RESEARCH ARTICLE – VÝZKUMNÝ ČLÁNEK

Exploitation of radiolarites at the Milovice I Gravettian site

Využití radiolaritů na gravettienské lokalitě Milovice I

Martin Moník – Martin Kováček – Petr Hamrozi – Zdeňka Nerudová

The lithic assemblage from the Gravettian site at Milovice I was predominantly composed of radiolarite. To reconstruct the mobility patterns of the Gravettian population, we addressed the question of whether the radiolarites were imported from the Pieniny Klippen Belt (PKB) of the Western Carpathians or elsewhere. Another plausible source was the gravels from under the Pavlovské vrchy Hills. These are known to have been exploited in the Upper Palaeolithic, most notably at the Milovice I site during the Aurignacian. Our research revealed that local gravels were not the primary source of the Gravettian radiolarite artefacts, as the two differ macroscopically. Some flakes, and possibly microgravettes, are an exception, as their material is sometimes similar to gravel radiolarites. The occasional exploitation of local gravels, along with the small dimensions of the Gravettian industry, possibly reflects a shortage of material at a certain point of the site's occupation and the necessity to adopt curated lithic technology when trips for new material were unfeasible. Moreover, the curated lithic technology observed in the Milovice I assemblage is dissimilar to large Pavlovian sites, suggesting more economic behaviour and influence from radiolarite-supplied sites along the Váh River in the Late Gravettian.

Gravettian – radiolarite – chemical fingerprint – LA-ICP-MS – microscopy – mobility

Kamenná štípaná industrie z gravettienské lokality Milovice I byla přednostně vyrobena z radiolaritu. Pro rekonstrukci mobility gravettienské populace jsme řešili otázku, zda byly tyto radiolarity donášeny z pieninského bradlového pásma (PKB) Západních Karpat nebo z jiných zdrojů. Dalším možným zdrojem byly štěrky uložené pod Pavlovskými vrchy, které byly v mladém paleolitu rovněž využívané, typicky na lokalitě Milovice I v období aurignacienu. Náš výzkum odhalil, že místní štěrky nebyly primárním zdrojem gravettienských radiolaritových artefaktů, protože jsou makroskopicky odlišné. Výjimkou jsou některé úštěpy a snad i mikrogravetty, jejichž materiál je v několika případech podobný štěrkovým radiolaritům. Příležitostné využívání místních radiolaritů spolu s malými rozměry gravettienské industrie pravděpodobně odráží nedostatek suroviny v určité fázi osídlení lokality a nutnost aplikovat úspornou (curated) technologii štípání, když nebylo možné realizovat výpravy za novou surovinou. Kromě toho se úsporná technologie zpracování kamenné industrie, pozorovaná v gravettienském souboru z Milovic I, liší od technologie pozorované na velkých lokalitách pavlovienu a naznačuje ekonomičtější chování a vliv pozdně gravettských lokalit z Pováží, rovněž zásobovaných radiolaritem.

gravettien – radiolarit – chemický otisk – LA-ICP-MS – mikroskopie – mobilita

Introduction

One of the defining characteristics of Gravettian sites located beneath the Pavlovské vrchy Hills in Moravia, Czech Republic, is their non-economic management of fine-grained chert and flint materials. There is evidence of the stockpiling of nodules of erratic flints (EFs) and Cracow cherts without their subsequent exploitation. Debris from the first stages of core exploitation and processing was produced excessively (*Oliva 2002 and 2007*; *Polanská*

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2020). This high-cost strategy was, however, accompanied by a more economically efficient pattern of raw material exploitation in certain parts of some Gravettian locations. The same applies to the lithic assemblage from the Milovice I, sector G (hereafter Milovice I) Late Gravettian site (*Oliva et al. 2009*). The excavation between 1986 and 1991 yielded a lithic assemblage composed, unlike other Gravettian collections from the area, predominantly of radiolarite (*Oliva 2009a*, 162; *Moník et al. 2025a*, supplementary material). The original dimensions of raw material blocks reached up to 8–10 cm in length and approximately 6 cm in width, but most cores were smaller, reflecting a desire for maximum exploitation of the used raw material (*Neruda – Nerudová 2009*, fig. 3: 2; *Oliva 2009a*, graf 2). The larger core remnants were split lengthwise employing the bipolar technique and then used as chipping tools (for either bone splitting or the acquisition of tiny blanks (typological determination based on *Demars – Laurent 1989*, 94–95 and *Floss 2012*, 444), while tool fragments were also reutilised (*Neruda – Nerudová 2009*).

The study aims to explain the causes of the specific pattern of raw material exploitation at the Milovice I site. Two possible hypotheses of intense raw material exploitation and small core/tool dimensions have so far been suggested:

- Radiolarite material from local Tertiary/Quaternary gravels was primarily used. This material was already small-sized when collected (*Moník et al. 2025a*).
- The small dimensions of local radiolarite industry were driven by the functional specificity of the site (cf. *Polanská 2020*).

Interestingly, the presence of knappable materials in gravels beneath the Pavlovské vrchy Hills has long been recognised (*Soták 1990*; *Mrázek 1996*, 25; *Přichystal 2013*; *Vít 2014*; *Important Geological Localities of the Czech Republic*, Milovice–ID 4232), yet it was rarely applied to archaeological reconstructions of Upper Palaeolithic mobility patterns (*Moník et al. 2025a*; *2025b*). Radiolarites from local Gravettian sites were always considered to be long-distance imports from the White Carpathians, i.e. the Slovak part of the Pieniny Klippen Belt (PKB; *Svoboda 1994*, 72; *Wilzyński et al. 2019*, 5). This suggests either the movement of individual Gravettian hunters or social interaction with the PKB territory (cf. *Maier et al. 2022*).

Methods

To test the postulated hypotheses, we measured the dimensions of radiolarite samples from their natural occurrences under the Pavlovské vrchy Hills and selected Gravettian radiolarite artefacts and used macroscopic and stereomicroscopic observations of radiolarites from Central European outcrops (*Přichystal 2013*), their chemical fingerprints (*Moník et al. 2025b*), and techno-typological characteristics of the Milovice I and Dolní Věstonice I (excavated by B. Klíma 1966–1968) Gravettian assemblages (those held at in the Moravian Museum in Brno). Techno-typology was adopted from the original research by *Oliva* (*2007*; *2009a*). Metrics of the radiolarite gravel and artefacts were taken using a sliding gauge and later processed with the PAST programme. Thin section microscopy was applied to 15 selected radiolarite outcrop samples, providing insight into the composition of radiolarian and other microfossils that may aid in provenance estimation. It is unlikely that Hungarian radiolarites were transported by Miocene Ocean or fluvial currents to the gravel deposits under the Pavlovské vrchy Hills. Therefore, we only prepared one thin section of Hungarian (Gerecse Mts.) radiolarite.

