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Chronological data from Estonian Pleistocene

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Abstract. Pleistocene chronostratigraphy in Estonia is based on 60 radiocarbon (^{14}C, ^{14}C AMS), 63 TL/OSL, and 17 ^{10}Be datings from 57 studied sites/sections that cover a time span from approximately 200 000 yr BP to the Pleistocene–Holocene chronostratigraphic boundary. For the first time all scattered data from 40 years of chronological study into Estonian Pleistocene are presented together and critically analysed in regard to validity of obtained ages. Half of the relatively abundant but scattered chronological data cover only the youngest 5000–6000 year part of the Late Weichselian. New OSL datings, together with the results of earlier palynological, carpological, and diatom studies, have invalidated almost one-third of the available ^{14}C dates, obtained mostly in the late 1960s and 1970s. Thermoluminescence ages from tills, available from the early 1980s, are very inconsistent within the studied sections and are considered to be unreliable because of questionable bleaching of the TL signal. The results of the ^{10}Be method, recently applied to the study of deglaciation chronology of the Estonian territory, do not contradict the earlier age estimations. However, due to relatively large uncertainties of the method, the results were not able to refine the existing Late-Glacial chronology in Estonia.

Key words: geochronology, Late Weichselian, deglaciation, Estonia, dating methods.

INTRODUCTION

The first attempt to date directly the ice-marginal formations and to correlate them with adjacent regions was undertaken by Serebryannyj & Raukas (1966). All subsequent published summaries of Pleistocene stratigraphy in Estonia (Kajak et al. 1976; Liivrand 1991; Raukas & Gaigalas 1993; Raukas & Kajak 1995; Pirrus & Raukas 1996; Raukas 1998) were based on correlations of biostratigraphic (palynological) data and the superposition of till beds to other analysed and dated sections in the region. The commonly accepted model designates at least five till beds macroscopically distinguishable in glacial accumulative heights and buried bedrock valleys, occasionally separated from each other by Karuküla (Holsteinian) and Prangli (Eemian) interglacial deposits or interstadial beds (Liivrand 1991; Raukas & Kajak 1995, 1997). The two youngest till beds are attributed to Weichselian glaciations (Raukas et al. 2004), whereas the uppermost till likely includes Late-Glacial interstadial organic-containing beds in a few places. Often the obtained dates have been rejected as unsuitable for the model supported by the authors. The aim of this paper is, firstly, to present a systematic and detailed review of relatively numerous chronostratigraphic data from Estonian Pleistocene and, secondly, to give a critical evaluation of the existing abundant (albeit scattered) chronological data, while presenting new information on the age of the Rõngu (Eemian) and Kõrveküla (Holsteinian) sections and an assessment of the earlier ^{14}C datings from the sections.

MATERIAL AND TERMINOLOGY

Mainly dates older than the Pleistocene–Holocene boundary at 10 000 uncalibrated ^{14}C years BP (Harland et al. 1982) were incorporated into the analysis. Only few younger dates provided by Raukas (2004) were included in the database because they were obtained from obviously Pleistocene-age objects – glacial erratics. At this moment from Estonian Pleistocene 60 radiocarbon (^{14}C, ^{14}C AMS), 63 luminescence (TL, OSL), and 17 cosmogenic ^{10}Be datings are available from 57 studied sites/sections (Fig. 1), which span approximately 200 000 years (Table 1).

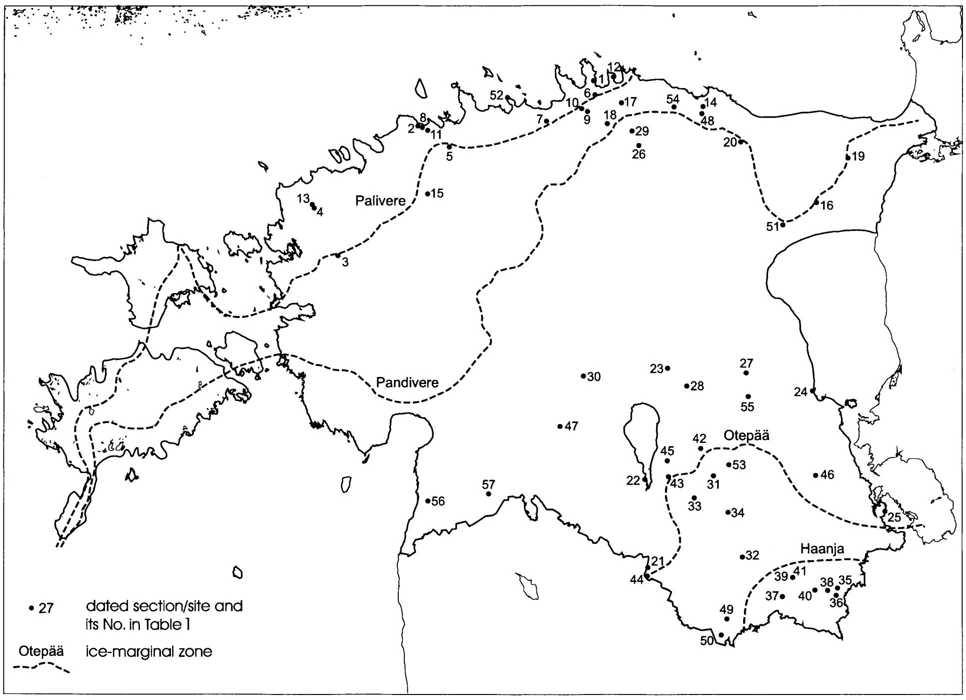

Fig. 1. Major Late-Glacial ice-marginal formations and location of dated Pleistocene sections/sites in Estonia: 1, Kasispea; 2, Tabasalu 3; 3, Palivere; 4, Nõva 1; 5, Männiku; 6, Sillaotsa; 7, Kuusalu; 8, Tabasalu 2; 9, Valgejõe; 10, Kemba; 11, Tabasalu 1; 12, Käsmu; 13, Nõva 2; 14, Kunda; 15, Vaharu; 16, Iisaku; 17, Palmse; 18, Pikasaare; 19, Pannjärve; 20, Uljaste; 21, Taimeaia (Valga); 22, Naritsa; 23, Puurmani; 24, Saviku; 25, Kuliska; 26, Kallukse; 27, Vedu; 28, Laeva; 29, Loobu; 30, Tääksi; 31, Nõuni; 32, Kurenurme; 33, Äidu; 34, Kaagvere; 35, Remmeski; 36, Viitka; 37, Viitina; 38, Pütsepa; 39, Jaanimäe 1; 40, Petruse; 41, Jaanimäe 2; 42, Peedu; 43, Rõngu; 44, Valga; 45, Valguta; 46, Mooste; 47, Heimtali; 48, Lammasmägi; 49, Kallaste; 50, Tahkumägi; 51, Tudulinna; 52, Ihasalu; 53, Kammeri; 54, Pehka; 55, Kõrveküla; 56, Arumetsa; 57, Karuküla.

