Holocene development of the Pennala basin with special reference to the palaeoenvironment of Meso- and Neolithic dwelling sites, Lahti–Orimattila, Southern Finland

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Sirviö, Tommi and Meri Kajander (2003). Holocene development of the Pennala basin with special reference to the palaeoenvironment of Meso- and Neolithic dwelling sites, Lahti–Orimattila, Southern Finland. *Fennia* 181:1, pp. 85–101. Helsinki. ISSN 0015-0010.

The Holocene development of the Pennala basin, Southern Finland, was studied using lithostratigraphical and biostratigraphical methods, shore level surveys and radiocarbon dating in the areas adjacent to the I Salpausselkä ice-marginal formation. The study results give an improved picture of the shoreline displacement and palaeoenvironment of the Pennala basin during the period of 10000–2500 ^{14}C yr BP (ca. 11400–2600 cal yr BP).

The results indicate that the Ancylus Lake stage in the Pennala basin occurred during the Preboreal and Early Boreal chronozones around 9600–8900 ^{14}C yr BP (ca. 10900–10 000 cal yr BP). The transgression was followed by a long-term lake phase, which ended, due to overgrowth of the basin, at ca. 2900 ^{14}C yr BP (ca. 3000 cal yr BP). The highest Ancylus shoreline in the area is located at 71 m a.s.l. The altitude of the ancient Pennala Lake is located at 68.5 m a.s.l.

The Pennala basin and adjacent areas were inhabited by Stone Age dwellers during the Middle Neolithic period. The dated evidence of the Early Mesolithic settlement in the area remains scarce. During the Early Mesolithic period the Pennala basin was a sheltered bay of the Ancylus Lake and during the Middle Neolithic period of settlement ca. 5500–3500 ^{14}C yr BP (ca. 6300–3800 cal yr BP) the basin served Neolithic dwellers as a small inland lake.

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Introduction

Shoreline displacement during the Ancylus Lake stage in Southern Finland ca. 9500–8000 ^{14}C yr BP

The first evidence of a transgression that had occurred at the beginning of the Ancylus Lake stage was discovered in Southern Finland and Karelian Isthmus (Hyyppä 1937, 1943). Since then the nature, extent and dating of the Ancylus transgression in Southern Finland have been discussed and modified by several authors (e.g., Tynni 1966; Eronen 1976; Eronen & Haila 1982; Glückert & Ristaniemi 1982; Ristaniemi & Glückert 1987; Matiskainen 1989b; Glückert 1991).

The Ancylus transgression in Southern Finland began 9700–9500 ^{14}C yr BP (ca. 11200–10 700 cal yr BP) and reached its maximum level at 9200–9000 ^{14}C yr BP (ca. 10300–10200 cal yr BP) (Eronen & Haila 1982; Glückert & Ristaniemi 1982; Ristaniemi & Glückert 1987; Glückert 1991). The Ancylus transgression was followed by a rapid regressive stage of the lake, which in Southern Finland occurred around 9000–8000 ^{14}C yr BP (ca. 10200–8900 cal yr BP) (e.g., Eronen & Haila 1982). The altitude of the Ancylus shore level (the Ancylus limit) at the time of transgression maximum has been placed at 64–74 m a.s.l between the Helsinki–Pukkila and the II Salpausselkä isobases of current land uplift (Tynni 1966; Eronen & Haila 1982; Glückert & Ristaniemi 1982). The Ancylus limit is located approximately at 70 m a.s.l. in Lohja (the I Salpausselkä), and the amplitude of the transgression in the same area was 4–5 metres (Ristaniemi & Glückert 1987).

The regressive stage of the Ancylus Lake led to the final isolation of several independent basins. Some of these basins have remained as lakes to the present day while others have dried-up during the post-glacial time due to peat overgrowth and sedimentation. Finally, in order to increase the area of agricultural land, many lakes in Southern Finland were destroyed between 18th and 20th centuries by lowering the water level of the lakes or by totally drying them up.

Layers of gyttja typically indicate the lake stages in the sediments and these layers have been reported from several locations under peat deposits. Overgrowth of these presently non-existing lakes have been, in many cases, reported as "side products" from studies that seek isolation contacts and indicators of transgressions under peat bogs (e.g., Jantunen 1995). Korhola (1990a) has roughly estimated that in the Southern zone of raised bogs, at least 20% of the bogs were formed by overgrowth. The development history of such overgrown lakes has been of minor interest of geologists, geographers and archaeologists with few exceptions (e.g., Korhola 1990b; Tikkanen & Korhola 1993). The currently studied Pennala basin is one example of an overgrown lake isolated during the Ancylus regression. This paper will make a special reference to archaeological data and show the importance of such ancient lakes to Stone Age dwellers.

Palaeoenvironments and dating of Stone Age dwelling sites

The dating of Mesolithic and Neolithic (Stone age) dwelling sites in Finland has been traditionally based on known shore displacement of the Baltic Sea, the altitudes of dwelling sites and type of artefact found at excavation sites (e.g., Siiriäinen 1973; Matiskainen 1989a; Hyvärinen 1999). With a few exceptions, most of the Mesolithic and Neolithic dwelling sites are assumed to have been located very close to the shorelines and the archaeological shoreline displacement chronologies have been based on assumption that the prehistoric site must have been located in close contact with the shoreline of its time (Siiriäinen 1982; Matiskainen 1989a).

The chronology of the Mesolithic presented by Matiskainen (1989a) is divided into two chronological stages: Ancylus Mesolithic 9300–8000 ^{14}C yr BP (ca. 10450–8900 cal yr BP) and Litorina Mesolithic 8000–6000 ^{14}C yr BP (ca. 8900–6800 cal yr BP) stages. The Mesolithic stage was followed by the Neolithic period, during which Comb Ware ceramics was common in Finland. The upper limit of the Neolithic period has been defined at ca. 2500 ^{14}C yr BP (2600 cal yr BP) (Siiriäinen 1982).

During the Holocene (and Mesolithic) the palaeoenvironment in Finland was unsteady, and the Stone Age dwelling sites were subject to large scale environmental changes such as deglaciation, land uplift, shore displacement of the Baltic and development of vegetation (Siiriäinen 1987; Matiskainen 1989b). The shore-level fluctuations and overgrowth of small lakes, however, have been widely bypassed by researchers, whereas possible overgrown lakes in Porvoonjoki River valley have been found in preliminary studies from several locations including Kanteleenjärvi (Pukkila) and Luhdanjoki (Lahti–Hollola) areas (Sirviö 2000; Sirviö et al. 2002).

The most comprehensive studies made on palaeoenvironments of Stone Age dwelling sites in Finland have been presented by Matiskainen (1989b) who reconstructed the palaeoenvironment of the Mesolithic dwelling sites 10000–6000 ^{14}C yr BP (ca. 11400–6800 cal yr BP) based on shore displacement, vegetation history, refuse fauna and archaeological artefacts found from Askola area 40 km south of the Pennala basin. It was concluded that emergence of new land during the rapid Ancylus regression forced Early Mesolithic settlements to move south from the Porvoonjoki River valley down to the Askola region in order to carry on a subsistence strategy in a similar archipelagic palaeoenvironments.

