BIO- AND CHRONOSTRATIGRAPHY OF THE EARLY HOLOCENE SITE OF DOUBLE-STOREYED BURIED ORGANIC MATTER AT PAIKUSE, SOUTHWESTERN ESTONIA

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Abstract. Unique double-storeyed layers of buried organic matter at Paikuse, southwestern Estonia, were studied by means of pollen and diatom analysis and radiocarbon dating. The lower buried organic matter accumulated during the Pre-Boreal within *c.* 130 years. The Ancylus Lake transgression reached Paikuse after 9350 BP and covered the peat with 1.5 m of sand. After the Ancylus Lake regression the upper organic matter accumulated, which was after about 7100 BP covered by 1.5 m of sands of the Litorina Sea.

Key words: buried organic matter, pollen analysis, diatom analysis, radiocarbon dating, Ancylus Lake, Litorina Sea, Paikuse, Estonia.

INTRODUCTION

The investigated area is characterized by slow land uplift. Therefore the amplitude of transgressive sea level fluctuation has exceeded the isostatic land uplift, and numerous ancient peat, gyttja, and soil deposits are buried under either

the Ancylus Lake or the Litorina Sea transgressive sediments. A unique sediment sequence with two buried organic layers separated from each other by a 1.5-m-thick sand layer is preserved on the left bank of the Pärnu River at Paikuse (58°22´45´´ N, 24°36´45´´ E) (Fig. 1, Photo 1), close to the mouth of the Türgioja Stream, near Paikuse Police and Elementary Schools. It offers an excellent tool for palaeogeographical reconstruction of the Baltic Sea. The river bank is 7–8 m high, but only the upper part of it was studied. The site was found and first described by Thomson (1928). Kessel (1963) investigated by means of pollen analysis a similar sediment section, which she called Sindi, a few hundred metres upstream from Paikuse. Buried organic layers are found also at Lõpe, Kõdu, Urge, Pulli, Sikaselja, and Sindi (Fig. 1). The Pulli site has revealed the earliest traces of human activity in Estonia. It was inhabited by the Mesolithic hunters and fishermen around 9600 ^{14}C years ago (Jaanits, 1969; Selirand & Tõnisson, 1984).
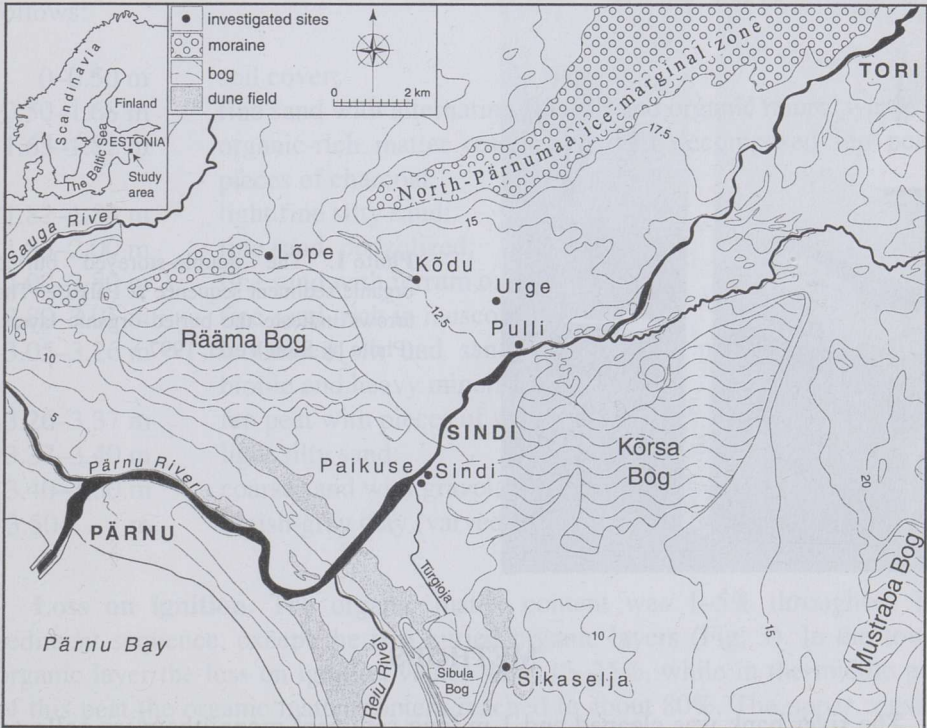

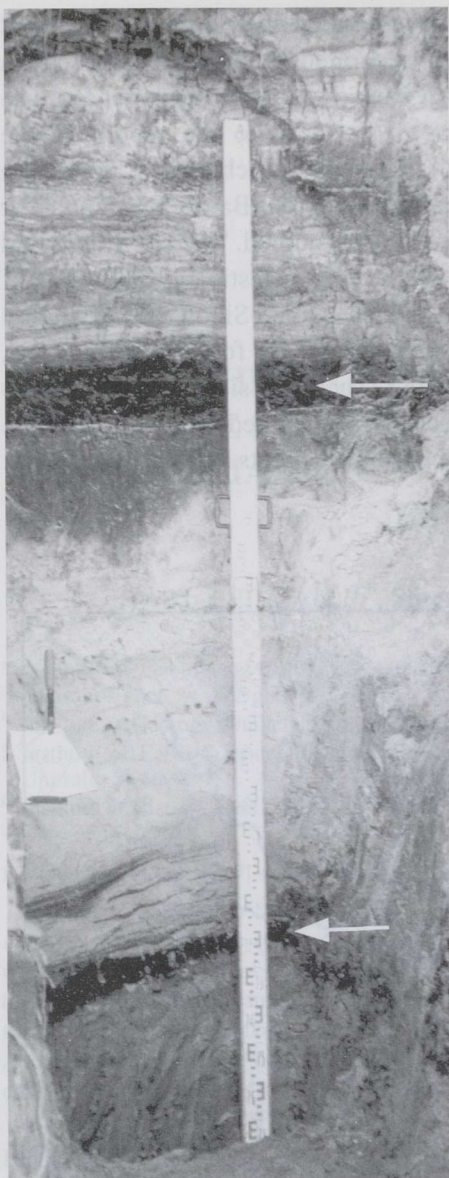**Fig. 1.** Location of the study area.