Table 1. Age determinations of deposits from Pleistocene sites in Estonia

No. on map	Sample	Section/ location	Coordinates		Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
			x	y							
Dated Late-Glacial samples taken above the Palivere stadial deposits											
1	1	Kasispea	na	na	^{10}Be	Edelakivi erratic	na	Surface	4057 ± 458	EST-9	Raukas 2004
2	2	Tabasalu 3	na	na	^{10}Be	Rahneli erratic	na	Surface	5464 ± 615	EST-3	Raukas 2004
3	3	Palivere	23°55′43.2″	58°58′12.6″	OSL	Sand	4.6	Sand layer in gravel	9800 ± 1300	R-29	Raukas 2004
	4	Palivere	23°55′43.2″	58°58′12.6″	OSL	Sand	4.6	Sand layer in gravel	10 900 ± 1300	R-30	Raukas 2004
4	5	Nõva1	23°45′07″	59°08′59″	^{10}Be	Eedukivi erratic	na	Surface	12 002 ± 1078	EST-4	Raukas 2004
5	6	Männiku	24°43′08″	59°21′43″	OSL	Sand	2.0	Delta deposits	10 200 ± 1200	R-31	Raukas 2004
	7	Männiku	24°43′08″	59°21′43″	OSL	Sand	4.0	Delta deposits	21 000 ± 2500	R-32	Raukas 2004
	8	Männiku	24°43′08″	59°21′43″	OSL	Sand	6.0	Delta deposits	12 300 ± 1700	R-33	Raukas 2004
6	9	Sillaotsa	25°46′37.1″	59°32′00.2″	OSL	Fine sand	4.7	Sand in gravel pit	11 300 ± 1300	R-34	Raukas 2004
7	10	Kuusalu	na	na	^{10}Be	Nameless erratic	na	Surface	11 499 ± 914	EST-7	Raukas 2004
8	11	Tabasalu 2	na	na	^{10}Be	Noorgeoloogide erratic	na	Surface	11 938 ± 1053	EST-2	Raukas 2004
9	12	Valgejõe	25°45′28″	59°27′46″	OSL	Fine sand	4.4	Delta deposits	12 400 ± 1200	R-35	Raukas 2004
	13	Valgejõe	25°45′28″	59°27′46″	OSL	Fine sand	4.4	Delta deposits	12 200 ± 1200	R-36	Raukas 2004
	14	Valgejõe	25°45′28″	59°27′46″	OSL	Fine sand	7.0	Delta deposits	59 000 ± 5000	N-3	Raukas 2004
10	15	Kemba	na	na	^{10}Be	Urita Suurkivi erratic	na	Surface	12 832 ± 940	EST-8	Raukas 2004
11	16	Tabasalu 1	na	na	^{10}Be	Kallaste erratic	na	Surface	13 017 ± 1236	EST-1	Raukas 2004
12	17	Käsmu	na	na	^{10}Be	Nameless erratic	na	Surface	14 470 ± 1146	EST-10	Raukas 2004
13	18	Nõva 2	na	na	^{10}Be	Nameless erratic	na	Surface	15 435 ± 1348	EST-5	Raukas 2004

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Table 1. *Continued*

No. on map	Sample	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
Dated Late-Glacial samples taken above the Pandivere stadial deposits between the Pandivere and Palivere ice-marginal zones											
14	19	Kunda	26°32′52″	59°29′19″	^{14}C	Reindeer horn	na	In lake marl	10 170 ± 95	Hela-597	Ukkonen et al. 2005
	20	Kunda	26°32′52″	59°29′19″	^{14}C	Fen moss	1.20–1.25	Silt below lake marl	11 690 ± 150	Ta-194	Ilves et al. 1969
	21	Kunda	26°32′52″	59°29′19″	^{14}C	*Bryales* peat	ca 1.2	Silt below lake marl	13 170 ± 200	Tln-837	Moora 1998
15	22	Vaharu	24°32′04″	59°09′18″	^{14}C	Lake marl	5.2–5.3	Beginning of lake sediments	10 290 ± 130	Ta-174	Kessel & Punning 1969
16	23	Iisaku	27°19′03″	59°07′25″	OSL	Fine sand	3.0	Interlayers in gravel	11 600 ± 1100	R-46	Raukas 2004
	24	Iisaku	27°19′03″	59°07′25″	OSL	Fine sand	5.0	Interlayers in gravel	114 000 ± 8000	N-5	Raukas 2004
17	25	Palmse	na	na	^{10}Be	Nameless erratic	na	Interlayers in gravel	12 872 ± 910	EST-11	Raukas 2004
18	26	Pikasaare	25°51′22.1″	59°26′16.8″	OSL	Sand	3.2	Sand in kame field	13 700 ± 1300	R-37	Raukas 2004
	27	Pikasaare	25°51′22.1″	59°26′16.8″	OSL	Sand	6.4	Sand in kame field	23 000 ± 6000	R-38	Raukas 2004
	28	Pikasaare	25°51′22.1″	59°26′16.8″	OSL	Sand	8.2	Sand in kame field	16 200 ± 4200	R-39	Raukas 2004
19	29	Pannjärve	27°34′00″	59°16′40″	OSL	Medium sand	5.0	Sand in kame field	72 000 ± 11 000	N-9	Raukas 2004
	30	Pannjärve	27°34′00″	59°16′40″	OSL	Medium sand	5.0	Sand in kame field	75 000 ± 9000	N-10	Raukas 2004
	31	Pannjärve	27°34′00″	59°16′40″	OSL	Medium sand	8.0	Sand in kame field	9800 ± 1100	R-41	Raukas 2004
	32	Pannjärve	27°34′00″	59°16′40″	OSL	Medium sand	8.0	Sand in kame field	11 500 ± 1200	R-42	Raukas 2004
	33	Pannjärve	27°34′00″	59°16′40″	OSL	Medium sand	15.0	Sand in kame field	13 400 ± 1200	R-43	Raukas 2004
20	34	Uljaste	26°48′19″	59°21′00″	OSL	Sand	2.2	Esker deposit	96 000 ± 12 000	R-40	Raukas 2004

