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Pleistocene ice limits in the Russian northern lowlands

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Introduction

This paper is an explanatory note to the digitized map of ice limits compiled by the author for the Russian North, beyond the limits of the Fennoscandian glaciation. The glacial limits presented here are cartographically based on data from the Russian Geological Survey obtained during general geological mapping at standard scales of 1:200,000 and 1:1,000,000. It also incorporates results of specialised studies in critical areas performed by various researchers, the author included. The outermost limit of Pleistocene glaciation is mostly derived from standard geological maps and drilling projects, whereas the Late Pleistocene ice limits are largely products of stratigraphical and photogeological studies during the last two decades. The result is presented in simplified form in Fig. 1.

Although the principal ice limits in Central Russia were already established at the beginning of geological mapping by the Emperor's Geological Committee in the late 19th century, the size of Pleistocene glaciers in the north and east, excluding the Fennoscandian ice dome, was poorly known until after extensive surveys of these remote areas in Soviet times. Indeed many sheets of the National Geological Map of the USSR appeared in the 1940-50s. This information was summarised in synthetic maps of Quaternary deposits at scales 1:2,500,000 and 1:1,500,000 (Yakovlev, 1950; Zarrina *et al.,* 1961) derived from the first generation geological maps. The second generation of geological maps, that included complementary Quaternary maps, began to appear in the 1960s. The new survey and drilling data were incorporated into more accurate small-scale maps of the Quaternary deposits of European Russia and the entire Soviet Union (Krasnov, 1971; Ganeshin, 1973). Many of the second generation maps were also published in the 1980-90s, albeit at a slower pace. The most inaccessible areas of Central Siberia did not have published Quaternary maps by the end of the 20th century, when the Russian Geological Survey had already commenced compiling the third generation maps in digital form.

The maximum Pleistocene ice limit, related to pre-Eemian glaciations, has only undergone minor changes during the last decades. However, younger ice limits have been under incessant stratigraphic discussion. The number of known ice limits in each given region depend very much both on the logistical accessibility and geographical peculiarities of the area. Several ice limits mapped in European Russia are hardly traceable beyond the Urals, because photogeology, the main tool in the north, does not produce good results in swampy lowlands. Also, topographically expressive ice marginal zones of the Central Siberian ice sheets cannot be directly connected with limits of the Barents-Kara ice sheets in the flat West Siberian Plain. Several morphological boundaries discussed in academic works (e.g., Arkhipov *et al.,* 1980, 1986; Grosswald, 1980, 1993) are not used in the present map, if they are not supported by stratigraphic evidence.

Three main sets of data are presented on the digital map:

1. Ice limits, subdivision of which into certain and uncertain ones is not exactly the same for different glaciations. In the case of Middle Pleistocene glaciations, a certain ice limit in the lowlands is a line distal to the southernmost sections that show glaciotectonised and till-covered interglacial formations. In the uplands of Central Siberia this line is drawn between the last mapped ridge-like diamicton accumulations and heavily dissected fluvial landscape to the south. This line is considered uncertain where no distinct morainic features have been mapped, and only diamicton facies in rare boreholes or erratics on the surface suggest the glacial drift limit. In the case of the Early Weichselian glaciation, the ice limit is shown as certain where it can be drawn between sections of interglacial sediments of Eemian type (mostly marine with warm-water mollusc fauna), overlain by till, on the one hand, and not covered by till, on the other. An uncertain Early Weichselian ice limit is a line interpolated between known stratigraphic sites using such signatures of former glaciation as occurence of buried bodies of stratiform massive ice in the lowlands of West Siberia and/or assemblages of ice-pushed ridges in higher terrains. In many cases marginal features are very spectacular, such as the double Laya-Adzva ridge in the Pechora Basin, which can be seen even from the Moon. Nevertheless the lack of Eemian sites makes this author designate the ice limit there as uncertain. Similarly, the limit of Late Weichselian ice sheet in Central Siberia is drawn as certain where sequences of Weichselian sediments with finite radiocarbon dates have been reported as overlain by till. Where no finite dates are known from sediments beneath till, it is shown as uncertain, even if the limit is clearly expressed by very fresh end moraines. All these distinctions are omitted in the simplified overview map (Fig. 1).

