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THE SEARCH FOR FIREPLACES IN MORAVIAN (CZECH REPUBLIC) LATE GLACIAL SITES

ABSTRACT: The existence of fire/hearths at Upper Palaeolithic sites is highly expected due to the cold glacial climate. However, fireplaces/hearths are missing at several Late Upper Palaeolithic Moravian (Czech Republic) sites. Here we discuss the possibilities of how to identify the presence of fire at archaeological sites using indirect methods. Our analysis focused on both potentially heated/burned artefacts and spatial distribution of fireplaces from within four Moravian (Czech Republic) sites. Colour and magnetic measurements may be indicative of heated cherts/flint recognition but macroscopic visual observation remains key for such estimations. Concerning the distribution of hearths within the four analysed sites, only Brno-Štýřice III site seems to have witnessed little post-depositional disturbance of its anthropogenic sediments and, at the same time, shows a good correlation of presumed fireplaces with the distribution of heated artefacts.

KEY WORDS: Late Upper Palaeolithic – Hearths – GIS analyses – Colour measurement – Magnetism (IRM)

INTRODUCTION

Fire and its management has a long history in the context of human evolution (Attwell *et al.* 2015, Gowlett 2006, Gowlett, Wrangham 2013, Chazan 2017, Roebroeks, Villa 2011) and, undoubtedly, fire has a wide range of uses, both practical and symbolic (Clark, Harris 1985, Oakley 1956). Traces of fires/hearths are documented on many Palaeolithic sites in the area occupied since at least the Middle Pleistocene up to the end of the Palaeolithic. Not only direct combustion features of fires/hearths, but different types of burned archaeological materials usually indicate the use of fire at a site (Alperson-Afil 2012). Apart from distinguishing the natural or anthropogenic origin of fire, the next important question is how to indirectly identify a fire/hearth if direct evidence at a site is missing.

Generally, missing archaeological evidence is a common feature (Alperson-Afil 2012). This fact is influenced by many factors. There are many explanations to account for the absence of a fire/hearth

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at a site. Either the peoples in question did not use fire (Dibble *et al.* 2017), or archaeological excavation did not uncover hearth remains, or the remains have not been preserved until today due to depositional/post-depositional changes. Evidence of a fireplace/hearth can be also destroyed or lost due to archaeological excavation. (a number of Palaeolithic sites were excavated "too early", at the start of the scientific approach, and much information is lost today).

In the following, we present four Late Upper Palaeolithic sites where the presence of fireplace(s) has been previously confirmed by archaeological excavation but direct data are missing today, or the sites are without hearths but indirect evidence of their presence is still available in the archaeological record. The main aim of our project was the spatial reconstruction of each analysed site regarding the position of fireplaces and burnt lithic artefacts.

MATERIALS

For our analyses we selected four stratified and archaeologically excavated LUP (Late Upper Palaeolithic) sites situated in the Moravian region (Czech Republic): Balcarka Cave, Kůlna Cave Layer 6, Loštice I open-air site (all Magdalenian) and Brno-Štýřice III (Epigravettian; *Figure 1*). They differ from each other in their geomorphological position, the character of occupation, the raw materials used, the presence of burnt pieces, the presence or absence of fireplaces, and, especially, the quality of archaeological excavation (*Table 1*).

Some of the sites were archaeologically excavated early in the 20th century and due to this fact a lot of information, nowadays obtained with modern methods, was not acquired and is lost. Contrary to these early excavated sites, the modern archaeological

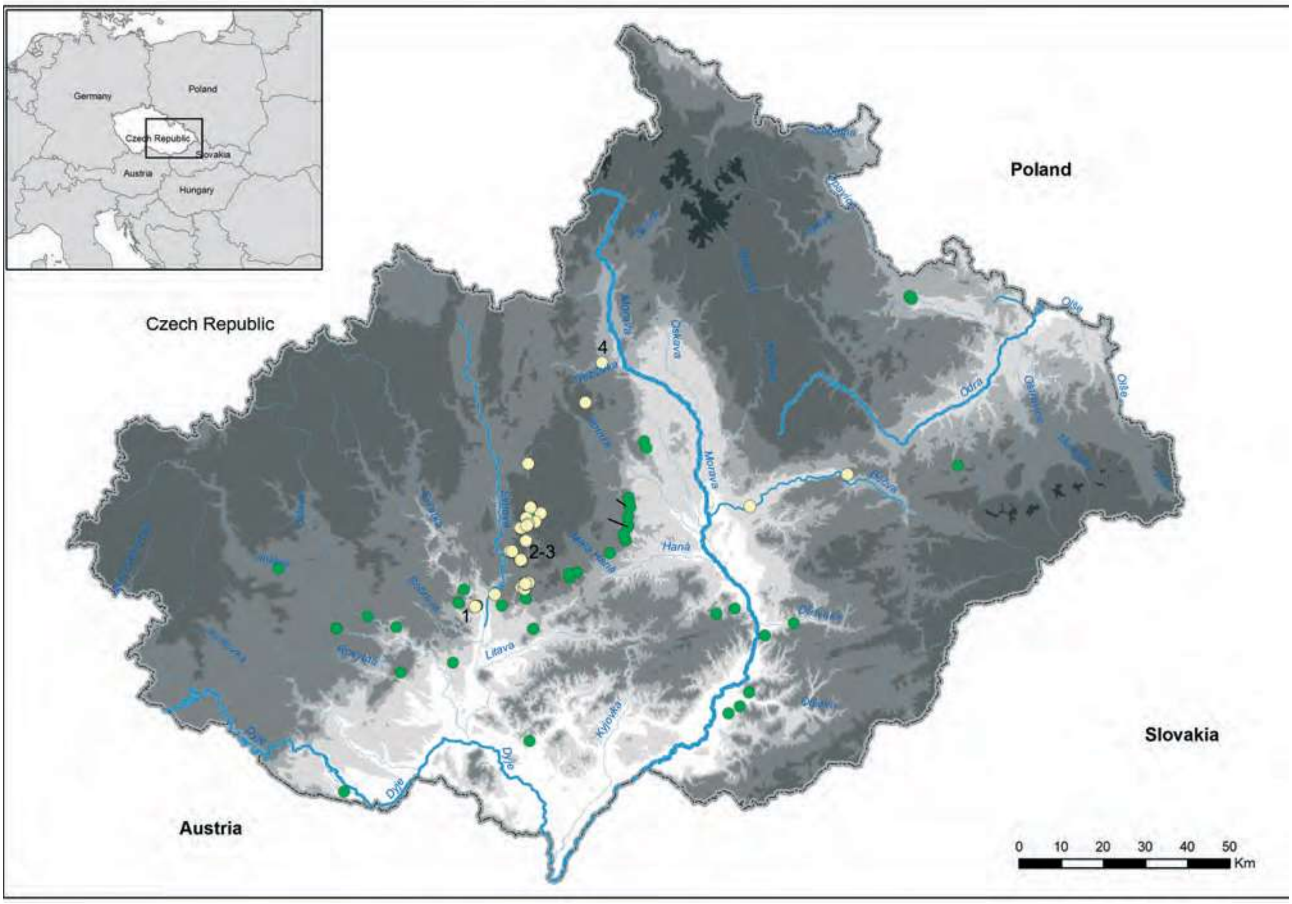

FIGURE 1: Moravian (Czech Republic) sites from the analysed period. Yellow circles – Magdalenian sites, green circles – Epigravettian sites; sites discussed in the text: 1, Brno-Štýřice III; 2, Kůlna Cave; 3, Balcarka Cave; 4, Loštice. Digitalization by P. Neruda and Z. Nerudová.

TABLE 1: Overview of analysed sites and lithics. *not analysed.

