Shore Displacement in Western Uusimaa 500 BC – AD 1500

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Abstract

Numerous shore displacement studies have been completed in Finland, but the shore displacement history regarding the last four millennia is still poorly investigated. In this study, the shore displacement history of the coastal area of Western Uusimaa, in southern Finland, is reconstructed especially for the period 500 BC–AD 1500. The isolation of 17 basins located in five areas (Kirkkonummi/Espoo, Orslandet (Ingå), Älgö (Ekenäs in Raseborg), Tenala (Raseborg) and Prästkulla (Ekenäs, Raseborg)) is determined. The methods include lithostratigraphic interpretation, diatom analyses and radiocarbon dating.

The shore displacement history varies within the Western Uusimaa area. The highest ancient shoreline representing sea-level at 500 BC is about 8.5 m above present sea-level (a.s.l.) in Prästkulla, and 6.5 m a.s.l. in Kirkkonummi. In other areas, the shoreline representing this time falls between these elevations. The shoreline representing sea-level at AD 500 is 1–1.5 m a.s.l. in Western Uusimaa. These differences in shore level elevations are due to differences in isostatic uplift rates, which are slower in the east. The main trend in relative shore displacement along the southern coast of Finland is characterised by a generally decreasing uplift rate during the last 3500 years. It is not possible to detect any clear sea-level transgressions during this investigated period. The available data suggests possible local land uplift anomalies in the study area, but more investigations are needed to verify these results.

Keywords: shore displacement, sea-level, land uplift, isolation, diatoms.

1.Introduction

During the Iron Age (500 BC–AD 11/1200) and Medieval Period (AD 1200–1550), people settled close to the shore line at the time. The sites representing younger cultural stages are situated at successively lower altitudes, following the shore displacement. Thus, shore displacement reconstructions are very important for archaeological and historical studies (e.g. Asplund 2008).

Numerous shore displacement studies have been completed in Finland, but they have mostly focused on the early and middle Holocene, i.e. 10 000–4000 cal. BP. From southern Finland, east of Helsinki, many shore displacement studies including several radiocarbon dated isolation basins have been carried out, partly covering the late Holocene period (Eronen 1974;

Fig. 1. Location of the study areas in Western Uusimaa. Sites numbering at Table 1.

Matiskainen 1989; Miettinen et al. 1999; Seppä et al. 2000), but only two studies exist from the coastal area of Western Uusimaa (Hyvärinen 1999; Eronen et al. 2001). However, all of these studies have paid less attention to the late Holocene shore displacement history. Hence, the shore displacement history of Western Uusimaa, as well as southern Finland, during the last four millennia is still relatively poorly known. This fact, together with relatively poorly known settlement history in the coastal area of Western Uusimaa (Alenius 2009; 2011; Haggrén 2009; 2011; Jansson 2009; 2011), was the motivation for reconstructing more detailed records of shore displacement in this area.

Based a total of 20 isolation basins, shore displacement was reconstructed for five areas located in Western Uusimaa; Kirkkonummi/Espoo, Orslandet, Älgö, Tenala and Prästkulla (Fig. 1). In this work, we determined the isolation of 17 basins, which are located between 0.2 and 13 m above present sea-level (a.s.l.). In addition, results from three previously investigated isolation basins situated in Kirkkonummi and Prästkulla were used in the reconstructions (sites 4, 19 and 20 in Fig. 1 and Table 3). This is the first shore displacement study for the southern coast of Finland focused solely on the last 4000 years. Some preliminary results of this study were previously summarized by Miettinen et al. (2007).

The study area extends across 120 km of coastline that is characterized by archipelago and narrow topographical zones stretching in an east-west direction. In the middle archipelago zone there are several east-west geological valley formations that even today form good fairways, while deep, fjord-like bays cut the mainland in the north-south direction. Many fracture zones exist in the bedrock of the study area (Vuorela 1982). The present apparent land uplift rate varies from 3.1 to 2.5 mm/year from west to east in this area (Ekman and Mäkinen 1996). The area is suitable for shore displacement studies due to the abundance of small lakes situated at various elevations above present sea-level.

1.1 Reasons for shore displacement and its main research methods

The two main reasons for shore displacement in the Baltic Sea basin are the glacio-isostatic land uplift and eustasy (i.e. the global changes in the ocean level). The areas formerly covered by the Late Weichselian ice sheet are now rebounding. Uplift was most rapid during and immediately after the Late Weichselian glaciation and although a marked decrease in uplift rate occurred c. 9500 years ago (Eronen 1983), the rate has been remained relatively high until today, with a gradual slowing down of uplift. The uplift of the crust relative to mean sea-level is called the apparent land uplift, which in the northern part of the Gulf of Bothnia, in the centre of the area of uplift is between 8 and 9 mm/year (Ekman and Mäkinen 1996). Land uplift seems to take place on a regional scale in a plastic manner, but on the local scale as discrete blocks of the bedrock (Kuivamäki et al. 1998). Because of the relatively high land uplift rate, the drop in relative sea-level has been the dominant feature of the Holocene shore displacement in the Baltic basin, except for relatively short transgressive periods during the Ancylus Lake and Litorina Sea stages (e.g. Björck 1995; Miettinen 2002; Eronen 2005).

A number of shore displacement studies have been published in Finland (e.g. Eronen 1995), which investigate the land uplift and history of the Baltic Sea. Earlier studies reconstructed ancient shore levels using geomorphological shoreline features. The downfall of the most of these earlier shoreline reconstructions is the poor resolution and/or imprecise chronology. The dating was often based on pollen analysis. In the 1970s, the radiocarbon dating method became common in shore displacement studies and it was a huge improvement in the research method.

The precise information on regional shore displacement is obtained from small uplifted lake basins where the isolation of the basin from the sea can be detected in the changes of sediment composition and diatom assemblages. In sediments, the isolation can usually be detected as a change from greyish clayey sediments deposited in the Baltic Sea basin to organic-rich gyttja deposited in the freshwater lake basin. Also during the isolation process, diatom assemblages show a clear succession from a deep and brackish pelagic environment to a shallower and less saline coastal environment, and finally, the brackish-water diatom taxa are replaced by freshwater taxa during the isolation itself. The contact between Baltic and lake sediments is called the isolation contact, which can be dated by radiocarbon method and then used as shore level (or sea-level) index-points.

1.2 Earlier studies on isolation basins in the Western Uusimaa area on the last 4000-year period

The shore displacement reconstruction based on 14 isolation basin for Helsinki–Kirkkonummi area covers the period 8000 BC–AD 50, and focuses particularly on the period 8000–5000 BC, i.e. the Ancylus and Litorina stages of the Baltic Sea (Hyvärinen 1999). The shore displacement curve shows a gradual lowering of sea-level since the nearly stable relative sea-level phase during the Litorina transgression 6000–4000 BC when the highest Litorina shoreline was located around 34 m a.s.l. in the Helsinki area.

Eronen et al. (2001) reconstructed shore displacement in the Tammisaari–Perniö area for the period 8300–1500 cal BP (c. 6300 BC–AD 500), and focused especially on the period 8300–3000 cal. BP. The reconstruction was based on 15 isolation basins located between 7.3 and 39.9 m a.s.l. The results indicate a relatively regular rate of uplift and overall relative sea-level lowering though some small-scale bends seen in the shore displacement reconstruction could indicate short-term changes in sea-level or land uplift trends. The shore displacement reconstruction of Hatakka & Glückert (2000) is mostly based on the same data of Eronen et al. (2001). Despite some different interpretations of the data, the results of

Hatakka & Glückert suggest a gradual lowering of sea-level.

Although the shore level data of previous studies is more or less incomplete regarding the last 4000 years, their results suggest a gradual lowering of sea-level during this period. The elevation of the shoreline representing the same point in time increases from east to west due to the higher land uplift rate in the west, e.g. the shoreline representing the sea-level at 1000 BC is now located about 9 m a.s.l. in Helsinki (Hyvärinen 1999), but about 13 m a.s.l. in the Tammisaari–Perniö area (Eronen et al. 2001).

2. Material and method

2.1 Sampling

Sediment cores were taken from 18 isolated basins (17 lakes and 1 mire), located between 0.2 and 13.0 m a.s.l. (Table 1 and Fig. 1). Basin elevations were determined from topographic maps at a scale of 1:20 000. In the Orslandet area, the elevations were also levelled. The investigated lake basins are relatively small and shallow; their size varies between 0.1–0.5 km^2 (mostly between 0.1–0.2 km^2), and the depth between c. 1.0–5.5 m (mostly between 1–3 m).

The cores were taken from the deepest part of the basins, where the stratigraphy is normally the most complete. The samples were taken through the ice in the wintertime using a Russian peat sampler (length 1 m, Ø 5 or 8 cm) (Fig. 2). Also two freeze-box samples from surface sediments were taken from Lake Petarträsk, Orslandet, and Lake Storträsket, Älgö.

To define the isolation contacts, the sediment core sampling extended across the isolation contacts. The isolation contacts were initially identified during coring in the field by the visual observations of sediment composition. For pollen analyses (Alenius 2009, 2011), long

Study area	Lake basin	Site no.	Location	Altitude (m a.s.l.)	Water depth (cm)	Core length (cm)
Espoo	Hannusjärvi	1	60°10’N, 24°40’E	8.1	230	180
Kirkkonummi	Storträsk	2	60°05’N, 24°30’E	0.8 (1.8)	310	200
	Djupström	3	60°06’N, 24°25’E	2.5	150	100
	Molnträsk	4	60°05’N, 24°25’E	12.5	525	300
Orslandet	Hälftesträsket	5	59°57’N, 23°55’E	2.5	395	80
	Kvarnviksträsket	6	59°58’N, 23°51’E	3.0	95	150
	Rövassträsket	7	59°58’N, 23°55’E	3.4	160	60
	Petarträsk	8	59°58’N, 23°54’E	9.5	470	190
Älgö	Lillträsket	9	59°53’N, 23°23’E	1.6	195	60
	Storträsket	10	59°52’N, 23°23’E	5.9	280	180
	Byträsket	11	59°56’N, 23°25’E	7.3	260	177
Tenala	Hemträsket	12	60°04’N, 23°28’E	2.5	355	90
	Sidsbackaträsket	13	60°04’N, 23°23’E	4.6	140	100
	Tjärnen	14	60°05’N, 23°23’E	13.0	550	260
Prästkulla	Levisträsket	15	59°59’N, 23°16’E	0.2	0	200
	Tronsböleträsket	16	59°56’N, 23°12’E	6.2	220	45
	Djupdalsträsket	17	59°59’N, 23°12’E	8.2	180	100
	Gundbyträsket	18	59°59’N, 23°10’E	12.6	190	70

Table 1. Studied basins in Western Uusimaa. Core length = the length of the investigated sediment sequence. The present (lowered) threshold altitude of Lake Strortäsket (site 2) is 0.8 m a.s.l. and the original 1.8 m a.s.l.

