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EVOLUTION OF ST. LAURENT MOUNTAIN NEAR CHEŁMNO BASED ON LUMINESCENCE DATING

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Abstract: Luminescence dating was applied in the studies on the evolution of the St. Laurent Mountain in Kałdus (Lower Vistula Valley, Poland), where archaeological excavation revealed a settlement sequence. The core of the hill is constituted by eolian sands which formed the dune. Above them there is a sequence of deposits consisting of three levels of the silty sand anthropogenic deposits separated by top eolian cover and a layer of the burnt material. Three samples from the eolian base and one from the eolian cover were taken for luminescence analysis. The absolute age was established by a comparison of TL and OSL results. The basement of the St. Laurent Mountain (till and ablation sands) was created by a receding glacier during or short after the last glacial period. It suggests the age limit for the dune not older than 18,000 years. Luminescence dating indicates, that the dune formation was initiated in Pleniglacial just after deglaciation, ca. 16,500 years ago and the top eolian cover was established in Neolithic Age, between 6000 and 8000 years ago. Numerous archaeological findings from the upper part of the mountain and C-14 dates of the burnt material provided data for reconstruction of the last phase of this formation.

1. INTRODUCTION

St. Laurent Mountain is located in a small village called Kałdus in Chełmno Lakeland, nearby Toruń. Geomorphologically it lays on the border of the moraine plateau and the Vistula river valley. The archaeological excavations that have been conducted in Kałdus for many years revealed there a settlement sequence spanning from the Neolithic Age (ca 7 thousand years ago) up to the medieval times. The aim of the interdisciplinary research is to reconstruct the natural conditions of the area since the Late Glacial Period up to a present moment. The geomorphological and sedimentological investigations supported by absolute dating are important part of this project. The radiocarbon method was applied in dating of one layer containing the remains of the burnt organic material. Along with a numerous of archaeological findings from an upper part of the mountain it provided data for reconstruction of the last phase of its formation. However, the only way for establishing chronology of eolian accumulation that formed the core of the mountain was to apply the luminescence methods.

2. GEOLOGICAL STRUCTURE OF ST. LAURENT MOUNTAIN

Near Chełmno the moraine plateau (**Fig. 1**) gently descends towards North-West to the border of the Vistula river valley. The slope of the valley is cut by denudational-erosive synclines in a way that they create a sort of peninsula appropriate to build there an old rampart. Above this area dominates an anthropogenic form called: St. Laurent Mountain with a culmination on height of 98.27 m a.s.l. The hill's bed is on 82.5-83.0 m a.s.l. and its average height reaches 15.0-15.5 m. The shape of the sand landform resembles an asymmetric crescent roll with the steep slope that bends towards North.

Geological structure of the St. Laurent Mountain is rather complex. In order to establish its genesis there were conducted sedimentological and geomorphological analyses. Detailed textural research let distinguish three main groups of sediments (**Fig. 2**): (1) deposits of a basement built of till and ablation sands, (2) sediments with eolic features (dune sands, eolic covers' sand) and (3) silty-sand anthropogenic deposits. Sediments of a basement (1) are