Site	∑ of lithic pieces	∑ of burnt pieces	∑ of analysed pieces	∑ of hearts/ fireplaces
Balcarka Cave	314	4	24	5 or 6
Loštice I	3,333	7	29	none
Kůlna Cave Layer 5	783	unknown	*	18
Kůlna Cave Layer 6	1,429	unknown	12	
Brno-Štýřice III	9,149	183	10	Probably 3

excavations (Loštice I, Štýřice III) did not uncover any fireplaces/hearths. This was probably due to the stratigraphic situation on the site, or we have only documented indirect evidence for the existence of fireplace(s) based on the analysis of micromorphological soil sample.

Balcarka Cave

Balcarka Cave (Moravian Karst, Czech Republic) was excavated at the end of the 19th and the beginning of the 20th century (*Figure 2*). The cave is situated near the village of Ostrov u Macochy, in the Suchý žleb valley. According to previously published articles, six hearths were uncovered in the only Magdalenian layer together with a small collection of lithic industry, bone and antler supports as well as final products and decorated objects (Pfeifer 2017, Rašková Zelinková

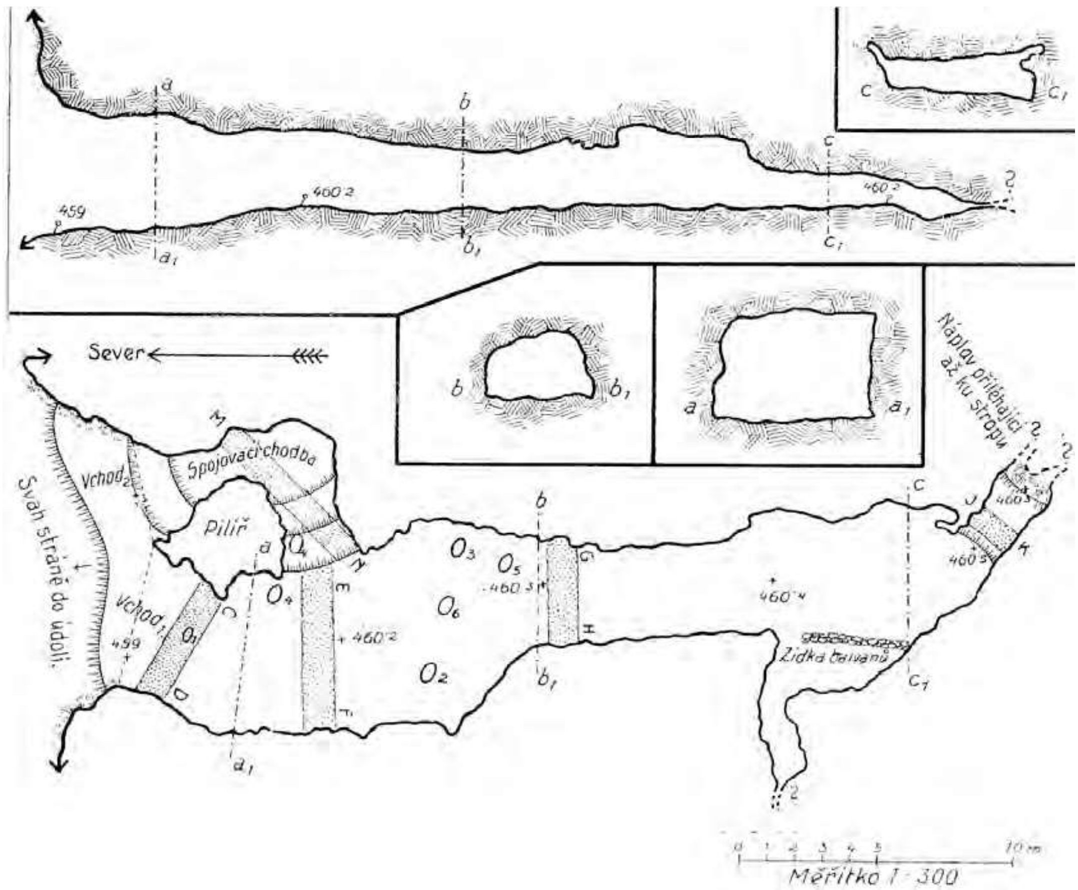

FIGURE 2: Balcarka Cave and the reconstruction of the uncovered hearths (marked O1–O6) in the cave. The exact position of the archaeological finds is not known; the excavator (Jan Knies) expressly mentioned the lithics and decorated animal bones in the context of all the hearths. Two isolated human incisors were found in the context of the third hearth. A fragment of human jaw-bone was discovered in the context of the second hearth.

2010). The whole collection is associated with the oldest Magdalenian occupation of Moravia (Valoch 1960, Valoch, Neruda 2005). According to the published data, the uncovered hearths can be characterised as extensive – sometimes discontinuous – black spots of ash of variable thickness between 8-14 cm (Valoch 2010), some surrounded by arranged blocks of limestone.

Kůlna Cave

Kůlna Cave in the Moravian Karst is one of the most important Middle Palaeolithic sites in Central Europe with a thick stratigraphic sequence from the Middle Palaeolithic with Levallois Technology (Layer 14) up to LUP, the Epimagdalenian and the Mesolithic. It is located in the cadastral area of Sloup village (Blansko District), 30 km north of Brno, in the northern part of the Moravian Karst at 470 metres a. s. l. Modern archaeological research of the cave was conducted by Karel Valoch in 1961-1976 (Valoch 1988) and briefly in the 1990's (Valoch 2002). Jindřich Wankel, Jan Knies and Martin Kříž carried out the first archaeological excavations at Kůlna Cave at the end of the 19th century. During the excavations, they more or less systematically excavated the central part of the cave, mostly sediments with Upper Palaeolithic archaeological finds. The excavators gradually uncovered 17, or 18 hearths respectively (Kostrhun 2005, Valoch 2011, *Figure 3*). These old excavations and the exact positions of the finds are not possible to reconstruct today and, unfortunately, the georeferencing of newly excavated finds is also rather problematic (Blinková, Neruda 2015).

Loštice I

Loštice I – "Kozí Vrch" is situated in the northern part of Central Moravia, SSW of Loštice, on the right bank of the Třebůvka river valley. The site is situated on the south-western hillside of a prolate ridge approximately 315 m above sea level (50 metres above the river). The distance between the site and the Morava river is 5 km without the possibility of visual

