Origins and development of the ancient outflow channel of the river Vantaanjoki, southern Finland, as indicated by fluvial sediments

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The city of Helsinki was founded in 1550 at the mouth of the River Vantaanjoki on the Gulf of Finland. There is a clearly distinguishable overgrown river bed located to the west of the present channel which would seem far too large for the minor stream flowing through it nowadays. The aim here was to determine whether this stream and its valley do in fact represent an ancient channel of the larger river, for how long this channel functioned and how and when it ceased to do so. The problem was approached by means of morphological surveys, corings, stratigraphic analyses and radiocarbon datings.

It may be concluded from the shoreline displacement data and the topography of the area that the threshold of the ancient channel emerged from beneath the sea around 4500 BP (5100 cal. BP). Subsequently two shallow lakes developed at approximately the same altitude around 4000–3500 BP (4500–3800 cal. BP), later drying up as the thresholds that retained them were eroded away. A channel some 50–70 m broad, 5–8 m deep and 8 km in length was created in the valley of the River. The channel began to fill rapidly with fluvial sediment around 2200 BP (2200 cal. BP), however, once the present course of the river was opened up over a low glaciofluvial ridge which had previously restrained its waters in the east. As the new channel gained in depth, the flow in the old one came to an end around 2000 BP (1900 cal. BP), by which time substantial quantities of fluvial sediment had accumulated in it.

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Introduction

Rivers are constantly eroding, transporting and depositing sediments, thereby shaping their channels and drainage basins, although there are numerous interfering factors such as tectonic effects, mass movements and glacial activity that force them to perform these actions under radically altered circumstances.

Tectonic movements have led to changes in the courses of rivers on the upper reaches of the Rhine and Danube in Central Europe, for instance (Becker-Haumann 2001), while the creation of the Andes Mountains in South America during the Late Miocene eventually prevented the waters of the Amazon and Orinoco from flowing north into the Caribbean Sea and diverted them to their present routes eastwards into the Atlantic Ocean (Hoorn et al. 1995). The rivers of Finland are young by comparison, having arisen since the last glaciation, so that they have not in general had time to erode very deep channels for themselves. Thus many of them are still flowing in preglacial valleys, on top of thick layers of glacial and postglacial sediment (Koutaniemi 1979, 1987). The largest river valleys that have been cut down into clay sediments are located in South-Western Finland and are about 30 m deep (Aartolahti 1975). Changes in river channels have nevertheless taken place here, too, in response to tilting of the terrain as a consequence of land uplift.

The greatest alterations in the courses of rivers were nevertheless those that took place in the ice-free areas during the Pleistocene, when the vast glaciers prevented them from flowing north in accordance with the slope of the terrain. Ice-dammed lakes arose in Northern Eurasia and in front of the glacial margin in North America, where periodic disastrous discharges from the Missoula Ice Lake towards the valley of the Columbia River eroded the now dry Channelled Scabland terrain (Bretz 1923; Baker & Nummedal 1978; Baker & Bunker 1985; Eronen 1991; Grosswald 1998; Baker 2002). There were also numerous ice lakes in the supra-aquatic areas of Finland during the deglaciation, and the discharge channels of these differed greatly from the present-day river systems (Miettinen 1996; Saarelainen & Vanne 1997; Tikkanen & Oksanen 2002).

The tilting of the land surface that took place during the Holocene is clearly reflected in features such as the differences in the heights of the highest markers of ancient shorelines, which are located around 220 m a.s.l. in the area north of the Bothnian Bay (Saarnisto 1981) but only at about 100 m a.s.l. in South-Eastern Finland in spite of the greater age of the latter (Tikkanen & Oksanen 2002). These major changes in height have meant that the major waterway systems of the inland parts of Finland have changed their outflow routes in the course of the post-glacial period, many of them several times (Saarnisto 1971; Tikkanen 1990, 2002). Their original outflow rivers were located in the north-west, but as tilting of the land surface proceeded, new routes opened up to the south, mostly in the interval 8000–4500 BP (Tikkanen 1995; Tikkanen & Seppä 2001). The most recent natural change in an outlet channel was that affecting Lake Längelmävesi in South-Western Finland, in AD 1640 (Blomqvist 1926; Jones 1977).

Not all alterations in outlet channels have caused far-reaching changes in the watercourses themselves, however, and some have taken place only as a consequence of gradual developments in river valleys (Koutaniemi 1987). Also, there are many rivers in Finland that have multiple outlets or bifurcations in their course at various points. The most devious watercourse in the country is probably the Karvianjoki river system, which flows into the Gulf of Finland through three rivers of different names and has at least five internal bifurcations (Kuusisto 1984). It has also been proposed that the River Vantaanjoki, which flows into the Gulf of Finland at Helsinki, may have had a second outflow branch at one time that has subsequently dried up (Petterson 1925; Hyyppä 1935, 1950a, 1950b; Roos 1950). The channel in question is located in the western part of Helsinki, in the valley now occupied by the River Mätäjoki. The size of the valley, at least, is out of proportion with the small stream currently flowing through it and is suggestive of the ancient course of a large river, but no research has been carried out to date to establish whether this was really another branch of the River Vantaanjoki and when it functioned as such. The aims of the present work were therefore to determine 1) whether the valley of the present-day River Mätäjoki once served as a second channel of the River Vantaanjoki, or possibly as its only channel, 2) when the channel was formed and for how long it functioned in this capacity, 3) what length of the present Mätäjoki valley served as an outflow channel for the larger river, and 4) what factors caused that channel to dry up.

Material and methods

For the above purposes, precise levellings and corings were carried out both in the valley of the present-day stream known as Mätäjoki and on both sides of the threshold dividing the two basins. Some reference measurements and corings were also made in the present-day channel of the River Vantaanjoki. Altogether about an 8 km stretch of the ancient channel was examined. The measurements were aimed at determining how wide and deep the assumed ancient channel must have been and what types of sediments were deposited on its bed. A longitudinal section of the River Mätäjoki and several cross-sections were constructed on the basis of the measurements and by reference to cartographic data. The thickness of the sediments and depth of the river bed were determined using a Russian corer (Jowsey 1966) with a chamber of length 0.5 m and diameter 10 cm. The measurements were also used to calculate the water throughput in different parts of the channel.

