NGU UNIVERSITÄT LEIPZIG

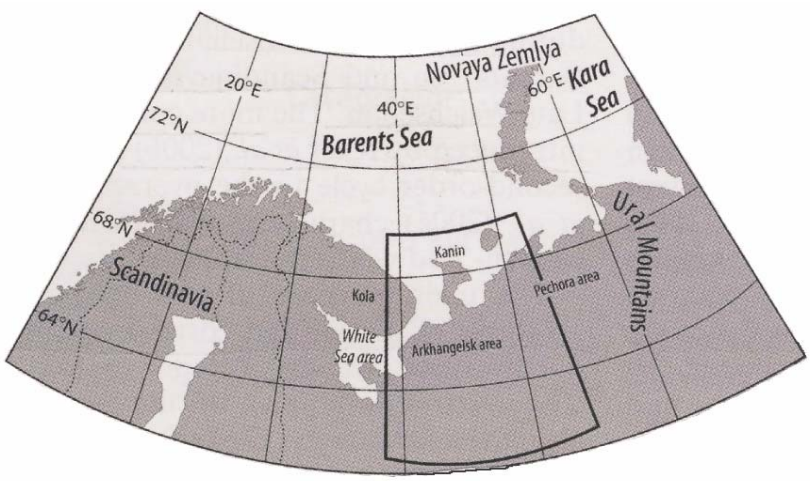
# Tolokonka on the Severnaya Dvina - A Late Pleistocene history?

**Field study in the Arkhangelsk region (Архангельская область), northwest Russia**

**Russia Expedition – a SciencePub Project**

**25th May – 2nd July 2007**

written by Udo Müller (Universität Leipzig)
to obtain a B.Sc. degree's equivalent




SciencePub APEX INTERNATIONAL 2007 2008 POLAR YEAR

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## Introduction

The Russian North has been subject to many different research expeditions over the last decade, most of them as an integral part of the QUEEN Programme (Quaternary Environment of the Eurasian North), in order to reconstruct the glacial events throughout the Quaternary and their relation to sea-level change and paleoclimate. Fig.1 shows the localities that have been investigated between 1995 and 2002 – river sections along the Severnaya Dvina and its tributaries, the Mezen River Basin, the coasts of the White Sea and the Barents Sea, as well as the Timan Ridge (KJÆR et al. 2006a).


*Fig. 1.* The Arkhangelsk region in NW Russia. Dots mark localities investigated between 1995 and 2002 (KJÆR et al. 2006a). For orientation see frontpage.

According to KJÆR et al. (2006a), the Arkhangelsk region represents a key area for the understanding of Late Pleistocene glaciation history, since it was overridden by all three major Eurasian ice sheets: the Scandinavian, the Barents Sea and the Kara Sea ice sheets.

During the weeks from May 25th until July 2nd 2007 an expedition to the northwest of Russia was organized by members of the research group "Climate & Landscape" from the Geological Survey of Norway (NGU – Norges geologiske undersøkelse). Expedition participants were NGU scientists Maria Jensen, Astrid Lyså, Eiliv Larsen and Achim Beylich, also the journalist Gudmund Løvø. Furthermore, Denis Kuznetsov (Limnological Institute of St. Petersburg), Udo Müller (University of Leipzig), Alexander Smirnov and Yevgenij Vyotkin.

Sedimentological profiles were taken in river sections along the Severnaya Dvina, Vaga, Vychegda and the Mezen. We also collected samples for Optically Stimulated Luminescence (OSL) dating and made detailed photographical documentation on sections and the surrounding geomorphology. Our investigation in the Arkhangelsk region and the Republic of Komi shall contribute further evidence to the fluvial and lacustrine sedimentary history of northwest Russia during the Late Pleistocene. According to the project description (see Ref.), the Russian northwest represents a key area to understand the continental-scale environmental change related to the hydrological cycle, with river drainage shifting completely between glacial and non-glacial periods.

This year's expedition is part of SciencePub (From Science to Public awareness: arctic natural climate and environmental changes and Human adaptation), an interdisciplinary project under NGU leadership, involving a number of cooperating Norwegian and international institutions (http://www.ngu.no/landscape/Projects.html). SciencePub is the coordinated Norwegian contribution to APEX (Artic Palaeoclimate and its EXtremes) which is the IPY (International Polar Year) endorsed programme #39 and an ESF (European Science Foundation) proposed network (SciencePub Project Description: see References). SciencePub is studying natural climate archives in terrestrial and marine sediments from the European Arctic region; e.g. Svalbard, northern Norway, northwest Russia and the adjoining seas and continental margins

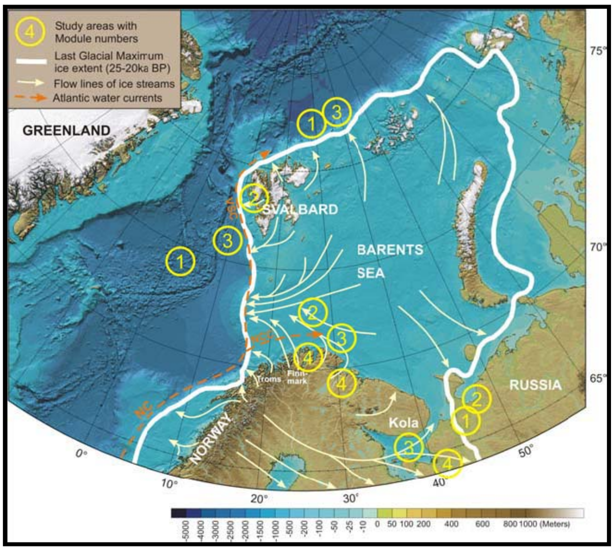


*Fig. 2.* Study area of SciencePub. Extent and flow directions of the latest ice sheet. Numbers indicate working areas of the different SciencePub modules. (Project description)

(see Fig. 2), in order to reconstruct changes in climate and physical environment during the last glacial-interglacial cycle.

It is important to point out, that SciencePub has a visionary strategic goal which is the dissemination of research results to the public. Besides the assemblage of palaeoclimate data, and the recruitment of a new generation of polar scientists, the improvement of (often neglected) communication between the public and the scientific community is the major challenge. "From Science to Public awareness" (SciencePub) contains the implementation of public outreach activities to communicate knowledge on Arctic environmental change, and thereby implies the participation and training of science journalists. The SciencePub homepage (http://www.ngu.no/sciencepub/eng) provides a web-log, where the scientists themselves write about their current activities, the purpose of their expedition or their latest discoveries.

The present paper will investigate on a sedimentological profile that has been taken at Tolokonka – a 4.2 km long river section on the Severnaya Dvina, approximately 90 km northwest of Kotlas (Arkhangelsk region).

In a first part, our study will give a short overview on the Late Pleistocene glacial history and its associated physical environments in northwest Russia. In the following, the field data will be presented in detail, in order to elaborate a first interpretation of how the collected evidences might fit into the overall picture of the Late Pleistocene. Fig. 3 shall help to keep track of all the different place names, eventually mentioned in the text.

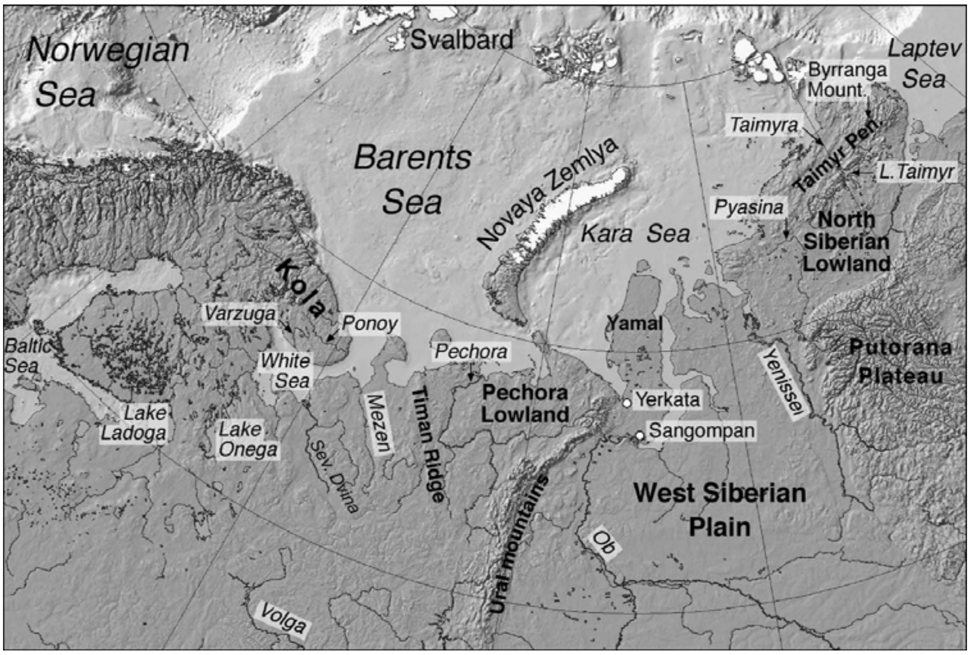


*Fig. 3.* Place names in northern Russia (taken from MANGERUD et al. 2004)

## The Late Pleistocene in northwest Russia

Throughout the Pleistocene, the Arctic environment and its climate had been subjected to extreme shifts between glacial and interglacial periods (Project Description). Not only has there been a significant impact on marine and terrestrial ecosystems, the decay and build-up of ice sheets also changed ocean circulation and sedimentation patterns through the release of melt-water and icebergs.

A large group of QUEEN scientists (BAUCH, 2001) has reconstructed the extent of different, mainly Late Pleistocene ice sheets on the present land and on the shelf areas of the Eurasian Arctic. During peak glaciations huge volumes of water were trapped in ice sheets, global sea level fell up to 150m which caused vast continental shelf areas to fall dry, particularly the shallow shelf areas bordering the Arctic Ocean (INGÓLFSSON). Thus, "continental" ice spread across the shelves onto land and blocked the northbound drainage of the large Russian rivers towards the Arctic Ocean, thereby causing the formation of huge ice-dammed lakes along the southern margin of the ice sheets at different stages (BAUCH, 2001; MANGERUD et al. 2004; LARSEN et al. 2006), succeeded by at least 3 catastrophic melt water releases, or rather outbursts to the ocean (KNIES & VOGT 2003; SPIELHAGEN et al. 2004).

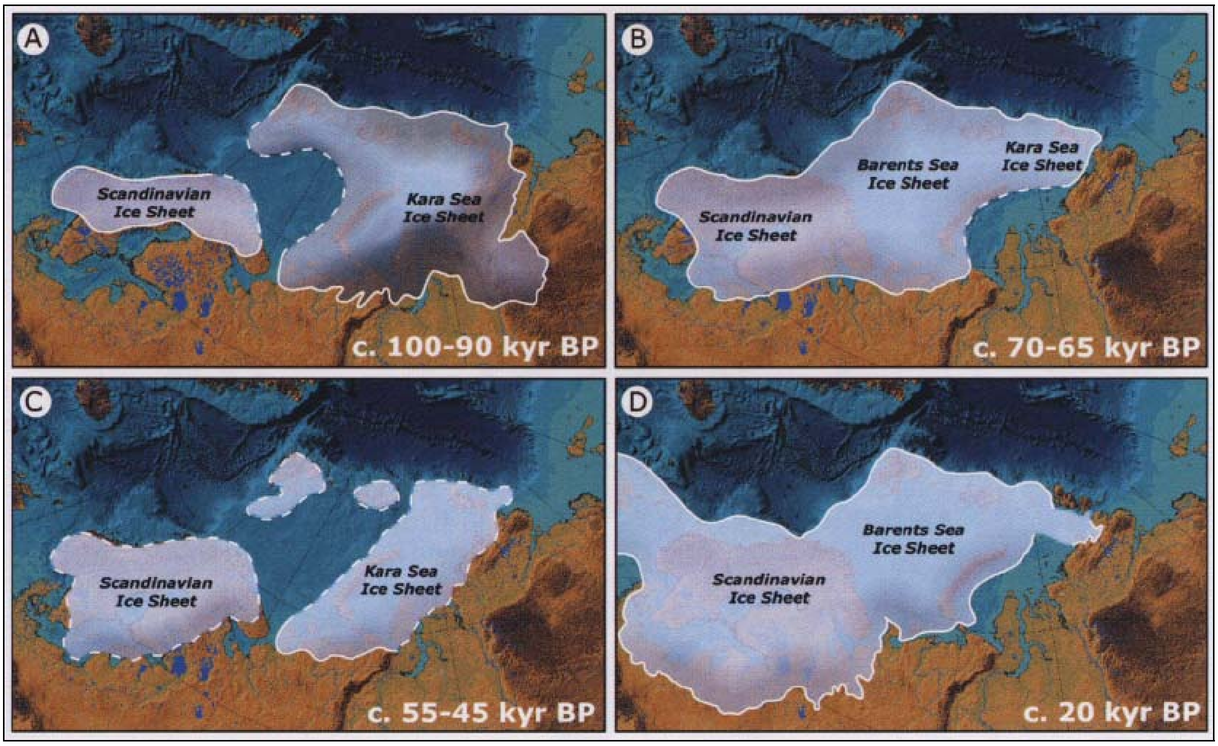


*Fig. 4.* Reconstruction of Eurasian ice sheets during the Weichselian (LARSEN et al. 2006, after SVENDSEN at al. 2004). The Scandinavian Ice Sheet shows a growing extent towards the LGM, whereas Barents Sea and Kara Sea Ice Sheets display a more shifting character.