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Photo 1. The double-storeyed buried organic sediment sequence at Paikuse. The arrows indicate the buried organic layers. (Photo by Siim Veski, 1997.)

METHODS

The river bank was cleaned and 1-m-long sediment monoliths were collected into wooden boxes and transported to the laboratory by T. Moora.

Preparation of diatom analysis followed the hydrogen peroxide method (Battarbee, 1986). Naphrax was used as the mounting medium, and analysis was carried out under the Zeiss Axiolab microscope with the magnification of × 1000.

Pollen preparation followed the standard procedure (Berglund & Ralska-Jasiewiczowa, 1986). Pollen percentages were calculated as Arboreal Pollen (AP) + Non-Arboreal Pollen (NAP) = 100%; the percentages of other micro-fossils were calculated from their actual value plus this sum. The pollen and diatom diagrams were plotted with TILIA and TILIA GRAPH programs (Grimm, 1992).

The organic and $CaCO_3$ contents in the sediment were estimated by loss on ignition at 550 °C and 825 °C, respectively.

Samples for conventional [14]C (TA) dating were taken from the sediment monoliths and for AMS ^{14}C dating (Ua) from the wall of the cleaned sediment section. Radiocarbon dates are presented as uncalibrated ^{14}C years BP.

RESULTS

The sediment stratigraphy of the investigated sequence from the left bank of the Pärnu River at an altitude of 8.50 m a.s.l. (Fig. 2, Photos 1–3) is as follows:

0–0.50 m	soil cover;
0.50–1.68 m	fine sand with alternating fine silt and organic microlayers;
1.68–1.82 m	organic-rich matter resembling well decomposed fen peat, pieces of charcoal;
1.82–1.83 m	light fine silty sand;
1.83–2.00 m	fine sand, podzolized;
2.00–2.80 m	fine sand with ferrum oxide spots;
2.80–3.05 m	fine sand, rich in muscovite;
3.05–3.26 m	laminated silt and sand with organic microlayers, rich in biotite and heavy minerals;
3.26–3.37 m	fen peat with pieces of wood;
3.37–3.40 m	light silty sand;
3.40–3.50 m	coarse sand with gravel;
3.50+ m	bluish-grey clay (varved clay), hiatus at the upper border.

Loss on ignition. The organic matter content was 1–5% throughout the sediment sequence, except the two buried organic layers (Fig. 3). In the lower organic layer the loss on ignition values were 15–25%, while in the middle part of this peat the organic matter content reached to about 80%. The upper organic layer had the loss on ignition between 9% and 30%. Due to the organic micro-layers, the organic content above the upper organic layer slightly fluctuated under 5%. The sediment sequence was characterized by a low carbonate content (0.5–2.0%). $CaCO_3$ increased up to 10% in the sands overlying, and in sand and clay underlying the lower organic layer.
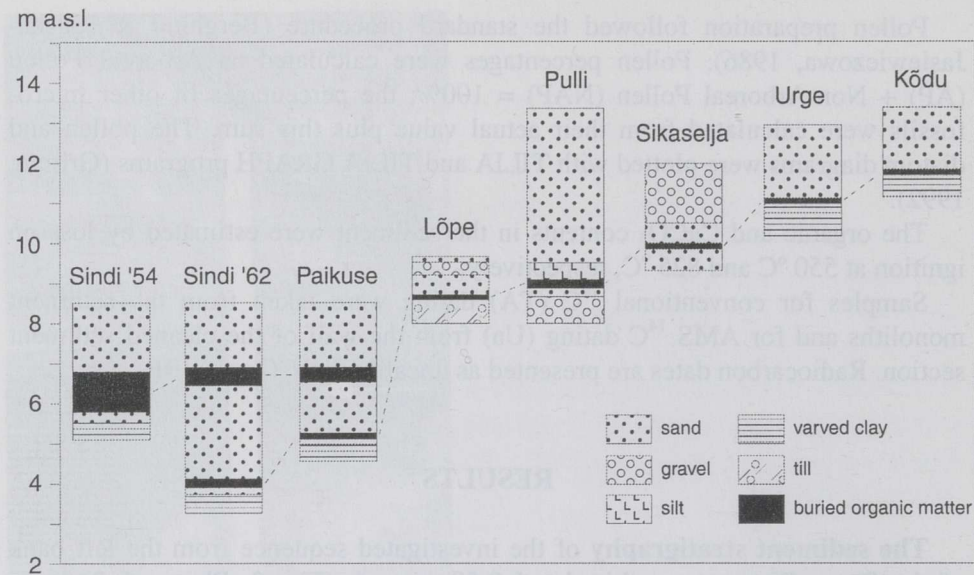
m a.s.l.