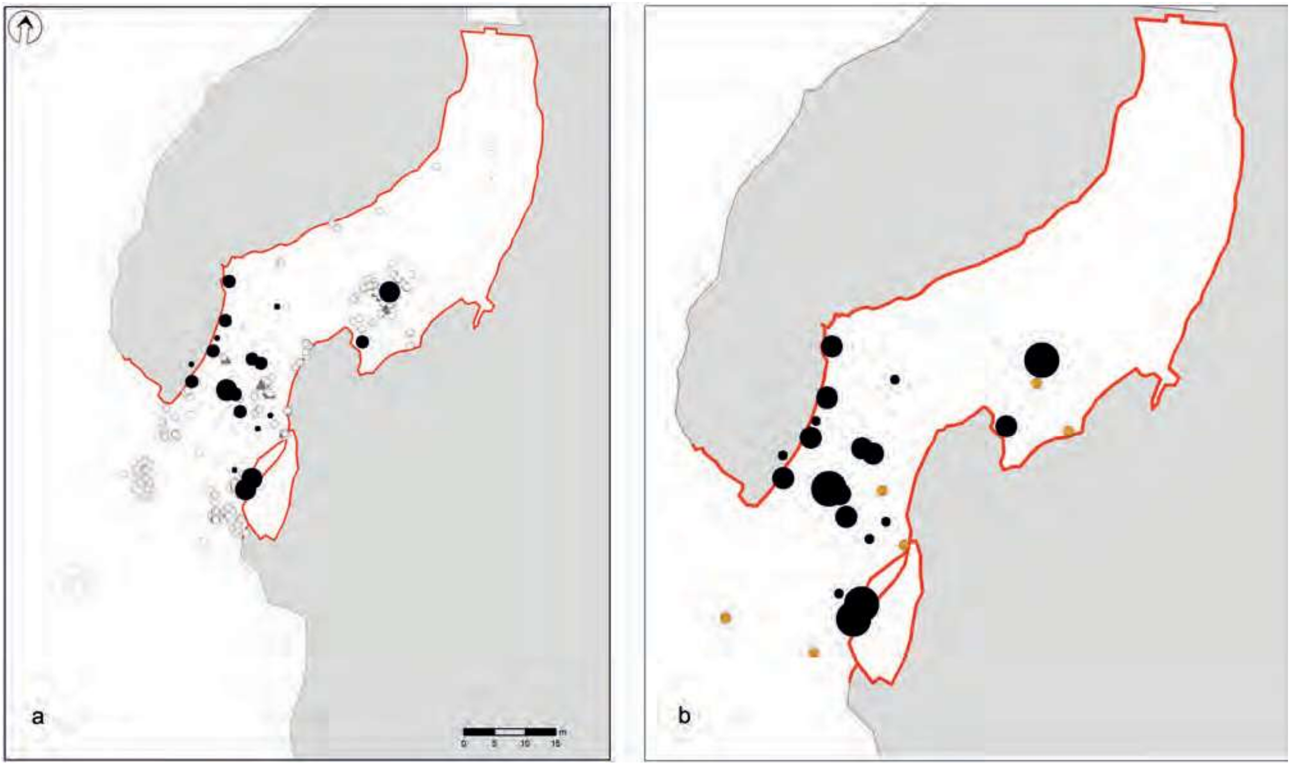

FIGURE 3: Kůlna Cave; a) localization of hearths (black spots) and distribution of raw materials (white circles; Olomučany chert by grey triangles) within layer 6; b) artefacts from within layer 6 sampled for analysis (brown circles) and their relation to hearths (black spots). Artefacts without coordinates are not shown. Digitalization by P. Neruda and Z. Nerudová.

contact. Nowadays, a large part of the site has been destroyed by a local quarry. Excavations were conducted between 2006–2008, during which two sectors with concentrations of chipped stone industry and greywacke were documented (Neruda *et al.* 2009).

Brno-Štýřice III

The Brno-Štýřice III site is located in the south-western part of Brno (South Moravia, Czech Republic), approximately 300 m to the south of the current bank of the Svratka river. The elevation of the site is 210 m above sea level (10 m above the river). The site is situated on a step in the terrain which rises on the west side into the low but steep cliff of Červený kopec (Red Hill) which has a maximum height of 311.42 m a. s. l. The site was first excavated at the beginning of the 1970's; in 2009 and 2011–2014 further large-scale rescue excavations were carried out. The excavations yielded a large number of lithics, osteological material, malacofauna and charcoals concentrated in five separate spots (Nerudová 2015).

METHODS

To distinguish heated cherts and flints, we applied macroscopic observation in combination with spectrophotometry, i.e. measuring in CIEL*a*b*

FIGURE 4: Analysed artefacts from Loštice I (a), Brno-Štýřice III and Balcarka Cave (b). Pieces estimated as heated are marked bold.

TABLE 2: Analysed artefacts from the Kůlna and Balcarka caves, the Brno-Štýřice III and Loštice I sites. Highlighted red (2nd column) are artefacts estimated as heated, green are unheated. Highlights in the 8th column are artefacts comprising only magnetite from among iron oxides. Green = verified as unheated, orange = verified as heated at high temperature, red = either unheated or heated at >500°C. RM, raw material; olom, Olomučany chert; flint, erratic flint.

Site	Evid. No.	RM	Length [mm]	Width [mm]	Thickness [mm]	Artefact description	Macroscopic surface description	Earlier mentions
Kůlna	4558	olom	22	13	3.5	blade, basal fragment	fresh, no signs of heating	Nerudová, Moník 2019
Kůlna	4201	olom	28.5	21.5	4.5	flake	fresh, no signs of heating	Nerudová, Moník 2019
Kůlna	1168	olom	22	7	3.5	backed bladelet, terminal part	light grey	Nerudová, Moník 2019
Kůlna	4401	olom	27	15	2	blade, terminal part	fresh, no signs of heating	Nerudová, Moník 2019
Kůlna	12745	flint	17	7	3.5	backed bladelet, mesial part	intensively burnt, dark black colour	Nerudová, Moník 2019
Kůlna	4315	chocolate flint	57	16.5	6	crested blade, terminal part	fresh, no signs of heating	Nerudová, Moník 2019
Kůlna	860	olom	41	28	17	core	fresh, no signs of heating	Nerudová, Moník 2019
Kůlna	2964	olom	38	18.5	5	flake	light patina	Nerudová, Moník 2019
Kůlna	10952	flint	41	49	52	core	light grey colour, no signs of heating	10972 in Nerudová, Moník 2019
Kůlna	11732	olom	23	9	6	blade, mesial part	light grey, patinated	Nerudová, Moník 2019
Kůlna	14961	radiolarite	47.73	28.97	9	flake	dark, matte	Nerudová, Moník 2019
Kůlna	49162	olom	32.97	17.84	12.58	core	greyish	Nerudová, Moník 2019
Kůlna	144463	olom	27.96	19.78	12.7	core	whitish grey, cracked	Nerudová, Moník 2019
Kůlna	11734	olom	15.6	8	2	bladelet	lustrous	Nerudová, Moník 2019
Kůlna	4318/66	olom	17	16	4	mesial part of retouched blade	spots, cracks, lustrous	
Kůlna	12891	porcellanite	37	19	4.9	broken blade	somewhat dull	Nerudová, Moník 2019
Loštice	118009	flint	31.74	30.36	5.57	flake	white patina	
Loštice	116424	flint	34.32	15.37	8.32	blade-burin	light patina	
Loštice	116305	flint	36.63	22.41	5.83	flake	white patina	
Loštice	117015	flint	53.17	21.32	6	blade	white patina, light-reddish colour, grey-black spots	
Loštice	116981	flint	40.99	10.89	8.19	blade	white patina, light-grey colour, thermal fractures	
Loštice	116982	flint	43.37	12.29	6.48	blade	white patina	
Loštice	116983	flint	30.76	9.43	7.62	blade	white patina	
Loštice	116984	flint	28.51	12.33	4.35	blade	white patina	
Loštice	116985	flint	33.44	15.82	6.5	blade	white patina, light-reddish colour	
Loštice	117241	flint	30.89	21.57	15.84	core	white patina, light-reddish colour	
Loštice	117027	flint	28.36	28.94	5.74	flake	white patina	
Loštice	116969	flint	49.59	22.62	8.69	blade-tool	white patina	
Loštice	117056	flint	26.4	22.62	6.15	blade	light patina	
Loštice	117062	flint	54.87	23.54	6.06	blade-tool	white patina, light-reddish colour, grey-black spots	
Loštice	117163	radiolarite	34.97	14.94	5.6	blade	grey colour	
Loštice	117019	flint	26.35	17.34	7.27	blade	light patina	
Loštice	117082	flint	53.31	22.89	5.96	blade-tool	white patina	
Loštice	117037	flint	44.21	21.28	7.15	blade-tool	white patina, light-reddish colour	
Loštice	116966	flint	52.25	21.87	23.44	core	white patina, light-grey colour	
Loštice	118010	olom	28.86	26.21	28.91	core	without patina	
Loštice	117642	olom	26.62	5.21	6.11	burin-blow	light-grey colour	
Loštice	117901	olom	22.24	6.43	3.07	blade	light-grey- reddish colour	
Loštice	117977	olom	14.57	11.62	3.24	mesial part of blade		

TABLE 2: Continued.