The nature of the sediment was also examined while taking the cores, and the depths of clearly distinguishable boundaries between horizons were measured. A total of five long sequences were taken for more detailed analyses in the laboratory, including loss-on-ignition (LOI), to deter-

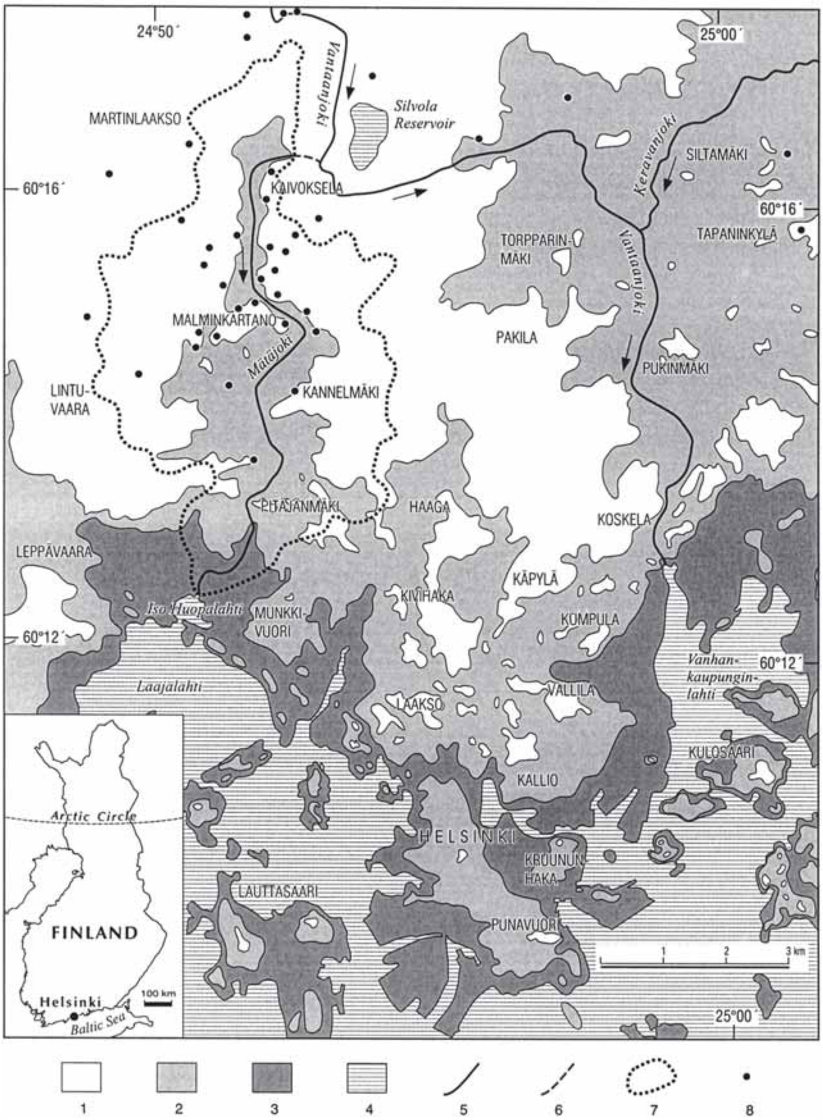

Fig. 1. The area studied and its emergence from the sea. 1. Areas that emerged before 4000 BP (4500 cal. BP), 2. areas that emerged 4000–2000 BP (4500–1900 cal. BP), 3. areas that emerged after 2000 BP (1900 cal. BP), 4. present-day water bodies, 5. present-day rivers and streams, 6. dried-up Djupbäck channel, 7. boundary of the Mätäjoki drainage basin, 8. prehistoric dwelling sites.

mine the organic content of the sediment (Bengtsson & Enell 1986). The cores, of which the longest was 560 cm in length and the shortest 190 cm, were sampled at five centimetre intervals for analytical purposes, and a total of five samples were taken from two of them for radiocarbon dating. The dates were obtained at the Helsinki University Dating Laboratory and calibrated with the CALIB 4.3 program (Stuiver et al. 1998). The timing of the origins of the ancient channel was assessed with the aid of shoreline displacement curves constructed for nearby areas (Ristaniemi & Glückert 1987; Seppä & Tikkanen 1998; Seppä et al. 2000).

The area and its emergence from the sea

The valley of the River Mätäjoki is located in the western part of the city of Helsinki and the southern part of the urban district of Vantaa (Fig. 1). It begins north of Kaivoksela and the small stream that occupies it flows into the Gulf of Finland at

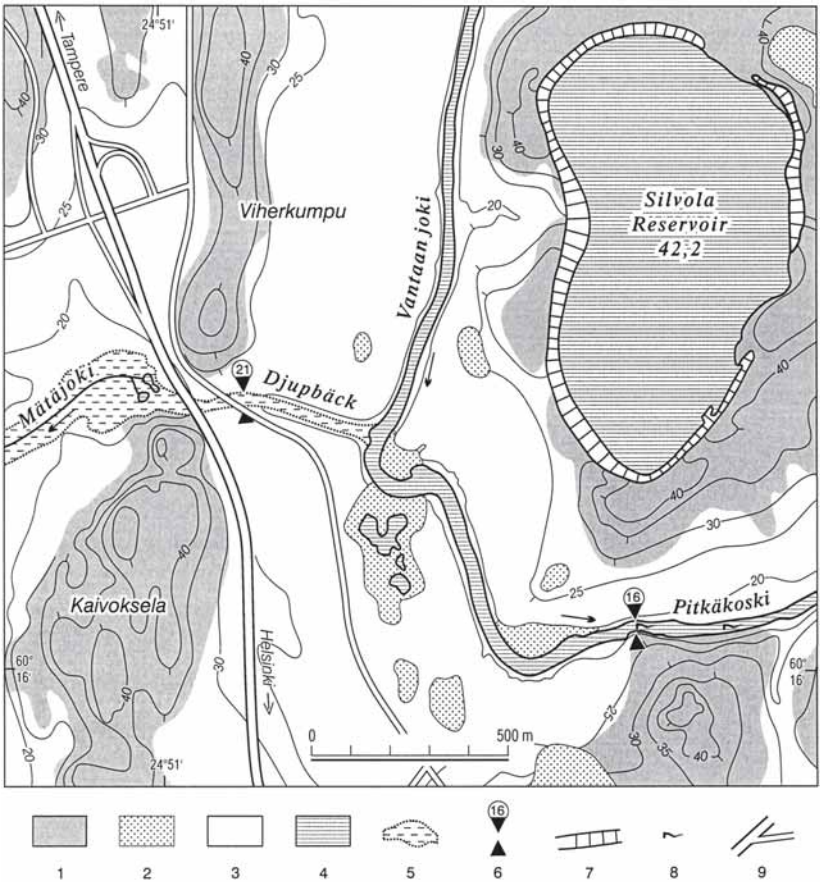

Fig. 2. Topography and surficial deposits of the bifurcation area. 1. Till and exposed bedrock, 2. sand and gravel, 3. clay and silt, 4. water, 5. ancient channel, 6. threshold and its altitude, 7. embankment of retained water basin, 8. rapids, 9. road. Contours are drawn at 5 m intervals.

