GEOCHRONOMETRIA 36 (2010), pp 47-54
DOI 10.2478/v10003-010-0011-7

Available online at
versita.metapress.com and www.geochronometria.pl

CHRONOLOGY OF THE LAST DEGLACIATION IN THE SOUTH-EASTERN BALTIC REGION ON THE BASIS OF RECENT OSL DATES

ANTO RAUKAS[1], WOJCIECH T.J. STANKOWSKI[2], VITĀLIJS ZELČS[3] and PETRAS ŠINKUNAS[4]
[1]*Institute of Geology, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia*
[2]*Institute of Geology, Adam Mickiewicz University, Makow Polnych 16, 61-606 Poznan, Poland*
[3]*Department of Geomorphology and Geomatics, University of Latvia, Rainis Blvd. 19, LV 1586 Riga, Latvia*
[4]*Institute of Geology and Geography, T. Shevcenkos 13, 03223 Vilnius, Lithuania*

Received 7 October 2009 Accepted 24 March 2010

Abstract: The study of the deglaciation chronology in the south-eastern Baltic Region belonging to the outer zone of the last Pleistocene glaciation has a long history. The Finnish investigator H. Hausen (1913) who worked in the north-western portion of the East-European Plain at the beginning of the 20th century was the first to attempt a reconstruction of the course of glacial retreat during the last glaciation. At that time investigators had no physical dating methods and the time scale based on varvometric method, introduced by the Swedish geologist G. de Geer (1912) who divided the deglaciation history of Scandinavia into Daniglacial, Gotiglacial and Finiglacial, each of which had different palaeoglaciological conditions. During last decades different dating methods, including ^{14}C, ESR, luminescence methods and ^{10}Be techniques have been used, but they could not help essentially improve the existing stratigraphical charts and many problems of topical interest in the history of deglaciation have not been solved yet. During last years the first two authors have studied the suitability of OSL method for the geochronological purposes, paying the most attention to the waterlaid sediments. In the first step they have found the most promising genetical varieties of glaciofluvial sediments (glaciofluvial deltas and sandurs) and in this paper they widened the study area to all three Baltic states with close cooperation with Latvian and Lithuanian colleagues. The obtained results demonstrated, that not all mineral grains in the uppermost glaciofluvial and glaciolacustrine sediments were fully bleached during the last deglaciation. Probably the older sediments also influenced to the luminescence results. It means, that stratigraphic conclusions based on single dates or their small sets are inadmissible and in each case luminiscence dating requires a verification using other methods.

Keywords: deglaciation chronology; South-eastern Baltic Region; ice marginal formations; glaciofluvial deposits; TL and OSL dates.

1. INTRODUCTION

Karl Eduard Eichwald (1795-1876) was the first who spoke about the ancient ice sheets in the Baltic Provinces (Eichwald, 1853). Already in 1879 Constantin Caspar Andreas Grewingk (1819-1887), professor of mineralogy at the Tartu University, established that southern Estonia and northern Latvia (Livonia) had been glaciated at least twice (Grewingk, 1879). The Finnish investigator Hans Magnus Hausen (1884-1979), who worked in the north-western portion of the East-European Plain at the beginning of the 20th century, was the first to attempt a reconstruction of the course of glacial retreat during the last glaciation. In his famous monograph *Materialen zur Kenntnis der Pleistozänen Bildungen in den russischen Ostseeländern* (Hausen, 1913) he presented palaeogeographical schemes, which showed successive locations of the active glacier`s margin and the distribution of proglacial lakes. At that time the investigators had no physical dating methods and the age calculations based on the varvometric method, introduced by the Swedish geologist Gerard de Geer (1912). He divided the deglaciation history of Scandinavia into three major stages – Daniglacial (20,000-13,000), Gotiglacial (13,000-10,000) and Finiglacial (10,000-8,000 years ago) – each of which had different palaeoglaciological conditions. Varvometric method of investigation enabled the establishment of a more or less real geochronology based on counts of annual sediment layers.

Corresponding author: A. Raukas
e-mail: anto.raukas@gi.ee

ISSN 1897-1695 (online), 1733-8387 (print) © 2010 GADAM Centre,
Institute of Physics, Silesian University of Technology.

Nowadays we have in use many different physical methods of dating, including radiocarbon (^{14}C), electron spin resonance (ESR), cosmogenic beryllium (^{10}Be), thermoluminescence (TL) and optically stimulated luminescence (OSL) methods. Up to now the results of different physical dating methods did not prove satisfactory, alongside reliable dates a lot of entirely unreliable dates were obtained (Raukas, 2004; Raukas and Stankowski, 2005 a.o). Controversial results are mainly depending on geological factors, because the deposits have accumulated in extremely different sedimentological environments and often re-deposited. But with no doubts physical grounds of study methods need significant improvement also.