The postglacial vegetation history during the Mesolithic and Neolithic stages in Southern Finland is well known (e.g., Donner 1971). The research on the vegetation history close to the Pennala basin includes studies made on the Työtjärvi Lake, Varrassuo bog (Hollola) (Donner et al. 1978), Joutjärvi and Alasenjärvi Lakes (Lahti) (Vuorela 1978). According to the analysed pollen on the Työtjärvi core, the first indication of

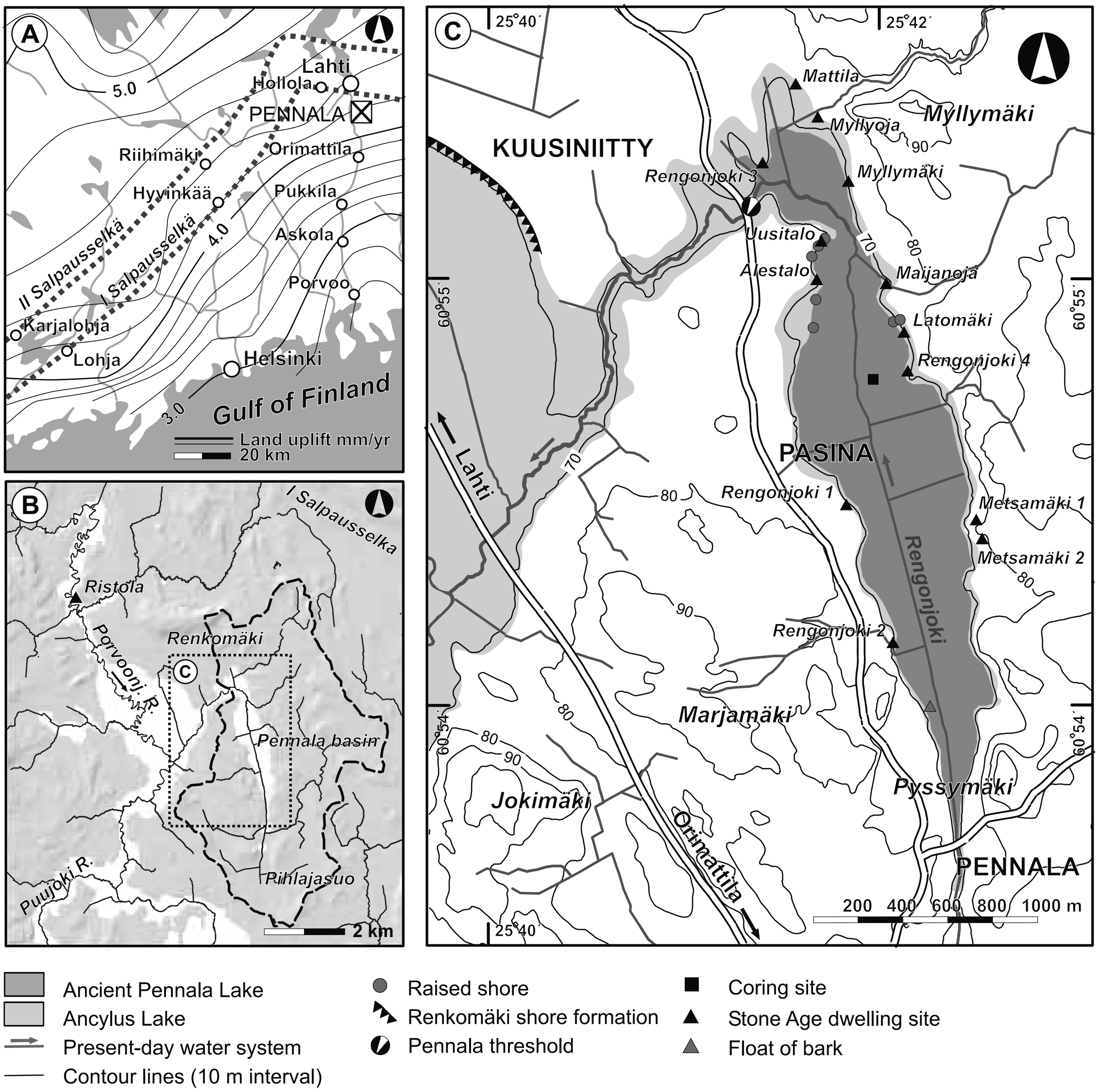

Fig. 1. The location of the study area in southern Finland. A) Location of the investigated Pennala basin south of Lahti, and isobases of current land uplift (mmyr^{-1}). B) The extent of the Pennala drainage area and the extent of Ancylus Lake during the transgression maximum at ca. 9100 ^{14}C yr BP (ca. 10200 cal yr BP) with reference to the Mesolithic Ristola dwelling site. C) The extent of the ancient Pennala Lake at 8900–2900 ^{14}C yr BP (ca. 10000–3000 cal yr BP) and the maximum coverage of Ancylus Lake with reference to the location of Mesolithic and Neolithic dwelling sites and raised shore formations.

forest clearing in the area occurred ca. 5600 ^{14}C yr BP (ca. 6400 cal yr BP). Pollen analyses on Työtjärvi and Varrassuo cores have indicated that the slash-and-burn agriculture arrived in the area ca. 3200–2400 ^{14}C yr BP (ca. 3400–2400 cal yr BP) (Donner et al. 1978).

Site description

The Pennala basin

The Pennala basin (Figs. 1 and 2) is located 5 km south of the I Salpausselkä, by the border of Lahti

Fig. 2. The Pennala basin northwest of Pyssymäki Hill. The investigated coring site is marked with an arrow and the shore level of the ancient Pennala Lake with a broken line. (Photo: Tommi Sirviö).

and Orimattila communes (60°55'N, 25°42'E). The altitude of the basin varies from 66.6 m a.s.l. (the threshold) to 130 m a.s.l. (Renkomäki hill) and both heights are located in the northern parts of the drainage basin. The Rengonjoki River flows gently to the north in the middle of the basin.

The middle parts of the Pennala basin consist of flat, low-lying and mostly cultivated areas at 67.5–70 m a.s.l. The width of flat and low-lying area varies between 200–600 m and is widest in the middle and northern parts of the basin. The length of the flat area is approximately 3.5 km. The low-lying area consists of 1.3–1.7 m thick layer of Carex and Sphagnum peat, below which a deposit of gyttja and clay gyttja over 3 m thick is present. Another noticeable peat deposit, the Pihlajasuo bog (70.5 m a.s.l.), is located in the village of Pennala at the southern end of the drainage basin. In general, the areas located slightly over 70 m a.s.l. consist of clayey and silty soils, and are in most cases cultivated. Higher altitudes, on the other hand, are dominated by forests and contain till and unevenly distributed sand and gravel deposits of glaciofluvial origin re-worked by wave action (for example the Renkomäki, Latomäki and Pyssymäki hills). The total area of the drainage basin is approximately 24 km^2.

Earlier archaeological studies in the Pennala basin

A total of 12 Stone Age dwelling sites and one secondary site (float of bark) have been found in the Pennala basin (Poutiainen & Takala 2001). The altitudes of the dwelling sites vary between 68.5–75.5 m a.s.l. Several other Stone Age dwelling sites have been found in the adjacent areas, including Ristola (e.g., Matiskainen 1989b; Takala 1999), Luhdanjoki (Lahti–Hollola), Puujoki (Orimattila) and Kanteleenjärvi (Pukkila) (e.g., Poutiainen 1998).

The first archaeological finds in the Pennala basin were made in 1948 (Itkonen 1949). A wooden sledge-runner was found beneath peat deposits (depth 1.6 m) from the western side of the Rengonjoki River, near the Alestalo dwelling site. The find resulted in pollen analytical studies (Valovirta 1949), based on which the sledge-runner was dated to the stage, typical of Comb Ware ceramics ca. 5000 ^{14}C yr BP. Further small excavations were carried out in the same year on the eastern side of the Rengonjoki River at Maijanoja dwelling site at approximately 70 m a.s.l. (Luho 1950).

A second period of excavations was carried out during 1959. The most important finds at the Alestalo dwelling site contained pieces of Comb Ware ceramics (at 67.0–67.3 m a.s.l.) and remnants of a hearth (68.6–68.8 m a.s.l.) (Meinander 1960). Two radiocarbon dates, 5370 ± 140 and 4840 ± 190 ^{14}C yr BP (ca. 6200 and 5600 cal yr BP), were obtained from a layer of Comb Ware ceramic pottery, rich in *Trapa natans* (water chestnut) fruits (Meinander 1971).