Fig. 2. The altitude and the lithology of the buried organic layers in the surroundings of Paikuse. Sindi '54 and Sindi '62 are the sediment sections investigated by Kessel (1963).
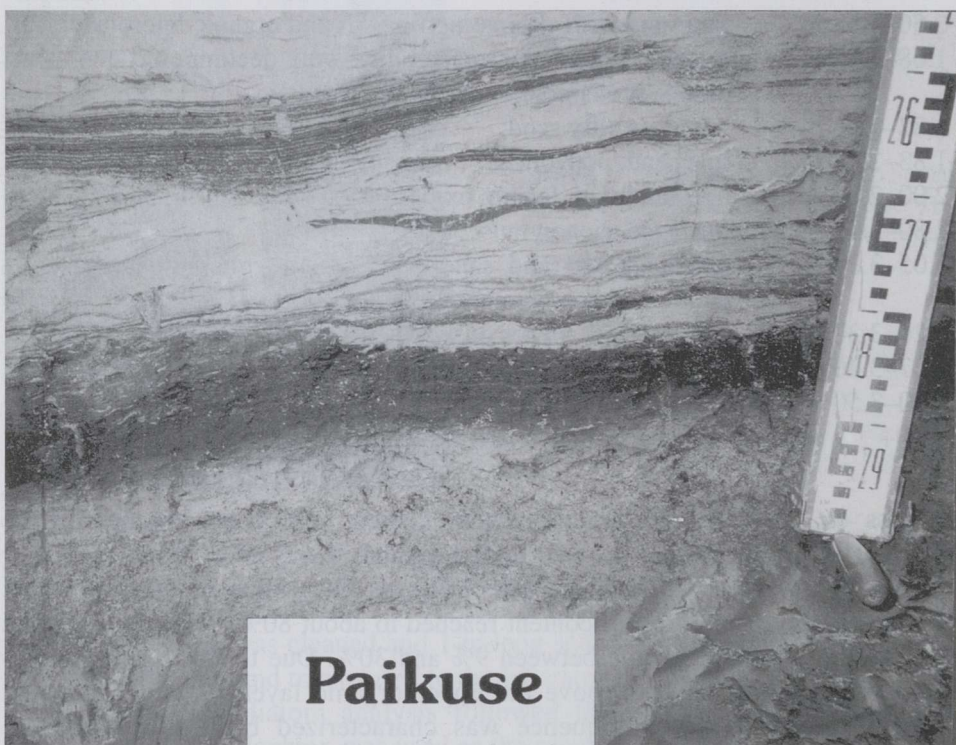

Photo 2. The lower part of the sediment sequence. (Photo by Siim Veski, 1997.)
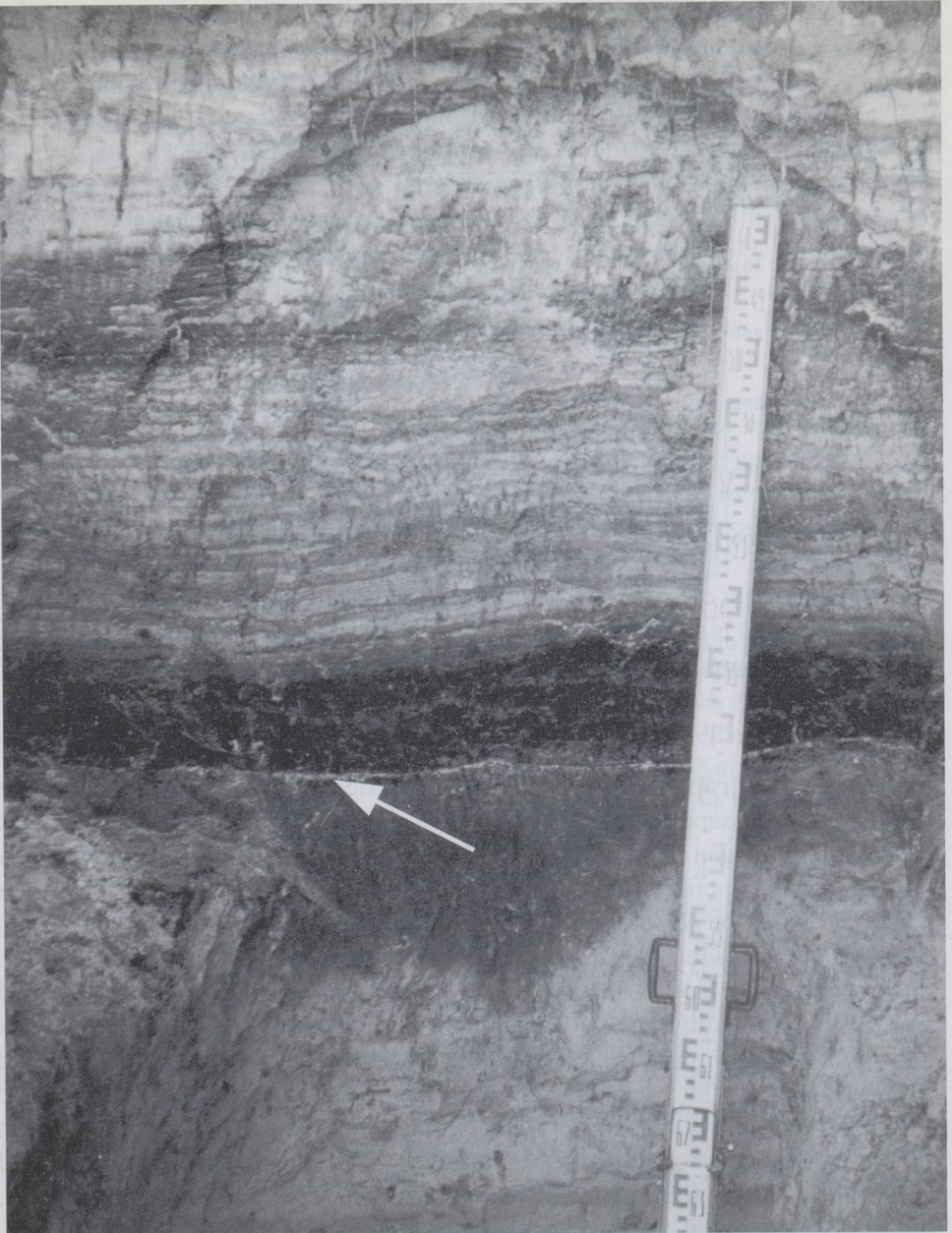
Photo 3. The upper part of the sediment sequence. The arrow indicates the thin sandy layer at a depth of 1.82 m under the upper buried organic layer. (Photo by Siim Veski, 1997.)
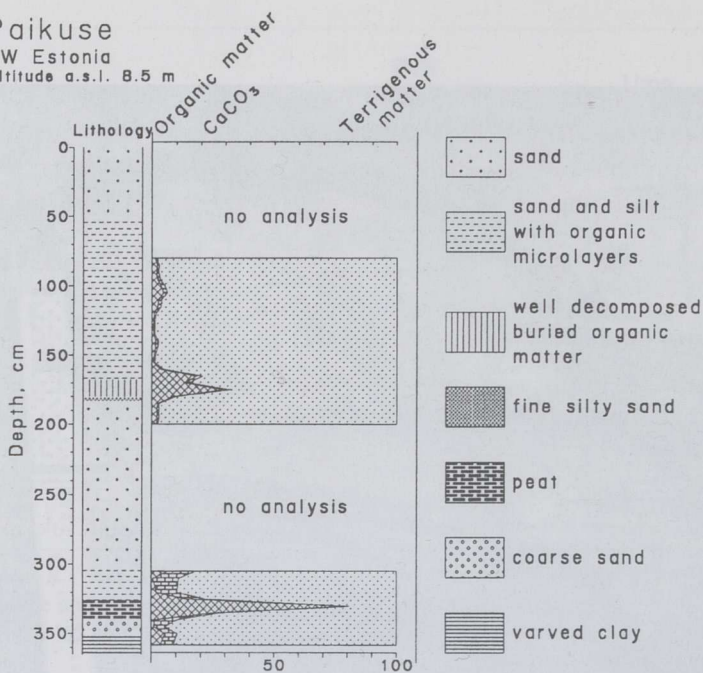
Paikuse
SW Estonia
Altitude a.s.l. 8.5 m

