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LITORINA SEA SHORE DISPLACEMENT ON THE ISLAND OF SAAREMAA, ESTONIA

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Abstract. Sedimentological and magnetic susceptibility analyses, and radiocarbon datings of six Holocene sequences (Ohtja, Kihelkonna, Vedruka, Vesiku, Lümanda, Jõempa) were used to elucidate the Litorina Sea development on the Island of Saaremaa, Estonia. The Litorina Sea beach formations are located between 20.5 and 15.5 m above the present day sea level. Spatial distribution of the Litorina Sea shore displacement was reconstructed. The onset of the Litorina Sea transgression in the study area is dated to 8200 cal yr BP. The measure of a single transgression was about 4.5–5.0 m.

Key words: Litorina Sea, ^{14}C dates, Saaremaa Island, Baltic Sea, Estonia, Holocene.

Abstrakt. Badania sedymentologiczne i analiza podatności magnetycznej oraz datowania radiowęglowe w 6 stanowiskach holoceńskich (Ohtja, Kihelkonna, Vedruka, Vesiku, Lümanda, Jõempa) umożliwiły przedstawienie rozwoju morza litorynowego na wyspie Saaremaa w Estonii. Formacje plażowe morza litorynowego występują na wysokości od 20,5 do 15,5 m n.p.m. Zrekonstruowano położenie brzegu morza litorynowego. Początek transgresji morza litorynowego określono na 8200 lat kalendarzowych. Wielkość pojedynczej transgresji wynosiła około 4,5–5,0 m.

Słowa kluczowe: morze litorynowe, datowania ^{14}C, wyspa Saaremaa, Morze Bałtyckie, Estonia, holocen.

INTRODUCTION

Water level in the Baltic Sea was characterized by several remarkable fluctuations caused by the character of isostasy, formation of drainage system and existence or absence of the connection between a sea and the ocean. During the Litorina Sea stage two functioning inlets, Öresund and Great Belt assured influx of saline oceanic water into the Baltic Sea (Björck, 1995). Saline water ingression started already 9500–8800 cal yr BP (Eronen *et al.*, 1990; Andrén *et al.*, 2000), but the initial rise of water level and salinity in south-eastern Sweden occurred later, between 8500 and 8000 cal yr BP and marked the true onset of the Litorina Sea (Berglund *et al.*, 2005; Yu *et al.*, 2005; Björck, 2008). Data from the south-eastern Sweden show that local sea level rose from 8500 to 6500 cal yr BP and there was a rapid transgression around 7600 cal yr BP, related to the increase in ocean water mass, caused by final melting of the Laurentide Ice Sheet (Lambeck, Chappell, 2001; Yu *et al.*, 2007).

The investigations of the Litorina Sea coastal formations on Saaremaa (Fig. 1A), Estonian largest island with an area of 2668 km^2, have lasted about 80 years (Ramsay, 1929; Orviku, 1934; Kents, 1939; Kessel, 1960; Kessel, Raukas, 1967, 1979; Hyvärinen *et al.*, 1988; Saarse *et al.*, 2003, 2009). During the Litorina Sea stage the territory of Estonia experienced a transgression, because the sea level rise surpassed that of the isostatic rebound and now the Litorina Sea beach formations are positioned between 20.5 and 15.5 m a.s.l. (Fig. 1B). A comprehensive description of the shore displacement curves and a correlation with the prehistoric settlement site pattern of the Saaremaa Island were published previously (Poska, Saarse, 2002; Saarse *et al.*, 2007, 2009). The main objective of our study was to make palaeogeographical reconstructions and to date environmental changes, which occurred on the coastal areas of the Litorina Sea episode.

To investigate the Litorina Sea shore displacement, lithology and radiocarbon dates of deposits from six lagoons (Ohtja, Kihelkonna, Jõempa, Lümanda, Vedruka and Vesiku) were used to prescribe their isolation event. Most of the studied lagoons were opened to the Litorina Sea waters, except Kihel-

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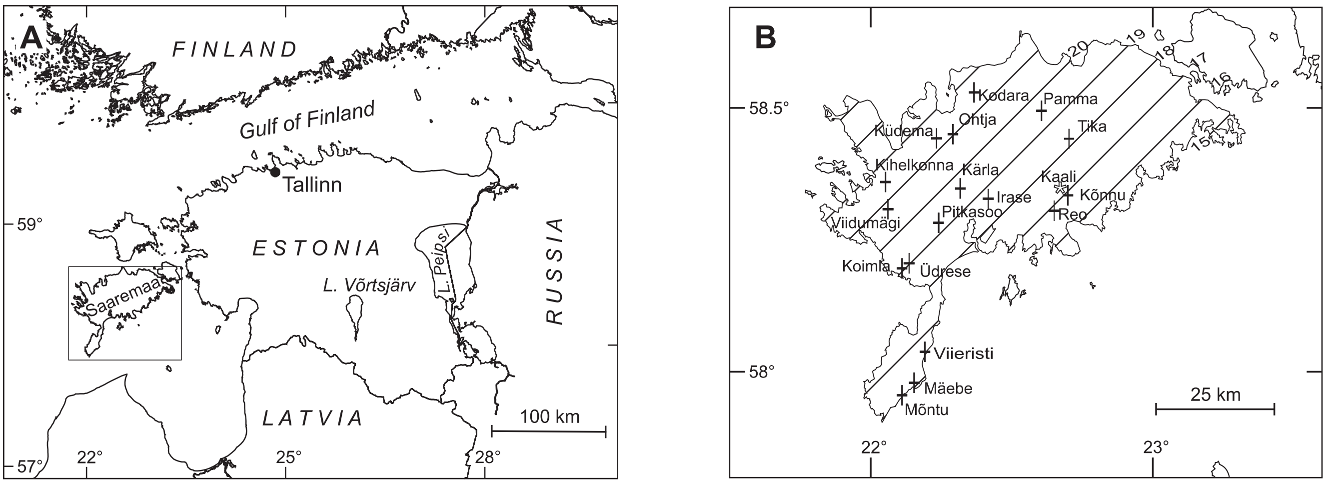