Loštice	117977b	olom	16.44	7.22	3.87	mesial part of blade		
Loštice	117983	flint	12.77	16.43	4.11	flake	light patina, reddish colour	
Loštice	118010a	olom	27.99	12.9	5.68	blade	cracks, reddish colour	
Loštice	118010b	chert	13.92	15.87	4.87	endscraper	dark black	
Loštice	118010c	olom	15.58	12.38	4.34	flake		
Loštice	118010d	spongolite	19.31	10.1	3.32	flake	light reddish	
Balcarka	3853-80	olom	44	29	8	flake	light patina	
Balcarka	3857-107	olom	50	15	3	blade laterally retouched	dark black colour, greasy lustre	
Balcarka	3852-63	olom	52	13	8.5	blade	grey colour, surface changes	
Balcarka	3958-135	olom	36	14	5	blade, mesial part	light-white patina, light-grey surface colour	
Balcarka	3850-21	olom	30	10	3	blade	light-white patina, light-grey surface colour	
Balcarka	3854-83	olom	60	24	9	blade	light colour, no patina; glossy surface?	
Balcarka	3966-284	flint	55	25	100	burin	grey-reddish colour, thermal fractures and cracks	Moník *et al.* 2019
Balcarka	3858-136	flint	36	16	3.5	blade, mesial part	light patina, polished?	Moník *et al.* 2019
Balcarka	3948-267	flint	34	28	8	flake, basal part	white-grey patina, porcelain-like structure	Moník *et al.* 2019
Balcarka	3954-273	flint	29	13	3.5	blade, terminal part	white-grey colour, porcelain-like structure	
Balcarka	3858-128	flint	30	15	4	blade, mesial part	intensive white colour, light red, surface changes cracks	
Balcarka	3851-35	flint	30	14	4	blade, terminal part	intensive grey colour, surface changes, no cracks or thermal fractures	
Balcarka	3851-30	flint	25	14	4	flake	intensive grey colour, cracks and thermal fractures,burned	
Balcarka	3858-124	flint	22	12	4	blade, mesial part	intensive white-grey colour, cracks, thermal fractures	
Balcarka	3883-199	flint	26	10	3.5	blade, basal part	dark-grey (reddish) colour	
Balcarka	3952-271	flint	57	14	7	blade, combined tool	light colour, shiny patina	Moník *et al.* 2019
Balcarka	3960-249	flint	67	21	10	blade	fresh colour, shiny patina	Moník *et al.* 2019
Balcarka	3860-175	flint	37	9	6	blade, burin blow	light white patina, dark colour	Moník *et al.* 2019
Balcarka	3955-92	spong	41	10	3	blade	intensive white patina, probably burnt	
Balcarka	3851-29	flint	24	13	2	proximal blade fragment	fresh colour/shiny patina	
Balcarka	3908-226	olom	38	8	2	bladelet	fresh colour	
Balcarka	3884-200	flint	33	8	2	backed bladelet – segment	fresh colour, shiny patina	
Balcarka	3955-274	olom	54	12	3	blade	fresh surface	
Balcarka	3852-61	black radiolarite	50	17	4	mesial part of blade	fresh surface	
Brno-Štýřice III	120926a	olom	50.9	23.5	6.7	blade	greenish grey, speckled, greasy lustre	
Brno-Štýřice III	120926b	olom	48.4	35	9.3	flake	dull greyish green	
Brno-Štýřice III	120926c	olom	38.4	18.7	8.2	blade	dark green, greasy lustre	
Brno-Štýřice III	120926d	olom	17.3	26.2	5.5	flake	greyish-green, speckled white, greasy lustre	
Brno-Štýřice III	120926e	olom	15.8	20.2	4.1	flake	dark green to black, both dull and lustrous	
Brno-Štýřice III	120926f	olom	29.4	19.7	6.2	flake	dark green to black, speckled	
Brno-Štýřice III	120871a	olom	29.4	18.9	5.8	flake	dull greyish green	
Brno-Štýřice III	120647	olom	50.9	21.1	10.3	blade	greyish green, speckled	
Brno-Štýřice III	120684	olom	44	36.3	7.7	flake	greyish-green, speckled, lustrous	
Brno-Štýřice III	120871b	olom	20.5	18.8	6.6	blade	dull greyish green	

colour space, to compare artefacts from Late Glacial sites (80 pieces in total, see *Table 2; Figure 4*) with unheated samples from outcrops/occurrences (80 pieces of erratic flints (EFs) and 58 pieces of Olomučany chert) and experimentally heated samples. The heating time in experimental heating was 1h in each case. The samples were placed in a pre-heated oven under oxidizing conditions and later left to cool to ambient temperature. In the cases of heating at 400°C and 500°C, the samples were pre-heated for 15 minutes at 200°C to avoid thermal shock. Following this, the temperature was rapidly increased to the desired final value. Two EF samples were burned in an argon atmosphere at 250°C and 350°C to simulate the reducing conditions under hearths (cf. Zeigen *et al.* 2019).

Our previous experience with erratic flints (Moník *et al.* 2019), widely used at Moravian Late Glacial sites, was that they are highly variable as regards colour, so that heated artefacts are hard to distinguish from unheated ones. In this research, we have also focused on other material, i.e., Olomučany chert (see Nerudová, Moník 2019 for results from Kůlna Cave). This chert is more homogeneous as regards colour, ranging from dark grey to greenish grey, although reddish hues were also observed (Bosák 1978) due to the precipitation of iron oxides within chert-bearing layers. Potentially heated lithic artefacts were macroscopically identified as pieces with pot-lid fractures, cracks or colour changes (reddish, greyish; *Table 2*). Not only seemingly heated pieces but also erratic flint and Olomučany chert artefacts without macroscopic changes (i. e. potentially unheated) were selected for analysis for comparison (*Table 2; Figure 4*). Similarly, four non-patinated erratic flint artefacts burned in the fire of Mikulov castle in 1945 (Jüttner 1945) were measured for colour for comparison. Similar to our previous studies (Moník *et al.* 2017; Moník *et al.* 2019), we used uni- and bivariate plots of colour coordinates (statistics performed in R environment) as the combination of all three (CIE)L*a*b* coordinates in the principal component analysis did not discriminate between heated and unheated samples. We only used PCA of all three colour coordinates in the Discussion to plot variability within Moravian cherts and erratic flints.

A third method employed was the measurement of isothermal remanent magnetism (IRM) in selected chert and flint artefacts (49 pieces in total; *Table 3*). This method can distinguish different iron oxides within a material. It has been shown experimentally (Moník *et al.* 2019) that flints containing only magnetite were either not heated at all, as the heating would lead to the formation of goethite or haematite at 250°C or 300°C, or heated at high temperatures (probably around 500°C; Moník *et al.* 2017) which led to the substitution of other iron oxides by magnetite. It is thus probable that any heat-treated (i. e. deliberately heated for mechanical improvement) chert and flint which contains magnetite will also contain a certain amount of goethite or haematite. IRM was acquired on pulse magnetizer LDA5-AMU1 in the field range 2 to 20 mT and MMPM10 in the field range 20mT to 2.5T. The magnetisation of the samples was measured on a 2G Enterprises 755 R cryogenic rock magnetometer. The IRM data were analysed using the IRMUNMIX program (Heslop *et al.* 2002) and the results were compared with the data published by Grygar *et al.* 2003.

Unfortunately, the spectrophotometric measurements were rather ambiguous (see Results). We thus plotted the supposedly heated artefacts on a map based mostly on macroscopic observation and IRM to potentially visualize their clustering, indicative of the location of hearths at Moravian Late Glacial sites. It has to be noted that only recently excavated sites made use of a recording of each artefact in three coordinates (Štýřice III, Loštice I); in older excavations, finds were localized unsystematically in two coordinates (Kůlna Cave, Valoch's excavations) or only period sketches were available (Balcarka and Kůlna caves, old excavations) with no precise locations.

In well 3D-documented sites, GIS analysis was also used to further visualize different raw materials and technological categories (flakes, blades, cores and hammerstones). The overall plan of each site was created with regard to available input data: the known position of hearths/fireplaces (distinguishable from the surrounding sediment based on colour and sediment texture), identified burnt artefacts or the position of the analysed samples. In the Brno-Štýřice III site, a micromorphological analysis was also conducted to verify the supposed position of one hearth.

