Quaternary Glaciations – Extent and Chronology
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Valdaian glacial maxima in the Arkhangelsk district of northwestern Russia

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Abstract

The marginal configurations and ages of the Valdaian (Weichselian) glacial maxima in northern Russia have hitherto not been well established, thus, numerous versions of the Last Glacial Maximum (LGM) positions of the Scandinavian Ice Sheet are known (Fig.1B). New data on ice sheet growth and decay indicate at least three glacial maxima during the Late Pleistocene each with individual spreading centres and different ages. Results of modern investigations in the Arkhangelsk region, conducted by the authors, are compared with an analysis of previous data on the Late Quaternary geology of Northwest Russia, which comprises a thorough presentation of Russian literature on this subject. This has allowed us to question and revise former models on Valdaian glaciation history and ice-marginal positions in a major part of the Russian North.

An Early-Middle Valdaian (*c.* 70 ka BP) glaciation from the east and southeast, possibly originating on the Timan ridge, crossed the Pyoza River basin and reached the White Sea coast along the Bay of Mezen. The southern terminus of the ice sheet is probably found along parts of the Mezen River (Fig.2 A,B). The presence of an Early-Middle Valdaian Scandinavian glaciation, which covered the Arkhangelsk region and in neighbouring areas of Karelia and Vologda is not supported by geological data. In the Middle Valdaian (*c.* 60 ka BP) an ice sheet from the Barents-Kara Sea flowed from the north, northeast and reached the lower Pyoza River and the south and western shores of Mezen Bay on the White Sea coast. The terminal formations of its maximal stage stretch from west to east just north of Pyoza River and then run marginal to the Timan ridge from the north joining with the Markhida end-moraines on the Pechora Lowland (Fig.2 A,B).

During the Late Valdaian, the Scandinavian Ice Sheet occupied the northwestern part of the Arkhangelsk region around 19-17 ka BP. The limit of this Late Valdaian glacial maximum runs from the White Sea shore of the Kanin Peninsula in the north, along the Kuloi River south of Mezen to the Middle Pinega River, crossing the rivers Severnaya Dvina and Vaga near the villages of Cherevkovo and Ust-Padenga. The glacial boundary bordered the Melovian and Nyandoma high ground and continued southwestwards to Lake Kubenskoe in the Vologda region. The Pyoza, Mezen and Vashka river basins remained ice-free during the Late Valdaian time, this area being covered by fluvial flood plains, with abundant evidence of permafrost and lakes. The latter have yielded pollen evidence indicating an arctic to subarctic environment between 18-10 ka BP (Fig. 2 A,B).

Introduction

During the last decade much new information about the timing and extent of the Late Pleistocene Eurasian ice sheets has been obtained. The age and position of the consecutive Scandinavian ice sheets during the Valdaian (Weichselian) glaciation is fairly well known in north-western Europe compared to that in eastern Europe especially northern Russia (cf. Mangerud *et al.*, 1999). Many questions concerning ice sheet configurations, ages and spreading centres since the Mikulinian (Eemian) interglacial still remains to be solved, however, new achievements on the stratigraphy and glacier-dynamics in northern Russia are now available (Larsen *et al.*, 1999b; Houmark-Nielsen *et al.*, 2001; Kjær *et al.*, 2001; Lyså *et al.*, 2001). Against this background it is important to present an outline of classical and more recent literature on the Valdaian glaciation in northern Russia especially the Arkhangelsk region. Since the vast majority of the literature cited is in the Russian language, which is not easily accessible to the majority of Quaternary geologists in Western Europe, this article contains an extensive review of previous Russian publications.

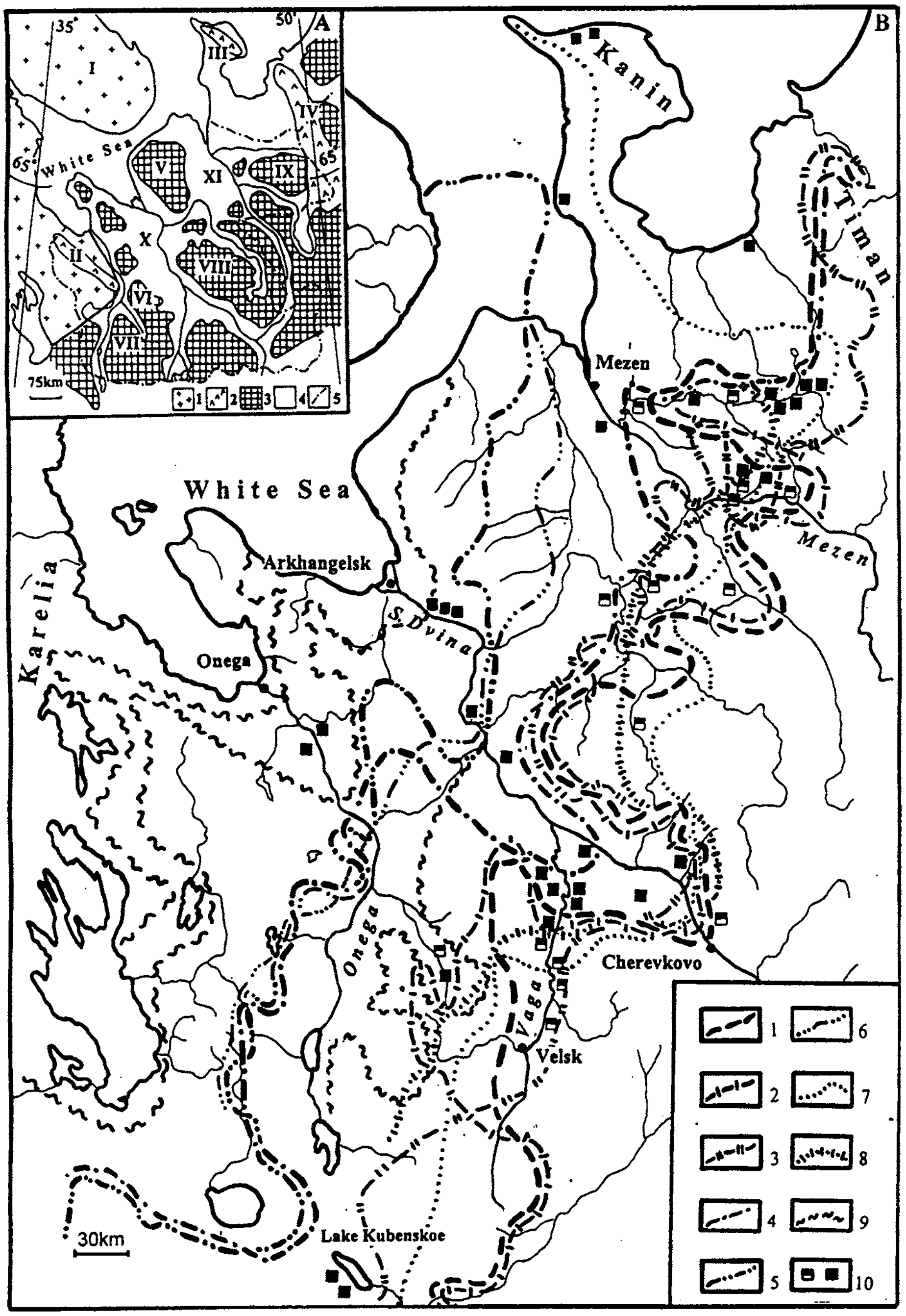


Fig. 1. Main geological-geomorphological setting (A) and main variants of glacial limits (B) in Arkhangelsk district and adjacent areas (compiled by I. Demidov).

A: 1- Archean and Proterozoic largely metamorphosed igneous, volcanic and sedimentary rocks , 2 - lower mountains are composed by Proterozoic or Palaeozoic igneous, volcanic and sedimentary rocks, 3 - water divide plateaux are composed of Palaeozoic sedimentary rocks, 4 - lowlands are composed of Palaeozoic and Mesozoic sedimentary rocks, 5 - administrative boundary of Arkhangelsk district. I - Fennoscandian Shield, II - Vetreny Poyas ridge (Windy Belt), III - Kanin Peninsula, IV - Timan Ridge, V - Belomorian-Kuloi plateau, VI - Melovian uplift, VII - Nyandoma - Konosha uplift, VIII - Pokshenga uplift, IX - Pyoza-Mezen waterdivide, X - Dvina lowland, XI - Mezen lowland.