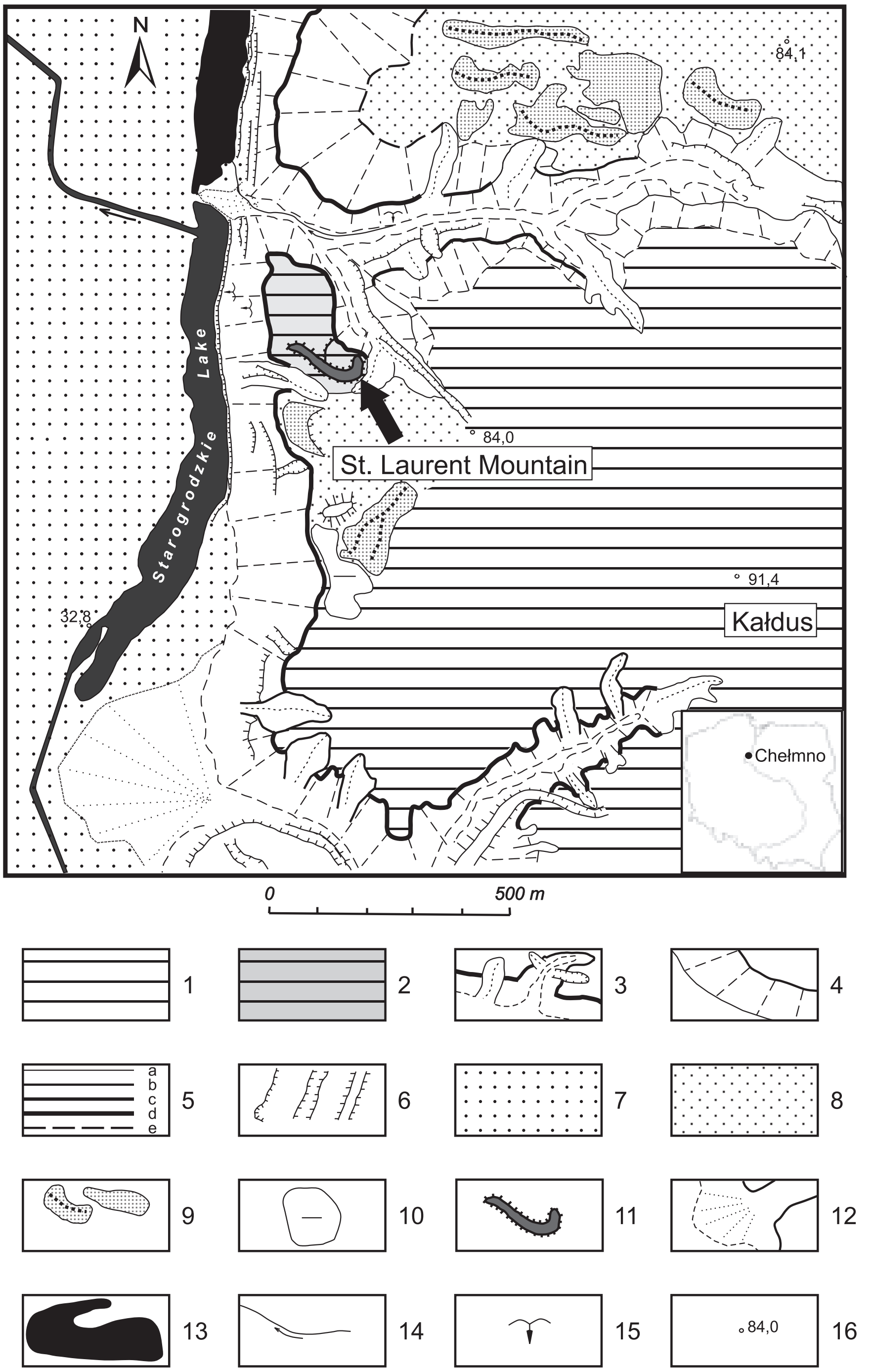

***Fig 1**. Geomorphologcial and hydrological sketch of the reaserched area in Kałdus. Legend:*
1 – flat morain plateau, 2 – denudationaly unduland and athropogenicly transformed morain plateau, 3 – valleys diessecting the Vistula valley slopes, 4 – long slopes, 5 – heigth of slopes: a) to 5 m, b) 5-10 m, c) 10-20 m, d) more than 20 m, 6 – young erosional and anthropogenic forms (scarps, trenches, embankments), 7 – flood plain, 8 – eolian-sands cover plain, 9 – dunes, 10 – wind-blown trough, 11 – embankment on the dune - St. Laurent Mountain, 12 – alluvial cones, 13 – ox-bow lakes, 14 – water courses, 15 – spring and natural effluents of underground water, 16 – height points

associated with two glaciogenic levels of till divided by glaciolacustrine and glaciofluvial deposits. On the top of the till there is ablation sand and silt (Wysota *et al.,* 2002). Eolian deposits (2) of the dune are fine and medium-grained sands which lye on a till and also build a sediment layer that divides the anthropogenic deposits.. The main fraction of eolian deposits consitutes of fine-grained sand (0.1-0.2 mm) which share is about 80%. Anthropogenic deposits (3) are mainly built of silty sands. A share of silty grains is growing up from 19% in central part of the mountain to 27% in its roof.

3. LUMINESCENCE DATING APPROACH

Luminescence dating makes use of mineral grains, which can act as natural dosimeters (Aitken, 1985). In general the age T is calculated from the formula:

$$T = ED / DR, \tag{3.1}$$

where ED is an equivalent dose, i.e. the radiation dose measured in laboratory by luminescence methods, which is equal to the dose accumulated by the grains during a geological period of burial, DR denotes independently measured annual dose rate of natural radiation to which the sample is exposed to.