Vuorela (1981) carried out pollen stratigraphical studies of the Pennala basin in the immediate vicinity of the Alestalo and Uusitalo dwelling sites (Fig. 1). A radiocarbon date 5310 ± 110 ^{14}C yr BP (ca. 6100 cal yr BP) was obtained from the previously mentioned level containing the sledge-runner and remnants of *Trapa natans*. Despite the presence of several Stone Age dwelling sites in the vicinity, apophytic evidence in the stratigraphy were too scarce to indicate a clear influence of human activities on vegetation. A distinct change in the upper part of the stratigraphy (including a change from coarse gyttja to peat) was interpreted as indicating the final drying up of the basin (Vuorela 1981). Layers rich in *Trapa natans* macro remnants were interpreted as cultural layers with fruits crushed by Stone Age dwellers (Aalto 1981). Vuorela (1981) concluded that water chestnut was possibly favoured or even intentionally cultivated in the area.

The most recent excavations in the Pennala basin have been carried out on five dwelling sites (Myllyoja, Alestalo, Uusitalo, Metsämäki 1 and Metsämäki 2) during 2000–2002. The majority of the finds of the recent excavations were made from the Myllyoja dwelling site located in the northern end of Pennala basin at 69.0–71.5 m a.s.l. Most of these finds consisted of ceramics from the Neolithic substages, and possible hearth remnants were found at 69.5–69.6 m a.s.l. (Poutiainen 2001). The preliminary results of the radiocarbon dating showed that the oldest date obtained from a burnt bone belonged to the Early Mesolithic period ca. 9300 ^{14}C yr BP (ca.10500 cal yr BP). Two other radiocarbon dates were obtained from the Neolithic ceramics, ca. 4000 ^{14}C yr BP (ca. 4500 cal yr BP), and one from charcoal, ca. 1200 ^{14}C yr BP (ca. 1100 cal yr BP) (Poutiainen 2002). The excavations carried out at the Alestalo and Uusitalo dwelling sites consisted of findings that included quartz artefacts, ceramics, and burnt bone. Most of the finds were made between 67.8 and 70.6 m a.s.l. (Takala 2001).

The dwelling sites of Metsämäki 1 and 2 are located noticeably above the dominating, low-lying level of the basin to the east of the Rengonjoki River at ca. 73–75.5 m a.s.l. (Poutiainen & Takala 2001). The finds made at the excavations in summer 2002 included quartz and ceramics, which suggest that the sites were inhabited at least during the Late Neolithic stage (Poutiainen 2002; Takala 2002). The Ristola dwelling site is located adjacent to the Porvoonjoki River, approximately 4 km northwest from the Pennala basin at 68–75 m a.s.l. The first finds from the Ristola site were made in 1966, and preliminary excavations were carried out during 1970–1971. More comprehensive excavations were carried out during 1995–1999 (Takala 1999). The most important finds from the site included flint artefacts and flake fragments, comparable to the Kunda Culture and Pulli site in Southern Estonia, dating back to the Early Mesolithic period. The radiocarbon age ca. 9250 ^{14}C yr BP (ca. 10500 cal yr BP) of the Ristola site gains support also from shore displacement chronology (Ristaniemi & Glückert 1987; Matiskainen 1989b). The radiocarbon dates from the in situ structures found at the site are much younger (from Neolithic to recent) than the typology of the artefacts and location of the site would suggest (Takala 1999; Takala 2002).

Field and laboratory methods

To verify the assumed levels of the Ancylus transgression and the ancient Pennala Lake, the altitudes of the raised shorelines and the threshold (Figs. 3 & 4) were surveyed in the area close to the level of Ancylus Lake (approx. 65–75 m a.s.l.) previously described by Ristaniemi & Glückert (1987). The altitudes were levelled with a tachymeter (total station), using the fixed points established by the City of Lahti and the National Land Survey of Finland as reference. For the purpose of biostratigraphical analyses, successive cores (500 mm, Ø 100–150 mm) were taken through 400 cm (110–510 cm) of the sediment using a Russian peat sampler (Jowsey 1966) at the bottom of the low-lying basin at 67.4 m a.s.l.

Loss-on-ignition analysis (LOI) and mineral magnetic measurements (specific susceptibility) (Fig. 5) were carried out to examine the changes in sediment organic content and possible changes in sedimentary environments. Both LOI and specific susceptibility were analysed at 5 cm intervals. Susceptibility measurements were carried out on individual subsamples with MS2B equipment, and the results are presented as specific susceptibility χ ($\mu m^{-3}\ kg^{-1}$).

Pollen analysis (Fig. 6) was carried out to examine major changes in vegetation history of the area and the results were compared with the dating results of the main pollen zone assemblage boundaries of the area (Donner 1971; Donner et al. 1978). Pollen preparations were made at 10–20 cm intervals with standard chemical methods (e.g., KOH, HF and acetolysis) (e.g., Moore et al. 1991). From each preparation at least 200 grains of pollens or spores were counted. The pollen nomenclature follows Moore et al. (1991) with the exception of *Dryopteris*-type, which corresponds to the Polypodiaceae taxon presented by Moore et al. (1991). The pollen zone boundaries presented as a reference in the pollen diagram are based

Fig. 3. An ancient shoreline (a wave-cut scarp) representing the Ancylus limit at 70.8–72.6 m a.s.l. south of Renkomäki Hill. (Photo: Tommi Sirviö).

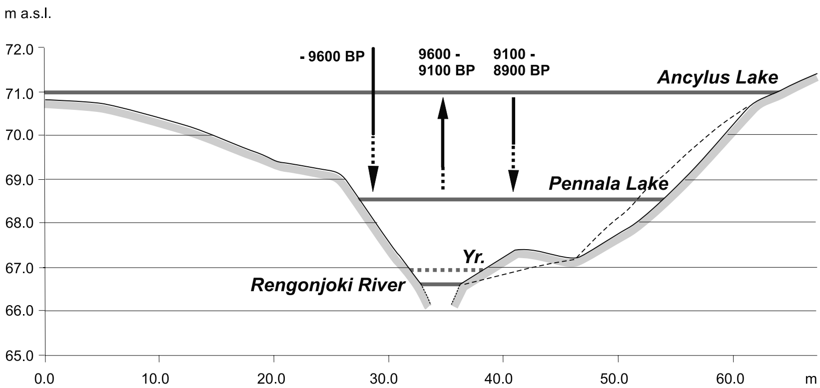

Fig. 4. Cross-sectional profile of the current threshold of the Pennala basin located at 66.6–69.4 m a.s.l. The investigated shore levels of Ancylus Lake (ca. 71.0 m a.s.l.) and the ancient Pennala Lake (ca. 68.5 m a.s.l.) are also presented. Conventional radiocarbon dates (^{14}C yr BP) of the shore level fluctuations are based on the analysed Pennala core. The theoretical minimum water level of the Yoldia Sea in the area and a recent landslide scar with toe formation are presented in the profile with grey dotted line and black broken line, respectively.

on Holocene regional pollen-assemblage zones of Southern Finland (Donner 1971; Tolonen & Ruuhijärvi 1976; Donner et al. 1978), which in the Työtjärvi Lake and Varrassuo bog have been dated as follows: the upper boundary of the *Betula* zone (P°) at 9000 ^{14}C yr BP (ca. 10200 cal yr BP), and the upper boundary of the *Pinus* zone (A°) at 8600 ^{14}C yr BP (ca. 9500 cal yr BP). The rise of *Picea* (Pc°) at 4200 ^{14}C yr BP (ca. 4800 cal yr BP) (Donner et al. 1978) and *Tilia* (T°) at ca. 7500–7000 ^{14}C yr BP (ca. 8300–7800 cal yr BP) (e.g., Hyvärinen 1980) are also presented in the pollen diagram.