the head of the bay of Iso-Huopalahti. The present-day River Vantaanjoki turns eastwards at Kaivoksela and enters the Gulf of Finland in the northern part of Vanhankaupunginlahti, the "Bay of the Old City", the point at which the city of Helsinki was founded in 1550. The River Vantaanjoki is almost 100 km long and its upper branches derive from the area north of the First Salpausselkä ice marginal formation (Tikkanen 1989). Its largest tributary is the River Keravanjoki, which enters it at a point east of Kaivoksela.

The present channel of the River Mätäjoki is about nine kilometres long and has a total drop of 17.6 m, of which 13 m is covered in the last two kilometres of its length (Ruth 1998), largely on account of a waterfall and stretch of rapids at Pitäjänmäki. The river above that point has a gradient of only 0.6 m km^{-1}, so that the water in the stream flows very slowly. The Mätäjoki valley above the rapids is largely peatland and broadens out and increases in depth towards the headwaters. At the uppermost point there is a further broadening of the valley that is again covered by a peat horizon, although it also features a number of pools.

Above the wetlands is the rocky threshold of Djupbäck, at an altitude of about 21 metres. It is difficult to define the true altitude any more precisely because the majority of the threshold area is now buried beneath roads. East of this threshold, however, lies an approximately 400 m stretch of dried-up river bed which connects the Mätäjoki valley with the present-day River Vantaanjoki (Fig. 2). The southern part of this channel has been filled in, so that it is no longer possible to determine its original width, but its full extent can be appreciated from old photographs (cf. Petterson 1925; Hyyppä 1935). The threshold is about five metres higher than the present-day surface of the River Vantaanjoki at this point and three metres above the surface of the wetlands from which the River Mätäjoki rises.

It may be deduced from shoreline displacement data (Ristaniemi & Glückert 1987; Seppä & Tikkanen 1998; Seppä et al. 2000) that there was still a long, narrow bay of the sea extending inland as far north as the Djupbäck threshold around 4000 BP (4500 cal. BP) (Fig. 1), although the surrounding area was already in a supra-aquatic position and the beginnings of the Mätäjoki channel had formed. By around 2000 BP (1900 cal. BP) the shoreline in the Mätäjoki valley had retreated to the point of the waterfall at Pitäjänmäki and that on the lower reaches of the present-day River Vantaanjoki was also close to the current estuary (Fig. 1).

Some signs of the oldest known human settlement in the area have been encountered in the surroundings of the Mätäjoki valley and the bay to which it led. The oldest Comb-Ceramic culture dwelling sites to be found here, dated to around 4300 BP (Erä-Esko 1980; Huuhka 1990), were located close to the shoreline of that time (Fig. 1). It is particularly significant, however, that the ancient settlement was grouped around the Mätäjoki valley, while few signs of early human presence have been detected in the present-day eastward outflow branch of the River Vantaanjoki.

Permanent agriculture commenced in the area in the 14th century and continued at an intensive level until the 1960s. The majority of the forests had been cleared for arable land by the beginning of the 20th century and there were three villages and a number of large estates in the vicinity (Sundman 1980). Suburban building connected with the Helsinki conurbation began during the 1960s, and the Mätäjoki basin now has a population of around 70 000 people (Ruth 1998; Ruth & Tikkanen 2001).

Results

We will now consider the results of the fieldwork and laboratory investigations focussed on an area about 8 km in length that begins at the present-day course of the River Vantaanjoki and continues to a point just north of the Pitäjänmäki waterfall on the lower reaches of the River Mätäjoki. The locations of the surveying and coring sites are indicated in Fig. 3.

Profile 1. A cross-section of the River Vantaanjoki was constructed for a point below the bifurcation of the dried-up Djupbäck channel and the present-day channel of the river. The maximum depth of the channel on this section is about seven metres, of which the water depth accounts for three metres. The current width of the river at the water surface is about 40 metres and that of the channel at its upper edges about 75 m (Fig. 3, profile 1). The deepest point in the channel is close to its eastern bank, and the bed is mostly covered by coarse sand and gravel containing some small stones, a material that is evidently associated with a N–S-oriented glaciofluvial deposit, the highest crests of which rise above the clay plain at a number of points close to the river (Fig. 2). This material is so coarse that it could scarcely have been transported to the site by the river itself, which has a slow rate of flow in this area.

Profile 2. The dried-up Djupbäck channel becomes steadily shallower from the bank of the River Vantaanjoki towards the bedrock threshold at Kaivoksela, being initially 4–5 metres deep. Its original width cannot be determined, as it has been filled in along its southern edge, but the survey by Petterson (1925) suggested that it must have been about 60–70 metres across in a natural state, i.e. practically as broad as the present-day channel of the River Vantaanjoki. The form of the channel at the threshold can similarly no longer be determined with accuracy, as a large part of it has been filled in in connection with road construction work, although again we can refer to the measurements reported by Petterson (1925), which indicate a total width of at least 55 metres and a maximum depth of 1–2 metres (Fig. 3, profile 2). Given a flow rate of 1–2 m s^{-1}, this could easily mean a discharge of 100–200 $m^3 s^{-1}$ over the threshold.