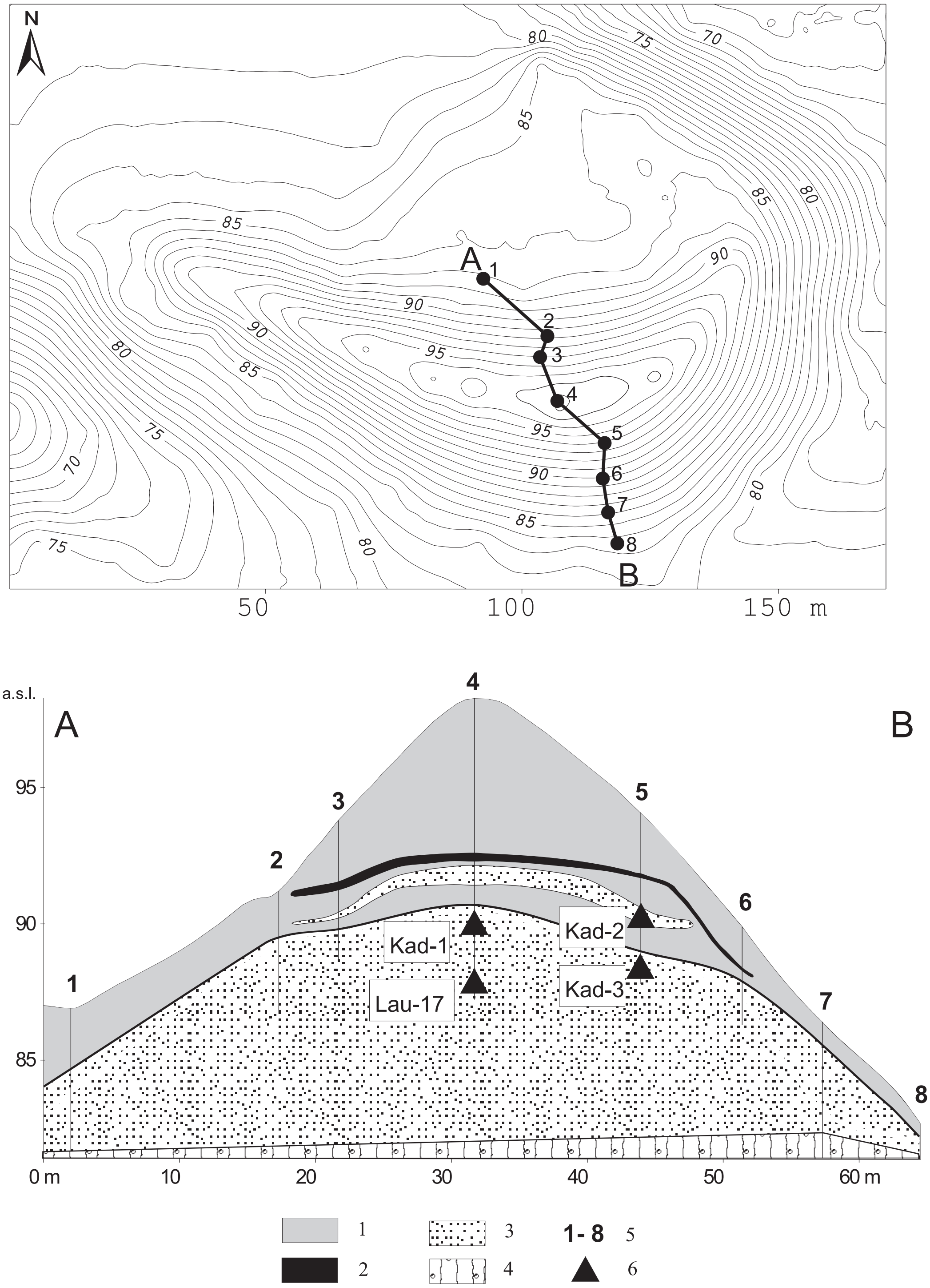

Fig. 2. *Geological a cross-section (A-B) of the St. Laurent Mountain. Legend: 1 – silty sand anthropogenic deposits, 2 – silty sand anthropogenic deposits with burnt material, 3 – eolian sand, 4 – till and ablation sand, 5 – profiles of the hand-boring, 6 – point of taking samples for luminescence dating*

The method enables dating the moment when a particular event, which could erase previously accumulated luminescence, has taken place. Transport and deposition of the mineral material can be associated with an exhibition to the sunlight, which causes the zeroing process. However, justification of this assumption should always be carefully considered, as the real extent of bleaching in nature is usually uncertain. Incomplete bleaching of luminescence signal may result in overestimation of the age of deposit. It is referred as partial bleaching and remaining part of luminescence is called a residual signal. The previous TL dating results of the dune material showed that a residual thermoluminescence (TL) in a relatively young eolian sediments could be as high as 40% (Oczkowski and Przegiętka, 1998).

The Optically Stimulated Luminescence (OSL) signal can be much easier bleached by sunlight than the TL signal (Huntley *et al.*, 1985). Hence, nowadays mainly the OSL method is used for dating geological deposits as it minimises the danger of over-aging. Nevertheless many attempts were undertaken to develop a method for detecting partial bleaching by OSL technique. Many of them are based on a Single Aliquot Regeneration Technique (SAR) (Murray and Wintle, 2000) and apply an analysis of *ED* results distribution obtained for an aliquot set representing one geological sample (Murray and Olley, 2002; Wallinga, 2002). Others (Bailey, 2000, Bailey *et al.*, 1997) try to examine the form of OSL decay, however there is no standard procedure established yet. Some older TL methods which were developed for detecting the partial bleaching are: R-Γ technique (Wintle and Huntley, 1980), the quartz-feldspar technique (Mejdahl, 1985) and a plateau technique (Prószyńska- Bordas, 1985). But currently these methods, which are more time- and work-consuming than modern OSL protocols are rather forgotten. Therefore it is interesting to compare the results of OSL method and a TL plateau test applied together for eolian sediments, usually regarded as one of the best-bleached geological deposit (Murray and Olley, 2002).