Different views to the ice retreat and sedimentation processes

That to decide about the reliability of the dates we should look at first to the possible mechanisms of the ice retreat and formation of landforms and deposits in the study area. Concerning the subglacial transport of debris, two mechanisms were considered in the Northern and Eastern Europe during the 19th and the first half of the 20th century: glacial drag under the ice sole, and transport of debris in the basal part of glacier ice. It was emphasized that till was left behind by passive melting of stagnant ice. Lavrushin (1970) stated that till had accumulated prevailingly below the moving ice and proposed a classification of dynamic facies and subfacies of ground moraines (in the sense of till), where several descriptive names of genetically diverse moraines (tills) appeared, such as facies of plastic flow, or monolithic (in sense of massive) moraine, facies of large rafts, facies of imbricate or scaly moraine, facies of altered moraine.

In the south-eastern Baltic Region palaeoglaciological processes differed significantly. Daniglacial in Lithuania and Belarus was characterised by the development of a thick cover of glacial deposits in the marginal areas of an extensive glacier. In contrast to the Daniglacial and Finiglacial, the Gotiglacial stage in Latvia and Estonia was specified by a high activity of the ice streams and lobes, and a highly variable environment of glacial morphogenesis in different areas.

The Scandinavian continental glacier had a radial-sectoral structure and formed almost concentric belts of the ice marginal formations around the central part of the ice sheet (Aseyev, 1974). Ice streams with different velocity and energy alternated regularly with ice-divide areas. Glacial accumulation accompanied by high glaciotectonic activity was concentrated to interlobate subglacial uplands resulting in the formation of a peculiar type of uplands – insular glaciostructural-accumulative heights (Karukäpp *et al.,* 1999). The formation of such heights included subglacial, englacial, frontal and stagnant ice stages of morphogenesis (ibid). These heights have a bedrock plinth and are composed of several till beds with related intertill deposits.

In the thirties of the last century, with the identification of the interstadial deposits between till units, investigators in the south-eastern Baltic Region started to discuss the oscillatory character of the ice margin recession and later on, in the mid-sixties, established the highly dynamic character of the receding ice sheet. Ice retreats of this kind were considered to have had a range of 600-700 km (Raunis interstadial) and even to 1000 km (Ula interstadial). In view of the relatively short duration of the above mentioned warm intervals doubts soon arose as to the reliability of such readvances (Serebryanny and Raukas, 1966).

Opinions differed regionally as well. Thus most of the Lithuanian scientists supported the idea that the glaciers stayed active practically until they melted (e.g. Basalykas, 1969). At the same time leading Quaternary geologist of Latvia Danilans (1963) believed that during deglaciation the whole Latvia was covered by a set of large dead ice fields. In Estonia scientists concluded that the hilly topography of South Estonia was formed mainly due to effect of stagnant ice, whereas that of North Estonia was shaped by active ice (Raukas and Karukäpp, 1994).

Nowadays most Quaternary geologists in the area under consideration support the concept of a limited scale of stadial movements of ice cover and remarkable spread of stagnant ice. Probably the areal deglaciation of ice sheet prevailed against the frontal one. This idea is also supported by the authors of this paper and is taken as a base for age interpretations. In the course of deglaciation active, passive and dead ice conditions probably underwent a gradual change depending upon the climate and bedrock topography. Supraglacial and re-deposited by meltwater subglacial tills, and collapses of ice cavities were common in dead-ice areas, which is why organic layers with different ages often occur in unusual stratigraphic position. They exhibit both horizontal and vertical displacement and as well as time transgressive overlapping of glacial processes.

2. CHOOSING THE MATERIAL FOR DATING

In the seventies and eighties of the last century all types of the Pleistocene deposits, including tills were dated by TL method. As already mentioned above, the basal till was mostly formed below the moving ice. Therefore its mineral grains could not be bleached. It is widely accepted that from all genetic types of Quaternary sediments traditionally most promising objects were thought to be aeolian, shallow basin and glaciofluvial sediments. Sands from the inland late-glacial dunes are really rather good objects for dating. Nevertheless they should be, at least partly, several times re-deposited and they are located sporadically, what hampers their correlation with ice-marginal formations.

According to Gudelis (1963), ice-marginal formations are divided into frontal, intramarginal and extramarginal ones. Deposits of radial eskers and fluviokames are conventionally regarded as englacial glaciofluvial deposits, and those of glaciofluvial deltas and outwash plains (sandurs) as extramarginal features. Glaciofluvial deposits form also kame terraces and often fill ancient valleys. In general, glaciofluvial deposits show great variations in the granulometric composition and structure, but also in the lithic and mineral composition, everywhere closely connected with the composition of adjacent till and bedrock.

In the first step of our studies we tried to sample all genetical varieties of glaciofluvial deposits (Raukas, 2004; Raukas and Stankowski, 2005), but received mostly unreliable dates. For example, for radial eskers of the last deglaciation in several sections the age dates were close to 100,000 OSL years. Sampling of kames (crevasse fillings) was not promising either. It is understandable, because eskers and kames formed in dead ice, often below or inside the ice and had very limited possibilities for bleaching.

Based on the palynological, varvometrical and radiocarbon dates from both the study area and its neighbourhood, it may be concluded that the deglaciation started in Lithuania somewhere 18,000 ^{14}C conventional years BP, and Estonia was freed from the ice no later than 11,000 ^{14}C years BP. It means that reliable OSL dates must fit to this time span.