Table 1. *Continued*

No. on map	Sample	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
Dated Late-Glacial samples taken above the Otepää stadial deposits between the Otepää and Pandivere ice-marginal zones											
21	35	Taimeaia	26°03′12″	57°49′28″	OSL	Fine sand	2.0	Outwash plain	7500 ± 1100	R-50	Raukas 2004
	36	Taimeaia	26°03′12″	57°49′28″	OSL	Fine sand	2.0	Outwash plain	13 200 ± 1400	R-51	Raukas 2004
	37	Taimeaia	26°03′12″	57°49′28″	OSL	Fine sand	2.0	Outwash plain	70 000 ± 12 000	R-54	Raukas 2004
22	38	Naritsa	26°02′50″	58°08′06″	^{14}C	Soil organics	na	Palaeosoil below lake sand	10 027 ± 67	Tln-2594	Moora et al. 2002
23	39	Puurmani	26°13′50″	58°32′20″	^{14}C AMS	Mammoth molar	na	In lacustrine silt	10 100 ± 100	Hela-423	Lõugas et al. 2002
	40	Puurmani	26°13′50″	58°32′20″	^{14}C AMS	Mammoth molar	na	In lacustrine silt	10 200 ± 100	Hela-425	Lõugas et al. 2002
24	41	Saviku	27°13′52″	58°26′05″	^{14}C	Peaty gyttja	6.9–7.0	Beginning of gyttja	10 200 ± 90	Ta-328	Sarv & Ilves 1975
25	42	Kuliska	27°41′55″	57°58′59″	^{14}C	Lake marl	5.7–5.9	Beginning of lake sediments	10 400 ± 350	Ta-44	Liiva et al. 1966
26	43	Kallukse	26°04′37″	59°21′22″	^{10}Be	Lodikivi erratic	na	Surface	13 020 ± 1117	EST-12	Raukas 2004
27	44	Vedu	26°46′41″	58°30′29″	^{10}Be	Nõiakivi erratic	na	Surface	13 448 ± 1037	EST-13	Raukas 2004
28	45	Laeva	26°21′36.6″	58°28′16.5″	OSL	Medium sand	7.8	Delta deposits	13 800 ± 1500	R-47	Raukas 2004
29	46	Loobu	26°01′51″	59°24′32″	^{14}C	Peat	1.60–1.69	On lacustrine clay	13 970 ± 115	Ta-137	Punning et al. 1968
	47	Loobu	26°01′51″	59°24′32″	^{14}C	Peat	1.70–1.78	On lacustrine clay	14 725 ± 260	Ta-138	Punning et al. 1968
30	48	Tääksi	25°38′31.6″	58°31′08.8″	OSL	Fine sand	6.2	Proglacial outwash	54 000 ± 5000	R-48	Raukas 2004
	49	Tääksi	25°38′31.6″	58°31′08.8″	OSL	Fine sand	6.2	Proglacial outwash	62 000 ± 7000	R-49	Raukas 2004

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Table 1. *Continued*

No. on map	Sample	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
Dated Late-Glacial samples taken between the Haanja and Otepää ice-marginal zones											
31	50	Nõuni	26°31′21″	58°08′25″	^{14}C	Plant detritus	1.25–1.45	Below gravel and sand	10 900 ± 110	Ta-241	Ilves et al. 1969
32	51	Kurenurme	26°41′59″	57°50′24″	^{14}C	Plant detritus	5.8	Between two uppermost tills	12 420 ± 100	Tln-35	Punning et al. 1974
	52	Kurenurme	26°41′59″	57°50′24″	^{14}C	*Salix* wood	5.8	Between two uppermost tills	12 650 ± 520	Ta-57	Liiva et al. 1966
	53	Kurenurme 3	26°41′59″	57°50′24″	OSL	Fine sand	8.1	Between two uppermost tills	12 710 ± 1800	TlnOSL-1433	This paper
33	54	Äidu	na	na	^{10}Be	Rehekivi erratic	na	Surface	13 031 ± 922	EST-16	Raukas 2004
	55	Kurenurme 1	26°41′59″	57°50′24″	OSL	Fine sand	5.2	Between two uppermost tills	14 490 ± 2060	TlnOSL-1434	This paper
34	56	Kaagvere	26°36′44″	58°00′18″	^{14}C	Plant detritus	3.46–3.62	Between two uppermost tills	15 150 ± 575	Ta-50	Liiva et al. 1966
	57	Kaagvere 1	26°36′44″	58°00′18″	OSL	Fine sand	3.3	Between two uppermost tills	21 070 ± 2330	TlnOSL-1432	This paper
	58	Kaagvere 2	26°36′44″	58°00′18″	OSL	Fine sand	5.8	Between two uppermost tills	14 930 ± 1790	TlnOSL-1426	This paper
	59	Kaagvere	26°36′44″	58°00′18″	^{14}C	Plant detritus	4.0	Between two uppermost tills	≥ 30 000	Ta-36	Liiva et al. 1966

