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Ancylus Lake and Litorina Sea transition on the Island of Saaremaa, Estonia: a pilot study

Leili Saarse, Jüri Vassiljev, Alar Rosentau

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Abstract Biostratigraphical, sedimentological and magnetic susceptibility analyses and radiocarbon datings of six Holocene lagoonal profiles of the Island of Saaremaa, Estonia were performed. The examined lagoons were formed during the Ancylus Lake regression and the Litorina Sea transgression. Spatial displacement of the Ancylus Lake and Litorina Sea shores was reconstructed using a digital terrain model with the grid size 50 m x 50 m and the development of the island in terms of the changing sea level and land uplift was described. Due to differences in the isostatic uplift rate, the Ancylus Lake beach formations are located between 35 and 25 m and those of the Litorina Sea between 20.5 and 15.5 m above the present sea level. Radiocarbon dates from buried organic sediments suggest that the Litorina Sea transgression started about 8300–8200 cal yr BP and lasted up to 7300 cal yr BP.

Keywords*: Ancylus Lake, Litorina Sea, Saaremaa Island, ^{14}C dates, Estonia.*

Leili Saarse [saarse@gi.ee], Jüri Vassiljev [vassilje@gi.ee], Institute of Geology at Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia; Alar Rosentau [alar.rosentau@ut.ee], Institute of Ecology and Earth Sciences, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia. *Manuscript submitted 15 January 2009; accepted 26 May 2009.*

INTRODUCTION

Changes in the ecosystem, palaeosalinity and water levels of the Baltic Sea were greatly influenced by the existence or absence of the connection between the sea and ocean. Two freshwater (Baltic Ice Lake and Ancylus Lake) and two brackish water stages (Yoldia Sea and Litorina Sea) have been recognized in the Baltic Sea history (Munthe 1910, 1940) and widely discussed in literature (Kessel, Raukas 1979; Björck 1995, 2008; Andrén *et al.* 2000; Miettinen 2002; Berglund *et al.* 2005; Yu 2003; Yu *et al.* 2007). The shore displacement of the Baltic Sea and prehistoric habitation on the coastal areas were caused by postglacial isostatic land uplift and eustatic sea level rise. Data from south–eastern Sweden show that local sea level passed five transgressive episodes between 8500 and 5000 cal yr BP (Berglund *et al.* 2005). A rapid transgression related to the increase in ocean mass due to the final melting of the Laurentide Ice Sheet, occurred around 7600 cal yr BP (Lambeck, Chappell 2001; Yu *et al.* 2007).

Saline water ingression into the Baltic Sea basin about 9800 cal yr BP (Berglund 1964, 1971; Eronen 1974; Eronen *et al.* 1990) marks the start of the Early Litorina Sea (Berglund *et al*. 2005) or the Initial Litorina Sea stage (Andrén *et al.* 2000), in the coastal zone known as the Mastogloia Sea (Hyvärinen *et al*. 1988), yet the significant rise in salinity between 8500 and 8000 cal yr BP refers to true onset of the Litorina Sea (Berglund *et al.* 2005; Björck *et al.* 2008). According to Swedish and Danish studies, the Litorina Sea transgression consisted of several waves (Berglund *et al.* 2005; Christensen 1995; Christensen, Nielsen 2008; Wohlfarth *et al.* 2008), while in Finland only one uniform transgression has been described (Eronen 1974; Eronen *et al.* 2001; Miettinen 2002; Miettinen *et al.* 2007). Such discrepancy is not thoroughly understandable, but could result from different rates of isostasy and eustasy in the mentioned regions (Yu 2003). A short–term regression phase about 8100 cal yr BP, recorded in coastal sediments of Blekinge, Sweden, has been correlated with the cold event at 8200 cal yr BP and described as regional climatic catastrophe for the Baltic Sea region (Berglund *et al.* 2005).

Two pronounced Litorina Sea transgression events have been described in Estonia (Kents 1939; Kessel 1960; Kessel, Raukas 1979; Hyvärinen *et al.* 1988). However, later only one main Litorina Sea transgression was recognized (Raukas *et al.* 1995a; Veski *et al.* 2005; Saarse *et al.* 2009).

The Island of Saaremaa (Fig. 1) is a good area to study the Ancylus–Litorina transition and their spatial distribution, because there are numerous ancient coastal formations and several sites where organic beds are coated by the Litorina Sea sand (Saarse *et al.* 2006). Owing to the ongoing land uplift of about 2 mm yr^{-1} (Torim 2004), the coastal formations of the Ancylus Lake are now positioned between 35 and 25 m a.s.l. and these of the Litorina Sea between 20.5 and 15.5 m a.s.l. As land uplift on Saaremaa surpasses the global sea level rise (1.7 ± 0.3 mm yr^{-1} over the last 100 years; Church, White 2006), the sea level rise is not yet a topical issue on the island. Global warming, however, can drive a new sea level rise if the ice-sheet melting accelerates in the Arctic and Antarctic.

The current paper summarises the main results of the shore displacement studies carried out on the Island of Saaremaa. The focus is on the Ancylus Lake–Litorina Sea transition and distribution of the Litorina Sea during the transgression phase.

MATERIAL AND METHODS

Fieldwork for the present study was carried out in summer 2008. A 0.5 m and 1.0 m long Russian peat sampler was used to reach undisturbed cores. The depth of the substratum (till, silt or sand) was determined and description of obtained cores is presented in Table 1. Pollen diagrams from all studied sites have been compiled earlier (Männil 1964; Kessel, Raukas 1967; Saarse 1994; Poska, Saarse 2002). In the frame of the current study magnetic susceptibility was measured, diatoms were checked, loss–on–ignition (LOI) was determined and 11 radiocarbon datings were obtained.

