Diring Yuriakh: A Lower Paleolithic Site in Central Siberia

Michael R. Waters,* Steven L. Forman, James M. Pierson

Lower Paleolithic artifacts have been recovered from a single occupation surface within stratified deposits at Diring Yuriakh, an archaeological site in central Siberia. Thermoluminescence age estimates from eolian sediments indicate that the cultural horizon is greater than 260,000 years old. Diring Yuriakh is an order of magnitude older than documented Paleolithic sites in Siberia and is important for understanding the timing of human expansion into the far north, early adaptations to cold climates, and the peopling of the Americas.

Understanding the colonization of Siberia during the Paleolithic is important to both Old and New World prehistory (1). Uncertainty surrounds the timing of population movements across northeast Asia and of human adaptation to its rigorous arctic environments. Over the past five decades, numerous Paleolithic sites have been excavated and dated in Siberia (2). These sites have consistently indicated that the earliest occupation of Siberia occurred sometime between 35 thousand years ago (ka) and 18 ka (2). Possible older archaeological sites (such as Ulalinka and Filimoshki), believed to date to the Lower Paleolithic, have been reported in Siberia; however, the proposed artifacts from these sites are now widely believed to be products of natural forces (that is, geofacts) and not human-made tools. This was the situation until the accidental discovery of Diring Yuriakh in 1982 and subsequent excavations at the site over the past 15 years by Mochanov (3). Unlike the geofacts from previously proposed early sites, the artifacts from Diring are unequivocally human-made (4). What is uncertain is the exact age of these artifacts. Mochanov (3), on the basis of stratigraphic arguments and geochronological evidence, believes that the artifacts from Diring are between 1.8 and 3.2 million years old. Others have examined the site and suggest that the artifacts are no older than 0.8 to 1.0 million years old (5), are between 200,000 and 300,000 years old (6), or are no more than 15,000 years old (7). In 1993, we undertook geoarchaeological investigations at Diring to evaluate its stratigraphy and age.

Diring Yuriakh is located 140 km south of Yakutsk (61°12′N, 128°28′E) on the highest terrace of the Lena River (the Tabaginsk Terrace), which lies about 120 m above the modern river (Fig. 1) (3, 5). At Diring, unconsolidated Quaternary sediments rest unconformably on Cambrian-age limestone. These Quaternary sediments are divided into four major stratigraphic units labeled I through IV (from oldest to youngest) and are further subdivided on the basis of lithostratigraphic criteria (Fig. 2). These sediments are of alluvial and eolian origin.

The oldest unit that overlies limestone bedrock is composed of well-rounded gravel (unit Ia). Most of the gravels are pebble-sized and composed of quartzite. The gravels are conformably overlain by sands (unit Ib). The sand ranges from coarse-to-fine, angular-to-subangular grains that occur in horizontal beds and crossbeds. A few thin beds of well-rounded fine gravel and granules are interbedded in the sand. Unit I represents fluvial deposition in a sandy braided channel of an ancestral Lena River.

The gravel and sand (units Ia and Ib) are cut by two sets of wedges (3, 5) filled with sand (unit II). Wedges in the first set are large, ranging from 0.6 to 5 m wide and 4 m deep. Wedges in the second set are less than 0.5 m wide and reach a maximum depth of 1.1 m. All the wedges are filled with well-sorted, subangular medium sand. In some cases, small gravels (0.5 to 1 cm in diameter) form distinct vertical beds in the sand wedge fill. Large pebbles or cobbles are absent from both wedge sets. The sand from unit II is well sorted and the grains show evidence of wind abrasion; thus, the sand appears to be of eolian origin. The larger wedges appear to have been truncated by later deflation, whereas the smaller wedges extend downward from the deflation surface.

Resting on top of the eroded surface of unit Ib and the truncated sand wedges (unit II) is a gravel lag. This is a loose lag with mostly small pebbles (92%), a few large pebbles (7%), and rare boulders (1%). Compositionally, most of the gravels are siliceous (70%), with the remainder composed of quartzite (20%) and vein quartz (10%). Most of the larger pebbles, and all cobbles and boulders, are quartzite. These quartzite clasts are generally well rounded. All gravels are wind-abraded, showing pits, facets, and polish. This lag appears to have been created by the eolian deflation of unit I. The upper part of unit I must have contained lenses of gravel and large boulders that were deflated to a common surface and concentrated into a loose lag as the fine-grained sediments were removed when the wind swept over the area. The artifacts from Diring are found on this deflation lag (Fig. 3) (3).