RESULTS

Colour change

Colour change of erratic flints upon heating had already been observed in our previous study (Moník *et al.* 2019) when it became clear that the variability of geological (i.e. unheated) sample also covers the colour

TABLE 3: Results of IRM analysis. Flint, erratic flint; Olomučany, Olomučany chert.

ID	comp	rel. cont.	mean	DP	**B/2**	%	**Mineral**	Site	Material
136I3858	1	0.57	1.71	0.35	**51**	**57**	**Magnetite**	Balcarka	flint
136I3858	2	0.43	2.37	1.14	**234**	**43**	**Hematite**		
175_3860		1	1.77	0.47	**59**	**100**	**Magnetite**	Balcarka	flint
249_3960		1	1.66	0.44	**46**	**100**	**Magnetite**	Balcarka	flint
267I3948		1	1.78	0.54	**60**	**100**	**Magnetite**	Balcarka	flint
271_3952		1	1.73	0.4	**54**	**100**	**Magnetite**	Balcarka	
284I3966	1	0.73	1.44	0.44	**28**	**73**	**Magnetite**	Balcarka	flint
284I3966	2	0.27	3.31	0.37	**2042**	**27**	**Goethite**		
3851_54	1	0.81	1.49	0.39	**31**	**81**	**Magnetite**	Balcarka	Olomučany
3851_54	2	0.18	3.15	0.19	**1413**	**18**	**Goethite ??**		
3852_54	1	0.61	1.72	0.4	**52**	**61**	**Magnetite**	Balcarka	Olomučany
3852_54	2	0.38	3.2	0.24	**1585**	**38**	**Goethite ??**		
3955_54	1	0.47	1.61	0.41	**41**	**47**	**Magnetite**	Balcarka	Olomučany
3955_54	2	0.53	3.32	0.1997	**2089**	**53**	**Goethite**		
116305	1	0.617	1.594	0.431	**39**	**62**	**Magnetite**	Loštice	flint
116305	2	0.383	3.51	0.731	**3236**	**38**	**Goethite**		
116424	1	0.809	1.746	0.53	**56**	**81**	**Magnetite**	Loštice	flint
116424	2	0.19	2.996	0.233	**991**	**19**	**Goethite ??**		
116966	1	0.664	1.664	0.442	**46**	**66**	**Magnetite**	Loštice	flint
116966	2	0.336	3.822	0.421	**6637**	**34**	**Goethite**		
116969	1	0.674	1.646	0.418	**44**	**67**	**Magnetite**	Loštice	flint
116969	2	0.326	3.2	0.223	**1585**	**33**	**Goethite**		
116981	1	0.98	1.636	0.397	**43**	**98**	**Magnetite**	Loštice	flint
116981	2	1.987	3.051	1.45	**1125**	**199**	**Goethit ??**		
116982		1	2.541	0.947	**348**	**100**	**Hematite**	Loštice	flint
116983	1	0.787	1.607	0.49	**40**	**79**	**Magnetite**	Loštice	flint
116983	2	0.213	3.825	0.49	**6683**	**21**	**Goethite**		
116984	1	0.674	1.687	0.48	**49**	**67**	**Magnetite**	Loštice	flint
116984	2	0.326	3.068	0.821	**1169**	**33**	**Goethite ??**		
116985	1	0.522	1.704	0.452	**51**	**52**	**Magnetite**	Loštice	flint
116985	2	0.478	3.261	0.297	**1824**	**48**	**Goethite**		
117015	1	0.424	1.7	0.48	**50**	**42**	**Magnetite**	Loštice	flint
117015	2	0.576	3.731	0.268	**5383**	**58**	**Goethite**		
117019	1	0.601	1.704	0.441	**51**	**60**	**Magnetite**	Loštice	flint
117019	2	0.399	3.347	0.977	**2223**	**40**	**Goethite**		
117027	1	0.675	1.598	0.379	**40**	**68**	**Magnetite**	Loštice	flint
117027	2	0.325	3.114	0.713	**1300**	**33**	**Goethite ??**		
117037	1	0.438	1.652	0.435	**45**	**44**	**Magnetite**	Loštice	flint

TABLE 3: Continued.

117037	2	0.562	3.192	0.331	**1556**	**56**	**Goethite**		
117056	1	0.527	1.676	0.451	**47**	**53**	**Magnetite**	Loštice	flint
117056	2	0.473	3.59	0.747	**3890**	**47**	**Goethite**		
117062	1	0.355	1.633	0.456	**43**	**36**	**Magnetite**	Loštice	flint
117062	2	0.645	3.207	0.317	**1611**	**65**	**Goethite**		
117082	1	0.485	1.664	0.433	**46**	**49**	**Magnetite**	Loštice	flint
117082	2	0.515	3.283	0.256	**1919**	**52**	**Goethite**		
117163	1	0.619	1.658	0.484	**45**	**62**	**Magnetite**	Loštice	radiolarite
117163	2	0.381	2.919	0.791	**830**	**38**			
117241	1	0.463	1.61	0.445	**41**	**46**	**Magnetite**	Loštice	flint
117241	2	0.537	3.503	0.597	**3184**	**54**	**Goethite**		
11734_70	1	0.575	1.566	0.382	**37**	**58**	**Magnetite**	Kůlna	Olomučany
11734_70	2	0.425	3.652	0.401	**4487**	**43**	**Goethite**		
117642	1	0.641	1.74	0.425	**55**	**64**	**Magnetite**	Loštice	Olomučany
117642	2	0.359	3.235	0.364	**1718**	**36**	**Goethite**		
117901		1	1.381	0.438	**24**	**100**	**Magnetite**	Loštice	Olomučany
117977	1	0.674	1.734	0.429	**54**	**67**	**Magnetite**	Loštice	Olomučany
117977	2	0.326	3.249	0.42	**1774**	**33**	**Goethite**		
117977B	1	0.63	1.759	0.418	**57**	**63**	**Magnetite**	Loštice	Olomučany
117977B	2	0.37	3.167	0.36	**1469**	**37**	**Goethite ??**		
117983	1	0.545	1.523	0.389	**33**	**55**	**Magnetite**	Loštice	flint
117983	2	0.455	3.12	0.783	**1318**	**46**	**Goethite ??**		
118010A	1	0.198	1.573	0.278	**37**	**20**	**Magnetite**	Loštice	Olomučany
118010A	2	0.802	3.214	0.304	**1637**	**80**	**Goethite**		
118010B	1	0.495	1.637	0.407	**43**	**50**	**Magnetite**	Loštice	Olomučany
118010B	2	0.505	3.368	0.324	**2333**	**51**	**Goethite**		
118010C	1	0.173	1.535	0.428	**34**	**17**	**Magnetite**	Loštice	Olomučany
118010C	2	0.827	3.37	0.347	**2344**	**83**	**Goethite**		
118010D	1	0.051	1.714	0.532	**52**	**5**	**Magnetite**	Loštice	Olomučany
118010D	2	0.949	3.264	0.251	**1837**	**95**	**Goethite**		
12891_76		1	1.749	0.332	**56**	**100**	**Magnetite**	Kůlna	porcellanite
136I3858	1	0.76	1.51	0.37	**32**	**76**	**Magnetite**	Balcarka	
136I3858	2	0.24	2.9	0.26	**794**	**24**	**Hematite ??**		flint
144463		1	1.57	0.401	**37.15352**	**100**	**Magnetite**	Kůlna	Olomučany
2964I64		1	1.852	0.372	**71.12135**	**100**	**Magnetite**	Kůlna	Olomučany
3884_54		1	1.681	0.46	**47.97334**	**100**	**Magnetite**	Balcarka	
4315I66	1	0.649	1.647	0.424	**44.36086**	**64.9**	**Magnetite**	Kůlna	Krakow chert
4315I66	2	0.351	3.39	0.324	**2454.709**	**35.1**	**Goethite**		
4318_66		1	1.684	0.379	**48.30588**	**100**	**Magnetite**	Kůlna	Olomučany

TABLE 3: Continued.