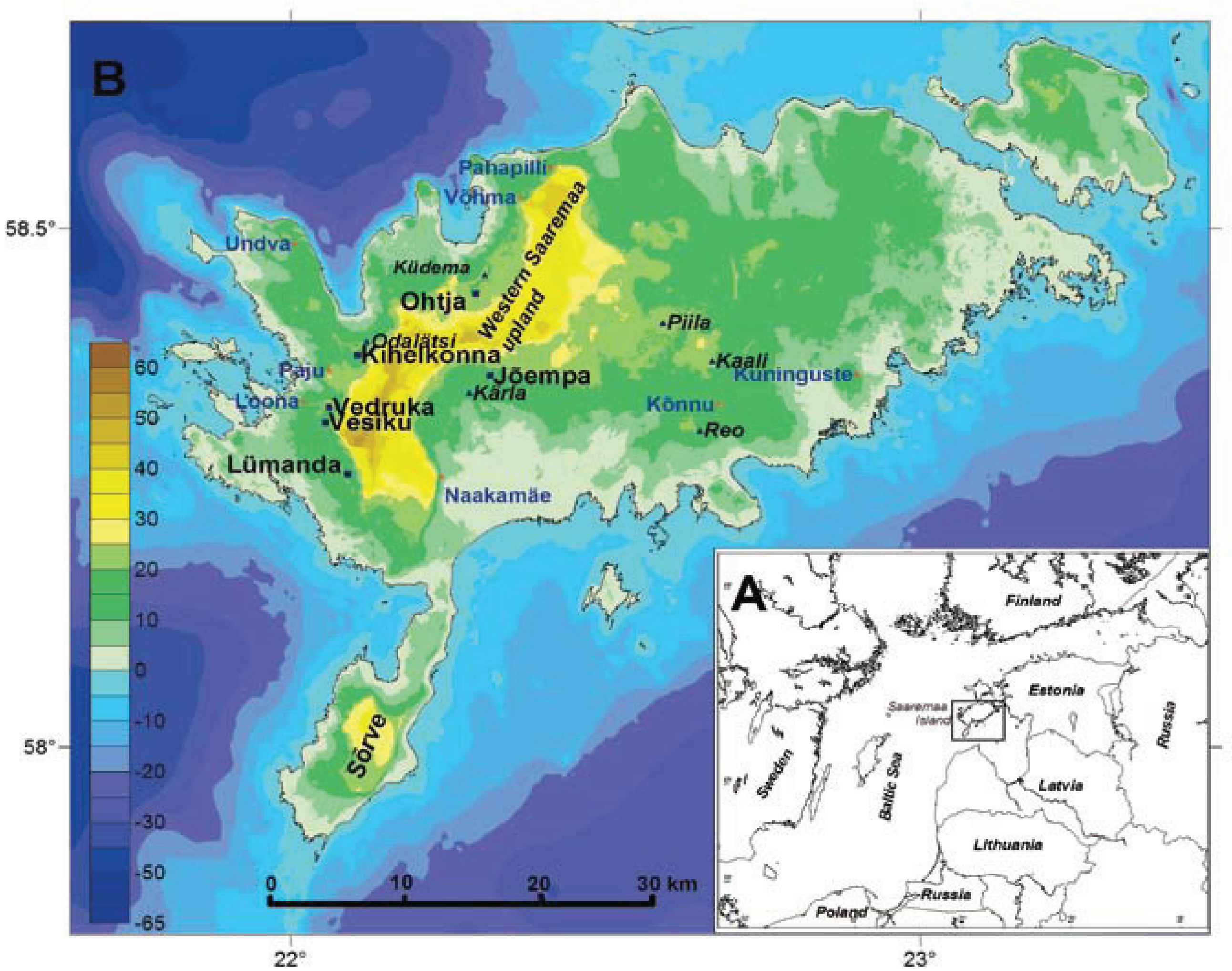

Fig. 1. Overview map of the study area (A) and modern digital terrain model for Saaremaa with indication of the sites mentioned in text (B). Compiled by J. Vassiljev.

Conventional radiocarbon dating was performed in the Institute of Geology at Tallinn University of Technology and the AMS ^{14}C dating of the bulk gyttja sample was carried out in Poznan Radiocarbon Laboratory. Additionally, 15 earlier published radiocarbon datings from buried organic beds and archaeological sites were considered to specify the Ancylus–Litorina transition and development of the Litorina Sea (Table 2). The radiocarbon dates were converted to calibrated age (cal yr BP) at one sigma range using the IntCal04 calibration curve (Reimer *et al.* 2004) and the Calib Rev 5.0.1. program (Stuiver *et al.* 2005). All ages mentioned in text refer to calibrated years BP.

Loss–on–ignition (LOI) at 525 and 900 °C was continuously measured on 1-cm thick slices of core. The organic matter (OM) content was expressed in percentages of dry matter. The carbonate ($CaCO_3$) content was calculated after burning the LOI residue for two hours at 900 °C. The amount of the residue containing terrigeneous matter and biogenic silica was described as mineral matter and calculated against the sum of organic and carbonate compounds. The sediment composition diagrams were composed with the TGView software (Grimm 2004).

Magnetic susceptibility was measured with the high-resolution surface-scanning sensor MS2E produced by Bartington Instruments Ltd. The sediment surface was cleaned with a microscope glass slide, covered with a thin plastic film, and the susceptibility was measured on the sediment surface at 1-cm resolution.

Table 1. Sediment lithostratigraphy of the studied sequences.

Site	Depth, cm	Sediment description
Kihelkonna	0–40 40–84 84–100 100–101 101–115 115–120+	Peaty soil, dark grey Silty lacustrine lime with mollusc shells and roots, light brown Calcareous silty gyttja, dark brown Sand Fen peat, black Medium-grained sand with plant and tree roots, beige
Lümanda	0–110 110–160 160–178 178+	Fen peat with woody pieces and *Phragmites* remains, black Silty lacustrine lime with mollusc shells and diffuse organic matter Fen peat, well decomposed, black Till with carbonate fraction
Ohtja	0–100 100–123 123–150	Sandy gyttja, black Coarse detritus gyttja with sand, black Fine-grained sand with rare plant remains, beige
Jõempa	0–30 30–80 80–125 125–200+	Peaty soil, black Lacustrine lime with mollusc shells, beige Fine-grained sand, grey Clay, bluish-grey
Vedruka	0–210 210–235 235–350 350–419 419–429 429–450+	*Sphagnum* peat Transitional peat Fen peat, well decomposed, black Coarse detritus gyttja, black Silty gyttja, dark grey Coarse-grained sand, grey
Vesiku	ca 300 300–352 352–350+	Aeolian sand, fine-grained Fen peat, from 347 cm well decomposed, black Sand

The palaeogeographic maps were compiled using interpolated surfaces of water levels and a digital terrain model (DTM). The DTM with a grid size of 50 m x 50 m was generated using topographic maps on a scale of 1:10 000 (Kikas 2005).