4. SAMPLES, EXPERIMENTS AND RESULTS

Three samples from the eolian base (Kad-1, Kad-3 and Lau-17) and one (Kad-2) from the eolian cover were taken for a luminescence analysis (**Fig. 2**). Quartz coarse grains (0.2 – 0.3 mm in size) were extracted in a standard procedure (Aitken, 1985).

Both TL and OSL measurements were carried out using a Riso reader (Bøtter-Jensen and Murray, 1999), and a full protocol of SAR OSL method was applied (Murray and Wintle, 2000). The Blue light (470 nm) LED diodes were used for stimulation of the samples (100 s at 125°C) and the U-340 filter (290-370 nm) was applied for detection. Before the main measurement some tests were run in order to establish the best preheat conditions (10s at 250°C) and to avoid the thermal transfer effects (Murray and Olley, 2002). The beginning part (0 – 0.8 s) of the OSL decay curve, i.e. its fast component (Bialey *et al.*, 1997), was used for determination of the ED_{OSL} values. The histograms showing the ED_{OSL} results are presented in **Fig. 3a-d**, whereas a detailed information is given in **Table 1**.

The TL multiple-aliquot regeneration technique involved: 10 independent read out of a natural TL, three aliquots for each residual TL and also three aliquots for

Table 1. *Comparison of OSL and TL results. The ED values and regenerative doses are expressed as seconds of irradiation by beta radiation source. The mean age T was calculated by the averaging of OSL and TL results (see text for details).*

Sample: Depth [m], Dose rate (mGy/a)	SAR Blue OSL		Multi aliquots regeneration TL					Mean age T (kyr)
	ED_{OSL} (s)	Age OSL (10^3 years)	Bleach. time (min)	Reg. doses (s)	Plateau range (°C)	ED_{TL} (s)	Age TL (kyr)	
			15	50, 100, 150	300÷320	128±2		
Kad-1:			30	100, 150, 200	310÷325	142±2		
8.70,	164±3	16.7±0.7	art. 45		310÷415	155±4	15.8±0.8	16.2±0.8
0.895			60	170, 220, 270	390÷415	201±2		
			600	170, 220, 270	335÷365	269±2		
			15	20, 40, 60	335÷390	62±2	5.1±0.3	6.8±1.0
Kad-2:	92±4	7.7±0.5	30	20, 60, 100	335÷380	89±1	7.4±0.3	
3.80,			60	40, 80, 120	340÷380	113±1		
1.089			600	80, 140, 200	360÷380	167±1		
			5	20, 50, 80	320÷340	56±2		
Kad-3:			30	80, 120, 160	300÷345	126±2		
6.30,	149±4	14.1±0.6	art. 45		300÷410	137±2	13.0±0.5	13.5±0.8
0.965			60	100, 150, 200	360÷395	156±2		
			600	150, 200, 250	375÷390	211±2		
			5	20, 60, 100	320÷335	87±5		
Lau-17:			30	80, 120, 180	310÷345	149±2		
10,	173±4	15.9±0.6	art. 45		300÷400	175±3	16.0±0.6	16.0±0.5
0.997			60	130, 180, 230	360÷390	212±4		
			600	160, 210, 260	385÷405	258±8		

each regeneration dose. The data were normalized according to the second glow curve resulted from the test dose and then averaged. The values of regeneration doses were carefully chosen to match in the region of expected *ED* (**Table 1**). The TL measurements (preceded by pre-heat of 10 s at 280°C) were carried out up to 450°C with heating rate of 5°C/s in nitrogen atmosphere. The 5-58 detection filter (380-440 nm) was used.

The sunlight bleaching experiments were carried out in a single layer of coarse quartz grains stuck to the disk surface by help of a silicon spray, as it was also applied in TL and OSL measurements to reduce the scatter of results. Four bleaching periods were used as it is shown in **Table 1**. It was checked that even after the longest bleaching (600 minutes) there was no mass loss of the sample.

The annual dose rates *DR* were determined on the base of gamma spectrometry (Oczkowski and Przegiętka, 1998). These results along with the values of *DR* and *ED* determined by both: OSL – ED_{OSL} and TL – ED_{TL} methods are presented in **Table 1**. Dates calculated according to these values are denoted as T_{OSL} and T_{TL} respectively. The uncertainty of *DR* values is so small (less than 0.2%) that it can be neglected in the age calculation. However, one must keep in mind that at this stage of investigation