Over 4000 artifacts have been recovered from activity areas in a 26,000-m^2 excavated area (3). These artifacts are mostly made from pebbles, boulders, or fragments of quartzite, and only a few are made from pebbles of diabase or siliceous rocks. Artifacts occur in distinct clusters that are typically oval and range from 10 to 30 m in diameter. In each cluster, there are usually 5 to 40 tools along with an anvil, hammerstones, and flakes; in many cases, flakes can be refitted to cores (8).

Most of the 4000 artifacts are cores and unmodified flakes, and a smaller number (about 500) are unifacial pebble choppers (Fig. 4), core scrapers, and scraper planes (3). A few tools made from flakes are present in the assemblage. Most of the artifacts have been wind-abraded and polished. In addition, many of them show evidence of microexfoliation on the surface caused by frost action.

Unit IIIa, a well-sorted sand, overlies the deflation lag and cultural horizon at the east end of the site. This unit has horizontal to

Fig. 1. Map of eastern Russia showing the location of Diring Yuriakh and other sites mentioned in the text. Ulalinka is located to the west in the Altai region.

M. R. Waters, Departments of Anthropology and Geography, Texas A&M University, College Station, TX 77843, USA.
S. L. Forman and J. M. Pierson, Department of Geological Sciences, University of Illinois, Chicago, IL 60607, USA.

*To whom correspondence should be addressed at the Department of Anthropology, Texas A&M University, College Station, TX 77843, USA.

slightly inclined bedding. Unit IIIa is overlain by unit IIIb, a massive silty sand that has been substantially reworked by solifluction and ice-wedge processes. This unit in turn is overlain by unit IIIc, a massive sand with some thin beds of silty sand. This unit has also been substantially reworked by solifluction processes and ice-wedge fill features. Unit IIId, the next unit in the sequence, is a massive clayey silt. This unit has been soliflucted, and sand stringers from overlying wedges extend into it. The next overlying deposit, unit IIIe, is primarily a massive silt that shows minor evidence of solifluction. A few sand veins extend into this unit from the overlying unit.

Units IIIa through IIIe are all eolian in origin. The sand units (IIIa and IIIc) are well sorted, and quartz grains show classic eolian surface features, including extreme edge rounding, upturned plates, smooth surfaces, and elongate depressions (9). The fine-grained silts from Diring (units IIIb, IIId, and IIIe) have the distinctive silt grain-size distribution found in other loess deposits, including loess specific to the Lena and Aldan valleys (*10*). Finally, the absence of gravel-sized clasts from unit III suggests an eolian origin of the sediments. In short, unit III makes up a thick eolian sequence that caps the alluvial terrace sediments (unit I) and the deflation surface. Toward the front of the terrace, units IIIa through IIIe were completely eroded, and the deflation surface was re-exposed.

On the re-exposed deflation surface, unit IV accumulated. This is wind-blown sand that forms an elongated dune. The dune axis lies parallel to the Lena River and the terrace edge. Unit IV is composed of well-sorted medium sand that ranges from massive to horizontally bedded and cross bedded. These sediments also show eolian characteristics (9). Toward the back of the site, unit IV drapes over the scarp and top of the outcrop of older sediments. At the base of unit IV, where it is in contact with unit III, there is a thin discontinuous gravel lag composed mostly of gravel 0.25 to 0.5 cm in diameter that become more abundant and larger at the back of the excavations. These gravels represent localized colluvial slopewash from above the site. Pedogenic processes have affected the dune, as indicated by the presence of numerous lamellae of silty sand within the dune midsection.