GEOLOGICAL SETTING AND STUDIED SITES

Saaremaa, with an area of 2668 km^2, is the largest island in Estonia. The main relief forms of the island are inherited from the last glaciation and have been reworked by waters of the Baltic Sea (see Fig. 1). The Quaternary cover is thin on the abraded till plains, usually less than 1 m, but exceeding more than 10 m on the West Saaremaa Upland and 150 m in an ancient valley on the Sõrve Peninsula. After deglaciation Saaremaa was submerged by waters of the Baltic Ice Lake (BIL), Yoldia Sea, Ancylus Lake and Litorina Sea. The highest parts of Saaremaa (54.5 m a.s.l.) emerged during the drainage of the Baltic Ice Lake about 11 600 years ago (Saarse *et al.* 2007).

To investigate the Ancylus Lake–Litorina Sea transition sediments of Kihelkonna, Lümanda, Ohtja, Jõempa, Vedruka and Vesiku ancient lagoons were examined (Fig. 1).

Kihelkonna lagoon (58°22´36´´N, 22°06´00´´E; threshold 19.5 m a.s.l.) behind the Odalätsi dune field isolated during the Ancylus Lake regression and paludified, as confirmed by 0.1–0.4 m thick buried fen peat of this age (Tables 1, 2). Due to water level rise during the Litorina Sea transgression, the Kihelkonna basin was filled in with water and a coastal lake formed, where a thin sand layer, calcareous silty gyttja and silty lacustrine lime deposited (Fig. 2A) up to the Subatlantic chronozone (Männil 1963). After that the bog came into existence.

Lümanda lagoon (58°15´48´´N, 22°05´29´´E; threshold 19.0 m a.s.l.) holds a bog where the upper part of peat has been removed in the course of peat extraction. The shallow part of the Lümanda basin was also paludified during the Ancylus Lake regression, which is confirmed by the discovery of basal buried peat through the present study. During the Litorina Sea transgression sand with plant remains and woody pieces deposited in the central part of the basin, which contained brackish-water diatoms such as *Campylodiscus clypeus* (Kessel, Raukas 1967, p. 105). An isolated coastal lake was formed in the western part of the basin, where calcareous silty gyttja was deposited (Fig. 2B).

Ohtja lagoon (58°26´20´´N, 22°17´30´´E; threshold 19.5 m a.s.l.) behind the Küdema spit and dune ridges is filled in with sand, detritus and sandy gyttja with a thickness of 1–2 m (Saarse 1994; Fig. 2C). Litorina Sea mollusc shells from the Küdema spit have been dated to 7000 BP using the EPR method (Kessel 1988).

Jõempa lagoon (58°20´51´´N, 22°17´19´´E) is located behind the Kärla beach formations at 19 m a.s.l. (Ramsay 1929). Basal clayey silts accumulated during Boreal time and are overlain by fine-grained sand corresponding to the Litorina Sea transgression. This is also confirmed by a sharp *Pinus* pollen peak (Männil 1963), typical of a transgression event (Saarse *et al.* 2007). Buried peat and gyttja under the Litorina beach ridge at Kärla have respectively been dated to 7820±80 and 7085±80 BP (Table 2; Kessel, Punning 1969).

Vedruka (58°19´47´´N, 22°03´56´´E; threshold 18.5 m, Litorina Sea coastline at 19.5 m a.s.l.) is a raised bog on the Litorina Sea terrace. Similarly to the Lümanda basin, the Vedruka basin was opened to sand deposition during the Litorina Sea transgression. It isolated from the sea about 7700 cal yr BP (Poska, Saarse 2002).

The Vesiku (58°18´41´´N, 22° 03´05´´E; threshold at 17.5 m a.s.l.) buried organic bed site, 2 km south of Vedruka, was discovered and levelled already in 1939 by Kents. The upper limit of buried peat at 15.16 m a.s.l. (Kents 1939) was later dated to 7960±80 (TA-179) (8820±130 cal yr BP) and gyttja to 6350±80 (TA-178) (7290±90 cal yr BP; Kessel, Punning 1969). A thin sand layer occurs between peat and gyttja. According to Kents (1939), peat was formed in an isolated water body, which was capped by sand during the Litorina Sea transgression. The buried peat site on the Vesiku Brook bank under ca 3 m thick aeolian sands studied by us turned out to be young and not associated with the development of the Litorina Sea (Table 2).

In the reconstruction of the shoreline age and position the age of the Võhma and Pahapilli archaeological campsites, Reo buried organic beds and the isolation contact of Piila bog have also been considered (Table 2). The well-developed Litorina Sea beach ridge near the Võhma campsites marks the maximum shoreline of the Litorina Sea, which has levelled to 20.4 m a.s.l. (Kents 1939). At Reo (58 °19´N, 22°40´E) the basal woody peat bed (7350±70, Tln-254; 8175±100 cal yr BP) was covered by gyttja (7165±70, Tln-253; 7960±85 cal yr BP) and ca 3 m thick Litorina Sea sand (Punning *et al.* 1980). Recent examinations of these sediments showed older ages, respectively 7730±120 (Tln-2554) and 7370±70 (Tln-2558; Reintam *et al.* 2008). Piila bog (58°24´30´´N, 22°36´E) on the Ancylus Lake terrace has been studied several times (Raukas *et al.* 1995b; Rasmussen *et al.* 2000; Veski *et al.* 2007). It isolated from Ancylus Lake just before the Litorina Sea transgression, as confirmed by pollen stratigraphy and radiocarbon dates (7875±75, Tln-1875; 8830±125 cal yr BP; 7870±135, Tln-1881; 8745±185 cal yr BP; Raukas *et al.* 1995b).

Table 2. Dated sequences, which give nformation of sea level fluctuations.