Fig. 2. Jaakko Latikka and Henrik Jansson sampling with Russian peat sampler in Lake Byträsk, Älgö. (Photo: A. Miettinen 2004)

sediment cores were collected extending from sediments below the presumed isolation contact up to the sediment surface.

2.2 Loss-on-ignition (LOI)

The organic matter was determined by loss-on-ignition (LOI). To measure LOI, samples (10–12 g) were dried overnight at a temperature of 105°C, after which their dry weight was measured. The samples were then ignited in an oven at a temperature of 550°C for 2.5 hours. Sediment types were confirmed through LOI and visual observation. LOI percentage values of 2%, 6% and 20% were used as limit values to determine sediment type boundaries of clay/gyttja clay, gyttja clay/clay gyttja, and clay gyttja/gyttja, respectively. Usually, when a basin becomes isolated from the Baltic Sea, the accumulating sediment shows a distinct change. The Baltic Sea sediments consist of clay or clay gyttja, but as lake basins became isolated, organic gyttja accumulates in the basins.

2.3 Diatom analyses

Diatom analyses were undertaken to assist in the identification of the isolation contacts. The presumed isolation contact was initially defined by LOI and lithostratigraphic interpretation. From this, the depths for diatom analyses were chosen from above and below the suspected isolation contact. Diatom samples were prepared according to standard methods (Battarbee 1986). At least 200 valves were counted in each sample. The taxonomy and grouping of diatoms according to their biotype and salinity preferences is based on the following sources: Mölder and Tynni (1967–1973), Tynni (1975–1980), Krammer and Lange-Bertalot (1986–1991), Snoeijs (1993), Snoeijs and Vilbaste (1994), Snoeijs and Potapova (1995), Snoeijs and Kasperovičienė (1996), and Snoeijs and Balashova (1998). The diatoms were grouped according to salinity preference into the following main groups: polyhalobous (marine; salinity >30‰), mesohalobous (brackish-water; 5–20‰), oligohalobous halophiles (<5‰) and indifferents (0–2‰) and halophobous (freshwater; 0‰). The diatoms were also grouped according to biotype into planktonic or littoral forms. In this paper, diatom diagrams are shown from two basins; Lake Hannusjärvi, Espoo (Fig. 4) and Lake Petarträsk, Ingå (Fig. 9).

2.4 ^{14}C analyses

A total of 36 ^{14}C AMS analyses were carried out from the 18 basins by the Dating Laboratory of Poznan, Poland (Table 2). Most of these analyses were used for the isolation reconstructions, but partly also to investigate environment, human activities, and settlement history (Alenius 2009; 2011). However, the analyses for latter purposes are useful also for shore displacement study by improving the chronological control. In addition, four conventional ^{14}C analyses were used from three isolation basins previously in-

Study area	Basin	Site no	Depth (cm)	Dated sediment	Lab.no.	^{14}C age BP	Cal yr BP (1 sigma) [start:end] relative area under distribution	Cal BC/AD (1 sigma) [start:end] relative area under distribution	Cal BC/AD (2 sigma) [start:end] relative area under distribution	Median probability
Espoo	Hannusjärvi	1	53	Gyttja	Poz-14673	1035±30	[928 BP:962 BP] 1	[988 AD:1022 AD] 1	[961 AD:1036 AD] 0,935383	AD 1002
			121	Gyttja	Poz-10690	2165±30	[2247 BP:2300 BP] 0,551034	[351 BC:298 BC] 0,551034	[261 BC:148 BC] 0,479984	240 BC
			136	Gyttja	Poz-10691	2410±35	[2353 BP:2471 BP] 0,966959	[522 BC:404 BC] 0,966959	[560 BC:397 BC] 0,803957	489 BC
			163	Gyttja	Poz-14721	2875±35	[2955 BP:3065 BP] 1	[1116 BC:1006 BC] 1	[1132 BC:968 BC] 0,879761	1052 BC
Kirkko-nummi	Storträsk	2	47.5	Gyttja	Poz-8271	455±30	[500 BP:522 BP] 1	[1428 AD:1450 AD] 1	[1414 AD:1472 AD] 1	AD 1440
			95	Gyttja	Poz-8268	890±30	[742 BP:798 BP] 0,599385	[1152 AD:1208 AD] 0,599385	[1117 AD:1216 AD] 0,636652	AD 1142
	Djupström	3	19	Gyttja	Poz-8276	1225±35	[1119 BP:1181 BP] 0,5554	[769 AD:831 AD] 0,5554	[759 AD:887 AD] 0,716401	AD 796
	Molnträsk	4	22,5	Gyttja	Poz-8269	635±30	[561 BP:596 BP] 0,615314	[1354 AD:1389 AD] 0,615314	[1338 AD:1397 AD] 0,57932	AD 1352
			60	Gyttja	Poz-8277	870±30	[732 BP:795 BP] 0,962764	[1155 AD:1218 AD] 0,962764	[1147 AD:1252 AD] 0,757675	AD 1176
Orslandet	Hälftesträsket	5	27	Gyttja	Poz-3546	1265±30	[1197 BP:1261 BP] 0,843226	[689 AD:753 AD] 0,843226	[667 AD:783 AD] 0,915617	AD 734
	Kvarnviksträsket	6	52	Gyttja	Poz-12510	1350±30	[1271 BP:1300 BP] 1	[650 AD:679 AD] 1	[637 AD:713 AD] 0,923579	AD 666
	Rövassträsket	7	109	Gyttja	Poz-3551	1665±30	[1532 BP:1573 BP] 0,682011	[377 AD:418 AD] 0,682011	[319 AD:434 AD] 0,907658	AD 383
	Petarträsk	8	15*	Gyttja	Poz-14675	365±30	[429 BP:493 BP] 0,675069	[1457 AD:1521 AD] 0,675069	[1449 AD:1528 AD] 0,540855	AD 1522
			16-18	Gyttja	Poz-4502	1350±30	[1271 BP:1300 BP] 1	[650 AD:679 AD] 1	[637 AD:713 AD] 0,923579	AD 666
			30-32	Gyttja	Poz-3547	1665±35	[1529 BP:1608 BP] 1	[342 AD:421 AD] 1	[316 AD:437 AD] 0,847327	AD 382
			54-56	Gyttja	Poz-3549	1960±30	[1878 BP:1934 BP] 0,909247	[16 AD:72 AD] 0,909247	[39 BC:87 AD] 0,960925	AD 40
			87	Gyttja	Poz-14723	2415±35	[2355 BP:2486 BP] 1	[537 BC:406 BC] 1	[567 BC:399 BC] 0,780643	494 BC
			94-96	Gyttja	Poz-3550	2440±40	[2361 BP:2494 BP] 0,712581	[545 BC:412 BC] 0,712581	[598 BC:406 BC] 0,642985	543 BC
Älgö	Lillträsket	9	20	Gyttja	Poz-12507	525±30	[517 BP:548 BP] 1	[1402 AD:1433 AD] 1	[1392 AD:1441 AD] 0,853589	AD 1414
	Storträsket	10	51	Gyttja	Poz-12508	1355±30	[1274 BP:1302 BP] 1	[648 AD:676 AD] 1	[632 AD:710 AD] 0,939024	AD 663
			82	Gyttja	Poz-10692	1745±30	[1615 BP:1678 BP] 0,767342	[272 AD:335 AD] 0,767342	[228 AD:388 AD] 1	AD 297
			105	Gyttja	Poz-14677	1790±30	[1692 BP:1740 BP] 0,563105	[210 AD:258 AD] 0,563105	[132 AD:263 AD] 0,767251	AD 232
			151	Gyttja	Poz-12509	2865±35	[2945 BP:3043 BP] 0,854627	[1094 BC:996 BC] 0,854627	[1130 BC:922 BC] 0,981608	1037 BC
	Byträsket	11	112	Gyttja	Poz-10689	2200±30	[2233 BP:2280 BP] 0,450823	[331 BC:284 BC] 0,450823	[375 BC:192 BC] 1	286 BC
Tenala	Hemträsket	12	42	Gyttja	Poz-14722	1400±30	[1291 BP:1328 BP] 1	[622 AD:659 AD] 1	[599 AD:668 AD] 1	AD 640
	Sidsbackaträsket	13	137	Clay gyttja	Poz-14676	2345±30	[2333 BP:2363 BP] 0,978488	[414 BC:384 BC] 0,978488	[511 BC:378 BC] 1	402 BC
	Tjärnen	14	70	Gyttja	Poz-17110	930±30	[796 BP:834 BP] 0,431242	[1116 AD:1154 AD] 0,431242	[1025 AD:1168 AD] 1	AD 1099
			88	Gyttja	Poz-17112	1045±30	[930 BP:968 BP] 1	[982 AD:1020 AD] 1	[947 AD:1029 AD] 0,910537	AD 996
			195	Gyttja	Poz-17113	2510±35	[2499 BP:2596 BP] 0,649806	[647 BC:550 BC] 0,649806	[790 BC:519 BC] 1	638 BC
			206	Gyttja	Poz-12513	2925±30	[3004 BP:3082 BP] 0,628299	[1133 BC:1055 BC] 0,628299	[1215 BC:1019 BC] 0,94755	1128 BC
Prästkulla	Levisträsket	15	33	Gyttja	Poz-8273	1100±35	[964 BP:1011 BP] 0,617695	[939 AD:986 AD] 0,617695	[883 AD:1017 AD] 1	AD 944
			69	Clay gyttja	Poz-8274	1660±30	[1528 BP:1572 BP] 0,737729	[378 AD:422 AD] 0,737729	[322 AD:436 AD] 0,906363	AD 389
	Tronsböleträsket	16	186	Gyttja	Poz-12511	1950±30	[1869 BP: 1933 BP] 0,991357	[17 AD:81 AD] 0,991357	[2 BC:125 AD] 0,95995	AD 50
			191	Gyttja	Poz-8279	2070±35	[1993 BP:2065 BP] 0,774366	[116 BC:44 BC] 0,774366	[184 BC:3 AD] 1	90 BC
	Djupdalsträsket	17	88	Gyttja	Poz-8275	1750±30	[1617 BP:1676 BP] 0,734513	[274 AD:333 AD] 0,734513	[219 AD:388 AD] 1	AD 294
	Gundbyträsket	18	192	Gyttja	Poz-12512	3040±30	[3215 BP: 3269 BP] 0,579509	[1320 BC:1266 BC] 0,579509	[1405 BC:1252 BC] 0,933418	1315 BC

Table 2. Radiocarbon analyses carried out in 18 sites in Western Uusimaa. Depth (cm) refers to depths below the sediment surface.
* Petarträsk 15 cm was obtained from freeze-box sample.

