First luminescence chronology of the Initial Upper Palaeolithic of Eastern Kazakhstan at Ushbulak

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Abstract

The paper presents the first results of a detailed geochronological study of the Central Asian reference section for the Upper Palaeolithic multilayered site at the Ushbulak. Seven main cultural layers were identified in the stratigraphic sequence in two excavations. Artefact’s properties distinguish four main stages of the occupation: Paleo-Metallic era; Final Upper Palaeolithic; advanced Upper Palaeolithic; initial stages of the Upper Palaeolithic. Detailed luminescence dating using both optically stimulated luminescence and infrared stimulated luminescence is used to provide a chronology for the main archaeological units and proluvial-colluvial deposits of the site. The sedimentology is described, based on detailed characteristics of all lithological layers, the geomorphological structure of the area and modern exogenous processes. Comparison of three luminescence dating signals indicate that it is likely that all 3 signals were sufficiently well reset before deposition, so that the IRSL ages reflect the time of deposition, and based on other laboratory tests we consider the individual ages and the final chronology to be reliable. We now characterise the Ushbulak site in three cultural-chronological stages, corresponding to different periods of the Upper Palaeolithic stone industries: the Initial Upper Palaeolithic, recorded in the interval 51–34 ka; the advanced Upper Palaeolithic between 25 and 21 ka and the Final Upper Paleolithic between 17 and 14 ka. Finally, this research identifies this initial main settlement of the site as occurring about 51 ka ago, i.e. during the initial warming stage of MIS 3c.

1. Introduction

In modern archaeology, Middle Palaeolithic cultures in Europe and Western Asia are primarily associated with Neanderthal, and - during the emergence and spread of industries of the Late/Upper Paleolithic - with the dispersion of anatomically modern humans (AMH) across the Eurasian continent. The process of cultural change was presumably initiated by the dispersion of archaic Homo Sapiens from Africa (Out of Africa ... 2010; Groucutt et al. 2015). Starting from about 50 ka ago, in various regions of Eurasia, changes are recorded in key elements of material culture associated with the emergence of new techniques for the splitting of stones, specific types of tools, the widespread use of bone material and the creation of non-utilitarian items (jewellery, art etc.). Establishing the causes, nature, routes of dispersion and especially the timing of this phenomenon is one of the central problems of world archaeology. In this context, the identification, at the end of the 20th century, of the stone industries of the initial Upper Palaeolithic (IUP) is one of the notable achievements of Palaeolithic archaeology. These complexes were initially characterized through materials from Boker-Takhtit and the Ksar Akil grotto in Levant (Douka et al 2013), and have since been identified in many regions of Eurasia (Vishnyatsky 2008; The Early ... 1988). There are several known centers of IUP industry: Central and Eastern Europe, the Middle East, and some regions of Central Asia. Whereas it is indisputable that similar lithic technologies can be found in all of these areas, it is not self-evident that they represent a unified cultural phenomenon. An alternative possibility is convergence, which commonly responses to adapting Levallois technology in the production of blade blanks, or some combination of multiple local origins with subsequent dispersal. In almost all cases, chronology is the key for establishing the origin(s), direction and speed of technological spread,
and for understanding the nature and timing of interaction with the “aboriginal” cultures in different territories.

In Central Asia, complexes associated with the early stages of the Upper Palaeolithic have been discovered relatively recently, and they seem to be less numerous than in the western part of the continent. Most of these sites are concentrated in northern and northeastern border – Altai, Transbaikalia and Northern Mongolia (Kara-Bom, Ust-Karakol-1, Kamenka, Podzvonkaya, Tolbor-4 etc.) (Derevianko et al. 1998; Derevianko et al. 2003; Derevianko et al. 2007; Rybin 2015). All these assemblages are oriented towards mass production of blades, have common primary splitting technologies and same forms of specific tools, usually include non-utilitarian items. This variant of the IUP was called Siberian-Mongolian or Asian (Rybin, 2015). The question of its origin is currently open. Two main hypotheses are currently being discussed. This could be either migration of carriers of these industries from Western Asia, about 50 ka ago (Rybin, 2015) or formation of local cultural features around the same time in Gorny Altai as a result of autochthonous development based on the final Middle Paleolithic industries recorded in Denisova Cave and Kara-Bom (Derevianko et al 2003). In the context of solving this problem, each new stratified site, outside the known area of distribution of the IUP in the region brings additional information in support of a particular hypothesis, especially if there is a reliable chronology. Until recently, vast areas of Central Asia were excluded from the IUP-problems due to the absence of any sites, but in recent years the situation has changed dramatically.