The chemical fingerprints from 151 Central European radiolarite samples and 8 selected artefacts from the Milovice I site (see all data under *Online Supplementary Material 1*; Milovice I Gravettian artefacts are marked MI01–MI08 in the database) were analysed using laser ablation induced coupled plasma mass spectroscopy (LA-ICP-MS). Outcrop samples were cut, abraded and fine-polished (artefacts only slightly abraded) prior to the analysis to get rid of the weathering rind. A total of 48 elements were quantified using an Analyte G2 193 nm excimer laser ablation unit (Photon Machines, USA). Samples were analysed using line scans 5–8 mm in length and data quantified using SRM NIST 610, for which a pre-made Excel spreadsheet was used. We employed the analysis of SRM NIST 612 and SRM NIST 614 trace elements in glass to control the reliability of the quantitative results (see *Gregar et al. 2025* and *Moník et al. 2025b* for further details).

LA-ICP-MS produced a raw dataset of compositional measurements (parts-of-a-whole proportions) describing the chemical composition of radiolarites, rather than absolute quantities. Considering this particular data type, in order to apply traditional statistical techniques such as PCA and LDA, we first had to transform our data using the centred log-ratio (clr) transformation (*Grunsky et al. 2017*). After applying this transformation, we identified outliers that distorted the results. In total, 10% of the original sample set was removed to offer a more representative subset for further analysis. Subsequently, feature selection techniques, including brute force approach or recursive feature elimination (*Guyon et al. 2002*), were applied to set aside a subset of elements. This step was important to improve generalisation of our model even for latent data, which has the biggest practical implications. We used an LDA algorithm to differentiate geographically-specific radiolarite groups based on their chemical elements (*James et al. 2013*). The methodology builds on the prior work by *Gregar et al.* (*2025*) or *Hamrozi et al.* (*2025*). However, rather than limiting ourselves to the original six groups – 1. Northern Calcareous Alps /NCA/, 2. St. Veit Klippen Belt, 3. Gerecse Mts., 4. PKB of west Slovakia, 5. PKB of southern Poland, and 6. Bakony Mts. – we introduced a seventh group representing natural occurrences of gravels beneath the Pavlovské vrchy Hills. We supposed that by comparing the eight artefacts selected from the Milovice I assemblage with these groups we would be able to estimate their provenance.

In comparison with our previous studies on the same problem (*Moník et al. 2025a*; *2025b*), we have also collected more radiolarite samples from different deposits around Pavlovské vrchy Hills for macro- and microscopic observation and size measurements (*Fig. 1*; *Tab. 1*). Local Tertiary (Miocene) gravels may lie at a considerable elevation above the current water level of the Nové Mlýny Reservoir. The location between the villages of Brod nad Dyjí and Dolní Dunajovice, for example, lies in the vineyard on the NE slope of Dunajovický kopec Hill, 210–260 m asl. and up to 90 m higher than the former floodplain of the Thaya River. Geologically, the Miocene marine sediments belong to the Carpathian Foredeep (*Geological Map of the Czech Republic 1:50 000*) of the Outer Western Carpathians. The radiolarite samples from Pasohlávky-Mušov and Dolní Dunajovice were subject to metric and chemical analysis (see below). In this way, we complemented our background sample collected around the Mušov Roman fort in 2023 (today in the Pasohlávky cadastre; *Moník et al. 2025b*), producing a total of 24 Miocene pebble-radiolarite samples. Radiolarites from the other sampling spots, from Miocene and Pleistocene gravels,

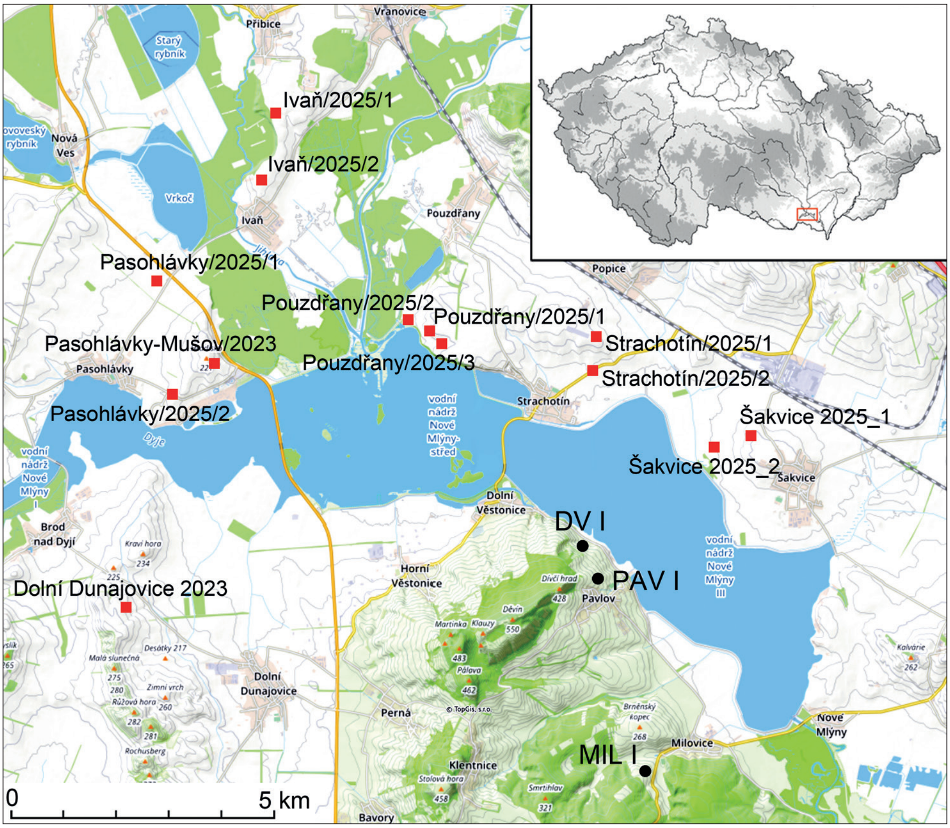

Fig. 1. Overview of locations around the Pavlovské vrchy Hills, where gravel samples were collected for comparative analysis and the position of the Dolní Věstonice I (DV I), Pavlov I (PAV I) and Milovice I (MIL I) Gravettian sites (data ČÚZK 2025). Red square – gravel samples collection sites.

were collected later and only assessed qualitatively, along with other knappable materials from the same context (see Discussion).