Study area	Basin	Site no	Depth (cm)	Dated sediment	Lab.no	^{14}C age BP	Cal yr BP (1 sigma) [start:end] relative area under distribution	Cal BC/AD (1 sigma) [start:end] relative area under distribution	Cal BC/AD (2 sigma) [start:end] relative area under distribution	Median probability
Kirkkonummi	Vintervägsträsket[1]	19	230-240	Clay gyttja	Hel-2006	2310±110	[2151 BP:2473 BP] 0,981082	[524 BC:202 BC] 0,981082	[674 BC:150 BC] 0,891165	390 BC
	Molnträsk[1]	4	225-235	Gyttja	Hel-2000	3730±100	[3963 BP:4237 BP] 0,94898	[2288 BC:2014 BC] 0,94898	[2411 BC:1897 BC] 0,965659	2142 BC
Prästkulla	Rombyträsket[2]	20	253-258	Clay gyttja	GrN-19650	3310±60	[3467 BP:3592 BP] 0,909678	[1643 BC:1518 BC] 0,909678	[1698 BC:1487 BC] 0,90745	1590 BC
			248-253	Gyttja	GrN-19649	3190±60	[3360 BP:3469 BP] 1	[1520 BC:1411 BC] 1	[1615 BC:1372 BC] 0,968042	1467 BC

Table 3. Radiocarbon analyses used from previously studied isolation basins ([1]Hyvärinen 1999; [2]Eronen et al. 2001).

vestigated by Hyvärinen (1999) and Eronen et al. (2001) (Table 3). Results appear as years beginning from the year 1950 AD and are based on the half-life of ^{14}C (5568 years). The radiocarbon ages (BP) were calibrated to calendar years (cal yr) with Calib v5.0 program (Stuiver and Reimer 1993) with the IntCal04.14c calibration dataset (Reimer et al. 2004). They result calibrated calendar years by calculating the probability distribution for the true age of the sample. Probabilities are expressed in time ranges for one sigma (68.3%) and two sigma (95.4%) confidence intervals. Also the relative area under the one and two sigma ranges, and median probability are presented. In this work, calibrated radiocarbon dates are expressed in terms of cal BC or cal AD in one sigma (68.3%) confidence interval, rounded to the nearest ten years with median probability in brackets. One sigma time range with median probability is used in the text and in the shore displacement reconstruction (Fig. 16) but only median probability in other figures, herein. Also calibrations in cal yr BP with one sigma time range are presented in Tables 2 and 3.

3. Results

Table 1 shows the location and elevation (m a.s.l.) of the studied basins, as well as water depth at the coring site and the length of investigated cores.

3.1 Espoo and Kirkkonummi

3.1.1 Lake Hannusjärvi, Espoo (site 1)

In the basal part of the Lake Hannusjärvi core, the sediment is light greenish grey clay gyttja with LOI 12–19% (Figs. 3 and 4). At 153 cm, the sediment changes to light greenish grey gyttja with some light laminae. LOI increases to 49% at 135 cm, but the sediment colour changes to dark brown as high as 120 cm.

For diatom analysis, the sediment core was analysed at 5 cm resolution, except for the interval 145–115 cm where the resolution was 2.5 cm. With respect to salinity, the core is subdivided into three diatom assemblage zones (I–III) from the base upwards (Fig. 4). At basal part of the core (zone I; 180–140 cm), the mesohalobous planktonic species *Melosira westii* fo. *parva* dominates but almost disappears towards the top of the zone. Other common species are planktonic *M. moniliformis*, littoral species *Navicula peregrina*, *Diploneis smithii* and *Surirella striatula*. As a whole, this diatom assemblage indicates a relatively deep environment. At the top of the zone, littoral species *Nitzschia scalaris* and *Campylodiscus clypeus* become dominant indicating that the sedimentation basin was becoming shallower.

In zone II (140–120 cm), freshwater diatom taxa appear; the planktonic *Aulacoseira ambigua* is the dominant species and other common species are littoral *Pinnularia* spp, *Eunotia* spp and *Navicula* spp. However, the brackish-water species (*N. scalaris* and *C. clypeus*), common in the previous zone, persist among several other littoral brackish-water species (e.g. *Amphora commutata, A. robusta* and *Mastogloia* spp). This 20 cm-long zone represents a transitional phase from a brackish-water to a freshwater lake environment indicating a relatively long-lasting isolation process of the basin. In addition, some very small-scale fluctuations can be seen within the lower part of the zone (135–130 cm). Initially, freshwater species start to dominate, but they are immediately replaced by brackish-water taxa for a very short period represented by only one sample. This suggests either a short-lived (annual-scale) eustatic sea-level rise or a momentary sea-level rise caused by meteorological factors (storm, low air pressure) at this time. In any case, this small-scale fluctuation cannot be classified as a sea-level transgression.

At the base of zone III, brackish-water species disappear (except *Nitzschia scalaris*) and fresh water species dominate indicating that the basin finally becomes fully isolated from the Baltic Sea basin. The occurrence of mesohalobous *N. scalaris* is very common in the nutrient-rich basins after the isolation (e.g. Fontell 1926; Miettinen 2002).

Four 14C analyses were carried out on the sediment sequence (Table 2 and Fig. 4); two of these dates occur within the isolation zone. The date 520–400 cal BC (490 cal BC) was determined at 136 cm on the lower limit of the isolation zone, and the second date 350–300 cal BC (240 cal BC) at 121 cm on the upper limit of the zone. These dates show that the isolation process lasted c. 250 years and the basin finally became isolated from the Baltic Sea at around 250 BC.

3.1.2 Lake Storträsk, Kirkkonummi (site 2)

The present threshold elevation of Lake Storträsket is 0.8 m a.s.l., but the threshold has been artificially lowered by approximately one metre (Luhtala 2004). The original elevation of 1.8 m was used in the shore displacement reconstructions. The lower part of the sediment core comprises a light grey clay gyttja with LOI 11–19%. At 105 cm, the sediment turns to dark brown gyttja (Fig. 5a).

Diatoms were analysed through the sediment sequence (Luhtala 2004). With respect to salinity, the sequence is subdivided into three diatom assemblage zones (I–III) from the base upwards. Zone I (200–150 cm) is dominated by the mesohalobous planktonic species *Melosira lineata* and *M. moniliformis*, which indicate a deeper water environment. In zone II (150–95 cm), the previous species almost disappear towards the top of the zone, and mesohalobous littoral *Navicula peregrina* becomes dominant

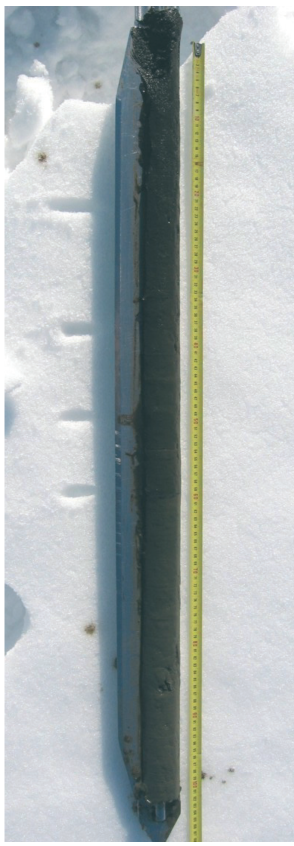

Fig. 3. The sediment core at 80–180 cm from Lake Hannusjärvi. At the bottom light grey clay gyttja from the Baltic Sea, at the top dark brown gyttja from the isolated lake. (Photo: A. Miettinen 2004)

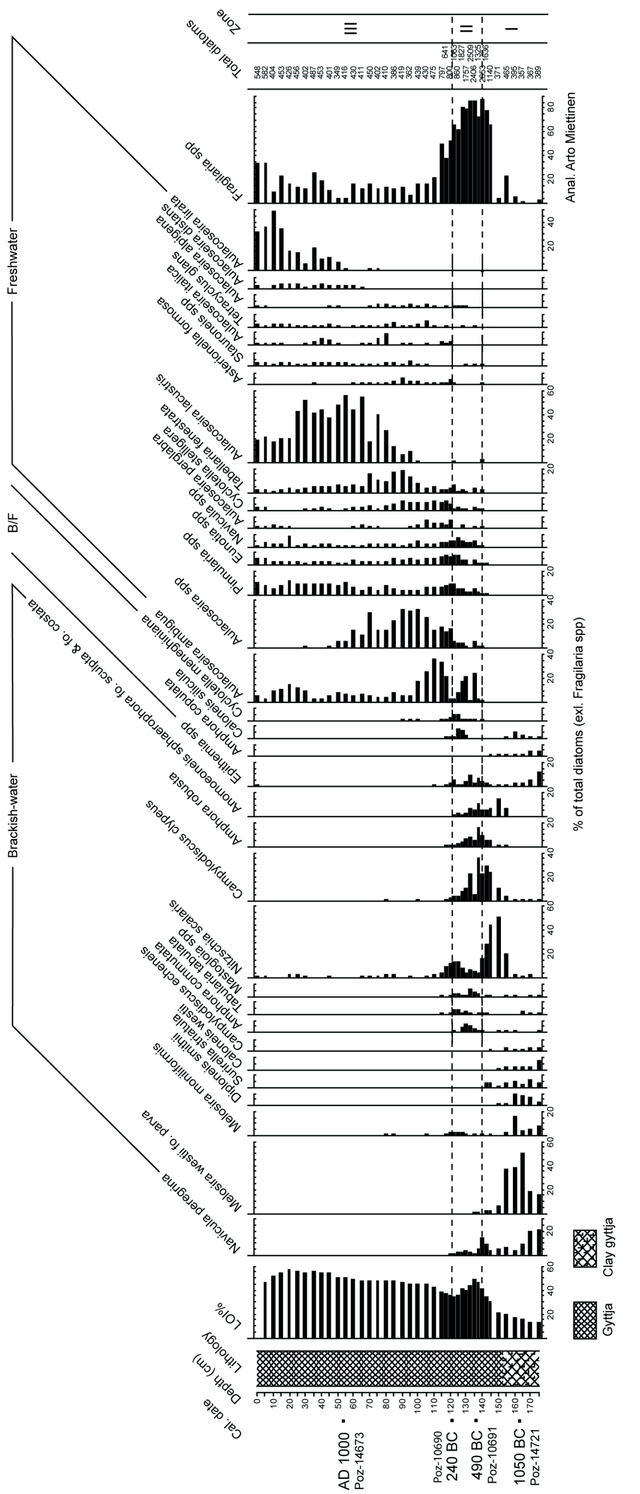

Fig. 4. Diatom diagram, lithostratigraphy, LOI and calibrated dates of Lake Hannusjärvi. B/F = species common in freshwater and brackish-water with low salinity, mainly oligohalobous species.

indicating a shallow sedimentation environment. Also a relatively high proportion (c. 30%) of freshwater species suggests a moderate connection to the sea this time. At the start of zone III (95-0 cm), the brackish-water species are replaced entirely by freshwater species (e.g. *Fragilaria* spp., *Eunotia* spp. and *Tabellaria flocculosa*) indicating complete basin isolation.

