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Luminescence Dating Results of Sediment Sequences of the Lena Delta

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Summary: The age correlation between the three main geomorphological terraces in the Lena Delta, especially that of the second sandy terrace (Arga Island) and the third terrace (Ice Complex and underlying sands) is still being discussed. Knowledge about the age of the Ice Complex and its underlying sands, and the Arga sands is necessary for understanding the past and modern structure of the delta. Geochronometric data have been acquired for three sediment sequences from the Lena Delta by luminescence dating using the potassium feldspar IR-OSL technique. Additionally, ^{14}C dates are available for geochronological discussion. Typical sediments of the upper part of Arga Island as found in the area of Lake Nikolay are of Late Pleistocene age (14.5-10.9 ka). Typical third terrace sediments from two sequences located at the Olenyokskaya branch are older. At the profile "Nagym" sandy sequences were most probably deposited between about 65 ka and 50 ka before present. The lower part of the sandy sequence at "Kurungnakh Island" is possibly older than the sediments of the section at Nagym. However, methodological difficulties in luminescence dating (insufficient bleaching at the time of deposition) and younger ^{14}C dates make the discussion of the results difficult.

Zusammenfassung: Die Altersbeziehungen zwischen den drei geomorphologischen Hauptterrassen des Lena-Deltas ist noch ungeklärt und Gegenstand laufender Diskussionen. Ihre Kenntnis ist jedoch nötig, um die Paläogeographie des Deltas zu rekonstruieren und seine heutige Struktur zu verstehen. Mit Lumineszenz-Altersbestimmung wurden geochronometrische Daten für drei Sedimentsequenzen des Lena-Deltas ermittelt. Dabei gelangte die Methode der IR-OSL Datierung an Kalifeldspäten zur Anwendung. Für eine geochronologische Diskussion der Untersuchungsergebnisse stehen desweiteren AMS ^{14}C-Alter zur Verfügung. Typische Sedimente des oberen Teils der Arga-Insel im Gebiet des Nikolay-Sees (zweite Terrasse des Lena-Deltas) haben ein spätpleistozänes Alter (14,5-10,9 ka). Die sandigen Sedimente der Schichtsequenzen des Olenyok-Arms (dritte Terrasse des Lena-Deltas) sind älter. Für den mittleren Teil des Profils Nagym ist eine Ablagerung vor etwa 65 ka bis 50 ka wahrscheinlich. Der untere Teil des Profils auf der Insel Kurungnakh ist möglicherweise älter als die Sedimente von Nagym. Methodische Schwierigkeiten der Lumineszenz-Datierung (unzureichende Bleichung zum Zeitpunkt der Ablagerung) und jüngere ^{14}C-Alter gestalten die Diskussion der Ergebnisse jedoch schwierig.

INTRODUCTION

Luminescence dating methods are able to determine the last light exposure of mineral grains and therefore the time of deposition of a great variety of sediments. Basic physical research and the development of new dating techniques led to their increasing importance for Quaternary geochronology in the last decade. Mostly they are the only methods to get reliable geochronometric information from aeolian or water-laid sediments in the age range from a few thousand to a few hundred thousand of years.

Luminescence dating methods are based on the characteristics of various minerals to store natural ionising radiation by its transformation into luminescence capability. Mineral grains are permanently exposed to such radiation owing to natural Uranium, Thorium and Potassium-40 in the sediment and to cosmic rays. During transport and deposition a former luminescence signal is deleted by light exposure. Stored in the dark, the luminescence signal increases and becomes a measure for the time of the sediment's deposition. Dating methods using optical stimulation of radiation-induced stored luminescence replace the thermoluminescence (TL) methods of the 1980's in sediment dating to a large extent. The signal of Optically Stimulated Luminescence (OSL) is reset to zero within a few minutes' light exposure, also under dimmed conditions. The Infrared Optically Stimulated Luminescence (IR-OSL, IRSL) method (HÜTT et al. 1988) based on feldspar minerals was applied in the present study. The internationally acknowledged age range of the IR-OSL method is about 1 ka to 150 ka (1 ka = 1000 a). Further basic physical research is necessary to get reliable results of greater age. Recent overviews of OSL, sediment dating and dating procedures are given by AITKEN (1998), PRESCOTT & ROBERTSON (1997) and WINTLE (1997).