For the dating in this paper we have choosen mainly sediments of sandurs, kame terraces, proglacial and ancient river deltas, and shallow meltwater basins as most promising varieties of glaciofluvial sediments from the south-eastern Baltic countries: Lithuania, Latvia and Estonia. The positions of examined sites and their relationship to the last glaciation retreat is shown in **Fig. 1**.

Fig. 1. *Location of the OSL dating sites and the most important ice marginal positions in the territory of the Eastern Baltic countries. Compiled by V. Zelčs and A. Raukas. Black triangles and codes to them indicate location of OSL dating sites:*

EE1 – Misso, EE2 – Aabissaare, EE3 – Laguja, EE4 – Tõrva, EE5 – Tääksi; LV1 – Pentsils-1, LV2 – Pentsils-2, LV3 – Dores, LV4 – Lorupe-1, LV5 – Lorupe-2, LV6 – Lodesmuiža, LV7 – Smeceres sils, LT8 – Svente, LT1 – Ula, LT2 – Kvestai, LT3 – Bebrujai, LT4 – Stupurai.

Ice marginal positions: 1 –limit of the Last glacial maximum (Brandenburgian (Grūda); 2 – Frankfurtian (Žiogeliai); 3 – Pomeranian (Aukštaičiai); 4 – South-Lithuanian; 5 – Middle Lithuanian; 6 – North-Lithuanian (Linkuva, Haanja); 7 – Otepää; 8 – Sakala (Valdemārpils); 9 – Pandivere, 10 – Palivere.

It should be mentioned that obtained results of dating varied and in many cases seems to be very difficult to accept them from simple morphogenetic point of view. To the verification of getting results we present also data of sediments from the Salpausselkä ice marginal formations in Finland and the Kaali impact site on the Island of Saaremaa, Estonia. For the geologically well documented Salpausselkä marginal formation, we have received OSL date of 10.42 ka (Gd TL-930). The sample was taken from the superficial position (~2 m in depth) of outcrop located on the N side of Lokia-Ekenes-Hanko road, in the neighbourhood of Ekenes – 60º06´49.8´´N, 23º47´55.9´´ Tschudi *et al.* (2000) dated the Salpausselkä I at Lahti, southern Finland, at 11.93±0.95 or 12.25±0.98 ^{10}Be ka (without or with consideration of erosion in ^{10}Be dating), while Rinterknecht *et al.* (2006) estimated ^{10}Be exposure error weighted mean age of Salpausselka I Moraine at 12.5±0.7 ka. The OSL dates from Kaali area showed a big dispersion between 11.4 and 4.25 ka. It can be explained by the influence of parent rocks (Palaeozoic bedrock and Quaternary deposits) as well as impact effects (Stankowski, 2009; Stankowski *et al*., 2007).

The field works and laboratory procedures

All samples were taken by the second author from outcrops. After the cleaning of the wall surface up to 20-30 cm, horizontal borings were performed (**Fig. 2**) to about 50 cm. Special care was taken to get sediment in natural condition (**Fig. 3**).

All laboratory measurements were done in the laboratory of the Institute of Physics at the Silesian University of Technology under A. Bluszcz management. The laboratory procedures were described in detail in the paper Raukas and Stankowski (2005).

3. OBTAINED RESULTS

The main aim of the present study was to find out the suitability of the OSL method for dating at least some varieties of glaciofluvial and glaciolacustrine deposits. Luminescence dating of the glacioaquatic sediments in the Baltic States goes back to the beginning of seventies of the last century, when Galina Hütt founded a radiometrical dating laboratory at the Institute of Geology of the Estonian Academy of Sciences. Together with the first author of this paper she collected and analysed a great number of samples of glaciofluvial and glaciolacustrine sediments of Estonia, partly published in Raukas (2004). Unfortunately, the untimely death of Galina Hütt did not allow completing the project for all three Baltic States. To check the reliability of the results obtained by G. Hütt and to fill gaps, cooperation started between the Estonian and Polish Academies of Sciences. Received new results together with older ones were published in Raukas and Stankowski (2005). New analyses were made in the Department of Radioisotopes of the Silesian University of

Fig. 2. *Samples as a rule were taken from a homogenous beds or interlayers. In photo we can see the technique of sampling. The sequence of thinly laminated sand is overlaid by the tongue-like structure of the gravity flow till at the Svente site.*

Fig. 3. *Sampling of shallow water glaciolacustrine fine grained sand at the Pentsils site, 4 km proximal to the recessional moraine of the North-Lithuanian phase, 10 km WNW of the Valka/Valga Town. All the samples used in this study were collected in opaque PVC tubes, driven into cleaned, horizontal sediment sections. All sample collection was conducted under a black tarp to prevent light exposure sections of sample tubes.*

Technology in Gliwice. In the Tallinn laboratory mainly feldspars and in Gliwice quartz were used for dating, what hampers the comparison of results.