Fig. 1. Location of study area (A), contour lines and sites with the most important beach formations (B)

konna and the littoral part of Lümanda. They were isolated and paludified already during the Ancylus Lake regression. Located close to the Litorina Sea coastline, the basins Kihelkonna and Lümanda were filled in with water during transgression and deposition of calcareous silty gyttja has been started. In the other studied lagoons sands were deposited, which in the central part of Lümanda contained brackish-water diatoms *Campylodiscus clypeus* (Kessel, Raukas, 1967). During the Litorina Sea transgression lagoons were bordered by spits and beach ridges, which often contained molluscs, dated

Table 1

Radiocarbon dates of sequences related to the Litorina Sea development

Name of site	Depth below sediment surface (cm)	Radiocarbon age (^{14}C yr BP)	Laboratory index	Calibrated age (cal ^{14}C yr BP)	Dated material	References
Kihelkonna	100–110	7490±60	Tln-3078	8300±70	peat	current study
Lümanda	90–95	5130±65	Tln-3083	5860±85	peat	current study
Lümanda	95–100	5255±55	Tln-3084	6055±90	peat	current study
Lümanda	160–165	7365±75	Tln-3085	8185±105	peat	current study
Lümanda	165–170	7650±70	Tln-3086	8465±60	peat	current study
Lümanda	170–177	7760±75	Tln-3087	8540±75	peat	current study
Ohtja	118–123	6890±55	Tln-3082	7735±55	gyttja	current study
Vesiku	500–503	6350±80	TA-178	7290±90	gyttja	Kessel, Punning (1969)
Vesiku	533–536	7960±80	TA-179	8820±130	gyttja	Kessel, Punning (1969)
Kärla	65–68	7085±80	TA-181	7905±75	gyttja	Ilves *et al.* (1974)
Kärla	95–98	7820±80	TA-182	8650±125	peat	Ilves *et al.* (1974)
Reo	200–220	7165±70	Tln-253	7960±85	gyttja	Punning *et al.* (1980)
Reo	220–230	7350±70	Tln-254	8175±100	peat	Punning *et al.* (1980)
Vedruka	375–380	6570±70	Ta-2580	7490±55	gyttja	Poska, Saarse (2002)
Vedruka	390–400	6860±80	Ta-2581	7715±80	gyttja	Poska, Saarse (2002)
Piila	335–340	7875±75	Tln-1875	8830±125	peat	Raukas *et al*. (1995)
Piila	335–340	7870±135	Tln-1881	8745±185	peat	Raukas *et al.* (1995)
Võhma	archaeol. site	6750±50	Ta-2646	7620±35	charcoal	Kriiska (1998)
Võhma	archaeol. site	6950±100	Ta-2650	7800±100	charcoal	Kriiska (1998)
Pahapilli	archaeol. site	6370±180	Le-5452	7240±190	charcoal	Kriiska (2007)