B: LGM positions .

Early Weichselian:

1 - Krasnov, 1974.

Late Weichselian:

2 - Aseev, 1971,

3 - Yakovlev,1956,

4 - Devyatova,1969,

5 - Ganeshin et al, 1980,

6 - Apukhtin & Krasnov, 1966, Krasnov, 1974, Legkova, 1967,1972,

7 - Stadial (Older Dryas) moraines by Chebotareva,1977.

Key sections of Mikulinian or Early-Middle Valdai interglacial sediments unburied (8) and buried by till (9), 10 – Detail area showed on Fig. 4.

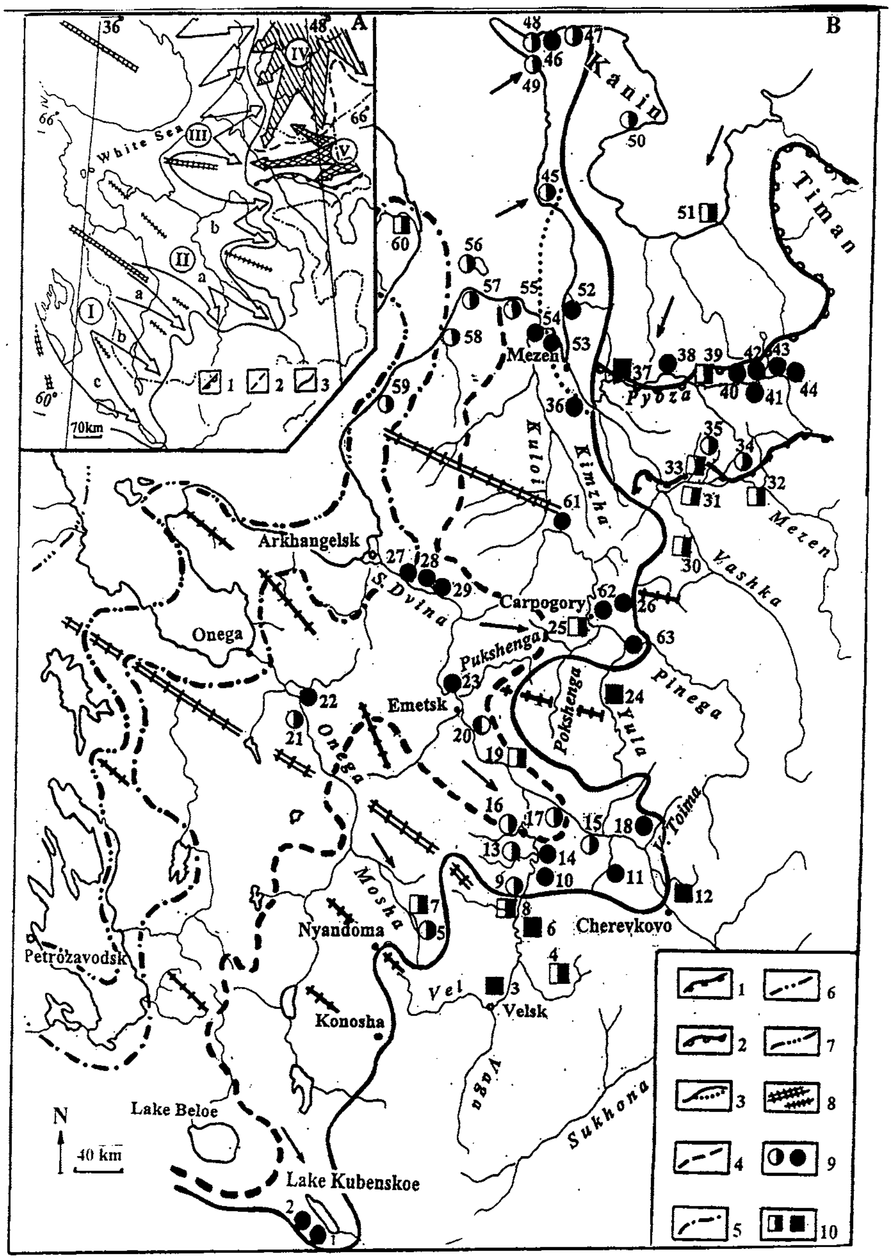
In the Arkhangelsk region, as in other parts of Russia, the outer limits of Pleistocene glaciations have chiefly been defined using geomorphological analyses. Areas of terminal formations - hummocky and end moraines, sandurs and kames – were pieced together into former ice-marginal positions. The development of the lake and river systems was also taken into account. So far, over 30 versions of the LGM position in northern Russia are known (Gey & Malakhovsky, 1998) (Fig. 1.B).

Although glacial deposits formed during the Valdaian have been investigated for over a century, the position and age of the maximum boundaries of ice sheets have not been well documented. This has happened because the areas of interest in North Russia are poorly accessible, and also because the lack of good stratigraphical control prevented reliable conclusions. For example, the geomorphology of older landforms formed during the Moscovian glaciation were often taken as ice-marginal formations formed in the Valdaian glaciation maximum. Moreover, younger lacustrine or fluvial sediments, especially in river valleys, often overprint glacial landscapes. In many areas, the formation of dead-ice landforms during deglaciation has resulted in complex and indistinct marginal zones adding further difficulties to the recognition the maximum position of former ice sheets. It is therefore difficult to trace ice-marginal belts using only aerial photographs and satellite images, even though this has been attempted with variable success (Punkari, 1985; Astakov *et al.*, 1999).

Fig. 2. Main glacial maximum positions of Upper Pleistocene glaciations in the Arkhangelsk district and adjacent areas (A) and current reconstruction of the deglacial stages for the retreat of the Scandinavian Ice Sheet at Late Valdai time (B).

A: Ice flows and tongues of Scandinavian Ice Sheet: I - Karelian ice lobe, a – Mosha ice tongue, b – Lacha ice tongue, c - Lake Onega ice tongue, II - Belomorian (White Sea) ice lobe, a – Dvina ice tongue, b – Pinega ice tongue, III - Kuloi-Mezen ice lobe; IV – Kara/Barents ice sheet, V – Timan (?) ice cap.

B: 1 – assumed maximum position of the southern flank of the Timan ice cap in Early-Middle Valdai time, 2 - maximum position of the southern flank of the Kara/Barents Sea ice sheet in Middle Valdai time, 3 – glacial maximum of the Scandinavian Ice Sheet in Late Valdai time. Deglacial phases of the last Scandinavian ice-sheet: 4 – Vepsovo Phase, 5 – Old Dryas (Luga) Phase, 6 – Middle Dryas (Neva) Phase, 7 - Younger Dryas (Salpausselkä I). 8 - ice-divides, 9 - sections with Mikulino or Middle Valdai interglacial sediments covered by till, 10 - sections with Mikulino or Middle Valdai interglacial sediments unburied by till. Arrows indicate ice flow directions.



Numbers and names of key sections (with ^{14}C, TL or ESR dates):*

1 - Puchka,*
2 - Irkhino,*
3 - Ustya (boring),
4 - Pasva,*
5 - Voiozero,
6 - Koleshka,*
7 - Iksa,
8 - Ust-Padenga,
9 - Osinovskaya,
10 - Raibola,*
11 - Yumizh,*
*12 - Erga**
13 - Led,
14 - Smotrakovka,*
15 - Boltinskaya,
16 - Tarnya,
17 - Konovalovskaya,
18 - Tomasha,*
19 - Krasnaya Gorka,
20 - Lipovic,
21 - Somba,
22 - Verkhnyaya Tyolza,*
23 - Chelmokhta,*
24 - Yula,*
25 - Shilega,
26 - Yezhuga,*
27 - Psaryovo,*
28 - Trepuzovo,*
29 - Bobrovo,*
30 - Olema,
31 - Tseb,yuga I,
32 - Kyma,
33-Tseb,yuga II,
34 - Ona (boring),
35 - Tseb,yuga III,
36 - Zaton,*
37 - Bych,e,*
38 - Viryuga,
39 - Jazevets, Orlovets,
40 - Yolkino,*
41 - Safonovo,
42 - Ust-Varchushka,
43 - Burdui,
44 - Bludnaya,
45 - Konushinskaya Korga,
46 - Krynka,
47 - Madakha,
48 - Tobuev,
49 -Tarkhnov,
50 - Oiva (Zhemchuzhnaya),
51 - Pyosha,
52 - Syomzha,*
53 - Tolstic,*
54 - Kargovsky,*
55 - Abramovsky,
56 - Morzhovets,
57 - Voronov,
58 - Megra,
59 - Tova,
60 - Ponoi,
61 - Kulogora,*
62 - Mezhdurechensky,*
63 - Verkola,*
64 - Kirillov.*

Fig. 3. Huge sections of Upper Pleistocene deposits along the Pyoza River (NE part of Arkhangelsk area). Middle-Early Weichselian till (grey) of the Kara or Timan ice sheet rests on Mikulino and Early Weichselian sediments and is covered by Late Weichselian fluvial sediments (yellow) with traces of cryogenesis. There is no Late Weichselian till present.