Estonia is a small country and our former results (Raukas, 2004; Raukas and Stankowski, 2005) showed that errors of dating in OSL years were often bigger than the duration of the deglaciation of whole Estonian territory. Besides, as it is noted by Kalm (2006), ^{14}C ages of the North Lithuanian (regionally named as Haanja, Linkuva, Luga) ice marginal formations, which are of great regional importance in south-eastern sector of the Scandinavian glaciations, are somewhat older than the weighted mean ^{10}Be age (13.1±0.8 ka) of nine boulders on the North Lithuanian moraine (Rinterknecht *et al.,* 2006).

Therefore we decided to widen the study to the larger territory starting from Belarus and ending in Finland. For political reasons we could not take samples from Belarus. All samples for this paper were collected in 2005 by W. Stankowski's leadership with the participation of P. Šinkunas in Lithuania, V. Zelčs in Latvia and A. Raukas in Estonia.

Information on the samples and measuring results are summarised in **Table 1**.

The samples are collected from extramarginal formations of Pomeranian (Aukstaičiai), Middle Lithuanian and North Lithuanian deglaciation phases of the Last glaciation in Lithuania (**Fig. 1**, **Table 1**). The samples LIT05/1, LIT05/2 and LIT05/3 are from outcrop in the bank of the Ula River valley. This sampling site is located in distal part of the outwash plain in front of the marginal formations of the Pomeranian (Aukstaičiai) deglaciation phase, inside the limit of the Last glaciation, close to its maximum extent. The sampling material is a fine cross-bedded sand sequence covered by an inland aeolian dune. The depth is measured from the dune foot. The samples from the site at Kvesai (LIT05/4 and LIT05/5) represent topset beds of fine sand in of the glaciofluvial delta formed just in front of the marginal formation of the Middle-Lithuanian deglaciation phase of the Last glaciation. Samples LIT05/6 and LIT05/7 from the Bebrujai site, near the Seduva Town are collected from outwash sediments that spreads out as a narrow belt along the edge of the marginal formations of the Middle-Lithuanian deglaciation phase. Subhorizontal interlamination of the medium grained sand and various grained sand with fine gravel are common. Thickness of laminas is up to 10-20 cm. Samples LIT05/8 and LIT05/9 are taken from cross-bedded various grained sand with fine gravel sequence of the glaciofluvial delta. This delta was formed just in front of the marginal formation of the North-Lithuanian deglaciation phase.

The samples in Latvia are collected from extramarginal and ice-contact formation of the Middle- and North-Lithuanian deglaciation phases (**Fig. 1**, **Table 1**). The Pentsils sampling site is situated 4 km proximal to the recessional moraine of the North-Lithuanian phase, 10 km WNW of the Valka/Valga Town. The upper part of the section comprises wave ripple cross laminated fine grained sand (sample LAT05/34) deposited in a shallow meltwater basin (**Fig. 3**). These sediments are covered by up to 1.0 m thick aeolian drift. Sample LAT05/35 locates 60 m WSW of LAT05/34 and is collected from topset sand series of the glaciofluvial delta. This delta sediments form the lowermost part of the glacioaquatic sequence outcropped in the Pentsils sand pit. In 2001, in the Tallinn Laboratory from the same glaciofluvial delta in the territory of Estonia three OSL dates from the same level at a depth of 2.00 m suggest an age of 7.5±1.0; 13.2±1.4 and 70.0±12.0 ka (Raukas, 2004). The Dores site is located in a distal part of the glaciofluvial delta superimposed by the recessional moraine ridge of the North-Lithuanian phase. It lies almost 10 km proximal to the outermost end moraine that delimits the position of the Burtnieks (North Vidzeme) ice lobe at its maximal extent during Haanja North-Lithuanian (Haanja, Linkuva) phase (ca. 13,500 BP according to Raukas *et al*., 2004). Samples LAT05/36 and LAT05/37 are collected from glaciofluvial thinly laminated fine grained sand with admixture of grains of coarser sand. Sample LAT05/37 is 20 m SE of sample LAT05/36. The sampling sites Lorupe-1 and Lorupe-2 are located 16 km upglacier from the ice marginal formations of the North-Lithuanian phase, 6 km WSW of the Sigulda Town. Sample LAT05/38 is from massive fine grained sand that has been deposited in shallow meltwater basin and overlaid by Late glacial coarse fluvial delta deposits (**Fig. 4**). Sample LAT05/39 is taken from Late glacial fluvial delta topset fine and medium grained sand, 380 m SSW of LAT05/38. The site Lodesmuiža is located in the central part of the Vidzeme interlobate upland, 30 km SE of the Cēsis Town. The samples are collected in a kame terrace located 10 km downglacier from the Middle-Lithuanian phase. The sampling site Smeceres Sils locates 2 km S of the ice lateral marginal formations on the S slope of the Vidzeme Upland and 30 km upglacier from terminal moraine of the Middle-Lithuanian phase, 4.5 km SW of the Madona Town. Here transgressive, presumable far transported outwash se-

Table 1. *List of luminescence dates of fine grained glacioaquatic sediments in the south-eastern Baltic Region (location of the sampling sites shown in Fig. 1.).*