In order to identify major shore-level changes in the area the core was subsampled at 10–20 cm intervals for diatom analysis (Fig. 7). Organic material was dispersed with 10% H_2O_2 solution, after which the fine mineral fraction was removed by settling. Diatoms were separated from the coarse mineral fraction by rotation method (Vuorela & Eronen 1978). Naphrax® was used as the mounting medium (refraction index 1.74). From each preparation 250–300 diatoms were calculated except when the preparations were poor in diatoms. In the two uppermost samples (110 cm and 120 cm) diatoms were too scarce to be included into the diagram. Identification of the species was based mainly on Krammer & Lange-Bertalot (1986, 1988, 1991a,b) and Forsström (1999). Pollen and diatom diagrams were both prepared with the TILIA and TILIA-GRAPH (version 2.0.b5) software (Grimm 1990).

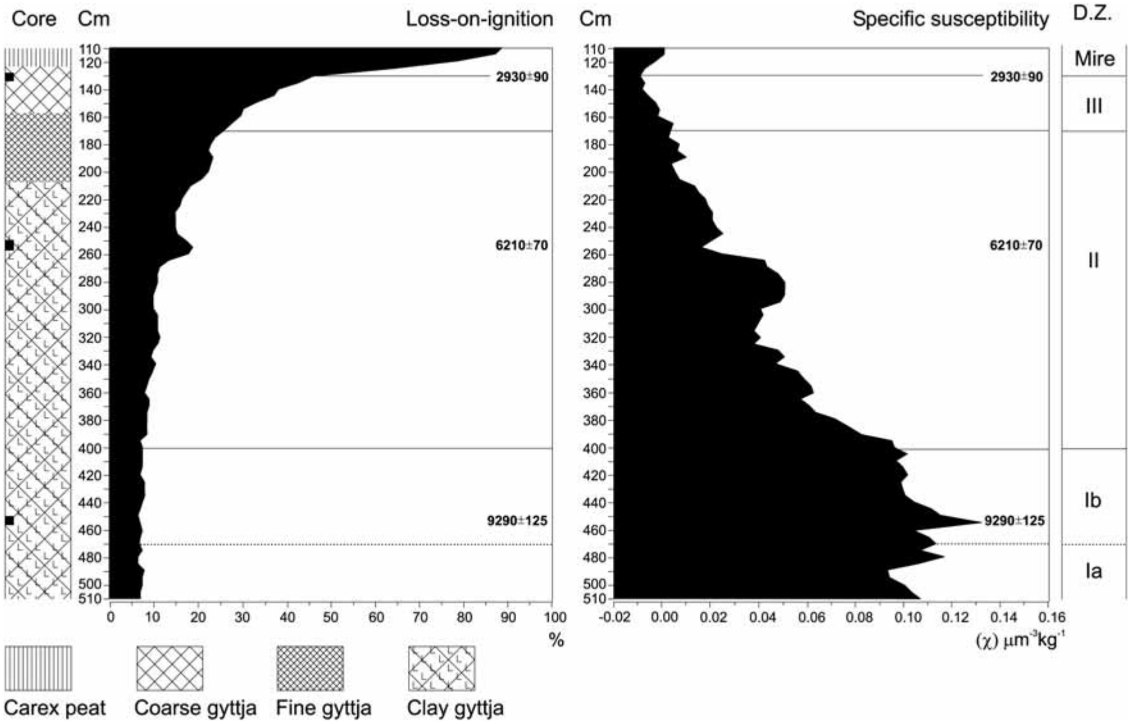

Fig. 5. Sediment lithostratigraphy of the Pennala core: Loss-on-ignition analysis and specific susceptibility with radiocarbon dating results and reference to the diatom zones (D.Z.) (for further details, see the text).

Three radiocarbon dates (Table 1) were obtained from selected samples. The ages are given as conventional radiocarbon dates (^{14}C yr BP) and as calibrated to calendar years (cal yr BP and cal yr BC; Stuiver & Reimer 1993; CALIB rev 4.3). The two uppermost samples (130 cm and 255–260 cm) consisted of the bulk material and were subjected to conventional dating (Hel-4550 & Hel-4552). The lowest sample consisted of a well-preserved *Betula* catkin scale sieved from the depth 450–455 cm and was dated with AMS technique (Hela-520). The samples were pre-treated using standard methods and dated in the Dating Laboratory at the University of Helsinki.

Results

Raised shores and the threshold of the Pennala basin

Twelve observations of raised shorelines were surveyed for the purpose of defining the extent and maximum limit of the Ancylus transgression and the ancient Pennala Lake in the area (see Fig. 1). Eight observations provide evidence of the Ancylus limit in the area, whereas four shore formations are assumed to be related to the ancient Pennala Lake. Raised shore formations typical for eskers and till formations (e.g., Sirviö 2000) were not found in the area. Fine soils together with small fetch area at the level of the Ancylus limit appear to have effectively suppressed the formation of shore marks, with only few exceptions. Agricultural activities have further smoothened and destroyed some of the old shore marks since fields typically extend above the Ancylus limit. A remarkable shore formation (Fig. 3) related to the Ancylus transgression was surveyed at several locations south of Renkomäki hill 1–3 km northwest from the Pennala threshold. This approximately 3 km long arched wave-cut scarp is highest at the north-western corner of the formation (70.8–72.6 m a.s.l.). Three other shore formations (small, partly disturbed wave-cut scarps), also related to the Ancylus transgression, were found at the