The age correlation between the different terraces in the Lena Delta, especially that of the second sandy terrace (Arga Island) and the third (Ice Complex) is still being discussed (ARE & REIMNITZ 2000). Knowledge about the age of the Ice Complex, the underlying sands, and the Arga sands is necessary for understanding the past and modern structure of the delta. Originally the second terrace was considered to be younger than the Ice Complex remnants and to be overlapping them. Later it was proposed that the sands composing the second terrace underlie the Ice Complex. No geochronometric data for the sediments were available until now. The present study comprises luminescence dating at three sediment sequences – one from Arga Island (adjacent to Lake Nikolay) and two from the third terrace (Olenyokskaya Branch) (Fig. 1). Additionally, seven AMS radiocarbon dates are available, which have been measured at the Leibniz Laboratory, University of Kiel.

LUMINESCENCE DATING

Samples have been taken from sandy fluvial sediments. At the section at Arga the outcrop was cleaned by melting the sediment with lake water. A layer of about 1.5 m was removed and the samples were taken using a metal hole corer, combined

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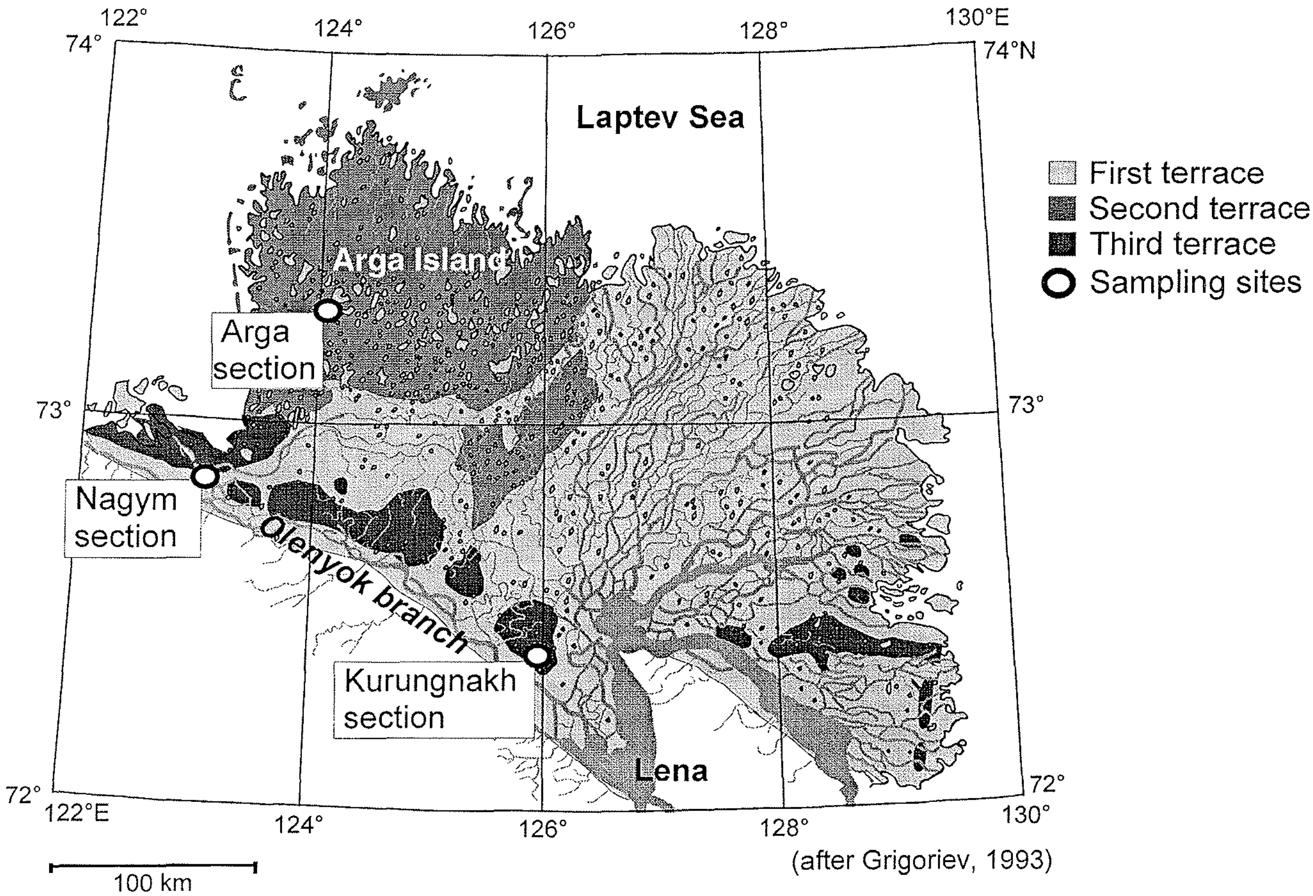

Fig. 1: Location map of the Lena Delta and the sediment sequences investigated.