Results

Metrics

A comparative analysis of the principal tool categories and cores from the Milovice I and Dolní Věstonice I sites—both produced from radiolarites and erratic flints (EFs)—indicates that most artefacts from Milovice I are smaller in length (*Tab. 2*). Statistically significant differences between the two assemblages were observed for radiolarite cores (Mann–Whitney *U* test, Monte Carlo permutation, p = 0.005), EF burins (p = 0.001), and microgravettes (p = 0.005). Within the Milovice I assemblage, radiolarite cores are also smaller than EF cores, although this difference is not statistically significant (p = 0.054). Some categories, such as endscrapers, were too few in number due to long-term external loan, making reliable testing impossible. Eight microgravettes (six made from radiolarite/

N	Sampling spot	Lat	Long	Dating (epoch)
1	Ivaň/2025/1	48.946825N	16.578025E	Pleistocene
2	Ivaň/2025/2	48.93588N	16.577133E	Pleistocene
3	Pasohlávky/2025/1	48.917608N	16.554702E	Pleistocene
4	Pasohlávky/2025/2	48.8998N	16.561812E	Miocene
5	Pouzdřany/2025/1	48.91566N	16.615927E	Pleistocene
6	Pouzdřany/2025/2	48.915258N	16.620468E	Miocene
7	Pouzdřany/2025/3	48.91474N	16.622749E	Pleistocene
8	Strachotín/2025/1	48.916297N	16.66253E	Pleistocene
9	Strachotín/2025/2	48.910782N	16.662148E	Pleistocene
10	Šakvice 2025_1	48.9031922N	16.7052739E	Pleistocene
11	Šakvice 2025_2	48.9005547N	16.6955319E	Pleistocene
12	Dolní Dunajovice 2023	48.8636408N	16.5563147E	Miocene
13	Pasohlánky-Mušov 2023	48.9059850N	16.5699833E	Miocene

Tab. 1. Overview of locations around the Pavlovské vrchy Hills, where gravel samples were collected for comparative analysis.

Length [mm]																
Site	Milovice I	DV I	Milovice I	DV I	Milovice I	DV I	Milovice I	DV I	Milovice I	DV I	Milovice I	DV I	Milovice I	DV I	Milovice I	DV I
Tool type	Burins				Endscrapers				Microgravettes				Cores			
Raw material	Erratic flint		Radiolarite		Erratic flint		Radiolarite		Erratic flint		Radiolarite		Erratic flint		Radiolarite	
N_samples	19	22	25	1	0	9	1	1	17	10	61	1	4	19	3	20
Min	16	28	15	18	-	30	34	45	9	17	7	32	34	32	14	30
Max	80	107	65	18	-	55	34	45	34	58	37	32	75	60	33	61
Mean	35.6	57.0	30.6	18	-	41.3	34	45	20.1	34.7	16.4	32	46.5	39.4	22.7	44.8
SD	15.9	25.5	10.7	-	-	7.9	-	-	7.6	13.6	6.5	-	19.3	9.4	9.6	8.3
Mann-Whitney p-value	0.001		-		-		-		0.005		-		0.373		0.005	

Tab. 2. Length of the principal tool categories (burins, endscrapers and (micro)gravettes) and cores from Milovice I and Dolní Věstonice I (DV I) lithic assemblages. Tools/cores made of radiolarite and erratic flint (EF) are compared with Mann-Whitney *U* non-parametric test and the p-values shown. Radiolarite cores, and EF burins and microgravettes are significantly smaller in Milovice I than in the Dolní Věstonice I assemblage.

two made of EF) and seven cores (4R/3EF) from Milovice I site could not be measured as there are on exposition in the Anthropos Pavilion. It is unlikely, though, that the size radiolarite artefacts resulted from preferential use of local gravels at either of the two sites. Local radiolarite pebbles from Miocene sediments commonly reach up to 8 cm on their longest axis (mean value = 6.6 cm from 24 measured pebbles; SD = 5.7), and in some cases as much as 14.5 cm (*Fig. 2*; see Discussion).

Macro- and stereomicroscopic observation

Macroscopic and stereomicroscopic observations of outcrop samples have revealed differences between radiolarites found in outcrops and those found in gravels (summarised

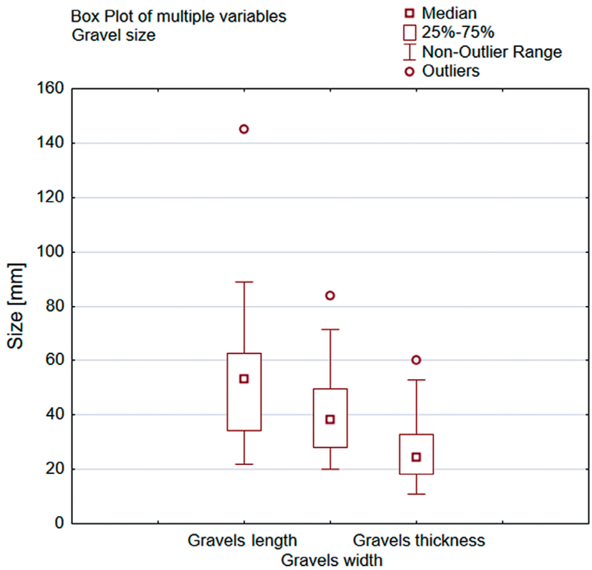

Fig. 2. Size of radiolarite pebbles from under the Pavlovské vrchy Hills. Pebbles of up to 14.5 cm can be encountered in local Miocene gravels.

in *Tab. 3* and *Fig. 3*). Iron or manganese oxides and thick cortex are relatively more present in radiolarites from gravels (*Fig. 3*: f; *Verpoorte 1997*). Fossils are usually poorly preserved in gravel radiolarites, but there are exceptions to this rule, even within our moderate sample. We often observed opaque dots in gravel radiolarites. These are not as frequent in radiolarites from the outcrops that we sampled. This feature might be characteristic of one specific area or outcrop. Finally, tectonic fissures are characteristic of both types of radiolarites, but selection of raw material free of such inhomogeneities is understandably easier on primary outcrops where the material is more abundant. The radiolarite artefacts from Milovice I are mostly macroscopically similar to the samples from the White Carpathian outcrops, particularly the banded ones (*Fig. 4*: a–c). Thus far, banding has only been observed by us on samples from White Carpathian outcrops. However, Alpine radiolarites are sometimes also banded (*Binsteiner 2011*, Abb. 4). Some of the microgravettes are dull and may also originate from local gravels (*Fig. 4*: d), as is most likely the case for the flakes with a gravel cortex (*Fig. 4*: e).

Features	Radiolarites from outcrops	Radiolarites from gravels under Pavlovské vrchy Hills
Banding	(+/-)	(--)
Good fossil preservation	(+)	(-)
Stains of Fe/Mn oxides	(+/-)	(+)
Tectonic fissures	(+)	(+)
Opaque matter	(-)	(+/-)
Thick cortex	(+/-)	(++)

Tab. 3. Differences and similarities between radiolarites from primary outcrops and from secondary occurrences in gravels: -- – not observed; - – usually absent; +/- – sometimes present; + – usually present; ++ – frequently present.