Table 1. *Continued*

No. on map	Sample	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
Dated Late-Glacial samples taken beyond the Haanja ice-marginal zone											
35	60	Remmeski	27°20′09″	57°42′40″	^{14}C	Dispersed peat	3.05–3.10	On varved clay and lacustrine silt	10 740 ± 130	Ta-215	Punning et al. 1971
	61	Remmeski	27°20′09″	57°42′40″	^{14}C	Dispersed peat	3.4–3.5	In lacustrine silt on varved clay	10 770 ± 130	Ta-216	Punning et al. 1971
36	62	Viitka	27°19′29″	57°41′07″	^{14}C	Plant detritus	3.5	Below topmost reddish till	10 950 ± 80	Tln-413	Punning et al. 1981
	63	Viitka	27°19′29″	57°41′07″	^{14}C	Peat	3.7–4.0	Below topmost reddish till	11 090 ± 135	Ta-132	Punning et al. 1967
37	64	Viitina	na	na	^{10}Be	Pikasaare erratic	na	Surface	11 004 ± 770	EST-21	Raukas 2004
38	65	Pütsepa	27°16′05″	57°42′15″	^{10}Be	Jeremi erratic	na	Surface	11 131 ± 863	EST-23	Raukas 2004
39	66	Jaanimäe 1	na	na	^{10}Be	Suurkivi erratic	na	Surface	11 574 ± 976	EST-18	Raukas 2004
40	67	Petruse	27°10′54″	57°42′28″	^{14}C	Plant detritus	na	Below topmost reddish till	12 670 ± 200	LU-130A	Punning et al. 1981
	68	Petruse	27°10′54″	57°42′28″	^{14}C	Plant detritus	na	Below topmost reddish till	12 080 ± 120	LU-130B	Punning et al. 1981
41	69	Jaanimäe 2	na	na	^{10}Be	Talukivi erratic	na	Surface	16 251 ± 1121	EST-19	Raukas 2004
Võrtsjärve (Late Weichselian) glacigenic deposits (other than Late-Glacial)											
42	70	Peedu	26°26′30″	58°14′30″	TL	Till	2.0	Topmost reddish-brown till	48 000	TlnTL-36	Kajak et al. 1981
43	71	Rõngu	26°12′43″	58°08′34″	TL	Till	0.9	Topmost reddish-brown till	≥ 75 700	TlnTL-??	Kajak et al. 1981
44	72	Valga	26°02′40″	57°46′57″	TL	Till	4.0	Topmost reddish-brown till	43 000 ± 3000	TlnTL-113	Kajak et al. 1981

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Table 1. *Continued*

No. on map	Sample	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
	73	Valga	26°02′40″	57°46′57″	TL	Till	6.0	Topmost reddish-brown till	80 000 ± 6000	TlnTL-112	Kajak et al. 1981
45	74	Valguta	26°12′26″	58°12′02″	TL	Till	4.1	Topmost reddish-brown till	≥ 124 000	TlnTL-59	Kajak et al. 1981
						Savala (Middle Weichselian) interstadial deposits					
46	75	Mooste	27°13′27″	58°07′33″	^{14}C AMS	Mammoth molar	na	In LG lake sediments	30 640 ± 830	Hela-418	Lõugas et al. 2002
47	76	Heimtali	25°28′16″	58°20′12″	^{14}C AMS	Mammoth tusk	2.5	In glaciofluvial gravel	> 37 000	Hela-420	Lõugas et al. 2002
48	77	Lammasmäe	26°32′14″	59°27′48″	^{14}C AMS	Mammoth tusk	na	In glaciofluvial gravel	> 38 000	Hela-424	Lõugas et al. 2002
49	78	Kallaste	26°34′38″	57°36′57″	^{14}C AMS	Mammoth molar	5.0	In glaciofluvial gravel	> 38 000	Hela-421	Lõugas et al. 2002
50	79	Tahkumägi	26°32′03″	57°33′28″	^{14}C AMS	Mammoth bone	na	In alluvial gravel	> 38 000	Hela-422	Lõugas et al. 2002
51	80	Tudulinna	27°04′24″	59°02′16″	^{14}C AMS	Mammoth tusk	na	In glaciofluvial gravel	> 40 000	Hela-419	Lõugas et al. 2002
52	81	Ihasalu	25°08′50″	59°32′10″	^{14}C AMS	Mammoth molar	na	In beach sand and gravel	> 41 000	Hela-426	Lõugas et al. 2002
53	82	Kammeri 1	26°37′57″	58°10′43″	OSL	Fine sand	7.9	Below 1st till and organic layer	17 180 ± 3050	TlnOSL-1428	This paper
	83	Kammeri 1	26°37′57″	58°10′43″	OSL	Fine sand	10.0	Below 1st till and organic layer	17 650 ± 2330	TlnOSL-1429	This paper
	84	Kammeri 2	26°37′57″	58°10′43″	OSL	Fine sand	9.3	Below 1st till and organic layer	14 060 ± 1640	TlnOSL-1431	This paper
	85	Kammeri	26°37′57″	58°10′43″	OSL	Fine sand	8.9	Below 2nd till	41 600 ± 3900	TlnOSL-1367	This paper
	86	Kammeri	26°37′57″	58°10′43″	OSL	Fine sand	9.1	Below 2nd till	41 300 ± 3500	TlnOSL-1368	This paper
	87	Kammeri	26°37′57″	58°10′43″	OSL	Fine sand	9.9	Below 2nd till	43 200 ± 3600	TlnOSL-1369	This paper
54	88	Pehka	26°20′17″	59°29′30″	OSL	Sand	6.9	Below beach and fluvioglacial gravel	26 800 ± 3500	TlnOSL-1337	Kadastik 2004