Fig. 3. The content of organic matter, CaCO₃, and terrigenous matter (in %) and the lithological description of the Paikuse outcrop.

Pollen stratigraphy. Pollen analysis was carried out from both organic layers and from the sands with organic microlayers (Figs. 4, 5). The organic sedimentation began around 9350 BP. The coarse sand between the varved clay and the peat contained no pollen, but abundantly seeds of *Schoenoplectus lacustris*. Seeds of *Nuphar lutea*, *Potamogeton* sp. (most probably *P. natans*), *Menyanthes trifoliata*, *Carex* spp., and Apiaceae were also observed (S. Hiie, pers. comm.). The pollen analysis of the peat showed a *Salix–Betula* dominated vegetation community. The microscopic material revealed several lumps of *Salix* and *Betula* pollen grains which had stuck together, suggesting their very local distribution and thus supporting closed growing conditions. This is also supported by the low amount of NAP. Similar very local growing conditions in the Pre-Boreal peats can be observed elsewhere (Veski, 1998). In the lower and upper parts of the peat, pollen grains of aquatic plants and algae are present, indicating occasional submergence of the peat. The central part of the peat, where the pollen grains are highly destroyed due to exposure to oxygen, shows no evidence of underwater conditions, but rather suggests relatively dry conditions. In the laminated silt and sand with organic microlayers overlying the peat, *Betula* and *Pinus* dominate. The share of NAP is high and is made up

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mainly of Poaceae (*Phragmites*) and Cyperaceae (*Carex*). The lithology and the pollen evidences suggest a periodically flooded near-shore environment.

The pollen diagram from the sands underlying the upper organic matter shows dominating *Alnus* and *Betula*. The NAP is low and the destruction degree high. In the upper organic layer itself, *Pinus* and *Alnus* dominate and the NAP appears abundantly. The latter is mostly represented as Poaceae and Cyperaceae, but other taxa, mainly indicative of a damp environment, such as *Filipendula*, Rosaceae, Apiaceae, *Typha angustifolia/Sparganium*, and *Equisetum*, occur. The degree of destruction is remarkably lower than in the sand. In the microlayered organic-rich sand above the upper organic layer, *Pinus* and *Alnus* dominate, the *Quercetum Mixtum* is rather stable, and NAP reaches up to 50%. Aquatic pollen and algae are represented, of which *Hystrix* might show brackish-water conditions.

Diatom stratigraphy. The basal part of the sequence was bare of diatoms. The sand between 2.00 and 1.90 m contained mostly broken central areas and ends of the valves belonging to the genus *Pinnularia* which were impossible to identify to the species level (Figs. 6, 7). Aerophilous diatom taxa *Pinnularia lata* (Brébisson) W. Smith and *Hantzschia amphioxys* (Ehrenberg) Grunow, as well as the acidophilous diatom *Eunotia praerupta* Ehrenberg, are represented in low frequency. A lot of chrysophycean cysts and phytoliths occur at that level.