According to ASTAKHOV (2004), as an area of inland glaciation, Northern Russia is very different from the classical glaciated regions of north-western Europe and North America. The thick and predominantly fine-grained composition of the Quaternary cover is basically due to a largely soft-rock flatland which is extending offshore as sedimentary basins of the Barents and Kara seas. The Russian northwest has been influenced by all three - the Barents, the Kara and the Scandinavian ice sheets.

The Saalian glaciation was particularly extensive in the high Eurasian north, covering vast areas of northern Russia, coastal Siberia and the Arctic Ocean. However, throughout the last glacial-interglacial cycle, Siberia, east of the Taymyr Peninsula, was ice-free and constituted an enormous steppe environment (INGÓLFSSON).

For the Weichselian, at least four main glacial events are recognized from field studies in northwest Russia. Fig. 4 shows the latest reconstructions that have been made for the glaciations during the Weichselian by LARSEN et al. (2006). Despite some adjustments the reconstructions A, B and D are largely corresponding to the ones made by SVENDSEN et al. (2004). The reconstruction C is based on results from KJÆR et al. (2006b).

Both, SVENDSEN et al. (2004) and LARSEN et al. (2006) give an elaborated synthesis on the Late Pleistocene history of northern Eurasia and northwestern Russia respectively.

*The uppermost Middle Pleistocene (>130 ka BP), Moscovian glaciation (Late Saalian), MIS 6*

The largest ice sheet existed during the Saalian. In fact, according to ASTAKHOV (2004) three major Middle Pleistocene ice advances have been stipulated in the Russian northwest, called Oka, Dnieper and Moscow. Following the Subcommission on Quaternary Stratigraphy (see Ref.) these Russian Plain Stages have been correlated with the Central European stages. Thus, the Okian is isochronous with the Elsterian, followed by the Likhvinian / Holsteinian interglacial. The maximum glaciation Dnieper and the penultimate Moscovian glaciation are correlated with the Saalian and the Warthe stage respectively. Fig. 5 shows a reconstruction (from SVENDSEN et al. 2004) of the maximum ice-sheet extent during the Late Saalian. Apparently the Don lobe (Fig. 5) belongs to a much older glaciation of Cromerian age (VELICHKO et al. 2004, cited by SVENDSEN et al. 2004). Also it remains unclear whether the Dnieper lobe (Fig. 5) is related to the penultimate Moscovian glaciation, which shows that a fully differentiated understanding of Middle Pleistocene glaciations in European Russia has not yet been established.

Yet, the only plausible explanation for the high Eemian sea levels (see below) along the northern margin of the continent is a strong glacio-isostatic depression, which supports the hypothesis of a huge coherent ice sheet reaching far south shortly before the Eemian (SVENDSEN et al. 2004).

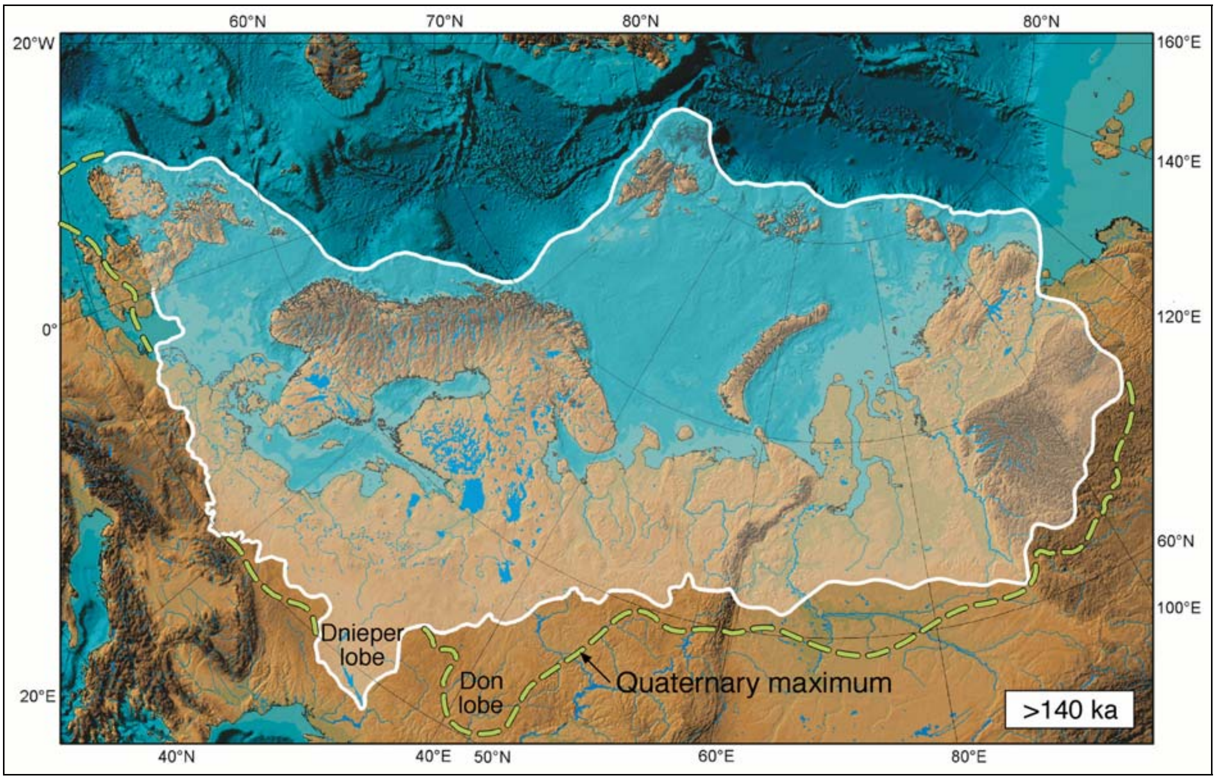


*Fig. 5.* A reconstruction of the maximum ice sheet extent in Eurasia during the Late Saalian (c. 160-140 ka BP), based on review of published material (SVENDSSON et al. 2004). Differentiation between the Saalian stages Dnieper and Moscovian is not elaborated.

According to ASTAKHOV (2004), the generalized results from LAVROV et al. (1986) unambiguously show a persistant N-S and NE-SW dispersal of glacial clasts over the northwestern Russian Plain (see Fig. 6A) during the maximum Pleistocene glaciation (Dnieper); whereas during the Moscovian glaciation ice flow indicators suggest W-E directions west of the Pechora river as can be seen in Fig. 6B. East of the Pechora river ice sheets advanced still southwards, which underlines a dominant position of the Kara Sea shelf as a major source of inland ice in northern European Russia throughout the upper Middle Pleistocene.

ASTAKHOV (2004) further describes the reddish brown Vychegda till that is widely to be observed on the surface west of the Pechora river. This till contains numerous western erratics, including the characteristic nepheline syenite from the Kola Peninsula, and therefore must have been deposited by an eastwards oriented ice stream. According to ASTAKHOV

(2004), only during the deposition of the Vychegda till (which is related to the Moscovian glaciation) the shelf ice domes were overpowered by a Fennoscandian ice sheet that advanced across the Timan ridge at right angles to the ice flow from the Kara Sea.

The Moscovian glaciation (penultimate Middle Pleistocene ice advance) is now ascribed to the marine isotope stage (MIS) 6 (SVENDSEN et al. 2004).

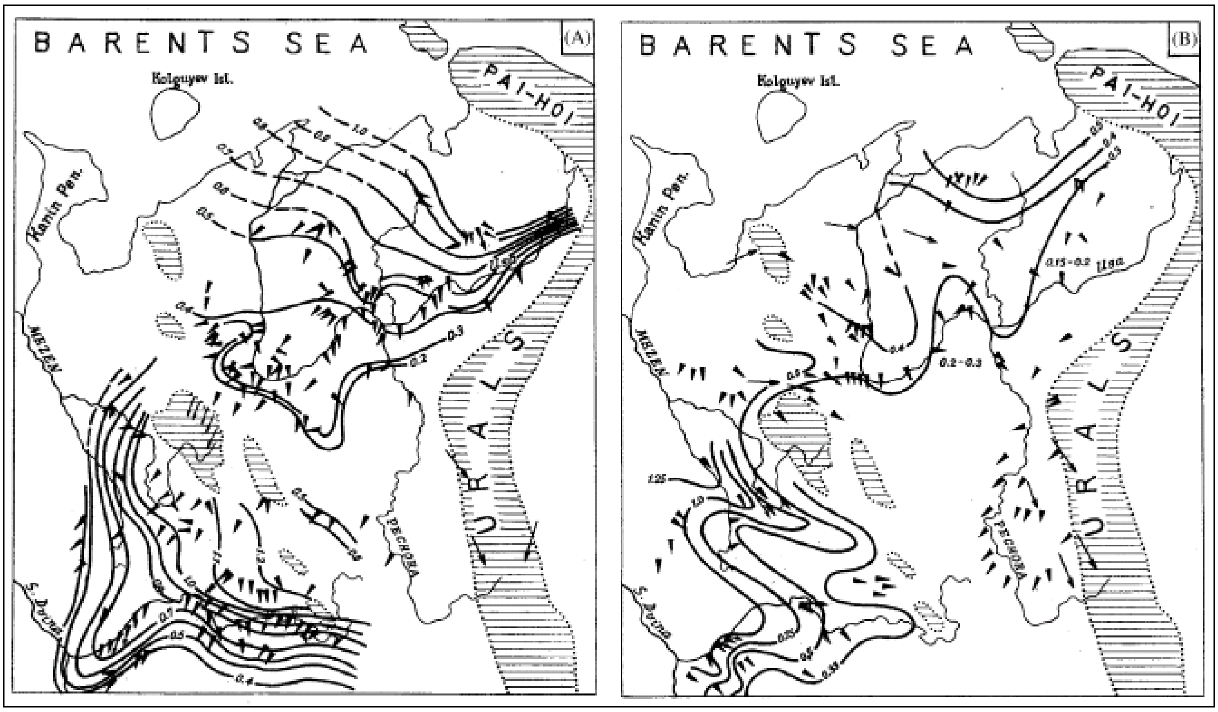


*Fig. 6.* Pebble content and ice flow indicators in Middle Pleistocene tills of northeastern European Russia: A—maximum glaciation, Dnieper stage; B—penultimate glaciation, Moscovian stage. (from ASTAKHOV 2004)

*The Mikulinian 'Boreal Transgression', Eemian (130-115 ka BP), MIS 5e*

During the last interglacial period (MIS 5e), the North Russian coastal lowlands were inundated by marine waters up to 400 km inland from the present coastline (GRØSFJELD et al. 2006). This so-called Boreal Transgression (Fig. 7) represents an important marker horizon in the sedimentary record (SVENDSEN et al. 2004). Marine and estuarine sediments are widely exposed in river sections from the Kola Peninsula in the West to the Taymyr Peninsula in the East (INGÓLFSSON) and can be traced locally up to 100 m a.s.l.. Due to their fossil content of warm boreal benthic faunas they can be used for long distance correlation (INGÓLFSSON; SVENDSEN et al. 2004).

After deglaciation of the thick and extensive Late Saalian ice load, sea level may have been up to 200 m above the present (LARSEN et al. 2006). KNIES & VOGT (2003) postulate a prominent freshwater pulse into the Arctic Ocean at the MIS 5/6 boundary and underline the collapse of a large-scale Saalian glaciation that lasted for about 2000 years. The significant isostatic depression made Fennoscandia an island (Fig. 7.), with an open seaway through Karelia that connected the Barents Sea with the Baltic and North Sea (SVENDSEN et al. 2004). By that time boreal forests were spreading all the way to the coast of the Arctic Ocean (INGÓLFSSON; LARSEN et al. 2006).

The Mikulinian marine sediments are correlated with the Eemian (MIS 5e) of Central Europe. The beginning of the interglacial is evidenced in the marine records by an abrupt shift to lighter isotope values (INGÓLFSSON). As can be seen in the palaeogeographical reconstruction from LARSEN et al. (2006), during Early Eemian, the present river valleys were occupied by shallow sea, which is particularly significant in the Severnaya Dvina area (Fig. 11-A).