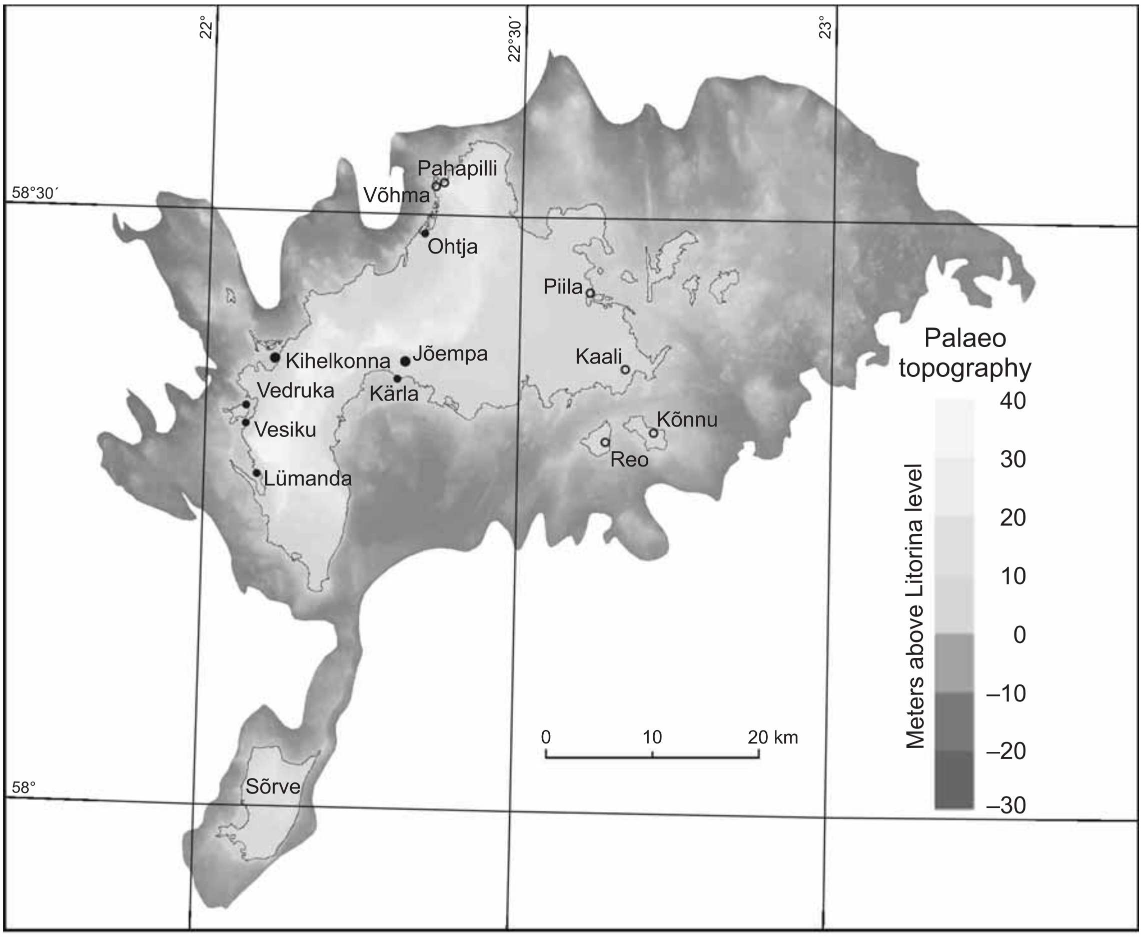


Fig. 2. Palaeogeographic reconstruction of the Litorina Sea shoreline on the Saaremaa Island with indication of the studied sites (black dots) and the other sites mentioned in text (black circles)

by EPR to 7000 yr BP in Küdema spit (Kessel, 1988). In several sites Litorina Sea transgressional sand coated the pre-Litorina organic beds, dated to 7165 ±70 (7960 ±85 cal yr BP) at Reo, 7085 ±80 (7920 ±80 cal yr BP) at Kärla and 6350 ±80 (7280 ±105 cal yr BP) at Vesiku (Kessel, Punning, 1969; Punning *et al.*, 1980; Table 1). Well-dated Mesolithic campsites at Võhma and Pahapilli also gave additional information on the position of the Litorina Sea coastline and confirmed that 7800 cal yr BP Võhma campsite area at 20 m a.s.l. was already a dry land (Fig. 2).

MATERIAL AND METHODS

Selected for sediment sampling four ancient lagoons (Ohtja, Jõempa, Vesiku, Vedruka) are located below the upper limit of the Litorina Sea, whereas Kihelkonna and a littoral part of Lümanda – above this limit. The sampling was performed with a 0.5 and 1.0 m long Russian peat auger. All studied cores were subsampled with a 1-cm interval for loss-on-ignition (LOI) analyses. Samples were dried at 105°C, then ignited at 525°C and 900°C to calculate contents of organic matter and carbonates. The organic matter (OM) content was expressed in percentages of dry matter. The percentage of carbonates ($CaCO_3$) content was calculated after burning the LOI residue for two hours at 900°C. The amount of residue containing terrigeneous matter and biogenic silica was described as mineral matter and calculated against the sum of organic and carbonate compounds (Fig. 3).

Ten radiocarbon dates from bulk gyttja or peat samples were performed in the Institute of Geology at the Tallinn University of Technology (Table 1). Radiocarbon dates from the buried organic beds and charcoal from the archaeological sites have been also considered to specify the development of the Litorina Sea. 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 calendar years BP (0 = AD 1950).