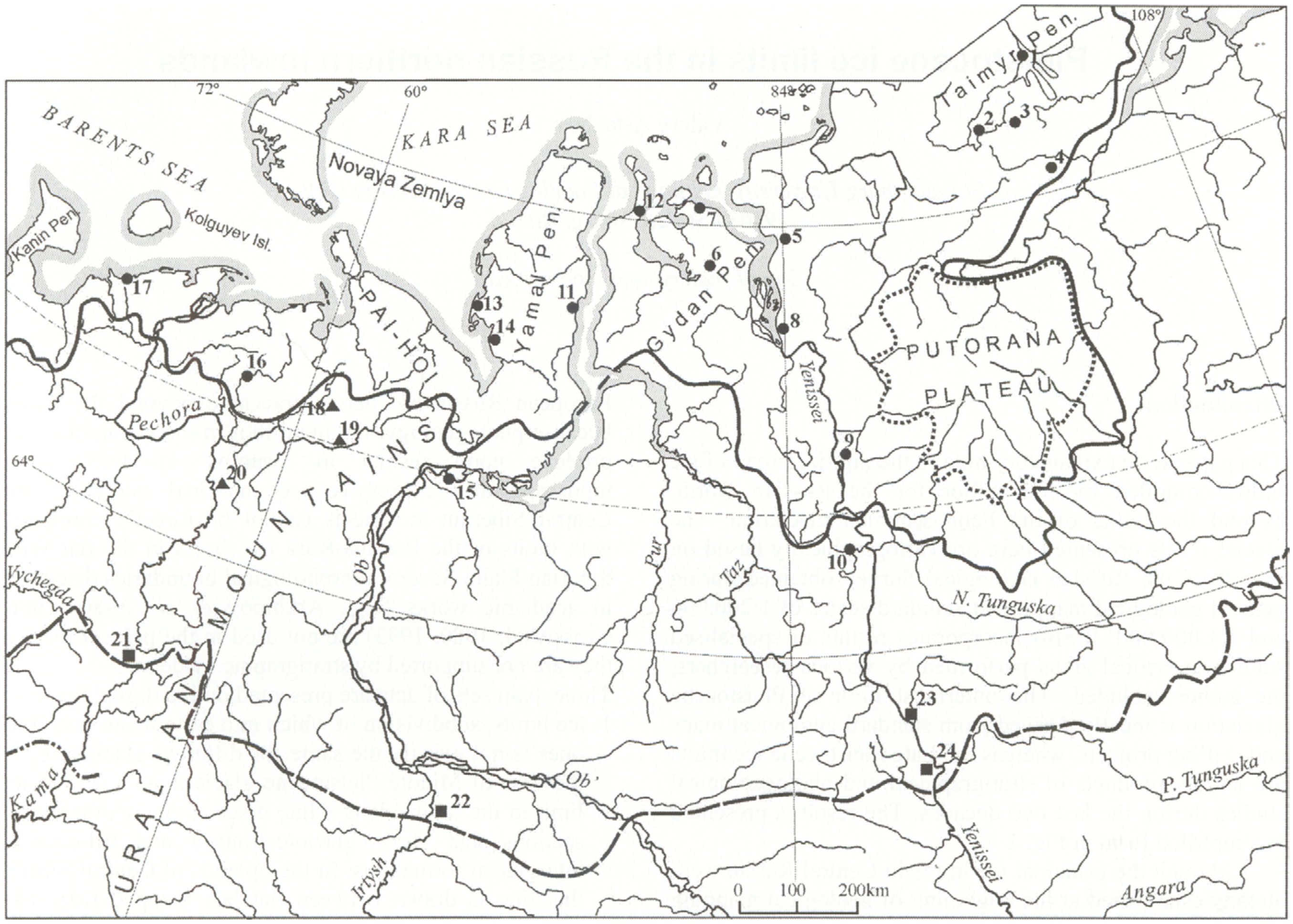


Fig.1. Generalised Pleistocene ice limits of northern Russia beyond the Fennoscandian glaciation.

Dotted line: Late Weichselian glaciation, solid line: Early Weichselian glaciation, dashed line: Saalian glaciation, dash-and-dot line: Don glaciation.

The black circles indicate sites with dated Middle and Late Weichselian sediments not covered by till with their radiocarbon (or OSL) ages:

1- Cape Sabler, 39 to 17 ka (Kind & Leonov, 1982; Möller et al., 1999);
2 - River Logata, 45 to 28 ka (Fisher et al., 1990);
3 - Lake Logata, 45 to 25 ka (Fisher et al., 1990);
4 - Lake Labaz, > 48 to 20 ka (Siegert et al., 1999);
5 - Mokhovaya mammoth, 35.8±2.7 ka (Heintz & Garutt, 1964);
6 - Gyda mammoth, 33.5±1 ka (Heintz & Garutt, 1964);
7 - Leskino mammoth and plants, 30.1±0.3 and 29.7±0.3 (by F. Kaplyanskaya in Astakhov, 1998);
8 - Cape Karginsky, 15.3±0.2 (Kind, 1974);
9 - Igarka permafrost pit, >50 to 35 ka (Kind, 1974);
10 - Farkovo, 42 to 34 ka (Kind, 1974);
11 - Syo-Yakha, 40 to 17 ka (Vasilchuk et al., 2000);
12 - Mongotalyang, 31 to 21 ka (Vasilchuk et al., 1984);
13 - Marresale, 28 to 26 ka (Forman et al., 1999);
14 - Mutny Mys, 30.5 to 27.5 ka (Gataullin et al., 1998);
15 - Salehard moraines covered by interglacial sediments (Astakhov, 2001);
16 - bones in river Kolva terraces, 37 to 26 ka (Mangerud et al., 1999);
17 - Timan Beach, OSL age 52 to 13 ka (Mangerud et al., 1999).

The black triangles are similar sequences at superficial Palaeolithic sites:

18 - Pymva-Shor, 26 to 10 ka (Mangerud et al., 1999);
19 - Mamontovaya Kurya, 37 to 24 ka (Mangerud et al., 1999);
20 - Byzovaya, 33 to 25 ka (Mangerud et al., 1999).

The black quadrangles are interglacial lacustrine and fluvial sediments of Holsteinian type covered by till:

21 - Lake Chusovskoye (Stepanov, 1974);
22 - Semeika (Kaplyanskaya & Tarnogradsky, 1974);
23 - Bakhtinsky Yar (Zubakov, 1972);
24 - Khakhalevsky Yar (Zubakov, 1972).