Abb. 1: Karte des Lena-Deltas und Lage der untersuchten Sedimentsequenzen.

with an accumulator drilling machine. During the drilling process the frozen sediment material was transferred into a light-tight black plastic tube inside the corer. The sediment samples from the Olenyokskaya Branch area are of non-frozen material. About 0.5-1 m sediment was removed and light tight plastic tubes and a nylon hammer were used for taking the samples. All containers have been sealed to prevent any loss of water.

The sample preparation was carried out under laboratory light conditions (dimmed red light) and for additional light safety most of the time the material was handled in light-tight containers. In-situ and saturation water content were analysed at first. After sieving (100-160 µm), removing of organic substances and carbonates by H_2O_2 and HCl treatment, respectively, mineral separation was carried out. Potassium feldspar extraction was performed by a feldspar flotation procedure, followed by heavy liquid density separation (sodium polytungstate) of the fraction <2.58 g cm^{-3}. Standard HF, HCl etching was applied to remove the alpha ray affected part of the grains. Between all steps of separation the material was washed in distilled water to a neutral pH-condition.

The palaeodose (D_E) has been determined by the additive-dose method. Luminescence measurements of the 410 nm feldspar IR-OSL emission (KRBETSCHEK et al. 1997) using an optical interference filter (peak-max. 410 nm, 20 nm width at half peak transmission) have been carried out on a modified Riso-TL/OSL-DA 12 reader, running the IR stimulation at 40 mW cm^{-2}. 48 sample aliquots of about 4 mg (volume normalisation) were used. Natural sample aliquots were IR-OSL normalised by pulse measurements (0.1 s), irradiated (^{90}Sr/ ^{90}Y ß-source, dose rate 0.92 Gy/min, 6-8 additive dose values) and measured after storage for at least 1 week at room temperature and preheat for 48 h at 140 °C. After a 0.1 s pulse measurement (short shine) the IR-OSL signal of the aliquots was detected at 100 s stimulation duration (shine down).

Data evaluation is illustrated in Figure 2 a-c. A single exponential saturation dose characteristic growth curve fit was used to calculate the palaeodose. The IR-OSL measurements (Fig. 2a) were normalised by the natural short shine signal. After "late light" (80-100 s) background subtraction (AITKEN & XIE 1992) the shine down plateau was calculated (Fig. 2b). The growth curve fit was repeated to calculate the final palaeodose and error determination using the integral values of the plateau (Fig. 2c). A fading test has been carried out for each sample (>2 month storage at RT). The U, Th and ^{40}K concentration of the sediment samples have been determined by low level high resolution gamma spectrometry. No significant radioactive disequilibrium was observed. The internal dose rate of ^{40}K was calculated based on the potassium concentration of the feldspar grains determined with a recently developed spectral radiophosphorescence technique (DÜTSCH & KRBETSCHEK 1997). Cosmic dose rate estimation is based on PRESCOTT & HUTTON (1988). The age and error calculations have been