Site	Coordinates	Deglaciation phase	Sample No.	Depth, (m)	Lithological features of sampled material	D_E (Gy)	Num	D_R (Gy/ka)	Age (ka)
LITHUANIA									
Ula, LT1	54°06`38.2´´N 24°28´25.7´´E	Pomeranian (Aukstaičiai)	LIT05/1	5.50	Distal part of outwash	17.7±0.7	12	17.35-48.1	32.4±1.6
			LIT05/2	8.50		29.8±2.0	11	7.95-79.3	8.87±0.55
			LIT05/3	12.20		15.0±0.93	15	10.08-74.7	30.40±1.6
Kvesai, LT2	55°00´45.9´´N 23°39´37.7´´E	Middle Lithuanian	LIT05/4	1.80	Topset beds of the glaciofluvial delta		14	15.03-109.4	–
			LIT05/5	2.50		22.3±1.2	14	13.05-104.2	32.8±1.5
Bebrujai, LT3	55°44´19.9´´N 23°37´50.0´´E	Middle Lithuanian	LIT05/6	1.20	Outwash sediments		13	5.83-48.9	10.5±1.0
			LIT05/7	3.30			12	7.04-24.1	12.85±0.63
Stupurai, LT4	56°06´58.9´´N 23°33´45.7´´E	North Lithuanian	LIT05/8	0.90	Cross-bedded various grained sand with fine gravel of glaciofluvial delta	30.2±2.6	13	16.2-176.0	77.1±3.1
			LIT05/9	1.30			12	25.4-78.5	38.6±1.3
LATVIA									
Pentsils-1, LV1	57°47´32.6´´N 25°51´32.2´´E	North Lithuanian	LAT05/34	4.20	Shallow water glaciolacustrine fine grained sand		15	35.6-106.1	52.5±2.2
Pentsils-2, LV2	57°47´32.4´´N 25°51´28.5´´E	North Lithuanian	LAT05/35	11.00	Topset sand series of glaciofluvial delta, 60 m WSW of LV05/34		13	34.6-187.0	74.1±3.2
Dores, LV3	57°42´55.4´´N 26°03´12.1´´E	North Lithuanina	LAT05/36	3.20	Glaciofluvial thinly laminated fine grained sand with admixture of grains of coarser sand		12	27.5±1.7	27.5±1.7
			LAT05/37	3.20	Glaciofluvial thinly laminated fine grained sand, 20 m SE of LV05/36		–	15.97-76.8	36.9±2.8
Lorupe-1, LV4	57°07´53.3´´N 24°45´56.7´´E	North Lithuanian	LAT05/38	4.00	Massive fine grained shallow meltwater basin sand		19	31.0-143.9	36.0±2.2
Lorupe-2, LV5	57°07´41.1´´N 24°45´49.5´´E	North Lithuanian	LAT05/39	5.00	Topset fine and medium grained sand of spillway delta		13	20.1-96.6	26.7±3.6
Lodesmuiža, LV6	57°08´00.2´´N 25°38´44.6´´E	Middle Lithuanian	LAT05/40	2.00	Fine to medium grained sand of kame terrace		15	4.86-11.96	9.85±0.37
			LAT05/41	6.00			11	12.09-51.5	14.55±0.50
Smeceres Sils, LV7	56°49´37.5´´N 56°49´37.5´´N	Middle Lithuanian	LAT05/42	3.00	Thinly laminated sand of kame terrace	52.7±2.1	21	18.7-101.7	19.6±1.0
			LAT05/43	5.00			15	14.4-40.2	26.8±1.1
Svente, LV8	55°54´50.5´´N 26°22´11.7´´E	Middle Lithuanian	LAT05/44	2.00	Thinly laminated sand of kame terrace		13	6.42-25.81	10.65±0.41
			LAT05/45	>4.00			15	4.33-16.5	6.24±0.28
ESTONIA									
Misso, EE1	57°36´39.1´´N 27°14´18.1´´E	Haanja	EST05/10	13.00	Gravel with sand layers of small outwash		22	13.37-74.0	29.0±1.2
Aabissaare, EE2	58°04´9.1´´N 26°44´25.8´´E	Otepää	EST05/11	2.00	Gravel with sand layers of glaciofluvial delta		14	10.75-116.1	19.5±0.8
			EST05/12	3.60			9	28.5-70.9	28.0±1.5
Laguja, EE3	58°10´31.5´´N 26°27´52.4´´E	Otepää	EST05/13	3.70	Gravel with sand layers of glaciofluvial delta		10	7.2-33.9	24.9±2.3
			EST05/14	5.10			9	28.5-70.9	48.2±2.1
Tõrva, EE4	58°01´18.4´´N 25°55´32.4´´E	Otepää	EST05/15	1.502	Silty sand and sandy silt of kame terrace		8	29.0-78.8	49.4±2.9
			EST05/16	6.002			12	14.43-66.6	26.2±1.5
Tääksi, EE5	58°31´11.4´´N 25°38´30.0´´E	Sakala	EST05/19	1.30	Sand with gravel of the ancient valley filling (valley sandur)		9	57.4-201.0	66.8±5.9
			EST05/17	10.00			11	22.4-103.1	52.9±1.9
			EST05/18	11.50		117±6.0	14	45.0-167.8	52.8±3.7

D_E – equivalent dose; Num –aliquot number; D_R – total dose rate; 1 – indexes too much scatter; 2 – beneath mining level.