2. Topographically expressed features of glaciotectonic accretion are shown in the digital map as red arcs the radii of which can be taken as representing former flowlines. There are two kinds of these features dependent on the quality of the substrate. Where substrate is solid bedrock that allowed an easy sliding, these horseshoe-shaped ridges may be positioned close to the outer till limit and thereby considered as end moraines (Fig. 2, a). The internal structure of terminal ridges is poorly known and is normally described as chaotic agglomeration of stony or clayey diamictons distorted together with underlying sand and sometimes massive ice (e.g., Kind & Leonov, 1982; Astakhov *et al.*, 1999). The ridges of sedimentary basins are generally larger and predominantly occur far upglacier irrespective of any marginal formations. In all the sections they invariably demonstrate a regular imbricate structure, with folded slices of various soft rocks divided by listric thrusts and sometimes by clay or ice diapirs (Astakhov, 1979; Astakhov *et al.,* 1996). They are often expressed in the landscape as typical `hill-hole pairs' (Fig. 2, b). In the Middle Pleistocene glaciation area, the imbricate assemblages are mostly constructed of Palaeogene and Cretacious sediments, such as the largest arc between the Urals and the Ob river, the `Malososvinsky Amphitheatre'. The depth of these glacial disturbances may reach 400 m and their width up to 20-25 km. The morainic arcs on the map only show crests of such large structures. These forms, derived from glacial crumpling of perennially frozen clayey formations, must have originated under very thick ice (Astakhov *et al.,* 1996) and therefore cannot be called end moraines. They provide evidence of glacial overriding but not of a quasi-stationary ice margin. In the northern plains where the ice front was fringed by a large proglacial lake and where glacier motion was obstructed neither orographically nor thermally extension ice flow failed to produce any terminal elevations.

3. Named (or numbered) sedimentary sequences (Table 1), constraining temporal and spatial brackets for former ice sheets, are shown mostly for the Late Pleistocene glaciations area, where geochronometric methods can be employed. They are of four kinds: i) interglacial formations of Eemian type which were apparently not overridden by glaciers, ii) glacially disturbed or till-covered Eemian sediments, indicating a Late Pleistocene ice advance, iii) Weichselian sediments with successions of `old' (40 to 15 ka BP) radiocarbon dates, lacking any sign of overriding by a Late Weichselian ice advance, and iv) Weichselian sediments, with finite radiocarbon dates, covered by a till. The most important and well-dated sections are shown in Fig. 1, other can be found on the digital map. For the Middle Pleistocene glaciation area with till-covered interglacial formations of Likvin/ Tobol (i.e. Holsteinian) type only several famous sites have been selected. These formations are known for their typical forest pollen spectra that include exotic taxa, indicating warmer and more humid environments than at present.

The Western European terms Early, Middle and Late Weichselian are rarely applied in the Russian North for specific geological objects, the local names being more popular. However, because of the size of the area considered, with many semi-formalised stratigraphic labels, below the author has used these terms in their geochronological sense common in Russian literature, i.e. as equivalents of the subdivisions of the Wisconsinan.

Pleistocene Glacial Maximum

The spatial resolution of pre-Eemian ice limits, presented here, is mainly in accord with the general maps of Quaternary deposits (Krasnov, 1971; Ganeshin, 1973; Zarrina *et al.,* 1961). However, in many places the configuration of ice margins is corrected using information from later geological maps (Bobkova, 1985; Chumakov *et al.,* 1999; Potapenko, 1985; Rudenko *et al.,* 1981, 1984) and several specialised studies, including Stepanov (1974) for the Pechora-Volga interfluve (21 in Fig. 1), Kaplyanskaya & Tarnogradsky (1974) for river Irtysh (22 in Fig. 1), Astakhov & Fainer (1979) and Zubakov (1972) for Yenissei Siberia (23, 24 in Fig, 1), Arkhipov *et al.* (1976) and Isayeva (1984) for Central Siberia.

The maximum glaciation was traditionally mapped in the USSR as a counterpart of an early Saalian ice advance in Western Europe, which was stratigraphically-traced eastwards across Poland and the Ukraine (Yakovlev, 1956). In the 1980s it was discovered that the till of the southernmost lobe of the Middle Pleistocene glaciation in Central Russia, unlike in the Ukraine, was overlain by interglacial sediments with fauna of the Tiraspol (Cromer) Complex and by 4-5 palaeosols of interglacial character. Accordingly, this so-called Don glaciation, presumably *c.* 0.5-0.6 ma old, could no longer be correlated with either the Saalian in Western Europe, the Dnieper glaciation in the Ukraine, or with the Samarovo glaciation of Siberia (Shik, 1995; Velichko, 1991). In new 1:1,000,000 maps the Pleistocene drift limit is related to the Don glaciation (Marine Isotope Stage 16 or 12, by different estimates), even in the extreme east of the Russian Plain (Chumakov *et al.,* 1999) (Fig. 1).

This age of the maximum glaciation is supported by the coring results around lake Chusovskoye on the Pechora-Volga interfluve (21 in Fig. 1), where two or three more tills occur beneath the superficial pre-Eemian till. Interglacial lacustrine sediments, with pollen of Likhvin (Holsteinian) type, have been found between the two upper tills of this area. The unique find of forest elephant *Palaeoloxodon sp.* is also related to this interglacial sequence (Stepanov, 1974). The uppermost till was previously related to the maximum glaciation of the East European Plain, presumably Saalian (Krasnov, 1971), which is currently split into two different stages - the