Sites and coordinates	Depth below sediment surface, cm	Age (^{14}C yr BP)	Lab. No	Calibrated age, BP	Dated material	Reference
Kihelkonna	100–110	7490±60	Tln-3078	8300±70 8210-8380	buried peat	Current study
Lümanda	90–95	5130±65	Tln-3083	5860±85 5750-5940	peat	Current study
Lümanda	95–100	5255±55	Tln-3084	6055±90 5930-6170	peat	Current study
Lümanda	160–165	7365±75	Tln-3085	8185±105 8050-8310	buried peat	Current study
Lümanda	165-170	7650±70	Tln-3086	8465±60 8390-8540	buried peat	Current study
Lümanda	170-177	7760±75	Tln-3087	8540±75 8450-8600	buried peat	Current study
Ohtja	118–123	6890±55	Tln-3082	7735±55 7670-7790	gyttja	Current study
Ohtja	128	7030±50	Poz-27421	7880±55 7830-7935	organic band in sand	Current study
Vesiku	500–503	6350±80	TA-178	7290±90 7170-7410	buried gyttja	Kessel & Punning 1969
Vesiku	533–536	7960±80	TA-179	8820±130 8720-8980	buried gyttja	Kessel & Punning 1969
Vesiku	300–305	560±60	Tln-3079	585±45 540-640	buried peat	Current study
Vesiku	324–329	1190±50	Tln-3080	1120±65 960-1165	buried peat	Current study
Vesiku	347–352	3275±55	Tln-3081	3510±60 3700-3855	buried peat	Current study
Kärla	65–68	7085±80	TA-181	7920±80 7840-8000	buried gyttja	Ilves *et al.* 1974
Kärla	95–98	7820±80	TA-182	8650±125 8460-8750	buried peat	Ilves *et al.* 1974
Reo	200–220	7165±70	Tln-253	8005±70 7880-8040	buried gyttja	Punning *et al.* 1980
Reo	220–230	7350±70	Tln-254	8175±100 8040-8290	buried peat	Punning *et al.* 1980
Reo	92–105	7370±70	Tln-2558	8180±130 8055-8315	buried peat	Reintam *et al.* 2008
Reo	105–117	7730±120	Tln-2554	8515±110 8395-8635	buried peat	Reintam *et al.* 2008
Vedruka	375–380	6570±70	Ta-2580	7490±55 7430-7560	gyttja	Poska & Saarse 2002
Vedruka	390–400	6860±80	Ta-2581	7715±80 7620-7790	gyttja	Poska & Saarse 2002
Piila	335–340	7875±75	Tln-1875	8830±125 8580-8960	peat	Raukas *et al.* 1995
Piila	335–340	7870±135	Tln-1881	8745±185 8550-8980	peat	Raukas *et al.* 1995
Võhma		6750±50	Ta-2646	7620±35 7580-7660	charcoal	Kriiska 1998
Võhma		6950±100	Ta-2650	7800±100 7690-7920	charcoal	Kriiska 1998
Pahapilli		6370±180	Le-5452	7240±190 7030-7460	charcoal	Kriiska 2007

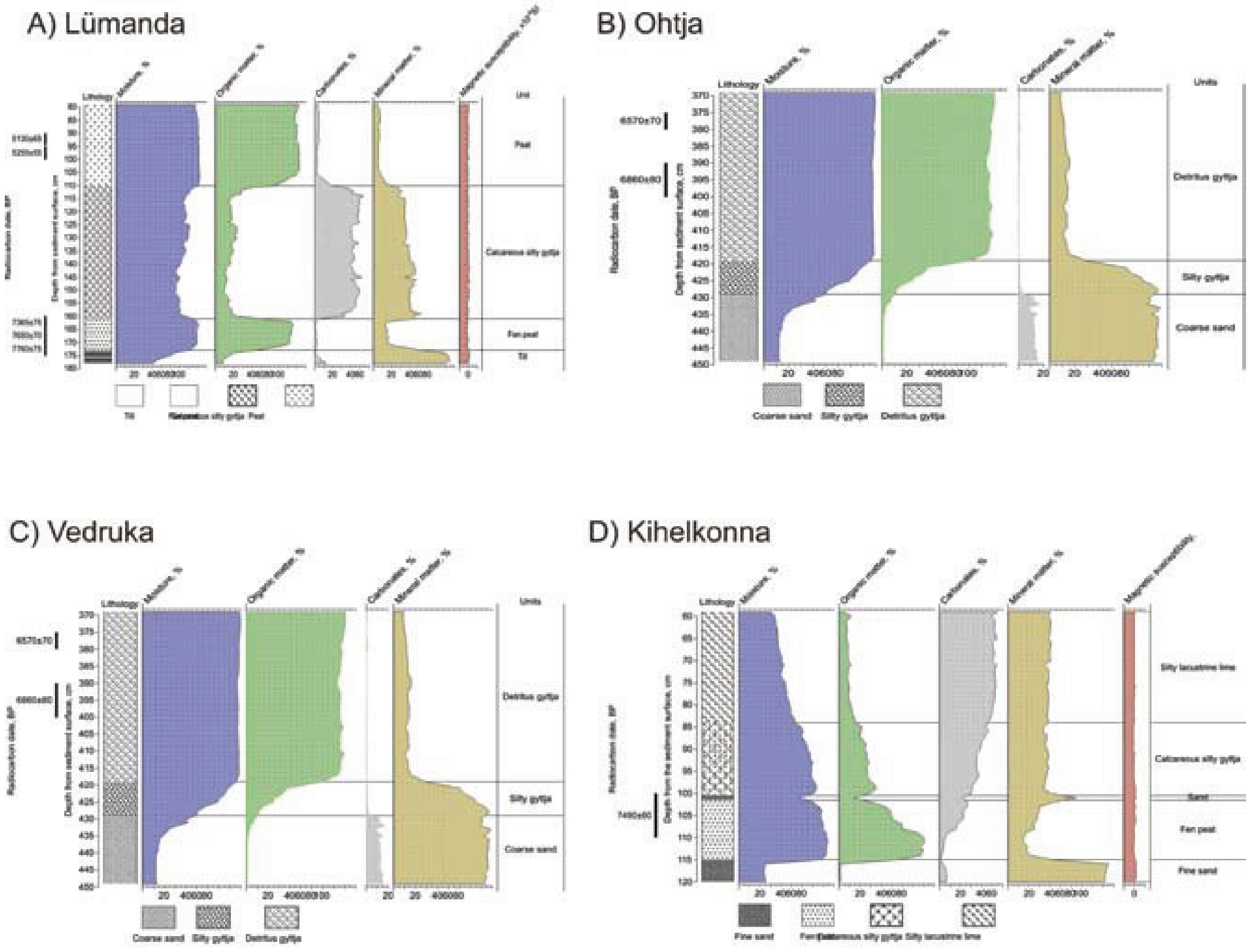

Fig. 2. Sediment composition of Kihelkonna (A), Lümanda (B), Ohtja (C) and Vedruka (D) sites.