Thermoluminescence (TL) dating of sediments (*11*, *12*) was the only acceptable technique available to assess the age of the stratigraphy and artifact horizon at Diring because of the proposed antiquity of the site and the absence of materials suitable for other dating methods. Loess and cover sands at Diring Yuriakh are suitable for TL dating because these sediments presumably received prolonged light exposure during subaerial eolian transport and deposition. This process resets the TL signal to a low definable level. As a test, we exposed the sediment from Diring to sunlight for 16 hours. As a result, natural TL emissions were substantially reduced by >84% (*13*). A slightly greater reduction in TL occurred after 8 hours of exposure to an ultraviolet (UV) light–dominated source, which approximates sunlight exposure for >24 hours and provides a better estimate of the full solar resetting level (*13*). The 8-hour UV exposure values were used to calculate the TL ages reported here because they provide a maximum estimate of the predepositional TL level and a finite estimate on eolian deposition. The fine-grained (4 to 11 μm) feldspar-dominated fraction was used for dating because of the greater likelihood of solar resetting of the grains and because the grains are ubiquitous in the stratigraphic sequence. The paleodose was determined by the total-bleach technique (*14*); there was no discernable instability in the laboratory-

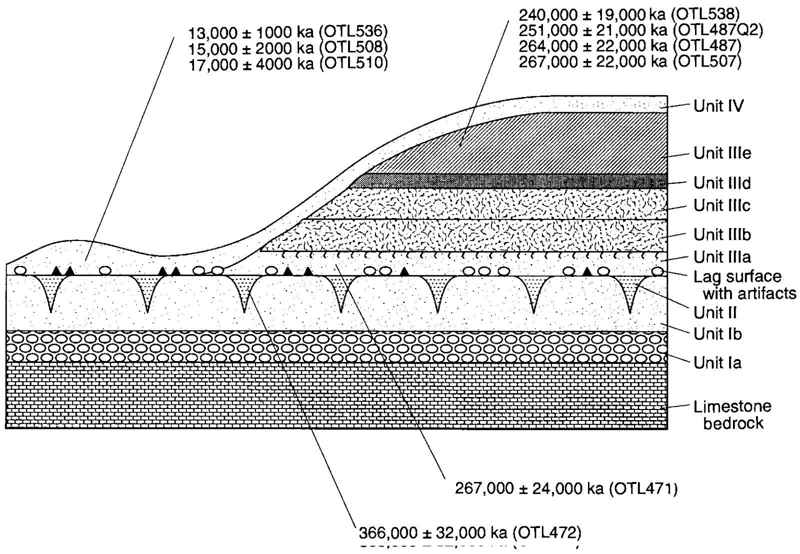

Fig. 2. Generalized cross section of the stratigraphy at Diring Yuriakh and associated TL ages. Solid triangles indicate the positions of the artifacts.

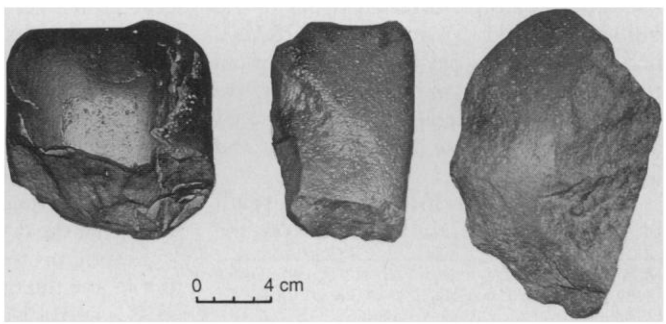

Fig. 3 (left). View of the deflated surface on which the artifacts are found. Note the loose nature of the lag and the battered anvil to the right. **Fig. 4 (right).** Typical unifacial choppers from Diring.

Table 1. Thermoluminescence data and age estimates with one-sigma errors from Diring Yuriakh (*14, 16*).

