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Holocene buried organic sediments in Estonia

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Abstract. An overview of 85 sites of Holocene buried organic sediments in Estonia is presented. This number includes 45 sites of pre-Ancylus and Ancylus age, which were buried during the Ancylus transgression, 31 sites of pre-Litorina and Litorina age, buried under Litorina transgression sediments, and 9 sites formed after post-Litorina time and mostly covered by aeolian sand. According to radiocarbon dates, the Ancylus Lake transgression started about 9500 yr BP (10 800 cal BP), and culminated several hundred years later. Around 9000 yr BP (10 100 cal BP) a rather rapid regression followed. Its magnitude reached up to 30 m in the areas of rapid uplift. Pollen spectra of these beds are characterized by a high frequency of *Pinus* pollen, which seems to be typical of the coastal waterbodies of this age and confuses determination of their Preboreal age. ^{14}C dates of Litorina buried beds differ considerably. We have evidence that the Litorina transgression started about 7500–7000 yr BP (8300–7800 cal BP) and culminated at different times in different regions. Pollen spectra of Litorina buried organic strata vary considerably between sites; however, their Atlantic age is easily discernible. The simulated isobases of the Ancylus Lake and Litorina Sea shorelines and organic beds showed discrepancy in the surroundings of Pärnu and Narva bays.

Key words: buried organic sediments, ^{14}C dates, Ancylus Lake, Litorina Sea, Estonia.

INTRODUCTION

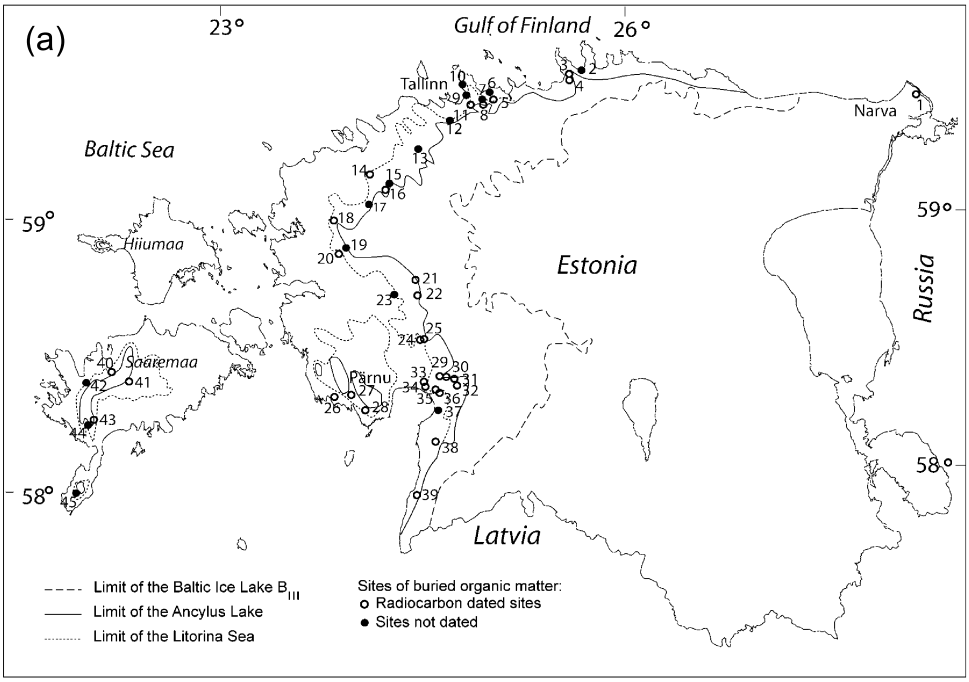
Buried organic sediments along ancient seacoasts offer a good possibility for dating transgressions and regressions of the Baltic Sea. Regressive phases brought about isolation of coastal lakes and lagoons, which due to land uplift became shallow, paludified, and during the following transgression were coated by water-laid deposits. In buried conditions patches of peat and gyttja were sealed and preserved up to the present, offering material for radiocarbon dating. As such peat and gyttja lenses were formed during a relatively short time and later compressed by overlying minerogenic deposits, their thickness is commonly less than 50 cm, rarely exceeding 100 cm.

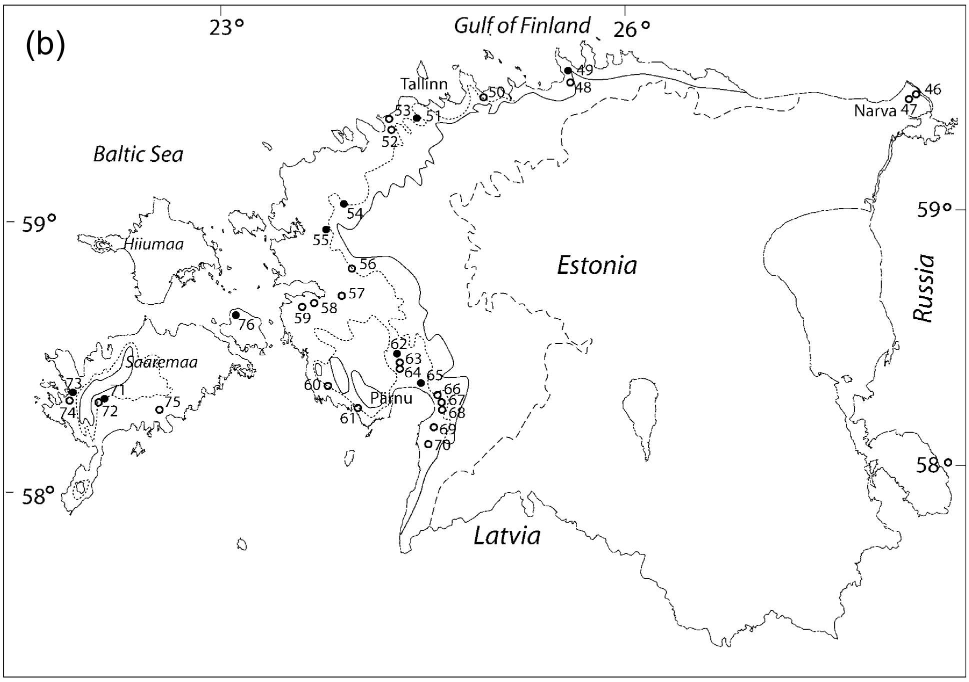
Hausen (1913) and Thomson (1933) reported the first evidence on the occurrence of buried organic deposits of Holocene age in Estonia. Hausen (1913) mentioned soil below the Ancylus sand and gravel at Piirsalu, Thomson (1933, 1937) described buried peat on the banks of the Pärnu and Narva rivers. Kents (1939) presented material on 37 sites with different beach formations and in 174 occasions adjusted their elevation. He proposed an idea of two transgressions of the Litorina Sea and their diachroneity in Estonia. In the 1960s, Helgi Kessel (Photos 1, 2) studied the Baltic Sea coastlines with biostratigraphic methods (pollen, diatom, and molluscs) and combined those with radiocarbon and archaeological approaches to justify the different stages of the Baltic Sea and their ecology on a firmer ground. In 1960, ten localities of Holocene buried organic sites were known: Jälgimäe (Thomson 1933), Päärdu (Laasi 1937), Kallavere, Jõelähtme, Võidu, Järise, Mustajõe (later renamed as Sikaselja), Piirsalu, Laitse, and Vakalepa (Kessel 1960; Fig. 1a; Appendix 1). Eight years later Kessel (1968) described already 38 sites with buried gyttja and peat, most of them found during the exploitation of gravel pits and mires. This year Helgi Kessel (21.06.1926–17.12.1989) would have celebrated her 80th birthday and on this occasion we decided to create and publish

Photo 1. Buried organic bed, 20 cm thick, outcropping in Iru gravel pit (year 1958). Photo by A. Miidel.