Two 14C analyses were carried out on the sediment sequence (Table 2). The first date cal AD 1150–1210 (cal AD 1140) was carried out at the depth of 95 cm on the isolation contact, and the second date cal AD 1430–1450 (cal AD 1440) at 47.5 cm. The older date indicates that the isolation took place c. 1150 AD.

3.1.3 Lake Djupström (site 3)

Most of the Lake Djupstöm core comprises a greenish grey clay gyttja with LOI 9–18% (Fig. 5b). At 19 cm, the sediment changes to dark greenish brown gyttja, but soon after that, LOI starts to decrease and the sediment changes to silty gyttja in the uppermost part of the core. Diatoms were analysed from 30 cm upwards. They indicate a slow isolation process as brackish water species, common in the bottom part, start to be replacing by freshwater species at 20 cm, but the obvious freshwater environment settles down as high as at 10 cm. The date cal AD 770–830 at 19 cm indicates the minimum age for the isolation is 800 AD.

3.1.4 Lake Molnträsk (site 4) and Lake Vintervägsträsket (site 19)

In this study, a 300 cm-long core was taken from the Lake Molnträsk for pollen analysis (Maarit Eskola 2009, pers. comm.; Alenius 2009, 2011). Two 14C analyses were carried out on the sediment sequence at 60 cm and 22.5 cm giving cal AD 1160–1220 (cal AD 1180) and cal AD 1350–1390 (cal AD 1350), respectively (Table 2).

The isolation results of Lake Molnträsk (Fig. 6a) and Vintervägsträsket (Fig. 6b) are

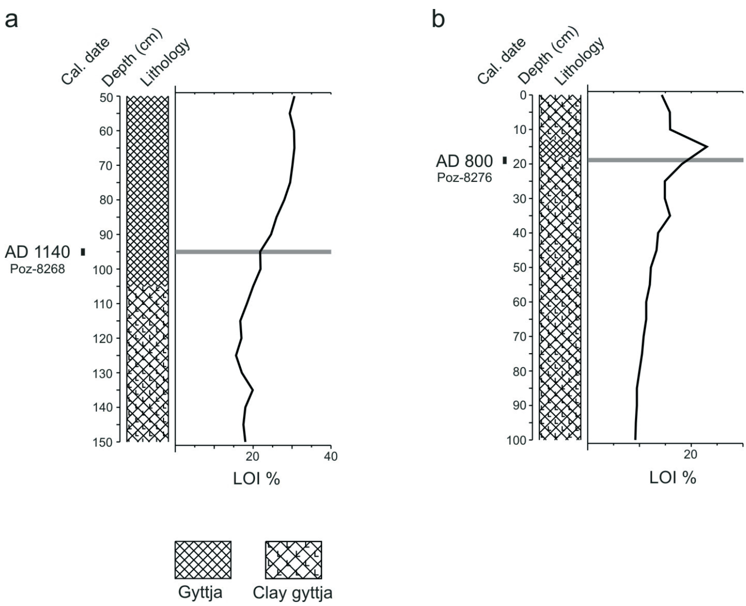

Fig. 5. Lithostratigraphy, loss-on-ignition, calibrated date and the isolation contact (grey line); a) Lake Strorträsk; b) Lake Djupström, Kirkkonummi.

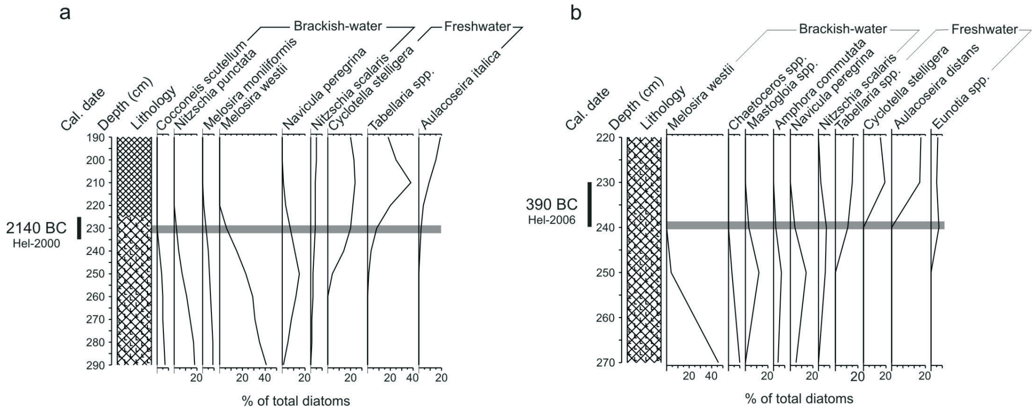

Fig. 6. Lithostratigraphy, selected diatom taxa and calibrated date; a) Lake Molnträsk; b) Lake Vintervägsträsket, Kirkkonummi (redrawn from Hyvärinen 1999). Sediment symbols in Fig. 5.

based on the previous study by Hyvärinen (1999). The isolation of both of the basins is indicated by the clear change in diatom stratigraphy with replacement of brackish-water taxa by freshwater taxa. Calibrated radiocarbon dates show that Lake Molnträsk was isolated from the Baltic Sea c. 2150 BC, and Lake Vintervägsträsket after 400 BC (Table 3).

3.2 Orslandet, Ingå

3.2.1 Lake Hälftesträsket (site 5)

The lower part of the Lake Hälftesträsket core comprises a greenish grey clay gyttja with LOI 15–20%. At 28 cm the sediment becomes dark brown gyttja (Fig. 7a). Diatoms were analysed from the sediment sequence between 35 and 10 cm. The dominant mesohalobous taxa (like planktonic species *Hyalodiscus scoticus* and *Melosira westii*, and littoral species *Camplydiscus echeneis*) in the lower part are replaced by freshwater taxa (e.g. *Fragilaria* spp, *Aulacoseira distans* and *Tabellaria* spp) between 30 cm and 25 cm indicating the isolation of the basin. According to the date cal AD 690–750 (cal AD 730) at 27 cm, the isolation took place around 750 AD.

3.2.2 Lake Kvarnviksträsket (site 6)

The lower part (97–78 cm) of the Lake Kvarnviksträsket core comprises a light blueish grey gyttja clay with LOI <6% (Fig. 7b). After this, the sediment is blueish grey clay gyttja, until it changes to greenish brown gyttja at 57 cm and further to dark brown gyttja at 45 cm. Diatom preservation is poor between 80 and 55 cm, but the assemblages represent a brackish-water environment. A rich diatom assemblage comprising freshwater taxa (e.g. *Eunotia* and *Tabellaria* spp) appears at 50 cm indicating that the basin became isolated from the Baltic Sea. The date cal AD 650–680 (cal AD 670) at 52 cm indicates the timing for the isolation event.

3.2.3 Lake Rövassträsket (site 7)

In the basal part of the Lake Rövassträsket core, the sediment is light greenish grey gyttja clay with LOI around 18% (Fig. 7c). It changes to light brown striped gyttja at 118 cm, and further to dark brown gyttja at 110 cm. Diatoms were analysed from the core between 120 and 85 cm. The brackish-water taxa is replaced by a composite of brackish-water and freshwater diatoms within the interval 110–100 cm, after

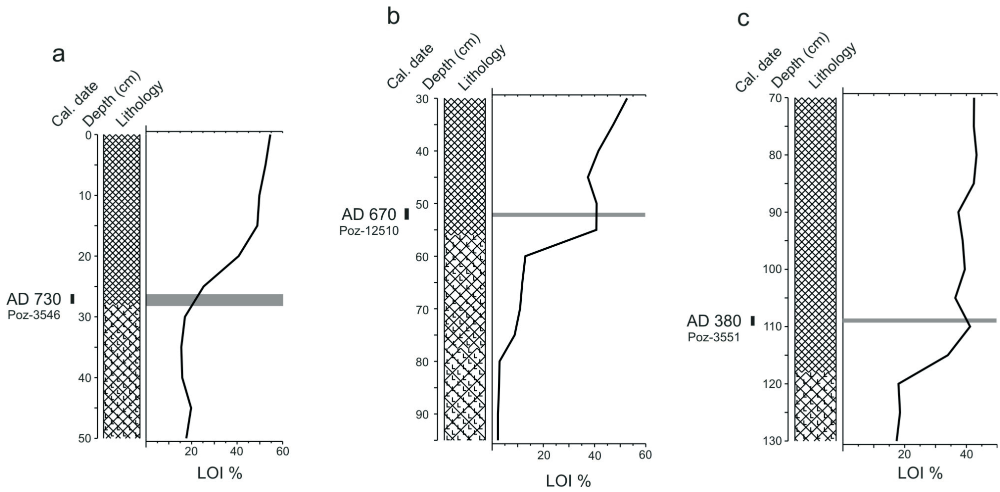

Fig. 7. Lithostratigraphy, loss-on-ignition, calibrated date and the isolation contact (grey line) from; a) Lake Hälftesträsket; b) Lake Kvarnviksträsket; c) Lake Rövassträsket, Orslandet.

which freshwater taxa dominate with small proportions of *Nitzschia scalaris*. The date cal AD 380–420 (cal AD 380) at 109 cm on the lower limit of the isolation horizon suggests the minimum age for isolation c. 400AD.

3.2.4 Lake Petarträsk (site 8)

The basal part of the sediment sequence of Lake Petarträsk comprises a greenish grey, laminated clay gyttja (Fig. 8). A major lithological change occurs at 103 cm, where the sediment changes to organic, greyish brown, slightly laminated gyttja (103–97 cm). Above this, the sediment consists of greyish brown gyttja (97-85 cm), and a dark brown gyttja with fine plant detritus (85–0 cm).

Diatoms were analysed from the sediment sequence from 110 cm up to the sediment surface. The sequence between 110 cm and 60 cm is subdivided into two diatom assemblage zones (I and II) from the base upwards (Fig. 9). The basal part of the zone I (110–96 cm) is dominated by the mesohalobous planktonic species *Melosira westii* fo. *parva* and *Melosira moniliformis*. In the uppermost part of the zone, mesohalobous littoral species *Navicula peregrina, Amphora commutata* and *Nitzschia scalaris dominate*. Other common species are oligohalobous species *Epithemia* spp., mesohalobous *Surirella striatula* and *Campylodiscus clypeus*. At the start of the zone II (96–60 cm), the mesohalobous diatoms are replaced by oligohalobous and halofobous (freshwater) species *Fragilaria* spp. and *Fragilaria construens* var. *venter*. After the short *Fragilaria maximum*, *Epithemia* spp., *Cymbella* spp, *Pinnularia* spp. and *Tabellaria* spp. become dominant. The diatom stratigraphy indicates a shift from a pelagic and brackish-water environment to a shallower and less saline coastal environment. The isolation of the basin is indicated by a clear change in the diatom stratigraphy with the up-core replacement of brackish-water taxa by freshwater taxa.

Five ^{14}C analyses were carried out on the sediment sequence, and on one the frozen surface sample (Alenius 2009, 2011). Two analyses were performed close to the isolation contact (Table 2): the first date 550–410 cal BC (540 cal BC) at 94–96 cm on the isolation contact, and the second date 540–410 cal BC (490 cal BC) at 87 cm on the lake sediment. The dates indicate that the isolation took place at c. 550 BC.