As in Western Europe, the coupling of morphology and stratigraphy did not necessarily clarify understanding of the timing and extent of Valdaian glaciations. Stratigraphical examination of numerous cross-sections along the banks of the rivers Severnaya Dvina, Vaga, Pyoza, Onega and their tributaries, and sections along the White Sea and Barents Sea coastlines have been undertaken since the beginning of the early 20th century. Before the availability of reliable dating methods, such as radiocarbon and luminescence, stratigraphical subdivisions of the Pleistocene successions, including interglacial, interstadial and glacial strata were based on a simple 'counting-from-the-top' method. The inaccurate interpretations of diamict deposits and sedimentary successions and palaeo-ecological data has been substantially affected by theoretical concepts on the evolution of the Pleistocene. It has therefore been essential to revise and reinterpret the results of previous studies. Thus, this article presents the history, age and extents of Valdaian glaciations in the Arkhangelsk region, based on a critical review of previously published data and on new results from investigations in northeastern part of the study area.

Fig. 4. Tall cliffs along the Severnaya Dvina River with tills of the Moscovian and Late Weichselian glaciations, separated by Mikulinian and Middle Weichselian marine and fluvial sediments. Section near Bobrovo village.

Diamict beds that rest on marine sediments in the Severnaya Dvina River basin were recognised in the late 19th century by Vollosovich (1900). On the lower Mezen River and on the Kanin Peninsula, Ramsay (1911) recognised three till units separated by marine deposits. Based on the composition and provenance of boulders in these tills, Ramsay concluded that, in addition to the Scandinavian glaciation centre, a second centre existed on Novaya Zemlya. Kalyanov & Androsova (1933), Androsova (1938), Gorbatsky (1932) and Spridonov & Yakovleva (1961) continued research on the Kanin Peninsula. Tolstikhin & Tolstikhina (1935), Barkhatova (1941), Lukoyanov (1941), Devyatova (1961), Evzerov *et al.* (1976) Ekman *et al.* (1974) and Ekman & Iljin (1995) investigated the Onega River basin. The Severnaya Dvina and Vaga basins were studied by Likharev (1933), Zhuze & Poretsky (1937), Pokrovskaya (1937), Lavrova (1937), Legkova & Schukin (1972), Pleshivtseva (1977), Atlasov *et al.* (1978), Ostanin *et al.* (1979), Smirnova (1991), Devyatova & Punning (1976), Devyatova *et al* (1981), Devyatova (1982), Liivrand (1981), Lavrushin & Spiridonova (1995) and Larsen *et al.* (1999b). The Mezen and Pyoza rivers areas were investigated by Korchagin (1937), Malakhov (1934, 1939, 1940), Kalberg (1968), Zekkel (1939), Devyatova & Loseva (1964), Lavrov (1968, 1973, 1974, 1975, 1977) and Filippov & Borodai (1987). The evidence from the Quaternary superficial deposits and the position of different generations of marginal formations recognized by the early 1930s were generalised and published by Yakovlev (1932), Yaunputnin (1934), Gerasimov & Markov (1939) and Sokolov (1946). Yakovlev (1956), Apukhtin & Krasnov (1967), Devyatova (1969), Chebotareva & Makarycheva (1974), Chebotareva (1977), Faustova & Velichko (1992), Grossvald (1980) and Velichko (1997) presented regional summary papers, including the latest information, while Apukhtin & Krasnov (1967), Krasnov *et al.* (1974), Ganeshin *et al.* (1980) and Sergeev *et al.* (1981) contributed to maps showing the Quaternary geology and geomorphology of the USSR, Eurasia and Northwest of the USSR some of which formed part of an international map series under the auspices of INQUA.

Setting

The Arkhangelsk region, in the northern part of the Russian Plain, covers an area of 587 000 km^2, including the polar islands and Nenenian district (Fig. 1A, 2A). Tundra landscapes dominate the subarctic ocean coast grade southwards into north- and middle-taiga forests. According to *The Geology of the USSR* (1963), the north-western part of the region occupies the eastern Fennoscandian Shield, that is composed of highly metamorphosed Precambrian rocks that range up to 120-150 m. a.s.l. On the Vetreny

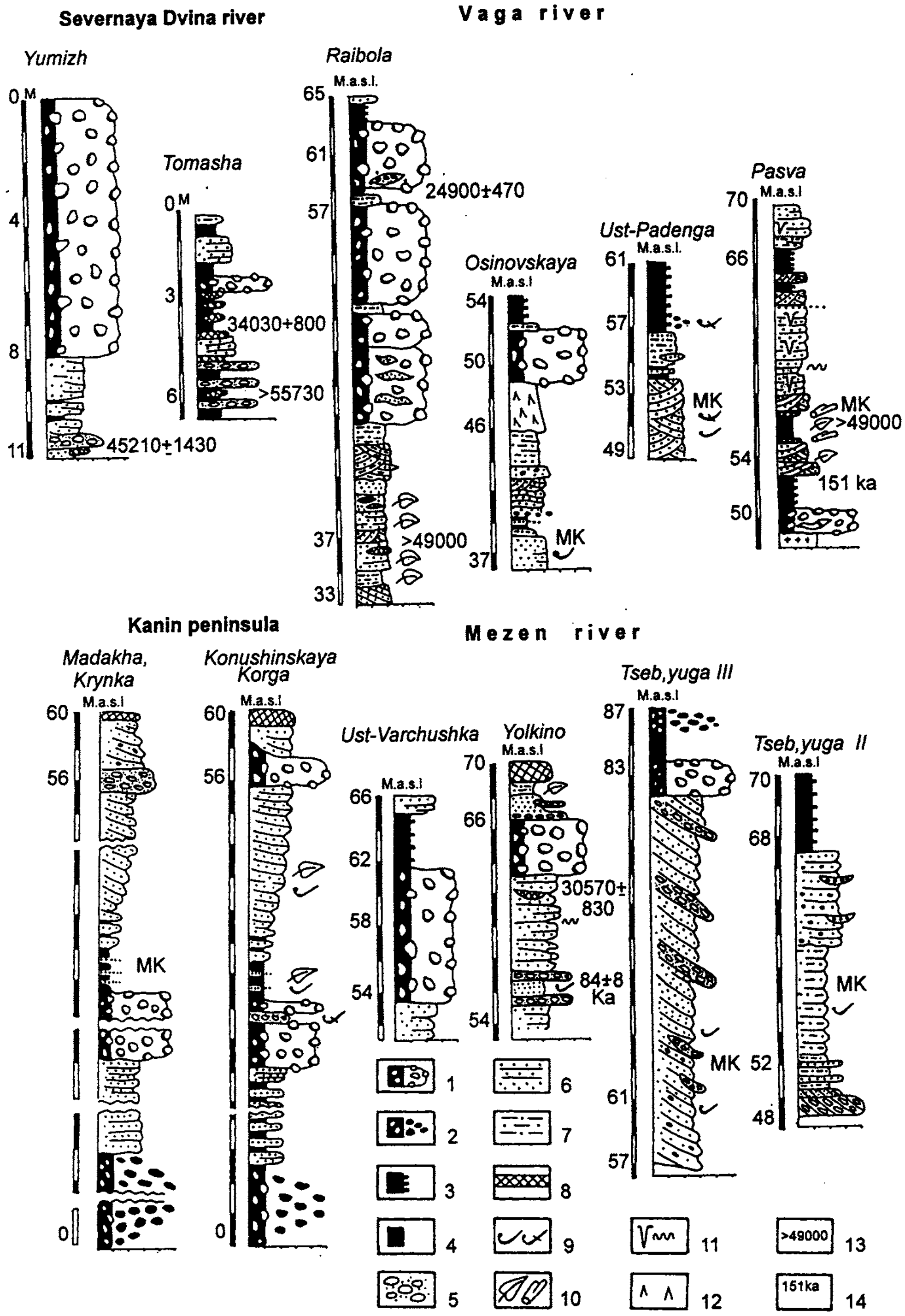


Fig. 5. Key sections (compiled by I. Demidov from the following data: Yumizh and Tomasha - by Arslanov et al. 1984, Krynka, Madakha, Konyshinskaya Korga- by Spiridonov & Yakovleva ,1961, Yolkino - Devyatova, Loseva,1964, Molodkov,1989, Lavrov,1977, Tseb,yuga, Ust-Varchushka - Devyatova, Loseva, 1964, Raibola, Osinovskaya, Ust-Padenga- by Devyatova,1982, Devyatova et al, 1976, 1981):