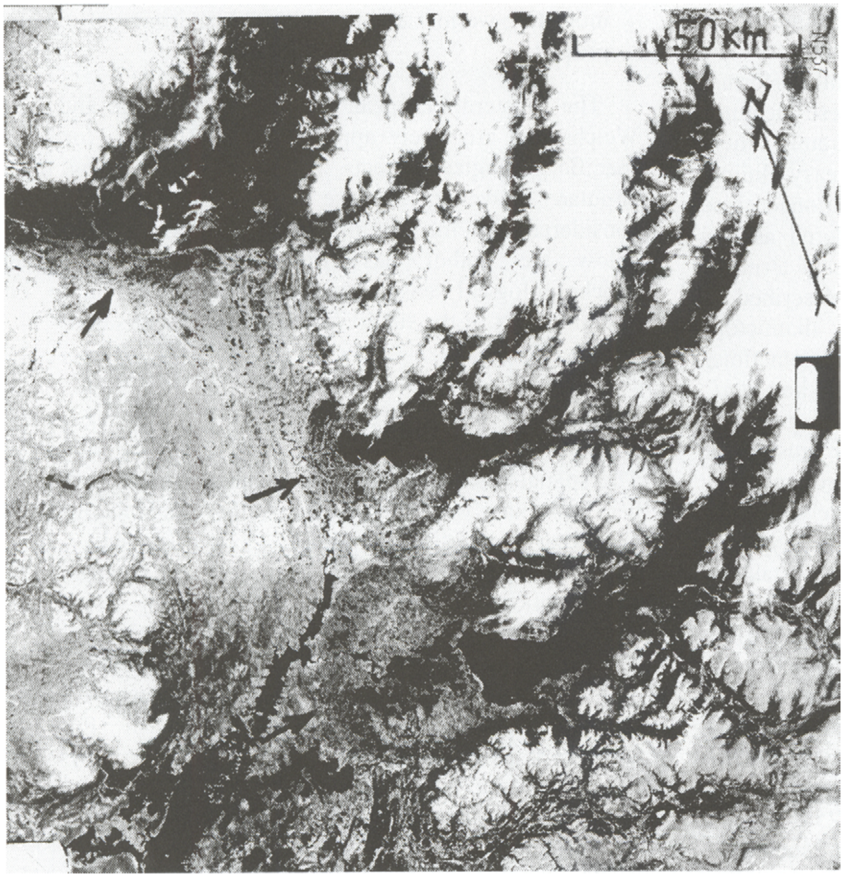
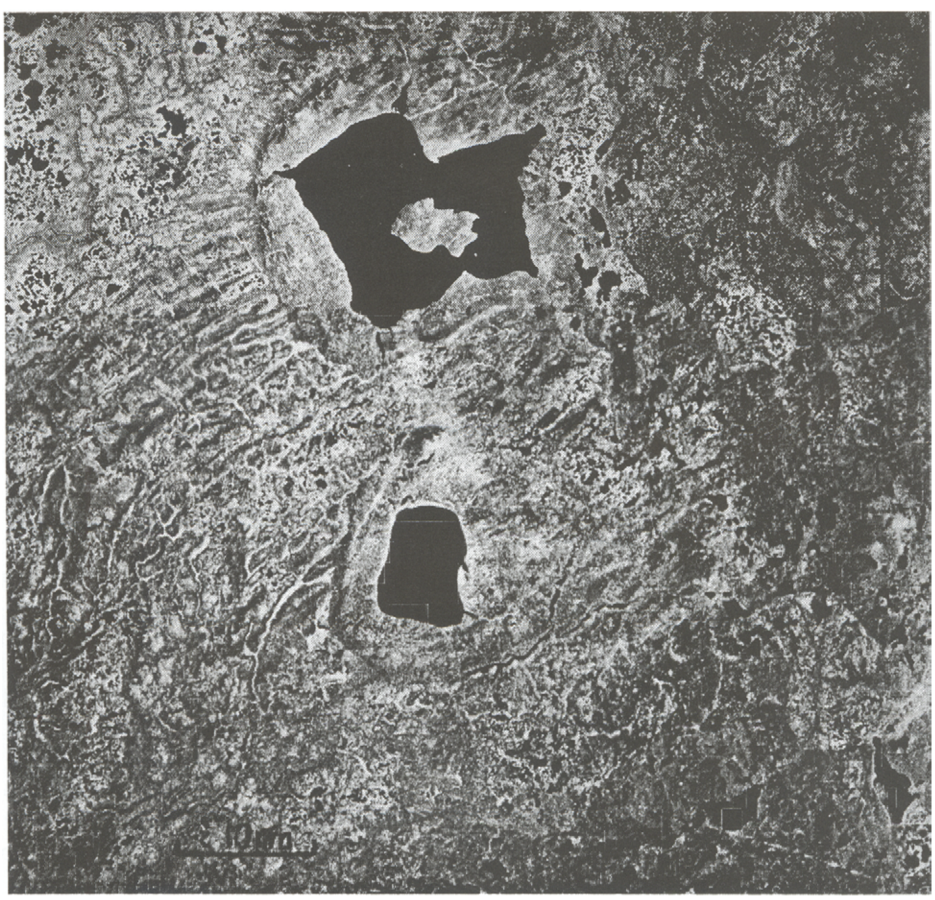


Fig. 2. Ice-pushed ridges in the Yenissei catchment (satellite images).

a. Horseshoe-shaped end moraines (marked by arrows) bounding fjord-like lakes in the western foothills of the Putorana Plateau, Norilsk moraines.



b. Two hill-hole pairs in the sedimentary basin west of the Yenissei, inside the Early Weichselian ice sheet, 60 km upglacier from of its western margin. The northern glaciotectonic ridge, according to Arkhipov et al., 1976 constructed of stony diamicton and cobbly sand, is 130 m above lake Makovskoye which is 65 m deep in the western part.

Dnieper (Saalian) and the Don (Cromerian) (Shik, 1995). It is likely that the new Pleistocene maximum (the Don ice advance) is represented by one of the pre-Holsteinian tills in the lake Chusovskoye area.