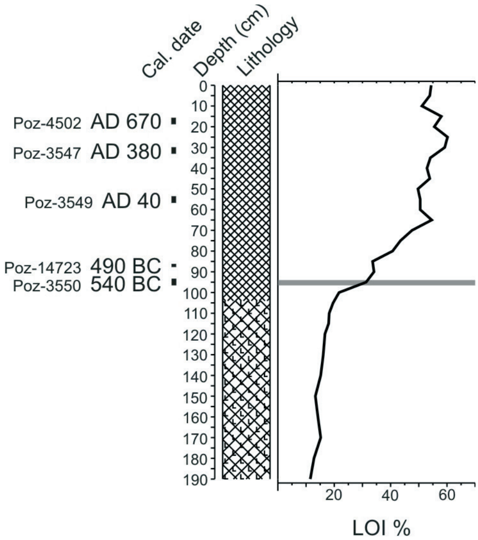

Fig. 8. Lithostratigraphy, loss-on-ignition, calibrated dates and the isolation contact (grey line) from Lake Petarträsk, Orslandet.

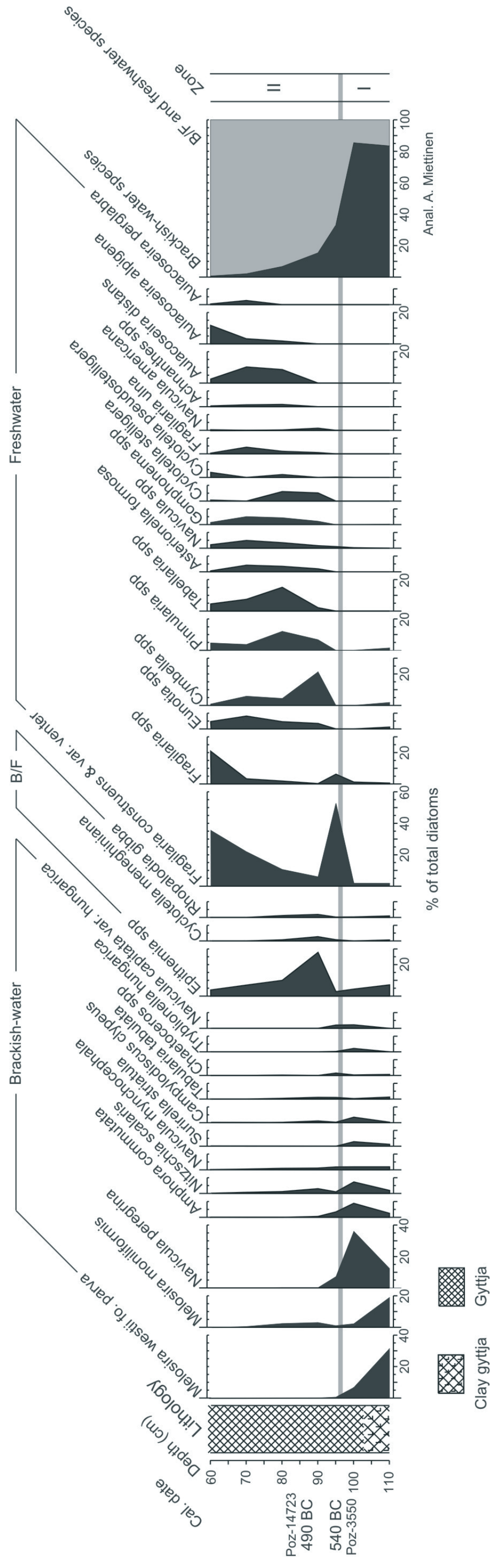

Fig. 9. Diatom diagram of Lake Petarträsk.

3.3 Älgö, Ekenäs

3.3.1 Lake Lillträsket (site 9)

The basal part of the Lake Lillträsket core consists of light greenish grey clay gyttja, which changes to greenish brown gyttja between 45 cm and 40 cm (Fig. 10a). After that, its colour is gradually darkened, until at 15 cm, the colour is finally dark brown. Diatoms were analysed in the interval 40–10 cm and they indicate that the isolation contact occurs between 20 cm and 15 cm. The date cal AD 1400–1430 (cal AD 1410) at 20 cm gives an estimated date of around 1400 AD for the isolation event.

3.3.2 Lake Storträsket (site 10)

The lower part of the 180 cm thick sediment core comprises a light grey clay gyttja with LOI 13–14% (Fig. 10b). A distinct lithological change occurs at 108 cm, where the sediment changes to dark brown organic-rich gyttja.

Diatoms were analysed from the core between 120 cm and 65 cm. This interval is subdivided into three diatom assemblage zones (I–III) from the base upwards. In the zone I (120–105 cm), the mesohalobous planktonic species *Melosira westii* fo. *parva* and *Melosira moniliformis* clearly dominates indicating a pelagic environment. In the next zone (II; 105-82 cm), the planktonic species almost disappear, and littoral mesohalobous species (like *Campylodiscus clypeus, Navicula peregrina* and *Nitzschia scalaris*) dominate indicating shallower water. Furthermore, the occurrence of halophiles *Epithemia* spp from the base upwards, and the appearance of some freshwater species (e.g. *Pinnularia* spp and *Eunotia* spp.) in minor proportions in the middle of the zone, suggests the beginning of the isolation process. At the base of the zone III (82–65 cm), the freshwater species become dominant (like *Aulacoseira ambigua, Cyclotella stelligera* and *Tabellaria* spp.) indicating that the basin had finally isolated from the Baltic Sea.

Four ^{14}C analyses were carried out on the sediment core (Table 2) and two of them were used for the isolation reconstruction: the date cal AD 210–260 (cal AD 230) was carried out at the depth of 105 cm at the transition limit from pelagic to shallower environment and the beginning of the isolation process, and the sec-

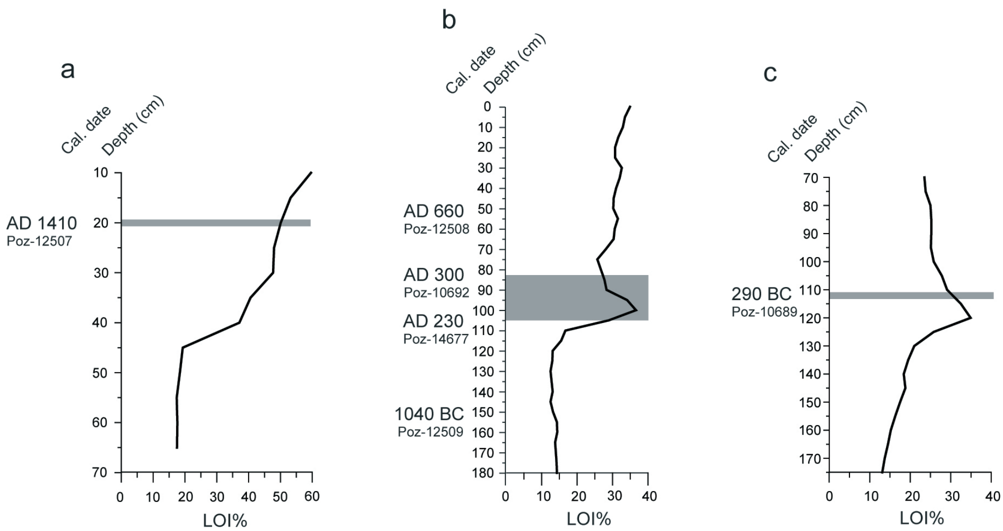

Fig. 10. Loss-on ignition, calibrated date(s) and the isolation contact (grey line); a) Lake Lillträsket; b) Lake Storträsket; c) Lake Byträsket, Älgö.

ond date cal AD 270–340 (cal AD 300) from the final isolation contact at 82 cm. These dates show a gradual isolation process within the period 230–300 AD.

3.3.3 Lake Byträsket (site 11)

The lithostratigraphy of the Lake Byträsket core was studied between 175 cm and 70 cm. The lower part of the sediment core comprises a greenish brown clay gyttja until it changes to gyttja of the same colour at 133 cm (Fig. 10c). The colour changes sharply to dark brown at 118 cm with the highest LOI (c. 35%) of the core. Diatoms were analysed between 120 cm and 100 cm. They indicate a relatively rapid isolation process as brackish water species (e.g. *Camplydiscus clypeus, Anomoeoneis sphaerophora* et var.) dominating in the lowest samples are almost totally replaced by freshwater species (e.g. *Pinnularia* spp, *Aulacoseira ambigua* and *Cyclotella radiosa*) at 110 cm. The date 330–280 cal BC (290 cal BC) carried out at 112 cm shows the age for isolation at c. 300 BC.

3.4 Tenala, Ekenäs

3.4.1 Lake Hemträsket (site 12)

The basal part of the 90 cm thick Lake Hemträsket core consists of greenish grey clay gyttja. It changes gradually to dark brown gyttja at c. 46 cm (Fig. 11a). Diatoms were analysed through the sequence, which was subdivided into three diatom assemblage zones (I– III) from the base upwards. In zone I (90–63 cm), brackish-water species (such as planktonic *Melosira moniliformis* and littoral *Navicula peregrina*) dominate indicating a relatively shallow environment. The diatom taxa in next zone (II; 63–43 cm) represent a mixed diatom flora with brackish-water (e.g. *Navicula peregrina*) and freshwater species (e.g. *Pinnularia* spp and *Tabellaria fenestrata*). Thus, this c. 20 cm thick zone suggests a relatively long-term isolation process. At the beginning of the zone III (43–0 cm), the planktonic freshwater species (e.g. *Aulacoseira lirata* and *A. lacustris*) become dominant indicating that the basin was finally isolated from the Baltic Sea. The date cal AD 620–660 (cal AD 640) carried out at 42 cm indicates the timing for this event.

3.4.2 Lake Sidsbackaträsket (site 13)

The 100 cm thick sediment core of Lake Sidsbackaträsket consists of greenish grey clay gyttja with LOI values between 12 and 18% (Fig. 11b). The organic content is its highest at c. 140 cm. Clear changes in the sediment composition are not visible in the core.

Diatoms were analysed between 180 cm and 90 cm and the core was subdivided into eight diatom assemblage zones (I–VIII) from the base upwards. The results of zones I–V are presented here. In zones I (180–173 cm) and II (173–160 cm), littoral mesohalobous species *Navicula peregrina* and *Surirella striatula*, planktonic *Melosira moniliformis* and halophiles *Epithemia* spp. dominate indicating a relatively shallow depositional environment. In zone III (160–148) cm, some freshwater species (e.g. *Fragilaria* spp, *Eunotia* spp) appear in minor proportions and brackish-water species start to decrease. At the start of zone IV (148–137 cm), several freshwater species appear and become dominant, such as *Aulacoseira ambigua* and *Tabellaria* spp. Brackish-water species are common (like *Melosira moniliformis*) but their proportion falls below 50%. Although some brackish-water species still exist (e.g. *Cyclotella meneghiniana* and *Nitzschia scalaris*) in the next zone (V; 137–128 cm), the dominance of freshwater species indicate the isolation of the basin. After a gradual isolation process, the basin was finally isolated from the Baltic Sea around 400 BC according to the date of 410–380 cal BC (400 cal BC) carried out at 137 cm (Table 2). The occurrence of some brackish-water species in minor proportions up-core to 90 cm indicates a high nutrient content in the isolated lake basin.