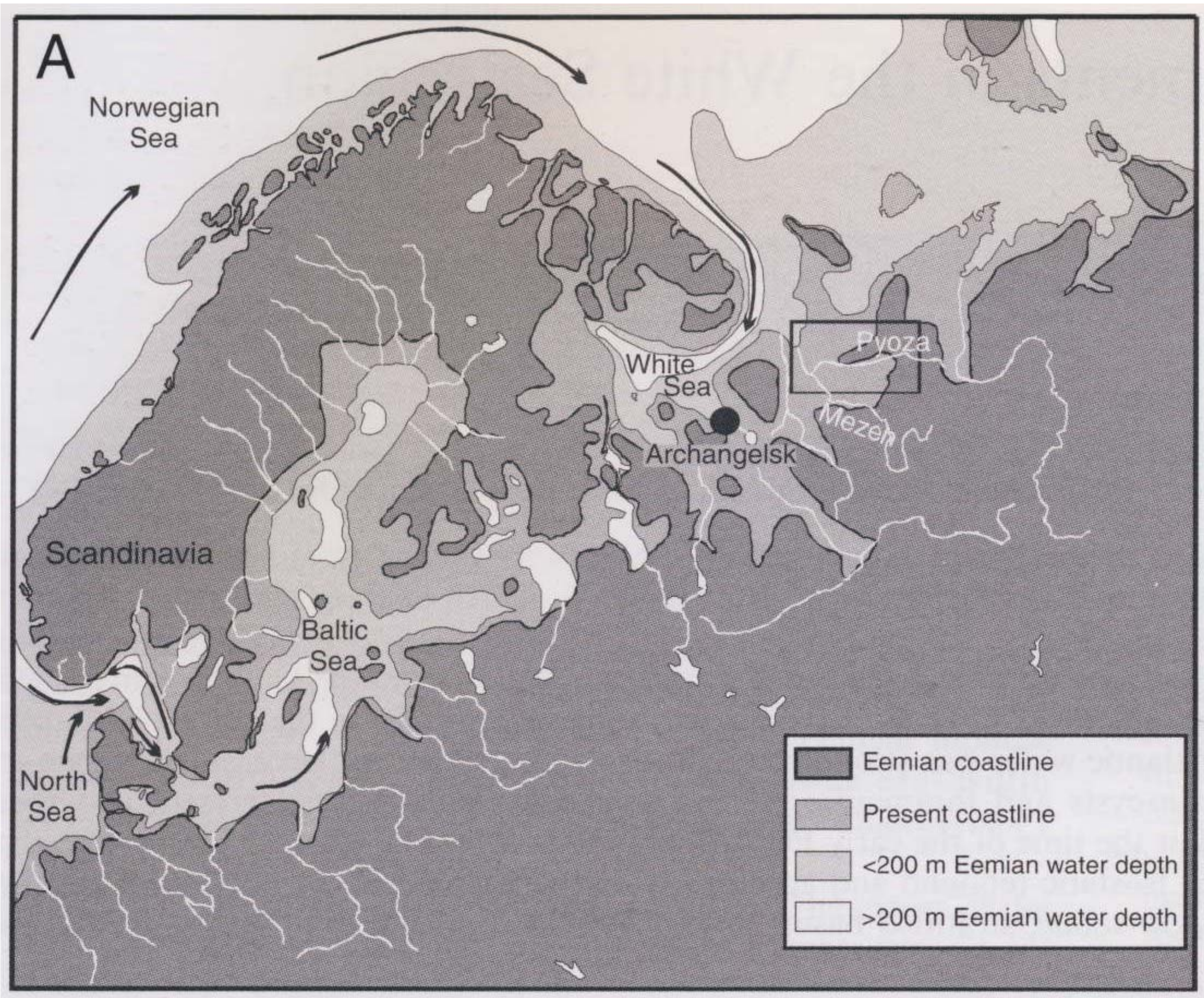


*Fig. 7.* The Eemian and present coastlines of the Baltic Sea and White Sea area. (from GRØSFJELD et al. 2006)

*The Early Weichselian (Valdaian) glaciation (110-90 ka BP), MIS 5d-5b*

On mainland Russia the maximum ice sheet extent after the Last Interglacial (LIG) occurred during the Early Weichselian (MIS 5d-5b) (SVENDSEN et al. 2004), penetrating far into Siberia (Fig. 4-A and Fig. 8) (LARSEN et al. 2006). This stands in contrast with the ice sheet over Scandinavia, which at that time was much smaller than during the Late Weichselian Last Glacial Maximum (LGM) (SVENDSEN et al. 2004).

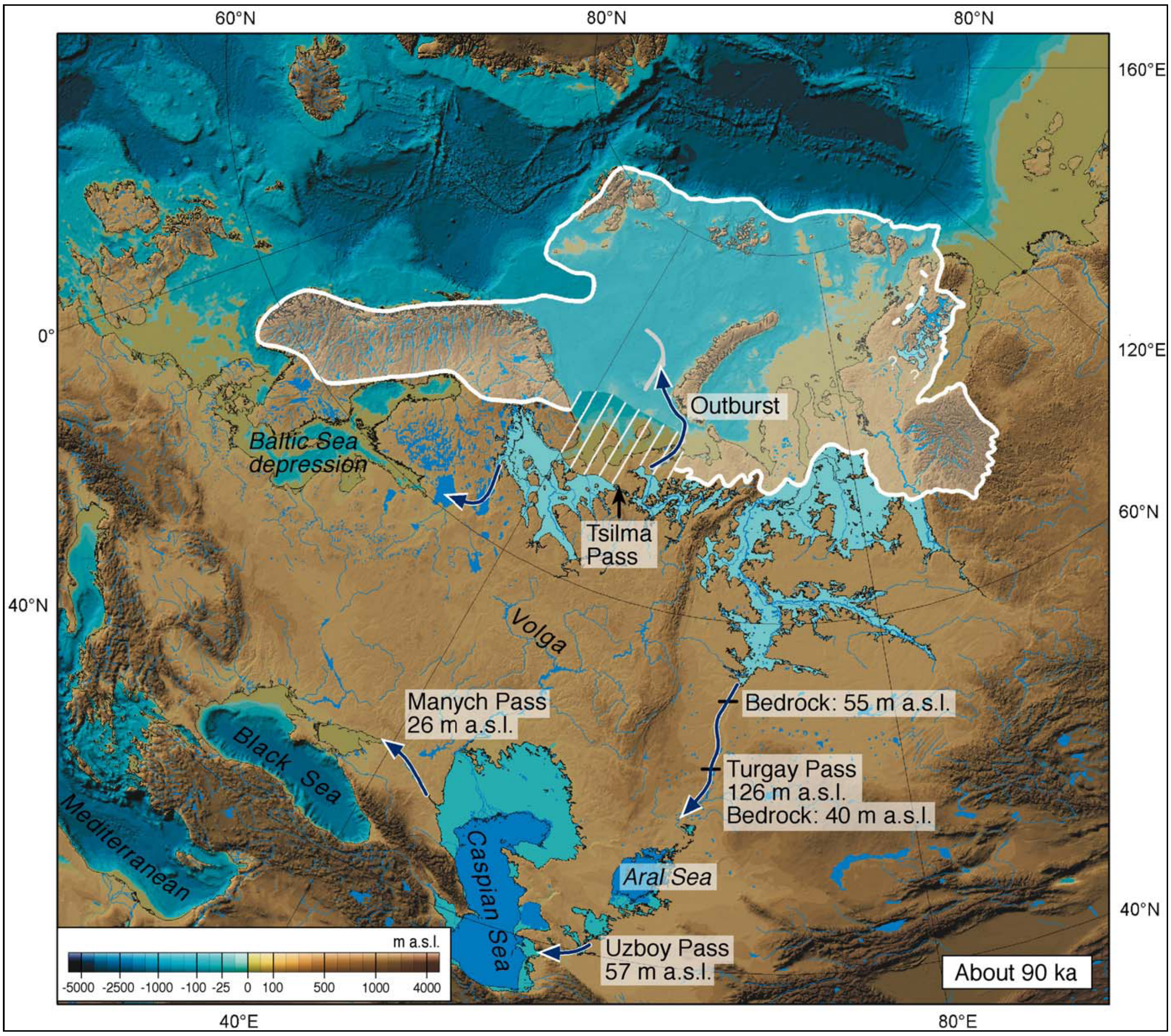


*Fig. 8*. Reconstruction of the Eurasian ice sheet extent, ice-dammed lakes and rerouting of rivers during the Early Weichselian glacial maximum (90-80 ka BP). Ice margins are taken from SVENDSEN et al. (2004). In the hatched area the ice margin position is unknown, probably because it was overrun by the 60 ka ice advance (compare also Fig. 4-A where the Barents Sea is suggested to be ice-free). Sea level is lowered by 50 m. (taken from MANGERUD et al. 2004)

The north-flowing Russian rivers were blocked by an ice sheet that was emanating from the Kara Sea shelf. As can be seen in Fig. 8, ice-dammed lakes, larger than any present freshwater body on Earth would have had reversed outlets towards the Caspian Sea (MANGERUD et al. 2004).

In northwest Russia however, the large proglacial Lake Komi has been mapped out in the Pechora lowlands (Fig. 11-B), presumably dammed by the predominant Kara Sea ice sheet. SVENDSEN et al. (2004) conclude a short-lived damming period at about 90-80 ka BP (MIS 5b). Then, the Lake Komi outlet was across the Tsilma Pass (Fig. 8 and Fig. 11-B), a threshold in the Timan Ridge. New evidence presented by LARSEN et al. (2006) suggest that further on the water was discharged towards the Barents Sea via the Mezen Bay area and an ice-free corridor between the Scandinavian and Kara Sea ice sheet (Fig. 11-B); and not over a White Sea Lake towards the Baltic Sea (see Fig. 8) as suggested by MANGERUD et al. (2004).

In the Severnaya Dvina area no indication has been found that the Early Weichselian ice sheet reached the river valleys (SVENDSEN et al. 2004). As suggested in Fig. 11-B, the westernmost Russian rivers had a prevailing northbound drainage towards the Barents Sea.

*Interstadial (90-75 ka BP), MIS 5a*

The Early Weichselian glaciation is followed by an interstadial period, evidenced by a transgression in the northern part of the West Siberian Lowlands (SVENDSEN et al. 2004). It is suggested to be a long ice-free period (LARSEN et al. 2007). Related to that deglaciation, is the outburst of Lake Komi, which occurred over the period of only a few months. This sudden discharge of Early Weichselian ice-dammed lakes within MIS 5a is supported by the results from KNIES & VOGT (2003). Fluvial terraces, incised into the bottom sediments of Lake Komi, suggest that the normal northbound fluvial drainage was re-established no later than 80 ka BP (MIS 5a), giving a latest date for the interstadial deglaciation (MANGERUD et al. 2004; SVENDSEN et al. 2004).

In the Arkhangelsk region, rivers continued to flow to the North, while periglacial conditions prevailed (Fig. 11-C). According to LARSEN et al. (2006), there is an erosional boundary between fluvial and underlying Eemian sediments along the river Severnaya Dvina, which suggest that missing Early Weichselian records might have been removed.

*The lower Middle Weichselian (Valdaian) glaciation (70-65 ka BP), MIS 4*

A regrowth of the Eurasian ice sheets occurred during MIS 4. Ice sheets in Scandinavia and on the Barents Sea shelf merged and must have dammed a huge lake in the White Sea area west of the Timan Ridge (LARSEN et al. 2007) at around 70-65 ka BP (Fig. 9 and Fig. 11-E). Yet, no correlative lake sediments have been found to demonstrate the existence of a White Sea Lake. According to Larsen et al. (2007) there was no large lake in the Pechora basin (Lake Komi; see above) at this time, because probably only a minor version of the Kara Sea ice sheet existed (Fig. 4B). But the pass-point on the Timan ridge was reused, only now the lake drainage was from the presumed White Sea Lake in the West towards the East.