The Samarovo glacial maximum of West Siberia is still considered to be of Saalian age. This age is inferred from the underlying Tobol interglacial alluvium (Arkhipov, 1975), which contains forest fauna, shells of central-asiatic fresh-water mollusc *Corbicula tibetensis (fluminalis),* shows normal magnetic polarity and yields thermoluminescence dates in the range 260 to 390 ka BP. A bone of the elk *Alces latifrons* has been found in sediments beneath till at Bakhtinsky Yar on the Yenissei (23 in Fig. 1). Overlying the Samarovo Till, only one horizon of interglacial soils and peats have been described. Beneath this till two pre-Holsteinian tills can be distinguished in the sedimentary sequences filling buried valleys, overdeepened to 200-300 b.s.l. (Zubakov, 1972; Arkhipov, 1989). These ancient tills have been found proximally to the Samarovo glaciation limit, rather close to it. A pre-Holsteinian glaciation may be the most extensive in the east of Central Siberia, as suggested by Bobkova (1985).

The lingering stratigraphic uncertainty is connected with the relationship between the Moscow till of Central Russia and Dnieper till in the Ukraine. Both are currently related to the Marine Isotope Stage (MIS) 6 by Russian geologists (Shik, 1995), but in the Ukraine the Dnieper till is commonly thought as belonging to an earlier Saalian substage, as suggested by several thermoluminescence dates *c.* 280 ka (Gozhik, 1995).

A similar problem occurs in Siberia where the less extensive Taz till is thought to represent MIS 6, whereas the maximum Samarovo glaciation is related to MIS 8, based on a few thermoluminescence dates (Arkhipov, 1989). Traditionally the Samarovo Stage was correlated with the Dnieper glaciation. Although, unlike in European Russia, both pre-Eemian tills are known in superposition, the independence of the Taz glaciation is questionable, because no unequivocal interglacial formations have ever been described from between this and underlying Samarovo glacial complex. In the present digital map the boundary of the Taz glaciation, commonly drawn along hummocky plateaus and morainic ridges of unknown age (e.g., Arkhipov *et al.*, 1976, 1986), is omitted as unreliable.

Today the only clue for the spatial differentiation betweeen Saalian and pre-Saalian ice sheets is glacial topography which is partly preserved in the Saalian area and totally absent in older glacial landscapes. However, this feeble tool can hardly be employed in the primordially flat lowlands of central West Siberia, where only rare drilling profiles, undertaken for mapping and geotechnical projects, help to interpolate the drift limit between key sections in river valleys. Immediately west of the Urals, the Saalian ice limits are very controversial in different survey maps. Thus the author has assigned the Saalian limit in the Volga-Pechora interfluve using available literature and personal experience in the Pechora Basin. In the extreme northeast of Central Siberia the pre-Eemian ice limits could not so far be defined for want of any reliable data.

Late Pleistocene ice limits

The first cartographic concepts of the last glaciation of northern Russia without the area of the Scandinavian glaciers were put forward by Sachs (1953) and Yakovlev (1956), who authored fundamental syntheses of previous investigations. They established the pattern after which

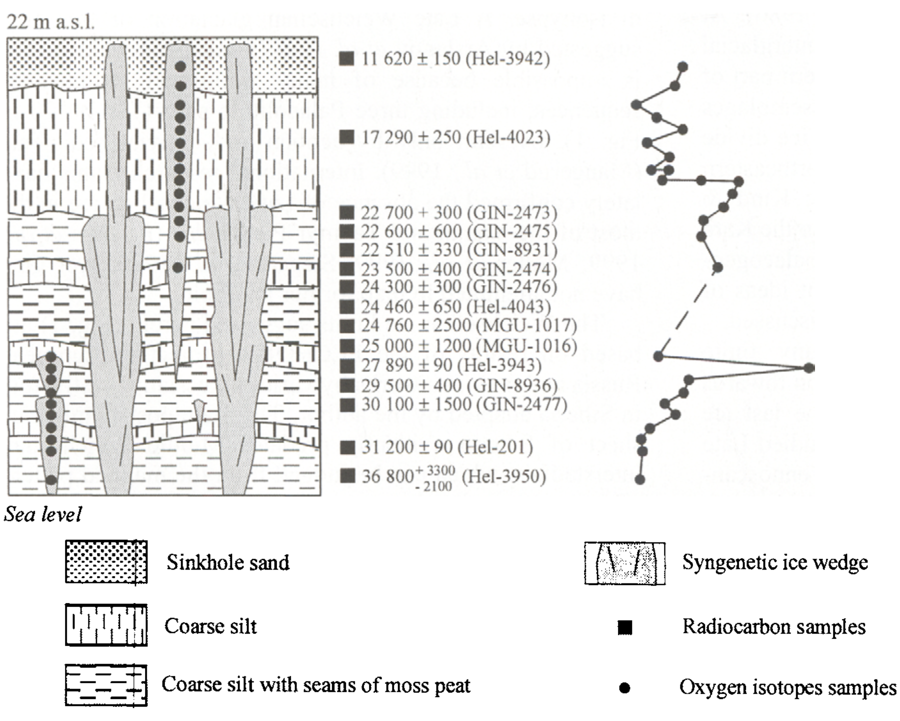


Fig. 3. Syo-Yakha section on the eastern coast of Yamal (11 in Fig. 1), after Vasilchuk et al. (2000).