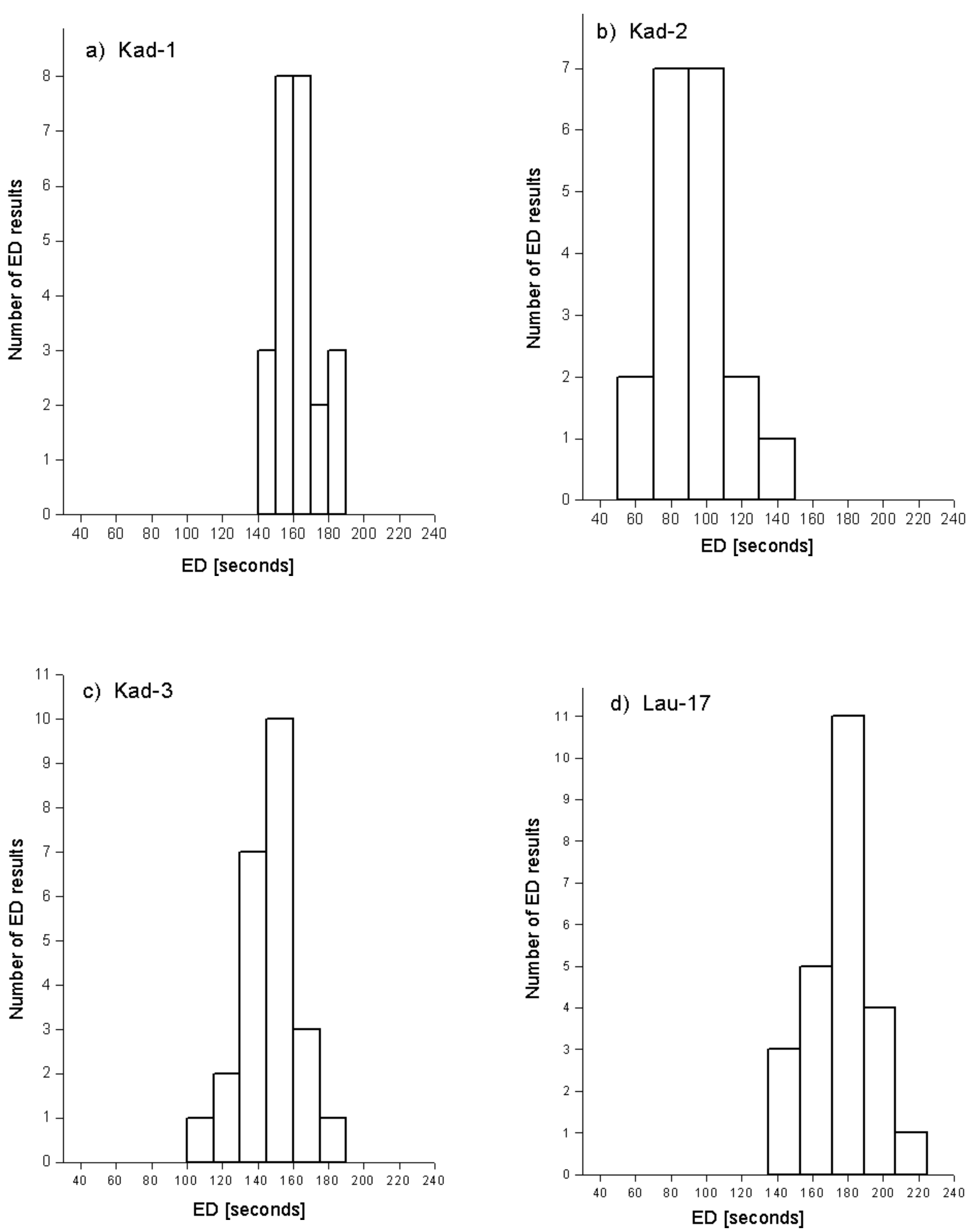

Fig. 3. *The OSL results. Histogram bar width represents the standard deviation of Equivalent Dose (ED) expressed as seconds of irradiation by beta radiation source*

homogeneity of natural radiation field was not tested. There is a potential risk that surrounding layers can influence *DR* to some extent, especially in a case of sample Kad-2. The *ED* values and regeneration doses presented here are expressed as seconds of irradiation by beta radiation source, instead of Gy units. This enables a direct comparison of the *ED* results obtained by TL and OSL methods, without incorporating the uncertainty of the beta source calibration 91±2 mGy/s.

5. DISCUSSION AND CONCLUSIONS

In a glow curve of quartz two regions differentiated in bleaching characteristics can be distinguished. The easy-bleachable one is centered on 325°C and the difficult-bleachable one appears around 375°C (Spooner, 1994). This allows undertaking an attempt to determine the *ED* not affected by the residual TL even in a case of partially bleached sediments (Mejdahl, 1988). The method consists of the TL regeneration after a laboratory bleaching and a subsequent comparison between an obtained glow curve and a natural one. The best fit is approached by varied bleaching duration time. The dose that regenerates residual TL to the natural TL is assumed as *ED*. Although it seems there are many possible combinations of bleaching conditions and regenerated dose values, but most of them reproduce a natural glow curve only locally.

