ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 416, No. 7, pp. 1022–1026. © Pleiades Publishing, Ltd., 2007.
Published in Doklady Akademii Nauk, 2007, Vol. 416, No. 4, pp. 509–513.

GEOLOGY

The Geochronometric Age of Late Pleistocene Terraces on the Lower Yenisei*

V. Astakhov[a] and J. Mangerud

Presented by Academician A.P. Lisitsyn September 15, 2006

Received October 2, 2006

DOI: 10.1134/S1028334X07070094

New radiocarbon-AMS and optically stimulated luminescence (OSL) dates from key sections of postglacial terraces of the Yenisei River near the Arctic Circle demonstrate that the bulk of the Second Terrace alluvium was deposited during the early marine isotope stage 3 (MIS 3) some 45–60 ka BP. The glacifluvial cover of the Third Terrace was formed by melting Putorana glaciers approximately 60–75 ka BP.

The terrace sequences of the Yenisei River between the cities of Turukhansk and Igarka (Turukhansk District, 66°–67° N) have been used since the 1970s as stratigraphic markers for reconstructing climatic fluctuations in Siberia and their correlation with Late Pleistocene events of western Europe. Following Sachs [1], many authors correlated all waterlain sediments, which cover the Zyryanka glacial complex at 30–60 m asl, with the Karginsky marine strata representing the last boreal transgression of Siberia north of 69° N. Based on conventional radiocarbon dating, the Karginsky thermochron with interglacial climate was attributed to the interval of 50–22 ka BP [2–4], i.e., to MIS 3. This correlation was often restricted to the Second Terrace at 30–40 m asl. The Third Terrace at 50–60 m asl was considered as the Zyryanka glacifluvial plain of MIS 4, and the First Terrace at 20–25 m asl was thought to have formed during MIS 2 [4, 5].

Recently obtained AMS, OSL, and U/Th dates have demonstrated that the Karginsky warming in key sections is older than 80 ka BP. Consequently, they correlate not with MIS 3, but with MIS 5 (probably, 5e) [6–8]. Therefore, it was necessary to obtain updated chronometry of the fluvial strata in the Turukhansk Yenisei key sections, where they clearly overlie tills and glacilacustrine rhytmites of the last (Zyryanka) glaciation.

METHODS

In 2003, we resampled the key exposures and obtained 25 AMS-radiocarbon dates from T. Goslar at the Poznan Laboratory, Poland (table). Because 10 mg of organic material is sufficient for an AMS dating, we preferred to date only delicate plant remains, such as leaves, seeds, and moss tissue, which are least likely to survive redeposition. These tiny fossils were selected under a binocular microscope. We consider the resultant AMS dates to be more accurate than earlier published conventional dates [3, 4] measured on bulk samples. The calibration of radiocarbon dates is still controversial for the period discussed in this paper, although one should probably add 3–5 ka to the ^{14}C age in order to obtain "calendar years" [9] which could be compared with OSL values.