ARCHAEOLOGICAL BACKGROUND

As evidenced by the richness of Stone Age artefacts the geological history of Saaremaa created favourable conditions for the establishment of settlements along the seacoast. The number and importance of archaeological monuments make Saaremaa the most outstanding region for the prehistory of Estonia (Ligi 1992) where at present more than 550 objects are under protection. The Late Mesolithic campsites of Võhma and Pahapilli are located in the northern part of the island, on the Litorina Sea terrace at about 20 m a.s.l. (Kriiska 1998; Jussila, Kriiska 2004). Their Mesolithic age is proved by artefacts and radiocarbon dates (Table 2). The Paju campsite near Kihelkonna obviously originates from the same period (Tamla. Jaanits 1977). Some artefacts characteristic of the Mesolithic period have been found from the Kõnnu temporary campsite (Kriiska 2007). The most significant Neolithic settlement sites are Kõnnu, Naakamäe, Kuninguste, Undva and Loona, whose location followed the retreated shoreline.

RESULTS

Sediment lithostratigraphy

On the basis of sediment composition several lithostratigraphical units were distinguished (Table 1, Fig. 2). The sediment composition of the Kihelkonna sequence is rather complex (Fig. 2A). In basal peat, which rests on fine-grained sand, organic matter (OM) content decreased upwards steadily and that of carbonates and mineral matter increased (Fig. 2A). A thin sandy layer on top of buried peat was obviously formed during the sea level rise when stormy waves surpassed the basin threshold. The Kihelkonna sequence ends with silty lacustrine lime and a peaty soil layer (Table 1). Moisture content is in good correlation with OM content. The magnetic susceptibility curve is a nearly straight line without any peaks (Fig. 2A).

The basal part of the Lümanda core opened up sediments that have deposited in different environments and have been divided into four lithostratigraphical units. The basal till is slightly calcareous (up to 13%), and is overlain by well decomposed buried peat containing 80–89% OM and ca 15% mineral matter. Calcareous silty gyttja has an abrupt boundary with the basal and topmost peat (Fig. 2B). The contents of carbonates and mineral compounds were almost equal in this unit; OM fluctuated between 10 and 20% (Fig. 2B). The composition of the topmost peat is similar to that of the basal peat unit.

The Ohtja sequence starts with fine-grained sand, overlain by coarse detritus gyttja and sandy gyttja (Table 1). The OM content of detritus and sandy gyttja reached 80% (Fig. 2C), but carbonates were practically absent.

Basal coarse-grained sand in the Vedruka sequence contained less of 1% OM but was rather rich in carbonates (Fig. 2D). Silty gyttja between coarse-grained sand and detritus gyttja is a transitional unit where OM content increased gradually from 10 to 80%. The topmost detritus gyttja contained about 10–15% mineral matter. Carbonate content was about 12–15% in the basal sand (Fig. 2D) and decreased to zero in detritus gyttja.

Vesiku buried peat, 50 cm thick, was enriched with OM, reaching up to 90%. Carbonate content fluctuated between 2 and 7% and mineral matter content between 7 and 13%. This peat unit is underlain by fine-grained sand and overlain by ca 3 m thick aeolian sand.

Radiocarbon dates

The sediment chronology of the studied sites is supported by 17 radiocarbon dates (Table 2). Additionally nine ^{14}C dates were used to specify the shore displacement of the Litorina Sea. The limit between peat and gyttja or peat and lacustrine lime was interpreted as the contact between regressive and transgressive sediments. Calibrated radiocarbon ages of buried peat, corresponding to the sediment of the Ancylus Lake regressive phase, are scattered between 8600 and 8200 cal yr BP, and these of gyttja between 8100 and 7300 cal yr BP (Table 2). Unfortunately, the newly discovered buried peat layer in the Vesiku outcrop proved to be too young (600–3500 cal yr BP) and not associated with the Litorina Sea development (Table 2).

Biostratigraphical records

As pollen diagrams from Kihelkonna, Lümanda, Jõempa, Ohtja, Vedruka, and Vesiku deposits have been published earlier we included into the present study only selected pollen diagram from the Vedruka site (Fig. 3; Poska, Saarse 2002). Pollen diagrams of all sequences are quite similar showing the prevalence of *Pinus* and *Betula*, high *Alnus* and *Corylus*, and few and fragmentary *Picea* pollen in sediments corresponding to the Ancylus Lake and Litorina Sea (Männil 1963, 1964; Kessel, Raukas 1967; Kessel 1968; Saarse 1994; Poska, Saarse 2002). Only the Ohtja diagram exhibited well developed *Picea* (Saarse 1994). A sharp peak of *Pinus* in the Vedruka, Kihelkonna, Lümanda and Ohtja profiles is considered refer to the proximity of the shoreline (Saarse *et al.* 2007). In the Vedruka sequence, just before the *Pinus* peak, the originally marine plankton *Hystrix* (Hystrichospheroid cysts) was identified (Fig. 3) which is regarded as indicative of salinity (Berglund 1971; Königsson *et al.* 1998; Veski 1998).

The previously studied Lümanda sequence contained fresh- and brackish-water diatoms (*Cocconeis disculus*, *Epithemia muelleri Fricke*, *Campylodiscus clypeus, Epithemia turgida, Navicula radiosa, N. ha-*