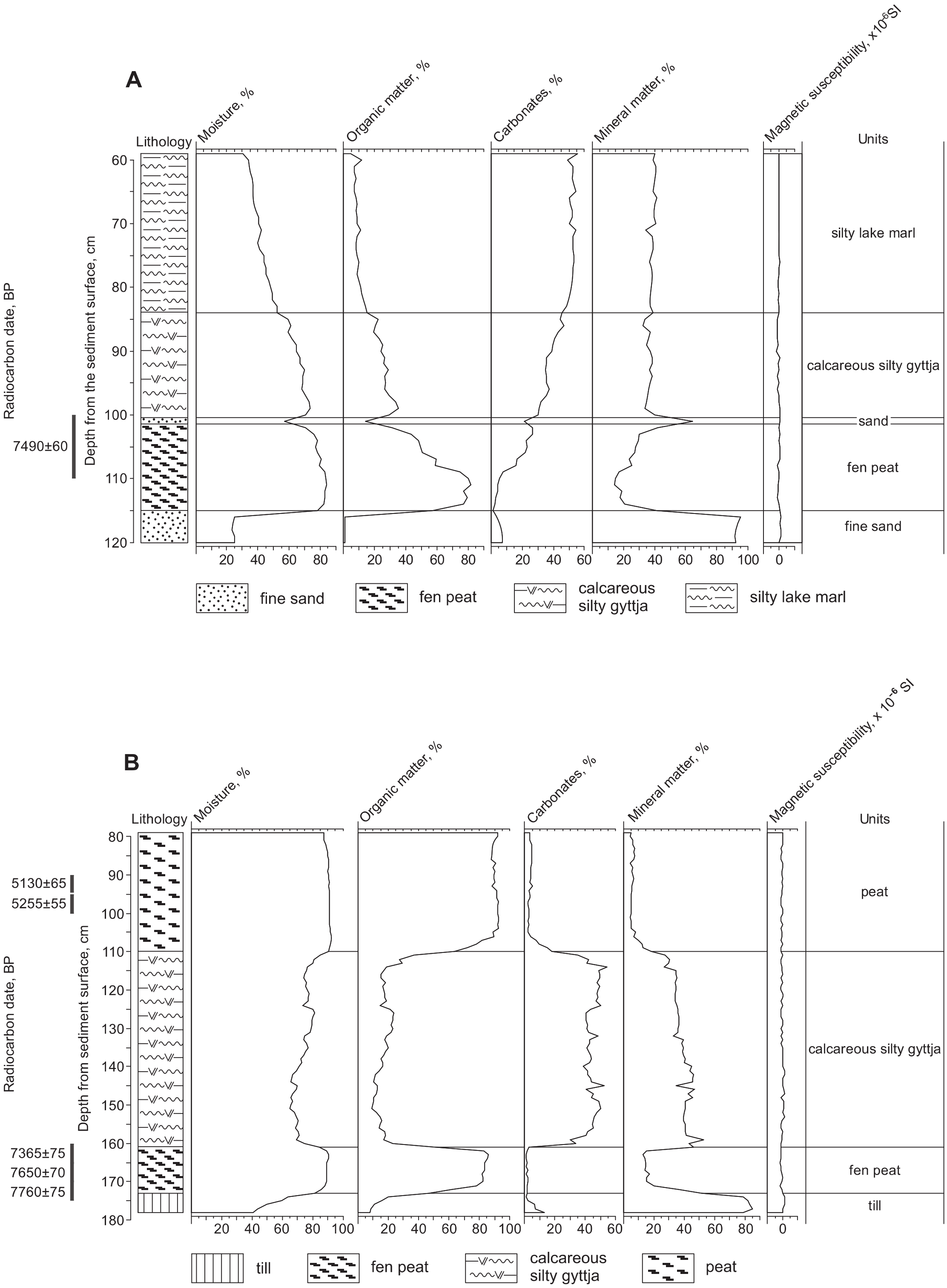
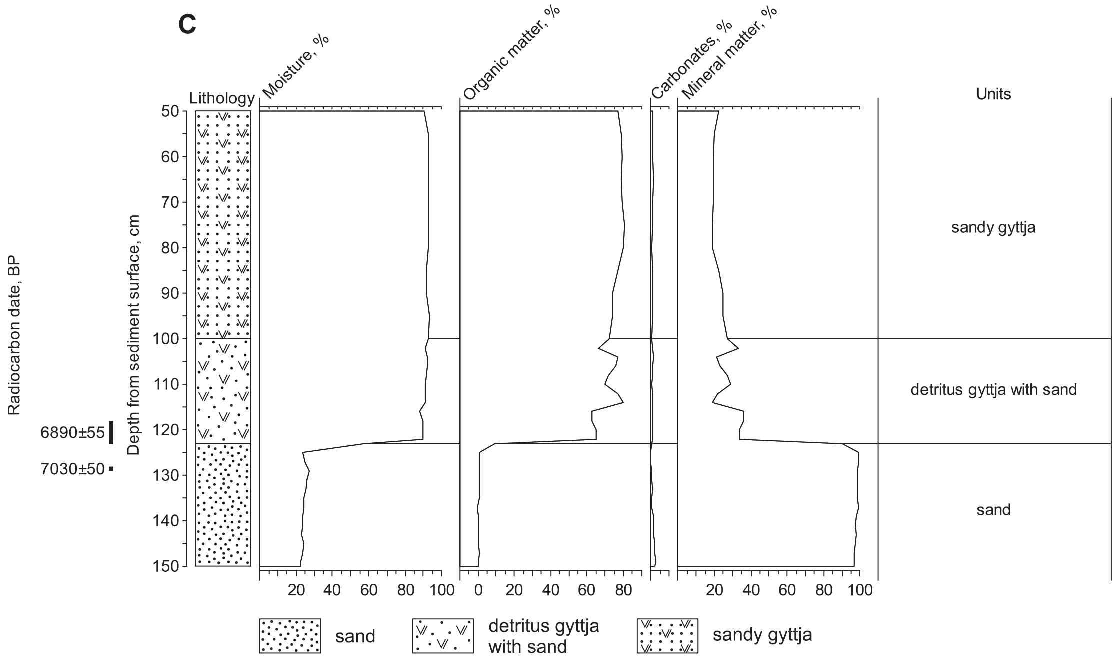
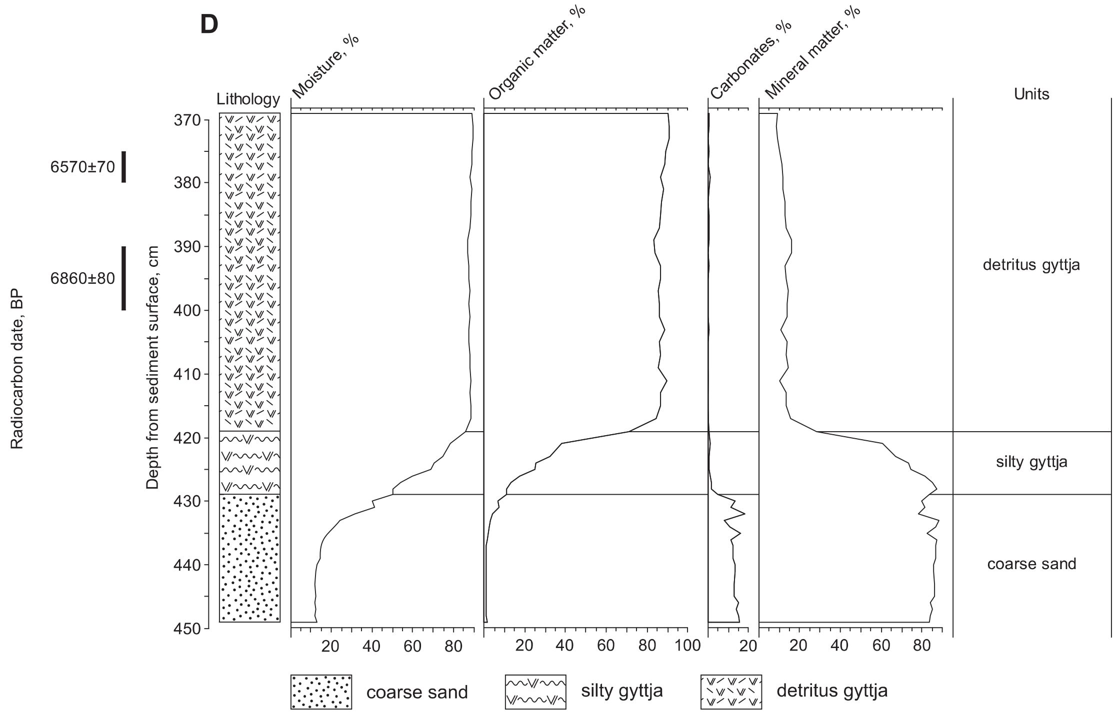