49162	1	0.305	1.61	0.433	**40.73803**	**30.5**	**Magnetite**	Kůlna	Olomučany
49162	2	0.695	3.51	0.297	**3235.937**	**69.5**	**Goethite**		
63I3852	1	0.118	1.326	0.134	**21.18361**	**11.8**	**Magnetite**	Balcarka	Olomučany
63I3852	2	0.76	1.564	0.462	**36.64376**	**76**	**Magnetite**		
63I3852	3	0.122	3.322	0.272	**2098.94**	**12.2**	**Goethite**		
83_3854	1	0.755	1.763	0.486	**57.94287**	**75.5**	**Magnetite**	Balcarka	Olomučany
83_3854	2	0.245	3.23	0.844	**1698.244**	**24.5**	**Goethite**		
860I62	1	0.2	1.45	0.666	**28.18383**	**20**	**Magnetite**	Kůlna	Olomučany
860I62	2	0.502	1.73	0.389	**53.70318**	**50.2**	**Magnetite**		Olomučany
860I62	3	0.298	3.436	0.372	**2728.978**	**29.8**	**Goethite**		Olomučany
K14961	1	0.039	1.041	0.145	**10.99006**	**3.9**	**Magnetite**	Kůlna	radiolarite
K14961	2	0.591	1.706	0.254	**50.81594**	**59.1**	**Magnetite**		
K14961	3	0.37	3.259	0.831	**1815.516**	**37**	**Goethite**		

range of samples heated up to 300°C. Even the modest sample of 80 erratic flints from their occurrences in Middle Pleistocene glacial deposits at Závada u Opavy (Czech Silesia, Czech Republic; Macoun, Šibrava 1957) shows a large colour range between -0.3–9 on a* scale (green to red), -0.8–15.4 on b* scale (blue to yellow) and 33.7–81.4 on L* (lightness) scale (*Figure 5a*). It is thus virtually impossible to distinguish heated and unheated samples based on colour only, even if all three colour coordinates are combined in PCA. Artefacts from the Loštice I site possess slightly lower values of Lighntess (L*) – this is, however, given by their strong patination which, apart from changing their colour and lightness, blurs the difference between potentially heated and unheated samples. The important information is that the two pieces experimentally heated in reduction atmosphere are not different, as regards colour, from samples heated under oxidizing conditions. Flint artefacts heated by chance under hearths (in reduction atmosphere at given temperatures of 250 to 350°C), may possess similar colours to deliberately heated pieces dropped on embers (a technique described by Griffiths *et al.* 1987).

Olomučany chert is more homogeneous than erratic flints regarding colour, its values ranging from 1.2 to 4 on a* scale, 3 to 14.2 on b* scale and 30.4 to 57.5 on L* scale (*Figure 5b*) are indicative of its dark colour. With heating, however, it turns progressively red, reaching values of >6 on a* scale at 300°C and >7 at 400 or 500°C. When plotted in PCA scatterplot (*Figure 5b*), the unheated (Geo) samples partially overlap with any experimental temperature but samples heated at 300 and 400°C frequently (but not exclusively) possess higher positive values of L* and a* colour components.

We have thus plotted these two variables in a bivariate plot to identify potentially heated artefacts (*Figure 6*). Five artefacts from Kůlna Cave (mostly pictured in Nerudová, Moník 2019, Fig. 8; nos. 14463, 49162, 2964, 86062 and 4318)), two of the measured artefacts from Brno-Štýřice III (nos. 120926e, f) and two or three artefacts from Balcarka Cave (nos. 3851, 3852, 3955) do not fall within the variability of unheated samples. Apart from the possibility that our reference sample (Geo) was too small to cover the colour variability of the cherts , it is possible that eight of these artefacts (i.e., those with values <1 on a* axis) were heated at experimentally untested temperatures or experienced some other modification during post-depositional processes, whereas no. 3851 from Balcarka Cave was probably heated under oxidizing conditions due to its reddish hue.

IRM measurements

From among the 49 measured artefacts, 38 contained both magnetite and either goethite or haematite. These may or may not have been heated in the past. The remaining 11 pieces contained only magnetite. This means they could not have been heated at T> cca 200°C (when oxidation of magnetite occurs) or were heated at an elevated, usually destructive temperature around 500°C. Artefacts no. 12891 from

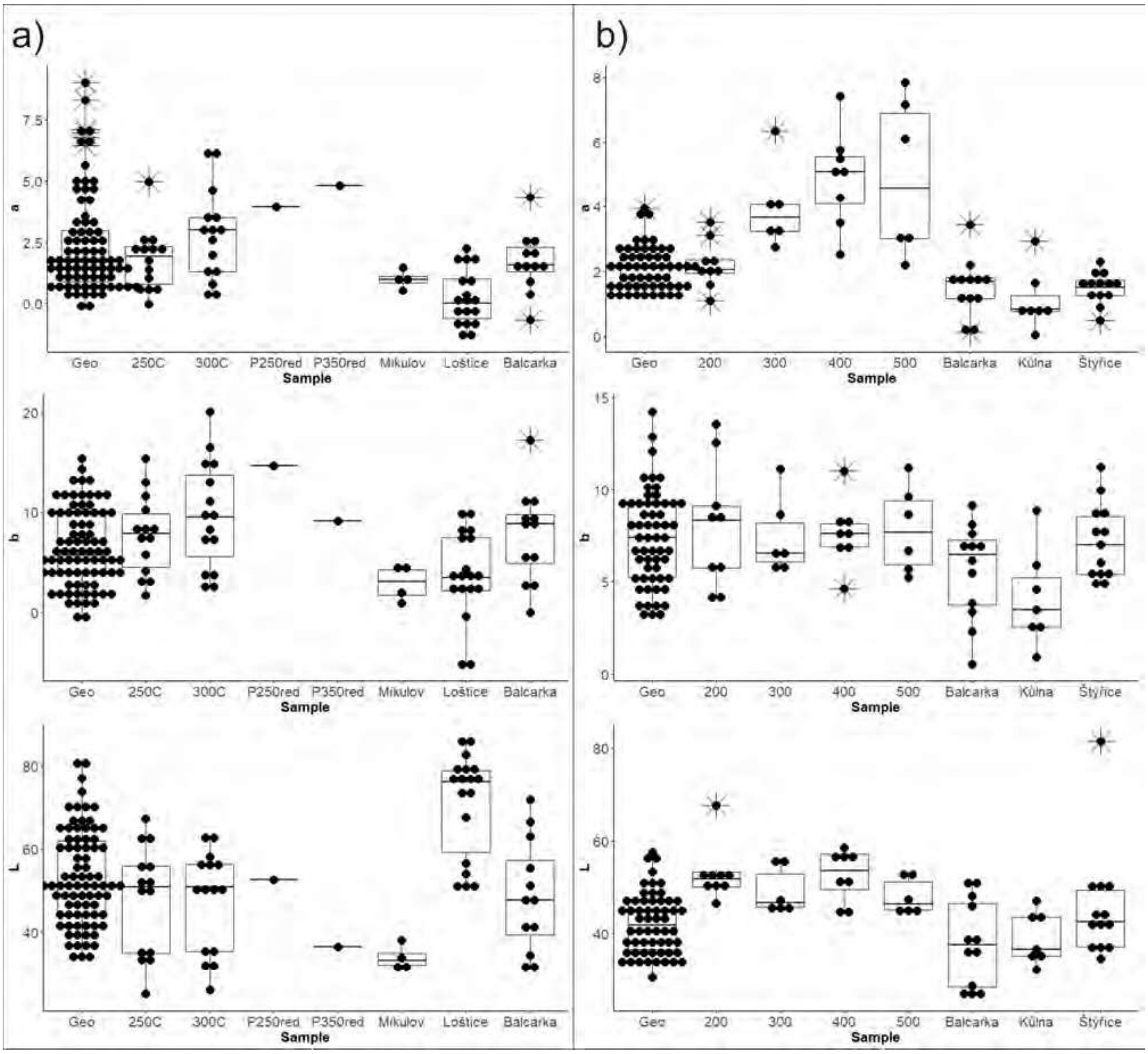

FIGURE 5: Erratic flint (a) colour components (L*a*b*) from outcrop samples, samples heated at temperatures between 200°C and 500°C, and artefacts. Two samples were heated at reduction conditions, four samples come from the fire at Mikulov castle; b: Colours (L*a*b*) of unheated samples of Olomučany chert (Geo), samples experimentally heated at temperatures between 200°C and 500°C and potentially heated artefacts from the studied Late Glacial sites.