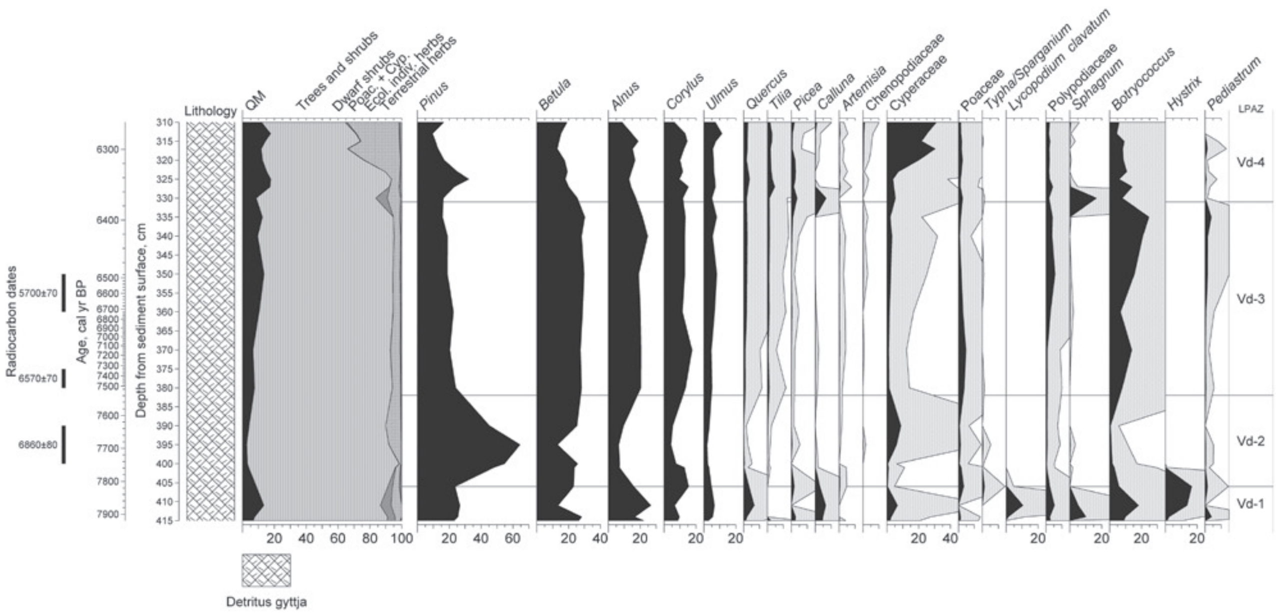

Fig. 3. Simplified pollen diagram from Vedruka. Analysed by A. Poska.

lophila), which give evidence of the brackish-water environment and connection with the sea during the Litorina Sea transgression (Kessel, Raukas 1967). In the currently studied sequence brackish-water diatoms have not been found (A. Heinsalu, pers. comm.).

Mollusc fauna of the Saaremaa palaeolakes is rather well studied (Männil 1963). Calcareous sediments of lacustrine origin are represented by shells of *Radix peregra*, *Bithynia tentaculata*, *Pisidium nitidum* and a few specimens of *Hippeutis complanatus* which show freshwater conditions (Männil 1963). However, malacofauna from the Litorina Sea beach ridge 7.5 km east of Kärla contains the following mollusc assemblage: *Cardium edule* (46%), *Macoma baltica* (20%), *Mytilus edulis* (4%), *Theodoxus fluviatilis* (3%), Hydrobidae (21%) and *Limnaea peregra* (0.5%) (Kessel, Raukas 1967, p. 110), among which *Hydrobia ulvae* and *Mytilus edulis* are brackish- water taxa (Männil 1963).

Palaeogeographical maps

New palaeogeographical maps of the Ancylus Lake and Litorina Sea shore displacement exhibit an indented shoreline with several lagoons and capes, especially during the Litorina Sea stage (Figs 4, 5). The Western Saaremaa Upland formed a curved island in Ancylus Lake with the shoreline between 35 and 25 m a.s.l. The highest parts of the Sõrve Peninsula had also emerged (Fig. 4). The Litorina Sea beach formations near the northeastern corner of the Western Saaremaa Upland are running quite close to the Ancylus Lake coastline. East of the Võhma village the Litorina Sea formed a little bay with an islet at its mouth. The Võhma and Pahapilli Mesolithic campsites dated to 7200–7800 cal yr BP (Table 2) were located on the western and eastern coasts of this bay. At the Võhma village the Litorina Sea coastline turned south, which is marked by dunes and a shelving coast up to Küdema. Near Küdema, the spit and dunes formed one of the most impressive bays of the Litorina Sea, lined with Ohtja lagoon to the south. Northeast of Kihelkonna the ancient coast is once again well marked by a dune field, elongated cape and lagoon (Fig. 5). At Kärla beach ridges and dunes formed two bends with Jõempa lagoon behind them. Several small islets such as Reo and Kõnnu emerged south and east of the main coast. On the Sõrve Peninsula the Litorina Sea formations are located around the bedrock elevation, forming several well-developed escarpments (Orviku 1935).