Note the two generations of telescoped ice wedges that were growing simultaneously with accumulation of organic-rich silts, the latter of probable aeolian origin. No sign of any glacial activity has been found overlying this periglacial sequence. In other sections this formation is underlain by the latest till with blocks of fossil glacial ice.

many subsequent models have been developed. It was proven beyond any doubt that Late Pleistocene glaciers were much smaller than pre-Eemian ice sheets. On the basis of mapped boulder trains and occurrence of fresh-looking hummock-and-lake landscapes the latest ice sheets of the West Siberian and Pechora Lowlands were thought to have been confined to the Arctic and fed from upland ice domes of the Urals, Novaya Zemlya, Putorana Plateau of Central Siberia and Byrranga Mountains in the Taymyr Peninsula. Yakovlev (1956) also suggested an additional ice dome on the dry shelf of the Barents Sea.

The Late Pleistocene age of the uppermost till was inferred from the underlying interglacial marine formation with warm-water mollusc fauna considered to be a product of the Eemian transgression. These marine sediments, called the 'Boreal Strata' in Europe and the Kazantsevo Formation in Siberia, were described in many places as glacially disturbed and overlain by the uppermost till. The latter was correlated with the Early Weichselian (Sachs, 1953; Yakovlev, 1956). The limits of this glaciation were drawn around main Palaeozoic uplands, but only in the west was the marginal zone found to parallel the Barents Sea coast. Later, Lavrov (1974) extended the limit of the last Barents Sea ice sheet farther south and east, maintaining its coalescence with the Uralian ice sheet.

The wide use of remote sensing data in the 1970-s revealed many push moraines, the configuration of which totally contradicted the mountain glaciation hypothesis and testified to upslope ice flow from coastal lowlands towards Urals and Taymyr highlands, a direction supported by till composition (Astakhov, 1976, 1979; Andreyeva, 1978). The mapped pattern of ice-pushed ridges could only form if the thickest inland ice resided on the low coastlands and totally blocked the northbound drainage. Beyond the Kara ice sheet only traces of small alpine glaciers were mapped in the Urals (Astakhov, 1979; Arkhipov *et al.*, 1980). At that time, very large morainic loops overlying interglacial marine sediments were also mapped in the southern part of the Taymyr Peninsula. These morainic assemblages together with boulder trains pointed to a former ice divide north of the Byrranga Mountains, i.e. in the northeastern Kara Sea (Andreyeva, 1978; Grosswald, 1980; Kind & Leonov, 1982; Isayeva, 1984). When ice domes on the Kara Sea shelf were demonstrated to have existed, the palaeogeographical paradigm changed, and totally different ideas of Weichselian ice limits in the Arctic began to be discussed.

At the same time the determination of many finite radiocarbon dates tipped the scale of the discussion towards concepts of a very extensive last glaciation. The last ice sheet was viewed as a counterpart of the well-studied Late Wisconsinan Laurentide and Late Weichselian Fennoscandian glacial systems. Grosswald, the most ardent proponent of the maximalist model, maintained that Weichselian ice sheets culminated in northern Russia *c.* 20 ka ago and extended very far south of the Arctic Circle, close to the Middle Pleistocene ice limit (Grosswald, 1980, 1993). This model was applied for Quaternary mapping of the Pechora Basin based on photogeology (Arslanov *et al.*, 1987).

However, subsequent testing of the maximalist concept in West Siberia has led to rejection of a Late Weichselian age for the most of the Kara Sea catchment area. It appeared that finite radiocarbon dates from sediments overlying the uppermost till greatly outnumbered those from beneath the till. There are several successions of 'old' radiocarbon dates in the right stratigraphic order derived from soft superficial silts, in places with syngenetic ice wedges, plainly indicating a lack of any glacial overriding (sites 1, 4, 11, 12, 13, 14 in Fig. 1). Frozen mammoth carcasses on the surface (sites 5, 6 in Fig. 1) underline the absence of glacial activity during the last 35 ka. Thus only moderately-sized Late Weichselian ice sheets, mainly north of the Polar Urals and in the Pechora Basin, were deemed possible on the basis of the available radiocarbon evidence (Astakhov, 1992, 1998).

A new investigation of the Weichselian morainic system was initiated in 1993 by a joint Russian-Norwegian team in the area between the Uralian Mountains and Timan Ridge (the PECHORA project). During this project marginal formations of the Weichselian maximum have been mapped using photogeological interpretation and dated by the radiocarbon and luminescence methods (Astakhov *et al.*, 1999; Mangerud *et al.*, 1999). This work has established the Weichselian maximum along the Markhida Line, north of the Arctic Circle, and demonstrated the age of this ice advance to be *c.* 70-90 ka BP. The main evidence for an older Weichselian age of the last ice dam across the Pechora Lowland is beach formations of the proglacial Lake Komi postdated by alluvial terraces containing Palaeolithic artefacts and abundant remains of mammoth fauna. The latter have been radiocarbon dated to 25-37 ka BP. Traces of Late Weichselian glaciation east of the Fennoscandian moraines have been found neither on the plains of European Russia, nor in the Urals below the 600 m isohypse. A Late Weichselian glaciation of this area suggested by Arslanov *et al.* (1987) and Grosswald (1993) is impossible because of many well-dated sedimentary sequences, including three Palaeolithic sites (18, 19, 20 in Fig. 1), overlain only by aeolian and alluvial sediments (Mangerud *et al.*, 1999). International research teams have lately confirmed the absence of Late Weichselian ice in the most of the Yamal and Taymyr Peninsulas (Forman *et al.*, 1999; Möller *et al.*, 1999; Siegert *et al.*, 1999), yet they have not attempted to map former ice limits.