Stratigraphic unit	Sample number	U (ppm)	Th (ppm)	K_2O (%)	A value	Dose rate (Gy/ka)	Paleodose (Gy)	TL age estimate (ka)
Unit IV	OTL536	4.9 ± 0.7	1.3 ± 0.2	2.94 ± 0.03	0.05 ± 0.01	3.03 ± 0.14	38.5 ± 1.4	13 ± 1
(eolian sand)	OTL508	5.6 ± 0.7	1.1 ± 0.3	2.89 ± 0.03	0.05 ± 0.01	2.96 ± 0.14	44.2 ± 3.0	15 ± 2
	OTL510	5.6 ± 0.7	1.5 ± 0.3	2.96 ± 0.03	0.05 ± 0.02	3.14 ± 0.15	53.6 ± 10.8	17 ± 4
Unit IIIe	OTL538	8.3 ± 1.0	2.6 ± 0.4	2.97 ± 0.03	0.08 ± 0.02	3.99 ± 0.18	957.4 ± 15.5	240 ± 19
(loess)	OTL487Q	9.4 ± 1.2	2.2 ± 0.4	3.00 ± 0.03	0.07 ± 0.01	3.94 ± 0.18	990.5 ± 22.8	251 ± 21
	OTL487	9.4 ± 1.2	2.2 ± 0.4	3.00 ± 0.03	0.05 ± 0.01	3.73 ± 0.16	984.0 ± 16.6	264 ± 22
	OTL507	8.2 ± 1.2	2.4 ± 0.4	2.92 ± 0.03	0.06 ± 0.01	3.68 ± 0.16	981.7 ± 13.2	267 ± 22
Unit IIIa (eolian sand)	OTL471	4.1 ± 0.6	1.1 ± 0.2	2.96 ± 0.03	0.05 ± 0.02	2.88 ± 0.13	770.5 ± 17.4	267 ± 24
Unit II (sand wedge)	OTL472	4.2 ± 0.6	0.9 ± 0.2	3.00 ± 0.03	0.12 ± 0.01	3.14 ± 0.15	1149.3 ± 23.1	366 ± 32

induced emission (*15*). An attribute of the sediments from Diring that contributes to rendering TL ages >100 ka is the uniform and relatively low dose rate for loess and eolian sand units at 3.7 to 4.0 grays (Gy)/ka and 3.6 to 2.8 Gy/ka, respectively (*16*).

We obtained nine TL ages at Diring (Fig. 2 and Table 1). Fine-grained polymineralic samples from units IIIa and II (large truncated wedge) that bound the artifact-bearing horizon responded sufficiently to laboratory addititive dose and yielded ages of 267 ± 24 ka (sample OTL471) and 366 ± 32 ka (OTL472), respectively (*17*). The most securely dated deposit is loess unit IIIe, from which three fine-grained polymineralic samples gave ages of 264 ± 22 (OTL487), 267 ± 22 (OTL507), and 240 ± 19 ka (OTL538). The quartz extract from sample OTL487 had TL emission that was an order of magnitude lower than the polymineral fraction and yielded an age of 251 ± 21 ka (OTL487Q). The similarity among TL ages on polymineral samples and quartz grains, despite different levels of luminescence emissions, indicates that TL ages reflect burial time and are not an artifact produced by combining TL signals of various apparent ages. There is no indication of saturation or measurable instability of TL emissions for these sediments. Three fine-grained polymineralic samples from unit IV yielded TL ages of 13 ± 1 (OTL536), 15 ± 2 (OTL508), and 17 ± 4 ka (OTL510). These ages indicate that unit IV was deposited in the late Pleistocene to early Holocene.

The TL ages and stratigraphy indicate that there were three major periods of Quaternary deposition within two different types of environments separated by two major periods of erosion at Diring. The initial deposition at Diring occurred sometime before 400 ka, when an ancestral Lena River scoured the limestone bedrock and deposited unit I. This was followed by sand wedge formation (unit II) sometime around 370 ka, which in turn was followed by wind erosion, when the deflation lag was created. After the lag was created, people came onto the site and used the lithic material on this surface to make tools. This was followed by eolian sand and silt deposition, which created unit III. Eolian deposition ceased around 240 to 260 ka. This deposition was followed by erosion, when the gravel lag surface was re-exposed to the surface. This surface was later reburied during the late Pleistocene and early Holocene by the eolian sands of unit IV.

TL ages from the loess of unit IIIe that overlies the archaeological material at Diring provides a minimum age estimate for the artifact-bearing surface of about 260 ka, whereas the TL age from unit II underlying the artifact surface provides a maximum age of about 370 ka. The artifact surface, then, may date to about 300 ka (*18*). Mochanov (*3*) reported that this early habitation of Siberia was not limited to Diring because similar sites and artifacts in a similar stratigraphic position have been found at 14 other localities along an 800-km segment of the Lena River.