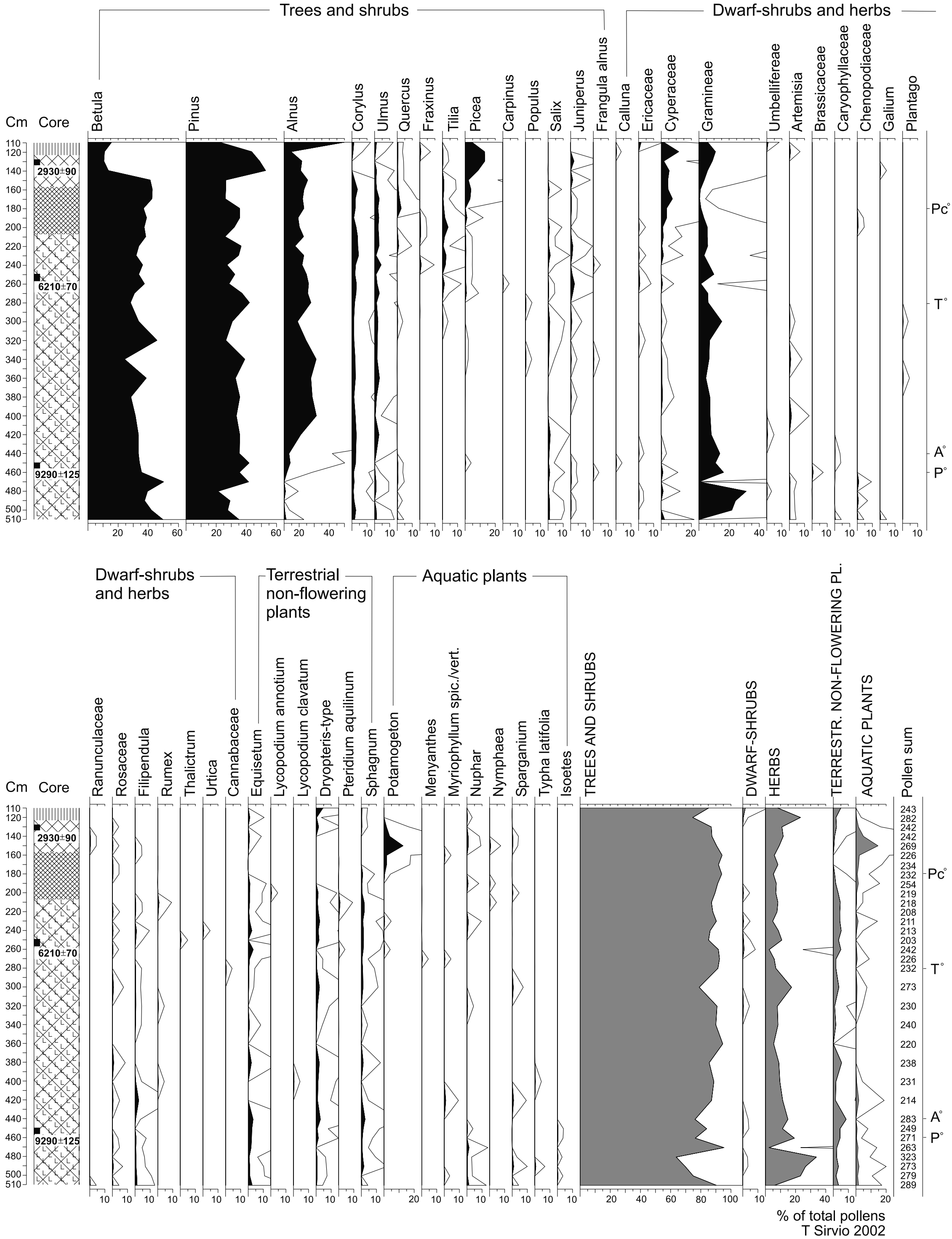

Fig. 6. Core description (symbols as in fig. 5) and pollen stratigraphy of the Pennala core with radiocarbon dating results and reference to the Pinus (P°) and Alnus (A°) pollen assemblage zone boundaries. The rise of Tilia (T°) and Picea (Pc°) limits are also presented.

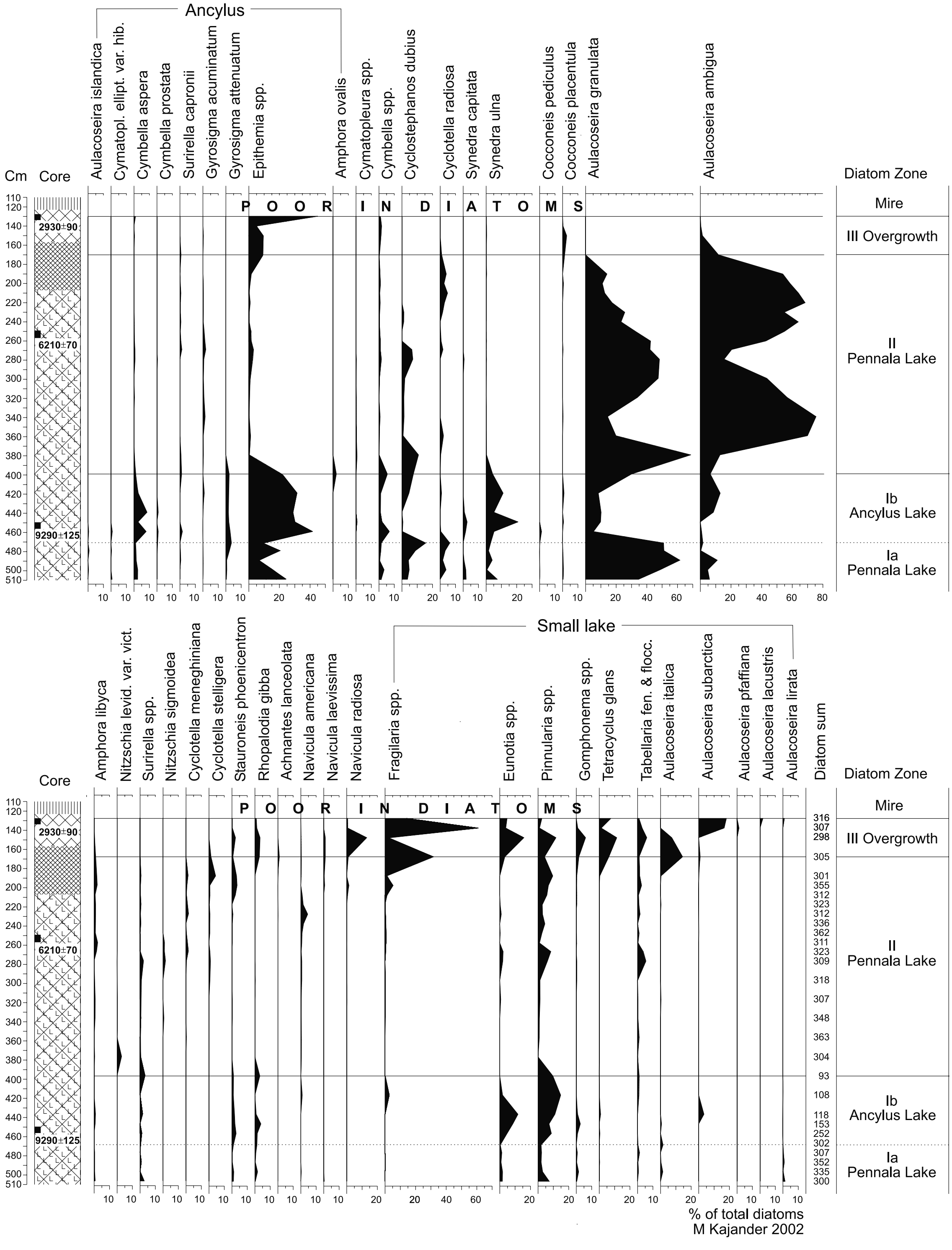

Fig. 7. Core description (symbols as in fig. 5), diatom stratigraphy (selected species) and diatom zones of the Pennala core with radiocarbon dating results.

Table 1. Radiocarbon dating results of the Pennala core.

Lab.No.	Depth	Material	$\delta^{13}C$	^{14}C yr BP	cal yr BP	cal BC
Hel-4550	130 cm	Coarse gyttja	-29.3	2930±90	3120 (3140-3080)	1170 (1190-1130)
Hel-4552	255-260 cm	Clay gyttja	-30.9	6210±70	7100 (7170-7030)	5150 (5230-5090)
Hela-520	450-455 cm	*Betula* catkin scale	-28.7	9290±125	10450 (10490-10430)	8510 (8550-8480)

northern part of the Pennala basin at 70.8–71.5 m a.s.l.

The level of the ancient Pennala Lake was surveyed in the northern part of the basin at four locations with wave-cut scarps. The altitudes of the shore marks varied between 67.9 and 68.4 m a.s.l. Some of the shore formations had been partly disturbed by agricultural activities, and the most reliable results were obtained from undisturbed shore marks (68.3–68.4 m a.s.l.) adjacent to the Uusitalo and Alestalo dwelling sites. The same level of the ancient Pennala Lake was observed in the form of a clear shift from highly organic soils of peat and gyttja to minerogenic clayish soils throughout the Pennala basin below 70 m a.s.l.

A cross-sectional profile of the threshold of the basin in the north-west was surveyed (Fig. 4). The Rengonjoki River has cut a 5 m deep channel through the clayish soil at the threshold, and the narrow channel has been subsequently re-worked by landslides. The altitude of the current threshold varies between 66.6–69.4 m a.s.l., as measured from the current water level of the Rengonjoki River to the break of slope at the side of the channel.

LOI, susceptibility measurements and radiocarbon dates

The lithostratigraphy of the Pennala basin was described in detail with the aid of loss-on-ignition (LOI) analysis, susceptibility measurements, radiocarbon dates and pollen and diatom analysis. The general lithostratigraphy of the Pennala core (Fig. 5) from the bottom to the top is as follows: 510–210 cm clay gyttja, 210–155 cm fine detritus gyttja, 155–125 cm coarse detritus gyttja and 125–110 cm *Carex* peat (110–0 cm not analysed).