Coring site 3. The old channel opens out below the threshold to form a partially open mire about 200 m in diameter and with its surface more or less at the level of the surrounding terrain, so that it is difficult to perceive any true river channel. There are a few small pools in the eastern part of this mire area (Figs. 2 and 4) with their water surface at an altitude of 17.6 m (Ruth 1998). Cores taken in the mire indicate that the surface of the mineral soil lies at a depth of 7–8 metres and that the base of the basin varies in quality from bedrock or stones to sand or a bluish-grey marine clay. There is also an extensive area over which the surface peat is found to be in effect floating on water, so that it subsides under foot. The whole mire area thus obviously rep-

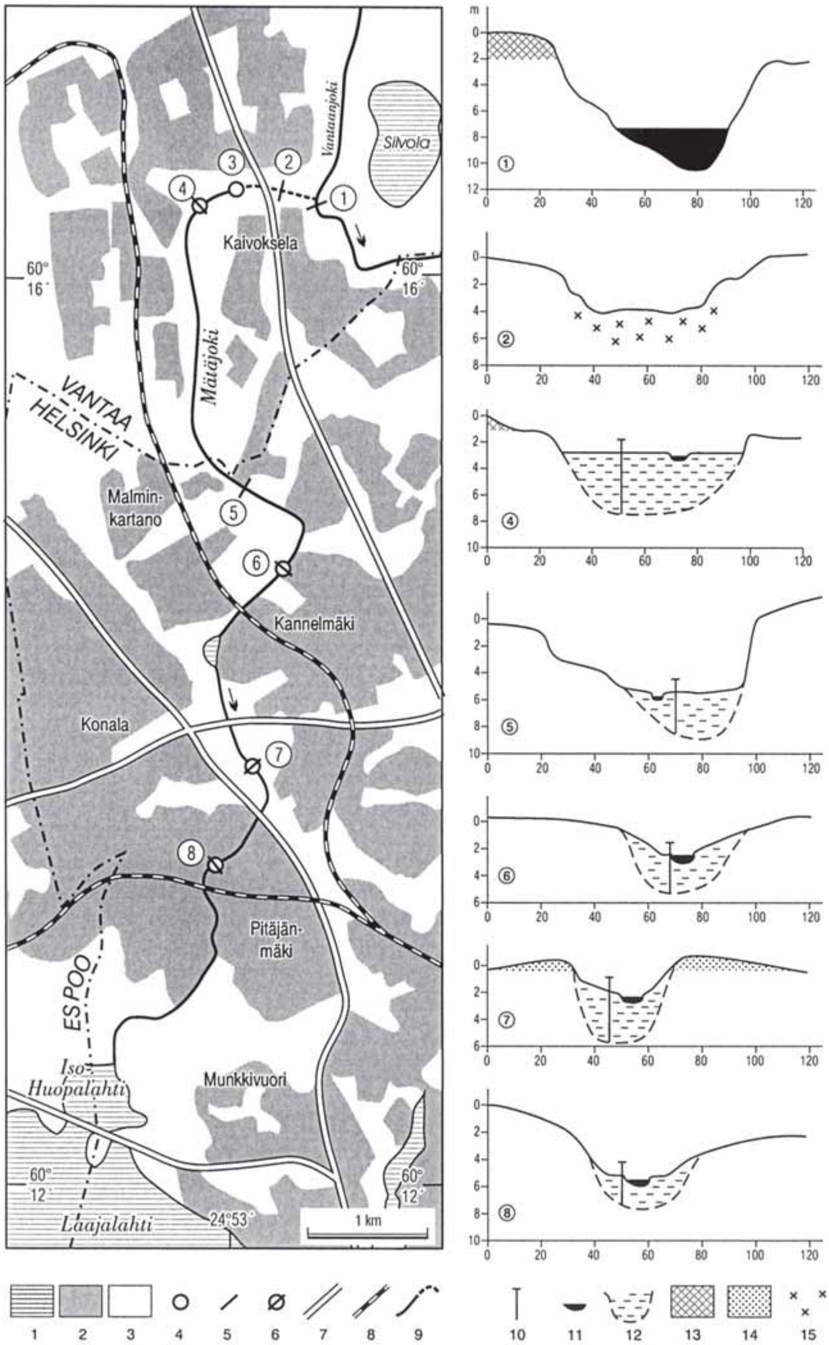

Fig. 3. The profiles and their locations. 1. Water, 2. built area, 3. green area, 4. sampling site, 5. profile, 6. profile and sampling site, 7. main road, 8. railway, 9. stream and dried-up channel, 10. coring site, 11. present-day channel of the River Mätäjoki, 12. sediment-filled ancient channel, 13 landfill, 14. levée, 15. bedrock. Profile 2 is based on survey details published by Petterson (1925).

resents a broad pool of standing water that once existed below the rapids that marked the threshold, similar to the pools to be found today below the stretches of rapids on the River Vantaanjoki.

A core obtained from the sediment below one of the pools on the mire, with a water depth of four metres, showed the total thickness of sediment to be 370 cm, with coring interrupted by

Fig. 4. A small pool below the Djupbäck threshold in the headwaters of the present-day River Mätäjoki. The samples representing coring site 3 were taken from this lake. (Photographs by the authors.)

the bedrock or a loose boulder at a depth of 770 cm from the water surface. This hard substrate was overlain by an approx. 40 cm horizon of sandy sediment containing large amounts of ligneous material, giving loss-on-ignition readings of 60–70% (Figs. 5 and 6A). Numerous further cores confirmed that this same sediment horizon, the ligneous material in which gave a radiocarbon date of 2220 ± 110 BP (2200 cal. BP), exists at the bottom of the stratigraphy throughout the mire basin. Above it in the core described here is a layer of clay gyttja (depths 320–160 cm) with a loss-on-ignition varying in the range 6–20%, and beyond this (160–12 cm) a sediment composed chiefly of gyttja with highly variable loss-on-ignition values in the range 20–45%. The surface sediment was black in colour and had a loss-on-ignition of only 10%, suggesting that emissions arising from human activities in the area had caused an oxygen deficiency in the basin, so that the youngest sediments were a sulphide clay-gyttja.

Profile and coring site 4. The mire area narrows once the basin that had been located below the threshold comes to an end and the infilled river channel itself is again clearly visible, although its surface is only about a metre below that of the surrounding terrain. A further core taken about 500 m downstream from that representing the mire basin (Fig. 3, site 4) indicates a thick layer of sediments that vary greatly in character down to a depth of 540 cm, at which point a blue-grey clay is encountered (Figs. 5 and 6B). Immediately overlying the clay is a 10 cm sand horizon (540–530 cm) and above this a horizon of sandy gyttja (530–502 cm). The layer between 502 and 244 cm is then occupied by a thick deposit of gyttja and clay-gyttja with loss-on-ignition values in the range 6–33% and varying particularly markedly in the lower part, those in the upper part being more stable and somewhat lower. The lower part of this layer gave a radiocarbon date of 2220 ± 70 BP (2200 cal. BP), i.e. the same as for the ligneous material at the base of the previous core, and a very similar date, 2270 ± 70 BP (2330 cal. BP), was obtained for a point 2.5m higher in the stratigraphy, in the upper part of the same layer. The nature of this sediment and the dates obtained for it suggest that it was deposited very rapidly by flowing water.