Hardly any diatoms were found in the upper organic layer, but some valves were recognized in the sand layer at a depth of 1.82 m. The species indicating brackish-water conditions, such as *Campylodiscus echeneis* Ehrenberg, *Campylodiscus clypeus* Ehrenberg, *Diploneis interrupta* (Kützing) Cleve, and *Diploneis smithii* (Brébisson) Cleve, together with freshwater large-lake species *Cocconeis disculus* (Schumann) Cleve and *Ellerbeckia arenaria* (Moore) Crawford, as well as *Pinnularia* spp., were found.

At a depth of 1.66 m, in the sand overlying the upper organic layer, diatoms appear again. In the interval of 1.66–1.40 m of the sand, freshwater large-lake taxa dominate. Of them, periphytic *Cocconeis disculus*, *Navicula scutelloides* W. Smith, *Ellerbeckia arenaria*, *Epithemia adnata* (Kützing) Brébisson, *Epithemia goeppertiana* Hilse, *Epithemia turgida* (Ehrenberg) Kützing, and *Opephora martyi* Héribaud are dominant. The share of brackish-water species increases regularly from 1% to 21%. Among these *Diploneis smithii*, *Diploneis didyma* (Ehrenberg) Ehrenberg, and *Campylodiscus echeneis* are the most characteristic species. Further up in the sequence the brackish-water forms increase progressively and constitute up to 97% of the diatom assemblage. *Diploneis interrupta* is the dominant taxon. *Diploneis smithii*, *Navicula peregrina* (Ehrenberg) Kützing, and halophilous species *Navicula pusilla* W. Smith occur in moderate frequency. Freshwater diatoms almost disappear from a depth of 1.10 m and upwards.

Fig. 4. Pollen diagram from the Paikuse outcrop. Part 1. The dotted curves represent the actual percentages × 10. Analysed by Siim Veski, 1996. For lithology see Fig. 3.