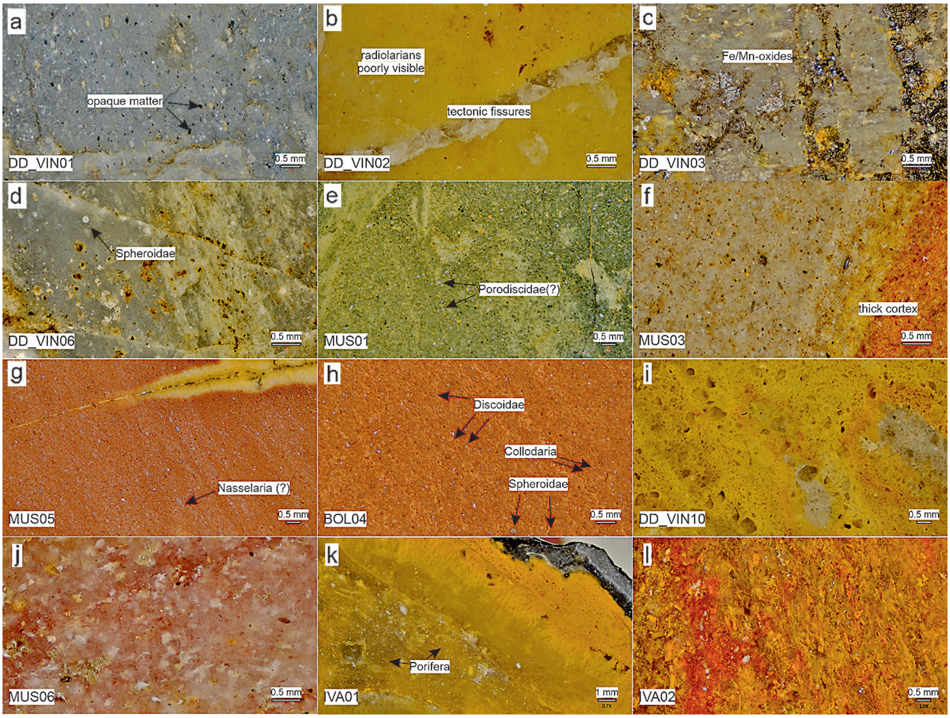

Fig. 3. Stereomicroscopy of radiolarites and other materials from Pleistocene and Miocene gravels from under the Pavlovské vrchy Hills (a-g; i-j) and a PKB (White Carpathian) outcrop (h). Materials: a–h – radiolarites; i – 'sun-boulder' silcrete; j – Alpine (?) chert; k, l – Cretaceous spongolites (also *Fig. 6*: e, h). Sampled sites: DD_VIN – Dolní Dunajovice-vineyard; MUS – Pasohlávky-Mušov; BOL – Bolešov-Kráľov vrch; IVA – Ivaň.

Thin section microscopy

The study of thin sections of radiolarites employed the method of *Andrejeva-Grigorovič et al.* (*2004*), with respect to the traditional systematics of *Haeckel* (*1887*). Apart from radiolarians, spicules of siliceous sponges were also observed in the radiolarites, including the following: Hexactinellida: monoaxons and triaxons; Demospongiae: Tetractinellida monoaxons and the suborder of Megamorina?; and Monactinellidae: monactin spicules with only one ray and one axis. Thin section microscopy enables most taxa to be identified at the family level and some at the genus level. A total of 21 taxa were identified from the 15 thin sections.

All identified species belong to the Polycystina order, with two dominant suborders. The first, Spumellaria, forms basic concentric and radial structures with numerous fine pores. They are further divided into the families of Sphaeroidea, Prunoidae, Discoidae, Porodiscidae, Hexastylidae, Orbiculiformidae, Actinommidae, Xiphostylidae, Heliodiscidae, and Spongodiscidae. Spumellarians are mostly colonial and played a significant role in the rock-forming processes of cherts. The second suborder, Nassellaria, is mostly solitary and first appeared in the Triassic period. Unlike Spumellarians, Nassellarian species could usually be identified at the genus level (e.g. *Ristola sp.*, *Bathropyramis sp.*, *Dictyomitra sp.*,

	Group														
	I: Northern Calcareous Alps; St. Veit Klippen Belt					II: Gerecse Mts.	III: Pieniny Klippen Belt (PKB)						IV: Miocene gravels (Pavlovské vrchy Hills)		
Country	AUT	AUT	AUT	AUT	AUT	HUN	SVK	SVK	POL	SVK	POL	POL	CZE	CZE	CZE
Taxon	ELS 01	ELS 10	ELS 32	BAU 01	WMA 04	GER 05	BOL 08	CEK 10	CZA 11	KRIR 05	SZA 04	ZDZ 03	DDI 02	DDI 03	MUS_VIN 05
Porifera spicules	Hexactinellida		Hexactinellida; Tetractinellidae (monoaxons)	Hexactinellida; Monoaxons, triaxons		?	Hexactinellidae		Megamorina?		Hexactinellida		Spicules ?	Hexactinellida-; Monactinellidae	
Orbiculiforma		■		■								+++			+++
Sphaeroidae	■	■	░	■	■	■	■	■	■	■	■	■		■	■
Collodaria				+++		?			■		+++			+++	
Ristola sp.		░		*								+++			
Discoidae			*												
Porodiscidae					+++		■								
Prunoidae	+++						■		■		+++				+++
Hexastylus sp.					+++					░					
Nassellaria	░	░			+++						░	+++			
Bathropyramis sp.							*		*						
Xiphosphaera sp.									+++					*	
Dictyomitra sp.												*			
Xiphostylidae						?					*	░			
Cenosphaera sp.								■							+++
Heliodiscidae	░	*													
Lophocyrtis sp.		*													
Stylodictya sp.		*													
Sethoconus sp.								░							
Tripospyris sp.										*					
Cenodiscus sp.															
Lithocampida						░									

Tab. 4. Radiolarian and other microfossil content in radiolarites from Central European outcrops and secondary occurrences in Miocene gravels: black – abundant, more than 7 specimens; +++ – common, 3–7 specimens; grey – rare, ≤ 3 specimens; * – sporadic occurrence; white – absent; ? – uncertain. Sites: ELS – Elsbethen-Glasenbachklamm; BAU – Baunzen; WMA – Wien-Mauer; GER – Gerecse Mts.; BOL – Bolešov-Kráľov vrch; CEK – Červený kameň; CZA – Jaworki-Czajakowa skała; KRIR – Krivoklát-rozhľadňa; SZA – Szaflary; ZDZ – Maruszyna-Zdżar; DDI – Dolní Dunajovice I; MUS_VIN – Pasohlávky-Mušov-vineyard.