On top of the clay gyttja layer was a 12 cm horizon of gyttja clay (244–232 cm) with a loss-on-ignition of only 4–6%, and above this a horizon of peat and gyttja extending to the surface (232–0 cm) and having loss-on-ignition values reaching as high as 86% in places, although entering a distinct decline from 70 cm upwards and being no more than 15% at a depth of 10 cm. A date of 1540 ± 70 BP (1410 cal. BP) was obtained for the lower part of this peaty layer, and one of 330 ± 70 BP (380 cal. BP) for a depth of 70–65 cm.

The core results indicated that a deep channel had also existed at this point at one time, and that

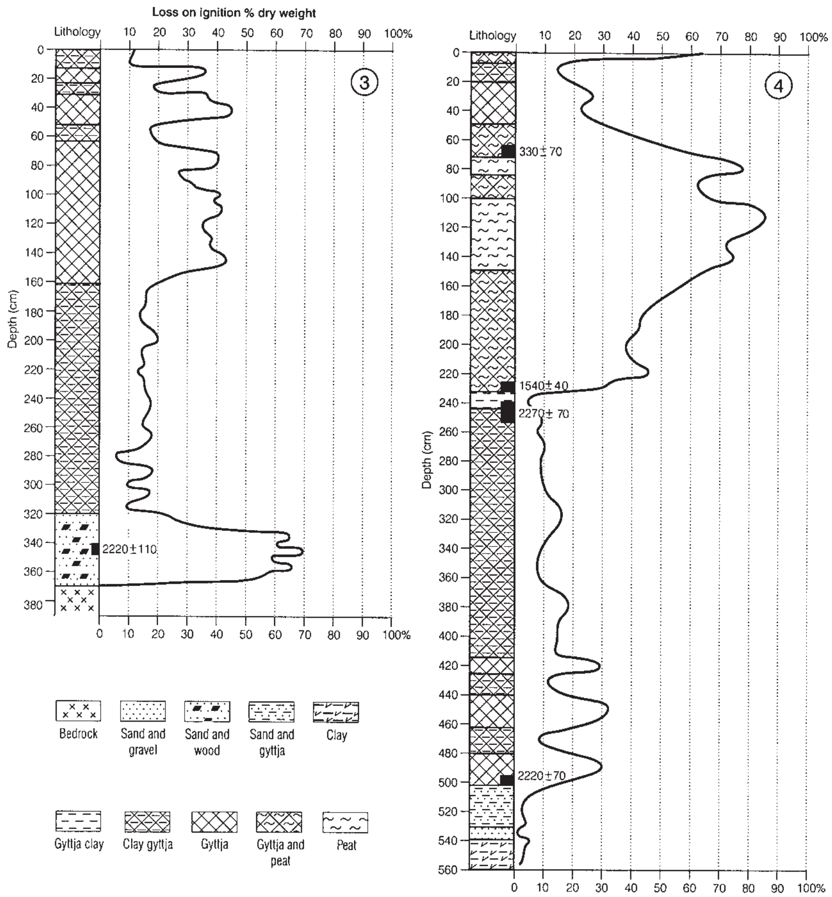

Fig. 5. Stratigraphies and loss-on-ignition curves for coring sites 3 and 4. For locations of the sites, see Fig. 3.

it had later been filled in with sediment. Profile 4 in Fig. 3 shows a reconstruction of the form of this ancient channel, based admittedly on only one core, as coring by hand proved especially laborious at that site. The profile may thus be regarded as representing a minimum depth for the channel, since it is quite possible that deeper points could be found elsewhere. In any event, it is clear that the channel, which is nowadays virtually filled in with sediment, was once some 70 m broad and at least 5.4 m deep.

Profile 5. This profile has been constructed for a site located close to Malminkartano where there is nowadays a minor stretch of rapids on the River Mätäjoki. The valley is at its largest in this area, with a width of at least 60 m and a maximum depth of 8 m (Fig. 3, profile 5), thus corresponding well to the size of the channel of the River Vantaanjoki at the site of profile 1. The profile is based on three cores, so that the depth of the channel and form of its bottom may be regarded as fairly reliable. No loss-on-ignition determinations were performed, but visual observation suggests the following stratigraphy for the core:

0– 25 cm	peat
25–55 cm	silty gyttja or clay gyttja
55–80 cm	sandy gyttja or clay gyttja
80–100 cm	homogeneous gyttja or clay gyttja
100–270 cm	gyttja containing ligneous or other organic material
270–310 cm	gyttja with silt bands
310–320 cm	gravel

It is significant that the surficial peat horizon is considerably thinner here than at the previous coring site, but that the majority of the sediment depth is again taken up by deposits laid down by

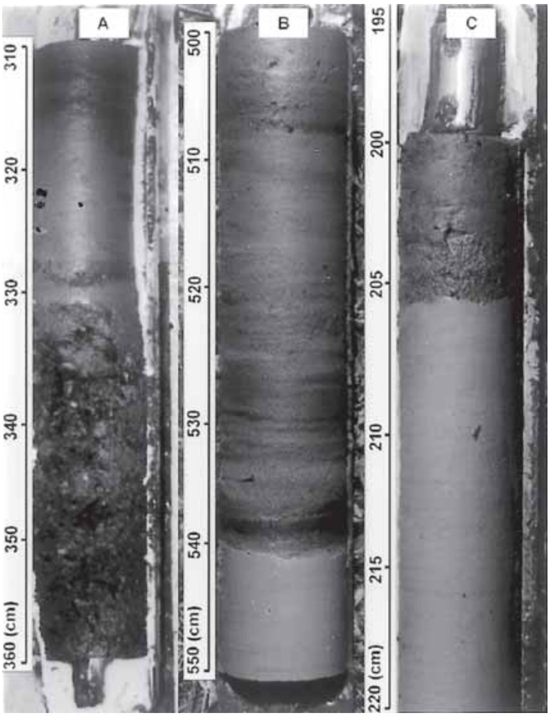

Fig. 6. Sediment samples from the bed of the old channel. A. The sample from the Djupbäck basin (coring site 3) has a clay gyttja horizon above the layer that is rich in ligneous material. B. The core from site 4 has marine clay at its base, overlain by sand and then clay gyttja and gyttja. C. The base of core 6 consists of clay, overlain by clay gyttja.

flowing water and containing large amounts of ligneous material and other plant remains. The gravel layer at the base indicates that there was probably a large, swiftly flowing river here at one time, capable of transporting coarse material and depositing it on the channel bed.