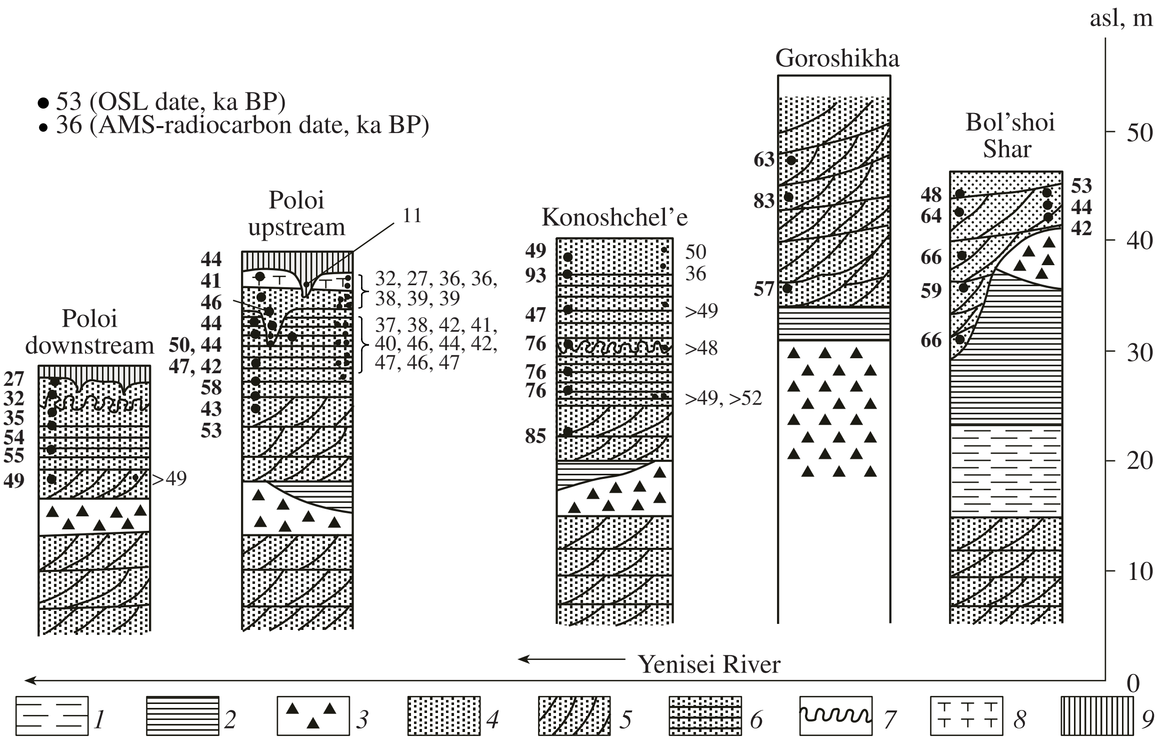
We also present 35 dates obtained by measuring optically stimulated luminescence (OSL) of quartz grains [10] at the Nordic Laboratory of Luminescence Dating in Risoe, Denmark, under the guidance of A. Murray (table). The OSL dates are here cited with an error given as one standard deviation of the laboratory counting procedure in the same manner as for ^{14}C dates. However, other uncertainties of OSL dating, such as incomplete bleaching, fluctuating water content, migration of nucleides, and instability of the signal, lead to additional errors, which often are larger than for the radiocarbon analysis. For example, our OSL ages have been calculated as though the sediments were continuously water-saturated since deposition. In our opinion, this is a reasonable hypothesis, although it may lead to an overestimation of the age. If we extrapolate the low water content of the sampling moment to the entire postdepositional period, then the calculated ages would

* This article was translated by the authors.

[a]Geological Faculty, St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199034 Russia
e-mail: val@nb15514.spb.edu
[b]Department of Earth Sciences, University of Bergen, Allegt. 41, N-5007 Bergen, Norway
e-mail: mangerud@geo.uib.no

Dates: AMS radiocarbon (Roman print) and OSL (italics)