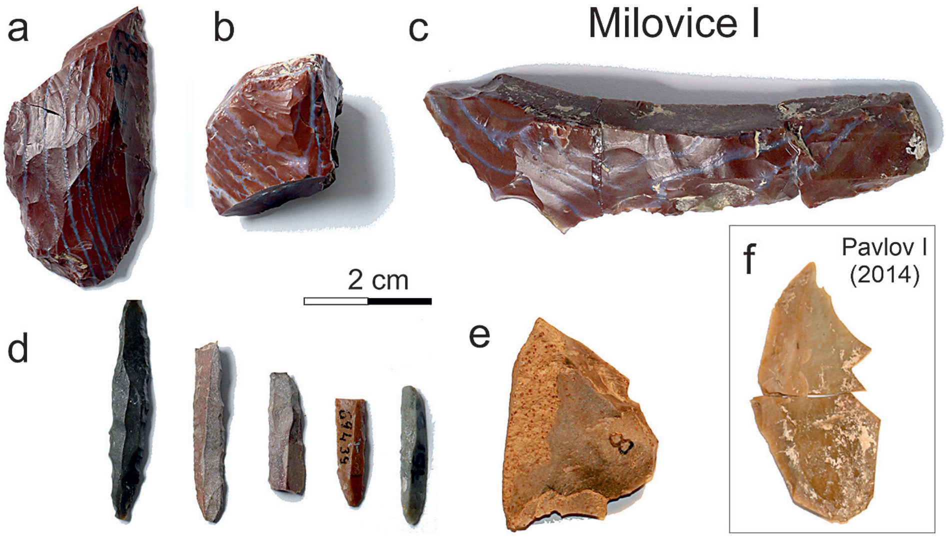

Fig. 4. Selected radiolarite artefacts from the Gravettian sites of Milovice I and Pavlov I (excavated in 2014): a – burin; b – core remnant; c – burin; d – (micro)gravettes; e, f – flakes. The pieces made from banded radiolarites (a, b, c) most likely originate from the White Carpathians. The origin of the radiolarites used for microgravettes (d) is more ambiguous, and the two flakes (e, f) were probably made from gravel radiolarites.

Lophocyrtis sp., *Sethoconus sp.*, *Tripospyris sp.*). Two specimens were identified as belonging to the family Lithocampidae and the suborder Nassellaria. In addition to the two dominant suborders, the third suborder, Collodaria, represents a solitary or colonial polycystine group with a simple skeleton containing simple or branched spicules. These spicules could also be misinterpreted as Porifera axons. It is not possible to determine these spicules more closely, and there is currently no valid classification system for them.

Overall, the composition of the analysed radiolarian fauna favours Spumellarian species, which form 66% of all identified specimens. Nasselarian species make up 26%, and Collodaria can be found in 9%. Generally, most cherts comprise Spumellarians, which are evolutionarily older and therefore more prevalent due to their colonial life strategy. On the other hand, the solitary Nassellarians formed more complicated skeletons, which could be observed when they were well-preserved. Spumellarian Sphaeroidae were present in all samples except DDI 02. Specimens containing more Spumellarians and Porifera are usually affected by dissolution and recrystallisation. The microfossil composition indicates relatively poorer preservation in gravel radiolarites, particularly in samples DDI 02 (where only sponge spicules were preserved) and DDI 03 (where only three taxa were observed; see *Tab. 4*). Sample GER 05 also has few radiolarians and shows heavy recrystallisation. However, the MUS VIN 05 sample shows good preservation of radiolarians.

Ožvoldová et al. (*2000*) presented the quantitative composition of radiolarians from the Pieniny Klippen Belt radiolarites, which is consistent with our findings and highlights the dominant Spumellarian species alongside the accessory Nasselarian fauna. The richest sample, ELS 10, shows seven species (three Nassellarians and four Spumellarians). Sphaeroidae are the most prevalent type of radiolarian throughout Central European outcrops and are frequently found alongside sponge spicules. In general, the microfossil content of gravel materials overlaps between geographical groups. This means that the provenance of radiolarite gravel, or artefacts, cannot be determined based purely on microfossil content. For this reason, we did not conduct a more detailed microfossil analysis of the radiolarite artefacts from the Milovice I site.

Chemical fingerprinting

Plotting the seven radiolarite Groups on the LDA graph (*Fig. 5*), it transpires that the radiolarites from gravels beneath the Pavlovské vrchy Hills (labelled 'Moravia') overlap somewhat with the Austrian- (more those from St. Veit Klippen Belt than from NCA), PKB- (west Slovakia and southern Poland), and even Hungarian (Gerecse Mts.) sources. The chemical analysis by itself is not suitable to clearly distinguish between the gravel radiolarites and those acquired on the outcrops. However, most analysed artefacts are closest to the cluster formed by either the gravel- or White Carpathian radiolarites. Even the two artefacts in the top right of the LDA graph cluster somewhere between the PKB and Hungarian sources when LDA 3 is plotted. The acquisition of Milovice I radiolarites, based on their chemical fingerprint, thus probably occurred either in local Miocene/Quaternary gravels or in PKB.

Discussion

Chemical fingerprinting of Gravettian radiolarite artefacts from the Milovice I site did not yield clear results, but most of the radiolarites resemble samples from the White Carpathian (PKB) outcrops in terms of macroscopic characteristics. A few artefacts were most likely acquired from local gravels, but it is generally unlikely that locally sourced gravel radiolarites predominated over those transported from primary outcrops in any of the Gravettian assemblages from the settlement cluster under the Pavlovské vrchy Hills (except for the small Pavlov I/2014 assemblage; see *Fig. 4*: f; *Svoboda et al. 2016a*; *2016b*; *Moník et al. 2025a*). Radiolarite pebbles from local Miocene (or even Oligocene — see the Milovice sand pit *in Important Geological Localities of the Czech Republic* database) and Quaternary gravels under the Pavlovské vrchy Hills were rarely used not because of their size but due to frequent tectonic fracturing (the poor *quality* mentioned by *Polanská 2020*, 431). On primary outcrops, where such fractures also occur, Palaeolithic flint-knappers had a much wider material spectrum to choose from and selected blocks free of inhomogeneities (*Fig. 3*: h; *cf. Verpoorte 1997*, 221). Gravel radiolarites appear to have been used more frequently for dull-coloured flakes and (micro)gravettes, which could be produced from relatively small cores (*Fig. 4*: d). This is consistent with the previous observation in the Dolní Věstonice II Gravettian assemblage made by *Polanská* (*2016*). In different sectors, she observed and re-assembled radiolarite nodules and river pebbles used preferentially for the production of blades and bladelets (*Polanská 2016*, 193). Interestingly, she did not document such pebbles in either of the Pavlov site lithic assemblages.