At the site of the profile the channel occupies the bottom of a narrow valley, the original surface level of which is difficult to determine. It would seem from the present-day topography, however, that a threshold at a height of at least 20 m a.s.l. had existed at this point at first, i.e. it had been very close to the level of the Djupbäck threshold. This would have meant the creation of a lake basin some 1–2 metres deep between these two thresholds at that early stage and its subsequent draining as the lower threshold was eroded.

Profile and coring site 6. The next cross-section was surveyed across a level field and parkland area (Fig. 3, profile 6). The channel is narrower at this point than at the previous coring site, but it is difficult to estimate its original width precisely as cultivation has been extended right up to its edge and the old river bank has been rendered less steep as a consequence of ploughing. The span between the upper edges of the channel is at least 50 m, however, and signs of low levées deposited by floodwater are to be detected beyond these. The core indicated that the basal clay was covered by 205 cm of sediment, implying that the total depth of the channel had been about five metres.

Although fluctuating considerably, the organic content of the sediment overlying the clay increased in general terms until a depth of 75 cm, where the loss-on-ignition value was 77% (Figs. 7 and 6C). This lower part of the sediment horizon was composed of a clay gyttja, which graded to gyttja at a depth of 180 cm and contained an abundant admixture of peat from 125 cm upwards. The surface horizon of about 50 cm contained a silty mineral material that reduced its loss-on-ignition values to 10–25%.

Profile and coring site 7. The channel at this point was more or less of the same width as at the previous site, but it was edged with somewhat larger outward sloping levées (Fig. 3, profile 7). It also proved to have been deeper than at site 6, as a 390 cm bed of sediment had accumulated on top of the basal clay. The difference in altitude between the levée and the bottom of the channel at the coring site was about 7 m.

Immediately overlying the basal marine clay was an approximately 30 cm horizon of sand containing large amounts of ligneous material in places (Fig. 7), while above this the sediment was composed of clay gyttja and gyttja. A horizon occupying the interval 198–83 cm contained an abundance of peat, reaching a maximum loss-on-ignition of 72% at a depth of just over 120 cm, from which point the values declined as the deposition of silty material increased. Loss-on-ignition fluctuated markedly throughout the sediment sequence, however, pointing to constant variations in deposition conditions.

Profile and coring site 8. The last coring site was located close to the rapids and waterfall of Pitäjänmäki (Fig. 3, profile 8), where the channel was both deeper and broader than at the previous two sites. This is partly due to the fact that the terrain outside the channel lies at about 17 m a.s.l., or 1–2 m higher than in the previous cases.

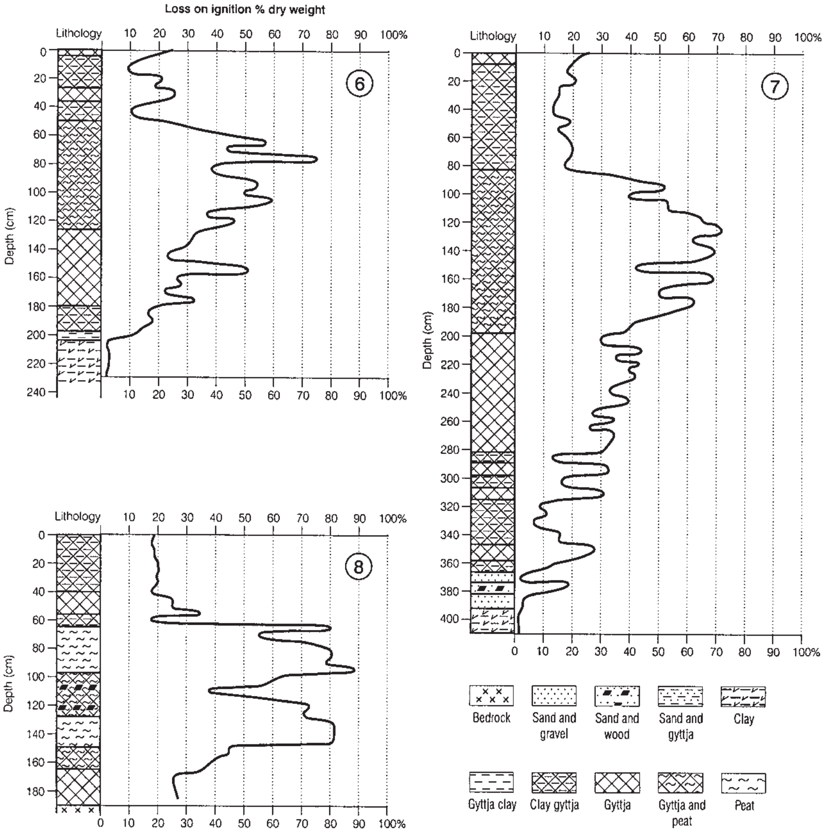

Fig. 7. Stratigraphies and loss-on-ignition curves for coring sites 6, 7 and 8. For locations of the sites, see Fig. 3.

It is also probable that here, too, a shallow lake existed above the threshold initially, possibly extending upstream as far as sites 6 and 5. The total thickness of the sediment deposited in the bottom of the channel was 190 cm at this point (Fig. 7), the corer then encountering either the bedrock or a loose boulder. The bottommost sediment was gyttja, above which an admixture of peat and ligneous material started to accumulate from a depth of 165 cm upwards. The maximum loss-on-ignition value, 89%, was recorded at 95 cm, but readings dropped sharply to around 20% at the 60 cm level with the appearance of silty material. As the flow rate in the area close to the threshold was presumably high, around 1 m s^{-1}, the channel would have been capable of supporting a discharge of at least 150 $m^3 s^{-1}$.