Fig. 3. Loss-on-ignition results from Kihelkonna (A), Lümanda (B),

Pollen diagrams from all re-visited sites have been compiled and published earlier (Männil, 1963, 1964; Kessel, Raukas, 1967; Saarse, Königsson, 1992; Saarse, 1994; Poska, Saarse, 2002). Diatom preservation was very bad and analysed only from the Lümanda site (Kessel, Raukas, 1967). Unfortunately diatoms were missing in the Lümanda sequence that was studied by us (Heinsalu, *pers. comm.*).

The magnetic susceptibility measured from the sediment surface at a 1-cm resolution by Bartington Instruments Ltd. high-resolution surface scanning sensor MS2E has not indicated





Ohtja (C), Vedruka (D) sites

any changes and was therefore excluded from a discussion, but as a result was displayed in two loss-on-ignition diagrams.

The palaeogeographic map (Fig. 2) was reconstructed using interpolated surfaces of water levels and a modern digital terrain model (DTM). DTM with a grid size of 50x50 m was generated using topographic maps in a scale of 1:10,000 (Kikas, 2005).

RESULTS

CHRONOLOGY AND LITHOSTRATIGRAPHY

The sediment chronology of the studied sequences is supported by 10 recently obtained radiocarbon dates. The dates are listed in Table 1 together with previously published ^{14}C dates associated with the Litorina Sea shore displacement. Mostly buried peat and gyttja have been radiocarbon dated because beach ridges and spits contained very little datable material. According to ^{14}C dates buried peat was deposited between 8600 and 8200 cal yr BP and corresponds to the pre--Litorina transgression.