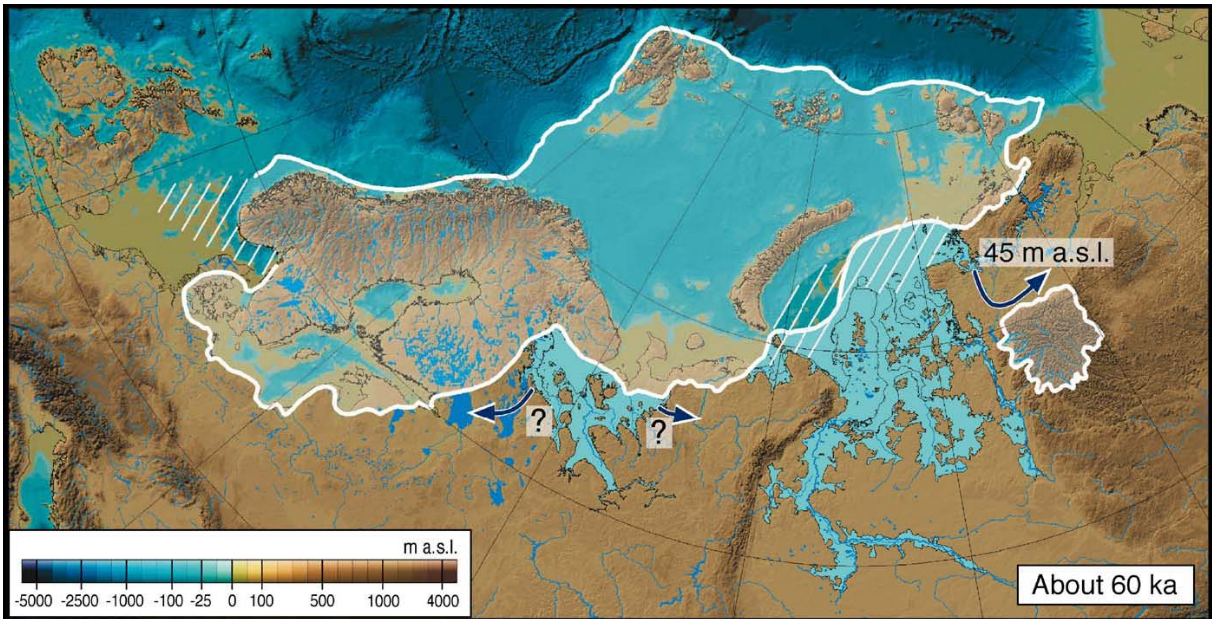


*Fig. 9.* Reconstruction of Eurasian ice sheets, ice-dammed lakes and rerouting of rivers during the Middle Weichselian (70-45 ka BP). Ice margins are taken from SVENDSEN et al. (2004). In the hatched area, the position of ice margin is unknown. The lakes are mainly hypothetical predictions that are based on the configuration of the ice margin and should be tested (MANGERUD et al. 2004). Sea level is lowered 60m. According to the latest reconstructions from LARSEN et al. (2006) (see Fig. 4) the Barents and the Kara Sea ice sheets did not exist simultaneously.

The Scandinavian ice sheet did not reach as far to the East as during the Late Weichselian (Fig. 4), but the Kola Peninsula and the northern White Sea basin were glaciated (SVENDSEN et al. 2004). The early Middle Weichselian glacial event represents the last maximum southern extent of the Barents Sea ice sheet onto European Russia.

Note that the reconstruction of LARSEN et al. (2006) (Fig. 4 and Fig. 11-E) differs from the one made by SVENDSEN et al. (2004). It is assumed that the early Middle Weichselian is dominated by the Barents Sea ice sheet, whereas a sizeable Kara Sea ice sheet only occurs after the Mezen Transgression (see below).

*The Mezen Interstadial, Middle Weichselian transgression (65-55 ka BP), MIS 3/4*

According to JENSEN et al. (2006), deposits from a marine event are bracketed between two ice advances from the Barents and the Kara Sea shelves. Their wide-spread occurrence allows to use them as a marker horizon. It further allows the stratigraphical division of the two Middle Weichselian shelf-based glaciations that are separated by almost complete deglaciation (KJÆR et al. 2006b). The Mezen transgression occurred between 65 and 60 ka BP, corresponding to a rapid eustatic sea level rise across the MIS 4 to 3 transition. KJÆR et al. (2006b) suggest that the Barents Sea ice sheet suffered from marine down-draw, which led to its collapse and to a rapid drainage of the White Sea Lake into the Barents Sea. Marine inundation and interstadial conditions followed, evidenced by the description of marine terraces of Middle Weichselian age from several Arctic islands (SVENDSEN et al. 2004), and succeeded by marine regression due to isostatic rebound before the area was glaciated again.
Northbound drainage of the Russian rivers can be seen in Fig. 11-F.

*The late Middle Weichselian (Valdaian) glaciation (55-45 ka BP), MIS 3*

The subsequent glaciation was centred in the Kara Sea area around 55-45 ka BP. This time, ice-flow came from the northeast and the ice advance was probably farther south in the Pechora basin area (Fig. 11-G) than during the previous glaciation (LARSEN et al. 2006). Further to the East, the Kara Sea ice sheet expanded onto the north Russian continent between the Ural mountains and the northwesten rim of the Taymyr Peninsula (Fig. 4), also leading to the blockage of rivers that were draining to the North and the formation of huge, ice-dammed lakes (Fig. 9) (MANGERUD et al. 2004)

Results from the Severnaya Dvina river show northward directed fluvial run-off in the Arkhangelsk region, indicating that the mouth of the White Sea was not blocked (Fig. 11-G) and thereby suggesting that the Kara Sea ice sheet was independent from the Scandinavian ice sheet and that the Barents Sea remained ice free (LARSEN et al. 2006).

*Interstadial (45-25 ka BP)*

Before ice sheets grew to their last glacial maximum extent, a c. 20 ka long ice-free period probably existed. LARSEN et al. (2006) underline, that despite some evidence in the Arkhangelsk region there is little record of the period between the Kara Sea dominated glaciation and the following Scandinavian dominated glaciation. Most likely a low sea level mainly resulted in river incision. Fluvial sediments show northbound drainage (Fig. 11-H), ice-wedge casts suggest severe climate.

*The Late Weichselian (Valdaian) glaciation (25-15 ka BP), MIS 2; LGM (20-18 ka BP)*

Interpretations of the northern Eurasian glacial record suggest that most of northern Russia remained ice-free during the LGM. According to SVENDSEN et al. (2004), the Barents Sea and the Kara Sea ice sheets were smaller than during the preceding glaciations and did not expand onto the Russian and Siberian mainland, with the exception of the Taimyr Peninsula that did not remain ice-free.

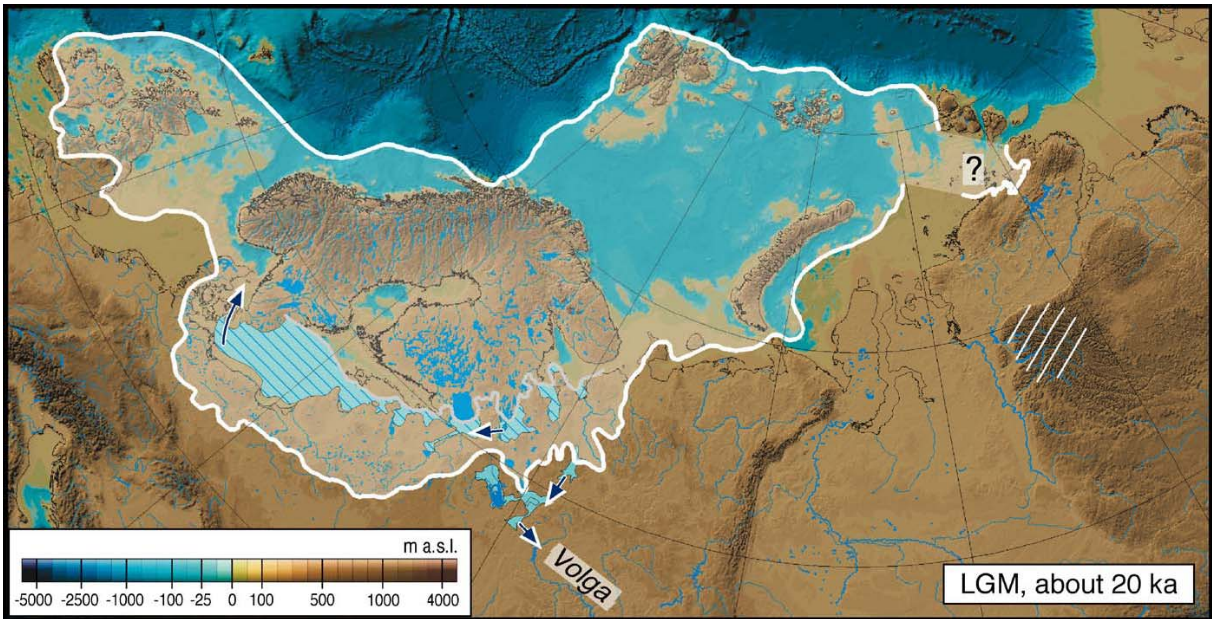


*Fig. 10.* Reconstruction of the Eurasian ice sheet, ice-dammed lakes and rerouting of rivers during the LGM about 20 ka BP. Inside the LGM limit are also shown younger (about 14 ka BP) ice-dammed lakes around Lake Onega and in the Baltic Sea depression, and their outlets. Sea level is lowered 120m. (MANGERUD et al. 2004, SVENDSEN et al. 2004)

The LGM is a Scandinavian dominated glaciation, reaching far onto the mainland of Western and Central Europe. SVENDSEN et al. (2004) assume that the southern flank of the Barents Sea ice sheet coalesced with the Scandinavian ice sheet near the northern tip of Kanin Peninsula, but stood off the present coastline of northwest Russia. In the Kara Sea, the ice front probably stood just east of the deep Novaya Zemlya Trough (BAUCH, 2001).

According to LARSEN et al. (2006), the eastern flank of the Scandinavian ice sheet penetrated far up the Severnaya Dvina drainage basin at c. 20 ka BP, what led to the damming of “minor” proglacial lakes that flooded the river valleys, and to the rerouting of the water discharge to the South via the river Volga (Fig. 11-I). MANGERUD et al. (2004) underline that no ice-dammed lake of comparable size to the Early and Middle Weichselian lakes had formed. As can be seen in Fig. 11-I, meltwaters drained northwards along the ice-margin, eastwards across the southern part of the Kanin Peninsula and most likely towards the Kara Sea (SVENDSEN et al. 2004).

To conclude the short synthesis of the Late Pleistocene glaciation history of northern Russia, it is important to point out the shifting aspect from maximum glaciation in the East (early Late Pleistocene) to maximum glaciation in the West (Last Glacial Maximum). Ice-flow directions are NE-SW for a Kara Sea dominated ice sheet, NW-SE for the Barents Sea dominated ice sheet and W-E for the Scandinavian dominated ice sheet.

The palaeogeographical reconstructions from Larsen et al. (2006) for north-western Russia (Fig. 11) show, that reconstructing the Late Pleistocene history in that area will include the investigation of marine deposits as well as fluvial, lacustrine, glaciolacustrine and glacial sediments.

Fig. 11 shall help to follow the reconstructions that will be made for the profile from the Tolokonka section. The location is marked there with a red dot.

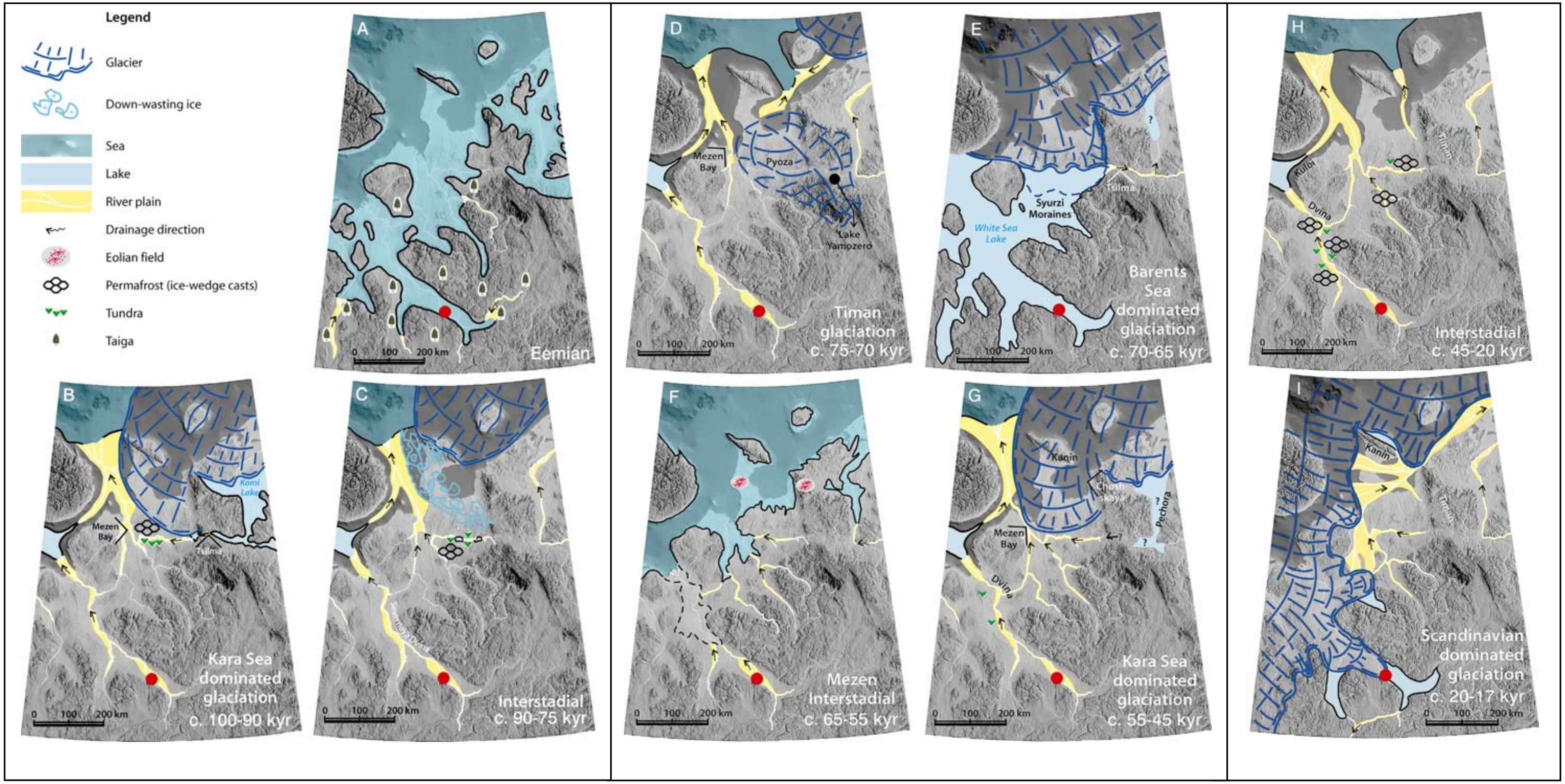


*Fig.11*. Palaeogeographical reconstruction for north-western Russia from the Eemian, through the Late Pleistocene until the Last Glacial Maximum (taken from Larsen et al. 2006). The red dot marks the location of the Tolokonka section.