Discussion and conclusions

There have been a number of suggestions in the literature that the Mätäjoki valley may have served as the outflow channel for the River Vantaanjoki at one time, or at least as a second branch of its outflow (Petterson 1925; Hyyppä 1935, 1950a, 1950b; Roos 1950; Tikkanen 1989; Ruth 1998; Ruth & Tikkanen 2001). These have been based mostly on the considerable size of the Mätäjoki valley in its upper reaches and the existence of a dried-up channel joining this to the present River Vantaanjoki via the Djupbäck threshold. It is obvious that a valley of those proportions could not have been created by the small stream that occupies it at present, especially since the shallow gradient in the area means that the flow rate is ex-

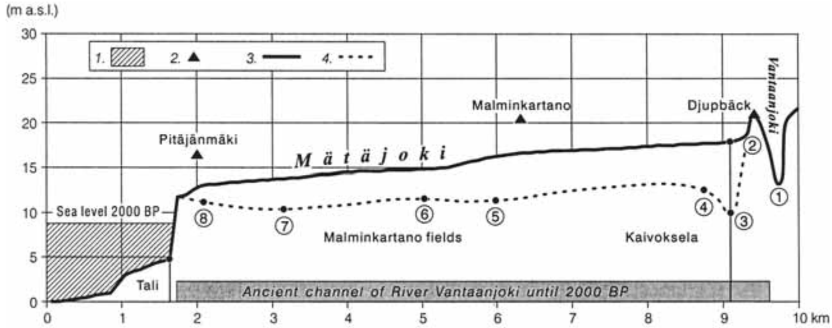

Fig. 8. Longitudinal profile of the stream Mätäjoki channel from the Gulf of Finland to its intersection with the present-day River Vantaanjoki. Numbers (1–8) refer to the coring and profile sites (see Fig. 3). 1. Sea level 2000 BP (1900 cal. BP), 2. Thresholds of the ancient River Vantaanjoki, 3. Longitudinal profile of the present-day Mätäjoki channel and dried-up Djupbäck channel, 4. Longitudinal profile of the ancient River Vantaanjoki channel bed. The depths of the old channel are estimated from the coring results.

tremely slow. In addition, the stretch of the channel east of the Djupbäck threshold no longer has any permanent flow of water, so that an erosional factor of the magnitude of the waters of the River Vantaanjoki would have been necessary for its creation.

The sedimentology of the channel serves to confirm that the waters of a major river must have flowed through the Mätäjoki valley at some time, for otherwise it would be difficult to explain why the present-day stream first eroded a channel several metres deep and several tens of metres broad through the area, only for it to be filled in with fluvial sediments and peat deposits. The present-day River Mätäjoki occupies a small channel in the bottom of this valley which has scarcely been eroded to any depth into the fluvial sediments of the original formation. A further indication of the action of a major river is the broad, deep depression to be found below the Djupbäck threshold, the creation of which would have required powerful fluvial erosion forces. The present cores indicated that the deep basin below the rapids and the broad river valley that served as a continuation of it had been eroded several metres down into the clay horizons, and that as the rate of flow in the channel subsequently declined, fluvial sediments rapidly came to be deposited in it. Once the flow from the River Vantaanjoki ceased altogether, the long, narrow body of water that occupied the channel gradually became filled in by vegetation. This process was accelerated by the very shallow gradient of the River Mätäjoki, which has been shown by Ruth (1998) to be 0.6 m km^{-1} in the stretch studied here (see also Fig. 8).

In view of the beds of sediment several metres deep that line the present-day channel of the River Mätäjoki, the river valley may be said to have been of such proportions that it would correspond well to that of the modern River Vantaanjoki in terms of size, especially in its upper reaches. Thus it is possible that the waters of the ancient River Vantaanjoki could have flowed into the Gulf of Finland exclusively via the Mätäjoki valley at first. The 55 m wide channel at the Djupbäck threshold would have been capable of supporting a discharge of some 100–200 $m^3 s^{-1}$, given a water depth of 1–2 m and a mean flow rate of 1–2 m s^{-1}. Admittedly the maximum discharge of the present-day River Vantaanjoki at its mouth is 317 $m^3 s^{-1}$, but the mean discharge is no more than 16.9 $m^3 s^{-1}$ and the minimum 1.4 $m^3 s^{-1}$ (Ekholm 1999). Of these figures, only the maximum would have been too high for the Mätäjoki channel, but it is also too high for the river's channel nowadays, for it floods over into the surrounding area even at lower discharge rates than this. Also the channel at profiles 4 and 5 could easily have been capable of supporting a discharge of over 100 $m^3 s^{-1}$ and at the profile 8 close to the present-day Pitäjänmäki waterfall channel would have been capable of supporting a discharge of at least 150 $m^3 s^{-1}$.

Peaks in discharge are short-lived in the River Vantaanjoki and they have always involved flooding beyond the banks of the channel proper. It should also be remembered that the flood peaks were very much less acute in earlier times, when the drainage basin was in a natural state and had a continuous cover of forest. Nowadays it contains extensive built-up areas and 30% of its surface area consists of arable land, whereas only 2.6% is occupied by lakes (Tikkanen 1989), all of which features have served to exaggerate the flood peaks. The drainage basin lying above the bifurcation at Djupbäck was also very much smaller than that of the modern River Vantaanjoki, as the River Keravanjoki, for instance, the drainage basin of which accounts for 24% of the latter, does not join it until below Djupbäck. When we consider as well the size of the drainage basin surrounding the lower reaches of the River Vantaanjoki, it may be calculated that the basin that drained into the Mätäjoki valley in earlier times was less than three-fourths of the area of the basin of the present River Vantaanjoki.

It is also significant that the old channel was narrower in the middle and lower reaches of the River Mätäjoki than in the upper reaches, its development there having presumably been retarded by the till threshold at Pitäjänmäki, as the lake that formed behind it in the early stages will have prevented any channel from developing for some time. In any case, mean discharge rates in the ancient River Vantaanjoki will have been so low that the volumes of water involved could have been contained many times over in this channel. Even so, flood waters evidently accumulated on the banks of the channel at times of maximum discharge, as indicated by the presence of levées beyond the confines of the channel proper in many places. However, as the channel is deep, and as it is covered by fluvial sediments and peat in precisely the same manner as on the upper reaches, this stretch, too, as far downstream as the Pitäjänmäki waterfall, must have served as a channel for the River Vantaanjoki.