Based on techno-typological grounds, radiolarites were imported *directly* to the sites under the Pavlovské vrchy Hills (*Oliva 1998a*; *1998b*; *2007*, 149; *Polanská 2020*; *Moník et al. 2025b*, 14), i.e. not acquired through social exchange with neighbouring Gravettian groups. This is supported by the fact that, apart from EFs, radiolarites are the only raw

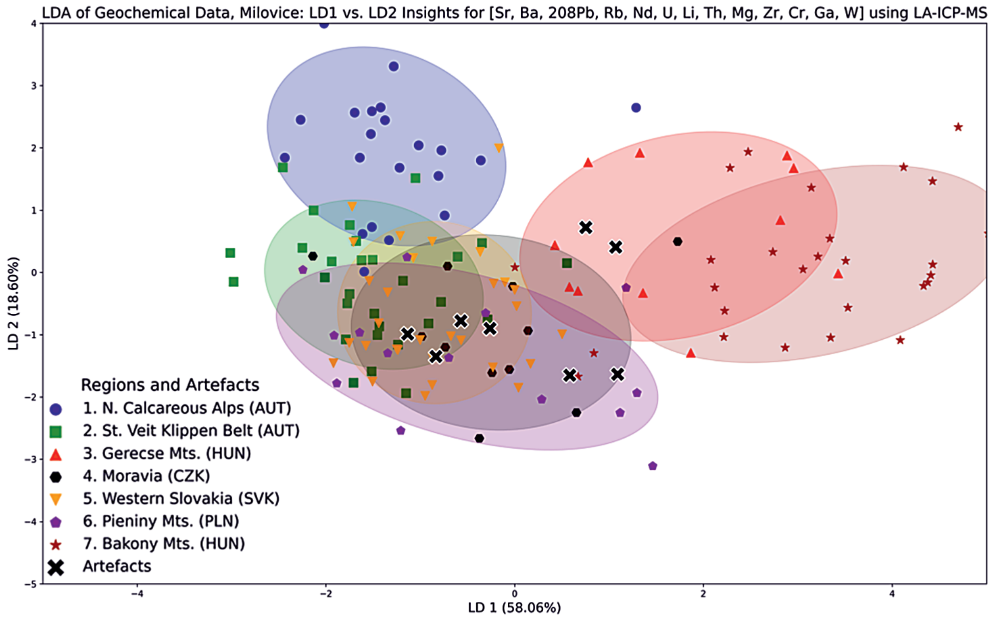

Fig. 5. Chemical fingerprint of Central European radiolarites. Those encountered in gravels from under Pavlovské vrchy Hills ('Moravia') overlap with PKB (nos. 6 and 7) and St. Veit Klippen Belt radiolarites.

material frequently present in the form of cores. Their complete reduction sequences have been refitted by archaeologists (*Škrdla 1997*; *2001*) at the Milovice I, Dolní Věstonice I, Dolní Věstonice II and Pavlov I–NW sites. In contrast, other exotic materials (obsidian, limnic chert, jasper, etc.) were brought to the sites as final products, e.g. as blades or bladelets. The treatment of radiolarite raw material varied. Sometimes, the further away we get from the sources, the more curated the treatment becomes (*Oliva 2007*, 149). However, the assemblages from the Pavlov I–NW and Dolní Věstonice I sites also comprise unused or unretouched radiolarite blanks, which may depend on the presence or absence of inhomogeneities (*Škrdla 1997*, 316; *Oliva 2007*, 146; *Oliva 2012*, 7). Cretaceous spongolites, predominant at the Milovice I and Pavlov I sites during the Aurignacian culture (*Svoboda et al. 2016a*, 104; *Moník et al. 2025b*, table 2), were almost ignored in the Gravettian period, while other rocks washed down from the Bohemian Massif, the Carpathian Flysch Belt or the Alpine region were only occasionally exploited. These rocks include Krumlovský les cherts, chert breccias, and 'sun-boulder' silcretes (*Fig. 6*). Furthermore, local gravels probably also provided the thermal metamorphite and graphite observed in the Milovice I assemblage, different cherts in the Pavlov I–SE assemblage (where marlstones acquired from nearby outcrops were also favoured), and the reddish pebble limestones used for manufacturing retouchers in the Pavlov I–NW assemblage (*Mrázek 1996*, 24; *Oliva 1997*, 417; *Škrdla 1999*, 66; *Svoboda – Přichystal 2005*, 148–149; *Moník et al. 2025a*, supplementary material). There is a clear difference here compared to some Gravettian sites along the Danube, such as Krems-Wachtberg and Willendorf II-AH5 (*Brandl et al. 2014*, 160; *Moreau et al. 2016*, table 1). Both radiolarites from the Danube gravels and other local materials were favoured at these sites, and long-distance imports were rare (*Brandl et al. 2014*, 147).

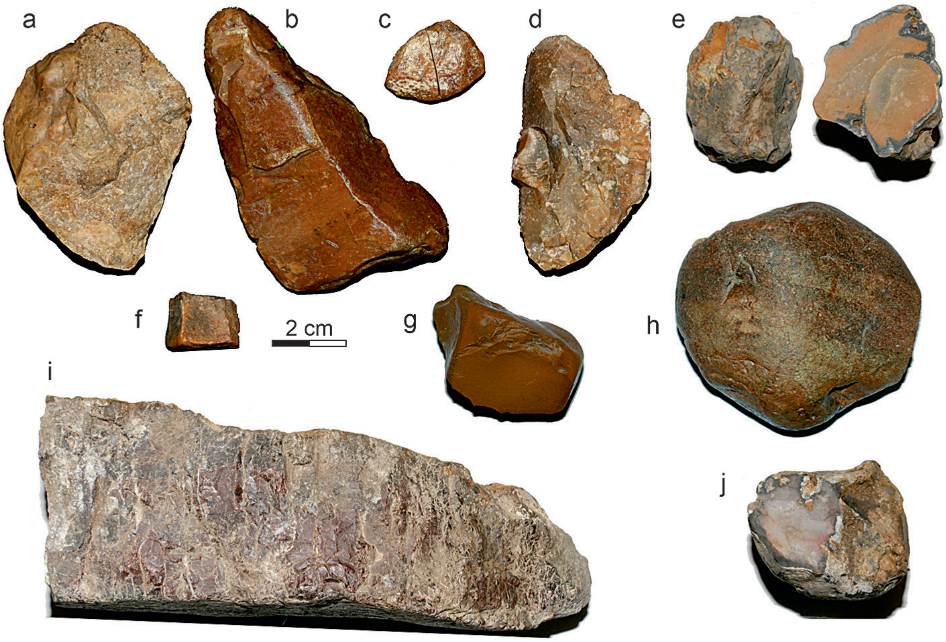

Fig. 6. Knappable raw materials encountered on Pleistocene (Riss- and older) terraces on the cadastres of Šakvice (a-d, f), Ivaň (e, h), Pouzdřany (g), Strachotín (j), and in Miocene marine sediments east of Dolní Dunajovice (i), under the Pavlovské vrchy Hills. Materials: a – 'sun-boulder' silcrete; b, c, e, h – Cretaceous spongolites; d – chert breccia from Krumlovský les; f, i – radiolarites; g – silicified claystone; j – chert of the Krumlovský les type, variety I.

The small size of the radiolarite artefacts at the Milovice I site is therefore more likely to be determined by their function than their origin. In the case of microgravettes, there is an obvious influence from west Slovak Late Gravettian assemblages, which are also dominated by radiolarites (*Kozłowski 2013*; *Polanská 2016*, 193). This is not the case of the somewhat older (classical Gravettian/Pavlovian) assemblage from Dolní Věstonice I, where just one radiolarite microgravette was identified (as regards Klíma's 1966–1968 excavation).