3.4.3 Lake Tjärnen (site 14)

In the lithostratigraphy of the Lake Tjärnen core, the basal part comprises a greenish grey clay gyttja (Fig. 11c). At 208 cm, the sediment changes to organic dark brown gyttja. Above that, the organic content of the sediment rises rapidly to as high as c. 80%. Diatoms were analysed from 220 cm to 180 cm. Brackish-water species (e.g. *Melosira moniliformis*) dominate the basal part (220–205) cm of the core. The first freshwater (e.g. *Aulacoseira* spp) species appear at c. 200 cm, and as soon as at 195 cm, they fully dominate, indicating freshwater environment.

Four ^{14}C analyses were carried out on the sediment sequence (Table 2) two of which for the timing of the isolation. The date 1130-1060 cal BC (1130 cal BC) was carried out at 206 cm, just below the isolation contact. The date 650–550 cal BC (640 cal BC) carried out at 195 cm shows that the isolation of the basin occurred at 1000–700 BC.

3.5 Prästkulla, Ekenäs

3.5.1 Leviskräsket mire (site 15)

The 200 cm thick core consists mainly of clay gyttja with light greenish colour with LOI 9–15% in the lower part of the core, and dark colour with LOI 16-19% above a short gyttja horizon (62–57.5 cm; LOI c. 23%) in the upper part of the core (Fig. 12a). At 32 cm, the sediment changes to gyttja and further to peat at 18 cm.

Diatoms were analysed from 50 cm to 15 cm. In the lower part of the core, the diatom composition indicates a very shallow environment based on the dominance of littoral species, such as *Campylodiscus clypeus*, *Nitzschia scalaris* and *Navicula peregrina*. Also *Fragilaria* spp are abundant, which indicates the very start of the isolation event. Freshwater species appear at 28 cm (e.g. *Eunotia* spp, *Stauroneis Phoenicenteron*) suggesting the isolation of the basin from the Baltic Sea. After a short lake phase, the basin became marshy.

There is no date from the isolation contact at 28 cm although two ^{14}C analyses were carried out on the sediment sequence (Table 2). Based on the date cal AD 940–990 (cal AD 940) at 33 cm, relatively close of the isolation contact, the timing for the isolation event could be roughly estimated at around 1200 AD. However, this estimation appears to be too old in relation to the present altitude of the basin of only 0.2 m a.s.l.

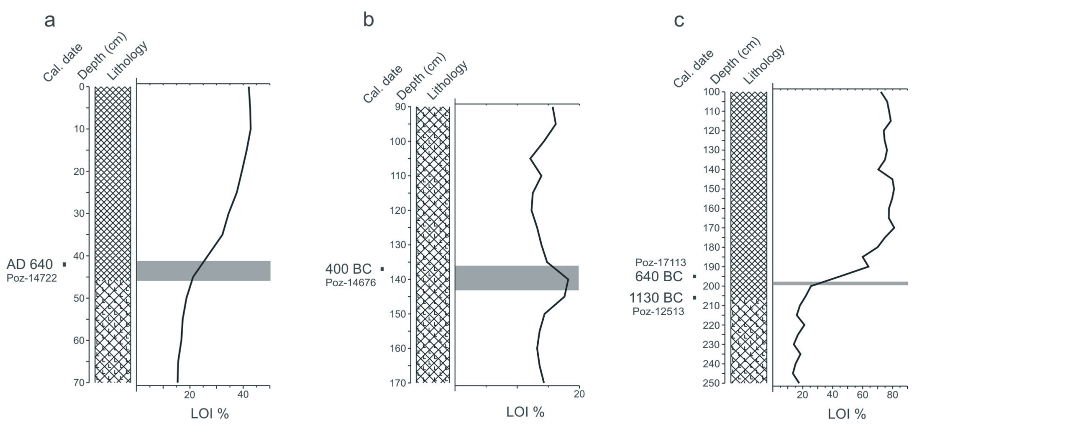

Fig 11. Lithostratigraphy, loss-on-ignition, calibrated date(s) and the isolation contact (grey line); a) Lake Hemträsket; b) Lake Sidsbackaträsket; c) Lake Tjärnen, Tenala.

3.5.2 Lake Tronsböleträsket (site 16)

The lithostratigraphy was investigated between 230 cm and 185 cm (Fig. 12b). The sediment core consists of gyttja with LOI 22–47%. It is light greenish grey coloured in the basal part of the core, but darkens upwards and finally to dark brown at 193 cm. Diatoms were analysed between 225 cm and 185 cm. They show that brackish-water diatom flora is replaced by freshwater taxa within the interval 190–185 cm. Two ^{14}C analyses were carried out on the sediment sequence (Table 2). The first date 120–40 cal BC (90 cal BC) at 191 cm just below the isolation contact and the second date cal AD 20–80 on the isolation contact at 186 cm, suggests that the isolation occurred at 50 AD.

3.5.3 Lake Djupdalsträsket (site 17)

The sediment is greenish brown weakly laminated gyttja in the base (100–85 cm) of the 100 cm thick sediment core, after which it changes to dark brown homogenous gyttja (Fig. 12c). Diatoms show that in the basal part of the core, mesohalobous species (e.g. *Melosira moniliformis, Nitzschia scalaris* and *Campylodiscus clypeus*) and freshwater Fragilaria spp dominate. At 87 cm, brackish-water species are almost completely replaced by freshwater species (e.g. *Cyclotella stelligera* and *Aulacoseira valida*) indicating the isolation of the basin. According to the radiocarbon date cal AD 270–330 (cal AD 290) at 88 cm (Table 2), this event occurred at c. 300 AD.

3.5.4 Lake Gundbyträsket (site 18)

The lithostratigraphy was investigated between 230 cm and 160 cm (Fig. 13). In the lower part of the core, sediment comprises a greenish grey clay gyttja. At 198 cm, the sediment changes to dark brown gyttja with LOI up to 47% (Fig. 14). Diatoms were analysed between 200 and 180 cm. They indicate a distinct succession from a brackish-water environment at 195 cm to fully freshwater conditions at 185 cm. A radiocarbon date of 1320–1270 cal BC at 192 cm gives c. 1300 BC for the timing of isolation event (Table 2).

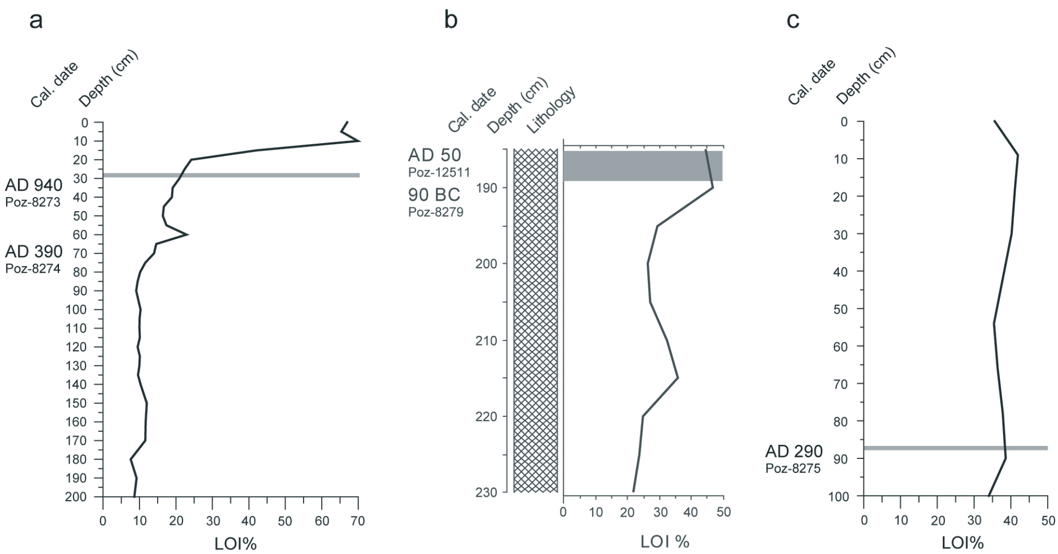

Fig. 12. Lithostratigraphy and/or Loss-on ignition, calibrated date(s) and the isolation contact (grey line); a) Levisträsket mire; b) Lake Tronsböleträsket; c) Lake Djupdalsträsket, Prästkulla.

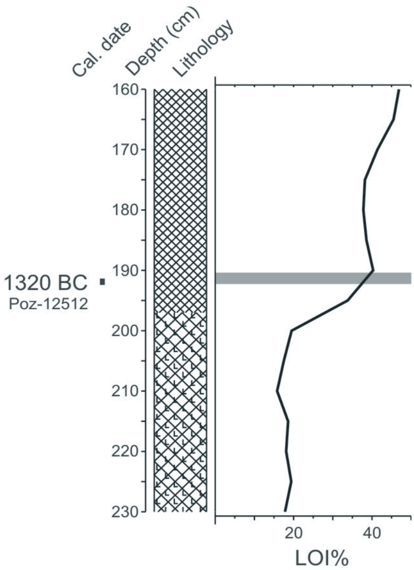

Fig. 13. Lithostratigraphy, loss-on-ignition, calibrated date and the isolation contact (grey line) of Lake Gundbyträsket, Prästkulla.

Fig. 14. The sediment sequence at 175–210 cm. At the bottom (on the right) light greenish grey clay gyttja from the Baltic Sea, at the top dark brown gyttja from the isolated lake. (Photo: A. Miettinen 2005)

3.5.5 Lake Rombyträsket (site 20)

The isolation results of Lake Rombyträsket are based on the previous study by Eronen et al. (1999), who determined the isolation of the basin by preliminary diatom analysis and the interpretation of lithostratigraphy (Fig. 15). After calibration, the original conventional radiocarbon dates (at 258–253 cm and 253–248 cm) show that the isolation process started at c. 1600 BC and ended 1470 BC (Table 3).

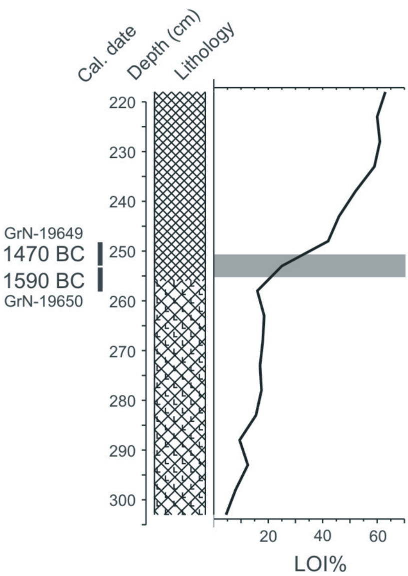

Fig. 15. Lithostratigraphy, loss-on-ignition, calibrated dates and the isolation contact (grey line) of Lake Rombyträsket, Prästkulla (redrawn from Eronen et al. 1999).