Sediment composition of four studied sites is displayed in Figure 3. The Kihelkonna sequence starts with fine-grained sand, covered by fen peat with LOI values up to 81%, thin sandy layer (OM 13%), calcareous silty gyttja (OM 35–10%) and silty lake marl (OM less 10%; Fig. 3 A). According to radiocarbon dates peat deposition ended *ca* 8300 cal yr BP (Table 1). A contact between the peat and the gyttja indicates obviously the isolation between the Ancylus Lake regressive and onset of the Litorina Sea transgressive sediments. In the Lümanda sequence a basal till is covered by fen peat (OM 80–85%), calcareous silty gyttja (OM 10–23%) and topmost fen peat (OM 70–91%, Figs. 3B, 4B). The basal peat layer was deposited between 8700 cal yr BP and 8200 cal yr BP. The topmost peat formed since 6050 cal yr BP onwards. In Ohtja and Vedruka sequences a sand forms the basal layer, overlain by gyttja and peat (Figs. 3C, D, 4C). A detritic gyttja in the Ohtja sequence contained OM 65–80% and in Vedruka around 80%. The last mentioned organic deposits are practically devoid of carbonates (Fig. 3C, D). Isolation contact in the Ohtja sequence was dated to 7750 cal yr BP (Table 1). In the Vedruka sequence a replacement of sand by silty gyttja occurred before 7700 cal yr BP (contact is not directly dated). The Vesiku sequence holds buried peat and gyttja beds dated to 8800 and 7300 cal yr BP accordingly (Kessel, Punning, 1969) and enveloped by 3–5 m thick Litorina Sea and aeolian sand. The buried peat sequence that was studied by us at Vesiku, was rich in OM fraction (up to 90%), but occurred to be too young and not associated with the development of the Litorina Sea and therefore, was not included into the Table 1. The sediment composition of the Jõempa sequence was similar to that of Kihelkonna.

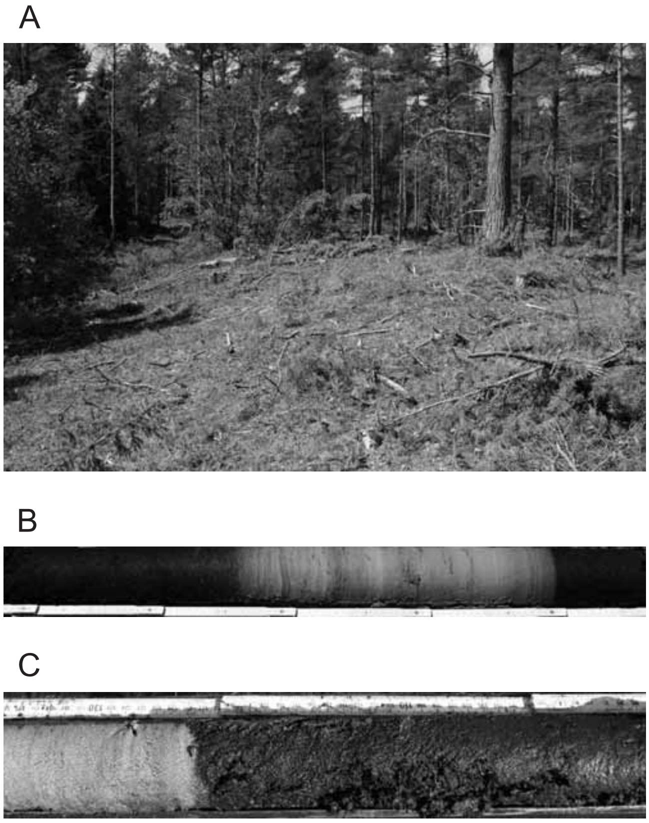


Fig. 4. Litorina Sea beach ridge at Kärla (A), basal and topmost peat intercalated with silty calcareous gyttja in Lümanda sequence (B), contact between sand and coarse detritus gyttja in Ohtja sequence (C). Photos by S. Veski

LITORINA SEA SHORELINE

On the Island of Saaremaa there is much evidence of the raised shorelines at the altitudes of 20.5 and 15.5 m a.s.l., which have been considered in palaeogeographic reconstructions. The palaeogeographical map of the Litorina Sea shore displacement presents an intended coastline with several lagoons and capes (Fig. 2). The highest Litorina Sea beach formations at an elevation of 20.5 m a.s.l are located in the NNW part of the study area and run quite close to the Ancylus Lake beach ridges. East of the Võhma village the Litorina Sea formed a little bay, with islet at its mouth. On the western and eastern coast of this bay the Võhma and Pahapilli Mesolithic campsites were discovered, dated to 7200–7800 cal yr BP (Table 1). From Võhma village the Litorina coastline turned to the south, indicated by dunes and shelving coast up to Küdema, where a spit and dunes cut off the Ohtja lagoon. Northeast of Kihelkonna the ancient coast once again is well marked by a dune field, an elongated cape and the Kihelkonna lagoon (Fig. 2). Lümanda, Vesiku and Vedruka were opened to sea waters. Beach ridges and dunes at Kärla formed two bends with the Jõempa lagoon behind (Fig. 4A). South and east from the main coast several small islets emerged, as Reo and Kõnnu (Fig. 2). The Litorina Sea formations on the Sõrve Peninsula were located around the bedrock elevation, with several well-developed escarpments in it (Orviku, 1934).