Paikuse
SW Estonia
8.5 m a.s.l.
Selected pollen taxa

Fig. 5. Pollen diagram from the Paikuse outcrop. Part 2. The dotted curves represent the actual percentages × 10. Analysed by Siim Veski, 1996. For lithology see Fig. 3.
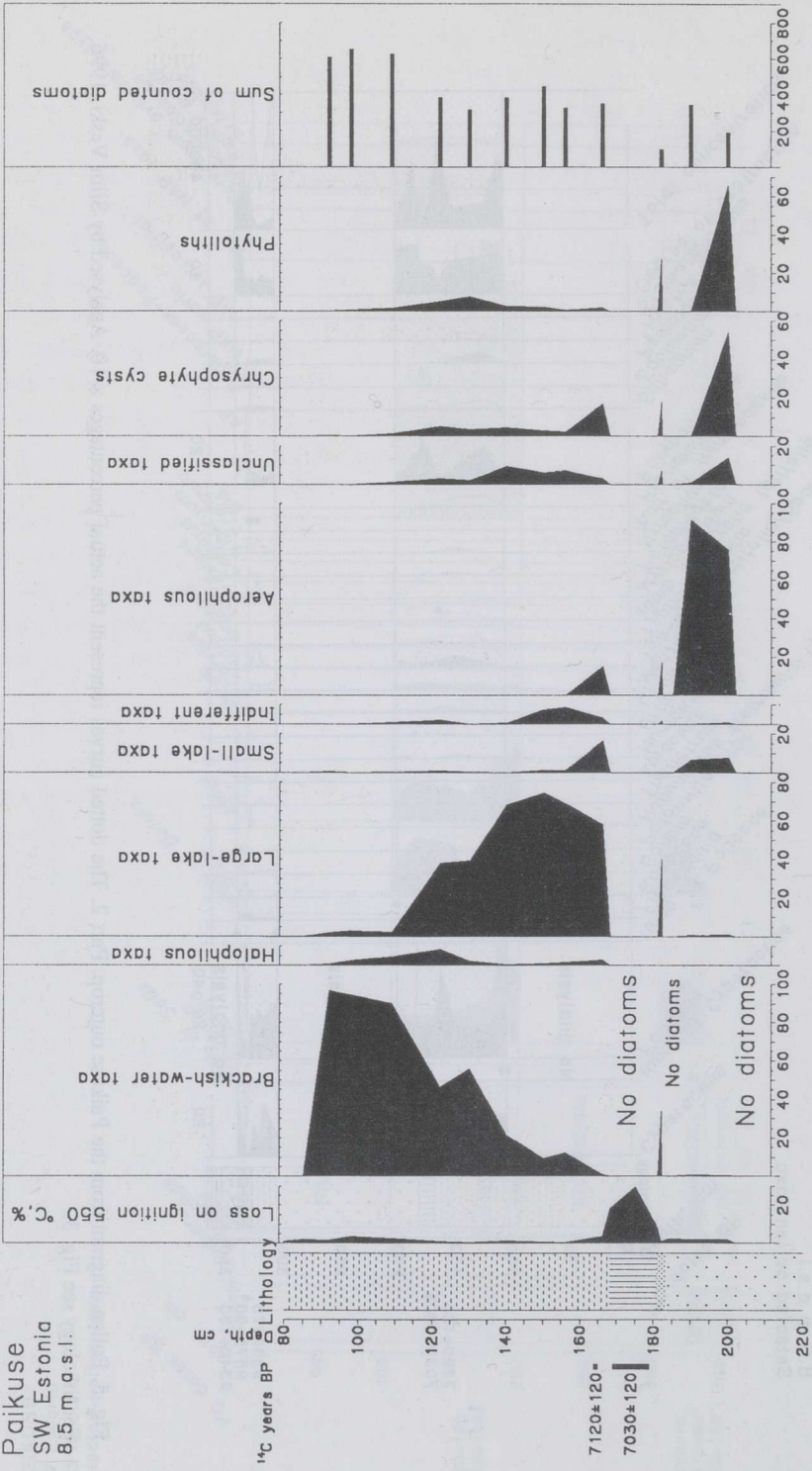
Fig. 6. Relative frequency of diatoms in the upper part of the Paikuse outcrop according to their ecological preferences. Analysed by Atko Heinsalu, 1997. For lithology see Fig. 3.
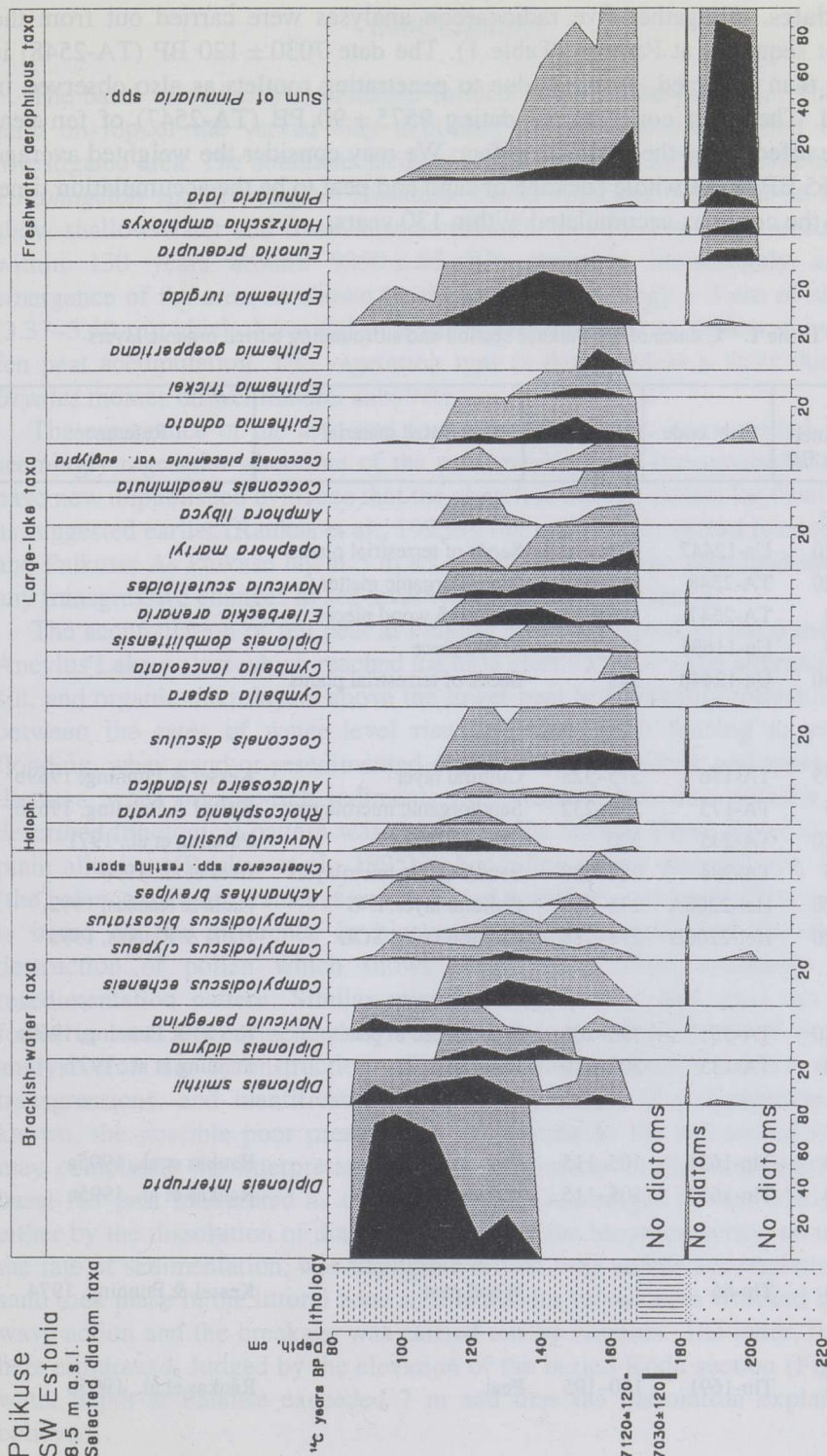
Fig. 7. Diatom diagram of the upper part of the Paikuse outcrop. The black curves represent the percentages and shaded curves per mil values. Analysed by Atko Heinsalu, 1997. For lithology see Fig. 3.

^{14}C dates. Altogether five radiocarbon analyses were carried out from the sediment sequence at Paikuse (Table 1). The date 7030 ± 120 BP (TA-2548) is younger than expected, probably due to penetrating rootlets as also observed in the field. The other conventional dating 9575 ± 90 PB (TA-2547) of fen peat could be affected by the reservoir effect. We may consider the weighted average 9350 ± 65 BP of the whole package of sand and peat to be the accumulation time. With 1δ the complex accumulated within 130 years.