Table 1. *Continued*

No. on map	Sample	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
43	89	Rõngu	26°12′43″	58°08′34″	OSL	Fine sand	2.8	Between topmost till and Eemian	32 100 ± 4400	TlnOSL-1364	This paper
	90	Rõngu	26°12′43″	58°08′34″	OSL	Fine sand	4.3	Between topmost till and Eemian	36 700 ± 6200	TlnOSL-1365	This paper
	91	Rõngu	26°12′43″	58°08′34″	OSL	Fine sand	9.0	Below Eemian organic layer	39 500 ± 2300	TlnOSL-1366	This paper
55	92	Kõrveküla	26°47′07″	58°25′29″	OSL	Fine sand	2.9	Above Holsteinian organic layer	68 400 ± 4200	TlnOSL-1360	This paper
	93	Kõrveküla	26°47′07″	58°25′29″	OSL	Fine sand	3.0	Above Holsteinian organic layer	69 500 ± 3700	TlnOSL-1363	This paper
	94	Kõrveküla	26°47′07″	58°25′29″	OSL	Fine sand	6.5	Below Holsteinian organic layer	81 200 ± 7800	TlnOSL-1362	This paper
	95	Kõrveküla	26°47′07″	58°25′29″	OSL	Fine sand	6.7	Below Holsteinian organic layer	93 400 ± 3700	TlnOSL-1361	This paper
Valgjärve (Early Weichselian) till and related glacigenic deposits											
42	96	Peedu	26°26′30″	58°14′30″	TL	Till	3.0	Second till from top	65 000	TlnTL-41	Kajak et al. 1981
	97	Peedu	26°26′30″	58°14′30″	TL	Till	5.75	Second till from top	75 000	TlnTL-40	Kajak et al. 1981
44	98	Valga	26°02′40″	57°46′57″	TL	Till	17.0	Second till from top	153 000 ± 10 000	TlnTL-114	Kajak et al. 1981
45	99	Valguta	26°12′26″	58°12′02″	TL	Till	10.1	Second till from top	46 000	TlnTL-51	Kajak et al. 1981
	100	Valguta	26°12′26″	58°12′02″	TL	Till	13.8	Second till from top	50 000	TlnTL-54	Kajak et al. 1981
	101	Valguta	26°12′26″	58°12′02″	TL	Till	18.0	Second till from top	59 000	TlnTL-55	Kajak et al. 1981
	102	Valguta	26°12′26″	58°12′02″	TL	Till	20.3	Grey till	76 000	TlnTL-65	Kajak et al. 1981
	103	Valguta	26°12′26″	58°12′02″	TL	Fine sand	22.0	Below 3rd till from top	66 500	TlnTL-67	Kajak et al. 1981

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Table 1. *Continued*

No. on map	Sample	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
						Prangli (Eemian) interglacial deposits					
42	104	Peedu	26°26′30″	58°14′30″	^{14}C	Plant detritus	6.68–6.77	Below 2nd till from top	20 673 ± 100	Ta-63	Liiva et al. 1966
	105	Peedu	26°26′30″	58°14′30″	^{14}C	Wood	7.6–7.8	Below 2nd till from top	39 180 ± 1960	Ta-136	Punning 1970
	106	Peedu	26°26′30″	58°14′30″	^{14}C	Peat	7.6–7.8	Below 2nd till from top	39 700 ± 850	Ta-254	Punning 1970
	107	Peedu	26°26′30″	58°14′30″	^{14}C	Humus from peat	7.6–7.8	Below 2nd till from top	31 200 ± 800	Ta-254a	Punning 1970
	108	Peedu	26°26′30″	58°14′30″	TL	Fine sand	4.43	Below 2nd till from top	90 000	TlnTL-37	Kajak et al. 1981
	109	Peedu	26°26′30″	58°14′30″	TL	Silt	5.3	Below 2nd till from top	100 000	TlnTL-38	Kajak et al. 1981
	110	Peedu	26°26′30″	58°14′30″	TL	Fine sand	5.75	Below 2nd till from top	40 000	TlnTL-39	Kajak et al. 1981
43	111	Rõngu	26°12′43″	58°08′34″	^{14}C	Peat	6.0–6.7	Below 1st till from top	≥ 30 000	Ta-45	Liiva et al. 1966
	112	Rõngu	26°12′43″	58°08′34″	^{14}C	Gyttja	6.7–7.2	Below 1st till from top	≥ 30 000	Ta-46	Liiva et al. 1966
						Upper Ugandi (Warthe) glacigenic deposits					
43	113	Rõngu	26°12′43″	58°08′34″	TL	Till	14.0	Till below Eemian organic layer	≥ 110 000	TlnTL-??	Kajak et al. 1981
44	114	Valga	26°02′40″	57°46′57″	TL	Till	60.0	3rd till from top	216 000 ± 10 000	TlnTL-115	Kajak et al. 1981
						Middle Ugandi interglacial deposits					
56	115	Arumetsa	24°32′54″	58°04′20″	^{14}C	Wood	2.0	In deformed lacustrine clay	≥ 35 535	Ta-2845	This paper
	116	Arumetsa	24°32′54″	58°04′20″	^{14}C	Wood	2.0	In deformed lacustrine clay	≥ 50 000	Ta-2846	Rattas et al. 2001

Table 1. *Continued*

No. on map	Sam-ple	Section/ location	Coordinates x	Coordinates y	Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
						Lower Ugandi (Drenthe) glacigenic deposits					
45	117	Valguta	26°12′26″	58°12′02″	TL	Till	32.0	Violet-reddish till, 4th from top	≥ 119 000	TlnTL-66	Kajak et al. 1981
						Karuküla (Holsteinian) interglacial deposits					
55	118	Kõrveküla	26°47′07″	58°25′29″	^{14}C	Wood	3.5	Under till, above gyttja	41 000 ± 700/2100	Tln-328	Punning et al. 1980
	119	Kõrveküla	26°47′07″	58°25′29″	^{14}C	Humus from gyttja	5.2–7	Below till and sand	47 760 ± 11 000	Tln-384	Punning et al. 1983
	120	Kõrveküla	26°47′07″	58°25′29″	^{14}C	Humus from gyttja	5.2–7	Below till and sand	≥ 50 300	Tln-384A	Rajamäe 1982
57	121	Karuküla	24°58′08″	58°05′44″	^{14}C	Peat ?	1.49–1.64	In sand below topmost till	≥ 33 000	Mo-375	Vinogradov et al. 1966
	122	Karuküla	24°58′08″	58°05′44″	^{14}C	Wood	1.5–1.7	In sand below topmost till	33 450 ± 800	Ta-99	Punning et al. 1967
	123	Karuküla	24°58′08″	58°05′44″	^{14}C	Wood	1.6	In sand below topmost till	≥ 52 780	LU-44	Arslanov 1971
	124	Karuküla	24°58′08″	58°05′44″	^{14}C	Peat	1.5–1.7	In sand below topmost till	48 100 ± 1700	Ta-100	Punning et al. 1967
	125	Karuküla	24°58′08″	58°05′44″	^{14}C	Peat	1.5–1.7	In sand below topmost till	≥ 53 240	LU-123	Arslanov 1971
	126	Karuküla	24°58′08″	58°05′44″	^{14}C	Peat	1.95–2.15	In sand below topmost till	48 100 ± 1650	Ta-101	Punning et al. 1967
	127	Karuküla	24°58′08″	58°05′44″	^{14}C	Gyttja	2.35–2.55	In sand below topmost till	≥ 45 000	Ta-106	Punning et al. 1967
	128	Karuküla	24°58′08″	58°05′44″	^{14}C	Wood	1.65	In sand below topmost till	40 800 ± 700	Ta-275	Ilves et al. 1974