1-till,

2-mud with clasts (till?),

3-laminated clay,

4-massive clay,

5- gravel,

6- sand,

7-sandy loam, loam,

8-peat,

9- shells and shell fragments,

10- plant remains and twigs,

11- ice wedge and cryoturbations,

12 - colluvial deposits,

13 - ^{14}C age,

14 - TL and OSR age.

MK- Mikulinian sediments.

Poyas (Wind Belt) Ridge, altitudes may reach as high as 320 m. The Timan Ridge is formed of Proterozoic and Palaeozoic magmatic and metamorphic rocks and located in the northeastern part of the region. The maximum altitude here is 250-400 m. The larger part of the region that lies between the Fennoscandian Shield and the Timan Ridge is a rugged, denudation plain consisting of Palaeozoic and, less commonly, Mesozoic sediments (Fig. 1A). Extensive depressions (0-100 m a.s.l.) and large water-divide plateaux (100-250 m a.s.l.) dominate the bedrock relief, just as the valleys of major northward-flowing rivers, such as Severnaya Dvina, Onega and Mezen, are confined to depressions in the present topography.

The Quaternary sequence is dominated by glacigenic sediments deposited mainly during the Moscovian and Valdaian glaciations (Fig. 5), and separated by interglacial Mikulinian and interstadial Middle Valdaian sediments (Apukhtin & Krasnov, 1967; Devyatova, 1969). Mikulinian marine deposits, which are widespread in the region, reach heights of up to 70 m a.s.l. They provide a solid marker bed in stratigraphic sequences. In the southern Arkhangelsk region, drill holes have penetrated strata formed during older, pre-Moscovian glaciations in the River Ustya area (Kotova *et al.* 1977).

Glacial maxima: Early-Middle Valdaian

Scandinavian Ice Sheet

The presence of a Scandinavian Ice Sheet in the Arkhangelsk region and in adjacent areas of Karelia and Vologda during the Early or Middle Valdaian is not supported by geological and geochronological evidence. Only one till bed is found overlying the Mikulinian sediments in Severnaya Dvina (Devyatova, 1982; Atlasov *et al.*, 1978; Ostanin *et al.*, 1979; Arslanov *et al.*, 1984; Larsen *et al.*, 1999b) and the Onega river basins (Barkhatova, 1941; Devyatova, 1961). A few boreholes have penetrated two diamict beds upon the Mikulinian sediments in the lower Vaga area. They are, however, situated inside a terminal belt of the Vepsovo stage (Figs 1B, 2B-4), and may represent readvance till beds of the Late Valdaian ice front (Atlasov *et al.*, 1978; Ostanin *et al.*, 1979). According to Devyatova (1961, 1982), the Mikulinian marine deposits are conformably overlain by Early Valdai lacustrine sediments in boreholes at Shegovary on the lower Vaga River, about 30 km north of Shenkursk (Fig. 6). The pollen analyses by Devyatova (1961, 1982) indicate that Early Valdaian glaciolacustrine laminated clays were deposited in the River Pinega area. However, their age and possible relation to a Scandinavian or Barents-Kara Sea ice sheet is not clearly understood.

It has been suggested (Apukhtin & Krasnov, 1967; Legkova, 1967) that that the Scandinavian Ice Sheet was larger during the Early Valdaian than in Late Valdaian and that it extended eastwards to the rivers Mezen and Pyoza and southeast to the Sukhona River (Fig. 2). These reconstructions were based on geomorphological observations alone and by delineating areas of hummocky moraine landscape and terraces of glaciolacustrine basins in river valleys. A critical examination of Devyatova's (1972) and Lukashov's (1982) evidence of the presence of a till unit between the Mikulinian marine strata and the Middle Valdaian lacustrine sediments in the Petrozavodsk borehole procludes this possibility. To sum up, no sections or boreholes containing Early Valdaian till of Scandinavian origin are known from northwest Russia. Thus, many authors have interpreted end moraines of the Moscovian glaciation as ice-marginal formations of Late Valdaian age (Apukhtin & Krasnov, 1967; Legkova, 1967).

Kara-Barents ice sheet and Timan ice cap

The stratigraphical position of tills in relation to interglacial strata and the age of inter-till deposits interbedded with till sequences are important for determination of LGM (Last Glacial Maximum) position. However, the last ice-sheet maximum position and the Pleistocene palaeogeography of the Mezen-Pyoza River area are still not adequately investigated. According to Malakhov (1934) and Rudovitz (1947), deposits formed during two marine transgressions, separated by Moscow Glaciation till have been recognised in the area (Spiridonov & Yakovleva, 1961; Devyatova & Loseva, 1964; Legkova, 1967). Also, in a section near the village of Yolkino on the River Pyoza, sandy-gravelly marine sediments with shells were interpreted as representing the maximum shoreline of the pre-Late Moscovian Northern transgression (Odintsovo interglacial) (Fig. 5). Further up the River Pyoza, Odintsovo lacustrine and fluvial deposits underlie Moscovian till, whereas Mikulinian marine sediments are common downstream from Yolkino. Bylinsky (1980), who has revised his earlier palaeogeographic concepts of the Mezen basin (Bylinsky, 1962), believes that the sediments were deposited during two glaciations (Moscovian and Valdaian). He also concludes that they were separated by a two-phase Mikulinian transgression. A geochronological study of the Mikulinian key sections at Bychie and Zaton, together with the 'Odintsovo' section Yolkino using electron spin resonance (ESR), support deposition during the Upper Pleisticene, some 100-80 ka ago (Molodkov, 1989) (Fig. 2B-3). Mikulinian marine sediments, identified by their fauna and flora, are present in the banks of the rivers Irasa and Tsebyuga (Devyatova & Loseva, 1964) and proved by a borehole in the River Ona valley (Kalberg, 1968). These sediments are overlain by till deposits in the upper Tsebyuga River valley and locally by glaciolacustrine clay in its middle reaches (Fig. 5).

Three till units, separated by interglacial sediments, are known from the northern and western Kanin Peninsula coasts. The upper till contains boulders derived from the Kola Peninsula, whereas the lower and the middle till contain clasts from the Kara Sea area (Fig. 2B-3). On the eastern Kanin Peninsula, the boulders are only of Kara Sea provenance (Ramsay, 1911; Gorbatsky, 1932; Spiridonov & Yakovleva, 1961).

North of the River Pyoza, a topographically-distinct marginal moraine belt extends roughly from west to east (Fig. 2B). In the Upper Pyoza River, this belt bends northwards and continues across Lakes Varshskie and along the western slope of Timan. Furthermore, a few minor end moraine ridges are situated north of this terminal belt (Korchagin, 1937; Lavrov, 1991). Hilly, morainic topography in the Mezen-Pyoza interfluve occupies large areas in the Upper Tsema River, along the River Ona, and in the Middle Kyma River valley (Korchagin, 1937; Malakhov, 1939, 1940; Devyatova & Loseva, 1964). Fresh glacial landscape is present on the left bank of Mezen at Yuroma village. In addition, a wide, hilly morainic zone extends north-south from the Pyoza River mouth to Yezhuga, a tributary of Pinega River (Lavrov, 1991). These areas, with dense hummocky moraines and the general lack of stratigraphical information, have provided the source for many suggestions on the position of the last glaciation ice maximum limit (Figs 1B, 2B).