Table 1. ^{14}C dates of the Paikuse section and surrounding buried organic layers

Age, uncalibrated ^{14}C years BP	Lab. code	Depth, cm	Dated material	Reference
PAIKUSE				
7120 ± 120	Ua-12447	165	Seeds of terrestrial plants	
7030 ± 120	TA-2548	167–177	Buried organic matter	
9575 ± 90	TA-2547	325–335	Peat with wood pieces	
9350 ± 75	Ua-11691	327	Wood piece	
9340 ± 130	Ua-12446	345	Seeds of terrestrial plants	
PULLI				
9575 ± 115	TA-176	315–325	Cultural layer	Kessel & Punning, 1969b
9300 ± 75	TA-175	230–232	Sand/organic microlayers	Kessel & Punning, 1969b
9600 ± 120	TA-245	320	Cultural layer	Punning et al., 1971
9285 ± 85	TA-284	280–290	Sand/organic microlayers	Ilves et al., 1974
9620 ± 120	Hel-2206A	278–288	Cultural layer, INS	Haila & Raukas, 1992
9290 ± 120	Hel-2206B	278–288	Cultural layer, SOL	Haila & Raukas, 1992
SINDI				
6710 ± 110	TA-55	195–202	Wood piece in peat	Kessel & Punning, 1969a
7215 ± 90	TA-133	300–310	Reed peat	Punning et al., 1977
LÕPE				
9215 ± 70	Tln-1631	105–115	Peat	Raukas et al., 1995a
9260 ± 70	Tln-1632	105–115	Wood	Raukas et al., 1995a
KÕDU				
8480 ± 90	Tln-66	?	Wood peat	Kessel & Punning, 1974
URGE				
9125 ± 85	Tln-1691	180–195	Peat	Raukas et al., 1995b

DISCUSSION

The basal varved clays at Paikuse formed in the Baltic Ice Lake. The coarse sand on top of the varved clay deposited as the shoreline shifted over the investigated area. The abundant seeds of *Schoenoplectus lacustris*, *Nuphar lutea*, *Potamogeton* sp., *Menyanthes trifoliata*, *Carex* spp., and Apiaceae in the sand show shallow-water and freshwater conditions. The sand and peat accumulated within 130 years around 9350 ± 65 BP, probably immediately after the emergence of the area, as shown by the isolation lithology – 3 cm of silty sand (3.37–3.40 m) which deposited in a small isolation hollow, followed by woody fen peat accumulation. The vegetation type is described as a *Salix* thicket and *Bryales* mosses on wet mineral substrate.

The emergence of the area and formation of the peat is connected with the seemingly regressive shoreline of the pre-Ancylus Lake transgression time. We have new unpublished evidence that the shoreline did not retreat far from Paikuse as suggested earlier (Raukas et al., 1995b), but more likely stayed between Pärnu and Paikuse. As Paikuse lay at 5 m a.s.l. and almost on the zero land-uplift line, any transgressive changes in sea level would inevitably affect it.

The accumulation of fen peat at Paikuse was interrupted by the transgressive Ancylus Lake waters which reached the area after 9350 BP. The alternating sand, silt, and organic microlayers above the lower peat bed probably reflect a balance between the rates of water level rise and land uplift leading to periodical flooding, when sand or resedimented organics was deposited, and emergence of the area, when organic-rich sediments were formed. It is also possible that the described lithological pattern was created by the ancient Pärnu River as a flood-plain alluvium (Raukas et al., 1995b). According to our material, the first idea (the balance between transgression and land uplift) is prioritized. This judgement is based on the difference in biostratigraphical material and the degree of destruction of pollen which shows better preservation conditions and no resedimentation pattern. Similar microlayering of peat and sand can also be found in areas not influenced by rivers. Although the potential of the diatom analysis for the reconstruction of past shorelines, indication of sea level transgressions, and identification of the environment of palaeobasins is well known, the possible poor preservation of diatoms in the calcareous sediments may complicate the interpretations. Lack of diatoms in the sand overlying the basal fen peat interpreted as of the Ancylus Lake origin is very likely caused either by the dissolution of diatom frustules, or the bioproductivity, compared to the rate of sedimentation, was negligible at that time and/or accumulation of the sand took place in the littoral zone so that diatom valves were wrecked by strong wave action and the breakage was carried out by currents. The latter, though, is here eliminated. Judged by the elevation of the buried Kõdu section (Fig. 2), the water depth at Paikuse exceeded 7 m and thus the dissolution explanation is believed.

The first diatoms were recorded at a depth of 2 m under the upper organic layer. Up to 90% of the diatom assemblage is constituted by broken valves of different *Pinnularia* spp. Species of the genus *Pinnularia* can be found in a wide range of water types, but most of them are indicative of acid, oligotrophic fresh water (van Dam et al., 1994). The common diatom taxon *Pinnularia lata* lives in acidophilous fresh water and/or in moist aerial conditions (Krammer, 1992) or nearly exclusively outside water bodies (van Dam et al., 1994). *Hantzschia amphioxys* is quite cosmopolitan. It is able to live in the soil but more often in the spray or surf zones or in freshwater lakes. *Eunotia praerupta* prefers acid waters but it survives also in euterrestrial surroundings (Hustedt, 1959). Douglas & Smol (1993) discussed that chrysophytes possess competitive advantage for nutrient uptake in oligotrophic ponds which are characterized by nutrient limitation, and the competition for nutrients between different algal groups plays a key role in their productivity. Siliceous phytoliths are inorganic supporting-structures found in some plants (Vuorela, 1991). The highest concentration of phytoliths is found in plants like Cyperaceae and Poaceae. In shoreline displacement studies sharp increases in the ratio of phytoliths to diatoms can indicate an offshore or even euterrestrial environment. The above supports the presumption that the sand directly underlying the pre-Litorina Sea organic layer was formed either in the spray zone of a beach of the regressive Ancylus Lake or, more likely, in a very shallow nutrient-poor pool which remained on the sandy coast of the retreating Ancylus Lake.