The basal level of the old channel lies below the altitude of the threshold at Pitäjänmäki for practically the whole of its length (Fig. 8). When the waters of the River Vantaanjoki ceased to flow into the Mätäjoki valley, the old channel was occupied by a long, narrow body of water. It had nevertheless been filled to a considerable extent with fluvial sediments from the River Vantaanjoki and the streams acting as its tributaries at the stage during which the flow from that river into the old channel was in the process of declining. At the final stage, water presumably flowed from the river into the old channel only at times of flooding. Finally the channel will have been filled in almost entirely by vegetation growth and the deposition of further sediment washed into it from the basin of the River Mätäjoki. The mean discharge of the present-day River Mätäjoki is only 0.2 $m^3 s^{-1}$ and the maximum about 3 $m^3 s^{-1}$ (Ruth 1998), so that it has not succeeded in eroding its present-day channel to any appreciable extent. Instead it has deposited more sediment on the paludified banks, as reflected in the decline in loss-on-ignition values towards the surface observed in the sediment sequences described here. This is a consequence of erosion brought about by agriculture and building, activities that gained in impact around 330 BP (380 cal. BP) at the latest.

But when did the Mätäjoki outflow channel develop and for how long did it function as a branch of the River Vantaanjoki? It may be estimated from the shoreline displacement history of the area that the Djupbäck threshold, at an altitude of 21 m a.s.l., must have emerged from the sea by 4500 BP (5100 cal. BP) at the latest (Hyvärinen 1980; Ristaniemi & Glückert 1987; Seppä & Tikkanen 1998; Seppä et al. 2000), and similarly it may be concluded that the banks of the Mätäjoki channel, at levels of 16–18 m a.s.l. as far downstream as Pitäjänmäki, must have been dry land by 4000–3500 BP (4500–3800 cal. BP). As shoreline displacement proceeded, at least two shallow lake basins in the Mätäjoki valley must have been isolated from the sea, only to dry up later as the channel was eroded at the thresholds.

It was suggested by Hyyppä (1935, 1950a) that the channel ceased to function as such at some time in the interval 3000–2000 BP, while Roos (1950) mentioned that the Mätäjoki valley must have still been serving as an outlet channel for the River Vantaanjoki around 1500 BP. These timescales were all conjectures, however, and were not based on research backed up by dating. The dates obtained here indicate that organic material began to accumulate on the bed of the Mätäjoki channel around 2200 BP (2200 cal. BP), and that up to that time the flow of water in the channel was of such a magnitude that the prevailing process was fluvial erosion, so that sand and gravel was deposited only at some points on the bed of the channel that had been cut down into the marine clay layer. The above timing would appear to be reliable in that the same date was obtained for two points on the bed of the channel (see Fig. 4).

This date probably also marks the point at which the present outflow channel of the River Vantaanjoki was opened up, after which the volume of water flowing through the Mätäjoki channel began to decrease and it began to fill with fluvial sediments. One indication of the rapid filling of this channel is the fact that approximately the same date was obtained for the surface of the sediment bed as for its base, 2270 ± 70 BP (2330 cal. BP), (Fig. 4).

The corresponding date for the base of the peat horizon deposited after the end of the river phase was 1540 ± 70 BP (1410 cal. BP), and there was still about 10 cm of gyttja clay below the sampling level that had been deposited under conditions in which no water from the River Vantaanjoki was flowing in the channel. In other words, the separation of the Mätäjoki channel from its connection with the River Vantaanjoki had taken place well before the earliest date obtained from the peat-rich sediment. It can thus be estimated that the passage of water from the river into the Mätäjoki channel came to an end around 2000 BP (1900 cal. BP), from which time onwards the present outlet channel of the River Vantaanjoki has been the only one. At the time when the change took place the mouth of the Mätäjoki channel was located at the present-day Pitäjänmäki waterfall (see Fig. 8).

Contrary to the suggestion of Hyyppä (1935, 1950a), it is highly probable that the present channel of the River Vantaanjoki did not arise at the same time as the Mätäjoki channel but considerably later. Otherwise is would be difficult to imagine why it should have taken more than 2000 years for it to be eroded down to a level below that of the Djupbäck threshold, given that the surficial deposits in the area were largely easily erodible clay, silt and sand. Since the altitude of the clay deposits bordering on the river at the bifurcation between the old channel and the present-day one is only 22–23 metres, even quite a minor deepening of the present channel would have sufficed to cause the Djupbäck threshold to dry up. The surface of the present-day River Vantaanjoki lies about 5 metres below the threshold, and deepening of the channel has come to an end at the level of the bedrock threshold of Pitkäkoski, located a kilometre away from the bifurcation (see Fig. 2).

It is probable that the present-day channel of the River Vantaanjoki was opened up suddenly as a consequence of particularly serious flooding around 2200 BP (2200 cal. BP), the floodwaters breaking through the low ridge to the east of the bifurcation of the channels. The core of this ridge is a glaciofluvial formation, the highest points on which still protrude from beneath the clays (Fig. 2). The bend in the river that arose at the bifurcation has subsequently shifted southwards, so that the original ridge that retained the waters of the river has been eroded away entirely. Altogether the following stages may be recognized in the sequence of events:

1) The Djupbäck threshold emerged from the sea around 4500 BP (5100 cal. BP) and the waters of the River Vantaanjoki began to flow over it in the direction of the Mätäjoki valley, so that a stretch of rapids existed at this point. A basin of still water began to form below the rapids, but its development was retarded at first by the presence of a shallow lake that formed at almost the same altitude, behind the Malminkartano threshold. This lake dried up in the course of time as the latter threshold began to be eroded away.

2) The plains of fine sediment that lined the Mätäjoki channel as far downstream as the Pitäjänmäki threshold emerged from beneath the sea in the interval 4000–3500 BP (4500–3800 cal BP). A shallow lake also accumulated above the Pitäjänmäki threshold initially, and deepening of the middle and lower reaches of the Mätäjoki channel was only able to go ahead after this till threshold had been eroded down to the level of the lake bottom. Since there was insufficient time for the channel on the lower reaches of the river to be eroded to the same extent as that on the upper reaches, it remained susceptible to flooding, but even so it was capable of carrying an amount of water that was many times greater than the mean discharge of the ancient River Vantaanjoki.

3) The present outflow channel of the River Vantaanjoki was opened up around 2200 BP (2200 cal. BP), after which the flow in the Mätäjoki channel weakened and the channel rapidly filled with fluvial sediment. The new channel was created by the water forcing its way through a glaciofluvial ridge lying east of the Djupbäck bifurcation.

4) The connection between the River Vantaanjoki and the Mätäjoki channel was finally severed around 2000 BP (1900 cal. BP), at which point the latter began to fill in with sediments and vegetation. The sea level at that stage was about 8 m above what it is nowadays, and the mouth of the Mätäjoki channel was located at the point marked by the Pitäjänmäki waterfall.

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