Curated behaviour (*Binford 1979*), apart from function, may explain the small size of some artefact categories at Milovice I, possibly linked to the high share of tools (*Tab. 5*; *Oliva 2009c*, 161; *Moník et al. 2025a*; supplementary material). When necessary, the Gravettian groups used even the smallest flint and radiolarite tools and fragments until new supplies became available (*Chlachula et al. 2025*). Such patterns occur during material shortages, which may have arisen in winter when chert and flint were difficult to obtain. Snow cover, low density, and limited daylight restricted the mobility of both game and hunter-gatherers (*Guthrie 1968*, 361; *1982*, 325; *Burch 1972*, 345; *Coady 1974*, 432; *Winterhalder 1981*, 72; *Lundmark – Ball 2008*, 116; *Pedersen et al. 2021*, 17; *Melin et al. 2023*, 21). While lowlands may have had little snow (*Coady 1974*, 428), mountainous zones such as the White Carpathians were likely snowbound, hampering access to radiolarite outcrops. At such times, gravel radiolarites served as a backup, and both radiolarite- and EF cores were maximally reduced (*Tab. 2*). Small cores and artefacts also suggest year-round

Site	% tools	% end-scrapers	% burins	% backed elements	% microlithic elements	Source
Milovice I G	25.7	5.6	9	46	0.3	*Oliva 2007*
Milovice I – north	30.4	13.9	18.9	11.5	-	*Oliva 2007*
DV I – bone heap	24.2	7.1	51.8	14.5	-	*Oliva 2007*
Dol. Věstonice I/central part	**	25.1	32.2	15.1	-	*Oliva 2007*
Dol. Věstonice I/feature 1	**	10.5	25.7	39.5	-	*Oliva 2007*
Dol. Věstonice I/feature 2	**	10.9	33.2	21	-	*Oliva 2007*
Dol. Věstonice II/lower etage	**	6.1	41.7	33.7	-	*Oliva 2007*
Dol. Věst. II/upper etage, 1986	3.5	18.1	30	43.7	-	*Oliva 2007; Klíma 1995*
Dol. Věst. II/upper etage, 1987	3.2	0	7.5	51.4	-	*Oliva 2007; Klíma 1995*
Pavlov I SE	9.2	9.2	31.8	28.1	10.4	*Verpoorte 2005*
Pavlov I Middle	9	9	28.5	13	15.7	*Verpoorte 2005*
Pavlov I NW	7.8	7.8	24.3	13.9	13.6	*Verpoorte 2005*
Pavlov I South-central	4.1	6.8	21.7	21.2	24.3	*Verpoorte 2005*
Pavlov II	12	11.7	49.4	12	-	*Oliva 2007*
Pavlov VI	6.8*	9.4	16	9.4	-	*Polanská 2011; Novák 2011**

Tab. 5. Proportions of tools in the cluster of Gravettian sites under the Pavlovské vrchy Hills. Note the high incidence of tools (and backed pieces) within the Milovice I G assemblage. * – information from *Novák 2011*; ** – not calculated.

occupation at Milovice I. Similarly, frequent use of local cherts from gravel deposits at nearby Gravettian sites (e.g. Dolní Věstonice II–III; Pavlov VI; *Klíma 1971*; *1995*; *Škrdla et al. 1996*; *Svoboda et al. 2015*) suggests mobility restrictions during certain seasons, especially winter.

The implication for the Gravettian lifestyle

Armed with information on the procurement of lithic material, we can tentatively reconstruct the year-round movements of hunter-gatherer groups to and from the Milovice I Gravettian site. Present-day herd animals often migrate north in spring and early summer (*Fischer 2007*; *Nicholson et al. 2016*), although this can vary depending on geography (*The World of Deer*). Accordingly, we can suppose that some Moravian Gravettian groups moved to present-day Silesia (southern Poland) or some hilly area free of mosquitoes during that season (*Fig. 7*). Although large residential camps, such as those evidenced under Pavlovské vrchy Hills, normally imply logistic forays (*Clark – Barton 2017*, 139), these are often hard to distinguish from residential movements based on lithic material (*Oliva 2007*, 149; *Mears – Wilson 2023*, 14). Both strategies were likely practised in certain periods of the Moravian Gravettian. Movements in a south-westerly direction towards the Alps seem less probable due to the barrier posed by the Danube River (cf. *Oliva 2009e*, 270; *Moník et al. 2025a*). Additionally, the geochemical signature of the radiolarites found at sites under the Pavlovské vrchy Hills does not usually indicate that they were imported from the Alps or the St. Veit Klippen Belt around present-day Vienna (*Moník et al. 2025a*, fig. 1).

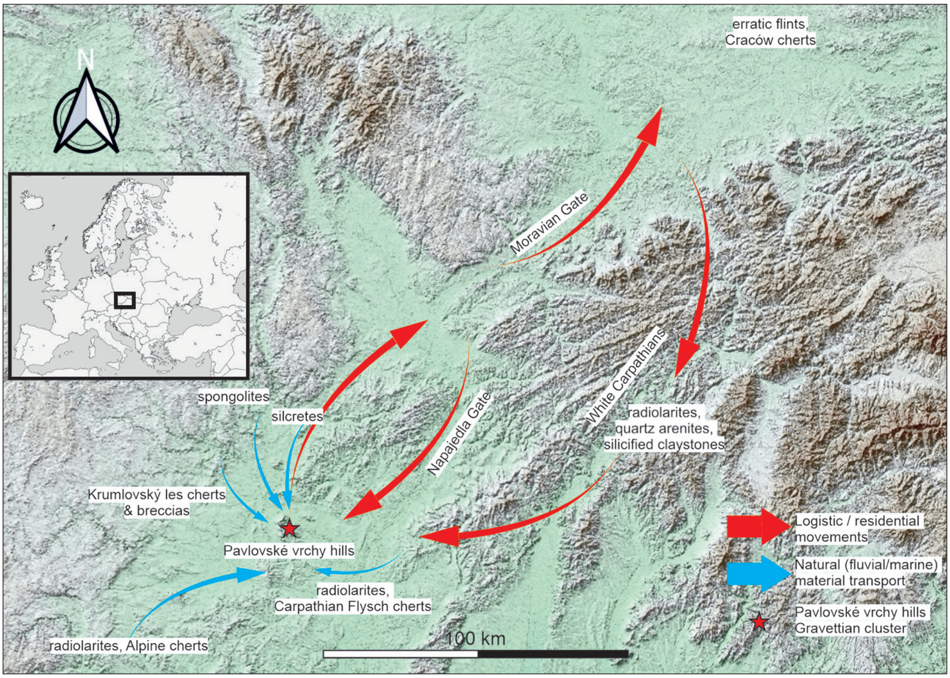

Fig. 7. The main directions of logistical and/or residential movements to and from the Gravettian sites under the Pavlovské vrchy Hills, as well as the directions of the natural marine and fluvial transport of knappable materials to the gravels deposited during the Tertiary and Quaternary periods. It is evident that some materials that were previously believed to have been imported from distant locations could have been sourced locally (based on our analysis and *Soták 1990*; *Oliva (ed.) et al. 2009*; *Přichystal 2013*; *Vít 2014*; *Moník et al. 2025a*; *2025b*).