3.6 Shore displacement in Western Uusimaa 500 BC–AD 1500

The reconstructed shore displacement curves for all five areas in Western Uusimaa are presented in Fig. 16. The curves for Älgö and Prästkulla are combined as the study resulted in similar shore displacement pattern both of these areas. Some of the results are questionable; especially the results from Orslandet and Tenala which should be treated with caution (see discussion). Unverified reconstructions for these areas are presented as dashed lines.

The shore level data for all areas covers the period 500 BC–AD 1500 although most of the index-points focus on the period between 500 BC and AD 800. The shore displacement reconstruction for Kirkkonummi extends as far back as 2200 BC based on the earlier result from Lake Molnträsk (Hyvärinen 1999). The reconstructions extend back to c. 1500 BC in Prästkulla, to c. 1000 BC in Tenala, and back to 500 BC in Älgö and Orslandet.

Based on the shore level elevations at Prästkulla and Kirkkonummi at 1500 BC, the calculated rate of emergence of the shoreline for these areas was 4 mm/yr and 2.9 mm/yr, respectively. Compared with present land uplift rates (3.1 and 2.5 mm/yr) in these areas, the results show decreasing uplift rate towards the present.

Table 4 shows the elevations of the reconstructed shore levels at 500-year intervals for the five areas in Western Uusimaa. At 500 BC, the shoreline was located at about 8.5 m a.s.l. at Prästkulla, where the land uplift rate is its second highest after the Tenala area, and about 6.5 m a.s.l. at Kirkkonummi, in the area of the slowest uplift rate. Generally, shore levels on the other areas are located between the shore levels of Kirkkonummi and Prästkulla. At 1000 AD, the elevation range of the shore levels is small, only 1 m (Fig. 16 and Table 4). At AD 1500, the elevation of the shoreline is between 1 and 1.5 m in all of the study areas. Because of the relatively small differences in uplift rates of the various study areas, and since the accuracy of the research method is of the order ±0.5 m, the data are not precise enough to distinguish any differences between the areas during the past 500 years (Table 4).

The shore displacement curves of Kirkkonummi and Prästkulla demonstrate regular land uplift with a gradually decreasing trend during the last 4000 years. There is no evidence for any distinct sea-level transgressions in this time period although relatively young dates from Lake Storträsket (site 10, Tenala) could

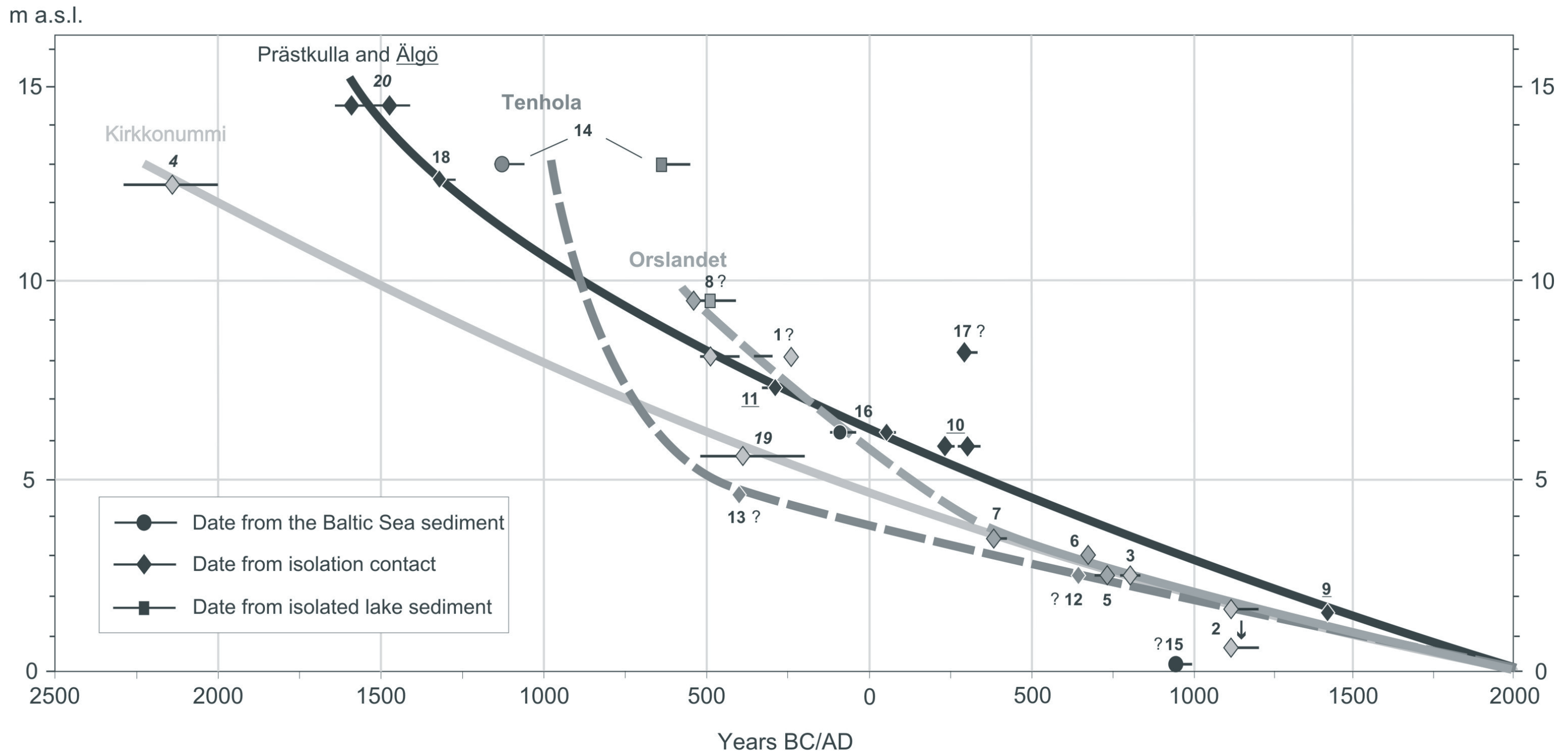

Fig. 16. Shore displacement curves for the Western Uusimaa area. Sites are numbered at Tables 1, 2 and Fig. 1. The shore level index-points are based on median probabilities of the calibrated ^{14}C dates with one sigma range. In the combined curve for Prästkulla and Älgö, the sites for Älgö are underlined. The unverified curve for Tenala and uncertain part (500 BC–AD 300) for Orslandet are presented as dashed lines. The sites with uncertain dates and/or ambiguous original threshold elevations are shown with a question mark, and previously investigated sites in italics.

Table 4. The Baltic Sea shore levels m a.s.l. in the study areas 1500 BC–AD 1500. Unverified results for Orslandet and Tenala are in parentheses.

	1500 BC	1000 BC	500 BC	0 BC/AD	500 AD	1000 AD	1500 AD
Kirkkonummi	10	8	6.5	4.5	3	2	1
Orslandet	No data	No data	(9.5)	(6)	3.5	2	1
Älgö	No data	No data	8.5	6.5	4.5	3	1.5
Tenala	No data	(13)	(5)	(4)	(3)	(2)	(1)
Prästkulla	14	10.5	8.5	6.5	4.5	3	1.5

suggest a short break in relative sea-level lowering 200–300 AD.

The results from Orslandet and Tenala differ markedly from those of Kirkkonummi, Älgö and Prästkulla (Fig. 16). The shore displacement curve for Tenala shows an extremely rapid sea-level lowering at 1000–500 BC. After that, the land uplift rate seems to be very slow compared with the other areas. The situation is somewhat similar in Orslandet, where the shore displacement curve shows a rapid fall between 500 BC and AD 300. However, after that it follows the uplift trends observed in the Kirkkonummi and Prästkulla areas.

4. Discussion

4.1 Comparison of the results with earlier shore displacement studies on Western Uusimaa

Generally, the results of this study are in good agreement with the earlier studies from the Western Uusimaa area. For example, Hyvärinen (1999) indicates slightly higher shore levels for the investigated period, e.g. at 1000 BC, the shore level was located at c. 9 m a.s.l. in Helsinki–Kirkkonummi, than the elevation of 8 m a.s.l. indicated herein. However, this metric difference is probably caused only by the different magnitudes of sea level change and time periods; the reconstruction by Hyvärinen (1999) covers 8000 years with shore levels up to 52 m a.s.l.

The magnitude of the study in the Tammisaari–Perniö area (Eronen et al. 2001) is also wide-ranging (8500 years, vertical scale 42 m), but generally, the results fit well with those of this study, e.g. the reconstructed shore level of 14 m a.s.l. in Prästkulla at 1500 BC fits the data by Eronen et al. (2001).

Previous studies also suggest gradually lowering sea-level without clear signals of sea-level transgressions during the last 4000 years. The results of the current study are also in agreement with the previous shore displacement data from the south-eastern coast of Finland, where the land uplift rate is slower (Miettinen et al. 1999; Seppä et al. 2000; Miettinen 2002; 2004) than in the west. However, any land uplift anomalies have not been verified in previous studies from southern Finland regarding the last 4000 years so far.

4.2 Isolation process of the basins

The isolation of a basin from the sea is a gradual process which may take tens to hundreds of years depending of the land uplift rate and the local shore facies. The local sea-level may vary considerably due to changing meteorological conditions, e.g. the sea-level in the gulfs of the Baltic Sea can vary locally by 2.8 m between a low level under an atmospheric high, and a high level during the subsequent cyclonic low pressure (Atlas of Finland 1986). Such short-term sea-level fluctuations may enable saline water to briefly re-enter recently isolated lakes which today lie only slightly above mean sea-level. Longer, on annual to multidecadal-scale variability in the sea-level of the Baltic basin can be caused by the North Atlantic Oscillation (NAO), which is the primary source of variability for North Atlantic climate on short-term time scales. The sea-level pressure distribution over the North Atlantic for the positive NAO phase has a well developed Icelandic Low and Azores High, associated with stronger westerly winds over the eastern North Atlantic and the European continent (Wanner et al. 2001 and references therein). In the Baltic Sea, these winds can result in a sea-level rise which magnitude can be in the order of dozens of centimetres.