Based on this evidence data from the Mezen and Pyoza rivers and on the results of comprehensive litho- and biostratigraphical studies supplemented by a modern geochronology, a revised regional stratigraphy has developed in the past few years. The marine sediments in the Yolkino section are now interpreted as of Mikulinian interglacial age and the overlying diamict is assigned to the last glaciation. Therefore an older ^{14}C date from this site must be regarded at infinite (Fig. 5). Clast fabric studies and the petrography of clasts in tills overlying the Mikulinian sediments along the River Pyoza have shown, that the ice was moving from the east and south-east by the end of the Early Valdaian and from the north and north-east at the beginning of the Middle Valdaian (Houmark-Nielsen *et al.*, 2001, Kjær *et al.*, 2001) (Fig. 3). The two till units, separated by glaciofluvial sediments, occur above Mikulinian deposits in a section near the Viryuga River confluence with the lower Pyoza River. Thus, two separate ice sheets deposited the tills during the Early and Middle Valdaian and it is suggested here that the older ice sheet possibly originated on the Timan Ridge and the younger with more confidence originated in the Barents-Kara Sea.

Three till units, separated by marine and glaciolacustrine sediments, have been recognised in a section on Cape Tolstik on the southern shore of Mezen bay (Fig. 2B). Here clast orientation and the petrographic composition in the lower (Early Valdaian) till, which is enriched by Mikulinian marine shells, indicate ice movement from the east and southeast. Thus, the preliminary results suggest that during the Early Valdaian an ice sheet, possibly from the Timan Ridge, extended westwards over large parts of the northern half of the Arkhangelsk region. The position of the ice margin and the direction of ice movement along the Pyoza-Mezen water divide during the Early Valdaian is unclear, but a tentative position of the LGM is sketched in Fig. 2B-1). Its southern boundary probably stretched along the topographically-distinct hummocky land in the Upper Bludnaya River catchment, intersects the River Kyma about 20 km northwards from its mouth, and extends westwards along the River Ona, where a borehole encountered Mikulinian marine sediments underlying the till (Kalberg, 1968) (Fig. 2B). The boundary might continue westward across the Upper Tsebyuga River, where deposits formed during the Boreal Transgression (Mikulinian) are overlain by till (Devyatova & Loseva, 1964), and intersects the Mezen River near Yuroma village in a hilly-morainic zone. In the Upper Kimzha River catchment (Fig 2B), fragments of marginal formations are truncated by younger Scandinavian Ice Sheet end moraines. On the Ona-Mezen interfluve, near Tsenogora, the ice probably dammed the River Mezen. The terraces of the ice-dammed lake in the Upper Mezen River lie at around 145 m a.s.l., and terraces in the Middle Mezen and Vashka River valley are 15 m lower (Lavrov, 1968, 1975). However, there is no reliable evidence of their age. The southern limit of the Early Valdaian glaciation was probably controlled by Mezen-Vashka-Pinega water divide where the ground reaches to around 250 m a.s.l.

The early Middle Valdaian Barents-Kara Sea ice sheet must have extended westwards at least as far as the Kuloi Plateau, which is over 100 m. a.s.l. high. Otherwise, ice-dammed lakes situated in front of the Barents-Kara Sea ice sheet, and which covered extensive areas in rivers Mezen and Pyoza basins, would have lower run-off thresholds along the Mezen and Kuloi valleys. The Barents-Kara ice sheet probably also blocked the White Sea strait.

Considering the mode of occurrence of Middle Valdai deposits in the Severnaya Dvina basin, Devyatova (1982) assumes that the base level was at least 10 m higher during the Middle Valdaian mainly because the White Sea was isolated from the Sea by glaciation. It is known that the Middle Valdaian Barents-Kara Sea ice sheet covered at least the southern part of Mezen Bay and the lower reaches of the Pyoza River. Here till of Kara Sea provenance rests on Mikulinian and Early Valdai deposits, the ages of interglacial sediments have been determined using ESR and OSL (Molodkov, 1989; Houmark-Nielsen *et al.*, 2001). Maine, glaciolacustrine and fluvial sediments overlying and underlying the Kara till along the River Pyoza and along the Mezen Bay coast give luminescence ages of 10-18 ka and 44 - 67 ka respectively. The huge terminal moraine belt consisting of the Loban-Viryuga, Pyoza and Varshsky end-moraine ridges extends along the Pyoza River and the western slope of the Timan ridge, and marks the maximal southerly advance of Kara-Barents ice sheet (Fig. 2B-2). Several end-moraine ridges located on the Pyoza – Chyoshskaya Bay watershed record recessional stages of the Barents-Kara Sea ice sheet. Glaciolacustrine sandy and clayey sediments, overlying the Barents-Kara Sea ice sheet till are widespread along the Mezen and Chyoshskay bays.

Glacial maxima: Late Valdaian

There is no record of Barents-Kara Sea ice sheets on the Russian mainland in the Late Valdaian (Svendsen *et al.*, 1999, Houmark-Nielsen *et al.*, 2001; Kjær *et al.*, 2001). However, new information on the ages of the last, Scandinavian Ice Sheet expansion and decay in northwestern Russia, is now available (Astakhov *et al.*, 1999; Mangerud *et al.*, 1999; Larsen *et al.*, 1999a). Consistent ages for the last ice sheet maximum have been reported in Russia from only three areas; the Zapadnaya Dvina River basin near the Russian-Belorussian border (^{14}C 17-18 ka BP: Arslanov *et al.*, 1971), near Lake Kubenskoe in the Vologda region (^{14}C 21 ka BP: Arslanov *et al.*, 1970) and in the Arkhangelsk region, where the River Vaga join the River Padenga (17 ka BP, Larsen *et al.*, 1999b). An outline of the Late Valdaian evolution of the Scandinavian Ice Sheet for the Arkhangelsk region is given below.

Scandinavian Ice Sheet

In the Arkhangelsk region, the last, Scandinavian Ice Sheet formed distinct lobes that occupied pre-Valdaian topographic lows (Aseev, 1974; Chebotareva, 1977). The western part of the region was occupied by the Karelian lobe (I), the central part by the Belomorian lobe (II), and the northeastern part by the Kuloi-Mezen lobe (III) (Aseev, 1974; Chebotereva, 1977; Figs 1A, 2A). The Belomorian ice moved along the Severnaya Dvina lowland with altitudes about 80 m a.s.l. and separates into the Dvina and Pinega tongues. Westwards, it was separated from the Karelian lobe by the Vetreny Poyas Ridge (320 m. a.s.l.) and the Melovian tectonic high (266 m. a.s.l.). Eastwards, it was separated from Kuloi-Mezen lobe by the Kuloi Plateau and the Pinega - Vashka watershed that reach 210 and 224 m.

Key elements in determining the maximum position of the last glaciation are the presence or absence of till overlying Mikulinian or Middle Valdaian sediments and the association of geomorphologically distinct landscape types (Fig. 4, Fig. 2B-3). An example of this is seen from the successive change from a landscape glaciated during the Valdaian, to a periglacial zone, and an area characterised by sediments deposited during the Moscovian glaciation.

Karelian ice lobe (I) - Onega-Mosha rivers glacier tongue

Although, the maximum ice-front position is rather well studied in the Severnaya Dvina basin (Atlasov *et al.,* 1978; Arslanov et al, 1984; Devyatova, 1982; Larsen *et al.,* 1999b) and around Lake Kubenskoe in the western part of the Vologda district (Arslanov *et al.,* 1970; Gey & Malakhovsky, 1998; Gey *et al.,* 2000; Lunkka *et al.,* 2001) there is a need to revise the interpretations between these two areas.

