknowledgement

The authors are grateful to V. S. Velichko and A. L. Grishin for their help in organising the field work in Chukotka and subsequent analytical investigations. This research was supported by the Grant of the Russian Foundation for Basic Research (project 97-05-65207).

Recommended for print by V. Šibrava

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