The archaeological sites of Kazakhstan occupy a broad territory connecting several large historical and cultural regions (South Central Asia, Siberia, Northern China and Eastern Europe). This region is distinguished by specific geographic conditions: a pronounced continental arid climate, and dominant denudation processes. This has resulted in the small number of Stone Age sites identified in the region, mostly represented by surface localities. Upper Palaeolithic materials occurring in situ are present at a number of sites in South Kazakhstan - Maibulak, im. Ch. Valikhanova, Rakhat et al. [Taymagambetov, Ozherelyev, 2009; Ozherelyev et al., 2019; Fitzsimmons et al., 2017]. There are several sites with stratified Late Palaeolithic industries in Central and Northern Kazakhstan (Batpak-7, Ekibastuz-15, Ekibastuz-18) (Taimagambetov and Ozherelyev 2009). In the eastern part of Kazakhstan, and despite its proximity to the Russian Altai (known to be rich in Palaeolithic sites) stratified complexes of the Upper Paleolithic were practically unknown until recently. However, in 2016 a joint Russia-Kazakhstan expedition discovered the Ushbulak multilayer site (Fig. 1A), and this site has now become key to studying the Upper Palaeolithic stages of the region (Shunkov et al. 2017).

**Geomorphology.** The Ushbulak site is located 1500 m asl at the foot of the southwestern slope of the Saur Ridge, in the northeastern end of the Shiliktinskaya valley (Fig. 1A) at the junction of the intermountain Shiliktinskaya depression with the Ridge. Tectonic uplift is recent and gives rise to a young tectonically-controlled relief (Geology of the USSR ... 1967).

The base of the southwestern macroslope of the Saur Ridge is characterized by significant slopes (from 15 to 25°), eroded by deeply incised gorges with steep sides and usually perennial watercourses; the
Ushbulak site is found in one of these gorges. The transition from the southwestern macroslope of the Saur ridge to the Shilikinskaya depression is morphologically clearly expressed by a sharp change in slope. A gently sloping piedmont surface begins at the foot of the ridge, formed by a mantle of deluvial-proluvial deposits and merged colluvial fans emerging onto the plain.

Modern relief-forming processes are largely determined by the landscape-climatic conditions of the region: continental climate, cold winters and hot summers (Gidrogeologiya SSSR... 1971). Southern windward slopes of the Saur ridge receive more than 700 mm of precipitation per year, and snow reserves are up to 300 mm; these cause a violent spring flood and, as a result, intense erosional activity within mountainous areas, accompanied by an active removal of material within the depression.

Archaeological material has been found both within and on both sides of the upstream channel within the ravine formed by flow from the Vostochny spring (Fig. 1C). The ravine cuts 6 m into the surface of the foothill plain; it has a V-shaped profile with a narrow bottom up to 3–5 m wide. Water emerges from loose sediments at the very foot of the slope of the Saur ridge, with a flow of ~6 l/s. The spring is located in a northwestern trending fault zone which controls massive intrusions of granodiorites and diorites; the water source appears to be associated with fractures in the intrusive complex.

**Stratigraphy.** The sedimentological sequence of the Ushbulak site reflects the successive replacement of alluvial-proluvial activity by processes of predominantly deluvial-slope movement and accumulation. The composite section, based on the description of two excavations and a series of exploratory pits on both sides of the stream, contains eight main lithological layers (Fig. 2 and Table 1).

L8 (6.8 (visible) - 5.9 m): Poorly sorted rubble-gravel sediments with the inclusion of randomly oriented single blocks in a heavy loamy pore-type aggregate. The petrographic composition is predominantly of local rocks but contains material exotic to the modern catchment geology. Archaeologically sterile. Presumed to represent ancient proluvial-mudflow accumulation.

L7 (5.9 – 5.6 m): Rubble-gravel with sandy-loamy pore-type filler of ochre-brown colour. Petrographically crushed stone, 90% from rocks of the nearest sources. Three generations of sediment were identified, occurring with a dip of about 5–7º, resulting in insets within each other and in the underlying layer 8. Genetically, layer 7 is sediment from a small stream with a variable hydrological regime, washing over the underlying coarse-detrital sediments.