Fig. 4. *A fine grained sand deposited in shallow meltwater basin and overlaid by a high energy ancient river delta sediments in a local ice dammed lake existed prior to the Baltic Ice Lake. Lorupe-1, Latvia (Site LV4).*

quence is overlaid by the boulder pavement formed as a result by washing out fines from the till sheet. Sample LAT05/42 is from thinly laminated glaciofluvial sand capped by gravel with pebbles and cobbles but sample LAT05/43 is taken from thinly laminated sand overlain by stratified basin sediments, and coarse grained outwash on the top, 30 m S of LAT05/42. The Svente sampling site represents lateral part of till plain of Middle-Lithuanian phase covered by sediments of the kame terrace at the foot of Middle-Lithuanian ice marginal formations, 11 km WNW of Daugavpils. Sample LAT05/44 is collected in thinly laminated sand overlaid by the tongue-like structure of the gravity flow till (**Fig. 2**). Sample LAT05/45 is from the similar thinly laminated sand that is covered by stony diamicton, 35 m E of LAT05/44.

The sampling sites EE1, 2 and 3 are from glaciofluvial delta and outwash sediments that belong to North-Lithuanian (Haanja) and two younger deglaciaton phases (**Fig. 1, Table 1**). Sample EST05/10 at the Misso site is collected in small outwash in the North-Lithuanian (Haanja) zone of the ice marginal formations, gravel with sand layers. Samples EST05/11 and EST05/12 at Aabissaare are taken in gravel with sand layers of glaciofluvial delta that lies in the Otepää zone of the ice marginal formations. The Laguja sampling site is located in the Otepää zone of the ice marginal formations, N of Otepää Town. Here for OSL age determination the outwash sand with gravel layers are sampled (samples EST05/13, EST05/14). Samples (EST05/15 and EST5/16) from Tõrva site represent silty sand and sandy silt of kame terrace sequence of the Otepää zone of the ice marginal formations, near the Tõrva Town. Samples EST05/17, EST05/18 and EST05/19 are collected in sand with gravel at the Tääksi site. Theses sediments fill in an ancient valley forming a valley sandur in the Sakala marginal zone. In 2001, from the same site in Tallinn Laboratory at a depth 6.2 m from the ground surface two similar dates: 54.0±5.0 and 62.0±7.0 ka were obtained (Raukas, 2004). Horizontal spacing of the sampling points was 10.0 m.

Looking at the dates we can conclude that with some excluding (LV05/4, LV05/42, and LV05/43) all dates received are unreliable. Often the results are not in stratigraphical order, i.e. lower sediments are younger than upper ones. At the same time dates from the same lithic complex in close lying sample points differ highly.

4. DISCUSSION

OSL method is widely used in Quaternary stratigraphy and glacial chronology and opinions vary significantly from very optimistic (Murray *et al.,* 2007; Molodkov, 2007 a.o.) to rather sceptic (Kolstrup, 2007 a. o.). We are not discussing here the dating possibilities of aeolian or marine sediments, but to date glacial stratified sediments particularly of ice decaying stage to our mind is hardly possible and glaciofluvial and glaciolacustrine sediments for that aim are not perspective. As known both, glaciofluvial and glaciolacustrine deposits, were accumulated in extremely different and rather fast changing sedimental environments including marginal, proglacial, intraglacial, extraglacial or subglacial deposition with time transgressive and spatial overlapping of processes and products. The material of fine fraction, transported in opened crevasses of highly turbulent conditions or in front of glaciers can potentially be bleached. At the same time the assumption that the luminescence of every grain was completely zeroed prior to final deposition is not only arguable but in many cases impossible. Incomplete bleaching gives higher ages and this phenomenon is evident in practically all of our datings. In outwash the glacial drift transport distances are short and meltwater is muddy, and besides, we cannot exclude transport and deposition of mineral grains at night time. Often in glaciofluvial and glaciolacustrine sediments can also comprise non-bleached particles of sandy-silty bedrock. It means that the results depend not only on the transport distance, but on many other factors, which role is difficult to establish.

5. CONCLUSIONS

Since the middle of the 19th century, many important studies have been conducted on the glacial geology in the outer zone of the south-eastern sector of the Scandinavian Ice Sheet and the deglaciation history has been studied more than a century. Different modern dating methods have been used, but up to now many problems of topical interest have not been solved yet. In last decades widely TL and OSL methods have been used in this field in different countries but to our mind the possibilities of mentioned methods are overestimated. We tried to check the possibilities of OSL method on the example of the Baltic States and found out, that the obtained data are extremely heterogeneous from the stratigraphical point of view and most of them are not reliable. This may be easily explained with a high mixture of unbleached mineral grains from older Quaternary deposits and Palaeozoic rocks and with a short duration of moving medium under sunlight. In and below the ice mineral grains were not exposed to the light at all. Moreover, transport and deposition of mineral grains likely took place partly at night.