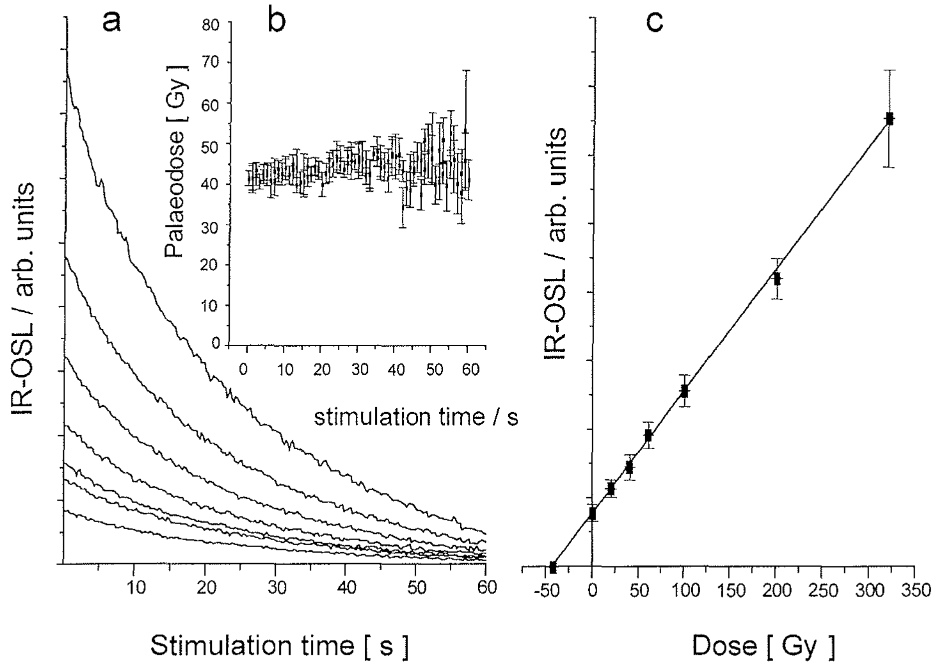

Fig. 2: Sample ARG 5: a) IR-OSL measurements (mean shine down curves: natural signal; additive dose 20, 40, 60, 100, 200, 320 Gy) b) DE *vs.* stimulation time (shine down plateau) c) IR-OSL dose characteristic (plateau-integral).

Abb. 2: Probe ARG 5: a) IR-OSL Messungen (Mittelwerte der Ausleuchtkurven: natürliches Signal ; additive Dosen 20, 40, 60, 100, 200, 320 Gy) b) DE in Abhängigkeit von der Stimulationsdauer (Ausleuchtplateau) c) IR-OSL – Dosis - Charakteristik (Integralwerte des Plateaus).

done using the computer-software of GRÜN (1992), based on the procedure described in AITKEN (1985). The error includes systematic and random errors which arise from: irradiation source calibration, possibly changing water content in the past, errors in radionuclide-, cosmic dose rate-, feldspar internal dose rate- and palaeodose determination.

DATING RESULTS AND DISCUSSION

The results of different analytical procedures are listed together with the final age calculations in Table 1. The radioisotope concentration of Uranium and Thorium is slightly higher in most of the Olenyokskaya sediment samples compared to those from Arga. The age data from the Arga sediment profile have relative errors in the range of about ±10 % whereas those of the Olenyokskaya sequences are significantly higher and reach more than ±40 % for some samples. This is caused by a generally high error in palaeodose determination due to a high scatter of IR-OSL measurement results. In the case of the samples OLE 4, 5, 9 the calculation of the palaeodose, based on such data, was not possible. For OLE 5 this is additionally caused by an insufficient number of sample aliquots for IR-OSL measurement due to low potassium feldspar concentration.

The natural IR-OSL of the sample aliquots (short shine normalisation values) characterises the samples' non-homogeneity to some extent. Although random errors of the aliquot-preparation and that of the measurement instrumentation are included, such measurements can uncover different effects caused by changing material composition. Large data scatter may occur, if the luminescence behaviour of the grains is highly variable (e.g. the signal is emitted by a few bright shining grains while most show weak luminescence dose response) or the feldspar fraction is a mixture of grains with large differences of the bleaching degree at the time of deposition. Insufficient zeroing of the luminescence signal prior to sediment deposition is known to be a main source of error in luminescence dating of some types of sediment. In the case of sediments from polar regions, deposited in a river delta, this is of particular importance. Both, the seasonal lack or reduction of sunlight and the ice-melting period may cause insufficient bleaching of the IR-OSL signal. The latter leads to sediment reworking, high sediment load of the water and transport over short distances, factors which drastically reduce the duration or intensity of sunlight exposure.

The natural IR-OSL normalization values of the samples are shown in Figure 3. It is obvious that the samples from the Olenyokskaya sequences are characterised by high scatter. Additionally a modern sample (NP 7) from the central delta region was investigated. It has the highest scatter of the normalization measurements (Fig. 3) and no reliable dose (which should be zero) could be obtained. The samples from the Arga/Lake Nikolay sediment profile seem to be less affected by insufficient bleaching. The reason may be a longer transport distance.