Photo 2. H. Kessel with Swedish colleagues U. Miller and L.-K. Königsson collecting Ancylus mollusc shells from Pärnamäe gravel pit in 1971. Photo by A. Miidel.

Fig. 1. (a) Location of pre-Ancylus and Ancylus buried organic sediment sites in Estonia with indication of the radiocarbon dated and not dated sites. 1, Sininõmme; 2, Kolga (Juminda); 3, Muuksi (Uuri); 4, Kahala; 5, Jõelähtme; 6, Kallavere; 7, Kroodi; 8, Lake Maardu; 9, Iru; 10, Merivälja; 11, Lake Ülemiste; 12, Jälgimäe; 13, Allikaküla (Laitse); 14, Põlluotsa; 15, Valgejärv; 16, Mustjärv; 17, Piirsalu; 18, Palivere; 19, Kullamaa (Kurisoo); 20, Ohtla; 21, Tapu; 22, Altküla; 23, Vakalepa; 24, Tagapere; 25, Oara; 26, Kastna; 27, Lake Ermistu; 28, Kõpu; 29, Lõpe; 30, Pressi; 31, Kõdu; 32, Urge; 33, Pulli; 34, Sindi; 35, Paikuse; 36, Sindi-Lodja; 37, Sikaselja; 38, Võidu; 39, Lemme-oja; 40, Pelisoo; 41, Tõrise; 42, Kasesoo; 43, Pitkasoo; 44, Järvesoo; 45, Siplase. (b) Location of pre-Litorina and Litorina buried organic sediment sites in Estonia with indication of the radiocarbon dated and not dated sites. 46, Tõrvala; 47, Leekovosoo; 48, Uuri (Maarikoja); 49, Mädajärve; 50, Kroodi; 51, Vahiküla; 52, Niitvälja; 53, Keila-Joa; 54, Kuijõe; 55, Väike-Lähtru; 56, Vigala; 57, Kirbla; 58, Tuudi; 59, Järise; 60, Kolga; 61, Seliste; 62, Jõõpre; 63, Oara; 64, Malda; 65, Audru; 66, Sindi; 67, Paikuse; 68, Sindi-Lodja; 69, Vaskrääma; 70, Rannametsa; 71, Jõempa; 72, Kärla; 73, Kihelkonna; 74, Vesiku; 75, Reo; 76, Lumiste.


(a)
23°
Gulf of Finland
26°
Tallinn
Narva
Baltic Sea
59°
Hiiumaa
Estonia
Russia
Saaremaa
Pärnu
58°
Latvia
Limit of the Baltic Ice Lake B$_{III}$
Limit of the Ancylus Lake
Limit of the Litorina Sea
Sites of buried organic matter:
Radiocarbon dated sites
Sites not dated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Pärnu
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Latvia

a database of Holocene buried organic sediments. In addition to all sites described by her, we have included in it several recently discovered sites. Up to now, this material was scattered in different publications and manuscripts. To fulfil this task, we collected and examined critically all the material available.

MATERIAL AND METHODS

To date, buried organic deposits of Holocene age are known from 85 sites. Of those, 45 are connected with the Ancylus Lake beach formations, 31 with the Litorina Sea, and 9 are younger and of various age. The compiled database of the Holocene buried organic deposits is presented in Appendixes 1–3. It includes radiocarbon-dated and undated sites, their coordinates, elevation, calibrated and uncalibrated ^{14}C dates, dated material, and references. All AMS ^{14}C dates were provided by the Ångström Laboratory, Uppsala University and are marked by the laboratory code Ua. Conventional radiocarbon dates were obtained at the ^{14}C laboratory of the University of Tartu (TA, Ta) and at the Institute of Geology, Tallinn (Tln). Radiocarbon dates were calibrated to calendar years using the Calib5.0 program at 1σ confidence level (Stuiver & Reimer 1993; Reimer et al. 2004). In the appendixes, the sites where pollen analyses have been carried out are marked with an asterisk. The location of the sites listed in Appendixes 1 and 2 is shown in Fig. 1. The reliability of the location and altitude of sites was checked using different sources of literature and topographic maps. Most elevations of sites were taken from the maps and are, therefore, marked with ca in the appendixes. Topographic maps indicate that some sites, reported as instrumentally measured, must have measurement errors, for example, Lõpe (Appendix 1) must lie about 2–3 m higher than reported. The database clearly shows that the elevation data are the most problematic and some extra work is required to improve the compiled database.

The shoreline displacement database of the Ancylus Lake and Litorina Sea was used to create water-level surfaces of the Ancylus Lake and Litorina Sea (Saarse et al. 2003a). The surfaces were compiled using a point kriging interpolation with linear trend approach (for details see Saarse et al. 2003a). The same approach was used to reconstruct the surfaces of buried organic sediments for two time intervals: 9500–8500 and 8400–7000 ^{14}C yr BP. First, all the data falling into this interval were used to reconstruct water-level surfaces. Then the data visually not matching with sites nearby were eliminated and new water-level surfaces were compiled. After data elimination the time intervals narrowed to 9300–8600 and 8000–7000 ^{14}C yr BP. The top surfaces of the buried organic sediments were then compared with the water-level surfaces of the Ancylus Lake and Litorina Sea, respectively (Figs 2, 3).

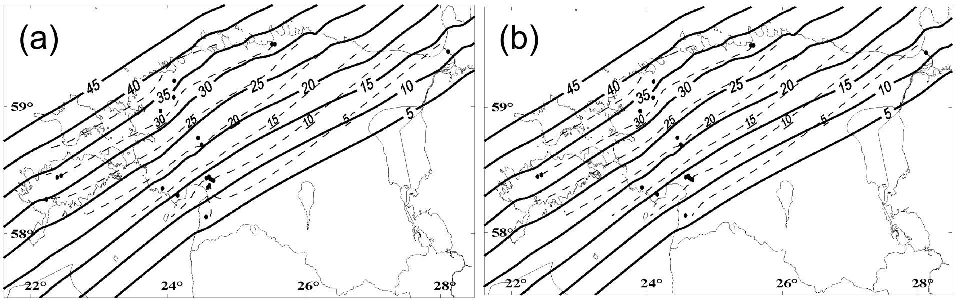

Fig. 2. (a) Isobases of the Ancylus Lake shorelines (solid line) and pre-Ancylus and Ancylus buried organic matter (dashed line) with indication of sites that were used in kriging point analyses. (b) Isobases modelled without sites 35 (Paikuse) and 36 (Sindi-Lodja) given in Appendix 1.

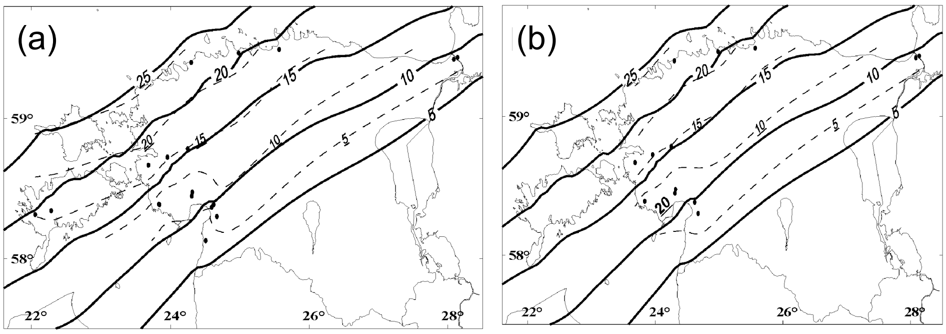

Fig. 3. (a) Isobases of the Litorina Sea shorelines (solid line) and pre-Litorina and Litorina buried organic matter (dashed line) with indication of sites that were used in kriging point analyses. (b) Isobases modelled without sites 68 (Sindi-Lodja), 70 (Rannametsa), and 72 (Kärla) given in Appendix 2.