In applying OSL data to studied fine fractions of aquatic and glacioaquatic sediments, it is important to assess whether the light-sensitive trapped charge of every grain was bleached prior to final deposition. If such is the case, the age of the deposit can be obtained using OSL dating of any number of grains. If not, special care has to be taken to use only the OSL signal from those grains that had their charge bleached or, alternatively, the age obtained should be interpreted as a maximum age of the deposits (Wallinga, 2002; Bluszcz and Botter-Jensen, 1993; Botter-Jensen *et al.,* 2000; Bluszcz, 2000; Bluszcz and Stypa, 2000; Gaigalas and Fedorowicz, 2002; Fedorowicz, 2003). To our mind, due to inadequate light exposure in the glaciofluvial environment the OSL signal can result in age overestimations. Depending on different sediment concentrations, sedimentation environment (subglacial, englacial, supraglacial or proglacial), turbidity and depth of water, velocity of outwash streams and transport duration, incorporation of older unbleached particles, limited time of exposure to the sun in non-summer time a.o. factors, the extent of bleaching of luminescence signal in studied environments is variegated and difficult to reconstruct in laboratory, so causing variability of dates. To our mind, this limits the use of the TL and OSL methods in solving the problems related to deglaciation history. Even more it influences the dating of older intertill deposits, where most of limiting factors are unknown. If the mechanism of formation of deposits is unknown the even most accurate measurements of their TL properties will be meaningless. Each sample exhibits unique TL and dosimetric characteristics and, therefore, the dating technique cannot be routinely applied.

ACKNOWLEDGEMENTS

First we would like to thank Prof. A. Bluszcz from the GADAM Centre of Excellence Department of Radioisotopes of the Silesian University, who did measurements and interpreted the dates. We thank Aivars Markots at the University of Latvia for help with preparing of GIS-based database and map. Our special thanks go to referees of the paper for their valuable comments. The research was financed from the research projects of the Institute of Geology at the Adam Mickiewicz University, Poznań, the Institute of Geology at the Tallinn Technical University (project SF 0320080/s07), University of Latvia (project No. 2007/ZP-87) and the Geological Survey of Lithuania.

REFERENCES

Aseyev AA, 1974. *Drevnie materikovye oledeneniya Evropy* (Ancient continental glaciations in Europe). Moskva, Nauka: 319pp (in Russian).

Basalykas A, 1969. Raznoobrazie rel'jefa lednikoj akkumul'ativnoj oblasti (Varieties of the glacial relief in the zone of accumulation). In Vaitiekunas P, eds., *Materikovoe oledenenie i lednikovyj morfogenez* (Continental Glaciation and Glacial Morphogenesis). Vilnius, Mintis: 65-154 (in Russian with French and German summaries).

Bluszcz A, 2000. Combined OSL and TL dating of young sediments – possibilities for new interpretation. Uniwersytet im. A. Mickiewicza, Instytut Geologii, Continuo, Wrocław. *GEOLOGOS* 5: 113-122.

Bluszcz A and Botter-Jensen L, 1993. Calibration of a beta source using TL and OSL on quartz. Risø National Laboratory, Roskilde, Denmark. *Risø report no.* Risø-I-725(EN).

Bluszcz A and Stypa K, 2000. New methods of the luminescence dating in Gliwice laboratory. Uniwersytet im. A. Mickiewicza, Instytut Geologii, Continuo, Wrocław. *GEOLOGOS* 5: 107-112.

Botter-Jensen L, Bulur E, Duller GAT and Murray AS, 2000. Advances in luminescence instrument systems. *Radiation Measurements* 32(5-6): 523 -528, DOI:10.1016/S1350-4487(00)00039-1.

Danilans I, 1963. To the history of distinguishing of ice marginal formations on the territory of Latvia. In: Goretski GI, Ivanova IK and Orviku K, eds., *Krayevye formy reliefa materikovogo oledenenija na Russkoj ravnine* (Marginal landforms of continental glaciations in Russian Plain). Trudy Kommissii po izucheniju chetevertichnogo perioda (Proceedings of the Comission of Quaternary Research), Moskva, AN SSSR, XXI: 76-83 (in Russian).

De Geer G, 1912. Geochronologie der letzten 12000 Jahre. IN: *XI International Geological Congress,* Stockholm 1910. *Compte Rendu* 1: 241-253.

Eichwald E, 1853. Lethaea Rossica on Paléontologie de la Russie. III. Dernière période. Stuttgart, Schweitzerbart Verlag: 518 pp.

Fedorowicz S, 2003. Thermoluminescence method: outline of history, foundations, principle, possibilities, perspectives and limitations. *Geologija* 41: 28-35.

Gaigalas A and Fedorowicz S, 2002. Thermoluminescence dates of Mid- and Late Pleistocene sediments in Vilkiškės exposure Eastern Lithuania. *Geologija* 38: 31-40.