## The Tolokonka section

On the 6th June the expedition set camp for one week on the left riverbank of the Severnaya Dvina to work in the sedimentary deposits of the Tolokonka section. The Severnaya Dvina is one of the large rivers in European Russia, flowing in north-westerly directions. It is 750 km long and empties through the Dvina Bay, just below Arkhangelsk into the White Sea. The section sits in a large meanderbend on the right riverbank (Fig. 12), located about 8km NNE of the small village Verkhnaya Sergejevskaya which is situated some 85 km NW of Kotlas and about 400 km SE of Arkhangelsk.

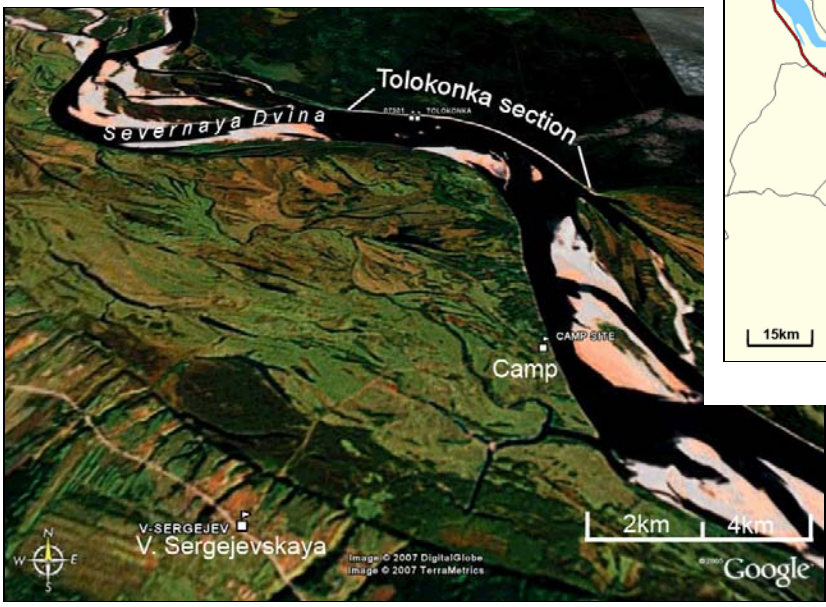



*Fig. 12.* Geographical setting: Tolokonka section is located NE of Krasnoborsk and Kotlas, on the right riverbank of Severnaya Dvina. The site is situated in a typical fluvial topography of a meandering river.

The location was numbered Loc.06025 during last year's expedition in 2006. The site was given a GPS (Global Positioning System) zero-point at the following coordinates: N61° 45 04.7 E45° 29 30.7 (UTM: 38 V 525972 6846573). All working localities in the section will be derived by giving the distance from that zero-point in kilometres.

In Fig. 12 we see a typical fluvial topography of a meandering river with channel bars and oxbow lakes, where Tolokonka clearly represents the undercut slope of the meanderbend. The outcrop is between 25 and 30 meters high and 4.2 km long, and therefore quite impressive when seen from the far distance already. Constant down-cutting from the river promotes the seemingly good exposure of the Quaternary soft sediment deposits. At a first glance they basically consist of sand, which is also mainly covering the lowermost 5 to 10 meters of the section. Preliminary investigations in the year 2006 however, figured that there are quite some


Fig. 13. Tolokonka section on Severnaya Dvina. The picture is taken towards the east at 3.24 km from the zero-point in the southeast.

changes in depositional environment, documented in the alternating succession of sands and clays. Fig. 13 shows a view along the section at 3.24 km downstream of the zero-point, where the log-profile presented in this paper will be taken.

One main goal of this year's investigation is of course to reconstruct the fluvial and lacustrine sedimentary history since the Last Interglacial (LIG), in order to find undoubtful evidence for the existence of ice-dammed lakes during the Weichselian - especially for the White Sea Lake (Fig. 11-E) that is presumed in the palaeogeographical reconstructions of LARSEN et al. (2006). According to these reconstructions (Fig. 11), we would expect to find mainly fluvial deposits, lacustrine or till deposits for the LGM (Fig. 11-I) and maybe even LIG marine deposits (Eemian, Fig. 11-A).

At 3.24 km downstream of the section, a profile is excavated with a shovel and then "cleaned" (to get an even surface) with a scraper. The sediment-log starts at 9.10 m a.r.l. (above river level); due to constant erosion by the river, the lower part of the section is not exposed anywhere nearby. All altitudes in the log will be given in meters above river level, only later the elevations will be calibrated with official data from institutions that monitor the river level, to get an exact elevation above sea level. Nevertheless, in this study we assume that the river level of the Severnaya Dvina on 8$^{th}$ June 2007 lies at about 40 m a.s.l. (above sea level) in the Tolokonka area.

Fig. 14 shows the log that has been elaborated from 9.10 m a.r.l. to the top of the section at 25.50 m a.r.l. During our field investigations, we were tracing boundaries and discussing the different sedimentary deposits. The following description of the units we could distinguish, will assemble our observations.

Interpreting the sedimentary succession will summarize our comprehension of the depositional history at the Tolokonka section.

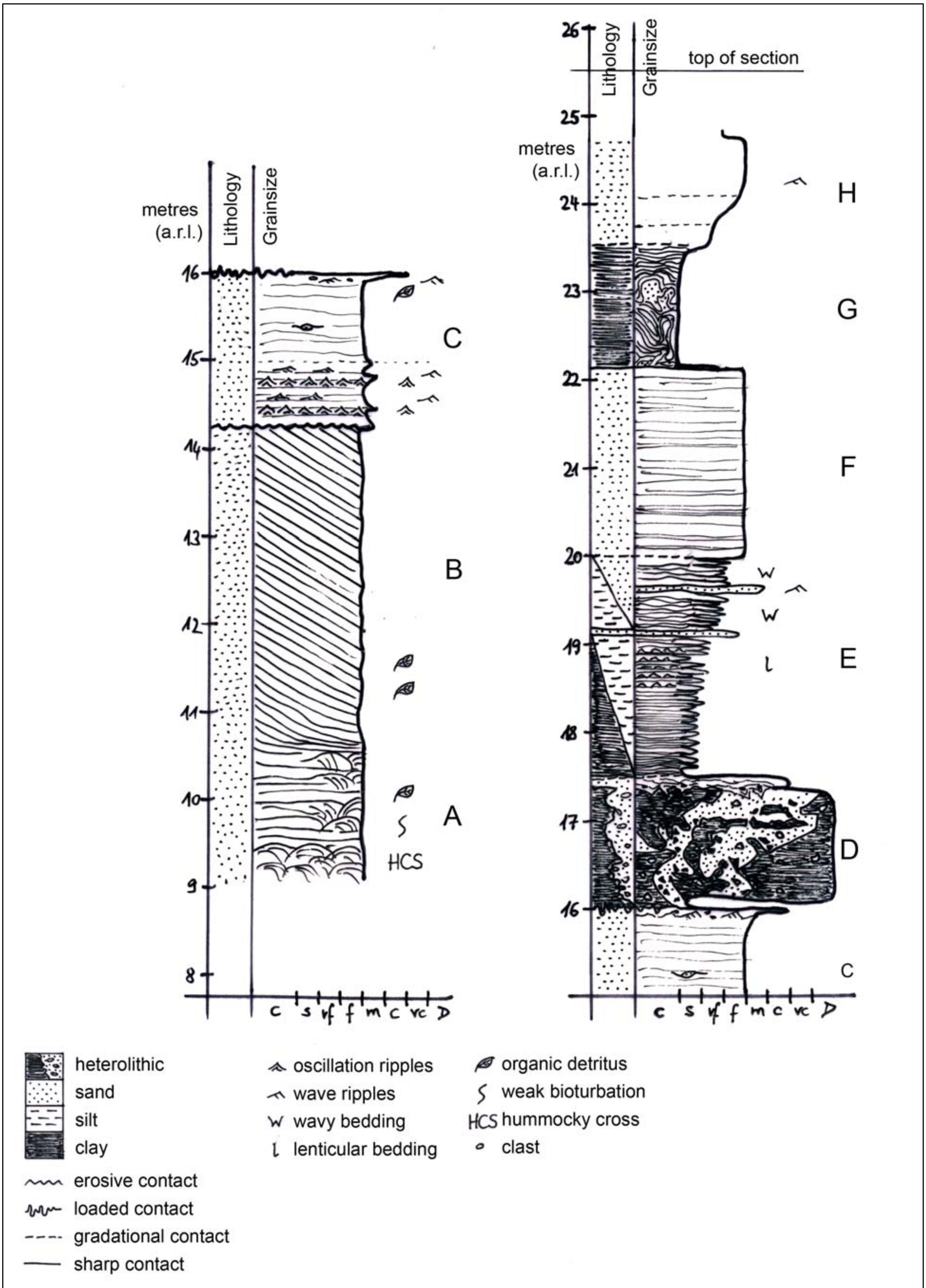


*Fig. 14.* Sediment log of the profile at Tolokonka Loc.06025, 3.24 km downstream Severnaya Dvina. Letters A to H indicate the different units that have been described. Elevations are given in metres above river level (a.r.l.).

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| **0 - 9.10 m a.r.l.** | This part of the profile is not exposed. Most likely, the lowermost 5 to 10 m are covered by eroded material (sand, clay and trees) throughout the entire Tolokonka section. To uncover these sediments would require a lot of digging, connected to an increased danger of getting buried by debris flows from above. |
| **9.10 - 10.60 m a.r.l.<br>Unit A<br>lacustrine** | In the lowermost exposed unit of the section, we find a clearly stratified unit of fine to medium sand, light-grey and beige in colour. Also the very fine sand fraction occurs in darker coloured layers. Horizontal bedding must be mentioned, the wavy aspect is however much more significant: in some layers Hummocky Cross Stratification (HCS) and Swaley Cross Stratification (SCS) can be seen (Fig. 15 and Fig. 16) only a few meters east of the log.<br>The hummocks show thicknesses up to 25-30 cm, the swales are up to 15 cm thick. More fine-grained material (silt) drapes the hummock crests and the swales and shows signs of little bioturbation here and there.<br>Around 10 m a.r.l. we find organic detritus, randomly distributed in thin lenses.<br>Features have been determined, that we refer to as water escape structures. It seems as if fluid has been injected downwards into the sediment, as they bend down the sediment layers. Some of these structures even penetrate from below unit D, all the way through into unit A and even further down (Fig. 17). |
| **10.60 m a.r.l.<br>transitional boundary** | As can be seen in Fig. 18-A and Fig. 33 we have here a transitional boundary from deltaic bottomsets to foresets. On the lateral extent this boundary is gradually “climbing” higher up in the section the farther we go upstream (to the east of the log). |
| **10.60 - 14.25 m a.r.l.<br>Unit B<br>lacustrine** | The mainly fine to medium sand of this unit is clearly stratified. There is a continuous alternation - interbedding of grey brownish very fine sand layers with brownish fine sand layers and light-beige medium sand layers. An outstanding coarsening upwards (CU) or fining upwards (FU) can not be determined. The colouring of the sediments is basically the same for the units A, B and C, and thereby suggests a relative temporal togetherness.<br>The parallel-bedded sand layers are dipping with an angle between 28° and |

30° into south-eastern directions. The following measurements were taken with a compass, giving the dip direction and the dip (after E. Clar): 148/28, 142/28, 143/30, 146/29. Fig. 18-B shows how the measuring was effectuated. According to the dip-angle and the transition to unit A, we are here obviously dealing with foresets of a delta (Fig. 33) that is prograding into a basin.