RESULTS AND DISCUSSION

Dating problems

Radiocarbon ages of the organic deposits formed during Yoldia regression and Ancylus transgression (73 dates) vary significantly: from 8440 ± 70 (TA-263) to 9980 ± 120 (Tln-2349) at Jõelähtme (Appendix 1). The ^{14}C dates (50 dates) obtained for Ancylus regression and Litorina transgression deposits range from 5520 ± 100 (Tln-178) at Oara to 8400 ± 190 (Mo-222) at Kärla (Appendix 2). Post-Litorina buried organic beds have been found at nine sites. Their radiocarbon dates fluctuate between 180 ± 60 (Tln-2441) and 3780 ± 50 (Tln-2504; Appendix 3). These young beds are mostly covered by aeolian sand. The variability of radiocarbon dates is caused by different factors. Firstly, in some places pre-Ancylus buried organic sediments contain deposits of both Yoldia regression and Ancylus transgression. In principal, the same is valid for the buried pre-Litorina beds, which can include the deposits of Ancylus regression and Litorina transgression. Secondly, radiocarbon dates depend on the material analysed (wood, seeds, bulk organic matter, insoluble or soluble fraction), its preservation and availability to weathering, contamination with older carbon or younger rootlets, hard water and reservoir effect, as well as the dating method used (Olsson 1986; Veski 1998; Wohlfarth et al. 1998; Olsson & Kaup 2002).

Buried organic deposits from several sites, such as Jõelähtme, Ülemiste, Tapu, Kõdu, and Rannametsa (Fig. 1; Appendixes 1, 2), have been newly examined and dated. Commonly, new conventional radiocarbon dates are older than those obtained earlier. At Jõelähtme the buried fen peat was earlier dated to 8700–8400 yr BP (Kessel & Punning 1974). New dates obtained in 1997 indicate a considerably older age (Appendix 1), which is consistent with pollen stratigraphy (Veski 1998, p. 44). The same is valid for the Tapu organic deposits where the new ^{14}C date (9325 ± 65, Tln-2185; Veski 1998) showed an older age than the earlier ones (8995 ± 125, TA-78 and 8460 ± 180, TA-75; Appendix 1). One and maybe the most important reason is the conservation of samples and the time span between collection and dating. For example, wood from the buried peat at Sindi (Appendix 2) was collected already in 1959 (Liiva et al. 1966), but analysed several years later and the age appeared to be 6710 ± 110 (TA-55). Comparison of conventional and AMS ^{14}C dates showed that in several cases AMS dates from seeds yielded younger ages than conventional radiocarbon dates from bulk peat, gyttja or wood. A good example is Lake Ermistu (Appendix 1), where woody fen peat at a depth of 520–530 cm was dated by the conventional ^{14}C method to 9515 ± 120 (Tln-1378) and seeds from the midpoint of the same interval (525 cm) were dated to 8870 ± 85 (Ua-13031; Veski 1998).

Geological setting

The coastal formations of the Ancylus Lake are located at a height of 45 m a.s.l. on the Island of Hiiumaa, 13 m in Narva, and 5 m in SW Estonia near the Estonian–Latvian border (Fig. 2). The Litorina Sea shorelines occur at lower elevation. The highest Litorina limit has been registered at 25 m a.s.l. also on the Island of Hiiumaa, 21–22 m a.s.l. in NW Estonia (Thomson 1936; Kessel & Raukas 1979), 9–10 m in Narva, and 5 m in SW Estonia (Fig. 3). Buried organic deposits are commonly located close to the Ancylus Lake and Litorina Sea transgression coastline, under beach ridges and spits where the sedimentation was rapid (Photo 1). Remarkable thickness (up to 1.3 m) and spatial distribution of these deposits have been traced on the lower reaches of the Pärnu River, where more than 20 buried organic sequences are exposed on the river bank and its tributaries within a 40 km^2 area (Veski et al. 2005). Here the height of pre-Ancylus and Ancylus buried organic beds ranges between 3 and 16 m a.s.l.

(Kessel 1963; Veski et al. 2005). In the Oara, Sindi, and Paikuse sequences two consecutive buried organic strata represent pre-Litorina and pre-Ancylus beds, respectively. At Pulli and Sindi-Lodja organic deposits are connected with the archaeological settlement sites.

Kessel (1968) divided the buried organic sediments in Estonia into two groups: (1) peat and gyttja, which deposited in terrestrial conditions and (2) reed peat and clayey gyttja, which accumulated in lagoons or bays. Peat and gyttja are enriched with green algae, insect remains, seeds, and other macroremains. Deposits of lagoons and bays are rich in mineral matter and contain few diatoms. The diatomite in Leekovo mire and Tõrvala is an exception, consisting almost entirely of diatomic frustules (Thomson 1937).

Buried peat was formed in two different ways. Firstly, due to rise in groundwater table, paludification, and overgrowing of relict lakes and lagoons isolated during the regression phases of the Baltic Sea. Such conditions seem to have existed at Ermistu, Sindi, Lemmeoja, and Pitkasoo where peat accumulation started before the Ancylus transgression, in the hollows and relict lakes on the Yoldia Sea terrace. Their pre-Ancylus age is confirmed by the pollen composition and radiocarbon dates. The basal part of buried peat is dated to 9850 ± 165 (Ua-13036) in Lake Ermistu, 9820 ± 130 (Tln-130) in Lemmeoja, and 9800 ± 80 (Ua-2285) in Pitkasoo (Appendix 1). Secondly, peat could have accumulated in the hollows and depressions due to water-level rise in the transgression phase. This seems to be the case at Kõdu where the swampy birch wood was drowned due to the rise in groundwater table. A question arises of how to differentiate the buried peat formed during the Yoldia Sea regression from that of the Ancylus Lake transgression if they occur in the same sequence. Commonly, the limit is placed along the lithological boundary between peat (regressional facies) and gyttja (transgressional facies), but if there is no clear lithological boundary, the limit between the Yoldia regressional and Ancylus transgressional bed is tentatively placed at 9500 yr BP (10 800 cal BP).

The complete sedimentation cycle formed during the Ancylus transgression (from the beginning up to the culmination) can be followed in a few coastal lake sequences (Maardu, Ülemiste, Mustjärv, and Ermistu) and in some buried sequences (Põlluotsa, Lõpe, and Kõdu), which register the transgression event quite clearly. At Põlluotsa the basal sand is covered by woody peat, herbaceous-*Hypnum* peat, gyttja, lagoonal clay, and gravelly sand (Ploom et al. 1996). Woody peat accumulated in the conditions of groundwater table rise, and the *Betula* wood from it has been dated to 9350 ± 70 (Tln-2023). A similar transgressive sequence has been found at Kõdu, which starts with clay overlain by peat (9340 ± 45, Tln-1993), gyttja, silty sand, and sand (Raukas et al. 1999). The Lõpe sequence, where till beds are overlain by *Phragmites* peat, alternating lagoonal silt and sand, and covered by gravel, also refers to the transgressive nature of sediments (Raukas et al. 1995a). The age of the buried peat in the Lõpe sequence has been dated to 9215 ± 70 (Tln-1631) and 9260 ± 70 (Tln-1632) (Appendix 1). In the Oara, Pulli, Sindi, and Paikuse sequences peat and gyttja are covered by alternating peaty and sandy layers, the origin of which has been interpreted differently (Raukas et al. 1999; Veski et al. 2005). At Skede Mose (Öland) such alternating sandy and gyttja layers have been interpreted as beds formed during the transgression maximum (Königsson 1968).