The Weichselian ice limits suggested herein (Fig. 1) are based on results of the PECHORA project in European Russia and previous works by various Russian investigators in Siberia adapted by the author. The main post-Eemian ice sheet of Siberia evidently predates Middle Weichselian interstadials, which can be judged from the mapped pattern of radiocarbon dated sequences not covered by tills (Table 1). Especially important are undisturbed surficial formations of loess-like silt and moss peat with syngenetic ice wedges and long series of radiocarbon dates from 37 to 11 ka BP in the right stratigraphic order - Cape Sabler (Kind & Leonov, 1982; Möller *et al.*, 1999), Syoyakha and Mongotalyang sections (Vasilchuk *et al.*, 1984; Vasilchuk *et al.*,

Table 1. Key stratigraphical sites for the determination of Pleistocene glacial limits

Eemian interglacial sequences not overlain by till	
Sula 22; Sula 21; Urdyuzhskaya Viska	(Mangerud *et al.*, 1999)
Aksarka	(Lazukov, 1970; Astakhov, 2001)
Hutty-Yakha; Varka-Sylky	(Troitsky, 1975)
Bol. He-Yakha; Lysomarra; Pancha; Russkaya-1	(Shatsky, S.B. *et al.*, 1956, manuscript, Tomsk)
A-434; B-59; IL-60; N-114	(Kind & Leonov, 1982)
Eemian interglacial sequences overlain by till	
Sopka; Vastiansky Kon; Kuya	(Mangerud *et al.*, 1999)
More-Yu-1; More-Yu-2; More-Yu-3; Golodnaya Guba; Vashutkiny lakes	(Astakhov, 1999)
Silova-Yakha	(Loseva & Duryagina, 1983)
Boreholes 703; 704; 710	(Lavrushin *et al.*, 1989)
Nurma-Yakha; Voivareto	(Dolotov M.S.*et al.*, 1981, manuscript, Moscow)
Yuribei; Tanama	(Lavrov A.S.*et al.*, 1983, manuscript, Moscow)
Lukova Protoka; Krestianka; Rogozinka; Igarsky Yar	(Sachs, 1953)
Cape Karginsky	(Troitsky, 1966)
Russkaya-2; Russkaya-3; Bol. Heta-1; Bol. Heta 2; Bol. Heta-3; Osetrovaya; Lodochnaya -1; Lodochnaya-2; Hikigli-1; Hikigli-2	(Shatsky, S.B. *et al.*, 1956, manuscript, Tomsk)
Uhelengde	(Strelkov & Troitsky, 1953)
Karaul; Dudinka	(Astakhov *et al.*, 1986)
Boreholes 28-BH; 31-BH	(Arkhipov *et al.*, 1973)
Turukhan -1; Turukhan-2; Turukhan-3; Potapovo-1; Potapovo-2	(Komarov, V.V., 1980, manuscript, Krasnoyarsk)
A-79; A-81; A-267; A-329; A-410; A-430; B-117; IL-254; borehole bh-5	(Kind & Leonov, 1982)
Radiocarbon-dated, non-glacial Weichselian deposits not overlain by till	
Podkova; Yarei-Shor; Pymva-Shor; Mamontovaya Kurya; Byzovaya; Timan Beach	(Mangerud *et al.*, 1999)
Marresale; Mutny Mys	(Forman *et al.*, 1999; Gataullin & Forman, 1997)
Syo-Yakha; Mongotalyang	(Vasilchuk *et al.*, 1984; Vasilchuk & Vasilchuk, 1998)
Syadei; Lysukanye; Parisento	(Bolikhovsky, 1987)
Yuribei; Gyda; Mongoche-Yaha	(Avdalovich & Bidzhiyev, 1984)
Mokhovaya; Gyda	(Heintz & Garutt, 1964)
Leskino; Kureika	(Astakhov, 1998)
Igarka Shaft; Karasino; Farkovo	(Kind, 1974)
Cape Sabler	(Kind & Leonov, 1982; Moeller *et al.*, 1999)
A-50	(Kind & Leonov, 1982)
F-8; F-9; F-17; R-10; R-59	(Fisher *et al.*, 1990)
Labaz	(Siegert *et al.*, 1999)
Kotuy-1	(Bardeyeva, 1986)
Radiocarbon-dated, non-glacial Weichselian deposits overlain by till	
Mal. Romanikha-1; Mal. Romanikha-2	(Isayeva *et al.*, 1976)
Maimecha	(Bardeyeva *et al.*, 1980)
Amnundakta: Kotuy-2	(Bardeyeva , 1986)
Interglacial sequences of Likhvin/Tobol (Holsteinian)-type overlain by Saalian tills	
Lake Chusovskoye	(Stepanov, 1974)
Semeika	(Kaplyanskaya & Tarnogradsky, 1974)
Bakhtinsky Yar, Khakhalevsky Yar	(Zubakov, 1972)

2000), and Marresale section (Forman *et al.*, 1999) (sites 1, 11, 12, 13 in Fig. 1).

Earlier the limit of Weichselian glaciations east of the Urals was suggested south of the Arctic Circle (Astakhov, 1992, 1998), based on the work by Arkhipov *et al.* (1977) who reported finite radiocarbon dates from presumably Middle Weichselian sediments overlain by till at the Salehard moraines. The latest study of various sections in this area by the PECHORA project found neither tills nor glacial disturbances within the range of radiocarbon method. Finite radiocarbon dates have been obtained only from fossil plants and mammal bones associated with a well-pronounced periglacial formation up to 9 m thick consisting of aeolian and slope deposits. The Late Weichselian till by Arkhipov *et al.* (1977) proved to be small lenses of soliflucted diamictic material at the base of the periglacial mantle, which also displays all kinds of permafrost disturbances. Underlying fluvial sands have been dated by optically stimulated luminescence (OSL) to 80-90 ka (site 15 in Fig. 1) (Astakhov, in press). The only sign of the last glaciation in the Salehard area is thick varved rhythmites, which probably correspond to the Sopkay morainic belt mapped along 67.5°N (Astakhov, 1979). Now it is clear that the Sopkay moraines mark the maximum extent of post-Eemian glaciers, i.e. Early Weichselian glaciers did not reach the Arctic Circle (Fig. 1).