Practical realization of plateau test makes use of presentation of the *ED* values versus rising temperature (**Fig. 4**). Closer the laboratory bleaching corresponds to the natural conditions - longer plateau of *ED* function is expected. Moreover, in quartz glow curve in low tempera-

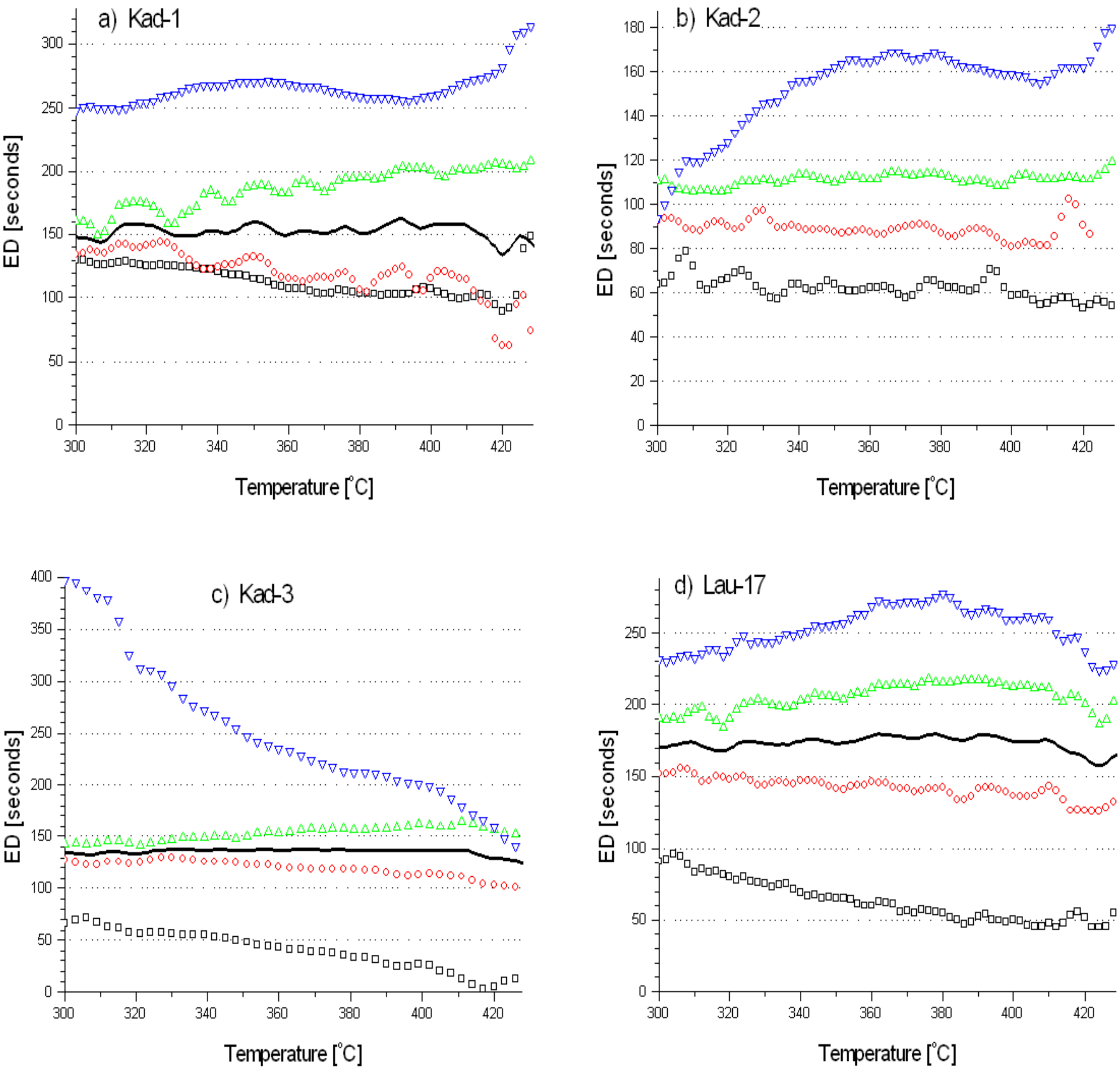

***Fig. 4.** The plateau test results. Bleaching time in minutes: □ 5 or 15; ○ 30; △60; ▽600 and - artificial (averaged from 30 and 60)*

ture region is bleached more rapidly, hence curved shape of draw of the plateau test can be used as indicator of the relationship between natural and laboratory bleaching. The rising tendency of *ED* plot indicates a weaker natural bleaching, while falling of *ED* draw suggests that a residual level in nature was even lower than that obtained artificially.

Presented results of plateau test (**Fig. 4**) were obtained by calculations performed with resolution of 1°C. The TL sensitivity was found out from the results of regeneration and the linear interpolation was applied to a natural TL signal for determining the *ED*. Narrow range of applied regenerative doses close to the *ED* value justified such approach.