The climatic conditions at the time of occupation at Diring are unclear. This early occupation of the Lena Basin may represent an opportunistic movement of people into the region during a warm climatic interval. Comparison of the ages from Diring and a high-resolution oxygen isotope record (*19*) suggests that people may have migrated into the Lena Basin at the end of a glacial period (stage 8) or the beginning of an interglacial episode (stage 7). However, even during a warmer period the climate of this region would have been severe, requiring the sophisticated use of fire, clothing, and shelter for survival. Diring clearly shows that people developed early a subsistence pattern that was capable of dealing with the rigorous conditions in Siberia. It is unknown how long this occupation continued and whether occupation in the Lena Basin extended uninterrupted into the Upper Paleolithic or if the region was abandoned as people were pushed south by returning glacial conditions. The extent of this occupation is also unknown.

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13. Sunlight conditions used were those in Columbus, OH. The TL emission remaining after 8 hours of exposure to a UV-dominated 275-W General Electric sun lamp was used in calculating ages and is a maximum estimate. Ages not reported here but calculated with the use of the residual level determined after 16 hours of sunlight exposure are within two sigma errors of the UV-derived ages (11).
14. The paleodose was determined on the polymineral fine-grained (4 to 11 μm) fraction by the total-bleach method [A. K. Singhvi, Y. P. Sharma, D. P. Agrawal, *Nature* **295**, 313 (1982)] for all samples and for the fine-grained quartz extract from sample OTL487Q. TL measurements were made with Corning 5-58 and Chance-Pilkington HA-3 filters in front of the photomultiplier tube. Samples were preheated at 124°C for 72 hours and subsequently stored at room temperature for 24 hours before analysis. Analyses were completed with a Daybreak 1100 Automated TL systems reader using a Thorn-EMI 9635QB photomultiplier tube. Individual paleodose determinations, at a particular temperature or light exposure time, were determined by means of a nonlinear least-squares routine, based on the Levenberg-Marquardt method, in which inverse-variance weighted data are modeled by a saturating-exponential function [D. J. Huntley, G. W. Berger, S. G. E. Bowman, *Nucl. Tracks Radiat. Meas.* **105**, 279 (1987)]. The highest radiation dose added to the natural TL was at least five times the calculated paleodose, resulting in a <20% extrapolation in determining the paleodose. Error estimates were derived for each paleodose from the inverted curvature matrix. The resultant uncertainties in paleodose calculations reflect dispersion in the data and related random errors from modeling the data by a saturating exponential function. A mean paleodose with errors was evaluated for a range of individual paleodose determinations over a broad temperature range, usually between 250° and 400°C, which included at least 80% of the measured TL signal and was also the temperature region that exhibited a pronounced plateau in paleodose.
15. We tested all samples for anomalous fading by storing irradiated (1000 to 1100 Gy) natural aliquots for at least 32 days and then comparing the TL signal to that of an unstored aliquot. In addition, two samples (OTL472 and OTL487) were tested for anomalous fading over 6 months. Uniformly, the anomalous fading ratio is between 1.00 and 0.94, which indicates little or no fading within analytical resolution.
16. The uranium and thorium concentrations were determined by thick-source alpha counting, which assumes secular equilibrium in the decay series [D. J. Huntley and A. G. Wintle, *Can. J. Ear. Sci.* **18**, 419 (1981)]. The ^{40}K level was calculated from the assayed percent of K_2O by inductively coupled plasma-emission spectrometry at Activation Laboratories, Ancaster, Ontario, Canada. A cosmic ray dose component was added [from J. R. Prescott and J. T. Hutton, *Rad. Meas.* **23**, 497 (1994)]. A moisture content of 25 ± 5% was assumed. Alpha efficiency (the A value) was determined as defined by M. J. Aitken and S. G. E. Bowman [*Archaeometry* **17**, 132 (1975)].
17. The TL samples OTL471 and OTL472 were not saturated and increased by 50 and 70%, respectively, above the natural TL level after exposure to about 5.6 kGy of beta dose from a calibrated $^{90}Sr/^{90}Y$ source. Nine additive doses to the natural TL between 0.1 and 5.6 kGy yielded increasing TL emissions, modeled by a saturating exponential function. The precision of analyses is high, with quadruplicate measurements of TL emissions made for applied beta doses, with a dispersion of <5% for sample OTL471 and <7.5% for sample OTL472.
18. The majority of artifacts were found on the re-exposed deflation surface overlain by unit IV. However, Mochanov (3) reports that artifacts were recovered under unit III. Current excavations have recovered additional artifacts beneath unit III.
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20. Support for the fieldwork and analysis of samples was provided by the National Geographic Society (research grant 5036-93), the Advanced Research Program sponsored by the Texas Higher Education Coordinating Board (research grant 010366-010), and NSF (grants ATM 9121944 and DPP-9222972). We thank G. Ingleright, R. Ackerman, R. Bonnichsen, and M. Bonnichsen for assistance and T. Goebel for comments. Finally, we thank Y. Mochanov and S. Fedoseeva for logistical support and hospitality. Both were invited to be co-authors on this paper; however, they declined.