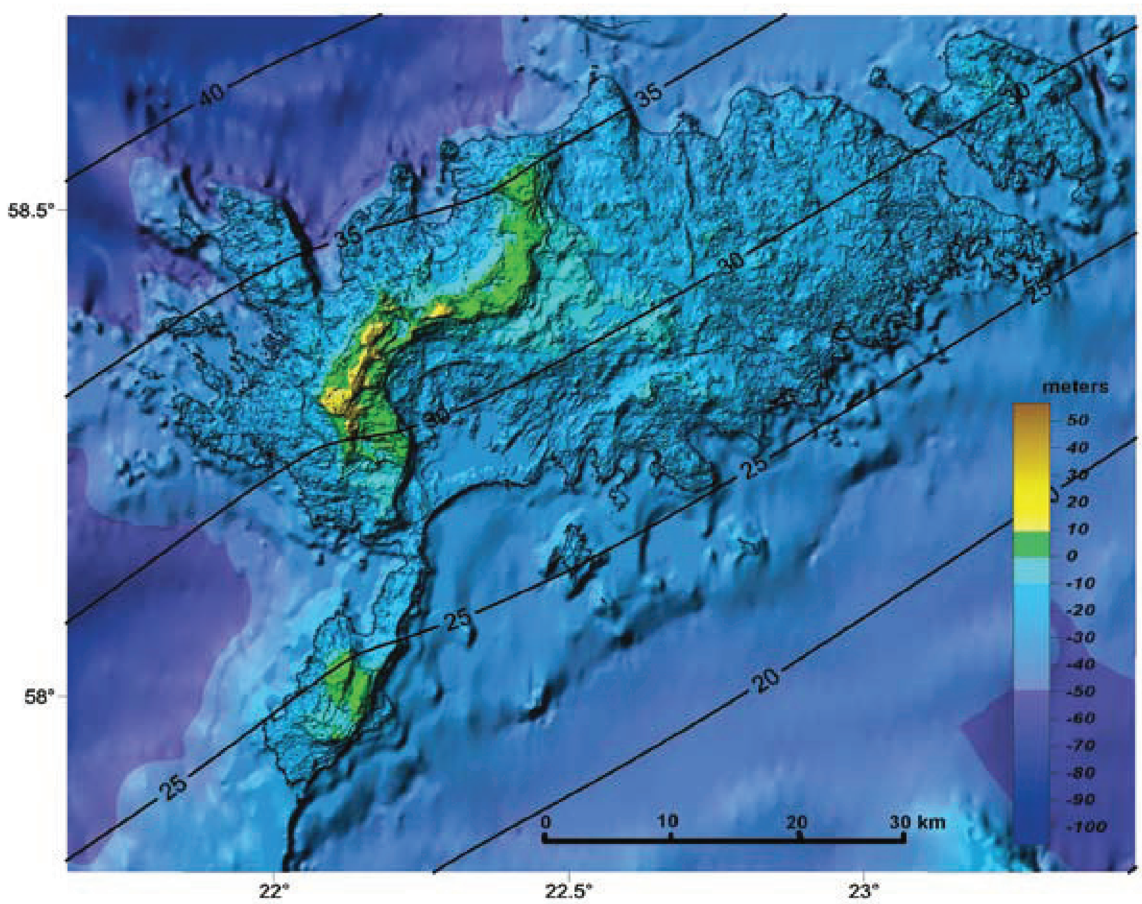

Fig. 4. Palaeogeographic reconstruction of the water level surface isobases and shoreline of the Ancylus Lake in Saaremaa Island. Compiled by J. Vassiljev.

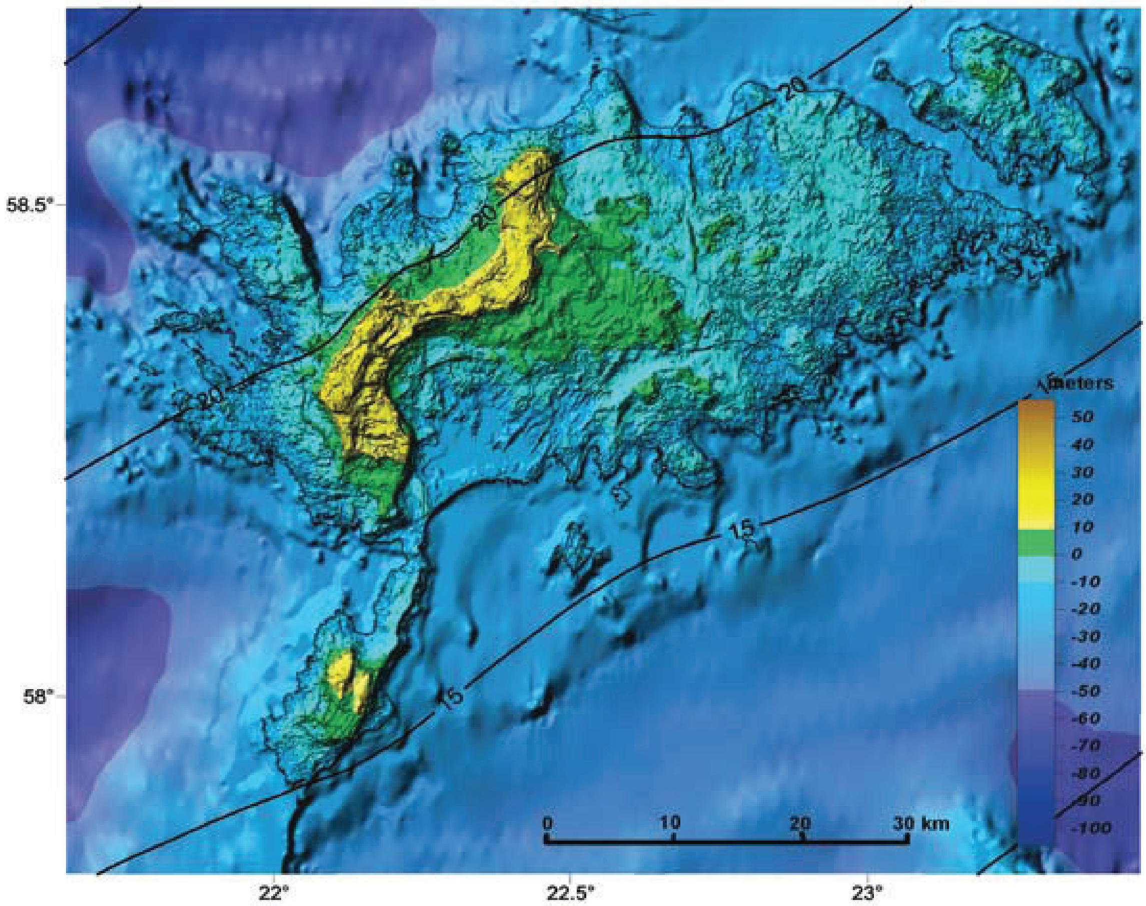

Fig. 5. Palaeogeographic reconstruction of the water level surface isobases and the shoreline of the Litorina Sea in Saaremaa Island. Compiled by J. Vassiljev.

DISCUSSION

The Ancylus Lake regression on Saaremaa Island resulted in a gradual drop in water level. At several sites first lagoons, then isolated coastal lakes were formed, which later paludified and were finally inundated by the Litorina Sea waters. The upper limit of the buried peat at 15–17 m a.s.l. roughly corresponds to the lowest Ancylus Lake level here and indicates the lake regression of about 13–15 m (Saarse *et al.* 2007). The radiocarbon date of peat/calcareous silty gyttja contact at Kihelkonna (Fig. 2A; Table 2) refers to low water level, which lasted up to 8300 cal yr BP and was followed by a water level rise due to the Litorina Sea transgression and deposition of calcareous-rich sediment in an isolated coastal lake. The date 8185±105 cal yr BP for the upper limit of the buried peat at Lümanda (Table 2) supports low water stand, lasting up to ca 8200 cal yr BP. After that the water level started to rise and the once paludified basins were filled in with water. In the coastal lakes calcareous silty gyttja started to deposit, which marks onset of the Litorina Sea transgression.

Studies in the SE Swedish Baltic Sea area with the use of numerous radiocarbon dates indicated that the Litorina Sea transgression (*sensu stricto*) began about 8500 cal yr BP (Berglund *et al.* 2005; Yu *et al.* 2005, 2007). It was followed by a sudden short-term drop in sea level around 8100 cal yr BP, which may be explained by climate disturbance during the 8200 yr cold event (Alley *et al.* 1997; Berglund *et al.* 2005).