Together with the increasing LOI towards the top of the core, the corresponding susceptibility values show a clear decreasing trend with a few exceptions. In the basal part of the core (510–395 cm), the susceptibility values vary between 0.094–0.133 $\mu m^{-3}kg^{-1}$ with the highest value at 455 cm. As the radiocarbon age 9290 ± 125 ^{14}C yr BP (10450 cal yr BP) (Hela-520) (455–460 cm) suggests, the increase in susceptibility values probably corresponds to a rise in water level due to the Ancylus transgression, whereas the subsequent decrease in susceptibility values is connected to the isolated Pennala Lake phase. These changes in the susceptibility values are not duplicated in the LOI values, which vary between 6.3 and 7.9% at same level without showing any significant trend.

Another clearly defined break in the decreasing trend of susceptibility values is observed at the depth of 320–285 cm, where the susceptibility of the samples increases from 0.038 up to 0.051 $\mu m^{-3}kg^{-1}$. The higher susceptibility values are followed by a slight increase (9.8–18.6%) in LOI at 290–255 cm. Based on the radiocarbon age 6210 ± 70 ^{14}C yr BP (7100 cal yr BP) (Hel-4552) obtained from the level 255–260 cm, the decrease in susceptibility and the local peak value of LOI coincide with the climatic optimum (e.g., Eronen 1990) during the Atlantic chronozone.

Towards the top of the core the susceptibility values approach zero together with a sharp increase in LOI. This is believed to represent the final overgrowth of the Pennala Lake, dated at 2930 ± 90 ^{14}C yr BP (3120 cal yr BP) (Hel-4550) at the depth of 130 cm.

Pollen stratigraphy

The general features in the pollen stratigraphy (Fig. 6) can be described in terms of regional pollen assemblage zones for Southern Finland (Donner 1971; Donner et al. 1978). References are also made to the Flandrian chronozones presented by Mangerud et al. (1974).

The basal section of the core belongs to the *Betula* zone corresponding closely to the Preboreal chronozone 10000–9000 ^{14}C yr BP (ca. 11500–10200 cal yr BP). This is followed by short period of *Pinus* zone corresponding to the Boreal chronozone 9000–8000 ^{14}C yr BP (ca. 10200–8900 cal yr BP). Except for trees and shrubs, herbs dominate the lowermost section. Gramineae, Cyperaceae, *Filipendula* and spores of *Equisetum* are abundant. The aquatic pollen in the basal part of the core is dominated by *Potamogeton*, *Nymphaea* and *Sparganium*. The upper boundaries of *Betula* (P°) and *Betula-Alnus-Corylus-Ulmus* (A°) zones are defined by the rational limit for the rise of *Pinus* and *Alnus*, respectively, though in the Pennala core the *Pinus* limit (P°) is not very distinct. Together with the two other radiocarbon dates, the date obtained from the middle of the *Pinus* zone (9290 ± 190 ^{14}C yr BP; Hela-520) allowed preparation of an age-depth curve with a 2nd order polynomial line fitting function. Based on the curve, the rise of Pinus has taken place at ca. 9450 ^{14}C yr BP (ca. 10700 cal yr BP) and the rise of *Alnus* at ca. 9150 ^{14}C yr BP (ca. 10200 cal yr BP).

The uppermost part of the core belongs to *Betula-Alnus-Corylus-Ulmus* zone and the Atlantic and Subboreal chronozones 8000–2500 ^{14}C yr BP (ca. 8900–2600 cal yr BP). Pollen of *Betula*, *Pinus* and *Alnus* dominate the zone. Relative proportions of *Corylus* and *Ulmus* remain constant and the total proportion of the pollen of trees and shrubs are at their maximum level throughout the zone. Two clearly detectable reference points on the diagram for the Atlantic and Subboreal chronozones include the rise of *Tilia* at 320 cm (T°) ca. 7200 ^{14}C yr BP (ca. 8000 cal yr BP) and the rise of *Picea* at 180 cm (Pc°) ca. 4300 ^{14}C yr BP (ca. 4900 cal yr BP). Both of these are in good agreement with the typical radiocarbon dates previously presented for T° (e.g., Hyvärinen 1980) and Pc° limits (e.g., Donner et al. 1978).

Above the *Picea* limit (Pc°) the proportions of both herbs and aquatic plants increase considerably, as shown by the rise of Cyperaceae, Gramineae and *Potamogeton* curves. At the same time, the relative proportions of tree species show wide fluctuations, such as the abrupt rise of *Pinus* and *Alnus* in the uppermost samples of the core. The radiocarbon date 2930 ± 90 ^{14}C yr BP (Hel-4550) obtained from the upper limit of aquatic plants indicates the final drying up of the lake directly after the dated level.

Diatom stratigraphy

The sediments were analysed for diatoms in order to determine the main phases of the development of Pennala basin, including the possible Ancylus transgression, the stages of isolation, and the final overgrowth. The diatom diagram (Fig. 7) can be divided into three sections: the small lake/Ancylus Lake stage (diatom zones Ia & Ib), the small lake stage (diatom zone II) and the overgrowth stage (diatom zone III). The uppermost part of the core was poor in diatoms and represents terrestric mire environment based on other litho- and biostratigraphic evidence.

The flora of the lowermost diatom zone Ia (510–470 cm) consists mainly of meroplanctonic *Aulacoseira granulata* (40–60%) and *A. ambigua*, plus genus *Epithemia*, with lesser proportions of species *Cymbella aspera*, *Cyclostephanos dubius*, *Cyclotella radiosa*, *Synedra capitata*, *Synedra ulna* and genera *Eunotia*, *Pinnularia* and *Cymbella*.

At the bottom of the diatom zone Ib (470–400 cm), the relative proportions of *Aulacoseira granulata* decline abruptly, while the relative proportions of mainly epiphytic and benthic species begin to increase. These include *Cymbella aspera* and genera *Epithemia*, *Pinnularia* and *Eunotia*. The following diatoms found from this zone belong to the flora typically observed in the Ancylus Lake sediments (e.g., Tynni 1969; Eronen 1976; Ignatius & Tynni 1978; Ristaniemi 1984): *Aulacoseira islandica*, *Cymatopleura elliptica* var. *hibernica*, *Cymbella aspera*, *C. prostata*, *Surirella capronii*, *Gyrosigma attenuatum*, *G. acuminatum*, *Amphora ovalis* and genus *Epithemia*. In addition to these typical Ancylus Lake species the following taxa are also present in the diatom zone Ib: *Cyclostephanos dubius*, *Cyclotella radiosa*, *Synedra capitata*, *S. ulna*, *Cocconeis pediculus*, *C. placentula*, *Aulacoseira granulata*, *A. ambigua*, *Amphora libyca*, *Stauroneis phoenicenteron*, *Rhopalodia gibba*, and genera *Cymbella* and *Surirella*.