Continued overleaf

Table 1. *Continued*

No. on map	Sam-ple	Section/ location	Coordinates		Method	Dated material	Depth, m	Superposition	Age, yr BP	Lab. ID/ refer. No.	Reference
			x	y							
	129	Karuküla	24°58′08″	58°05′44″	^{14}C	Wood	1.65	In sand below topmost till	≥ 48 750	Birm-249	Shotton & Williams 1973
	130	Karuküla	24°58′08″	58°05′44″	^{14}C	Peat from wood	2.05	In sand below topmost till	47 800 ± 1100	Ta-276	Ilves et al. 1974
	131	Karuküla	24°58′08″	58°05′44″	^{14}C	Peat	2.3	In sand below topmost till	48 800 ± 1200	Ta-277	Ilves et al. 1974
	132	Karuküla	24°58′08″	58°05′44″	^{14}C	Wood	1.6–1.7	In sand below topmost till	48 600 ± 1600	GSC-1976	Blake 1975
	133	Karuküla	24°58′08″	58°05′44″	^{14}C	na	1.8–1.9	In sand below topmost till	≥ 46 000	GSC-1975	Blake 1975
	134	Karuküla	24°58′08″	58°05′44″	^{14}C	Cellulose from wood	1.6	In sand below topmost till	≥ 51 200	Tln-443	Punning et al. 1983
	135	Karuküla	24°58′08″	58°05′44″	^{14}C	Lignine from wood	1.6	In sand below topmost till	≥ 52 100	Tln-461	Punning et al. 1983
	136	Karuküla	24°58′08″	58°05′44″	^{14}C	Cellulose from wood	1.6	In sand below topmost till	≥ 50 700	Tln-452	Punning et al. 1983
	137	Karuküla	24°58′08″	58°05′44″	^{14}C	Lignine from wood	1.6	In sand below topmost till	≥ 52 200	Tln-466	Punning et al. 1983
	138	Karuküla	24°58′08″	58°05′44″	^{14}C	Lignine, cellulose	1.3	In sand below topmost till	≥ 58 600	Tln-524	Rajamäe 1982
	139	Karuküla	24°58′08″	58°05′44″	^{14}C	Lignine, cellulose	1.9	In sand below topmost till	55 000 ± 8100/4000	Tln-525	Rajamäe 1982
	140	Karuküla	24°58′08″	58°05′44″	^{14}C	Lignine, cellulose	2.0	In sand below topmost till	54 000 ± 6600/3600	Tln-526	Rajamäe 1982

na – not available

Sixty-nine out of the 140 dates are from Late-Glacial times and should refine the deglaciation chronology. The information on the dated material, sections, results, and references is summarized in Table 1. In a few cases some data (e.g. coordinates of a dated section, depth of sampling, laboratory index of dating) were not available to the author. Datings in Table 1 are presented in the increasing order, based on the age of the uppermost sample if more than one date exists per section, and grouped by zones of deglaciation or by stratigraphic units to which the dated samples have been assigned. The Estonian stratigraphic terminology (Raukas & Kajak 1995; Pirrus & Raukas 1996; Raukas et al. 2004) is used throughout the text. The ^{14}C ages are given in uncalibrated format.

RADIOCARBON DATINGS

The oldest dated sequences in Estonia are the two known Holsteinian organogenic deposits (lacustrine, bog) in the Karuküla and Kõrveküla sections (Fig. 1, Nos. 57 and 55, respectively). Since its discovery in 1939, the Karuküla section had been correlated with the Riss-Würm Interglacial (Orviku 1944, 1960), Brørup Interstadial (Orviku & Pirrus 1965) or Middle Weichselian (Punning et al. 1969; Serebryannyj et al. 1969) interstadial or interglacial. The latest correlation was supported by 17 ^{14}C datings, most of which gave infinite ages (Table 1). The Holsteinian age of Karuküla deposits was first suggested by Danilans (1966). Later the Holsteinian age of the Karuküla and Kõrveküla sections was established by detailed palynological and carpological investigations (Velichkevich & Liivrand 1976; Liivrand & Saarse 1983; Liivrand 1984, 1991). Holsteinian pollen zones of the sections coincide fully and the biostratigraphic correlation with other known Holsteinian sections (Ulmale, Pulvernieki, Butenai, Likhvin) in northeastern Europe is certain (Velichkevich & Liivrand 1976; Liivrand 1984, 1991; Kondratiene 1993). However, detailed coring has established that the interglacial deposits at both Holsteinian sites are allochthonous (Liivrand & Saarse 1983; Levkov & Liivrand 1988; Liivrand 1991). In the course of our recent study four new OSL dates for fine-grained fluvial sands from above (68 400 ± 4200 and 69 500 ± 3700 OSL yr BP) and below (81 200 ± 7800 and 93 400 ± 3700 OSL yr BP) the interglacial deposits of the Kõrveküla section were obtained. The OSL ages of the fluvial deposits confirm the allochthonous bedding of the interglacial gyttja with wood and peat. They do not confirm the Holsteinian age of the interglacial strata but do endorse the conclusion of palynological investigations on invalidity of altogether 23 ^{14}C dates from the Kõrveküla and Karuküla sections.