It derives from the plateau test that for three samples: Kad-1, Kad-3 and Lau-17 30 minutes of a laboratory bleaching was still not enough to reach an appropriate residual level while 60 minutes bleaching appeared to be too much (**Fig. 4a, c** and **d**). Hence the averages from these plateau functions were calculated bringing in a long flat line each case. The ED_{TL} value corresponding to the most flat region of this line is presented in **Table 1** as related to 45 minutes of artificial bleaching. It was taken for age calculations.

The existence of three different plateau regions for sample Kad-2 (**Fig. 4b**) is not fully understood yet. Possibly it is connected to a relatively low natural TL intensity. Therefore bleaching of this sample is slower and more homogenous along the whole temperature range of the glow curve. This could result in a set of flat and shifted plateau draws as it is shown in **Fig. 4b**.

Only in a case of the longest bleaching it appeared impossible to keep natural TL glow curve between regenerated ones in the whole temperature range (300 – 450°C). Hence it is possible that the TL sensitivity determined from regenerated TL doesn't correspond to a natural TL. This is probably a reason of the strange effects appearing in a plateau test after 600 minutes of the bleaching for the sample Kad-3 (**Fig. 4c**).

From **Table 1** it derives that the best consistency between ED_{OSL} and ED_{TL} was achieved for two samples from a dune core (Kad-1 and Lau-17). Sample from the slope (Kad-3) seems to be a little younger according to the TL age. The TL results obtained for the eolian cover (Kad-2) are somewhat confusing (**Fig. 4b**). Nevertheless the longest plateau region was found to be related to the 15 minute bleaching which corresponds to the TL age of 5100±300 years. It is worth mentioning here that the ED_{OSL} value obtained for this sample also exhibits the greatest uncertainty. Standard deviation of 34% could be reduced to 19% only by rejecting the 5 most spread results of SAR OSL. That could suggest some problems concerning bleaching during deposition of the cover layer. For these reasons two ED_{TL} values derived from regeneration method and applied after two shorter laboratory bleaching times (namely 15 and 30 minutes) were taken into account in the final age calculations.

For each sample the final *ED* value was averaged from ED_{OSL} and ED_{TL} corresponding to the best plateau results. On this base the mean dates denoted as *T* were calculated (**Table 1** and **Fig. 5**). They were used for the reconstruction of the dune evolution.

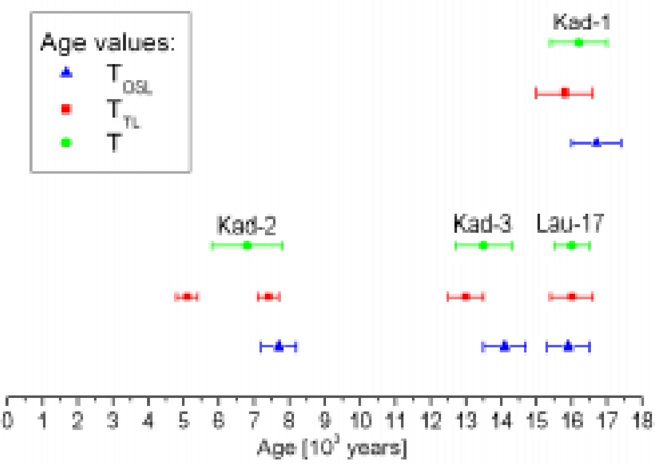

Fig. 5. *Luminescence dating results. The mean age T was calculated from averaging ED_{OSL} and ED_{TL} values. For comparison the T_{OSL} and T_{TL} dates are also shown.*

6. STAGES OF THE MOUNTAIN EVOLUTION

A receding glacier during or short after the Vistulian Glaciation – the last glacial period, formed the basement of the St. Laurent Mountain. The age of the basement can be established to ca 17,500 years ago by correlating it with the results of the previous investigations carried out by authors in the surrounding area (Wysota *et al.,* 2002). This value can be assumed as the lowest possible age limit for the subsequent genesis of the dune (**Fig. 6a**). During deglaciation (still in Pleniglacial) the dune was formed on the till (**Fig. 6a**). It was of about 100 m long, 50 m wide and approximately 6 m high. The time of its erection is based on a luminescence dating. The dates obtained for samples Kad-1 and Lau-17 overlap each other (**Fig. 5**) proving, that the deposition of the upper part of the dune's core took place between 16.5 and 15.4 thousands years ago, where the lower age *T* limit of sample Lau-17 and the upper age *T* limit of sample Kad-1 were used for such a range estimation (**Table 1**). Late Glacial age of the dune correlates with the age of the dunes in a neighbourhood of the Vistula river valley, in the Unisław Basin (Niewiarowski, 1987).