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Laser Rapid Prototyping of Photonic Band-Gap Microstructures

Michael C. Wanke,* Olaf Lehmann,† Kurt Müller, Qingzhe Wen,* Michael Stuke

Three-dimensional periodic microstructures of aluminum oxide, which are important for creating photonic band-gap structures (PBGs), were fabricated by laser rapid prototyping by means of laser-induced direct-write deposition from the gas phase. The structures consisted of layers of parallel rods forming a face-centered tetragonal lattice with lattice constants of 66 and 133 micrometers. These structures showed transmission minima centered around 4 terahertz (75 micrometers) and 2 terahertz (150 micrometers), respectively. PBGs will allow precise control of the optical properties of materials, including lasers without threshold.

Three-dimensional (3D) periodic microstructures of aluminum oxide, used to construct PBGs (*1*), were fabricated by laser rapid prototyping (*2*) by means of laser-induced direct-write deposition from the gas phase. PBGs are 3D periodic structures that are able to totally reflect electromagnetic radiation in a band of frequencies propagating in any direction (*3*). They represent a new class of materials that are capable of uniquely controlling radiation. The optical properties of these materials can be tailored in order to fabricate perfect mirrors, lasers without threshold, and unique optical waveguide devices. The lifetime of excited states can be influenced by the ability to modify the density of available optical modes. Difficulties in fabricating small structures have limited demonstrations to the high microwave frequency range, whereas potential applications (*4*) cover a broad frequency range extending into the visible and even to higher frequencies. The highest documented frequency for a fully 3D PBG is 500 GHz (*5*), corresponding to a wavelength of 600 μm. Short-wavelength structures (5 μm) have been fabricated in only two dimensions (*6*).

With few exceptions, the methods that have been proposed for construction of PBGs with gaps in the millimeter-to-optical range are subtractive, meaning that they start with a block of material and remove sections of it to generate the periodic structure. This is a nontrivial process at high frequencies, and incorporation of specific and well-defined defects, which are crucial for many proposed applications, is very difficult if not impossible. In addition, material can only be removed accurately within a few unit cells from the surface.

Here we describe the construction of 3D PBG materials by laser chemical vapor deposition (LCVD). In this approach, the PBG is built layer by layer directly from the gas phase, in a manner analogous to rapid prototyping. The structure selected by us for the first example represents a compromise between stability for handling, time for fabrication, and the relative amount of material filling the 3D volume (the filling factor). First measurements indicate transmission minima that scale with the period of the structure and have frequencies as high as 4 THz (75 μm). Unlike the techniques mentioned above, LCVD is additive: The structure is built up by deposition, so that desired defects and more complex structures can be incorporated into the underlying periodic structure. With this method, the number of unit cells is limited only by the size of the

Max-Planck-Institut für Biophysikalische Chemie, Post Office Box 2841, D-37018 Göttingen, Germany. E-mail: M. C. Wanke, mwanke@qi.ucsb.edu; M. Stuke, mstuke@gwdg.de

*Present address: Quantum Institute, University of California, Santa Barbara, Santa Barbara, CA 93106, USA.
†Present address: SAP, Neurottstrasse 16, D-69190, Walldorf, Germany.