GEOCHRONOMETRY / GEOCHRONOLOGY

A scheme of the sediment sequences with the luminescence dating results is given in Figure 4. AMS radiocarbon dates are added for further discussion (Tab. 2). The results of IR-OSL age determination show a very narrow age range in which the sediment sequence of Arga/Lake Nikolay must have been formed. Taking into account the errors of the data, its formation can be constrained to 14.5-10.9 ka before present. Taking into account the error ranges, the data are consistent and there should not be a basic influence of insufficient bleaching on the age data from Arga. It seems likely that the high accumulation rate implied by the overlapping ranges of the luminescence datings is associated with a fluvial environment under upper

Sample	Radioisotope Concentration U / ppm	Th / ppm	K / %	Water %	D_{nat} mGy a^{-1}	D_E Gy	Age ka
ARG 1	1.1 ±0.09	4.9 ±0.25	3.3 ±0.28	23 ±2	3.74 ±0.11	50 ±2.6	13.4 ±1.1
ARG 2	1.0 ±0.05	3.8 ±0.25	2.4 ±0.26	20 ±5	*	*	*
ARG 3	0.9 ±0.06	3.4 ±0.25	2.4 ±0.19	22 ±2	3.04 ±0.17	40 ±3.9	13.3 ±1.5
ARG 4	1.1 ±0.09	4.4 ±0.27	2.7 ±0.16	25 ±5	3.24 ±0.22	39 ±2.4	12.0 ±1.1
ARG 5	1.1 ±0.05	3.7 ±0.20	2.4 ±0.18	18 ±5	3.23 ±0.23	42 ±2.0	13.1 ±1.1
OLE 1	1.4 ±0.09	5.9 ±0.96	2.6 ±0.14	10 ±5	3.85 ±0.27	219 ±30	57 ±9
OLE 2	1.5 ±0.08	6.6 ±1.53	2.7 ±0.14	24 ±5	3.37 ±0.26	176 ±31	52 ±10
OLE 3	1.6 ±0.25	5.9 ±0.32	2.5 ±0.17	31 ±5	3.00 ±0.25	147 ±64	49 ±22
OLE 4	1.6 ±0.07	5.9 ±0.67	2.5 ±0.19	18 ±5	3.44 ±0.27	**	**
OLE 5	1.1 ±0.06	4.6 ±0.30	2.6 ±0.17	25 ±5	3.14 ±0.25	**	**
OLE 6	1.0 ±0.09	4.3 ±0.20	2.4 ±0.13	18 ±5	3.20 ±0.24	177 ±25	55 ±9
OLE 7	1.7 ±0.11	7.1 ±0.27	2.2 ±0.13	35 ±5	2.72 ±0.22	238 ±100	*
OLE 9	1.5 ±0.07	6.1 ±0.27	2.1 ±0.15	32 ±5	2.67 ±0.23	**	**
OLE 10	1.5 ±0.07	6.4 ±0.30	2.2 ±0.14	16 ±5	3.30 ±0.24	215 ±22	65 ±8

Tab. 1: Analytical results of IR-OSL dating. * not determined; **determination not possible; D_{int} = 0.78 ±0.08 mGy/a (ARG1, OLE1-10); 0.76 ±0.08 mGy/a (ARG 3-5)

Tab. 1: Analyseergebnisse der IR-OSL Datierung. * nicht bestimt, ** nicht bestimmbar, D_{int} = 0.78 ±0.08 mGy/a (ARG1, OLE1-10); 0.76 ±0.08 mGy/a (ARG 3-5)

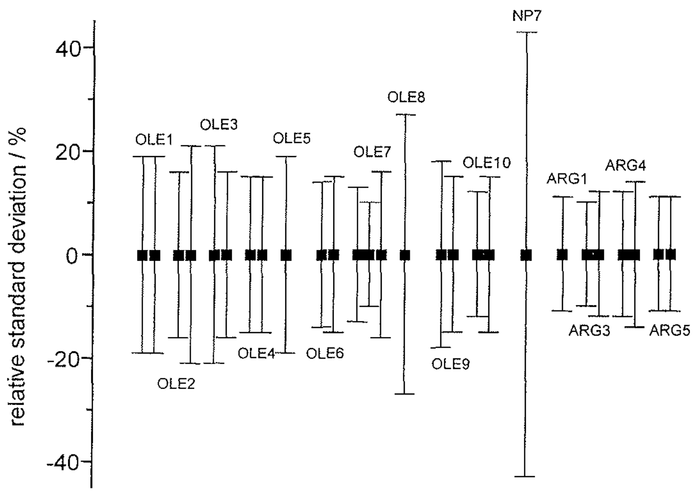

Fig. 3: Relative standard deviation of the natural normalization measurements (0.1 s short shine) calculated for 24 aliquots each, except the modern sediment NP7, where the value is based on the measurement of 12 aliquots.