In the sequences studied by us the start of the Litorina Sea transgression occurred about 200–300 years later than in SE Sweden (Berglund *et al.* 2005), but coincides with the age determined at sites with comparable threshold elevations in the northern part of the Gulf of Finland (Miettinen 2002), which lie on isobases similar to the Saaremaa sites. Transgression begins earlier in slow land uplift areas, such as Blekinge, which could explain the delay transgression in Saaremaa lying in areas with higher land uplift. Dating errors, however, should also be considered. Radiocarbon dates of buried peat from Gotland, below the Ancylus transgressional deposits, showed distinctly younger ages than those of timber due to contamination of down-growths of younger roots and rootlets especially when sandy deposits were concerned (Svensson 1989, p. 169).

At Saaremaa sites the Litorina Sea transgression and high sea level lasted throughout 7700–7800 cal yr BP or even longer. This is confirmed by the age of the isolation contact in Ohtja (7735±55 cal yr BP) and age of detritus gyttja in Vedruka (7715±80 cal yr BP), the basal part of which contained marine plankton *Hystrix* (see Fig. 3). Judging by Ancylus Lake minimum and Litorina Sea maximum water levels, the water level rose about 5 m and reached 20.5 m a.s.l. during the Litorina Sea transgression.

The Litorina Sea transgression substantially changed the coastline of Saaremaa Island compared with the coastline of Ancylus Lake (Figs 4, 5). Several small islands, lagoons and sea arms appeared, suitable for camp– and dwelling sites. The studied lagoons isolated from the sea at different times, first Kihelkonna (about 8300 cal yr BP), then Lümanda (ca 8200–8100 cal yr BP), Jõempa (ca 7900 cal yr BP) and Vedruka (ca 7700 cal yr BP). A detailed palaeogeographic map shows that the Litorina Sea did not reach to the Kaali meteorite field, however, the coastline was quite close to it (Fig. 5).

A tentative shore displacement curve corresponding to the 20 m isoline was compiled, based on the elevation of beach formations, studied lagoons and the settlement pattern (Fig. 6). This graph shows coastal orientation of settlements as coastal environment offered fish and game for hunting.

CONCLUSIONS

The highest shoreline of Ancylus Lake on the Island of Saaremaa is located between 35 and 25 m a.s.l. and that of the Litorina Sea between 20.5 and 15.5 m a.s.l. as a consequence of decreased southeastward land upheaval. The Litorina Sea transgression left behind an indented coastline with numerous lagoons suitable for camp– and dwelling sites. Due to marked water level lowering during the Ancylus Lake regression (13–15 m), several coastal lakes paludified and were later coated by the Litorina Sea transgressional sand.

Local mean sea level rose from ca 8200 cal yr BP onwards, which lasted up to 7700 cal yr BP or even longer. The magnitude of the Litorina Sea transgression was about 5 m on the Island of Saaremaa and beach formation now positioned up to 20.5 m a.s.l.

The presented new palaeogeographic maps display an ancient shoreline with lagoons, which are promising places to study the litho– and biostratigraphy of sediment and isolation contacts and can be used for searching for Mesolithic and Neolithic dwelling sites.

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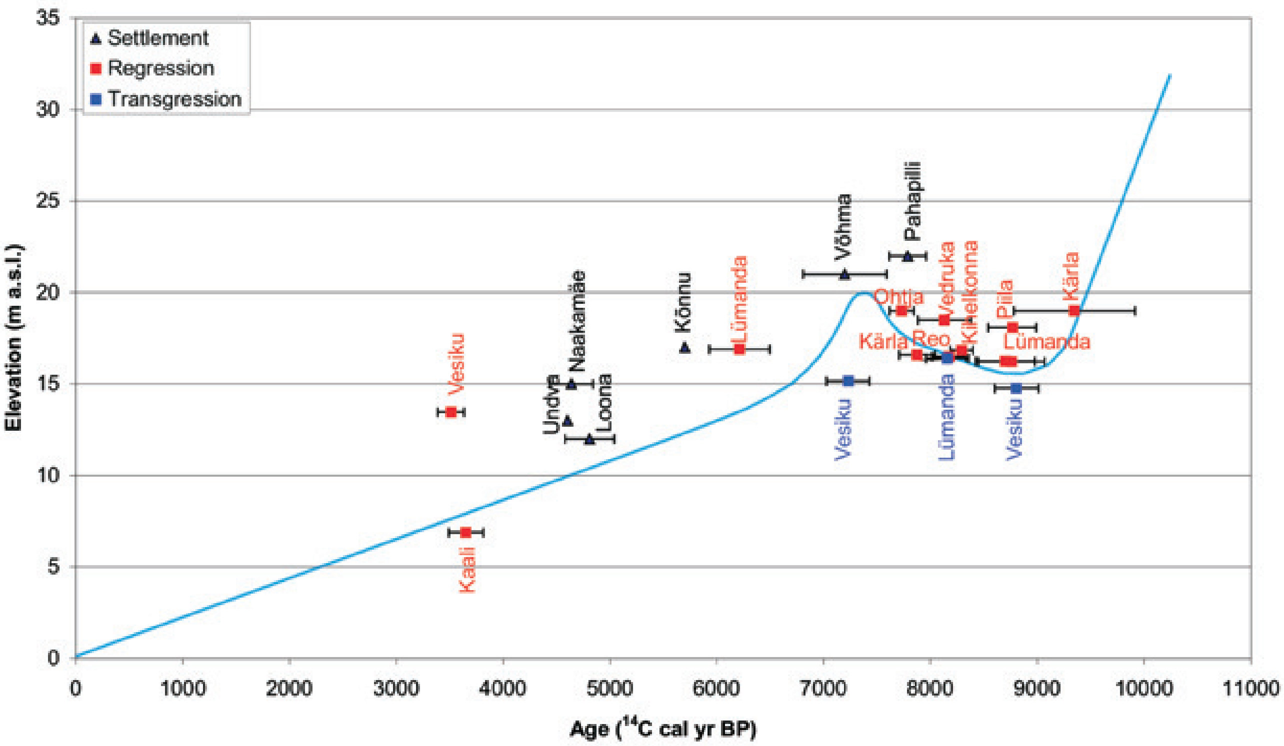

Fig. 6. Tentative shore displacement curve for 20 m a.s.l. (blue line) with indication of radiocarbon dates of buried peat (marked with red squares), gyttja (marked with blue squares) and dated settlement sites (marked with black triangles) related to the Litorina Sea coastline.

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