The Ancylus Lake culmination has been discussed and re-estimated recurrently. In the 1960s and 1970s it was suggested to have occurred between 8400 and 8200 yr BP (Kessel & Punning 1969a; Kessel & Raukas 1979), in the 1980s at about 8700 yr BP (Raukas et al. 1988), in the 1990s at 9000–9200 yr BP (Raukas et al. 1995b) or 9200–9300 yr BP (Saarse et al. 1997). The last mentioned ages are comparable to that suggested by Finnish and Swedish researchers (Berglund 1964; Eronen & Haila 1982; Svensson 1989; Björck 1995; Berglund et al. 2005).

The reconstructed shore displacement curves suggest that the Ancylus Lake regressed rather rapidly (Kessel & Raukas 1979; Björck 1995; Saarse et al. 1997; Berglund et al. 2005; Veski et al. 2005). The magnitude of the Ancylus Lake regression in Estonia varies from 30 m on the Island of Hiiumaa, judging by the low position of the Ancylus fauna (Raukas et al. 1996), to 11 or more metres in the vicinity of Pärnu (Veski et al. 2005), depending on the land uplift measure.

The development of the Litorina Sea was more complicated than that of the Ancylus Lake and opinions on the number of transgressions and timing of culmination vary considerably. Some authors have distinguished several transgressions in the history of the Litorina Sea (Kessel 1963; Kessel & Raukas 1979; Sandgren et al. 2004; Berglund et al. 2005). Others have defined only one major transgression (Eronen 1974; Hyvärinen 1980; Kaland 1984; Hyvärinen et al. 1992; Seppä et al. 2000; Miettinen 2002). H. Kessel and A. Raukas later also supported the idea of one Litorina transgression (Kessel & Raukas 1984; Hyvärinen et al. 1988). Lepland et al. (1996) studied the Narva area and tentatively distinguished there three transgression phases. It was explained with the circumstance that Leekovo lagoon had a limited connection with the sea and, therefore, could have been influenced by the water-level changes in the Narva River. In the Pärnu district, which lies on the same isobase as Narva, one Litorina transgression was recognized (Veski et al. 2005). Comparison of the shore displacement curves with the position of the settlement sites also supports the idea of one main transgression (Jussila & Kriiska 2004; Veski et al. 2005).

The transitional stage between the Ancylus Lake and Litorina Sea is the Mastogloia Sea, or the Early Littorina Sea (Berglund et al. 2005), or Initial Litorina Sea (Andrén et al. 2000). Two periods have been distinguished in the history of the Early Littorina Sea: at 9800–9400 cal BP (8700–8300 yr BP) and 9400–8500 cal BP (8300–7700 yr BP), the last being known as the Mastogloia stage (Berglund 1964; Hyvärinen 1984, 1988). The first period established in Blekinge is characterized by diatoms, which show saline water inflow, but considerably earlier than previously assumed (Eronen et al. 1990). Deposits of the second period contain mainly freshwater diatoms. Beds of the first period are not known in Estonia, at least not of such an early age. The deposits of the Mastogloia period, recognized as a transitional diatom-stratigraphic unit, have been found at Tuudi, Lumiste (Kessel & Pork 1974), Rannametsa (Hyvärinen et al. 1992), and Kõivasoo

(Kents 1939; Saarse et al. 2000). The ages of the Tuudi (7860 ± 70, Tln-33; 8550–8850 cal BP), Rannametsa (8080 ± 110, Hel-2207A, 8770–9200 cal BP; 8060 ± 110, Hel-2207B, 8730–9130 cal BP), and Kõivasoo beds (8190 ± 90, TA-530; 9030–9260 cal BP) coincide with the time span of 9400–8500 cal BP suggested by Berglund et al. (2005). According to Kessel (1975), the Mastogloia stage in Estonia occurred later, at about 7600–7200 yr BP (8400–8100 cal BP).

It is hard to determine the start of the Litorina transgression on the basis of buried strata, because organic beds are poor in or completely lacking diatoms and molluscs, in contrast to the covering minerogenic beds, which comprise typical Litorina Sea taxa, e.g. *Campylodiscus echeneis*, *Navicula peregrina*, *Diploneis interrupta*. The beginning of the brackish Litorina transgression has been registered at about 8500 cal BP in southern Sweden (Berglund et al. 2005), and 8400 cal BP in the east of the Gulf of Finland (Miettinen 2002). A clearly brackish-water mollusc fauna of the Litorina Sea appeared in western Estonia about 7200 yr BP or 7950–8150 cal BP (Kessel 1975).

The highest shoreline of the Litorina Sea in Estonia (25 m a.s.l. on the Island of Hiiumaa) is dated to 7500 yr BP (Königsson et al. 1998; 8150 cal BP), whereas in the Narva area (10 m a.s.l.; Ramsay 1929) it is dated to ca 6600 yr BP (7500 cal BP; Lepland et al. 1996). In the Pärnu area, which lies approximately on the same isobase as Narva (Fig. 3), the Litorina transgression culminated ca 6500 yr BP or 7300–7400 cal BP (Veski et al. 2005). It means that in the areas of slower land uplift the transgression maximum occurred later than in the areas with more rapid uplift (Miettinen 2002) and that the highest Litorina level is diachronous (Hyvärinen et al. 1988).

The Litorina buried beds like those of Ancylus age are also represented by lagoonal clayey silt, gyttja or peat (Appendix 2). At Oara the pre-Litorina buried deposits are mostly composed of 135 cm thick *Phragmites* peat, underlain and covered by lagoonal clayey gyttja. The upper part of the gyttja was dated to 6100 ± 50 (TA-193). At Sindi, Paikuse, and Sindi-Lodja, the Litorina beds occur together with the Ancylus beds, forming the upper organic set (Kessel 1961; Veski et al. 2005). In several places (Kolga, Rannametsa, and Vesiku) the surfaces of buried beds have been subject to wave action and erosion. The traces of abrasion are visually observable.

Pollen stratigraphy

Pollen analyses show that the deposits formed during the Yoldia Sea regression (before 9500 yr BP) are characterized by different pollen assemblages. Therefore it is hard to define their chronological position by palaeobotanical records only. Buried peat at Oara is dominated by *Betula* pollen, followed by *Pinus* (Kessel & Punning 1969b). Pollen of *Betula nana* and *Salix* is continuously present, *Alnus*, *Corylus*, *Ulmus*, and *Picea* occur sporadically. The proportion of herbs is high on account of Poaceae and Cyperaceae. Typical arctic flora elements, such as *Hippophaë rhamnoides* and *Dryas octopetala*, have been identified (Kessel & Punning 1969b). In contrast to Oara, bottom peat in Pitkasoo and Lake Ermistu is enriched with *Pinus* pollen (Königsson et al. 1998; Veski 1998). The quantity of other tree pollen is negligible, even *Betula* pollen does not exceed 10%.

Sediments deposited during the Ancylus transgression were examined palynologically at Jälgimäe, Põlluotsa, Tapu, Ermistu, Kõdu, Lõpe, Kõpu, Sindi, Paikuse, Võidu, Lemmeoja, Jõelähtme, and Pelisoo (Fig. 1a). They are characterized by the dominance of *Pinus* pollen, whose frequency fluctuates from 60 to 90%. The amount of *Betula* is commonly between 10 and 30%. *Salix*, *Juniperus*, *Populus*, *Alnus*, *Corylus*, and *Ulmus* are present sporadically or with low values. Among herbs, Poaceae and Cyperaceae are dominating. In lakes with continuous sedimentation, such as Ülemiste, Maardu, Mustjärv, and Ermistu, *Betula* pollen surpasses in frequency *Pinus* pollen (Saarse et al. 1997; Veski 1998) and the pollen assemblage is more similar to that of Preboreal age. The high *Pinus* percentages and sometimes considerably younger than expected ^{14}C age were the main reasons why in the 1960s and 1970s the Ancylus transgression was correlated with the Boreal chronozone (Kessel & Punning 1969a; Kessel & Raukas 1979).