Kůlna Cave, no. 117901 from Loštice I, and nos. 3948-267, 3952-271, 3960-249, 3860-175, 3884-200, 3955-274 and 3852-61 from Balcarka Cave (see *Tables 2 and 3*) are among the IRM-verified, probably unheated pieces. The strongly burned pieces are nos. 49162 and 4318/66 from Kůlna Cave and no. 117163 from Loštice I. Artefact no. 2964 from Kůlna Cave is difficult to explain as it is lustrous and was macroscopically estimated as heated (Nerudová, Moník 2019, Fig. 8/4) but contains only magnetite from among iron oxides. It is not cracked or crazed as we would expect in samples heated at high temperatures, sufficient for substitution of other iron oxides by magnetite. One possible explanation is that it was not heated and the

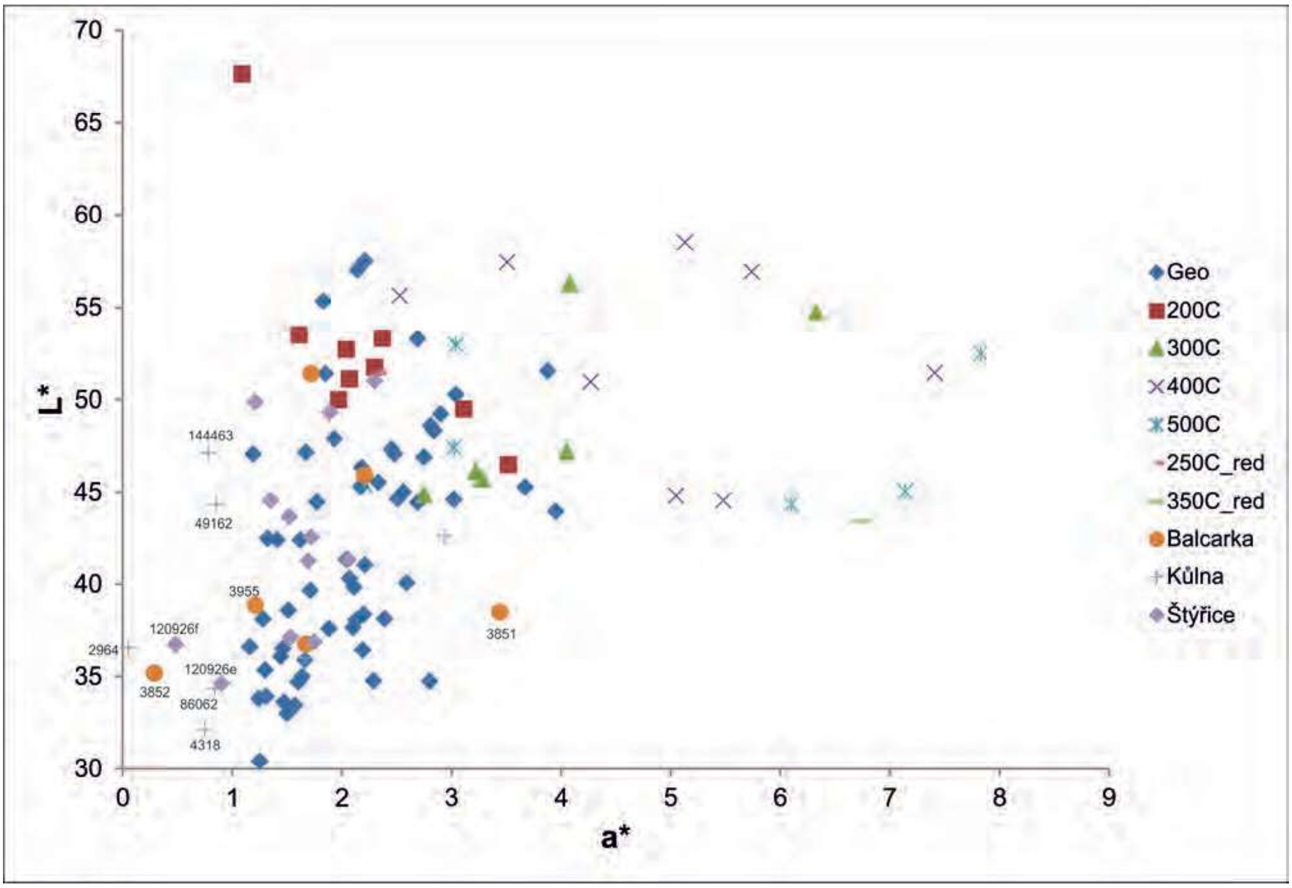

FIGURE 6: Comparison of colour components L* and a* in samples from outcrops (Geo) of Olomučany chert, samples heated at temperatures between 200°C and 500°C in oxidation and 250°C to 350°C in reduction atmosphere, and potentially heated artefacts from Late Glacial sites. The artefacts not falling within the variability of outcrop samples are numbered with their ID's.

lustre is a result of other pre- or post-depositional processes. Another possibility is that it was repetitively heated at non-destructive temperatures (i.e., not exceeding 300 or 350°C); this mechanism may theoretically lead to the final predominance of magnetite (Moník *et al.* 2017) from among the iron oxides present.

ARTEFACTS FROM SITES AND SPATIAL RECONSTRUCTIONS

Balcarka Cave

From among the eight analysed Olomučany cherts, 14 erratic flints, one spongolite and one radiolarite artefact from Balcarka Cave, we have macroscopically estimated 14 as having been heated (8 flints, 5 Olomučany cherts and 1 spongolite). The erratic flint samples were already analysed for heat-treatment in our previous study (Moník *et al.* 2019). Only one piece was possibly heat-treated there while another was burned; based on microscopic observation and IRM (i. e. the presence of both magnetite and other iron oxide doesn't exclude their heating) six further pieces are also burned. As regards the artefacts made of other materials, one piece (no. 3851) of Olomučany chert seems to have been heated under oxidizing conditions at 300 or 400°C whereas two other pieces (nos. 3852 and 3955) were probably burned at higher temperatures (probably >350°C) in reducing conditions as indicated by their dark colours (*Figure 6*). A further two pieces are probably also heated but unspecified. This low number of heated pieces is in apparent contradiction with the observations made by Jan Knies (Knies 1900, Knies 1902) and no lithic artefact can be associated with the uncovered fireplaces/hearths. Although Jan Knies mentions the presence of bones and many lithic artefacts in direct association with fireplaces (Knies 1900) we found only one clear notice: "*...frequently, generally near the fireplaces were scattered tools, made of different materials, mostly from flints...and one from rock-crystal*" (Knies 1900: 19). The specification of from which fireplace the rock-crystal comes is missing and, unfortunately, this piece is now lost.

Kůlna Cave

In Kůlna Cave, we analysed a total of sixteen artefacts from Layer 6. These were generally made of Olomučany chert (*Table 2*; see Nerudová, Moník 2019). As regards colour, five pieces made of Olomučany chert seem to have been heated. Due to their dark colour, this was probably done at reducing conditions (*Figure 6, Table 2*). Again, the heating temperature probably exceeded 350°C (see Balcarka Cave). A further piece of erratic flint and a radiolarite were probably also burned (see Nerudová, Moník 2019).