Organic detritus can be found randomly distributed.

Beside the dewatering structures described in unit A, in this unit we can find a feature that is most likely related to the same kind of process: it is more wedge shaped but does not deflect the primary stratification. As can be seen in Fig. 19-A, it seems as if fluid was seeping through the porous sand and bleaching the affected areas.

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**14.25 m a.r.l. erosional boundary**

The large scale deltaic foresets, described from unit B, are cut off by a medium to coarse grained sand layer from the overlying sand unit C (Fig. 19-B). Even though there is no significant change in colour, this is clearly an erosional boundary.

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**14.25 - 16.00 m a.r.l. Unit C lacustrine**

The lowermost 75cm of unit C display mainly medium with coarse grained sands that are beige in colour. They are planar-parallel horizontally bedded with a slight wavy appearance and show at least three distinct layers with oscillation ripples (Fig. 20). Also, one can find current ripples at three different levels, where the coarse sand fraction is deposited inside. The current ripple foresets are up to 5cm high. The oscillation ripples are very symmetrical and about 1-2cm high. Apparently, they always follow after one to three laminae of a more organic input (dark grey - black).

A CU or FU tendency cannot be noted down, it is more an alternating CU and FU inside the different layers.

There is no particular boundary between the lower and the upper part of unit C; still, the colour-change catches the eye (Fig. 21-A). The overlying 100cm are light brownish and appear rather massive, though weakly stratified. The wavy-parallel bedding (Fig. 21-A) is suggested by thin layers that are more silty/ fine sand. The wavy aspect is probably amplified by deformation due to loading from above, which is suggested by minor faults that can be found here and there (Fig. 20-A).

About 20 cm below the overlying boundary to the clay, lenses of organic

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| | material are deposited randomly (Fig. 21-B). Also lenses of coarse sand can be found, which are not bigger than 10cm. At one place this lens is associated with a water escape structure. |
| **16.00 m a.r.l. boundary** | The boundary between the sand unit C and the overlying blocky clay unit D appears to be rather sharp. In some parts though, it is deformed probably due to loading from above (Fig. 21-A).<br>The uppermost 5-10cm of the underlying sand unit C show a fining upwards sequence from coarse and very coarse sand with a few gravels, to medium and fine sand at the top where we can also find ripple structures with laminae of brownish clay/silt drawn into it (Fig. 22). The latter leads to the assumption that we have here a conformable, transitional boundary. However, deformation from above reaches into this sandy layer (Fig. 23-B), suggesting an erosive character. Also, investigations at other sites along the Tolokonka section strengthen the version of an erosional boundary.<br>An addition to that there is a slight change in colour and also in grain-size from the upper 100cm in unit C to its uppermost 5-10cm described above. Although evidence is sparse, it wouldn’t be impossible to put up an erosional boundary, if necessary, between 15.90 and 15.95 m a.r.l. |
| **16.00 - 17.35 m a.r.l.<br>Unit D<br>glacial** | This unit is very likely to have glacial influence. It starts with a mixture of dark brown and dark greyish clays that have a very blocky scattered texture. From above, there is a massive fine to medium sand mixed and worked into the clay (Fig. 23-A).This mixture has even reached the lower boundary at two spots, where it penetrates to the uppermost sand layer of unit C (Fig. 23-B).<br>The clay clasts inside the massive sand seem to have been ripped off very rapidly, as they appear very blocky and show no rounded edges.<br>Also one can find gravel and small pebbles in different sizes inside the sand and mainly in the clay. These gravel clasts differ very much in roundness and sphericity. They probably are of Scandinavian - in this case Karelian provenance.<br>Some packages of very fine sand are worked into the unit as well. Deformation and slumping are the preponderating aspects.<br>The unit seems to be a diamicton where the gravel component is rather small. |

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| **17.35 - 17.50 m a.r.l. boundary** | Above the diamicton (unit D) and below the laminated clay (unit E), there is a deposition of weakly but horizontally stratified medium to coarse sand with very coarse sand grains and gravel in the lower part. It seems to be levelling out the diamicton deposits below (Fig. 24).<br>In the uppermost 2-5cm, medium to coarse grained sand is interbedded with dark brownish silt/ clay in a more or less wavy pattern. The overlying laminated clay seems to follow this wavy pattern until the levelling out is completed.<br>This boundary is outstandingly similar to the one below the diamictic unit D. It seems as if there was a gradual transition into the laminated clay. Still, it is unclear whether the indications should be interpreted as a transitional or a rather erosional boundary. |
| **17.50 - 20.00 m a.r.l. Unit E glacio-lacustrine** | This unit is introduced as a warvite, where scientists from last year's expedition have counted 341 couplets at Loc.06025_3.19km (JENSEN 2006b).<br>Rhythmical deposition can be seen, especially in the lower part of the unit one can find distinct lamination: in the lower part, dark grey clays - in the lowermost part even organic rich black laminae - are interbedded with more light grey to dark brownish silt and very fine sands (Fig. 25-A). There is a gradual overall coarsening upward towards the overlying sand unit F.<br>At 19.10m, a 2-3cm thick layer of very fine/ fine sand can be seen, with iron precipitate at the sand - clay contact.<br>Towards this very fine sand layer, we get more and more lenticular bedding, showing oscillation ripple character (Fig. 25-B). Above this very fine sand layer, the clay component is very much decreasing. The rhythmic deposition continues, now by interbedding clayish silt with very fine to fine sand. The lenticular bedding is gradually taken over by more wavy bedding.<br>At 19.60m we get a 5cm thick layer of fine to medium sand. It shows an interesting hummock at one point (Fig. 26-A) that could be a current ripple. The interbedding continues for another 30-35cm, where it shows a wavy pattern with more and more sandier input until the deposition of fine-grained material stops completely (Fig. 26-B). |

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| | Compared on the lateral extend, this unit seems to be undisturbed in some parts, whereas in other parts deformation can be seen. This is probably related to the deformation described in unit F. |
| **20.00 m a.r.l. transitional boundary** | Here, the deposition of fine-grained material stops (Fig. 27-A). Thus, we have a gradual transition from the “warved” clay that is coarsening upwards, over to interbedded silts and sands until exclusively sandy input is taking over. |
| **20.00 - 22.10 m a.r.l.**<br>**Unit F** | Interbedding of mainly fine sand with medium sand and a few layers of very fine sand and silt. The planar-parallel horizontal bedding is basically visible because of this alternating switch in grainsize (Fig. 27-B). The layers in itself appear rather massive, no internal structures can be detected. 20cm below the boundary to the overlying clay, coarse to very coarse sand is deposited in thin lenses. Though, an overall CU or FU tendency cannot be reported. Description is difficult here, because a huge deformational structure dominates this interval of the profile.<br>Beside some minor water escape structures that are similar to the ones described in the lower units A, B and C, this deformational structure could be referred to as an ice-wedge cast from a first point of view. However, downwards bending and reverse faulting of the layers lead to the assumption, that the deformation is related to another kind of process (Fig. 28-A).<br>Indeed, the deformation structure seems to inject liquid down into the sediment, and even penetrates far into the underlying laminated clay unit E (Fig. 28-B). Thus, we have an explanation for the local deformation in unit E, but still cannot solve the reason for that deformation. |
| **22.10 m a.r.l. erosional boundary** | The boundary between underlying sand and overlying deformed clay appears very sharp and is draped by iron precipitate (Fig. 29-A). Very fine greenish sand is drawn into that boundary (Fig. 29-B). The deformation above (unit G) does not affect the underlying unit F, which clearly underlines the erosive character. |
| **22.10 - 23.50 m a.r.l.**<br>**Unit G** | It is very hard to work in the deposits of this unit. The clay we can find here is very wet and sticky. Also it is very much deformed and gives the impression that it was slumped to its final position (Fig. 30-A). The primary lamination however, is preserved. So, most likely this unit was |

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| | horizontally bedded, there where it was first deposited. Then the entire package was moved, which led to the complete slumping, where also very fine sand was worked into (Fig. 30-B). Only in the uppermost decimetres the deformation decreases, so that lamination is about horizontal again.<br>The laminae are very thin, about one millimetre. |
| **23.50 m a.r.l.**<br>**boundary** | It remains unclear, how the boundary should be traced here. Due to the very high water content in both, under- and overlying sediment, it is difficult to determine whether we deal with an erosional or a transitional boundary. For the time being, we would tend to describe a transition from laminated deformed clay with very fine sand worked into it, towards a very fine sand that is green in colour. |
| **23.50 - 24.75 m a.r.l.**<br>**Unit H** | Just below the top of the profile, seemingly the sediments get more and more influenced by pedogenetical processes. The lowermost greenish very fine sand lies above an aquiclude (unit G) and is therefore filled with water. The green colour probably resolves in reduced iron due to waterlogging. No internal structures can be detected inside this 25cm thick layer (Fig. 31-A).<br>Towards the top there is a coarsening upwards in fine to medium sand. The massive appearance in the lower part changes to a more stratified one towards the top, which is very hard due to iron-precipitation (podsol) (Fig. 31-B).<br>Only a few ripple-like structures can be guessed at 24.20m (Fig. 32-A) |
| **24.75 - 25.50 m a.r.l.** | Top of the profile. Soil cover. Pinewood on sandy substrate |

**A** **B**

*Fig. 15.* Hummocks and Swales, unit A (9.10 - 10.60 m a.r.l.). Weak bioturbation can be seen in more fine-grained material in swales and on hummock crests. Pictures are orientated W-E.

**A** **B**

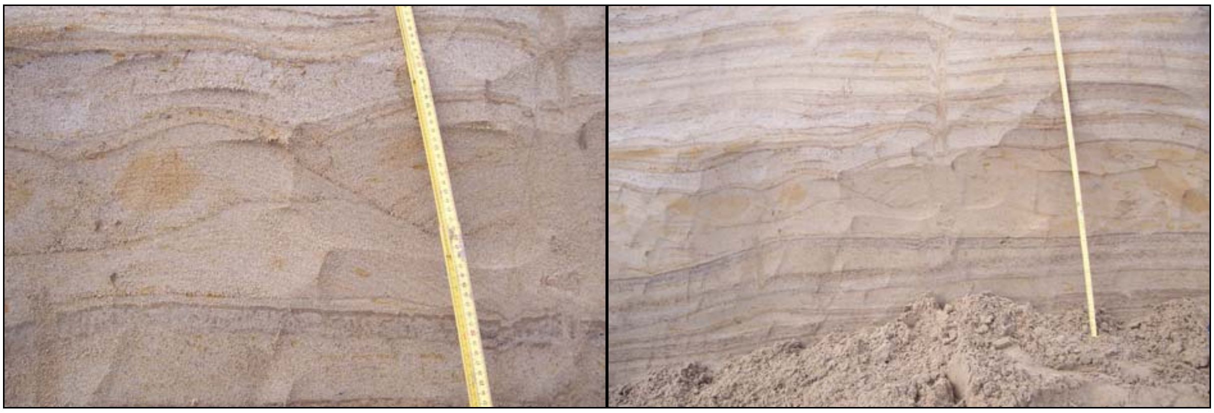

*Fig. 16.* **A**) Hummocky Cross Stratification, unit A (9.10 - 10.60 m a.r.l.). **B**) Horizontal bedding and HCS, unit A (9.10 - 10.60 m a.r.l.). Pictures are orientated W-E.

**A** **B** **C**

*Fig. 17.* Water escape structures draining downwards. **A**) unit C (14.25 - 16.00 m a.r.l.). **B**) unit B (10.60 - 14.25 m a.r.l.). **C**) unit A (9.10 - 10.60 m a.r.l.). Pictures are orientated W-E.

**A** **B**

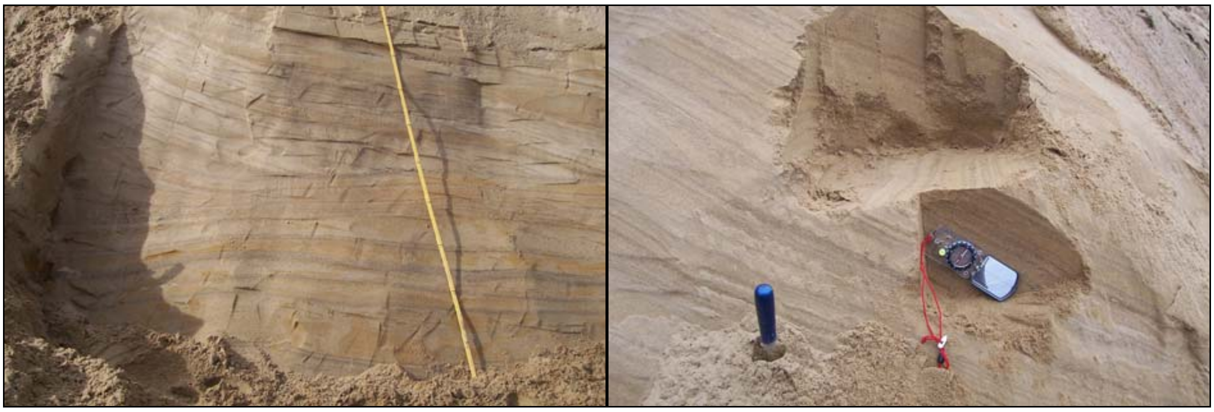

*Fig. 18.* **A**) Transition from delta bottomsets (unit A) to foresets (unit B). **B**) Measuring dip direction and dip of delta foresets with compass. Pictures are orientated W-E.