Field sample	Height above river, m	Age ^{14}C, ka BP	Lab no.	Field sample	Height above river, m	Age OSL, ka BP	Lab no.
Poloi downstream (First Terrace, 66°42.2′), *eolian sand*							
				406	21.8	***27 ± 2***	042576
				405	21.3	***32 ± 2***	H52529
				404	20.4	***35 ± 2***	H52528
				403	19.6	***54 ± 4***	042575
Alluvial sand							
				401	17.6	***55 ± 3***	042574
407	15	**>49**	Poz-4929	409	15	***49 ± 3***	042577
Poloi upstream (Second Terrace, 66°43.6′), *eolian sand with peat layers*							
391	30	**10.7 ± 0.06**	Poz-8307				
389	31.3	**31.8 ± 0.5**	Poz-8306	390	31	***44 ± 3***	042567
388	30.8	**26.7 ± 0.2**	Poz-5086				
387a	30.2	**36.2 ± 0.7**	Poz-8304	386	30	***41 ± 2***	H52527
387b	30.2	**35.5 ± 0.7**	Poz-8305	393	29.5	***46 ± 3***	042568
383	29	**38.4 ± 0.8**	Poz-5085	385	28.8	***44 ± 3***	042566
380a	27.4	**39.2 ± 1**	Poz-4924				
380b	27.4	**39 ± 1**	Poz-4925				
Underlying laminated alluvial sand with moss mats							
379	29.9	**37.1 ± 0.8**	Poz-4922				
378	29.4	**37.7 ± 0.9**	Poz-8301				
				377	29.2	***50 ± 3***	042565
382a	27.9	**42.5 ± 1.4**	Poz-4926	381	27.8	***42 ± 2***	H52526
382b	27.9	**40.5 ± 1.1**	Poz-4928	376	27.8	***47 ± 2***	H52525
375	27.5	**40.3 ± 1.2**	Poz-8300				
384a	27	**46 ± 2.5**	Poz-8303				
384b	27	**43.6 ± 1.8**	Poz-8922				
373	25.5	**42.2 ± 1.4**	Poz-4921	374	25.8	***44 ± 2***	H52524
371	23.6	**47.4 ± 2.8**	Poz-8299	372	24.5	***58 ± 4***	042564
369	23.3	**46 ± 2**	Poz-4920				
368	23	**46.5 ± 2.6**	Poz-8297	367	22.6	***43 ± 3***	H52523
				366	22	***53 ± 3***	042563
Konoshchel'e (Second Terrace, 66°17.4′), alluvial sand							
308	32.6	**50 ± 7**	Poz-5083				
307	32	**35.6 ± 0.8**	Poz-8294	304	32.5	***49 ± 3***	H52520
302	29.5	**>49**	Poz-8293	306	31.5	***93 ± 6***	042548
297	27	**>48**	Poz-8291	298	27	***47 ± 4***	H52519
				295	24.2	***76 ± 5***	042547
294	23.2	**>52**	Poz-5082	292	21.9	***76 ± 4***	042546
291	21	**>49**	Poz-5081	289	21	***76 ± 4***	042545
				288	15	***85 ± 9***	042544
Goroshikha (Third Terrace, 66°23.2′), *sandur*							
				309	42	***63 ± 4***	042551
				311	38	***83 ± 6***	042550
				312	31	***57 ± 4***	042549
Bol'shoi Shar (Third Terrace, 66°), *sandur*							
				275	37	***53 ± 4***	H52513
				274	36.2	***44 ± 7***	042540
				273	35.5	***42 ± 5***	H52512
				251	32.5	***48 ± 4***	H52509
				250	31	***64 ± 5***	042531
				249	30	***66 ± 4***	042530
				248	28.5	***59 ± 4***	H52508
				247	25	***66 ± 5***	H52507



Sections of terraces on the Peri-Polar stretch of the Yenisei River with radiocarbon and luminescence dates, ka. (*1*) Floodplain silt; (*2*) glacilacustrine clayey rhythmites; (*3*) till; (*4*) subaerial sand, in places with peat seams; (*5*) cross-bedded channel sand; (*6*) laminated sand with silt seams or moss mats; (*7*) cryoturbation; (*8*) peaty bed; (*9*) loesslike siltstone.

have been up to 15% lower. Due to all such uncertainties we consider only series of OSL dates as meaningful. The reliability of the ages is further verified by the internal consistency of each series and by comparison with ^{14}C series.

DISTRIBUTION OF DATES

Intercalated fluvial and lacustrine formations have been repeatedly described from the Bolshoi Shar bluff (66° N) exposing the Third Terrace at 50–60 m asl [2, 4, 5]. At 2 km from the upstream end of the 6 km long bluff, we discovered a thus-far unknown till with cobbles of Putorana dolerites and basalts, sandwiched between the underlying glaciolacustrine clayey rhythmite and the overlying gravelly sand. This cross-bedded sand is dark brownish due to an abundance of mafic clasts. This unit is interpreted as a sandur deposited by the same Putorana ice cap that produced the mentioned till (figure).

There are two sets of dates from the Bolshoi Shar section. The right-hand series in the figure is taken at 2 km downstream from the southern end of the bluff above the till bed, whereas the left-hand series is taken 2.8 km farther downstream. The sand, up to 30 m thick, fills a 600-m-wide channel there and penetrates the entire glacilacustrine unit. The date of 48 ka is obtained on a sample from the eolian (or lacustrine) mantle of the terrace. The unweighted mean of the seven remaining OSL dates from the sandur is 56 ± 5 ka BP. Eliminating the two youngest dates, we get the nucleus of the five most consistent OSL dates with a mean value of 62 ka BP.