West of the Vaga River, the maximum ice front position was chiefly determined through geomorphological evidence. Many researchers, primarily those who supported the existence of an extensive Early Valdaian Scandinavian Ice Sheet, have drawn the maximum position approximately N-S along the western flank of the Vaga depression, from the Melovian upland to the upper Vaga River, where it turned east towards Totma. Further to the west, it has been fixed along the left bank of the Sukhona River as far as the Vologda area (Legkova, 1967; Krasnov, 1974) (Fig. 1B). The present authors consider that the ice in the Onega-Vaga watershed bordered not only the Melovian upland (266 m a.s.l.), but also the equally high Nyandoma upland, 251m a.s.l. (Figs 1A, 2A, 2.B-4). Well-defined ice-marginal landscape formed by alternation of end-moraine ridges and glaciofluvial landforms near the villages of Nyandoma, Voloshka and Konosha was mentioned as early as the 1930s by Yaunputnin (1934); Gerasimov & Markov (1939) and Tolstikhin & Tolstikhina (1935). Some researchers assigned these marginal formations to a maximum stage during the last Valdaian glaciation (Gerasimov & Markov, 1939; Devyatova, 1961). Others were more specifical, however, assigning these features to a maximum during the Late Valdaian glaciation (Apukhtin & Krasnov, 1967) or to stadial moraines (Chebotareva, 1977) (Fig. 1B). Borings through these marginal deposits near Nyandoma, Voloshka and Konosha revealed till interbedded with sand and gravel-pebble beds. Devyatova (1961) interpreted this as an indication of the highly unstable environments along the ice margin. In the Nyandoma upland, the Valdaian deposits are 30-40 m thick, whereas the marginal landforms on the western flank of the southern Vaga depression near the Vel River and southwards are topographically indistinct (Atlasov et al, 1978, Fig. 6). Also of importance is the thick ice-marginal belt associated with deglaciation that occurred during the Vepsian phase, which lies 70 km northwest of the Nyandoma upland (Figs 1B, 2B).

Mikulinian marine sediments are widespread in the Onega River basin (Devyatova, 1961; Apukhtin & Krasnov, 1967; Evzerov *et al.,* 1976). Two sections of Mikulinian marine deposits are known near the Late Valdai maximum ice-front position in the River Mosha depression between the Nyandoma and Melovian uplands (Fig. 2B-4). Here, shell-rich sands containing *Astarte compressa, Gorbulla gibba, Saxicava arctica, Nassa reticulata* were exposed under a 7 m thick till in the Kanaksha River, a tributary to the Mosha, between Lake Voiozero and Lake Moshozero (Lukoyanov, 1941). A similar sequence is present in the left bank of the Mosha near the Iksa confluence. There sand, which contains marine fauna, is overlain by 2 m thick horizontally laminated clays. Apparently till is absent, although it may have been removed. Apukhtin & Krasnov (1967) and Legkova (1967) suggested that these deposits were formed in the younger Belomorian transgression during the Middle Valdaian. However, the present authors interpret them as Mikulinian in age because they contain a distinct boreal mollusc fauna.

Accordingly, there is no stratigraphical nor geomorphological evidence that clearly supports an ice-front position south of Velsk town, in the upper Vaga River valley, and on the left bank of the Sukhona River (Figs 1, 2, 4). Considering the ice-front limits in the Vaga valley and Lake Kubenskoye areas, the available data on bedrock relief and the occurrence of 'fresh' marginal deposits near Nyandoma, Voloshka and Konosha, the maximum ice-front position can be fairly reliably drawn through these villages from the Vaga River and the Melovian upland to Lake Kubenskoe (Fig. 2B-4).

Belomorian ice lobe (II) - Dvina glacier tongue

In the Vaga River (left tributary of Severnaya Dvina River) basin, most investigators have drawn the Valdaian glacial limit in a hilly-morainic zone between the villages of Osinovskaya and Ust-Padenga (Devyatova, 1961, 1982; Krasnov, 1974; Figs 1B, 2B, 5 and 6). At the base of a sequence on the left bank of the River Vaga, 1 km upstream of Osinovskaya, shell-bearing marine Mikulinian sand is overlain by Early Valdaian marine and lacustrine deposits (Fig. 5; Devyatova, 1982). Resting on these sediments is a 3

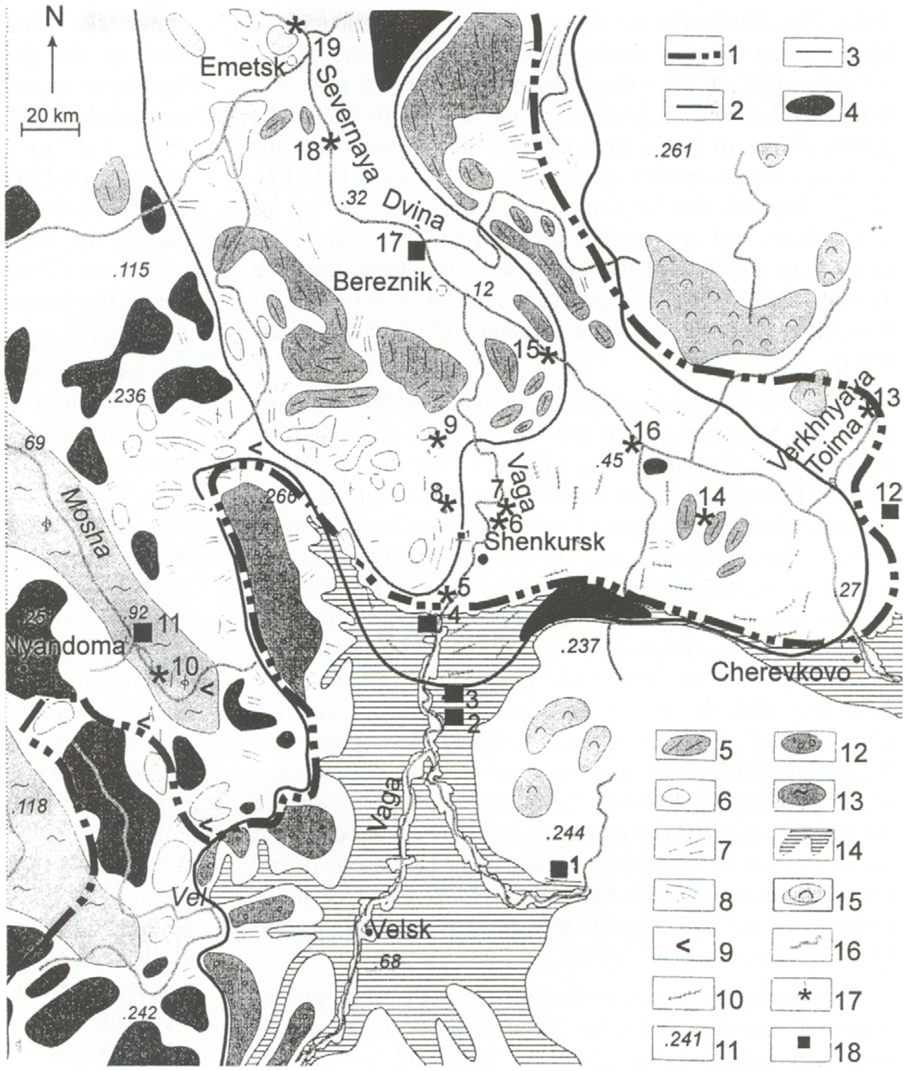


Fig. 6. Scheme of main terminal belts on the Onega-Vaga waterdivide and in the Vaga and Severnaya Dvina lowlands by Ostanin et al. (1979), Atlasov et al. (1978), with remarks. Late Weichselian glacial limit (Bl-Ed stage): 1 – by present authors, 2 - by Atlasov et al. (1978), Ostanin et al. (1979), 3 - glacial limit of the Vepsovian Phase by Atlasov et al. (!978), & Ostanin et el.(1979), 4 - hummock moraines, 5 - hummock-ridge moraines, 6 - kame fields , 7 - eskers, 8 - subglacial grooves (rills, ravines), 9 - valley train, 10 - outwash remains of hummock-ridge moraine in Vaga and Severnaya Dvina lowlands, 11 - altitude a.s.l. 12 - areas of hummock-sink hole water-glacial and lake-glacial relief in periglacial zone of Weichselian glacial limit, 13 - glacial depressions along rivers Mosha and Voloshka are covered with lake-glacial and lacustrine plains 14 - ice-dammed lakes (120-130m a.s.l.), 15 - hummocky topography of the Moscow glaciation, 16 - rivers, 17 - sections with Mikulino, Early and Middle Weichselian sediments overlain by till, 18 - sections with Mikulino, Early and Middle Weichselian sediments unburied by till.