Pollen assemblages of the Mastogloia beds (Lumiste, Tuudi) show the following frequencies: *Pinus* and *Betula* 30–50%, *Alnus* 13–22%, QM (*Ulmus*, *Tilia*, and *Quercus*) 4–10%, *Corylus* 5–12%. The pollen of *Picea* is low, less than 2% (Kessel & Pork 1974). Among other species in both lagoonal beds *Campylodiscus clypeus*, *C. echeneis*, and *Mastogloia smithii* have been identified (Kessel & Pork 1974).

The pollen composition of the Litorina beds varies considerably from site to site. The pollen assemblages in buried sediments on the lower reaches of the Pärnu River are dominated by *Betula*, *Pinus*, and *Alnus* with herbs composed mainly of Poaceae and Cyperaceae (Thomson 1933; Kessel 1963; Veski et al. 2005). In several pollen diagrams (Vesiku, Kärla, Seliste) at first *Pinus* pollen dominates (60–80%). It decreases upwards, directly corresponding to increase in *Betula*, *Corylus*, and QM. The Keila-Joa diagram displays equal pollen percentages (up to 30%) for *Betula* and *Alnus*, 3% for *Picea*, and 5% for QM. Pollen assemblages at Kolga differ by a high proportion of *Betula* (30–60%), at Seliste and Tõrvala by the prevalence of *Alnus* and *Betula* (up to 50%; Kessel 1963; Kessel & Punning 1969a). In the Kolga diagram QM reaches 10%, *Picea* 1–2%, and *Corylus* up to 20%. All this shows that pollen assemblages differ substantially with sites and reflect the local vegetation composition, and determination of sediment position in the chronological scale can fail.

Modelling results

The isobases of the modelled water-level surfaces of the Ancylus Lake and Litorina Sea are presented in Figs 2a and 3a. The modelled Ancylus Lake shoreline shows that the isobases are almost straight lines, with some minor exceptions (Fig. 2a). The Ancylus Lake water-level surface is plane, tilted from northwest to southeast. It refers to even and regular uplift of Estonia at that time, without noticeable connection between isobases, bedrock geology, and tectonics. The simulated sea surface of the Litorina transgression shows a more complicated pattern (Fig. 3a). It appears that some Litorina isobases are not straight lines: in NE Estonia the 15 m isobase has a greater inclination in an easterly direction than previously suggested (Kessel & Raukas 1979, 1984). Spacing between the Litorina isobases varies regionally, probably as a result of different land uplift and a non-contemporaneous Litorina transgression. In general, the modelling results (Figs 2a, 3a) are similar to those obtained earlier using trend-surface analysis (Miidel 1995).

Comparison of the Ancylus Lake water level with the isobases of the buried organic matter of Ancylus age (9500–8500 yr BP) shows discrepancies in the Pärnu area, especially at two localities – Sindi-Lodja and Paikuse (Appendix 1; Fig. 2). The organic matter of Ancylus age at Sindi-Lodja (9170 ± 200, Ta-2784) and Paikuse (9575 ± 90, TA-2547) lies about 4–5 m lower than at the sites nearby. Both these sites are located on the riverbank where varved clays underlie the studied deposits and landslides are quite common, thus one can suspect that these deposits are not in situ position. Furthermore, it is not reasonable to rule out other possibilities, e.g., erosion at the beginning of the Ancylus transgression during which the upper part of organic layers could have been removed, or erroneous elevation of the buried organic beds, as several sections were not levelled. Simulation of isobases without Paikuse and Sindi-Lodja sites improved the modelling results significantly (Fig. 2b). In general, the buried organic matter lies slightly (about 1–2 m) below the modelled level of the Ancylus Lake, which indicates that it deposited before the Ancylus transgression. In SW Estonia organic matter lies about 4 m below the modelled level of the Ancylus Lake (Fig. 2b). The reason for such a phenomenon is not clear and more detailed studies are required.

Comparison of the water level of the Litorina Sea with the isobases of the buried organic matter (time span 8400–7000 yr BP) shows discrepancies in the same area around Pärnu Bay (Fig. 3a). Here landslides at Sindi-Lodja and erosion at Kolga and Malda (Fig. 1b) could have affected the geological setting of the buried bed. The low elevation of the Rannametsa buried bed (Appendix 2) does not match with the elevation of the other sites nearby. Simulation without Sindi-Lodja and Rannametsa sites, but also Kärla which is much older (8400 ± 190, Mo-222; Appendix 2), improved slightly the results, but the discrepancy around Pärnu still remains (Fig. 3b). In general, the buried organic matter is almost at the same elevation with the modelled level of the Litorina Sea above the 15 m isobase, but some metres lower below that isobase, which is hard to justify.

CONCLUSIONS

- The database of Holocene buried organic sediments of Estonia, including 85 sites, was compiled. The transgressional and regressional phases of the Baltic Sea created suitable conditions for the deposition of peat and gyttja, which during the transgressions were coated by minerogenous deposits of the

Ancylus Lake and Litorina Sea. Such sites are now known in 76 localities. The post-Litorina buried peat (nine sites) is mostly covered by aeolian sand, not by marine one.

- Radiocarbon dates received on buried peat and gyttja differ considerably depending on the bedding conditions and material and methods used. In several cases, the ^{14}C ages obtained recently are older than earlier ones, possibly due to methodological reasons or mistakes at sample collection and preservation.
- Buried organic deposits of Ancylus age are mostly characterized by the dominance of *Pinus* pollen. This was the main reason why earlier the Ancylus transgression was connected with the Boreal chronozone, explaining also its 1000 years younger age compared to the results from Scandinavia.
- Comparison of shore displacement curves and the ancient settlement position does not support the opinion about the multiple Litorina transgression. We favour the idea that the Litorina transgression culminated at different times, first in the areas of rapid uplift.
- According to studies carried out in Estonia, the Ancylus transgression developed between 9500 and 9000 yr BP (10 800–10 100 cal BP), while the Litorina Sea culminated between 7500 and 6600 yr BP (8100–7400 cal BP).
- Simulation of buried organic matter beds and shoreline isobases shows discrepancies, especially in the surroundings of Pärnu Bay. This can mainly be explained by landslides.
- Detailed bio- and chronostratigraphic analyses are needed to register more precisely the beginning and end of transgressions, especially the character of the Litorina transgression.

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Holotseensed mattunud organogeensed setted Eestis

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On esitatud holotseensete mattunud setete andmebaas, mis sisaldab leiukohtade loendit, koordinaate, lasumite kõrgusi, ^{14}C dateeringuid, analüüsitud materjali nimetust ja viiteid allikmaterjalidele. Kokku on andmeid 85 leiukoha kohta. Radiosüsiniku dateeringute põhjal on väidetud, et Antsülusjärve transgressioon algas umbes 9500 ^{14}C aastat tagasi (10 800 cal BP) ja kulmineerus 200–300 aastat hiljem, millele järgnes suhteliselt kiire regressioon, mis maakoore kiirema kerke alal ulatus kuni 30 m. Mattunud setetes leiduv rohke männi õietolm oli peamiseks põhjuseks, miks Antsülusjärve transgressiooni Eestis loeti varem boreaalseks, ligi 1000 aastat nooremaks. Seni on Eestist andmeid vaid ühe Litoriinamere transgressiooni kohta. Litoriinamere transgressioon algas 7500–7000 ^{14}C aastat tagasi (8300–7800 cal BP) ja kulmineerus varem maakoore kiirema kerkega aladel, olles seega eriaegne. On esitatud Antsülusjärve ning Litoriinamere rannajoone modelleeritud isobaasjooned ja vastavate mattunud setete pealispindade korrelatsioon.