We have also obtained OSL dates from two sites of the Second Terrace: (i) at Konoshchel'e (66°17.4′ N) 29 km upstream from the Settlement of Kureika and (ii) at the Poloi upstream section (66°42.2′ N). In both cases, one can see a till overlain by a glacilacustrine rhythmite at the base of the terrace (figure). Higher up, a cross-bedded sand is overlain by a very striking sediment: light fine parallel- or ripple-laminated sand with numerous moss mats. At Konoshchel'e, the sand locally fills 1- to 3-m-deep troughs with dense moss mats along the banks and purer sand in deeper parts. This sand with forest pollen was interpreted as a signature of a warm climate of the Karginsky Stage [2, 4]. A ^{14}C date of >36 ka BP was reported by Zubakov who related it to the Igarka interstadial [4]. A finite ^{14}C date of 32 ka obtained by Kind from the cryoturbated layer in the Konoshchel'e section (figure) was used for dating the "Konoshchel'e cooling" [2]. However, we obtained a nonfinite ^{14}C date (>48 ka) and an OSL date of 47 ka from this layer and a ^{14}C date of >49 ka just above this layer (figure).

We sampled only one exposure of the First Terrace, the Poloi downstream section (66°43.6′ N). The upper part of the orange sequence appeared to be eolian sand,

and the underlying light alluvial sand yielded dates not different from the Second Terrace (figure).

DISCUSSION

The OSL ages from the Bolshoi Shar sandur (table and figure) suggest that this site was last glaciated from the Putorana Plateau during MIS 4. This conclusion contradicts our former suggestion that the last Putorana glacier reached the Yenisei as early as 90 ka BP [11]. The latter age should better be attributed to the underlying glacilacustrine rhythmite formed during the damming of the Yenisei River by a glacier that advanced from the north. The Boshoi Shar sandur was formed by an already free northbound drainage during the advance of the second Late Pleistocene ice from the uplands. It is clear that the Third Terrace here is of glacifluvial origin, as was suggested by Lavrushin [5] and Zubakov [4]. Only Kind considered the sand as a Karginsky alluvium [2]. Analogous sand above the till and varved rhythmites in a bluff 1.5 km upstream from the Settlement of Goroshikha (66°23.2′ N) has yielded similar OSL ages (mean value 68 ka) (figure).

On the whole, our AMS and OSL dates from the Second Terrace at Konoshchel'e and Poloi show older ages than the earlier published conventional radiocarbon dates. However, the conventional dates of 35, 40, 41, and 40 ka BP at Farkovo on the Turukhan River obtained from alluvium of the Second Terrace with washed plant detritus and forest pollen spectra [2] are very similar to our dates from the Poloi upstream section.

The basal dark brownish cross-bedded sand at Konoshchel'e may be contemporaneous to the sandur at Bolshoi Shar and Goroshikha. It might be even older, judging by the OSL series of 85 to 76 ka at Konoshchel'e (figure). There is a persistent geochronometric difference between similar sand units with moss mats at Konoshchel'e and Poloi. At Poloi, the light sand with moss mats yielded an exceptionally consistent series of old finite ^{14}C dates ranging from 47 ka in the lower part to 40 ka in the upper. This series of decreasing ages continues higher above the alluvial sand. Certainly, a single radiocarbon age close to the limit of the method should be regarded with skepticism. However, the stable series of 18 dates (table) in our case strongly suggests their reality. The ^{14}C dates are also supported by a number of parallel OSL ages in the same range.

At the Poloi upstream section, the alluvial sand is overlain by eolian sand with two levels of large ice wedge casts (figure). The dates around the oldest ice wedge are crucial for determining the moment of the final alluvial deposition. The wedge cast filled with eolian sand (^{14}C dates 38, 39, 39 ka; OSL dates 41, 44, 46 ka) cuts into alluvial mossy sand with ^{14}C dates of 44, 42, 41 ka and an OSL date of 42 ka. Thus, alluvial deposition ceased very close to 40 radiocarbon and 44 luminescence ka BP. The eolian sand is overlain by a peat bed with sand interlayers. The lowermost peat layer yielded ^{14}C ages of 35 and 36 ka, whereas the younger peat yielded 27 and 32 ka BP, supporting the interpretation presented above. The infill of the uppermost ice wedge cast, which pierces all three peats, has yielded a ^{14}C date of 10.7 ka BP indicating the early Holocene degradation of the permafrost.

At Konoshchel'e, nonfinite ^{14}C ages are accompanied by OSL ages higher than at Poloi (table), indicating that this characteristic sand is really older at Konoshchel'e. The absence of driftwood tree trunks and the predominance of moss and delicate shrub twigs in this alluvium of the river flowing from the south suggest that the climate, which was milder than immediately before and after the interstadial of early MIS, was more severe during this interstadial than today in the subzone of northern taiga. The large ice wedge casts at Poloi are located approximately 350 km south of the present-day limit for active ice wedges in mineral soils, suggesting drier and possibly colder winters than today.