Once again the area emerged and organic sedimentation took place as a result of the regression of the Ancylus Lake. As Thomson (1928) and Kessel (1963, 1968) describe up to 1.32 m of gyttja and *Phragmites–Carex* fen peat 0.5 km upstream at Sindi (Fig. 2), we may presume that better drainage conditions existed at the edge of this bog at Paikuse and the organic matter here is therefore thinner and well decomposed. The vegetation type during the formation of that organic layer at Paikuse was *Pinus–Alnus* with abundant NAP, such as Poaceae, Cyperaceae, *Filipendula*, Rosaceae, Apiaceae, *Typha angustifolia/Sparganium*, *Equisetum*, all mainly indicative of a damp environment on mineral substrate.

During the formation of the upper organic layer, which indicates a terrestrial environment before the transgression of the Litorina Sea, conditions were too dry for the survival of diatoms. Diatoms in the thin sand layer under the upper organic layer (1.82–1.83 m) show that the shoreline of the Baltic Sea was not far from the Paikuse area. We do not want to make a conclusion that a minor transgression preceded the main transgression of the Litorina Sea. Southwestern Estonia belongs to the zone of very slow land uplift. As the area is very flat, then under the influence of a heavy storm the water level could rise several metres and the sea water could penetrate inland across the former river valley and inundate the place. Berglund & Sandgren (1996), although, discuss possible brackish-water influence between 8800 and 8200 BP during the transition from the Ancylus Lake to the Mastogloia Sea in Blekinge. The transition from the

Ancylus Lake to the Litorina Sea, when the shoreline displacement was relatively small, minor deviations from the regular land uplift could also produce apparent transgressions in coastal basins (Hyvärinen, 1980).

A new rise in sea level is marked by the lithostratigraphical change from the upper organic layer to sand alternating with organic microlayers, seen in the Paikuse section. According to the ^{14}C date 7120 ± 120 BP obtained from the upper surface of the organic layer at a depth of 1.65 m, the Litorina Sea transgression must have reached the area later than 7100 BP. The diatom assemblage with the freshwater Ancylus Lake flora and the presence of a few brackish-water diatom species is assumed to belong to the Mastogloia Sea phase. Similar diatom assemblages have been found at Rannametsa, 30 km south of Paikuse, where several ^{14}C dates from the peat reveal that the regression of the Ancylus Lake reached its minimum $c.$ 8000 BP. The sandy gyttja and sandy silt overlying the peat at Rannametsa contain brackish-water (*Campylodiscus clypeus*, *Campylodiscus echeneis*, *Diploneis smithii*) as well as freshwater flora commonly occurring in the sediments of the Ancylus Lake (*Ellerbeckia arenaria*, *Opephora martyi*, *Cocconeis disculus*, *Cocconeis placentula*) (Hyvärinen et al., 1992). Hyvärinen (1984) reports comparable diatom records between 8000 and 7500 BP in the littoral facies of the Mastogloia Sea stage from southern Finland. A slightly brackish transitional stage occurs also in the sublittoral sediments in the Gulf of Finland, southeast of Helsinki (Åker et al., 1988). The longer existence of slightly brackish-water conditions at Paikuse compared to the neighbouring regions is explained by the inflow of the Pärnu River into the lagoon which existed around Paikuse.

The disappearance of the Ancylus Lake flora and the progressive increase in brackish-water species marks the beginning of the Litorina Sea. The diatom assemblages of both the Mastogloia Sea and the Litorina Sea consist of periphytic diatoms, whereas planktonic species are almost missing. This indicates that the sedimentation took place in a shallow lagoon. In the uppermost sands of the Litorina Sea only diatoms with a robust structure like *Diploneis interrupta* are preserved with complete valves, while most of the diatoms occur as fragments. Vos & de Wolf (1993) described *Diploneis interrupta* as a brackish-water aerophilous diatom, which is more frequently observed in the recent supratidal sediments in the Netherlands. Consequently, the waters of the Litorina Sea transgression submerged the Paikuse area for a short period and most of the upper part of the investigated sediment section formed already in the near-shore environment.

ACKNOWLEDGEMENTS

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PAIKUSE (EDELA-EESTI) KAHE MATTUNUD ORGAANIKAKIHI BIO- JA KRONOSTRATIGRAAFIA

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Setete õietolmu ja diatomee analüüsi ning radiosüsiniku meetodi abil uuriti kahte Paikuselt leitud mattunud orgaanikakihti. Alumine turbakiht moodustus preboreaalis umbes 130-aastase ajavahemiku jooksul. Antsülusjärve transgressiooni tagajärjel mattusid uuritud piirkonnas orgaanilised setted 1,5 m paksuse liivakihi alla hiljem kui 9350 aastat tagasi. Ülemine mattunud orgaanikakiht moodustus, kui Antsülusjärve veetase oli alanenud, ning see ujutati taas üle umbes 7100 aastat tagasi riimveelise Litoriinamere poolt.

БИО- И ХРОНОСТРАТИГРАФИЯ ДВУХСЛОЙНОЙ ПОГРЕБЕННОЙ ОРГАНИКИ В ОКРЕСТНОСТЯХ ПАЙКУЗЕ, ЮГО-ЗАПАДНАЯ ЭСТОНИЯ

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Изучены двухслойные погребенные отложения в окрестностях Пайкузе по данным спорово-пыльцевого анализа, а также диатомовых и радиоуглеродных датировок. Установлено, что формирование нижнего слоя торфа происходило в пребореале, на протяжении примерно 130 лет. Во времена трансгрессии Анцилового озера органогенные отложения оказались погребенными песками мощностью около 1,5 м позднее 9350 лет т. н. Верхний слой органики формировался в ходе регрессии Анцилового озера и был погребен водами Литоринового моря примерно 7100 лет т. н.