Quaternary Glaciations – Extent and Chronology, Part III
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Quaternary glaciation of north-eastern Asia

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North-eastern Asia (east of the Lena River and north of the Stanovoi Range) is a region with a very diverse, mostly mountainous topography. The most prominent mountains are the Verkhoyansk Range, the Chersky Range (with elevations up to 3000m), the Chukotka Mountains, the Koryak Highlands and the Central Kamchatka Range. Intramontane basins and lowlands are also widespread, the Primorskaya (Maritime) Lowland on the Arctic Ocean coast being the largest.

The territory has a frigid continental climate, with great diurnal and seasonal fluctuations of air temperatures and low precipitation, most of which occurs as rain in the frost-free part of the year. Because of the severe climate the most common vegetation types are taiga, forest tundra and tundra. Permafrost occurs almost everywhere. Modern glaciers are confined to the highest mountains and are rather small. The interior part of the continent is marked by a high snowline (2000 – 2400 m), and low ice temperatures, close to the permafrost temperature in the ice-free areas (-8 to -10° C). Consequently, glaciers in this region are sluggish and rather inefficient geological agents. In the maritime regions (Koryak Highlands) the snowline lies much lower, in places as low as 400m and ice temperature in glaciers is somewhat higher.

No palaeobotanical evidence for drastic changes of vegetation throughout the Quaternary is known. This suggests that the climate was stable and that climatic fluctuations did not result in major environmental changes. It follows that the main features of today's glaciers were also characteristic for the glaciers of the past.

Many years of research and geological mapping in north-eastern Asia have established that there were no large ice sheets to compare with those of Europe and North America and glaciation was mostly restricted to the mountains. The lowlands and many intramontane basins remained ice-free. The types of glaciers ranged from small cirque and hanging glaciers to large dendritic glaciers, piedmont glaciers and reticulate glaciation depending on elevation, topography and the amount of snow accumulation. In some cases former glaciation developed into mountain ice caps where the rugged mountain topography was completely buried by ice, and only isolated summits towered as nunataks above the ice surface. The South Verkhoyansk ice cap, a few hundred kilometres in diameter, is a good example of an ice cap of this type. Most glaciers terminated on land; only on the Chukotka Peninsula did glaciers in some places reach the sea and occupy part of the modern shelf.

A specific feature of glaciation in north-eastern Asia was a sharp distinction between the area of today's glaciers and that during the Pleistocene. The area covered by modern glaciers is about 560 km^2 (Kamchatka excepted) whereas in the Pleistocene the glaciated area exceeded 500,000 km^2. Thus, Pleistocene glaciation was about nine hundred times more extensive than modern glaciers. This difference results from the topography and the distribution of precipitation throughout the year.

Most of the glaciated parts of north-eastern Asia are mountain ranges only of medium height. As soon as the climate became cooler, vast areas found themselves above the snow line and became accumulation areas for glaciers. Today, most of precipitation falls as rain. However, under a cooler climate the share of snow was much increased, and as a consequence the accumulation area expanded enormously, giving rise to extensive glaciation. It is most likely that the Late Pleistocene was not only the time of maximum cooling (Velichko, 1973) but also the time of the most extensive glaciation.

Low ice temperatures and low ice-flow velocity, as well as the nature of the topography, affected the process of deglaciation. As soon as the snow line rose, many large glaciers lost their precipitation supply and thus stagnated. As a consequence most of them decayed by downwasting, rather than retreating in the step-like fashion that typifies an active ice margin. This latter retreat mode only occurred for some of the smaller glaciers. In the process, outwash sediments and landforms were produced rather than terminal moraines. Roundness, sorting and bedding characteristics of the sediments indicate deposition by running water for most of the 'glacial' deposits. Comparison of pebble roundness in glacial deposits with that in recent alluvial sediments supports this view. It has been shown that pebble roundness in glacial deposits is equal to or even greater than that in the deposits of modern rivers of the same region the length of which is comparable with that of the pre-Holocene Quaternary glaciers. For instance, mean pebble roundness in glacial formations of the Allakh-Yun' River valley (Aldan catchment area) is 0.50, whereas in modern alluvium of the Allakh-Yun', it is 0.51. In Western Chukotka (Zamoruyev, 1983), on the right bank of the Malyi Anyui River, mean pebble roundness in glacial deposits is 0.39 as compared to 0.37 in the modern alluvium. The same relationship exists in the Stanovoi Range, in the Malaya Tuksani valley (Aldan catchment area) with 0.34 and 0.32 respectively. Grain-size parameters of glacial deposits and alluvium are the same or very close.

Depositional landforms, which came into existence during deglaciation, mostly comprise kames and kame terraces. In places, they can show a very intricate pattern, especially where they are superimposed on a rugged topography. Some workers consider the glacial formations as till and the depositional landforms as moraines, taking into account the relatively coarse composition of the deposits and the presence of isolated large clasts.