In most basins in this study, the isolation process was rapid and the isolation contact is clear, evident in both in the lithostratigraphy and diatom stratigraphy. In some basins (e.g. Hannusjärvi, site 1), the isolation process was more gradual, as reflected by the lithostratigraphy and/or diatom stratigraphy. In the majority of the studied basins, gyttja was deposited in the basins before the final isolation of the basin from the sea. This indicates that during the final phase of the isolation process, the connection between the sea and isolating basin was limited, and organic gyttja accumulated in the basin. Diatom analysis has proven a very practical method for determining the isolation contact. Caution is needed in this method, however, because brackish-water diatom species can often be found in sediments of a recently isolated basin. However, the abundance of these species is usually small and their occurrence in recently isolated systems near the coast is well known.

The results show that the sediments of isolated basins in Finland are well suited for radiocarbon dating, because there are no large age differences between the uppermost brackish-water Baltic Sea sediment and the freshwater sediment of the isolated basin. This indicates negligible reservoir age effect on the coastal sediments of the northeastern Baltic Sea (cf. Hyvärinen 1999; Eronen et al. 2001; Miettinen 2002). The main reasons for that are the low salinity (c. 6‰) in this part of the Baltic Sea and the dominance of Precambrian crystalline rocks in the southern Finland where no limestones occur (Korsman et al. 1997).

4.3 Uplift anomalies or errors in shore displacement data?

The reconstructed rapid sea-level lowering in Tenala between 1000 and 500 BC and Orslandet between 500 BC and AD 300 indicates a very rapid uplift rate compared with the present uplift rates in these areas. In the Tenala area, the uplift trend is reversed after 500 BC, when the uplift rate becomes very slow in comparison with the other areas. However, the present uplift rate, particularly in the Tenala area, should be the most rapid of all the areas studied. In this context, the isolation date for the uppermost basin (Lake Tjärnen, site 14) in Tenala appears to be reliable.

Because the relative sea-level lowering is slow and steady in Kirkkonummi, Älgö and Prästkulla, and is also very similar to present uplift trends, the cause for the observed anomalies in the shore displacement data is not related to eustatic sea-level changes, but to anomalies in the regional land uplift pattern, or to erroneous reconstructions. The essential question is whether the observed anomalies are real, caused by the irregularities in land uplift, or an artefact arising from erroneous radiocarbon dates or incorrect interpretation of the isolation data, or the uncertainty of the threshold altitude.

After isolation, the thresholds may have been naturally lowered by the erosion of the outlet channel, or artificially lowered. The artificial lowering of the thresholds has been common in Finland since the 18th century. Usually, the artificial lowering has been 0.5–3 m, but the data of these lakes or the magnitude of the lowering are not always available. Sometimes it is possible to estimate, or even exactly measure, the lowering from the structure of the outlet channel. E.g. in this study, the present threshold altitude of Lake Strortäsket (site 2) is 0.8 m a.s.l., but it was artificially lowered by one metre as it was seen in the outlet channel. Probably at least the threshold altitude of Levisträsket (site 15) mire has been artificially lowered based on the location of the basin at very low elevation (0.2 m a.s.l.) and “old” radiocarbon date (cal AD 940) close to the isolation contact.

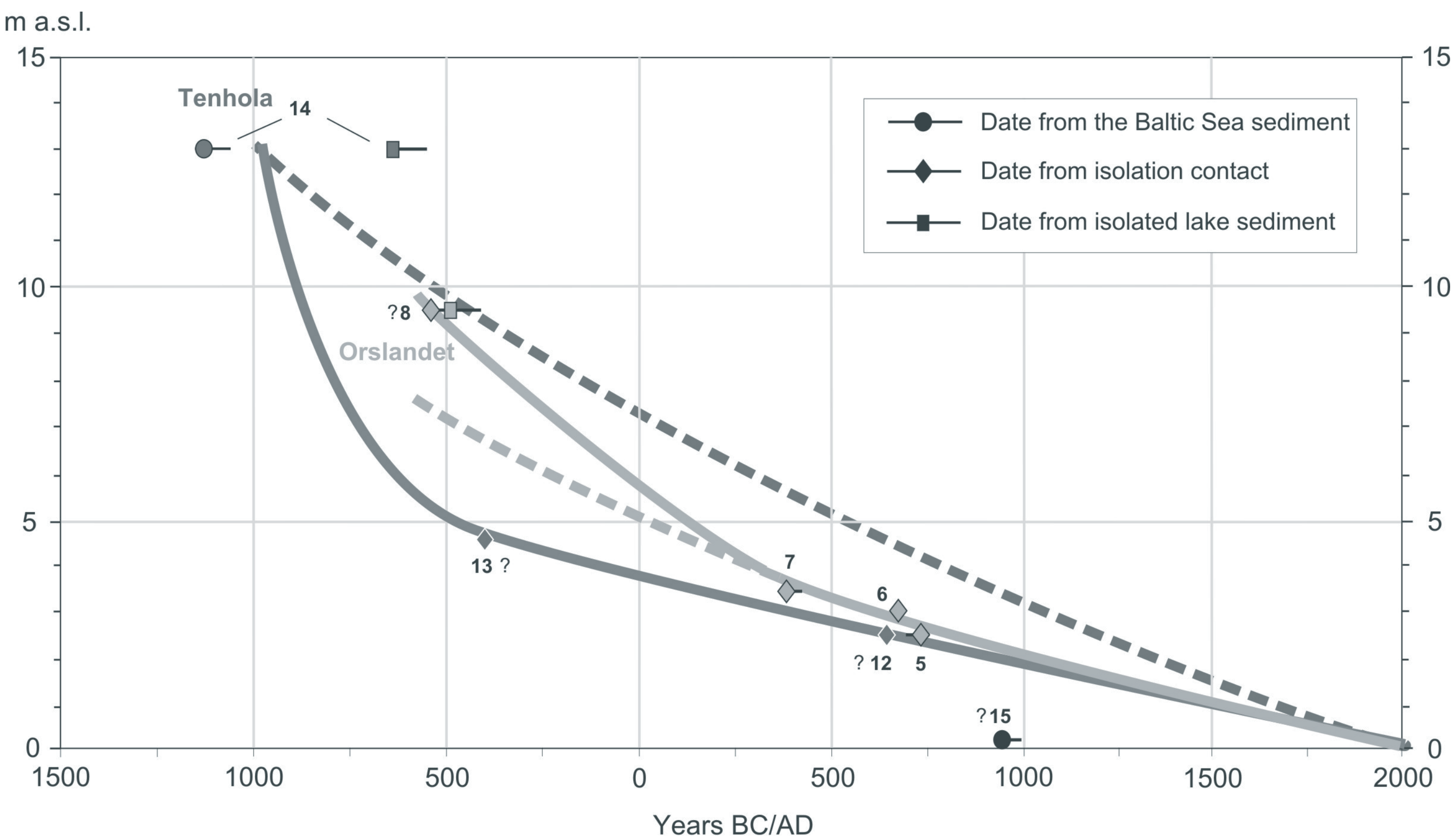

Fig. 17. The reconstructed shore displacement curves (solid line) and the hypothetical curves (dash line) for the Orslandet and Tenala areas based on the shore displacement reconstructions on other areas.

Moreover, the basin is currently surrounded by large cultivation areas. In some cases, but not so often, the threshold altitudes have also been raised (e.g. by damming).

It is noteworthy that the different results from Tenala and Orslandet are based on the isolation data from only three basins (Lake Hemträsket (site 12) and Sidsbackaträsket (site 13), Tenala, and Lake Petarträsk (site 8), Orslandet). Fig. 17 illustrates both the reconstructed shore displacement curves and the hypothetical shore displacement curves for Orslandet and Tenala as they should exist, according to land uplift pattern based on the results from other study areas. The anomalous shore-level index-point from Lake Petarträsk, Orslandet appears to be reliable with two dates and an apparent isolation process. There is no evidence for uplift of the threshold altitude of Lake Petarträsk, hence suggesting a real uplift anomaly for this area. However, to verify this anomaly more investigations are needed. Also, isolation processes from the basins located in the Tenala area are evident. However, there are two radiocarbon dates only for the uppermost site, Lake Tjärnen (site 14) (Table 2 and Figs. 16 and 17), whilst at the other two sites, Hemträsket and Sidsbackaträsket, each have only a single date and may therefore be in error (Table 2 and Figs. 16 and 17). Moreover, the latter two basins in Tenala belong to the same water system. So, it is probable that this presumed anomaly is only caused by the lowering (naturally or artificially) of the threshold altitudes of the basins after the isolation.

The isolation of Hannusjärvi (site 1, Espoo) should concur with the shore displacement pattern of Kirkkonummi, but for some reason, the dates are c. 500 years too young. Because the site is located furthest east as a solitary basin in Espoo, the present material does not help to find an explanation for this anomaly. The only date from Lake Djupdalsträsket (site 17, Prästkulla) is almost 800 years too young in comparison with the shore displacement trend in the Prästkulla area.

In summary, the main cause for the observed anomalies in this study appears to be uncertainty of original threshold elevations. The change of threshold elevation has always taken place after isolation process, and so, the age for the isolation of the basin is correct, if the radiocarbon date itself is not erroneous. It was not possible to prove the radiocarbon dates erroneous from the basins of this study with single dates. That is why it is advisable to carry out at least two dates on isolation contact in shore displacement studies. Moreover, it should always be taken into account that the best possible accuracy of the isolation research method is of the order of only ±0.5 m.

However, it can be hypothesised that the unverified anomalies seen in this study may record movements of blocks along old fracture zones which exist around the study areas. Present geophysical levelling profiles certify that local changes in the present land uplift rate exists between bedrock blocks (Veriö et al. 1992; Kuivamäki et al. 1998). The published late Holocene shoreline data provide no evidence for remarkable vertical displacement between bedrock blocks in Finland. However, the possibility of local disturbances of uplift caused by vertical faulting in the course of glacio-isostatic rebound has also been discussed for southern Finland (e.g. Kakkuri 1985; Donner 1995; Lehmuskoski 1996; Kuivamäki et al. 1998; Eronen et al. 2001).

5. Conclusions

In this paper, a detailed shore displacement reconstruction has been carried out for the Western Uusimaa area for the previously poorly investigated period of the last 4000 years, and in particular for the period 500 BC–AD 1500.

The results show that the shoreline representing Baltic sea-level at 500 BC is now located about 8.5 m a.s.l. in Prästkulla, and about 6.5 m a.s.l. in Kirkkonummi. In other areas, the shoreline is located between these elevations. These differences are solely due to the different land uplift rates, which decrease eastwards along the coastal area. Because of the relatively small differences in uplift rates of the various study areas, it is not possible to distinguish any differences between the areas after AD 1500. The Baltic Sea shoreline representing that time is located at 1–1.5 m a.s.l. in the Western Uusimaa area.

It is not possible to detect any clear sea-level transgressions in the shore displacement data during the investigated period. In general, results suggest gradually lowering sea-level and land uplift during the past four millennia. Possible land uplift anomalies representing local events were detected in Tenala and especially in Orslandet although these interpretations can be erroneous and more investigations are needed to verify these results. However, the available data suggests that the late Holocene uplift in the coastal area of southern Finland may not have proceeded as regularly as previously believed.

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