**A** **B**

*Fig. 19.* **A**) Bleaching water escape (unit B). **B**) Erosional boundary from unit B to unit C. Pictures are orientated NW-SE.

**A** **B**

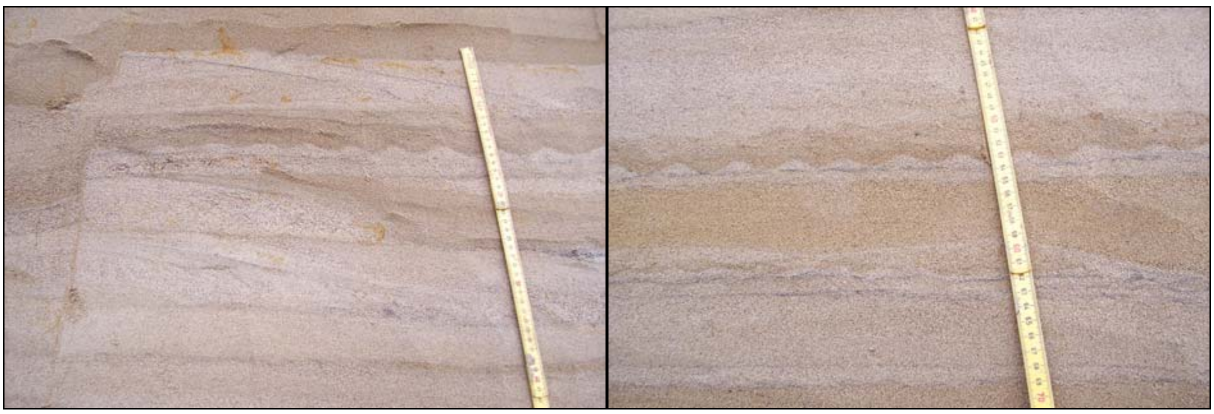

*Fig. 20*. **A**) oscillation ripples and current ripples (lower unit C). Normal faulting. **B**) oscillation ripples associated with black organic-rich lamina. Pictures are orientated NW-SE.

**A** **B**

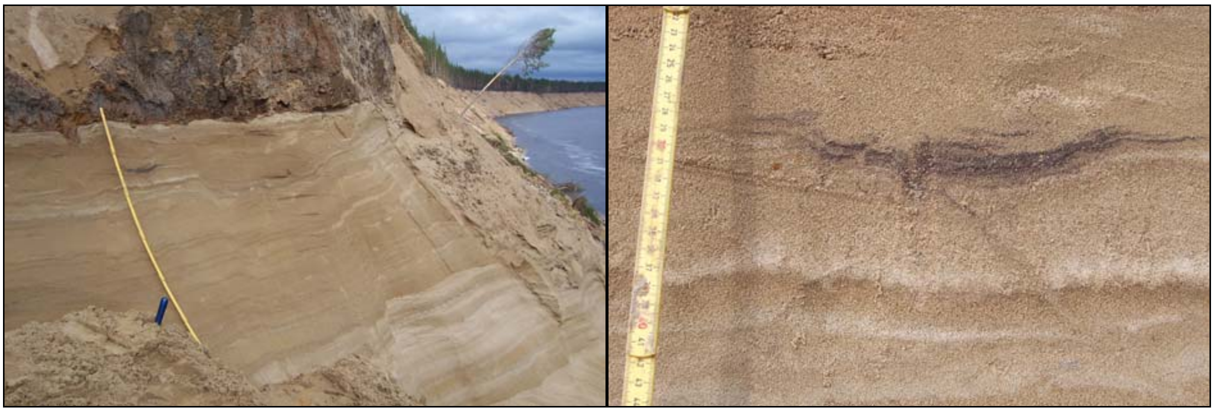

*Fig. 21.* **A**) Colour-change from lower to upper unit C; diamicton (unit D) on top. **B**) lens of organic material (upper unit C). Pictures are orientated NW-SE.

**A** **B**

*Fig. 22.* Ripple structures with brownish clay/silt, below the boundary from unit C to unit D. Pictures are orientated W-E.

**A** **B**

*Fig. 23.* A) massive sand slumped with clay (till unit D). B) boundary, where deposits from unit D penetrate in the underlying unit C. Pictures are orientated W-E.

**A** **B**

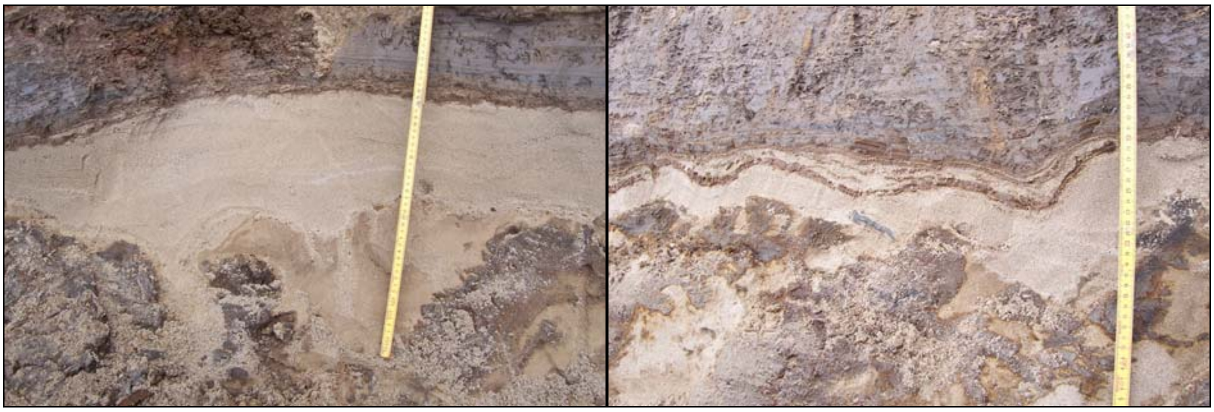

*Fig. 24.* Boundary between the diamiction (unit D) and the overlying rhythmite. It is unclear whether the light-coloured sand in between belongs to unit D below or if it is the transition to the overlying “warvite”. Note that the sand seems to level out the unevenness, as does the laminated clay unit, too. Pictures are orientated NW-SE.

**A** **B**

*Fig. 25.* unit E. **A**) rhythmical deposition of clay and silt. **B**) lenticular bedding, coarsening upward sequence. Pictures are orientated NW-SE.

**A** **B**

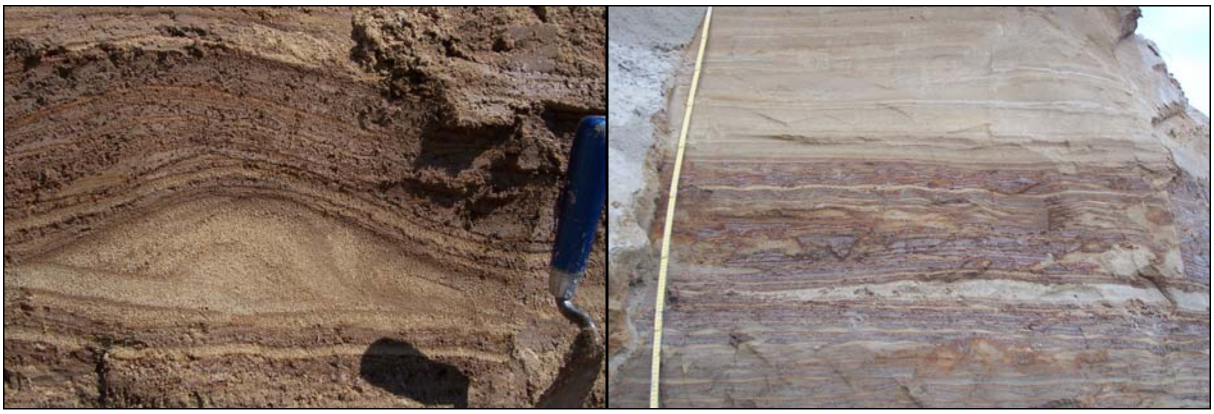

*Fig. 26.* **A**) hummock, ripple structure in the uppermost laminated clay unit E. Picture orientation W-E. **B**) wavy bedding in the upper unit F and gradual transition to overlying horizontally bedded sand unit F. Picture orientation N-S.

**A** **B**

*Fig. 27.* **A**) deposition of fine-grained material stops at the transition from unit E to unit F. **B**) stratification of sandy unit F due to switch in grainsizes. Pictures are orientated NW-SE.

**A** **B**

*Fig. 28.* **A**) downwards bending, normal and reverse faulting of the sand layers in unit F due to water escape. **B**) ongoing deformation, penetrating into the underlying laminated fine-grained unit E. Pictures are orientated NW-SE.

**A** **B**

*Fig. 29.* **A**) sharp boundary between underlying sandy unit F and overlying deformed clay unit G. **B**) iron precipitate drapes the unit F / G boundary. Note the very fine greenish sand that is worked into the deformed clay unit G. Pictures are orientated W-E.

**A** **B**

*Fig. 30.* **A**) very wet, deformed laminated clay unit G. **B**) preserved lamination in the clay. Sand is worked into the deformed unit G. Pictures are orientated NW-SE.

**A** **B**

*Fig. 31.* **A**) boundary between underlying deformed clay unit G and overlying sandy unit H. Note the 25 cm of very wet, greenish very fine sand. **B**) sandy unit H, considerably influenced by pedogenetical processes, iron-precipitate below soil cover. Pictures orientated W-E

**A** **B**

*Fig. 32.* **A**) ripple-like structures in sandy unit H. picture orientation W-E. **B**) till-wedge at the lower boundary of the diamictic unit D at Loc.06025_2.40km. Picture orientated NW-SE.

## Interpretation

Seemingly, the source area of the sedimentary input has not changed throughout the deposition of Unit A and Unit B. There is no doubt, that this part of the profile represents a deltaic environment with foresets (Unit B) that are prograding with south-easterly directions into a basin, and horizontally bedded bottomsets (Unit A) that are interbedded with layers of HCS and SCS from occasional storm events. This suggests that unit A was deposited below the fair-weather wave base, but above the storm-weather wave base.
Altogether we have here a textbook example for sequence stratigraphy (Fig. 33): superimposed strata from a vertical point of view is lying side by side to each other from a horizontal point of view.

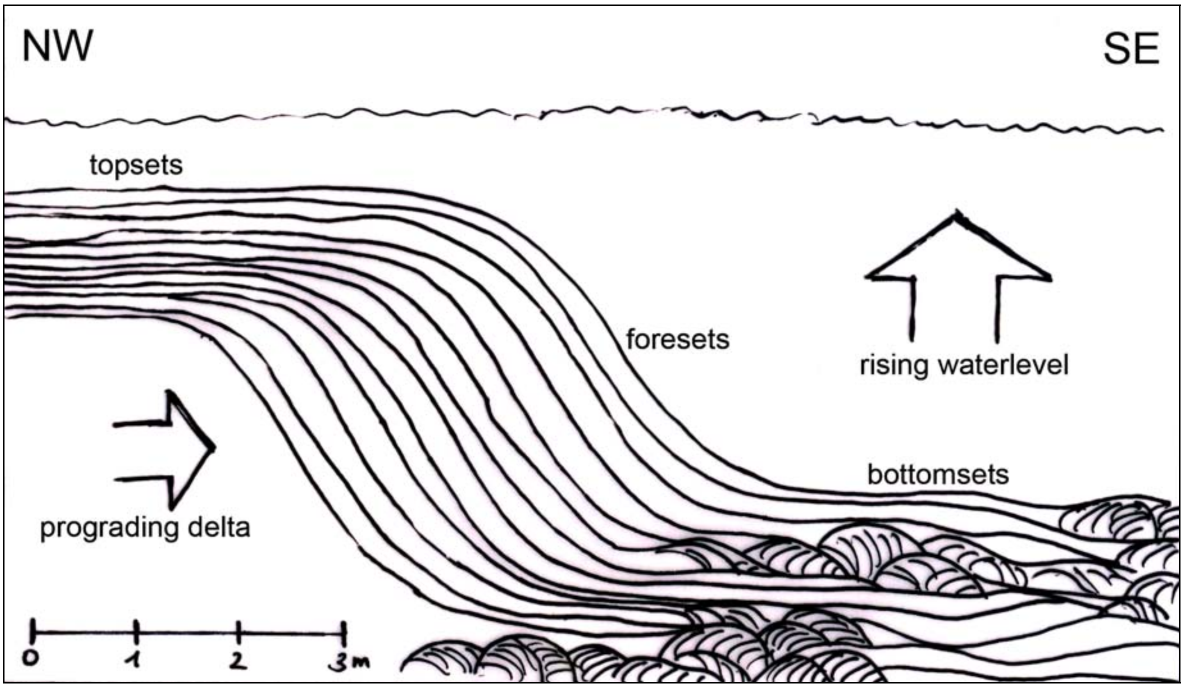


*Fig. 33.* Eventstratigraphical timing of deltaic foresets and bottomsets with hummocky cross-stratification. Climbing HCS suggests a rising waterlevel.