Abb. 3: Relative Standardabweichung der Normalisierungsmessungen des natürlichen Signals (0,1 s Pulsmessung) berechnet für jeweils 24 Präparate, ausgenommen für das rezente Sediment NP7, dessen Wert auf den Messungen von 12 Präparaten basiert.

flow regime. The deposits are derived most probably from the periglacial Lena River, which flowed on the exposed Laptev shelf at that time (SCHWAMBORN et al. 2001).

As mentioned above, for the dating results from the Olenyokskaya profiles high errors are typical, most probably caused by insufficient bleaching at the time of deposition. Therefore, limitations are set for the geochronological interpretation of the data.

The data from the Nagym sequence (OLE 1, 2, 3, 6) span a range from 49 ka to 57 ka. No further time resolution is possible because the errors overlap. Deposition between about 65-40 ka before present is most probable, based on the IR-OSL dating results. However, the ^{14}C data (root horizons) of the lower part may narrow this range. It seems likely, that the deposition took place between about 65-50 ka. Predominantly wavy bedding interrupted by root horizons indicate a fluvial sedimentation under shallow water conditions.

The OSL data from the sequence at Kurungnakh Island (OLE 7, 10) are between 88 ka and 65 ka. A deposition of the lower part of the sequence between about 100 ka and 60 ka is likely. This is not in accordance with the ^{14}C dates, which are of younger age. Thus, the age determinations from both methods are suitable only to narrow the sedimentation time to Early to Middle Weichselian time. The OLE-samples may be influenced by insufficient bleaching. This can cause age overestimation. However, there is a chronological order. It seems, that age overestimation due to partial bleaching does not describe the discrepancy between the IR-OSL and ^{14}C ages sufficiently. The measured AMS ages are placed at the limits of the age range covered by the ^{14}C method. Contamination by young allochthonous carbon is the biggest problem in radiocarbon dating of old samples. Whereas 1 % contamination with recent carbon yields a value of age underestimation of 200 a for a 10 ka old sample, it is 7 ka (!) for a 40 ka old sample (GEYH & SCHLEICHER 1990). Because even small contaminations influence such old data drastically radiocarbon ages of more than about 30 ka should thus be viewed as minimum ages (GEYH & SCHLEICHER 1990). The small sample amount used in AMS dating may intensify this problem. According to the IR-OSL data, therefore, the lower part of the Kurungnakh Island profile is possibly older than the Nagym sediment sequence.

CONCLUSION

Geochronometric data have been acquired for three sediment sequences from the Lena Delta by luminescence dating using the potassium feldspar IR-OSL technique. Furthermore, ^{14}C