Appendix 1. Database of pre-Ancylus and Ancylus buried organic sediments. Asterisks mark the sites where pollen analysis has been carried out

No.	Site	Coordinates	^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
1	Sininõmme	59°26′ 28°7′	9700 ± 75	Ua-3193	10 870–11 220	ca 1.3		Wood	Lepland et al. 1996
			9480 ± 80	Ua-3192	10 590–11 070	ca 2.5		Wood	Lepland et al. 1996
			9380 ± 70	Ua-3191	10 510–10 690	ca 1.5		Wood	Lepland et al. 1996
			9190 ± 70	Ua-3190	10 250–10 420	ca 2.5		Wood	Lepland et al. 1996
2	Kolga (Juminda)	59°30′ 25°37′	Not dated				ca 30	Organic matter	Kessel & Linkrus 1979; Linkrus 1988
3	Muuksi (Uuri)*	59°29′30″ 25°34′20″	9230 ± 80	Tln-202	10 280–10 440	28.24	28.24–28.34	Wood	Kessel & Linkrus 1979
4	Kahala*	59°29′30″ 25°32′	8595 ± 75	TA-59	9 500–9 630	30.8–30.9	30.55–30.9	Peat	Kessel 1966; Ilves et al. 1974
5	Jõelähtme*	59°27′20″ 25°8′40″	9980 ± 120	Tln-2349	11 250–11 700	28.5–28.55	28.4–28.55	Peat	Heinsalu 2000
			9640 ± 100	Tln-2371	10 790–11 180	28.4–28.45	28.4–28.55	Peat	Heinsalu 2000
			9330 ± 90	Tln-2370	10 420–10 675	28.45–28.5	28.4–28.55	Peat	Heinsalu 2000
			8745 ± 75	TA-262	9 600–9 830		ca 30–30.1	Peat	Kessel & Raukas1967; Ilves et al. 1974
			8440 ± 70	TA-263	9 415–9 530		ca 30–30.1	Peat	Ilves et al. 1974
6	Kallavere*	59°29′ 25°1′	Not dated				ca 33	Gyttja	Kessel 1962
7	Kroodi	59°27′10″ 24°59′30″	Not dated					Organic matter	Veber 1950; Kessel 1962
8	Lake Maardu*	59°26′40″ 24°59′50″	9490 ± 110	Ua-2390	10 645–11 070	25.75		Wood	Veski 1998
9	Iru	59°27′20″ 24°53′50″	Not dated				ca 32	Clay gyttja	Künnapuu 1957; Kessel 1962
10	Merivälja*	59°29′45″ 24°51′40″	Not dated				29.4–29.45	Peat	Kessel 1961; Saarse, pers. comm.
11	Lake Ülemiste*	59°24′ 24°46′	9480 ± 95	Tln-1859	10 590–11 070	25.71–25.8		Peaty gyttja	Saarse et al. 1997
			9300 ± 80	Tln-1856	10 380–10 590	25.8–25.9		Peaty gyttja	Saarse et al. 1997
			9145 ± 75	Tln-1861	10 230–10 400	26.3–26.4		Peaty gyttja	Saarse et al. 1997

Appendix 1. *Continued*

No.	Site	Coordinates	^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
12	Jälgimäe*	59°19′ 24°38′	Not dated					Peat	Thomson 1933
13	Allikaküla (Laitse)	59°10′ 24°27′	Not dated					Organic matter	Lõokene 1950
14	Põlluotsa*	59°12′10″ 24°5′50″	9350 ± 70	Tln-2023	10 500–10 680	ca 31		Wood	Ploom et al. 1996
15	Valgejärv*	59°6′30″ 24°7′30″	Not dated				ca 28.8	Peat	Männil 1964; Veski 1998
16	Mustjärv*	59°4′40″ 24°6′30″	9590 ± 120	Tln-2042	10 760–11 120	31.4–31.5		Gyttja	Veski 1998
			9080 ± 70	Ua-11689	10 180–10 300	31.42	31.38–31.45	Wood	Veski 1998
17	Piirsalu*	59°4′ 24°2′	Not dated				ca 32	Sandy peat	Hausen 1913; Kessel 1962, 1966
18	Palivere	58°58′0″ 23°53′50″	8640 ± 70	Tln-65	9 540–9 670		ca 32	Woody peat	Kessel 1966; Kessel & Punning 1974
19	Kullamaa (Kurisoo)	58°53′ 24°4′	Not dated					Organic matter	Kessel 1962
20	Ohtla	58°52′ 23°54′	8560 ± 110	TA-195	9 460–9 680			Woody peat	Kessel & Punning 1969a
21	Tapu*	58°45′15″ 24°26′55″	9325 ± 65	Tln-2185	10 430–10 650	21.11	20.96–21.11	Seeds, bark	Veski 1998
			8995 ± 125	TA-78	9 910–10 260		ca 21	Woody peat	Kessel & Punning 1969a
22	Altküla (near Tapu)	58°42′ 24°30′	8460 ± 180	TA-75	9 240–9 630		ca 20.5	Woody peat	Kessel & Punning 1969a
23	Vakalepa*	58°36′30″ 24°17′	Not dated				ca 20	Peat	Kessel 1962, 1963
24	Tagapere*	58°28′20″ 24°16′50″	9140 ± 90	Tln-2222	10 220–10 470	5.46–5.5	5.29–5.5	Woody fen peat	Veski 1998
			9140 ± 90	Ua-12445	10 220–10 470	5.5	5.29–5.5	Seeds	Veski 1998
			9010 ± 125	Tln-2219	9 910–10 270	5.29–5.33	5.29–5.5	Woody fen peat	Veski 1998
25	Oara*	58°28′20″ 24°17′20″	9765 ± 130	TA-133	10 800–11 330	ca 6.35–6.45		Fen peat	Kessel & Punning 1969b; Raukas et al. 1999
26	Kastna*	58°21′25″ 23°55′35″	8960 ± 45	Tln-1826	9 950–10 220	16.37–16.43	16.37–16.43	Wood	Veski 1998; Lepland, pers. comm.
			8780 ± 50	Tln-1824	9 700–9 900	16.37–16.43	16.37–16.43	Fen peat	Veski 1998; Lepland, pers. comm.