The boundary between diatom zones Ib and II is marked by a sharp increase in *Aulacoseira granulata* and *A. ambigua* species and a sharp decline in *Epithemia* spp. starting at around 420 cm with a clear indication of the final environmental change at ca. 400 cm. The fresh-water meroplanctonic *Aulacoseira ambigua* and *A. granulata* have high proportions (20–70%) throughout the diatom zone II (400–170 cm). Other species that occur

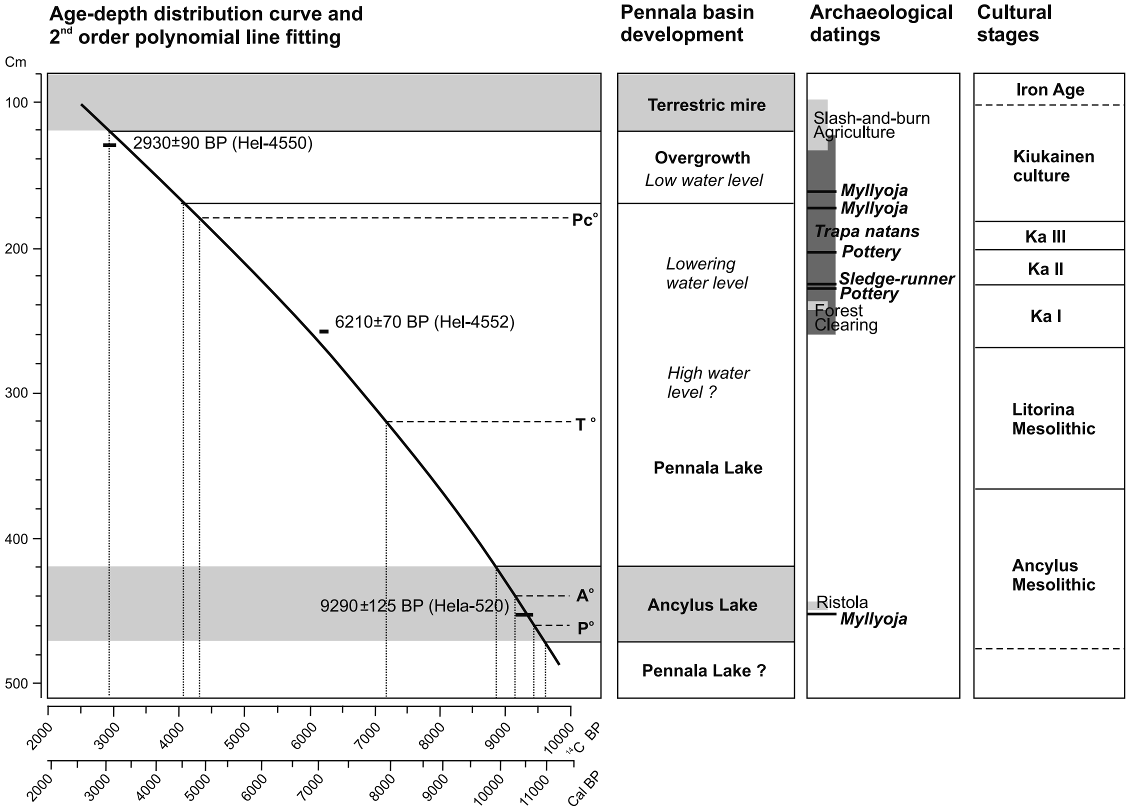

Fig. 8. Age-depth distribution curve (2nd order polynomial line fitting) with reference to the development of the Pennala basin. Also included are summaries of archaeologically relevant dating results in the Pennala basin (bold/italic) (Meinander 1960, 1971; Vuorela 1981; Poutiainen 2002) and in the nearby environments (Donner et al. 1978; Matiskainen 1989b) together with the main cultural stages (Siiriäinen 1982; Matiskainen 1989a).

through diatom zone II, although with rather small proportions, include *Cyclostephanos dubius*, *Cyclotella radiosa*, *Gyrosigma acuminatum*, *Tabellaria fenestrata*, *T. flocculosa*, *Nitzschia sigmoidea*, *N. levidensis* var. *victoriae*, *Cyclotella meneghiniana*, *Cyclotella stelligera*, *Stauroneis phoenicenteron* and *Navicula americana*. Contrary to the lower diatom zone, the genera *Eunotia*, *Surirella* and *Epithemia* are poorly presented here. At the top of this zone, genus *Fragilaria* begins to increase simultaneously with the sediment change from clay gyttja to fine gyttja.

Diatom zone III (170–130 cm) consists mainly of species *Aulacoseira italica*, *A. subarctica*, *A. pfaffiana*, *A. lacustris*, *A. lirata*, *Tabellaria fenestrata*, *T. flocculosa*, *Tetracyclus glans* and genera *Pinnularia*, *Gomphonema*, *Eunotia* and *Fragilaria*, which are typical to small lake conditions (e.g., Hyvärinen 1999). Diatom fauna found in the uppermost coarse gyttja bed represents the final phase of lowering water level and drying up of the ancient Pennala Lake. The overlying *Carex* peat (120–110 cm) was too poor in diatoms to be presented in the diagram. The presented results of diatom analysis are in good agreement with the pollen and LOI analysis described earlier.

Discussion and Conclusions

The current study gives new information on the Holocene development of the Pennala basin with reference to the Ancylus transgression, the ancient Pennala Lake, and the dated Stone Age dwelling sites in the area. The main conclusions from the Pennala site studied can be summarized as follows (Fig. 8): 1) The basal part of the studied core includes a possible small lake phase of the Pennala basin at the end of regressive stage of Yoldia Sea, 2) the Ancylus transgression started at ca. 9600 yr ^{14}C BP (10900 cal yr BP) and the final isolation occurred around 8900 yr ^{14}C BP (10000 cal yr BP) during the regressive stage of Ancylus Lake, and 3) the final isolation from the Baltic Sea was followed by a long-term lake phase which lasted until ca. 2900 yr ^{14}C BP (3000 cal yr BP), when the Pennala basin turned to a terrestric mire.

The interpretation of the basal part of the core – as representing an isolated, small lake phase of the Pennala basin from the Yoldia Sea until the Ancylus transgression – remains questionable. The upper boundary of the lowermost diatom zone Ia is marked by a sharp decrease in the proportion of *Aulacoseira granulata*, which may indicate small lake conditions before the transgression. The beginning of the small lake phase, however, is ambiguous, as the horizon of the isolation from the Yoldia Sea was not represented in the core.

The slight increase of typical Ancylus Lake species at the boundary between diatom zones Ia and Ib suggests that Pennala basin became a part of the Ancylus Lake. The approximate age for the lower limit of the diatom zone Ib (based on the 2nd order polynomial age-depth curve) suggests that the Pennala basin became a part of Ancylus Lake at ca. 9600 ^{14}C yr BP (ca. 10900 cal yr BP), which is confirmed by the radiocarbon date 9290 ± 190 ^{14}C yr BP (Hela-520) obtained from slightly above the maximum occurrence of *Epithemia* spp. at 460 cm. The given radiocarbon date is in good agreement with the dates of the Ancylus transgression presented previously (e.g., Ristaniemi & Glückert 1987).

The evidence of the transgression is supported by the fluctuations observed in the magnetic susceptibility (Fig. 5) at the level of the assumed transgression. The variation and slight increase in the susceptibility in the diatom zone representing Ancylus Lake is probably a consequence of increased erosion on the shores of the Ancylus Lake caused by water level fluctuations during the transgression. A similar susceptibility pattern has been reported from the Lake Babinskoye (Ingermanland, Russia) sediments during the Litorina transgression and explained by increased erosion on the shores (Miettinen 2002). Sandgren et al. (1990), however, have presented opposing results from the Lake Ådran (eastern Sweden), where the regressive phase of the Ancylus Lake is marked by an increase in susceptibility values, whereas the Litorina transgression coincided with low susceptibility values. The high susceptibility values during the regressive phase were explained as being induced by increased erosion. Low susceptibility values during the Litorina transgression were explained by dissolution of ferromagnetic minerals in brackish-marine water (Snowball & Thompson 1988).