The transition from bottomsets to foresets is migrating upwards to the south-east, which suggests not only a considerable influx of sediment but also shows a transgressive character. The forming of HCS needs to stay between fair- and storm-weather wave bases and therefore calls for a rising water level. This hypothesis is strengthened by the fact that investigations from 2006 have made a log at Loc.06025_3.19km (JENSEN 2006b) where HCS has been found at least up to 12 metres a.r.l., if not 14.50 metres a.r.l. which would correlate with the erosional boundary at 14.25 metres in this study. In addition to that, no foreset deposits are described from Loc.06025_3.19km, which underlines the erosive character of the boundary at 14.25 metres a.r.l.

It is important to point out that HCS and SCS are usually ascribed to marine facies. Nevertheless, we tend to believe that unit A and B are deposited in a lacustrine environment, because of the organic material and the complete absence of other marine indicators. Furthermore the depostition in a marine environment would imply a sea level more than 60 metres above the present (elevation of river level at Tolokonka + altitude in the log + storm-weather wave base). This can only be realized during the early Eemian, right after Saalian deglaciation, due to isostatic depression. But since we have a till in unit D that is most likely to be Saalian, this configuration sounds impossible.

However, an ice-dammed lake could in fact explain such a high water level too. In a way this is sensational, because HCS in a freshwater-body will suggest an enormously large lake to explain the building-up of sufficiently big waves, capable of forming HCS. It would also imply to explain the provenance of such strong winds that could come for example as catabatic winds from an approaching glacier. Indeed, unit D leads us to suspect a till deposit (see below).

Given the deltaic environment, at a first glance the sediments of unit C appear to be the topsets. We admit of course, that the described oscillation ripples and current ripples would not form in the main channels of the delta. But at a certain distance and above the fair-weather wave base these ripples could have formed easily. We would expect shallow water, meaning that the shoreline of a presumed lake was not too far away. The erosional boundary at 14.25 doesn’t stand in contradiction with the delta, which constantly changes the main channels of discharge and would easily erode its own deposits. However, data collected in 2006 at Loc.06025_3.19km, where HCS reaches up to 14.50 metres a.r.l., suggests that the erosional boundary in our profile represents a significant drop in water level. Still, to our understanding unit C represents a lacustrine environment, only with a shallower water level, and also because of the organic material deposited.

The boundary described at 16m a.r.l. is definitely hard to get. On one side we have clear ripple structures with mud-drapes, as can be seen especially at Loc.06025_3.50km and Loc.06025_3.57km which suggests a conformable boundary. On the other side we see erosion and at Loc.06025_2.40km there was found even a till wedge (Fig. 32-B). In addition to that, it was at Loc.06025_2.40km where the till unit was described in detail, and due to its reddish and brownish colour it was referred to as a Moscovian till. This caused most of the sediments in the Tolokonka section to be much older than previously expected.

Moscovian or Late Weichselian, an ice sheet was running over and most likely eroded the underlying sediments, even if only a little bit.

To summarize the main picture so far, we start with an ice-sheet that is damming the river outlets in the north and the White Sea Basin. Rising water level is forming a huge lake, but river discharge continues into the basin, because the water divide has not been reached yet. Since the ice sheet is still some hundred kilometres away, the sandy deposits reflect mainly the fluvial influx from the surrounding highlands.

Assuming, that the till unit D is of Moscovian age, we can imagine that there was an ice-dammed lake in front of the Moscovian ice sheet which was advancing into south-eastern directions (Fig.3B). Thus, the sudden opening of a pathway might have led to a partial outburst of the lake. This could explain a drop in lake-water level and an ongoing deposition in shallower water, until these sands were finally overridden by the ice sheet.

We could also imagine that there was an ice-dammed lake at an even earlier Saalian stage. As suggested in Fig.3A by ASTAKHOV (2004), an ice-lobe might have dammed the Severnaya Dvina in the south, which could explain the higher water level - and when the lobe retreated, some of the water in the lake was released towards the south, while in the north the river outlets where still dammed. But in a way this is probably too far fetched for this study.

As the ice-front approaches, probably there was a more and more fine-grained input of sediments. This could explain the mud-drapes on top of the current ripples in the uppermost unit C just below the boundary at 16m a.r.l.

The ice sheet was then eroding onto unit C, depositing unit D, and when it was retreating again the slumping occurred - that is, the deformation of the diamicton under subaqueous conditions. Given the topography of the Severnaya Dvina area, we assume that when the ice retreats, it would still have a periglacial lake in front of it until the pathway to the ocean finally opens. The laminated clay rhythmite (lower unit E) could stand for a proximal ice front, with deposition of fine-grained material. Thus, we have a typical glaciolacustrine sedimentary environment. As farther the ice is retreating, the more coarser-grained material is deposited from the influx of rivers into the lake. To our opinion, the glacial influence must considerably decrease, when the ice front stands 400 km further back in the northwest. This, we believe, is reflected in the upper part of unit E by the interbedded silts and sands. As the boundary to unit F is transitional, we might even go further and assume that unit F is also deposited under these lacustrine conditions.

We must admit however, that unit F is not completely understood. At one point, we think, the glacial retreat must have led to the release of the ice-dammed lake into the ocean. To our understanding this would lead to fluvial erosion and/or fluvial deposition. Possibly isostatic depression and the Eemian transgression are the reason for a low topographical inclination, and this would suggest more deposition than erosion.

As we cannot find any marine sediment in the profile, although they are suggested in the palaeogeographic reconstruction of LARSEN et al. (2006) (Fig. 11-A) and GRØSFJELD et al. (2006) (Fig. 7), we tend to believe that Eemian deposits have either never been deposited in the Tolokonka area, or more likely have been eroded by fluvial drainage to the north. This idea would be expressed in the erosional boundary at 22.10 m a.r.l. - no matter whether unit F expresses a lacustrine or a fluvial environment.

According to the reconstructions from Larsen et al. (2006), we would expect fluvial deposits in the Severnaya Dvina area almost throughout the entire Weichselian (see Fig. 11), but in our profile from Tolokonka, fluvial evidence is sparse.

Unit G, the deformed laminated clay, might represent the last remnants of the lower Middle Weichselian glaciation ice-dammed lake - the White Sea Lake presumed in Fig. 11-E. The process though, that might have caused the slumping and the deformation in this unit remains unclear. This is probably due to the little information we get from the overlying unit H.

Deposits from the LGM are also missing, and might have been eroded already or never have been here.

Thus, we would like to conclude with the depositional history of the sediments at Loc.06025_3.24km in the Tolokonka section, knowing that our explanations cannot be exhaustive.

Furthermore, we would like to draw once more the attention to the structures that have been referred to water escape, and which can be found throughout the profile.

In the segment between 9.10 and 16.0 metres a.r.l., we can find two different features, and in the interval of unit F a rather large-scaled structure catches the eye. From a first point of view, at least two of these structures could have been described as ice-wedge casts, as they would fit very well the expected periglacial environment. But the overall impression we got from these structures was, that fluids have been injected downwards into the sediment. Also we can see reverse faulting in the deformational structure of unit F (Fig. 28-A), which is very much unlikely to occur in ice-wedge casts.

One explanation could be the following example: the slumping of the very wet clay unit G onto unit F can be regarded as a sudden event that is capping the underlying sands as they are. Due to the loading, pore pressure increases but cannot escape to the top. That means, the water is now trapped between two clay units. Given that situation, it now appears that the pore pressure in the sand units (A, B and C) below the till is much lower, and somehow there is way  to "communicate" with the sand unit F through cracks for example.

So we have two aquifers - two groundwater levels that communicated with each other in order to equilibrate their pore pressure, after being suddenly capped by unit G. Before that event, there was not enough pressure to penetrate through the clay units that represent an aquitard or aquiclude.

## Conclusions

When the expedition set camp at Tolokonka this summer, we expected with excitement that the sedimentary succession in the 4.2 km long section would draw an unambiguous picture of the Late Pleistocene environmental history in northwest Russia. Preliminary investigation from 2006 made Tolokonka to be a promising site, not only for finding deposits of a presumed White Sea Lake, but also a more or less continuous record of the Weichselian age.

However, working with the diamictic unit found that the reddish - brownish till was most likely to be of Moscovian age - that is, late Middle Pleistocene or pre-Eemian. This means that most of the deposits in the Tolokonka section are much older than previously expected. Indeed, according to our interpretation, Late Pleistocene does not appear until 22.10 metres a.r.l. where deformed laminated clay is deposited.

Therefore the Tolokonka sediments tell a rather late Middle Pleistocene (Saalian) story and show that the conception of ice-dammed lakes in northwest Russia does not exclusively belong into the Weichselian age.

Yet, concerning our reconstructions, we must admit that at least two boundaries are difficult to determine whether they show conformable or rather erosive character. This makes interpretation a bit more uncertain; maybe units A and B are in fact of Eemian age, representing river discharge from higher areas into the basin postulated in Fig. 11-A. Then there would be a hiatus between the underlying sandy units and the overlying till unit, where deposition is not documented. The till might also be of Weichselian age after all - maybe the LGM, and the overlying rhythmite could be the evidence of an ice-dammed lake such as the White Sea Lake.

The dating of the sediments by means of Optically Stimulated Luminescence (OSL) for example, would throw some light into these uncertainties and would help to exclude the more unlikely interpretations. OSL data however, can not be presented in this study, but samples have been taken at several spots in the Tolokonka section. Their analysis will provide a more accurate interpretation, when the different units can be associated with an exact date.

If OSL dating would confirm that the till is of Moscovian age, then the Tolokonka section and other sites in the surrounding area that have been visited during the expedition in 2006 (e.g. Loc.06026) would be a very good place to study the late Middle Pleistocene.

Further investigation could draw a more differentiated picture of the palaeo-environmental setting during the Late Saalian in northwest Russia. Along the 4.2 km section of Tolokonka, we figured that the succession of the sedimentary deposits changes considerably on the lateral extent. Mapping out the configuration over the entire section could lead to more hints and evidences. Possibly it could reveal what is hidden in the lower part of the section (0-9 m a.r.l.); very fine-grained material at the river-level indicates that there might be another glacial till, also a coaly layer has been spotted between underlying fluvial and overlying lacustrine deposits.

The totally changed environment, the deflection of the drainage pattern on a continental scale by the damming of river systems and their subsequent filling of huge ice-dammed lakes is a fascinating fact. The implication of a sudden outburst of freshwater from these lakes or even from glacier ice itself, seems to me to be of great importance. As we know, the release of fresh- or melt water caused rapid and dramatic changes in ocean circulation and climate, and it might probably do so in the future in areas that are glaciated nowadays. To understand the timing of lake and fluvial phases in relation to the ice sheet history will lead to a better conception about the timeframe these environmental changes take place in.

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## Abbreviations

| | |
|---|---|
| a.r.l. | above river level |
| a.s.l. | above sea level |
| APEX | Arctic Palaeoclimate and its Extremes (http://www.apex.geo.su.se) |
| BP | Before Present |
| CU | coarsening upwards |
| ESF | European Science Foundation |
| FU | fining upwards |
| GPS | Global Positioning System |
| HCS | Hummocky Cross Stratification |
| IPY | International Polar Year |
| ka | kiloannum |
| LGM | Last Glacial Maximum (maximum extent of the latest Weichselian ice sheet between 25 and 15ka BP) |
| LIG | Last Interglacial (Eemian) |
| MIS | Marine Isotope Stage |
| NGU | Norges Geologiske Undersøkelse; Geological Survey of Norway |
| OSL | Optically Stimulated Luminescence |
| QUEEN | Quaternary Environment of the Eurasian North |
| SciencePub | From Science to Public awareness: arctic natural climate and environmental changes and Human adaptation (http://www.ngu.no/sciencepub) |
| SCS | Swaley Cross Stratification |

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