In the Yenissei area the principal uncertainty is connected with the stratigraphic problem of distinguishing between interglacial marine formations of different ages. Only one marine formation (the Kazantsevo strata) with boreal molluscs, indicating an influx of atlantic water, has for decades been identified in natural sections and correlated with the Eemian. This traditional correlation is geochronometrically confirmed in four sections of the interglacial marine sediments, between 68 and 73.5°N, by ESR dates in the range 109-134 ka (Sukhorukova, 1998). A subtill ESR date of 122 ka is known from the type site at Cape Karginsky (8 in Fig. 1) (Arkhipov, 1989). Superficial tills containing boreal shells are therefore commonly attributed to a Weichselian ice sheet. However, in some reconstructions this approach has led too far. E.g., according to Troitsky (1975), the last ice sheet ended in a very long Yenissei ice tongue reaching as far south as site 23 in Fig. 1.

The problem is that typical boreal fauna, such as *Arctica islandica,* sometimes occurs also in Middle Pleistocene tills, indicating that there was at least one transgression of warm-water sea older than the Eemian. Zubakov (1972) placed this marine event between the last two Middle Pleistocene ice advances, presumably *c.* 170 ka ago. A similar interglacial transgression is also known in northeastern European Russia (Yakovlev, 1956). Therefore, some interglacial sites with marine fauna, shown in the digital map, might be not Eemian but older, thereby calling to a conservative approach in drawing the Late Pleistocene glacial limit.

In the present map the Weichselian ice limit on the Yenissei is shown just south of the Arctic Circle (Fig. 1) as it was originally mapped by geological surveys (Zarrina *et al.*, 1961), with minor modifications. The main signature of the last ice sheet are the impressive glaciokarst hummocks and lakes described by Zemtsov (1976) and glaciotectonic `hill and hole pairs` (Fig. 2). South of the Arctic Circle the fresh-looking glacial landscape is truncated by a flat intravalley plain at 45-55 asl composed of thick glaciolacustrine rhythmites. The rhythmites are overlain by alluvium radiocarbon dated to 34-42 ka at Farkovo (10 in Fig. 1) and by sinkhole silts containing frozen logs with dates from 35 ka to infinite at Igarka (9 in Fig. 1) (Kind, 1974). Many 'old' finite and non-finite radiocarbon dates are known from sediments and mammoth remains overlying the uppermost till (Astakhov, 1992, 1998).

Besides the subtill marine sediments with boreal fauna and fresh glaciokarst topography there are other indications of a Late Pleistocene age of the last ice advance. These are thick (5 to 60 m) stratiform bodies of massive foliated ice with erratics which often occur within the hummocky landscape above the 66th parallel. The massive ground ice is believed to be mostly remnants of glacier sole preserved in the thick Pleistocene permafrost (Kaplanskaya and Tarnogradsky, 1986; Astakhov & Isayeva, 1988; Astakhov *et al.*, 1996). This direct signature of former glaciation is instrumental in delineating the Weichselian ice margin in the central lowland between the Ob and Yenissei where no ice limits have been mapped by the Geological Survey. In the Gydan and Yamal peninsulas the massive buried ice is sometimes overlain by cold-water marine silts with *Portlandia arctica.* However, it is very unlikely that buried glacial ice, normally found at low altitudes, could survive the warm Eemian transgression. Thus, the area with known sites of massive buried ice (Astakhov, 1992; Astakhov *et al.*, 1996) should probably to have been occupied by the last ice sheet.

The Last Glacial Maximum (LGM) ice limit is now identified well offshore in the Barents Sea based on marine drilling and seismic data (Gataullin *et al.*, 2001). The only refugium for Late Weichselian ice on the Russian mainland is the Putorana Plateau, where several finite radiocarbon dates were obtained from beneath well-pronounced end morainic arcs (Isayeva *et al.*, 1976; Bardeyeva, 1980; Isayeva, 1984; Bardeyeva *et al*, 1986). These piedmont morainic arcs of the Norilsk Stage (Fig. 2, a) reflect snouts of valley glaciers which probably were outlets of a flat ice cap of Norwegian type.

Several problems remain unsolved. In European Russia there are huge morainic loops protruding south of the Markhida Line, namely, the Laya-Adzva Ridge and adjacent ridges, unequivocally indicating a former ice flow from NE. No reliable Eemian sequences have been discovered in this area. Therefore, this ice stream is probably an Early Weichselian (Mangerud *et al.*, 1999), as shown in the digital map, but the Middle Pleistocene age maintained in the regional stratigraphic scheme cannot not be ruled out yet. The statistics on OSL dates in the Pechora Basin suggest that there were two Weichselian ice advances: *c.* 80-100 and *c.* 60 ka BP (Mangerud *et al.*, 2001), which agrees with OSL dates from the northern Taymyr Peninsula (Alexanderson *et al.*, 2001) and west of the Timan Ridge (Houmark-Nielssen *et al.*, 2001). However, an unambiguous lithostratigraphic proof of two Weichselian glacial complexes is still lacking. Also, dimensions of Late Weichselian glaciers in the Urals, on the Putorana Plateau and possibly on the northern shore of the Taymyr Peninsula are still disputable.

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