After obtaining EFs and Cracow cherts from Silesian sources—or along the way—the Gravettians would have continued to the White Carpathians in the PKB area to procure additional lithic raw materials, including radiolarite blocks and, nearby, Carpathian Flysch Belt lithologies such as quartz arenites and silicified claystones (*Moník et al. 2025*b, 22). They would then have returned to the Pavlovské vrchy Hills. Hunting might have taken place in late summer/early autumn when the herds returned to their winter ranges. Apart from hares, lions, and bears, a variety of large mammals, including mammoths, elk, red deer, reindeer, and horses, were hunted at Milovice I (*Oliva 2009b*; *Brugère – Fontana 2009*, fig. 8). However, the hunting seasons for these species likely varied, reflecting differences in the feeding behaviours and ecological preferences of proboscideans and ungulates (*Musil 2014*, 124, 135). The floodplain below the Pavlovské vrchy Hills offered a significant environmental advantage, as it could have supported a wide range of plant, fish, and bird species—some of which were available throughout the year—as evidenced by faunal and botanical records from nearby sites Pavlov I and VI, Dolní Věstonice I, and Milovice IV (*Bocheński et al. 2009*; *Svoboda et al. 2011*; *Revedin et al. 2015*; *Svoboda 2022*).

The late summer hunt is a common practice among hunter-gatherers in northern latitudes, as the bulls are fat and their furs are of good quality. A hunting technique known as 'head-em-off-at-the-pass' is common during the seasonal migration of herd animals. It involves waiting at selected spots, such as narrow valleys and fords (*Burch 1972*). This would apply to Gravettian sites within or at the mouth of the Moravian Gate (e.g. Předmostí and Ostrava-Petřkovice: *Klíma 1990*; *Svoboda et al. 1999*, 177; *Svoboda 2008*), along the middle course of the Morava River at the Napajedla Gate (e.g. the Jarošov II and Napajedla I sites: *Škrdla 2005*; *Škrdla et al. 2008*), and the cluster of sites in the Pavlovské vrchy Hills (*Svoboda – Sedláčková 2004*; *Oliva 2007*; *Svoboda 2020*; *2022*). In the latter case, north-facing Gravettian sites would also have allowed local hunters to monitor the arrival of herds from their summer pastures (cf. *Oliva 1997*; *2009d*, 136; *2016*).

Given the approximately 8,000-year duration of the Gravettian occupation of the Pavlovské vrchy Hills, this scenario may reflect the use of lithics and the landscape over the *longue durée* time frame, but it is probably one of many that occurred as conditions changed over time. The annual paths of herd animals, for example, must have changed for various reasons (*Ingstad 1971*; *Owen-Smith 1988*; *Hoppe et al. 1999*; *Fischer 2007*; *Joly et al. 2021*). The hunting and gathering strategies adopted at the Milovice I site must have varied accordingly, relying on diversified sources mentioned above. However, both direct and indirect evidence support the seasonal migration and hunting of reindeer, horses, and mammoths (*Wooller et al. 2021*, fig. 2; *Kowalik et al. 2023*, fig. 1; *Waters et al. 2023*). The relatively limited faunal record from the Milovice I site suggests that mammoths were hunted, and possibly also scavenged, during the autumn season (*Oliva 1997*, 426; *Brugère – Fontana 2009*; *Nývltová-Fišáková 2009*, table 1; *Bosch 2012*; *Nývltová-Fišáková 2013*), likely in connection with the procurement of winter supplies (*Binford 1978*; *Kelly 1983*, 278; *Burch 1998*). In contrast, evidence for fox hunting at Milovice I indicates activities carried out during the spring or summer months (*Nývltová-Fišáková 2009*, table 1). This seasonal variability supports the interpretation that the site was occupied for more than a brief period—although this view is not universally accepted (*Halámková 2009*, 117; *Oliva 2009d*, 269)—and is further corroborated by the presence of multiple hearths, albeit not analysed micromorphologically (*Oliva et al. 2009*, 135–153; *Oliva 2016*, 159). Analogues in the evidence for year-round occupation can be observed at other major Moravian Gravettian sites, such as Dolní Věstonice II (western slope), Pavlov I, Předmostí, and Jarošov-Podvršťa (*Svoboda et al. 1999*, 210–211; *Nývltová-Fišáková 2013*).

Conclusion

The fluvial and marine gravels beneath the Pavlovské vrchy Hills contain a wide range of materials (radiolarites, spongolites, Krumlovský les cherts, silcretes, and others) deposited in their present location during the Tertiary and Quaternary, having been transported from the Bohemian Massif, the Alps, and the Carpathians. The radiolarites used at the Milovice I Gravettian site for artefact manufacture, though, were predominantly acquired from primary outcrops in PKB (probably within White Carpathian Mts.); local gravels containing radiolarites were only occasionally exploited. This contrasts with the procurement pattern observed during the Aurignacian period, when local spongolites were favoured, and with the Gravettian pattern of procurement on some Danube River sites, which focused on radiolarite gravel. Despite this preference for exotic materials (radiolarites and EFs) over local ones at the Milovice I Gravettian site, several smaller sites under the Pavlovské vrchy Hills (Dolní Věstonice II – northern slope, Dolní Věstonice IIa and IIIa, and Pavlov VI) relied more heavily on local Moravian cherts, some of which might have comprised gravel material. As previously suggested, these sites may represent the remains of small, seasonally occupied camps established during periods when forays to procure flint nodules were difficult to realise. The possible winter occupation of the Milovice I site is indirectly indicated by faunal remains, which reflect autumn hunting of mammoths. This scenario may apply particularly to areas of the settlement where small radiolarite flakes and Gravettian points manufactured from dull, gravel-like radiolarite were recovered, suggesting activities associated with a winter occupation phase. However, the predominance of small artefacts in these contexts is more likely related to the technological trends of the Late Gravettian period, characterised by a preference for smaller tool types, such as microgravettes, and a more economical use of lithic raw materials. During this time, Gravettian sites situated along the Váh River in present-day Slovakia gained significance, coinciding with the increased exploitation of radiolarites from the Pieniny Klippen Belt (PKB).

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MARTIN MONÍK, Department of Geology, Faculty of Science, Palacký University in Olomouc, 17. Listopadu 12, CZ-771 46 Olomouc, Czech Republic; martin.monik@gmail.com
MARTIN KOVÁČEK, Regional Museum in Olomouc, nám. Republiky 823/5, CZ-779 00 Olomouc, Czech Republic; kovacek@vmo.cz
ZDEŇKA NERUDOVÁ, Centre for Cultural Anthropology, Moravian Museum, Zelný trh 6, CZ-659 37 Brno, Czech Republic; znerudova@mzm.cz
PETR HAMROZI, Centre for Cultural Anthropology, Moravian Museum, Zelný trh 6, CZ-659 37 Brno, Czech Republic; hamrozipetr@outlook.com