*Numbers of key sections (*with C14 or TL data):*

1 - Ustya (boring),
2 - Pasva,*
*3 - Koleshka**
4 - Ust-Padenga,
5 - Osinovskaya,
6 - Raibola,*
7 - Smotrakovka,*
8 - Led,
9 - Syuma,
10 - Voiozero,
11 - Iksa,
12 - Erga,*
13 - Tomasha,*
14 - Yumizh,*
15 - Konovalovskaya,
16 - Boltinskaya,
17 - Krasnaya Gorka,
18 - Lipovik,
19 - Chelmokhta.*

m thick Late Valdaian till bed. The boulders in this till are mainly of Karelian and Kola origin i.e. granites, gneisses and quartzites. The till is overlain by varved clay. Three kilometres south, in a section near Ust-Padenga, similar varved clay rests on periglacial sand, which, in turn rests on a Middle Valdaian silt bed. At the base of the sequence, a Mikulinian marine sand bed with shell fragments and intact shells of *Macoma baltica* and *M. calcarea*. Further south up the River Vaga, in the Pasva and Koleshka sections Mikulinian deposits are only overlain by varved clay but no Valdaian till (Fig. 1, 2, 5 and 6).

By contrast, north of Osinovskaya, down the River Vaga, in the Shenkursk, Raibola, Smotrakovka and Shagovara sections and boreholes, Mikulinian and Middle Valdaian deposits are overlain by till up to 8 m thick (Devyatova, 1982; Larsen *et al.,* 1999b) (Fig. 4). Till-covered Mikulinian sediments with typical fauna are also exposed along the banks of the rivers Led, Tarnya and Syuma, the left tributaries of River Vaga (Likharev, 1933; Devyatova, 1982; Smirnova, 1991) (Figs 2 and 5).

On the Severnaya Dvina, the Valdaian glacial limit is drawn between the villages of Verkhnyaya Toima and Cherevkovo (Figs 1, 2 and 6). Here, till resting on Middle Valdaian lacustrine deposits on the rivers Yumizh and Tomasha, is 8 and 0.4 m thick (Arslanov *et al.,* 1984) (Fig. 5). North of the Verkhnyaya Toima River mouth as far as Arkhangelsk, Mikulinian and Early to Middle Valdaian deposits are overlain by till in all sections (Lavrova, 1937; Smirnova, 1981, Devyatova, 1982; Larsen et al, 1999b). Outside ice-marginal formations, along the rivers Yula and Erga, Late Valdaian glaciolacustrine deposits rest on Middle Valdaian lacustrine sediments (Arslanov *et al.*

1984; Fig. 2B-3). On the River Yumizh, a left tributary of Dvina, in an outcrop located 18.4 km from its mouth and 3.2 km south of the village Nikolayevskoye, a peat lens from sand beneath till gives a ^{14}C age of 45 210±1430 (LU-1206). A lens of gyttja from deposits underlying till in the Tomasha River section is of 34030±810 years BP (LU-1257). Beyond the maximum ice-front position, in the Yerga River and in a section at the River Yula, peat layers underlying Late Valdaian lacustrine clay were dated at 43440 ±1460 (LU-1053) and 45000 ±1150 years BP (LU-1262). Here there is no Upper Valdaian till (Arslanov *et al.*, 1984).

Where absolute age estimates are obtained they all point to a Late Valdaian age of the last glacial maximum. For instance, the absolute dating (TL and ^{14}C) from the beds situated beneath Valdaian varved clay in the Koleshka and Pasva sections in the River Vaga yield ages from 31 to 62 ka BP (Devyatova *et al.*, 1976, 1981), and ages for sediments underlying till in river sections on the Yumizh and Tomasha (tributaries of the Dvina River) range from 34 to 45 ka BP (Arslanov *et al.*, 1984) (Fig. 2B-3). A radiocarbon date of 24900 ±470 BP (Vib-40) was obtained from the Raibola section, 10 km north of Shenkursk (Atlasov *et al.*, 1978, Ostanin *et al.*, 1979). New geochronological evidence from key sections on the rivers Vaga (Pasva, Koleshka, Raibola, Smotrakovka) and Severnaya Dvina (Bobrovo, Trepuzovo) from deposits above and below the till or proglacial varved clay have shown that glacial maximum in the Severnaya Dvina basin occurred about 17 ka BP and deglaciation may have started close to 15 ka BP (Larsen *et al.*, 1999b).

The area glaciated in Valdaian time is of 'fresh' glacial form with morainic hills, 10- 20 m high and up to 400 m wide and kames some 25-50 m high and 1-4 km in diameter. Subglacially-formed gullies are up to 5 km long (Atlasov *et al.*, 1978, Arslanov *et al.*, 1984). The maximum ice front position in the Vaga River valley and on the Vaga-Onega watershed has a well-defined festooned pattern (Figs 2 and 6). The Dvina ice tongue reached the Melovian upland (266 m a.s.l.) in the east and the Onega-Mosha tongue in the west, and occupied bedrock depressions near the Mosha River. The relative altitude of the Melovian upland above the surrounding plains is 160 m. In the western part of the Vaga depression a zone of glaciofluvial and glaciolacustrine sand-gravel and less abundant clay deposits *c.* 20 km wide, was formed distal to the ice-front position (Fig. 6). The topography in this zone is characterised by valley outwash trains that alternate with glaciolacustrine plains dissected by fluvial erosion. These sediments rest on Moskovian till or occasionally on Mikulinian deposits (Pasva and Koleshka sections) (Figs 5 and 6). Outside this zone of proglacial deposits lies a territory composed solely of Moscovian till with a characteristic relief subdued by erosion.

In the Vaga and Severnaya Dvina river catchments, the terminal formations of the Dvina tongue are rather indistinct. The end moraines are partially eroded and buried under lake sediments, deposited up to120-130 m. a.s.l.in front of the glacier. Erosional remnants of ice-marginal landforms are seen in aerial photographs as ridges and hills separated by sinkholes (Atlasov *et al.*, 1978, Ostanin *et al.*, 1979; Fig. 6). Terraces in this basin were formed at altitudes of 130 and 110 m a.s.l. on the distal side of the Severnaya Dvina ice-marginal formation. In the southern part of the Vaga basin, the absolute altitudes of terraces vary from 130 to 75 m, indicating a drop in the water level during the decay of the ice tongue.

In the Dvina and Vychegda river valleys, the position of two terminal belts has been mapped (Arslanov *et al.*, 1984). The outermost glacier position is represented in the lower levels of the Severnaya Dvina tributaries of Yumizh, Soiga, Verkhnyaya and Nizhnyaya Toima at altitudes of 60-90 m by a system of end-moraine ridges in the glaciolacustrine plain. In the central part of the Severnaya Dvina depression, end-moraine ridges form a series of convex arcs towards the east, and near the flanks of the depression, they are elongate resembling lateral moraines (Fig. 6). The ridges are 3-12 km long, 0.5 - 2 km wide and 5-10 m above the surroundings. On the Dvina-Pinega interfluve, the external terminal belt stretches NW and approximately N-S at 140-170 m, where they are 1-6 km long and 0.2-1.0 km wide. Inside the maximum position, a terminal belt formed by moraine and sand-gravel ridges in the Pukshenga and Pokshenga River basins and in the Severnaya Dvina-Pinega watershed is recognised at 50-80 m a.s.l. This represents a younger stage of deglaciation (Vepsian?) (Atlasov *et al.*, 1978). In the Vaga basin and on the left bank of Dvina, this stage occur as end moraines, radial and marginal eskers and kames towering 10 - 25 m above surrounding glacio-lacustrine plain. This terminal belt extends northwards as far as Yemetsk, where it merges with marginal formations, studied by Legkova & Schukin (1972). Two Valdaian till beds were revealed here by drilling in the basins of the Mekhrenga, Puya and other rivers, inside this possible Vepsian deglaciation position (Legkova, 1967; Atlasov *et al.*, 1978; Ostanin *et al.*, 1979).