In Neolithic Age 1 m thick layer of silty sand was added up on the dune. Subsequently, these deposits were covered by the eolic sands resulting in sediment layer of 0.5 - 1 m in thickness. The luminescence dating established its age from 5.8 up to 7.8 thousands years (**Fig. 6b**). Above this eolic cover there occur again sand anthropogenic deposits. They are divided by a layer containing burnt wood and organic materials (**Fig. 6c**), which appears c.a. 0.5 m above eolic cover. The radiocarbon dating was carried out on this material in Institute of Environmental Geochemistry of NAS of Ukraine in Kiev. The age of the burnt layer was established on a base of radiocarbon dating to ca. 2700 years. This result allows distinguishing the third phase of the St. Laurent Mountain evolution that is most likely related to Łużyce Culture from the Bronze Age. During this time the form was about 120 m long, 60 m wide and about 8 m high.

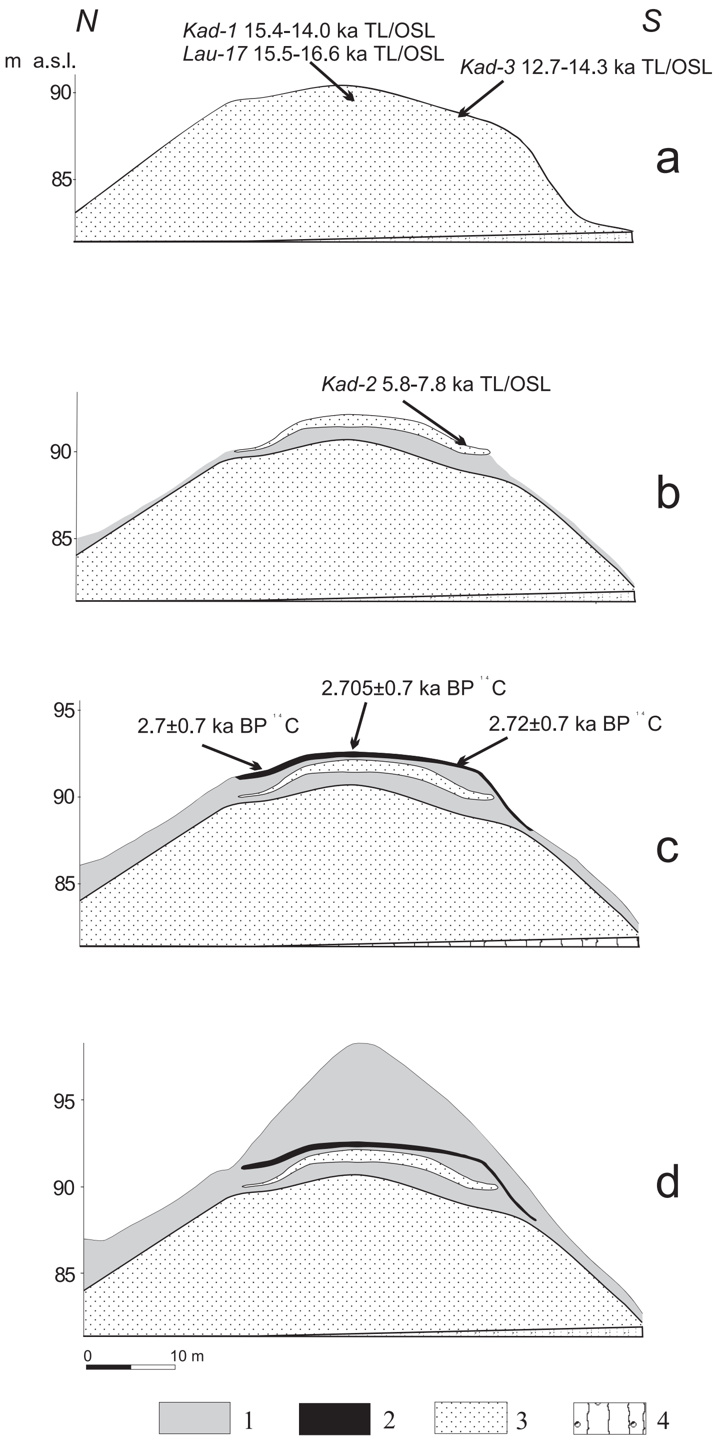

Fig. 6. Evolution of the St. Laurent Mountain.
Legend: 1 – silty sand anthropogenic deposits, 2 – silty sand anthropogenic deposits with burnt material, 3 – eolian sand, 4 – till and ablation sand, a – Late Glacial, 16.5 ÷ 13 ka – dune; b –Mezoholocene, 6 ÷ 8 ka (Neolithic Age) - sand bank with sand eolian cover; c – Neoholocene, 2.7 ka (Bronze Age) – sand bank with level of burnt material; d – Neoholocene, 1-2.7 ka (Bronze Age to Medieval Ages) – sand bank on the top of the mountain

Most probably between the Bronze Age and the Medieval Age a sand embankment covered the layer of the burnt wood. Its thickness is about 6 – 8 m (**Fig 6d**). The mountain reached size and shape similar to the present one. Nowadays further luminescence research is carried on to establish the precise time when this form was erected.

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