DISCUSSION AND CONCLUSIONS

During the Ancylus Lake regression a water level dropped and at several sites (Lümanda, Kihelkonna, Kärla, Jõempa, Reo, Vesiku) a peat was deposited, later covered by the Litorina Sea transgressive sands. A stratigraphic position of the basal peat between sand and gyttja/lake marl corresponds to the Ancylus Lake termination and low water level that lasted until 8200–8300 cal yr BP. After it a water level rose for about 4–5 m as deduced from a morphological and sedimentological evidence.

Studies in SE Sweden confirmed that the Litorina transgression began about 8500 cal yr BP (Berglund *et al.*, 2005) and were followed by a sudden short-term drop of a sea level around 8100 cal yr BP, explained by a climatic change, known as the 8200 cold event (Alley *et al.*, 1997; Berglund *et al.*, 2005). Such a short-term drop in sea level, as recorded in Blekinge, southern Sweden, has been traced neither in Saaremaa sites nor in Finish and Karelian sites (Miettinen, 2002; Miettinen *et al*., 2007). In the Lümanda sequence a peat deposition lasted from 8700 cal yr BP up to 8200 cal yr BP, being replaced by calcareous silty gyttja deposition, which indicates a rise of water level. As Lümanda is located almost at the same isoline as Virojärvi in southern Finland (Miettinen, 2002), the onset of transgression and isolation age fit well: at Lümanda a water level rise was dated to 8190 cal yr BP, at Virojärvi – 8160 cal yr BP and isolation contact at both sites about 6000 cal yr BP. At the Kihelkonna site the buried peat deposition terminated at 8300 cal yr BP and at Reo at 8200 cal yr BP. A thin sand layer occurred on a buried peat at Kihelkonna, obviously formed by erosional processes or indicates a storm event.

The Litorina transgression substantially changed the coastline of the Saaremaa Island. Several small islands, lagoons and sea arms appeared that have been isolated from a sea in different time. The Kihelkonna lagoon was isolated from a sea about 8300 cal yr BP, Lümanda *ca* 8200 cal yr BP, Ohtja 7800 cal yr BP, Vedruka *ca* 7700 cal yr and Vesiku *ca* 7300 cal yr BP. A detailed palaeogeographic map proves that the Litorina Sea has not reached the Kaali meteorite field, its coast remaining 1–2 km away.

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REFERENCES

ALLEY R.B., MAYEWSKI P.A., SOWERS T., STUIVER M., TAYLOR K.C., CLARK P.U., 1997 – Holocene climatic instability: a prominent, widespread event 8200 years ago. *Geology*, **25**: 483–486.

ANDRÉN E., ANDRÉN E., SOHLENIUS G., 2000 – The Holocene history of the southwestern Baltic Sea as reflected in a sediment core from the Bornholm Basin. *Boreas*, **29**: 233–250.

BERGLUND B.E., SANDGREN P., BARNEKOW L., HANNON G., JIANG H., SKOG G., YU S.-Y., 2005 – Early Holocene history of the Baltic Sea, as reflected in coastal sediments in Blekinge, southeastern Sweden. *Quatern. Intern*., **130**: 111–139.

BJÖRCK S., 1995 – A review of the history of the Baltic Sea, 13.0–8.0 ka BP. *Quatern. Intern.,* **27**: 19–40.

BJÖRCK S., 2008 – The late Quaternary development of the Baltic Sea. *In*: Assessment of climate change for the Baltic Sea Basin (eds. the BACC authors team): 398–407. Springer-Verlag, Berlin-Heidelberg.

ERONEN M., RISTANIEMI O., LANGE D., 1990 – Analysis of a sediment core from the Mecklenburg Bay, with a discussion on the early Holocene history of the southern Baltic Sea. *Geol. Fören. Stockholm Förhandl.*, **112**: 1–8.

HYVÄRINEN H., DONNER J., KESSEL H., RAUKAS A., 1988 – The Litorina Sea and Limnaea Sea in the northern and central Baltic. *Ann. Acad. Sc. Fennicae*, *ser. A III.*, *Geol.- Geogr.*, **148**: 25–35.

ILVES E., LIIVA A., PUNNING J.-M., 1974 – Radiocarbon dating in the Quaternary geology and archaeology of Estonia. Acad. Sc. ESSR, Tallinn [in Russian with English summary].

KENTS P., 1939 – Postglaciaalsed Läänemere rannajoone võnkumised Eestis illustreeritud Kõpu poolsaarel. Tallinn. Unpubl. Report. State Arch. Estonia.

KESSEL H., 1960 – Holozäne Küstenbildungen der Ostsee auf dem Territorium der Estnischeń SSR. *Eesti NSV Tead. Akad. Geol. Inst. Uurimused*, **5**: 279–303 [in Russian with German summary].

KESSEL H., 1988 – Coastal formations on the Island of Saaremaa. *In*: Geological structure and the history of the Baltic Sea and the peculiarities of the formation of the mineral resources (eds. A. Raukas, E. Tavast): 110–114. Inst. Geol., Tallinn [in Russian].

KESSEL H., PUNNING J.-M., 1969 – Über das Absolute Alter der holozänen transgressionen der Ostsee in Estland. *Proc. Acad. Sc. Estonian SSR, Chem., Geol.,* **18**, 2: 140–153 [in Russian with German summary].