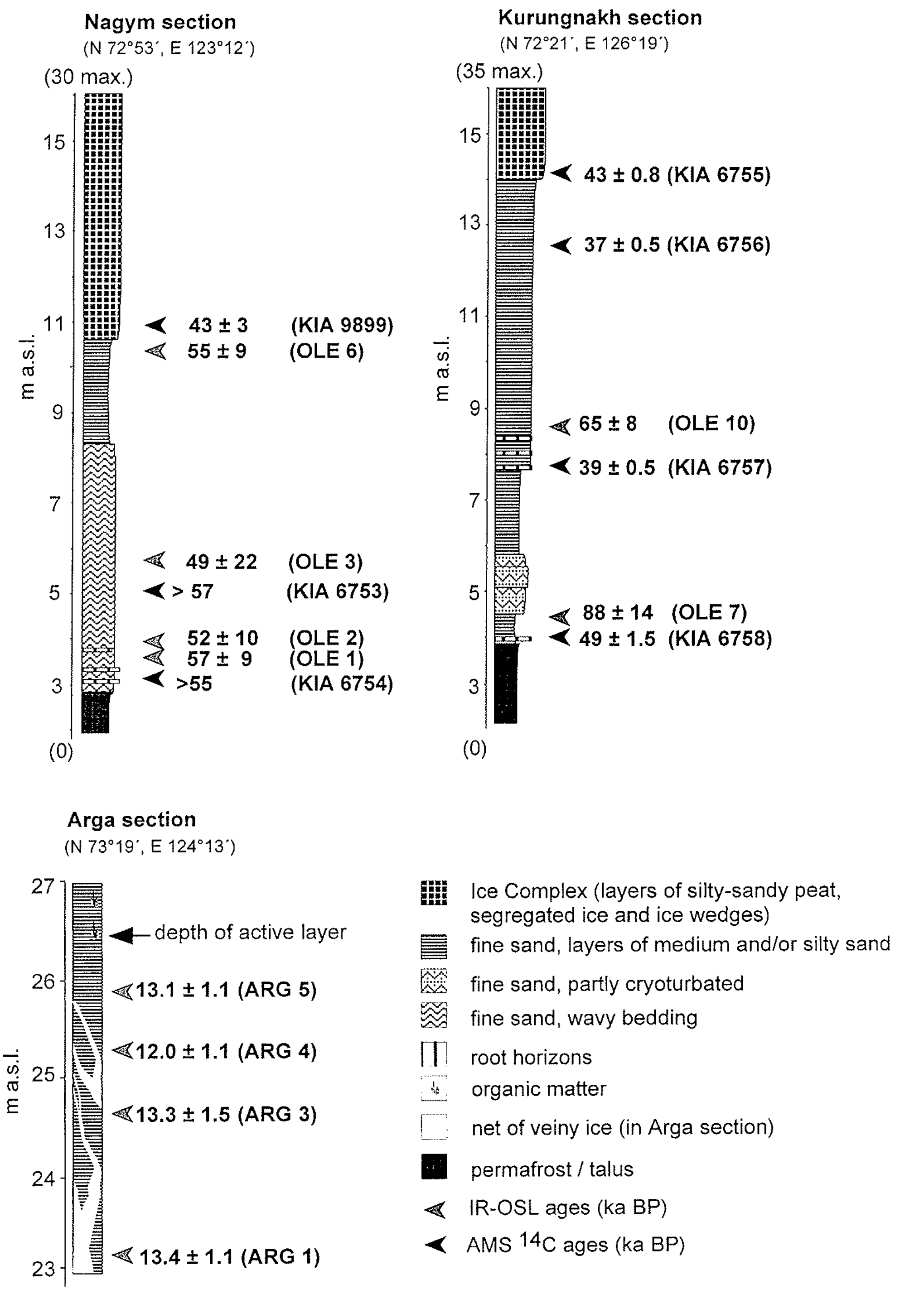

Fig. 4: Scheme of the sediment sequences investigated, compiled with the IR-OSL and ^{14}C age data.

Abb. 4: Schematische Darstellung der untersuchten Sedimentsequenzen zusammengestellt mit den IR-OSL und ^{14}C Altersdaten.

dates are available for geochronological discussion. The sediments of the upper part of Arga Island (second terrace), in the area of Lake Nikolay, are of Late Pleistocene age (14.5-10.9 ka). The sediments from sequences at the Olenyokskaya branch (third terrace) are older. At the profile Nagym the middle part was most probably deposited between about 65 ka and 50 ka before present. The lower part of the sequence at Kurungnakh Island is possibly older than the sediments of the section at Nagym, but methodological difficulties in luminescence dating (insufficient bleaching at the time of deposition) and younger ^{14}C dates make the discussion of the results difficult.

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Sample	Depth (m a.s.l.)	Lab. No.	Measured age (^{14}C yr BP)	
Nagym (base of Ice Complex)	11.0	KIA 9899	42,930	+3100/-2230
Nagym	5.1	KIA 6753	> 56,790	
Nagym	3.1	KIA 6754	> 54,520	
Kurungnakh (base of Ice Complex)	14.0	KIA 6755	42,910	+840/-760
Kurungnakh	12.5	KIA 6756	37,230	+510/-480
Kurungnakh	7.7	KIA 6757	39,400	+510/-480
Kurungnakh	4.0	KIA 6758	49,440	+1760/-1440

Tab. 2: AMS ^{14}C ages for third terrace deposits. (a.s.l. = above sea level, i.e. above Lena River water level, 08.-10.08.98, respectively)

Tab. 2: AMS ^{14}C-Alter für Sedimente der dritten Terrasse.

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