A long-standing view is that glaciers attained their maximum extension in the Middle Pleistocene and that there were two glacial stages in the Late Pleistocene (the so called Zyryan and Sartan glaciations), separated by an ice-free interval. This concept has recently been challenged. A growing number of investigators (Kind *et al.*, 1971; Kind, 1975; Svitoch, 1978; Degtyarenko, 1984) are inclined to consider the Last Glacial Maximum (LGM) as having included a very large glacial extension; in many cases the largest of the whole Quaternary. Traces of previous glaciations are thought to have been overridden and obliterated by the latest glaciation.

The most convincing evidence for the above interpretation is found in the Verkhoyansk Range. According to Kind *et al.* (1971) at the western foot of the range the so-called Zhigansk Stage was the most extensive, with glaciers reaching down to the Lena River. Radiocarbon dates on wood and peat samples from sediments underlying Zhigansk Stage glacial deposits have yielded ages of 33,700 ± 800 (GIN-155) at the Sobopol River and 35,000 ± 1000 (GIN-255) at the Oruchan River (sites 1 and 2 on the digital map). The Zhigansk Stage differs from the other glacial formations of the Verkhoyansk Range in its extent and short duration (Kind, 1975). It is not as well developed in other parts of the range. On the digital map, the western limit of the Zhigansk Stage is shown as a dashed line; the solid line denoting the more reliably-established glacial limits.

A rounded block of wood was preserved from glacial deposits in the valley of a right tributary of the Tumara River, 52 km upstream of its mouth (digital map, site 3). The radiocarbon age of this wood is 45,500 ± 1500 (GIN-531). This means that the glacial deposits containing the wood post-date this age (Kolpakov & Belova, 1980). On the eastern flank of the Verkhoyansk Range in the Ulakhan-Sakkyryr River valley, near the village of Batagai-Al'ta (4), glacial deposits are underlain by a fossil soil containing wood fragments. Radiocarbon dates obtained from the wood in this soil yield 44,000 ± 1500 (GIN-704) and 48,800 ± 2000 (GIN-705) which indicates that the glacial deposits, near the maximum glacier extent, are also younger than the dates (Kolpakov & Belova, 1980).

In the southern part of the Verkhoyansk Range, in the valley of a right-bank tributary of the Allakh-Yun' River (5) a fragment of a larch (*Larix* sp.) trunk was recovered from glaciofluvial deposits. Annual tree rings in this wood were found to be closely compressed which was interpreted as evidence of a very severe contemporaneous climate. The radiocarbon age of the wood was determined as 40,310 ± 1230 (LU-602). This suggests that the time span separating the two Late Pleistocene glacial substages was not an interglacial with a relatively mild climate. Instead, the glaciers probably had only slightly receded and the climate retained its severe cold character (Zamoruyev, 1978).

There are also some finds which help to determine the age of final stage of deglaciation. In the valley of the Bukhuruk River (6) on the eastern flank of the Verkhoyansk Range, lake sediments overlying glacial deposits have provided a radiocarbon date of 11,800 ± 70 (GIN-709) on scraps of bushes. The climate at the time when the lake existed remained severe (Kolpakov & Belova, 1980). Near the settlement of Kobyuma (7), glaciofluvial deposits contained well-developed larch logs which suggest a climate similar to the present. Here radiocarbon dating of wood samples have yielded an age of 9180 ± 130 (LG-174) (Zamoruyev, 1976). Further to the west, in the Vostochnaya Khandyga River valley, larch stumps in growth position were found in an alluvial fan. Their radiocarbon age of 8500 ± 140 (LG-134) suggests that by that time the place had already been ice-free for a considerable time (Zamoruyev, 1976).

There is no reason to assume that the chronology of glaciations in the Verkhoyansk Range was drastically different from that in other regions of north-eastern Asia. It may well be assumed that practically all observable traces of glaciation can be referred to the Late Pleistocene or more precisely to the Last Glacial Maximum.

The Quaternary maps of Russia (at the scale of 1: 1,000,000), which form part of the official Geological Maps of Russia, have been used as a main source for compiling the glacial map of north-eastern Asia. Topographic maps of various scales were also consulted. For the Kamchatka Peninsula, the glacial map by Olyunin (1965) has been also adapted. Minor glaciers (cirque glaciers, hanging glaciers, small valley glaciers) are not shown on the digital map because their deposits are so limited in extent that they cannot be shown on Quaternary maps at the 1: 1,000,000 scale.

In some cases the distribution of glaciers shown on the map is still controversial. This mostly applies to the lowlands of inner Chukotka, some parts of which are believed to have been glaciated and accordingly have been represented in the existing Quaternary maps. On the other hand, some workers (Svitoch *et al.*, 1980) consider that non-glacial sediments in the lowlands have been mistaken for till and outwash deposits, implying that glaciation had in reality been restricted to the mountains. Because of the lack of alternative maps, the author followed the available maps and thus shown much of the Chukotka lowlands as formerly glaciated.

A number of major problems remain to be clarified:

- The identification of traces of pre-Late Pleistocene glaciations is required. Reported traces of supposedly pre-Late Pleistocene glaciations need to be checked in the field.
- Dating of the glacial maximum must be improved.

- The problem of the so-called 'Karginsk Interglacial' in the middle of the Late Pleistocene glaciation should be clarified. It remains unclear how far the glaciers retreated during this period.

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