Appendix 1. *Continued*

No.	Site	Coordinates		^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
27	Lake Ermistu*	58°22′0″	23°59′0″	9850 ± 165	Ua-13036	10 910–11 700	12.35–12.40	12.3–12.6	Woody fen peat	Veski 1998
				9745 ± 85	Tln-1137	10 880–11 250	12.4–12.5	12.3–12.6	Woody fen peat	Raukas et al. 1988
				9635 ± 100	Tln-1380	10 790–11 180	12.3–12.4	12.3–12.6	Woody fen peat	Veski 1998
				9595 ± 130	Ua-13034	10 760–11 140	12.55–12.6	12.3–12.6	Woody fen peat	Veski 1998
				9565 ± 75	Tln-1323	10 750–11 080	12.75–12.85	12.3–12.6	Calcareous gyttja	Kessel 1966; Veski 1998
				9515 ± 120	Tln-1378	10 610–10 880	12.5–12.6	12.3–12.6	Woody fen peat	Veski 1998
				9345 ± 90	Ua-13035	10 420–10 690	12.45–12.5	12.3–12.6	Woody fen peat	Veski 1998
				9275 ± 185	Ua-11245	10 240–10 700	12.6	12.3–12.6	Seeds	Veski 1998
				9205 ± 185	Ua-11244	10 190–10 660	12.86	12.3–12.6	Seeds	Veski 1998
				9075 ± 95	Ua-13032	10 160–10 400	12.45	12.3–12.6	Seeds	Veski 1998
				8870 ± 85	Ua-13031	9 800–10 170	12.55	12.3–12.6	Seeds	Veski 1998
28	Kõpu*	58°18′10″	24°9′	9060 ± 70	Ua-11652	10 160–10 280	12.67	12.59–12.66	Wood	Veski 1998
29	Lõpe*	58°26′21″	24°34′19″	9260 ± 70	Tln-1632	10 300–10 550	8.6–8.78	11?	Wood	Raukas et al. 1995a, 1999
				9215 ± 70	Tln-1631	10 270–10 490	8.6–8.78	12?	Peat	Raukas et al. 1995a, 1999
30	Pressi	58°27′	24°36′30″	9135 ± 70	Tln-1991	10 230–10 390	ca 11.5		Peat	Raukas et al. 1999
31	Kõdu*	58°26′5″	24°37′25″	9340 ± 45	Tln-1993	10 500–10 650	ca 13		Organic matter	Raukas et al. 1999
				8480 ± 90	Tln-66	9 420–9 550	ca 13		Woody peat	Kessel & Punning 1974
32	Urge	58°25′30″	24°39′	9125 ± 85	Tln-1691	10 220–10 400	ca 11		Peat	Raukas et al. 1995b, 1999
33	Pulli*	58°25′10″	24°40′30″	9620 ± 120	Hel-2206B	10 790–11 170	ca 8.82–8.92	8.82–9	Cultural layer	Haila & Raukas 1992
				9600 ± 120	TA-245	10 770–11 130	ca 9	8.82–9	Wood	Ilves et al. 1974
				9385 ± 105	Ua-13351	10 420–10 760	8.95		Charcoal	Poska & Veski 1999
				9350 ± 60	TA-949	10 500–10 660	ca 9		Soil	Jaanits & Jaanits 1978
				9290 ± 120	Hel-2206A	10 290–10 650	ca 8.8–9	8.82–9	Cultural layer	Haila & Raukas 1992
				9285 ± 120	TA-284	10 280–10 640	ca 9.3		Charcoal	Ilves et al. 1974
				9145 ± 115	Ua-13353	10 220–10 490	9.27		Seeds	Poska & Veski 1999
				9095 ± 90	Ua-13352	10 190–10 400	9		Elk bone	Poska & Veski 1999
34	Sindi*	58°22′40″	24°36′40″	9575 ± 115	TA-176	10 750–11 100	ca 10.8	ca 10.1–10.8	Wood	Ilves et al. 1974
				9300 ± 75	TA-175	10 300–10 590	ca 10.2	ca 10.1–10.8	Peat	Ilves et al. 1974

Appendix 1. *Continued*

No.	Site	Coordinates		^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
35	Paikuse*	58°22′48″	24°36′50″	9575 ± 90	TA-2547	10 760–11 090	5.15–5.25	5.13–5.24	Woody peat	Veski 1998; Heinsalu et al. 1999
				9350 ± 75	Ua-11691	10 440–10 680	5.23	5.13–5.24	Wood	Veski 1998; Heinsalu et al. 1999
				9340 ± 130	Ua-12446	10 300–10 710	5.05	5.13–5.24	Seeds	Veski 1998; Heinsalu et al. 1999
36	Sindi-Lodja*	58°22′	24°35′40″	9170 ± 200	Ta-2784	9 970–10 680	4.45?		Peat/Cultural layer?	Veski et al. 2005
37	Sikaselja*	58°20′40″	24°38′40″	Not dated					Peat	Kessel 1962
38	Võidu*	58°8′	24°34′	9100 ± 125	TA-77	10 160–10 490			Peat	Kessel 1968; Kessel & Punning 1969b
39	Lemmeoja*	57°58′0″	24°24′35″	9820 ± 130	Tln-130	10 890–11 470	ca 3	ca 2.6	Woody peat	Punning et al. 1977
				9440 ± 100	Hel-2208A	10 520–11 060	ca 3	ca 2.6	Peat	Haila & Raukas 1992
				9430 ± 100	Hel-2208B	10 510–11 060	ca 3	ca 2.6	Humic fraction from peat	Haila & Raukas 1992
				9240 ± 85	TA-122	10 290–10 510	ca 3	ca 2.6	Peat	Kessel 1962; Kessel & Punning 1969b
				9100 ± 85	TA-123	10 190–10 390	ca 3	ca 2.57	Wood	Kessel 1962; Kessel & Punning 1969b
40	Pelisoo*	58°26′40″	22°23′	9575 ± 180	Ua-13044	10 690–11 180	29.05	28.72–28.8	Pollen concentrate	Veski 1998
				9140 ± 70	Ua-11692	10 230–10 400	28.71	28.72–28.8	Wood	Veski 1998
41	Tõrise	58°27′30″	22°26′30″	9210 ± 60	TA-1455	10 270–10 480	29.8–30		Woody peat/soil?	Raukas et al. 1988; Liiva, pers. comm.
42	Kasesoo	58°24′	22°19′	Not dated					Peat	Männil 1963
43	Pitkasoo*	58°16′22″	22°13′25″	9800 ± 80	Ua-2285	11 140–11 310	21.20		Wood	Königsson et al. 1998
44	Järvesoo*	58°15′20″	22°9′	Not dated					Peat	Männil 1963, 1964
45	Siplase*	57°59′	22°16′	Not dated					Peat	Männil 1963, 1964

Appendix 2. Database of pre-Litorina and Litorina buried organic sediments. Asterisks mark the sites where pollen analysis has been carried out

No.	Site	Coordinates		^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
46	Tõrvala*	59°26′5″	28°8′10″	7370 ± 210	Le-12	8000–8380		ca 4.7–6.5	Peat	Kessel 1963, 1975
47	Leekovo*	59°25′20″	28°5′	7755 ± 90	Tln-1705	8430–8600			Peat	Lepland et al. 1996
48	Uuri (Maarikoja)	59°29′30″	25°34′	7240 ± 90	Tln-201	7980–8160		16.76–17.31	Wood	Kessel & Linkrus 1979
				6820 ± 70	Tln-200	7590–7700		16.76–17.31	*Phragmites–Carex* peat	Kessel & Linkrus 1979
49	Mädajärve	59°32′30″	25°34′	Not dated					Organic matter	Kessel & Linkrus 1979
50	Kroodi	59°28′	24°59′	7730 ± 80	Tln-2668	8430–8580		ca 20	Peat	Orviku 1936; Saarse et al. 2003b
51	Vahiküla*	59°23′	24°27′	Not dated			ca 21		Macroremains in loam	Kessel 1962, 1963
52	Niitvälja*	59°19′5″	24°16′20″	7580 ± 70	Tln-261	8330–8450			Gyttja	Kessel 1962, 1975; Punning et al.1980
53	Keila-Joa*	59°24′	24°18′	7120 ± 270	Mo-223	7680–8180		ca 22–23	Gyttja	Kessel 1962, 1963; Ilves et al. 1974
54	Kuijõe	59°6′	24°	Not dated					Organic matter	Kessel 1962
55	Väike-Lähtru	58°55′	23°53′	Not dated					Organic matter	Kessel 1962
56	Vigala	58°47′	24°15′	7375 ± 70	TA-157	8060–8320		ca 15	Woody peat	Ilves et al. 1974
57	Kirbla*	58°43′25″	23°57′30″	6860 ± 60	TA-248	7620–7750	ca 15.4		Wood	Kessel 1962, 1975
58	Tuudi*	58°38′42″	23°47′5″	7860 ± 70	Tln-33	8550–8850			Clay gyttja	Ilves et al. 1974
59	Järise	58°40′	23°41′	6960 ± 70	TA-198	7700–7910		ca 18	Peat	Kessel & Punning 1969a
60	Kolga*	58°23′7″	23°50′35″	7555 ± 40	Tln-1822	8350–8400		ca 6.7–6.8	Fen peat	Veski 1998; Lepland, pers. comm.
				7505 ± 165	TA-165	8070–8510		ca 6.7–6.9	*Phragmites* peat	Kessel & Punning 1969a
				7390 ± 40	Tln-1825	8170–8300		ca 6.7–6.10	Wood	Veski 1998; Lepland, pers. comm.
		58°23′15″	23°50′	6900 ± 65	Ua-12443	7670–7820		ca 7.9–8.4	Seeds	Veski 1998