The history of dating the Prangli (Eemian) strata in Estonia is similar to that of Karuküla. Before the Eemian, the character of pollen assemblages zones was established in the Prangli, Rõngu, Peedu, and other sections (see Liivrand 1984, 1991). Six ^{14}C dates were determined, ranging between 20 000 and 40 000 ^{14}C yr BP

(Table 1). The first dates referring to the Eemian age (90 000 and 100 000 TL yr BP; Kajak et al. 1981) came from the alluvial sand and silt of the Peedu section (Fig. 1, No. 42) in southeastern Estonia. Recently the local stratotype section of the Eemian continental deposits at Rõngu (Fig. 1, No. 43) was re-examined and the fine laminated fluvial sand above and below the interglacial strata was dated using the OSL method. The dates obtained (32 100 ± 4400 from above, and 36 700 ± 6200 and 39 500 ± 2300 OSL yr BP from below, Table 1) confirm the ages (≥30 000 ^{14}C yr BP) of the earlier ^{14}C dates (Liiva et al. 1966) from the organic sediments. Nevertheless, palynological and diatom investigations have firmly established an Eemian age of the deposits in Rõngu and correlation to marine Eemian sections (Cheremisinova 1961; Liivrand 1984, 1991; Kondratiene 1993). Pollen diagrams compiled and interpreted by Liivrand (1984, 1991) show the entire interglacial cycle of vegetation development during this period. Similarly to Karuküla, most of the Prangli interglacial deposits in Estonia are found in glaciotectonically dislocated positions (Orviku 1939; Liivrand & Saarse 1976; Liivrand 1991; Rattas & Kalm 1999, 2004). Assuming that the conclusions from the pollen analysis and bedding conditions in the Rõngu section are valid, the OSL ages of the sands containing the erratics of Eemian layers designate glaciotectonic dislocations, which injected rafts of Eemian deposits into the Middle Weichselian sands. The seven oldest ^{14}C AMS dates of mammoth finds from Estonia published recently (Lõugas et al. 2002) cover a time span of 30 600 to over 41 000 ^{14}C yr BP (Table 1), suggesting the ice-free late Middle Weichselian in Estonia. However, most of the mammoth finds gave infinite ages and may be as old as Early Weichselian (Lõugas et al. 2002).

Since the beginning of research into the deglaciation history of Estonia, the Haanja Stade has always been considered the oldest Late Weichselian stadial on Estonian territory. The age of the Haanja Stade (ca 13 400–13 600 ^{14}C yr BP, Pirrus & Raukas 1996) was determined from dating the Raunis intermorainic section (Dreimanis & Zelčs 1995; Raukas 2004; Raukas et al. 2004; Zelčs & Markots 2004) in northern Latvia. All measured Estonian ^{14}C dates from beyond the Haanja marginal belt (see Table 1) are restricted to superficial organogenic deposits (Remmeski, Fig. 1, No. 35) or to plant detritus and peat buried under till on slopes of hummocky relief (Viitka, No. 36; Petruse, No. 40). They are all younger than that from the Raunis section (Zelčs & Markots 2004) and their interstadial nature is unclear. This feature may attest to a lengthy stagnant ice field on insular heights of glacial origin (Karukäpp & Raukas 1994; Lundqvist & Wohlfarth 2001), resultant slope- and thermokarst processes, and burial of organic sediments under colluvium. The ^{14}C dates obtained from those deposits do not indicate the age of possible ice advance, but instead may refer to the length of periglacial slope processes that were able to cover organic deposits under slumps and colluvium.

The distribution of ^{14}C ages against the chronostratigraphic scale (Fig. 2) shows a well-dated Late-Glacial, but also refers to ice-free late Middle Weichselian in Estonia.

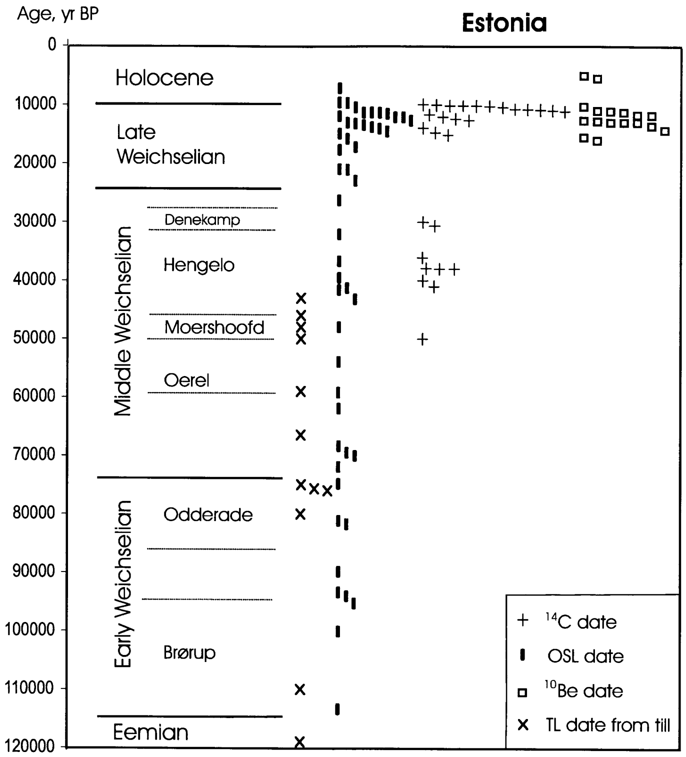

Fig. 2. Late Pleistocene datings from Estonia against the Late Pleistocene chronostratigraphy of Scandinavia (Donner 1995).

LUMINESCENCE (TL, OSL) DATINGS

Fifteen TL dates for different-aged tills in Estonia (Table 1) are available from the late 1970s (Kajak et al. 1981), the time of an over-optimistic approach to the developing TL method. Three of these dates are attributed to Ugandi (Saale) tills, the age of which originates from the superposition of the sampled layer (Kajak et al. 1981), i.e., the third (grey) or fourth (reddish-brown) till from the top, or under the Prangli (Eemian) interglacial sediments. Although the ages obtained are all older than 110 000 TL years and may be considered Ugandian, the dating of tills itself, because of their highly variable genesis and problematic zeroing is very questionable (Punning & Raukas 1983; Aitken 1985). Eight TL dates are available (Kajak et al. 1981) for the allegedly Valgjärve (Early Weichselian) purplish-grey till in southeastern Estonia (Raukas 1978; Kajak et al. 1981; Raukas & Kajak 1995), which range between 153 000 and 46 000 yr BP (Table 1). The TL method, arguably suitable for the dating of tills, gave the dates (the 153 000 year age excluded) mostly reflecting Middle rather than Early Weichselian (Valgjärve) ages.

The new Early Weichselian (68 400–93 400 yr BP) OSL dates from the Kõrveküla section discussed earlier, together with 86 000–105 000 yr EPR ages of *Portlandia arctica* shells from Latvia (Molodkov et al. 1998; Zelčs & Markots 2004) suggest an ice-free Eastern Baltic during the Early Weichselian. Other new OSL dates of fine-grained laminated sands from the Pehka (Kadastik 2004; No. 54 in Fig. 1), Kammeri, and Rõngu sections (see Table 1) cover a time span of 26 800–43 200 OSL yr BP. Although the OSL dates range widely in different sections at the Kammeri site (Fig. 1, No. 53), the remaining ages show that Estonia was ice-free at least in the time span of 26 800–39 500 yr BP.