Surprisingly, the OSL dates from the First Terrace of the Poloi downstream site just above the till indicate synchronicity of this alluvium with that of the Second Terrace. In other words, the First Terrace is an erosional feature at this site. The uppermost radiocarbon dates of the Poloi upstream section (39 to 27 ka), all collected from eolian sand, suggest that the river level fell rapidly from 35 to approximately 20 m asl after formation of the Second Terrace. Taking also into consideration the old age of the main part of the Konoshchel'e sequence, we infer that the Yenisei terraces mostly have high basements and their sediments are not necessarily genetically and chronologically related to the formation of the terrace staircase.

GEOCHRONOLOGICAL CONCLUSIONS

The sand of the Third Yenisei Terrace at Bolshoi Shar and Goroshikha was evidently formed by meltwater streams from a Putorana ice cap during MIS 4, some 75 to 60 calendar ka BP. This formation can also be traced as lithologically similar dark cross-bedded sand at the base of the alluvial mantle of the Second Terrace. The overlying light-colored alluvial sands of the Second Terrace with moss mats and forest pollen at the bottom and cryoturbations at the top are approximately 56 to 45 luminescence or 47 to 40 radiocarbon ka old at Poloi, but still older at Konoshchel'e. Previously, Kind assigned them to the Middle Karginsky warming 42 to 35 ka BP [2]. Zubakov assigned them to the Igarka thermochron, which presumably lasted from the beginning MIS 3 to 34 ka BP [4]. Although the new dates show older ages than those estimated by Kind and Zubakov, the containing strata are still younger than the stratotypic Karginsky alluvium [8]. The composite sequence is topped by eolian sand and silt with cryoturbations and peat layers formed slightly later than 45 luminescence or 40 radiocarbon ka BP but before MIS 2.

ACKNOWLEDGMENTS

The discussed data have been obtained in the course of the Russian–Norwegian research project PECHORA II (Paleo Environment and Climate History of the Russian Arctic) supported by the Research Council of Norway. The authors are also very grateful to A. Matyushkov (VSEGEI) and O. Kazansky (Igarka Geocryological Laboratory) for valuable assistance in the field research and to H. H. Birks (University of Bergen) who selected microscopic fossils for AMS dating.

REFERENCES

1. V. N. Sachs, *The Quaternary Period in the Soviet Arctic* (Vodtransizdat, Leningrad, 1953) [in Russian].
2. N. V. Kind, *Geochronology of the Late Anthropogene Based on Isotope Data* (Nauka Moscow, 1974) [in Russian].
3. S. A. Arkhipov, *Explanatory Note to Regional Stratigraphic Scheme of the West Siberian Plain* (Inst. Geol. Sib. Division USSR Acad. Sci., Novosibirsk, 1990) [in Russian].
4. V. A. Zubakov, *Recent Sediments of the West Siberian Lowland* (Nedra, Leningrad, 1972) [in Russian].
5. Yu. A. Lavrushin, *Alluvium of Plain Rivers of the Subarctic Belt and Periglacial Regions of Continental Glaciations* (Nauka, Moscow, 1963) [in Russian].
6. Kh. A. Arslanov, S. A. Laukhin, F. E. Maksimov, et al. Dokl. Earth Sci. **397**, 604 (2004) [Dokl. Akad. Nauk **397**, 796 (2004)].
7. V. I. Astakhov, Kh.A. Arslanov, F. E. Maksimov, et al. Dokl. Earth Sci. **401**, 298 (2005) [Dokl. Akad. Nauk **401**, 95 (2005)].
8. V. Astakhov and J. Mangerud, Dokl. Earth Sci. **403**, 673 (2005) [Dokl. Akad. Nauk **403**, 63 (2005)].
9. J. van der Plicht, J. Beck, E. Bard, et al, Radiocarbon **46**, 1225 (2004).
10. A. S. Murray and A. G. Wintle, Radiat. Measur. **32**, 57 (2000).
11. J. I. Svendsen, H. Alexanderson, V. Astakhov, et al. Quatern. Sci. Rev. **23**, 1229 (2004).