L6 (5.6 – 4.6 m): Represented by two generations of sediment. The lower layer is gray heavy loams with lenses of coarse-grained sands at the bottom of the layer. The upper deposit is gray sandy loam 40-50 cm thick with thin lenticular inclusions of light, organic reach loam, mainly of proluvial origin. Genetically, the interlayers of heavy loams and organically rich sandy loams of layer 6 were deposited by a low-flow stream without a morphologically pronounced channel giving rise to peats in some areas. There is a tendency for the inclination of the sediments to increase from 2–3º at the bottom of layer 6, to 5–6º towards the top. From the lithology and occurrence of archaeological material, eight sub-horizons have been identified.
L5 (4.6 – 3.5 m): A unit of interbedded sands brown-gray and rusty-ochre, silty sandy loam and loam, with abundant weathered granite gravel and inclusions of fine granite rubble. There are signs of erosional deposition of rubble layers at the base of layer 5 into the top of the underlying sediments (layer 6), reflecting an increase in proluvial activity.

L4 (3.4 – 2.7 m): Fine-grained sands and ochre sandy loams, underlain by an interlayer of poorly sorted gravel material with a sandy loam filler of variable thickness. They are represented by two horizons of a genetically single proluvial complex in zone of active accumulation.

L3 (2.7 – 1.6): Light sandy loams, pale-and gray-brown, with interlayers enriched in gravel-sandy material. Three horizons are distinguished, reflecting the transition from predominantly proluvial to deluvial processes.

L2 (1.6 – 0.4 m): Light gray silty sandy loam, with abundant gravel and saprolitized rubble. Three horizons are distinguished, genetically related to the activity of proluvial and colluvial processes of varying degrees of intensity.

L1 (0.4 – 0.0 m): Modern soil.

Archaeology. At present, there are two detailed excavations and 12 pits with a total area of 40 m² at the site (Fig. 1B). Archaeological material has been recorded in seven main lithological layers (layers 7-1). Based on the technical and typological characteristics of the artefacts, their stratigraphic position, as well as the accompanying faunal remains, four cultural and chronological complexes were identified at the site: the initial stages of the Upper Paleolithic (layers 7.2–5.2), the advanced Upper Paleolithic (layers 5.1–4), the Final Upper Paleolithic (layers 3.3–2.1), and the Palaeometal Epoch (layer 1) (Shunkov et al. 2019).

The primary reduction in the lithic industry of the lower layers of the site (~16 thousand artefacts) (Fig. 3) is characterized by the complete predominance of two-platform cores of counter-blade splitting; mainly elongated spalls, some large, up to 30 cm long; and extensive use of picketage in the preparation of the splitting zone. The tool kit includes end-scrapers, intensively retouched blades, truncated-faceted and spine-shaped items, as well as specific tool forms: blades with an interception, items with a ventral thinning of distal edge. A number of features allows confident attribution of this complex to the initial stage of the Upper Palaeolithic (Anoikin et al. 2019).

The upper layers are significantly poorer in archaeological material (~1300 artifacts), although they also show artefacts of characteristic lithic production (see Fig. 3). For example, in the primary reduction in layers 5.1–4, end-face and single-platform double-front forms of cores for micro-blades and small blades are recorded. Layer 3 is characterized by variations in small-lamellar and micro-lamellar double-flat cores with counter-cleavage and unidirectional forms, and in the most recent materials (layer 2), the appearance of prismatic cleavage is recorded. The tool kit is rather monotonous: single end-scrapers of various modifications, retouched knives and micro-blades (Anoikin et al. 2019).
The Ushbulak site appears to be unique in the region, with industries of different stages of the Upper Palaeolithic represented in a conformable occurrence. This makes it possible to reconstruct the chronology of the presence and evolution/replacement of these cultures throughout the second half of the Late Pleistocene. Especially because of these unique characteristics compared to other archaeological sites of Central Asia, one of the most important tasks is to develop a reliable chronology for the accumulation of the site, and particularly the cultural horizons (Kurbanov et al. 2021). We have undertaken detailed luminescence dating using optically stimulated luminescence (OSL) from quartz and infrared stimulated luminescence (IRSL) from K-rich feldspars, supplemented by AMS $^{14}$C dating of charcoal and bone material from layer 6.