KESSEL H., RAUKAS A., 1967 – The deposits of Ancylus Lake and Littorina Sea in Estonia. Valgus, Tallinn [in Russian with English summary].

KESSEL H., RAUKAS A., 1979 – The Quaternary history of the Baltic. Estonia. *In*: The Quaternary history of the Baltic (eds. V. Gudelis, L.-K. Königsson). *Acta Univ. Uppsaliensis, Annum Quingentesimum Celebrantis*, **1**: 127–146.

KIKAS T., 2005 – Automatic identification of streams and watersheds from a DEM model of Saaremaa and Muhu. Master thesis. Manuscr. Tartu University, Department of Geography.

KRIISKA A., 1998 – Mesoliitilised asustusjäljed Loode-Saaremaal. *Ajalooline Ajakiri*, **1**, 100: 13–22.

KRIISKA A., 2007 – Saaremaa kiviaeg. *In*: Saaremaa 2. Ajalugu, majandus, kultuur. (eds. K. Jänes-Kapp, E. Randma, M. Soosaar): 9–36. Koolibri, Tallinn.

LAMBECK, K., CHAPPELL J., 2001 – Sea level change through the last glacial cycle. *Science*, **292,** 5116: 679–686.

MÄNNIL R., 1963 – The fresh-water lime deposits of Saaremaa, their malacofauna and age. *Eesti NSV Tead. Akad. Geol. Inst. Uurimused*, **12**: 145–161 [in Russian with English summary].

MÄNNIL R., 1964 – Järvelubjalasundite levik ja stratigraafia Eestis. Eesti NSV Tead. Akad. Geol. Inst. Cand. Dissert. Manuscr. Inst. Geol. Tallinn Technical Univ.

MIETTINEN A., 2002 – Relative sea level changes in the eastern part of the Gulf of Finland during the last 8000 years. *Ann. Acad. Sc. Fennicae, Geol.-Geogr*., **162**: 1–102.

MIETTINEN A., SAVELIEVA L., SUBETTO D.A., DZHINORIDZE R., ARSLANOV K., HYVÄRINEN H., 2007 – Palaeoenvironment of the Karelian Isthmus, the easternmost part of the Gulf of Finland, during the Litorina Sea stage of the Baltic Sea history. *Boreas*, **36**: 441–458.

ORVIKU K., 1934 – Sõrve. Loodus ja Inimene. Äratrükk koguteosest "Saaremaa". Tartu.

POSKA A., SAARSE L., 2002 – Vegetation development and introduction of agriculture to Saaremaa Island, Estonia: the human response to shore displacement. *The Holocene*, **12**: 555–568.

PUNNING J.-M., RAJAMÄE R., JOERS K., PUTNIK H., 1980 – Tallinn radiocarbon dates VI. *Radiocarbon*, **22**, 1: 91–98.

RAMSAY W., 1929 – Niveauverschiebungen, Eisgestaute seen und rezession des Inlandeises in Estland. *Fennia*, **52**: 1–48.

RAUKAS A., PIRRUS R., RAJAMÄE R., TIIRMAA R., 1995 – On the age of the meteorite craters at Kaali, (Saaremaa Island, Estonia). *Proc. Estonian Acad. Sc., Geol*., **44**: 177–183.

REIMER P.J., BAILLIE M.G.L., BARD E. *et al.*, 2004 – IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon*, **46**: 1029–1058.

SAARSE L., 1994 – Bottom deposits of small Estonian lakes. Estonian Acad. Sc., Inst. Geol., Tallinn. [in Russian with English summary].

SAARSE L., KÖNIGSSON L.-K., 1992 – Holocene environmental changes on the Island of Saaremaa, Estonia. *PACT*, **37**: 97–131.

SAARSE L., VASSILJEV J., MIIDEL A., 2003 – Simulation of the Baltic Sea shorelines in Estonia and neighbouring areas. *J. Coastal Res*., **19**, 2: 261–268.

SAARSE L., VASSILJEV J., MIIDEL A., NIINEMETS E., 2007 – Buried organic sediments in Estonia related to the Ancylus Lake and Litorina Sea. *In*: Applied Quaternary research in the central part of glaciated terrain (eds. P. Johansson, P. Sarala). *Geol. Surv. Finland, Sp. Pap.,* **46**: 87–92.

SAARSE L., VASSILJEV J., ROSENTAU A., 2009 – Ancylus Lake and Litorina Sea transition on the Island of Saaremaa, Estonia: a pilot study. *Baltica*, **22**: 51–62.

STUIVER M., REIMER P.J., REIMER R., 2005 – CALIB Radiocarbon Calibration (HTML ver. 5.0). http://radiocarbon.pa.qub.ac.uk/calib/

YU S.-Y., BERGLUND B.E., SANDGREN P., FRITZ S.C., 2005 – Holocene palaeoecology along the Blekinge coast, SE Sweden, and implication for climate and sea-level changes. *The Holocene*, **15**, 2: 278–292.

YU S.-Y., BERGLUND B.E., SANDGREN P., LAMBECK K., 2007 – Evidence for a rapid sea-level rise 7600 yr ago. *Geology*, **35**, 10: 891–894.