Petrographic study of the Valdaian and Moscovian tills indicate some differences in their composition and supports the Late Valdaian maximum position determined earlier. For example, the Valdaian till typically contains a high percentage of Scandinavian crystalline rock clasts (50-95%) i.e. granites, gneisses, quartzites and 12-45% of local sedimentary rock fragments in the Vaga River valley. In the Moscovian tills, local Palaeozoic limestones, sandstones and dolomites represent 65-96% of the total whereas Scandinavian boulders represent 11-35% (Ostanin *et al.*, 1979).

Belomorian ice lobe (II) -Pinega glacier tongue

The maximal position of the Pinega tongue has still not been adequately studied. Most investigators believe that the Pinega tongue reached the Pinega-Dvina watershed

(Pokshenga Massif) marked by a zone of hummocky relief (Figs 1A, B, 2B). Pre-existing evidence has allowed data its boundary to be extended along the upper part of Berezovitsa River (a left tributary of the Okhtoma River) and continued north of Karpogory. This reconstruction is chiefly based on the fact that Mikulinian marine deposits are not overlain by till in both the upper and middle Beryozovitsa River valley area (Apukhtin & Krasnov, 1967; Chebotareva, 1977; personal communication T.A. Kuznetsova in: Chebotareva, 1977). At a site 20 km west of Karpogory, a 2 m thick Mikulino marine sand, gravel and shell layers unit was found at the base of the sequence (Devyatova, 1982) that was overlain by a periglacial 0.5 m thick sand interbedded with gravel and small boulders (possibly a till). According to the authors' observations, Mikulinian marine sediments, described by Filippov & Borodai (1987) from the River Ezhuga, 50 km north-eastward of Karpogory, are overlain by Scandinavian sandy outwashed till about 1 m thick. In this area the Quaternary sequence is only 1-5 m thick and the ice-dammed lakes in Vashka, Pinega and Severnaya Dvina valleys located at 130 m. (Lavrov, 1968, 1975) should intrude to the area. Thus, thin till might have been eroded both in the Karpogory and in the Ezhuga River areas.

Preliminary luminescence dating by the present authors shows that sand underlying a 1-2m thick till unit and a 1-4 m thick glaciolacustrine unit in the Verkola section and that at Mezhdurechensky was deposited between 100 –200 ka BP. This evidence leads to the assumption that the southern boundary of the Pinega ice tongue reached Verkola and probably overrode the Ezhuga River basin. At that time the ice front extended northwards as far as the watershed of the River Kimzha, where it merged with marginal formations of the Kuloi-Mezen ice lobe (Figs 1 and 2). Thus, the Pinega ice tongue was controlled by the Pokshenga Massif to the west, where ^{14}C-dated Middle Valdai deposits are not overlain by till on the River Yula (Arslanov *et al.*, 1984), and by the Pinega-Vashka watershed (250 m a.s.l) to the east.

Kuloi-Mezen ice lobe (III)

The Kuloi Plateau probably acted as a strong barrier to the flow of Scandinavian Ice Sheet into the Mezen basin (Fig. 1A, 2A). The thinness of the ice sheet is indicated by large areas practically devoid of a Quaternary sediment on the Kuloi Plateau. Scandinavian rock boulders are also encountered very seldom on the banks of the rivers Mezen and Vashka. The authors' data suggest that Mikulinian marine sand in the Olema section on the River Vashka are not overlain by till. Thus, there is no positive evidence of any Scandinavian Late Valdaian till along Mezen River. Consequently there is no stratigraphical evidence for the movement of Scandinavian ice into the Pyoza-Mezen watershed and further south along the Vashka River valley as far as Chuprovo and farther east along the Mezen across the Kyma River confluence, as some researchers have assumed (Krasnov, 1974; Lavrov, 1991) (Fig. 1B).

The zone of marginal formations, which extends approximately N-S across the central part of the Kuloi Plateau, was until recently regarded as the Late Valdai glaciation maximum limit (Legkova, 1967; Legkova & Schukin, 1972; Krasnov 1974; Figs 1B, 2B). However, the writers postulate that these formations probably formed in the younger Vepsian stage, which is represented by topographically-distinct marginal landforms in the Arkhangelsk and Vologda regions. The Valdaian glaciation limit was erroneously drawn along the tectonic scarp which delimits the Kuloi Plateau in the east (Yakovlev, 1956) (Fig. 1B).

Late Valdaian tills are absent along the Pyoza River valley, but practically all the Pyoza sections are overlain by thick, Late Valdaian periglacial fluvial sand beds with traces of cryogenesis (Fig. 3). Eleven OSL dates from these sands gave ages between 18 and 10 ka (Houmark-Nielsen *et al.*, 2001). A ^{14}C date from a thin peat unit in these sands gave an age of 10 150 ±100 BP (IU-556A) (Chebotareva, 1977). The occurrence of these sands up to 80 m a.s.l. (i.e. 18 m higher than modern water level in the Pyoza River) indicates that the Scandinavian ice dammed the Pyoza River near its mouth or somewhat to the north in the Mezen bay during Late Valdaian time (Fig. 3).

Boulders of Scandinavian origin (mainly granites, basic rocks and red sandstones) are widespread on the western Kanin coast. They occur in clayey diamicton and in probably glaciofluvial sediments capping sections near Cape Konushinskaya Korga and on the Tarkhanov River at 25-30 m a.s.l. Following the stratigraphical concept of Ramsay (1911) they are interpreted as 'upper till'. 'Fresh' glaciofluvial ridges up to 18 m high and with very clearly defined slopes were also found in the Shomokhovskie Sopki (Hills) area near Cape Kronushinskaya Korga. However, no Scandinavian boulders were found on the beach or in the sections near the mouth of the River Oiva on the eastern shore of Kanin (Fig. 2B).

Considering these data, it is suggested here that the maximum position of the Scandinavian ice-sheet advocated by some researchers is fairly accurate (Ramsay, 1911; Rudovits, 1947; Yakovlev, 1932; Aseev, 1974). The ice margin extended approximately N-S from the north shore of the Kanin Peninsula across the hilly-morainic landscape of the Shomokhovskie Sopki in the Konushinskaya Korga area and further south across a hummocky zone near the River Nes (Devyatova & Loseva, 1964), towards the lower part of the Mezen River. The margin then presumably intersected the Mezen River near the Pyoza confluence and extended along the Kimzha River, where it formed a wide zone of morainic hills (Lavrov, 1991). This is connected with the marginal formations of the Pinega ice tongue on the River Yezhuga (a tributary of the Pinega) and River Kimzha interfluve. Alternatively, the ice margin extended from the western shore of the Kanin Peninsula, from the hummocky terrain near Konyshinskay Korga, over the

Mezen Bay to the mouth of the Kuloi River and then to the south. This suggestion is based on the absence of Scandinavian till in the Cape Tolstik section, on the left bank of Mezen Bay, and the occurence of Scandinavian till on Cape Kargovsky near the Kuloi River mouth (Fig. 2.B). In this case, an ice-dammed lake must have existed in the southern part of the Mezen Bay and in the lower Pyoza River during Late Valdaian time. This finds some support from the fact that glaciolacustrine sediments are widespread capping the sections on Mezen Bay and along the lower part of the Mezen River.

Conclusions

The Scandinavian ice sheet, the Barents-Kara Sea ice sheet and possibly a Timan ice sheet occupied different parts of the Arkhangelsk region during the Late, the Middle and the Early Valdaian glaciations. Their tills, with a characteristic pattern of directional properties and clast provenances, are separated by marine, fluvial and lacustrine sediments, which have been dated by radiocarbon and luminescence. This means that since the Mikulian interglacial, ice sheets developed independently in different parts of the European North. In the Late Valdaian, the maximum of the last Scandinavian glaciation was asynchronous in various regions of Russia. Possibly, this is controlled by the distance from the centre of glaciation in the Gulf of Bothnia, but less dependent on peculiarities in the topography beneath different ice flows and the regional palaeoclimate.

At present there are three major uncertainties on the Valdaian glacial history in the Arkhangelsk area. One deals with the configuration and glaciation centre of the so-called 'Timan ice sheet' from the Early Valdaian. Another question is the position of the western boundary of the Barents-Kara Sea glaciation during the Middle Valdaian and whether or not it was confluent with a Scandinavian Ice Sheet west of the Arkhangelsk region. A third option is to map the distribution of deposits belonging to the Late Valdaian Scandinavian glaciation in the Kuloi area and possibly trace these deposits northwards to the Kanin Peninsula.

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