2. Samples And Experiments

A series of 26 samples were taken from the two pits shown in Fig. 1b for luminescence dating; the positions relative to the composite section are shown in Figure 2. Because of the abundance of gravel, it was not possible to sample in daylight with tubes. Sampling was undertaken at night; luminescence samples were sealed in aluminium foil bags and samples for gamma spectrometry and water content were taken separately from immediately beside the luminescence samples. The section description was updated and details of the sample positions were recorded the following day. Two of the samples were deliberately collected near a disintegrating granite boulder, to investigate the influence of grains from the decomposing rock on sediment doses.

Sample preparation and mineral separation was undertaken at the Luminescence Dating Laboratory of MSU/IGRAS (Kurbanov et al. 2019). Samples were first wet-sieved to give the grain size fraction 180–250 µm before treating with 10% solutions of HCl, H$_2$O$_2$ and HF. Separation of quartz and K-feldspar was carried out using an aqueous solution of sodium polytungstate ($r=2.58$ g/cm$^3$). The quartz-rich fraction was then treated with concentrated HF to etch the grain surfaces, and remove any remaining feldspar (Murray et al. 2021).

Luminescence dating was carried out at the Nordic Laboratory for Luminescence Dating in Denmark using Risø luminescence readers model TLDA 15 and 20. For quartz, OSL was measured using a SAR protocol with blue light stimulation (sample at 125 °C) with prior heating to 260 °C for 10 s for the regenerated doses and 220 °C for the test doses (Murray and Wintle 2000; 2003). Each reader is equipped with a calibrated Sr$^{90}$ beta source, with a known dose rate of ~0.1 Gy/s.

For K-feldspars, stimulation was performed with an infrared light source; measurements were obtained according using a post IR Ir SAR protocol, giving two IR stimulated signals, one stimulated with the sample at 50 °C (IR$_{50}$) and one at 290 °C (pIRIR$_{290}$) (Thiel et al. 2010).

All quartz samples were tested for purity by measuring the IR depletion ratio (Duller 2003), and the average depletion ratio was 0.98±0.02 (n=16). A standard dose recovery test (Murray 1996) on 4 quartz samples gave a ratio of 0.94±0.03 (n=16). A dose recovery test was also performed on five K-feldspars
samples (six aliquots per sample). The natural signal was first reset in a Hönle daylight simulator for 48 hours. For each sample, 3 aliquots were used to determine any residual dose, and 3 aliquots were given a known dose similar to the natural dose. After residual subtraction, the average pIRIR\textsubscript{290} dose recovery ratio was $1.04\pm0.02$ ($n = 15$). We conclude that our chosen measurement protocol is sufficiently able to accurately determine a known laboratory dose administered before any laboratory heating. No correction for anomalous fading was attempted for the pIRIR\textsubscript{290} signal (Buylaert et al. 2012)

External dose rates were derived using radionuclide activities determined using high-resolution gamma spectrometry (Murray et al., 1987; 2018), and conversion factors given by Guérin et al. (2011). Cosmic ray contributions were calculated following Prescott and Hutton (1994). Internal dose rates to feldspar grains assumed a K concentration of 12.5% (Huntley and Baril 1997).

### 2.1. Dosimetry

The results of gamma spectrometric analysis and the calculated infinite matrix dry beta and gamma dose rates for each sample are presented in Table 1. Measured saturation water contents were in the range 40 to 45%. Because these sediments were deposited in a relatively flat landscape in the presence of permanent water, they were probably saturated for some part of their burial history, before being drained by gully incision. Accordingly, we adopted a lifetime average water content of $22\pm4\%$; at 95% probability this covers the range from 33 to 71% of saturation. The total quartz dose rates are given in Table 2 and range from 2.7 to 3.7 Gy/ka (Table 2).

### 3. Results And Discussion

#### 3.1. Quartz OSL

Only in the upper four samples from excavation 2 was the OSL signal of sufficient sensitivity to allow the measurement of dose (Table 2). Visually, these samples appear to be dominated by the fast component (Fig. 4a) (Singarayer and Bailey 2004; Jain et al. 2003) and the measured $D_e$ do not exceed 45 Gy. These samples 208850–208853 are particularly useful, because they allow us to test the reliability of at least the youngest feldspar ages discussed below.