Appendix 2. *Continued*

No.	Site	Coordinates		^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
61	Seliste*	58°17′	24°5′20″	5950 ± 60	TA-183	6680–6880		ca 8.5	Peat	Kessel & Punning 1969a
62	Jõõpre*	58°29′	24°21′	Not dated					Gyttja and peat	Paas 1960; Kessel 1962
63	Oara*	58°28′24″	24°19′	7275 ± 80	Tln-179	8020–8170			Gyttja	Kessel 1975; Punning et al. 1977
				6100 ± 50	TA-193	6890–7150			Gyttja	Kessel & Punning 1969a
				5520 ± 100	Tln-178	6210–6410			*Phragmites* peat	Punning et al. 1977
64	Malda	58°26′47″	24°18′32″	7560 ± 65	Tln-2220	8320–8430	8.23–8.28	8.12–8.28	Woody fen peat	Veski 1998
65	Audru	58°24′	24°21′30″	Not dated					Peat	Kriiska, pers. comm.
66	Sindi*	58°22′40″	24°36′40″	7215 ± 90	Tln-133	7960–8160	ca 7		Peat	Kessel 1975; Punning et al. 1977
		58°23′5″	24°37′30″	6710 ± 110	TA-55	7490–7660			Wood	Kessel & Punning 1969a
		58°22′40″	24°36′40″	4975 ± 100	Tln-134	5600–5880			Peat	Punning et al. 1977
67	Paikuse*	58°22′50″	24°37′	7120 ± 120	Ua-12447	7790–8040	6.85	6.68–6.85	Seeds	Veski 1998; Heinsalu et al. 1999
				7030 ± 120	Ta-2548	7740–7960	6.73–6.83	6.68–6.82	Organic matter	Veski 1998; Heinsalu et al. 1999
68	Sindi-Lodja*	58°22′	24°35′40″	8250 ± 150	Ta-2787	9030–9410	3.2–3.25		Peat	Veski et al. 2005
				8210 ± 80	Ta-2786	9030–9280	3.2–3.3		Wood	Veski et al. 2005
				8190 ± 80	Ta-2789	9030–9250	3.30		Wood	Veski et al. 2005
				8070 ± 70	Ua-17013	8780–9120	1.80		Charcoal	Veski et al. 2005
				8035 ± 80	Ta-2788	8770–9050	4.65		Wood	Veski et al. 2005
				7980 ± 100	Ta-2736	8660–9000	4.65		Wood	Veski et al. 2005
				7870 ± 80	Ta-2774	8420–8720	3.30		Wood	Veski et al. 2005
				7780 ± 120	Ta-2737	8550–8950	3.30		Wood	Veski et al. 2005
				7630 ± 120	Ta-2783	8340–8580	3.33		Peat	Veski et al. 2005
				7300 ± 150	Ta-2785	7970–8300	4.70		Wood	Veski et al. 2005
69	Vaskrääma	58°18′	24°40′15″	7580 ± 170	TA-140	8200–8540		ca 6.5–7.5	Peat	Kessel 1962; Kessel & Punning 1969a

Appendix 2. *Continued*

No.	Site	Coordinates		^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
				6975 ± 110	TA-141	7700–7930		ca 6.5–7.5	Gyttja	Kessel 1962; Kessel & Punning 1969a
				6870 ± 110	TA-139	7610–7830		ca 6.5–7.5	Peat	Kessel 1962; Kessel & Punning 1969a
70	Rannametsa*	58°7′39″	24°30′34″	8080 ± 110	Hel-2207A	8770–9200		ca 2–2.5	Peat	Hyvärinen et al. 1992
				8060 ± 110	Hel-2207B	8730–9130		ca 2–2.5	Wood	Hyvärinen et al. 1992
				7860 ± 190	TA-54	8480–8980		ca 2–2.5	Wood	Kessel 1962; Kessel & Punning 1969a
				7725 ± 65	Tln-1994	8430–8550		ca 2–2.5	Wood	Raukas et al. 1999
				7610 ± 100	Hel-2207	8340–8540		ca 2–2.5	Humic fraction from peat	Hyvärinen et al. 1992
71	Jõempa*	58°21′	22°17′	Not dated					Peat	Männil 1964; Ilves et al. 1974
72	Kärla*	58°20′30″	22°17′	8400 ± 190	Mo-222	9100–9550	ca 16.27–16.4		Peaty gyttja	Kessel 1962; Kessel & Punning 1969a
				7820 ± 80	TA-182	8460–8750	ca 16.27–16.3	ca 16.25–16.6	Peat	Kessel 1962, 1975; Kessel & Punning 1969a
				7085 ± 80	TA-181	7840–8000	ca 16.57–16.6	ca 16.25–16.7	Peat	Kessel 1962, 1975; Kessel & Punning 1969a
73	Kihelkonna*	58°21′	22°2′	Not dated					Fen peat	Männil 1964
74	Vesiku*	58°18′50″	22°3′5″	7960 ± 80	TA-179	8720–8980	14.8–14.83	14.77–15.16	Peat	Ilves et al. 1969
				6350 ± 80	TA-178	7180–7410	15.13–15.16	14.77–15.16	Gyttja	Kessel 1962; Kessel & Punning 1969a
75	Reo	58°18′20″	22°39′0″	7350 ± 70	Tln-254	8040–8290			Woody peat	Punning et al. 1980
				7165 ± 70	Tln-253	7880–8040			Gyttja	Punning et al. 1980
76	Lumiste*	58°39′45″	23°10′45″	Not dated				ca 15–16	Clay gyttja	Kessel & Pork 1974

Appendix 3. List of post-Litorina buried organic sites. Asterisks mark the sites where pollen analysis has been carried out

No.	Site	Coordinates		^{14}C age, yr BP	Lab. No.	Calibrated age, yr BP	Dated sample altitude, m a.s.l.	Organic layer altitude, m a.s.l.	Dated material	Reference
77	Maardu	59°27′5″	24°59′	630 ± 45	Tln-2732	560–660			Peat	Veski, pers. comm.
78	Viadukti tee	59°25′2″	24°45′35″	2795 ± 50	Tln-2568	2810–2960	2.2–2.25		Peat	Saarse, pers. comm.
				375 ± 45	Tln-2567	330–500	1.5–1.53		Peat	Saarse, pers. comm.
79	Ülemiste	59°25′	24°47′	Not dated					Peat	Künnapuu 1968
80	Järvevana viadukt	59°24′10″	24°43′45″	Not dated					Peat	Künnapuu 1968
81	Mustamäe-Lepistiku	59°24′5″	24°41′50″	3780 ± 50	Tln-2504	4090–4240			Peat	Künnapuu 1968; Saarse et al. 2001
				2790 ± 60	Tln-2719	2800–2960			Peat	Künnapuu 1968; Saarse et al. 2001
				180 ± 60	Tln-2441	5–300			Peat	Künnapuu 1968; Saarse et al. 2001
82	Tusari	59°11′10″	23°39′	Not dated						Kessel & Raukas 1967
83	Kaali	58°22′	22°40′	3390 ± 35	Tln-1359	3590–3690			Peat	Saarse et al. 1991
84	Lehtma	59°4′20″	22°41′	Not dated					Peat	Kessel 1962
85	Ikla*	57°53′	24°21′30″	Not dated				ca 1–2	Peat	Kessel 1963