Recently a lengthy overview of the application of OSL and ^{10}Be methods to establishing deglaciation chronology for Estonia with a number of new datings was published (Raukas 2004). According to Raukas (2004), the errors of the OSL datings presented by him are often bigger than the duration of the whole deglaciation of the Estonian territory and the possibilities of the OSL method are highly overestimated. It may well be so. However, if we consider the OSL dates to refer solely to the time of the last natural bleaching of deposits, and do not assume that 100% of glacigenic sands and silts got bleached during the last deposition, we may easily explain, for example, the 59 000 OSL yr date (Valgejõe) from the bottom of the Late-Glacial section of the glaciofluvial delta. More questionable are the early Holocene ages (Raukas 2004) of the topmost samples from the Palivere, Pannjärve, and Taimeaia sections. Nevertheless, the youngest Late-Glacial OSL dates from each of the sections presented by Raukas (2004) are mostly in a fair agreement with the early datings from the same deglaciation zones (Table 1). Only the error bars of the OSL datings are greater than that of ^{14}C and also ^{10}Be datings. Whatever the correctly estimated bleaching time (OSL age) was, it does refer to the time of sediment's occurrence in surficial conditions, probably in ice-free or periglacial situation. When plotting all available OSL dates, regardless of the expected age and superposition of dated layers, next to the Late Pleistocene chronostratigraphic scale (Fig. 2), we see (with the exception of the final 6000 years of the Late Weichselian) relatively even distribution of the dates in time. From this we derive a conclusion that there is no space for long-lasting ice-covers – glaciations of over 20 000 years in duration – in Estonia during the Late Pleistocene.

COSMOGENIC ^{10}Be DATINGS

The first ^{10}Be datings from Estonia became available very recently (Rinterknecht et al. 2003; Raukas 2004). The boulder exposure age method, discussed by Raukas (2004), is applicable in Estonia only in Late-Glacial chronology if glacial geology is concerned. Raukas (2004) provides 17 ^{10}Be dates obtained in collaborative research with P. Clark, V. Rinterknecht, and others. Rinterknecht et al. (2003) and

Raukas (2004) dated the Palivere end moraine zone at 10 000 ± 1300 ^{10}Be yr BP (weighted mean age), one single boulder on the Pandivere end moraine at 13 020 ± 1117 ^{10}Be yr BP, and the Haanja (North Lithuanian) end moraine at 13 000 ± 800 ^{10}Be yr (weighted mean age). Earlier Tschudi et al. (2000) have dated the younger Salpausselkä I zone end moraine at Lahti, southern Finland, at 11 930 ± 950 or 12 250 ± 980 (with or without consideration of erosion in ^{10}Be dating) years ago. Unexpectedly young ^{10}Be ages of the Palivere zone between the older Pandivere zone and younger Salpausselkä I zone are explained (Rinterknecht et al. 2003; Raukas 2004) by submergence of boulders by the Baltic Ice Lake and other local water-bodies, which substantially reduced the production rate of ^{10}Be for that period of time. The ^{10}Be ages provided for the Pandivere and Haanja end moraines differ from the presently used deglaciation age-model (Raukas 2004; Raukas et al. 2004) less than the inaccuracy of ^{10}Be datings. Thus the ^{10}Be method, because of relatively large uncertainty, does not contradict the earlier age estimations, nor can it refine the existing Late-Glacial chronology in Estonia.

CONCLUSIONS

Chronological data on Estonian Pleistocene are relatively abundant (140 available datings), but scattered. Half of the data cover only the youngest, 5000–6000 year part of the Late Weichselian. The almost even distribution of OSL datings against the Late Pleistocene chronostratigraphic scale, together with new ^{14}C AMS dates of mammoth finds (Lõugas et al. 2002) and EPR ages of *Portlandia arctica* shells from Latvia (Molodkov et al. 1998) leave no time-space for long-lasting (> ca 20 000 years) glaciations in the Eastern Baltic during the last 100 000 years.

Results of the ^{10}Be method (Rinterknecht et al. 2003; Raukas 2004), for the first time applied to the study of deglaciation chronology of Estonian territory, do not contradict the earlier age estimations. However, due to relatively large uncertainties of the method, the results were not able to refine the existing Late-Glacial chronology in Estonia.

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Eesti Pleistotseeni kronoloogiline andmestik

Volli Kalm

Eesti Pleistotseeni kronostratigraafia põhineb käesoleval hetkel 60 radiosüsiniku- (^{14}C ja ^{14}C AMS), 63 TL- või OSL- ja 17 ^{10}Be-meetodiga tehtud vanusemäärangul, kokku 57 erinevast läbilõikest või objektist. Ajaliselt katavad dateeringud ligikaudu 200 000 aastat Pleistotseeni noorimast osast. Artiklis on esmakordselt kokku võetud ja süstematiseeritud 40-aastase geokronoloogilise uurimistöö kõik kättesaadavad faktilised andmed ning neid kriitiliselt hinnatud. Pooled 140 dateeringust langevad Pleistotseeni noorimasse, 5000–6000 aasta pikkusesse intervalli, iseloomustades eelkõige hilisglatsiaali. Uusimad OSL-dateeringud koos varasemate palünoloogiliste ja karpoloogiliste uuringute tulemustega lubavad väita, et ligikaudu kolmandikku 1960. ja 1970. aastatel tehtud ^{14}C-dateeringutest ei saa usaldada põhjusel, et dateeritava materjali tegelik vanus ületas meetodi määramispiiri. Samuti on 1980. aastatel moreenist saadud TL-vanused ebausaldusväärsed TL-signaali “nullistumise” problemaatilisuse tõttu. ^{10}Be-meetodi tulemused Balti jääpaisjärve veetasemest kõrgemale jäävate hilisglatsiaali servamoodustiste dateerimisel ei läinud konflikti varasemate vanusemäärangutega, kuid suhteliselt suure määramisvea tõttu ei võimaldanud neid ka täpsustada.