#### 3.2. Feldspar pIRIR\textsubscript{290}

Both IR\textsubscript{50} and pIRIR\textsubscript{290} signals were measured in all 28 samples. For the pIRIR\textsubscript{290} signal (Fig. 4b), $D_e$ increases from 45–60 Gy in the upper layers (7–5) to 130–140 Gy in the upper part of layer 2, with some fluctuations reflecting the variations in dose rate (see Table 2). Three samples (208826–208828) from the lower part of layer 2 and layer 1 at the base of the section were in full saturation (dose response curve reached a plateau) and the estimated dose exceeds 1000 Gy. Given the ages immediately above, it is most likely that this material was not bleached before sedimentation. This is consistent with the structure of layer 1 just 20–30 cm above disintegrating bedrock.
4. Chronology And Discussion

In total, 26 ages were obtained using the pIRIR$_{290}$ signal from excavations 1 and 2, as well as four OSL dates for excavation 1 (see Table 2). It is well known that the quartz OSL signal bleaches very much more rapidly than either of the two feldspar signals, but especially the pIRIR$_{290}$ signal (e.g. Murray et al 2012). Thus, when available, a comparison of the quartz and feldspar ages can be used to determine whether the feldspar signals are likely to have been well bleached. For the four youngest samples for which both quartz OSL and feldspar pIRIR290 ages are available (208850-53), the weighted average offset of the feldspar pIRIR$_{290}$ ages relative to quartz is 1.3±0.8 ka (see also Fig. 4c), suggesting that, in these samples at least, any incomplete bleaching of the pIRIR$_{290}$ signal is not detectable.

The OSL and pIRIR$_{290}$ ages are summarised in Figure 2. Feldspar ages in both excavations increase smoothly with depth. Excavation 2 shows a gradual increase in the age of the deposits from 21.1±1.8 ka at a depth of 30 cm to 48.6±2.3 and 52.5±7.6 ka in the bottom part of the pit. In this series, there is a gap between samples 208836 and 208835 of about 13 ka. The age of sample 208837 (160 cm) is clearly out of stratigraphic order. In the interval 410–420 cm we note a gravel layer indicating high velocity flow which had visibly eroded the top of layer 3. Sample 208837 was collected from this gravel layer may have been incompletely bleached, or perhaps more likely was contaminated by saturated grains from disintegrating gravel.

Two other samples (208844 and 208852) are also significantly out of stratigraphic order. Both were deliberately collected near disintegrating granite boulders to determine the likely size of any in situ contamination; the material in the layers from which two samples were collected was dominated by small pieces of stone. Thus, the overestimation is not considered surprising, and these samples together with 208837 discussed above, are not considered in development of the final chronology.

We created a Bayesian age-depth model (fig. 2) using OxCal 4.4 (Ramsey 2017) based on OSL and pIRIR$_{290}$ ages in both excavations to get more accurate data. We used P.Sequence code for associating dates with depth. Existence of a break in sedimentation was taken into account. To provide additional age control, we also carried out radiocarbon dating using bone remains from culture-bearing horizons. Despite the considerable age (~ 37.7–44.0 ka), close to the dating limit for $^{14}$C dating, the results obtained are entirely consistent with the feldspar ages (see Table 3).

We conclude that we have successfully determined the age of all lithological horizons of the Ushbulak Late Palaeolithic site (table 3):

1. The initial stage of sediment accumulation is marked by layer 7 with an age of 50.9±8.0 ka, which is consistent with the initial warming of the MIS 3c substage.

2. The age of layer 6 falls within the range 45.8±3.6 and 36.5±1.9 ka, consistent with the second half of MIS 3. However, the top of the layer was apparently partially eroded, and so there is no age control for the
uppermost horizon 6.1. Given the apparent rate of sedimentation, the upper boundary of layer 6 may have been somewhat younger, perhaps about 35-34 ka.

4. Layer 5 was formed in an environment of significant activation of slope processes, and the age from the bottom of this unit has been rejected because of likely (and anticipated) contamination by unbleached grains from disintegrating gravel. The upper part of the layer formed between 23.9–25.3 ka, i.e., during the time of maximum global cooling during MIS 2.

5. The sandy loam and sands of layer 4 were deposited during active slope processes, followed by stabilization of the relief and the formation of a small stream valley. The ages are perhaps more scattered in this interval, but indicate the age of the layer as 22-20 ka.