The relatively poor diatom evidence of the suggested small lake stage and the following Ancylus transgression are most rationally explained by the location of both the Pennala basin and its threshold. As shown in Fig. 1, the Pennala basin formed a sheltered bay during the Ancylus transgression, and was connected to more open areas of Ancylus Lake at Näkkimistö by 800 m long and 200 m wide strait. The whole Porvoonjoki River valley was connected to the more open Ancylus Lake by several narrow straits. This might have resulted in ecological conditions typical for small lakes or shallow bays showing diatom diagrams dominated by Epithemia spp. with only a slight rise in the curves of other typical Ancylus Lake species (e.g., *Aulacoseira islandica* and *Gyrosigma attenuatum*). As seen in Fig. 4, the Pennala threshold has been cut down to clayish soil by several metres whereas the upper value given for the threshold (69.4 m a.s.l.) together with the shoreline measurements suggest only a minor (probably 1.5–2 m) rise in the water level (up to 71–71.5 m a.s.l.) (Fig. 4) and small changes in ecological conditions in the area during the Ancylus transgression.

Since the Pennala basin is a part of a greater drainage basin, the relatively poor diatom evidence of transgression might be also due to mixing of sediments, and deposition of material derived from the upper Pihlajasuo bog area, where the independent small lake might have been isolated during the late regressive stages of the Yoldia Sea. Concurrence of the typical small lake flora of *Pinnularia* and *Eunotia* spp. with typical Ancylus Lake species at diatom zone Ib might be explained by erosion and re-deposition of sediment originally deposited during the small lake phase as the transgression proceeded.

Discrepancies were observed within the pollen analysis, where the limits of pollen assemblage zones of *Pinus* (P°) and *Alnus* (A°) almost overlap and show distinctively older ages (ca. 450 and 550 ^{14}C yr, respectively) than previously presented by Donner et al. (1978). However, similar differences have been observed elsewhere (e.g., Hyvärinen 1980), and radiocarbon dates obtained from the P° and A° limits in Southern Finland typically show regional differences (e.g., Donner et al. 1978; Ristaniemi & Glückert 1987). The older ages observed here for the limits might be explained by changes in the local palaeoenvironment adjacent to the Pennala basin, which would have encouraged the early spread of both *Pinus* (due to proximity to gravelly and sandy fluvioglacial formations) and *Alnus* (due to emergence of new shoreline during the Ancylus regression). Since the lowermost radiocarbon date (9290 ± 125 ^{14}C yr BP) was obtained from a single *Betula* catkin scale, there is always the possibility that this is a secondary deposit and that a dating of the primary deposits of the core would result to younger dates for both the P° and A° limits, and the Ancylus transgression.

The Ancylus lake phase ended in the Pennala basin at ca. 8900 ^{14}C yr BP (ca. 10000 cal yr BP) leading to the final isolation of the Pennala basin from the Baltic Sea. According to the currently analysed pollen and diatoms and earlier studies (Vuorela 1981), the ancient Pennala Lake can be described as shallow, eutrophic and alkaliphilous lake, as *Aulacoseira granulata* and *A. ambigua* diatom species have been typically found in small lakes indicating alkaliphilous eutrophic conditions (e.g., Korhola 1990b). This interpretation gains support also from the pollen analyses and the well-known presence of *Trapa natans* (Aalto 1981; Vuorela 1981), which typically favours such ecological conditions.

The evidence of possible water level fluctuations in the ancient Pennala Lake during the middle of the lake phase is scarce. The most distinct piece of evidence of a potential high water level is the clear rise in the susceptibility values during the Atlantic period at ca. 7000–6500 ^{14}C yr BP (ca. 7800–7400 cal yr BP). The significant variation in the proportions of *Aulacoseira* species remains unexplained and might be related to water level fluctuations as these changes correspond to the changes in the susceptibility measurements (the peak of *Aulacoseira granulata* at 280 cm coincides with high susceptibility). It has to be noted, that high water levels have been observed in many small lakes during humid Atlantic period (e.g., Donner et al. 1978; Donner 1995), and several authors have suggested that the low water level in lakes and mires was due to a cool and dry climate during the following Subboreal period (Korhola 1990b). In many cases, this might have accelerated the final overgrowth of lakes in Southern Finland during the early Subboreal period (Korhola 1990a). The absolute shore levels of possible fluctuations in the ancient Pennala Lake remain undetermined since only one distinctive ancient shoreline level has been detected at ca. 68.5 m a.s.l.

The final phase in the history of the Pennala Lake is marked by clear changes in both diatom and pollen stratigraphy dated close to the *Picea* limit (Pc°) during the early Subboreal period at 4000 ^{14}C yr BP (ca. 4500 cal yr BP). At this time, the relative proportions of small lake diatom species, and pollen of aquatic plants, increased abruptly. The abrupt increase in LOI also marks the change. The open area and the extent of the Pennala Lake may have decreased significantly during this stage. These observed changes clearly indicate overgrowth, lowering water depth, and decreasing extent of the lake. Paludification led to final overgrowth of the ancient Pennala Lake during the late Subboreal period at 2900 ^{14}C yr BP (ca. 3000 cal yr BP), after which the basin transformed to a terrestric mire. Further development of the Pennala basin as a mire was not investigated.

The dated archaeological data (Fig. 8) demonstrates that specific absolute dates for the Early Mesolithic dwelling sites in the area – during which the Pennala basin was a sheltered bay of the Ancylus Lake – are still scarce. The dwelling sites in Pennala basin have been inhabited mostly during the Neolithic period at ca. 5500–3500 ^{14}C yr BP (ca. 6300–3800 cal yr BP). In this period, the Pennala basin formed a small inland lake as a part of the Porvoonjoki River drainage basin.

The Neolithic stage of the evidence from the dwelling sites, dated with radiocarbon method, starts during the Late Atlantic period. The potential evidence of forest clearing, observed in the nearby Työtjärvi Lake (Hollola) (Donner et al. 1978) and the spread of *Trapa natans* into the Pennala Lake (Vuorela 1981), noticeably concur with the evidence of the Neolithic settlement. Earlier pollen analyses (Vuorela 1981) and analyses of macro remnants from the uppermost layers (Aalto 1981) of the core sampled near the shoreline of the Pennala Lake correspond well with the results presented in this paper on the final stages of the development of the ancient lake. The potential connection between the human impact on vegetation (Vuorela 1981) and the eutrophication preceding the final overgrowth of the lake, cannot be ignored. As a conclusion, the overgrowth of the lake has probably occurred as a result of several supporting factors, such as the Subboreal climate, the human influence and the shallow bathymetry of the lake (Tikkanen & Korhola 1993).

There is still a distinctive gap between the dated Early Mesolithic and Neolithic dwelling sites in the area. It is unjustifiable to use shore displacement of the Baltic as the basis for dating of the Mesolithic dwelling sites due to long lake phase of the Pennala basin. Similar limitations have been observed elsewhere while using shore displacement of the Baltic as a basis for preliminary dating of Stone Age dwelling sites e.g., in Kanteleenjärvi (Pukkila) (Sirviö 2000), Luhdanjoki (Lahti–Hollola) (Sirviö et al. 2002) and Askola areas (Matiskainen 1989b). It is, therefore, advisable to take great care while applying shoreline displacement chronology of the Baltic to the dating of the Mesolithic and Neolithic sites around bogs and extensive deposits of peat and gyttja, i.e. areas, where ancient lakes have potentially existed.

ACKNOWLEDGEMENTS

This research received financial support from the Finnish Cultural Foundation. We thank anonymous referees for their comments, Prof. Matti Eronen, Prof. Matti Tikkanen, Prof. Hannu Hyvärinen and Heikki Haila, Lic.Phil., for valuable comments during the research, Dr Juhani Virkanen for help in the laboratory, Maija Heikkilä, MSc, for grouping the pollen diagram and Minna Väliranta, MSc, for help in identification of macro remnants for radiocarbon dating. We also thank Hannu Poutiainen, MA, Hannu Takala, MA, Lic.Phil., and other enthusiastic archaeologists of the City Museum of Lahti for great help during the study. Thanks for the preliminary language corrections belong to Dr Andrew Rebeiro-Hargrave. The Dating Laboratory of the University of Helsinki provided the radiocarbon dates.

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