Grewingk C, 1879. Erläuterungen zur zweiten Ausgabe der geognostischen Karte Liv-, Est- und Kurlands. *Archiv für die Naturkunde Liv-, Est- und Kurlands (Dorpat)* 1(VIII): 343-466.

Gudelis VK, 1963. K voprosu terminologii i klassifikatsii kraevykh lednokovykh obrazovanij (On the terminology and classification of ice-marginal formations). In: Goretski GI, Ivanova IK and Orviku K, eds., *Krayevye formy reliefa materikovogo oledenenija na Russkoj ravnine* (Marginal landforms of continental glaciations in Russian Plain). Trudy Kommissii po izucheniju chetevertichnogo perioda (Proceedings of the Comission of Quaternary Research), Moskva, AN SSSR, XXI: 84-91 (in Russian).

Hausen H, 1913. Materialien zur Kenntnis der Pleistozänen Bildungen in den russischen Ostseeländern. *Fennia* 34(2): 181pp.

Karukäpp R, Raukas A and Āboltinš O, 1999. Glacial accumulative insular heights (otepääs) – specific topographic features in the Baltic States. In: Miller U, Hackens T, Lang V, Raukas A and. Hicks S, eds., *Pact* 57, Rixensart: 193-205.

Kalm V, 2006. Pleistocene chronostratigraphy in Estonia, southeastern sector of the Scandinavian glaciations. *Quaternary Science Reviews* 25: 960-975, DOI 10.1016/j.quascirev.2005.08.005

Kolstrup E, 2007. OSL dating in palaeoenvironmental reconstructions. A discussion from a user`s perspective. *Estonian Journal of Earth Sciences* 56(3): 157-166.

Lavrushin YA, 1970. Opyt vydelenija facij i subfacij v donnoj morene materikovogo oledenenija (Experience of distinguishing dynamic facies and subfacies of ground moraine of continental glaciations). *Litologia i poleznye iskopaemye* (Lithology and mineral resources) 6: 38-49 (in Russian).

Molodkov A, 2007. IR-OSL dating of uranium-rich deposits from the new late Pleistocene section at the Voka site, North-Eastern Estonia. *Quaternary Geochronology* 2: 208-215, DOI 10.1016/j.quageo.2006.06.004.

Murray AS, Svendsen JI, Mangerud J and Astakhov VI, 2007. Testing the accuracy of quartz OSL dating using a known-age Eemian site on the river Sula, northern Russia. *Quaternary Geochronology* 2: 102-109, DOI 10.1016/j.quageo.2006.04.004.

Raukas A, 2004. Application of OSL and ^{10}Be techniques for the establishment of deglaciation chronology in Estonia. *Proceedings of the Estonian Academy of Sciences, Geology* 53(4): 267-287.

Raukas A and Karukäpp R, 1994. Stagnant ice features in the eastern Baltic. *Zeitschrift für Geomorphologie, Neue Folge* 95: 119-125.

Raukas A and Stankowski W, 2005. Influence of sedimentological composition on OSL dating of glaciofluvial deposits: examples from Estonia. *Geological Quarterly* 49(4): 463-470.

Raukas A, Kalm V, Karukäpp R and Rattas M, 2004. Pleistocene glaciations in Estonia. In: Ehlers J and Gibbard PL, eds., *Quaternary Glaciations – Extent and Chronology. Part I: Europe*. Elsevier B.V.: 83-91.

Rinterknecht VR, Clark PU, Raisbeck GM, Yiou F, Bitinas A, Brook EJ, Marks L, Zelčs V, Lunkka J-P, Pavlovskaya IE, Piotrowski JA and Raukas A, 2006. The Last Deglaciation of the Southeastern Sector of the Scandinavian Ice Sheet. *Science 2006 10 Mar* 311(5766): 1449-1452, DOI: 10.1126/science.1120702.

Serebryanny L and Raukas A, 1966. Correlation of Gothiglacial ice marginal belts in the Baltic Sea depression and the neighbouring countries. Vilnius. *Baltica* 3: 235 – 250 (in Russian with English and French summaries).

Stankowski W, 2009. Nowe dane luminescencyjne wieku impaktów w Morasku i Kaali (The New Lumiscence data of the Morasko and Kaali impacts). Polskie Towarzystwo Meteorytowe, Sosnowiec. *Acta Societatis Meteoriticae Polonorum, Rocznik PTM* 1.

Stankowski WTJ, Raukas A, Bluszcz A, and Fedorowicz S, 2007. Luminescence dating of the Morasko (Poland), Kaali, Ilumetsa, Tsõõrikmäe (Estonia) meteorite craters. *Geochronometria* 28: 25-29, DOI 10.2478/v10003-007-0031-0.

Tschudi S, Ivy-Ochs S, Schlüchter C, Kubik P and Rainio H, 2000. ^{10}Be dating of Younger Dryas Salpausselkä I formation in Finland. *Boreas* 29: 287-293, DOI 10.1080/030094800448046.

Wallinga J, 2002. Optically stimulated luminescence dating of fluvial deposits: a review. *Boreas* 31: 303-322, DOI 10.1080/030094802320942536.