6. Layer 3 and bottom part of layer 2 were formed at the end of MIS 2, in the period 17.0±1.6 - 14.2±1.7 ka, during the phase of active warming that preceded the Holocene. After the formation of layer 3, the sedimentation rate reduced due to filling of the lower Saur Ridge slopes where they meet the Shilikty valley, and this resulted in a general flattening of the relief. Sensitive quartz appears for the first time in this layer. However, even at this stage, separate phases of the activation of proluvial activity are noted - in particular, at the base of layer 2.

The most interesting result, in our opinion, are ages obtained for the layers with the IUP assemblage. According to them, Ushbulak is one of the oldest sites with assemblages of this type known in Eurasia and comparable or even older than the materials of Denisova Cave and Kara-Bom. In addition, this is the only location where the continuous presence of the population with the IUP industry for more than 10 thousand years is recorded. At the same time, this industry appears in Eastern Kazakhstan ~51 ka already in an established form and remains unchanged until its disappearance ~37–36 ka. In addition, the industry of Ushbulak, which undoubtedly belongs to the circle of the Siberian-Mongolian-type IUP, differs from other assemblages of this community in the complete absence of the Levallois component (Kharevich et al. 2022). Understanding reasons for this phenomenon is still a topic for future studies. But obtained results allow us to state that this difference cannot be explained by the chronological differences with other IUP industries in this part of the continent.

5. Conclusion

A luminescence chronology based on the IRSL signals from K-rich feldspars has been obtained for the Ushbulak Palaeolithic site. The results of a comparison of two protocols (OSL, pIRIR\textsubscript{290}) as well as \textsuperscript{14}C dating indicate a sufficient zeroing of signal during before deposition. This allows us to conclude that the pIRIR\textsubscript{290} ages accurately reflect the time of sediment accumulation.

The main part of the culture-bearing sediments in excavation site 2 was formed in the interval 50.9 ± 8.0 to 20.4 ± 2.6 ka. A possible interruption in sedimentation is noted in the depth of 410 cm and 275 cm, first hiatus is ~7–10 ka, and the second is ~10–12 ka.
The initial settlement of the Ushbulak site most likely took place during the period 51 to 46 ka, i.e., in the second half of MIS 3. Three cultural-chronological stages have been distinguished, corresponding to different periods of the Upper Palaeolithic and differing industrially: the Initial Upper Palaeolithic (layers 7.2–5.2), between 51 and 34 ka; an advanced Upper Palaeolithic (layers 5.1–4) between 25 and 21 ka, and the Final Upper Palaeolithic (layers 3.3–2.1) between 17 and 14 ka. For the first time we have identified AMH occupation of Central Asia during the Initial Upper Palaeolithic as early as 51 ka ago.

**Declarations**

**Ethical Approval**

Not applicable

**Competing interests**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Authors' contributions**

Conceptualization: VAU, AAA, ZKT; Methodology: VAU, RNK; Investigation: VAU, AAA; Field studies: GDP, AAA, VAU, MPK; Data Curation: VAU, AAA, RNK; Geochronology: RNK, DVS; Visualization: DVS, RNK; Writing (Original draft): VAU, AAA, RNK.

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**Availability of data and materials**

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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Tables

Tables 1 to 3 are available in the Supplementary Files section

Figures
Figure 1

A. Location of the Ushbulak site; B. General view of the archaeological excavation pits. C. General view of the Ushbulak ravine: 1 – granite massive 30 m higher than the gully; 2 – Vostochny spring; 3 – position of the excavation pits.
Figure 2

The stratigraphy of the Ushbulak section and the chronological results (in ka).

Figure 3

Ushbulak site. Lithic artifacts: 1-4, 6 – layer 5.1; 5 – layer 2.2; 9, 13 – layer 6.2; 8 – layer 6.4; 7, 10-12, 14 – layer 7.1. Types of lithic artefacts: 1, 7, 8, 11, 12 – end-scrapers; 2 – hammerstone, 3, 4, 6, 14 – cores; 5 – micro-blade; 9 – end-scraper with haft element; 10 – a point with haft element; 13 – biface.
Figure 4

Luminescence characteristics and pIRIR\(_{290}/Q\) comparison

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx
- Table3.docx