Interpretative difficulties are also connected with this site. The Upper Palaeolithic layers had already been excavated in the 19th century and then again in the 1960s (see above). Among other finds, the researchers repeatedly reported disintegrated charcoals, some of which represented hearths (*Figure 3*). Concentrations of charcoal were, within Karel Valoch's excavations, rather rare. Layer 5 in Kůlna Cave is preserved only as a relic approximately 50 × 60 cm in size. The main problem is that today it is impossible to exactly relate the uncovered hearts in the current stratigraphy (Layer 5 or 6). The question of homogeneity of the assemblage retrieved from Layer 6 has been discussed many times (Blinková, Neruda 2015, Kostrhun 2005, Nerudová, Moník 2019). Due to the poor evidence, it was impossible to reconstruct the spatial organisation in Layer 5. The spatial reconstruction of artefacts in Layer 6 is rather problematic, because we cannot unequivocally associate these "hearths" with Layer 6. For this reason, our reconstruction is only tentative. The spatial reconstruction does not show any clear association between hearths and the analysed "seemingly burnt" lithic pieces (*Figure 3*).

Loštice I

Erratic flint was the most common raw material (*Table 2*) at the Loštice I site. In our analyses, we focused on 18 potentially heated erratic flints artefacts and one piece made of radiolarite and unidentified chert each. The problem with the estimation of heating of erratic flints is their colour variability (*Figure 5a*) and patination of artefacts so that, finally, we had to rely more on other visual criteria (see above) and our acquaintance with the heated and natural materials in question (cf. Collins, Fenwick 1974). Nine pieces of flints were estimated as heated, complemented by the two pieces made of other materials. A further of nine more closely observed erratic flints were unheated.

Rescue archaeological excavations (2006–2008) uncovered only a fragment of the original sediments (*Figure 7*) as local quarrying had destroyed a major part of the site. Archaeological sites with preserved Late Glacial sediments are relatively rare in Moravia due to intensive Holocene processes and repeated forestation; this is the case in Loštice I. Pleistocene organic remains (bones, charcoals) had not been preserved there. Occasionally, ceramic fragments and Palaeolithic artefacts were found together in the same layer. Although some burnt lithic pieces are present in the collection, no true hearth was found. Our spatial reconstruction focused only on the position of analysed (seemingly burnt) artefacts (*Figure 7; Table 2*).

Brno-Štýřice III

We selected exclusively Olomučany chert (10 pcs.) for further analyses (*Tables 1 and 2*). The remaining pieces were estimated only macroscopically as regards potential heating. Colour analysis, again, concurred with our macroscopic observation only in a few cases. In this case, it becomes clear that almost certainly burned artefacts (e.g. nos. 12096a or 12096d) fall within the variability of outcrop samples, meaning that spectrophotometry by itself is, again, unable to reliably distinguish heated and unheated artefacts (*Figures 5, 6*). The reason for this is probably the scope of the used spectrophotometer which focuses on a circle of about 1 cm in diameter. This leads to "swamping" of the speckled colour of heated cherts (see the two mentioned artefacts). The resulting spectrum is then something of an intermediate value of the dark and bright spots, similar to the samples of outcrops.

In general terms, the Brno-Štýřice site provided most material for further analyses. Although there was no direct evidence of hearths, we uncovered spots of reddish and black sediment within the orange B-horizon. One of these reddish smudges, the size of 40 × 50 × 3–5 cm, was found in 2012 between squares m 28 and 33 (*Figure 8*). It comprised of fragments of iron oxides, charcoals and knapped stone industry. A sample for palynological, malacological, micromorphological (Lisá 2015), and elemental analysis was taken from this smudge (Appendix 1). The thin sections of the reddish smudge and the black sediment differ from the B horizon (*Figure 9a, b*) in colour, the amount of iron oxides, burnt fragments of micro-charcoals and fragments of animal bones (*Figure 9, c-f*). It must stressed that neither the reddened sediments nor charcoals are, by themselves, prove of a hearth (Stahlschmidt *et al.* 2015), but here they are confined to concentrations of (mostly macroscopically estimated) heated cherts and flints. The micromorphological thin

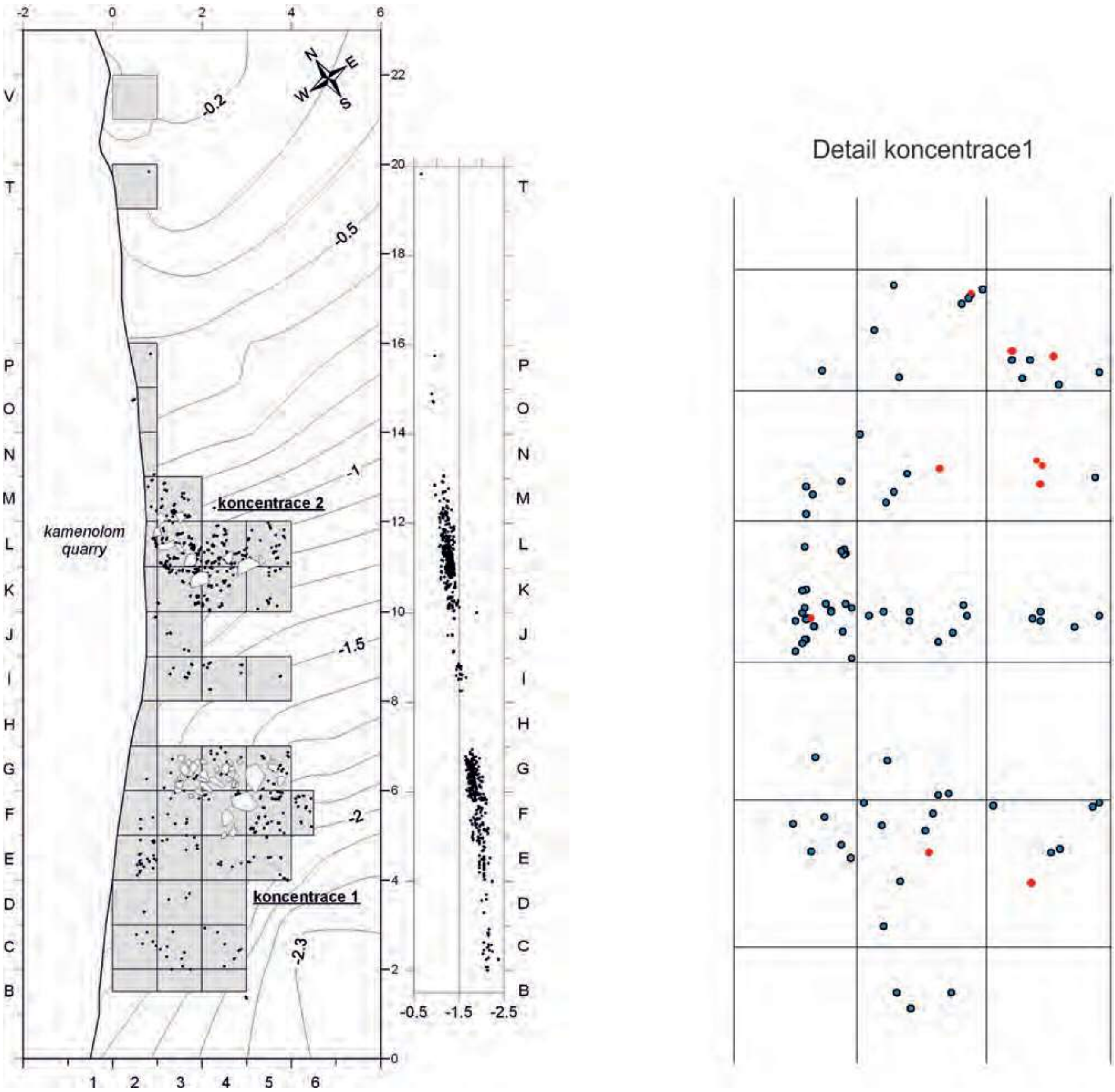

FIGURE 7: Loštice I; real (exact) position of both concentrations of lithic artefacts and detail of the first accumulation. The artefacts selected for further analyses are marked red. Two analysed artefacts are without coordinates and are not shown. Digitalization by P. Neruda and Z. Nerudová.

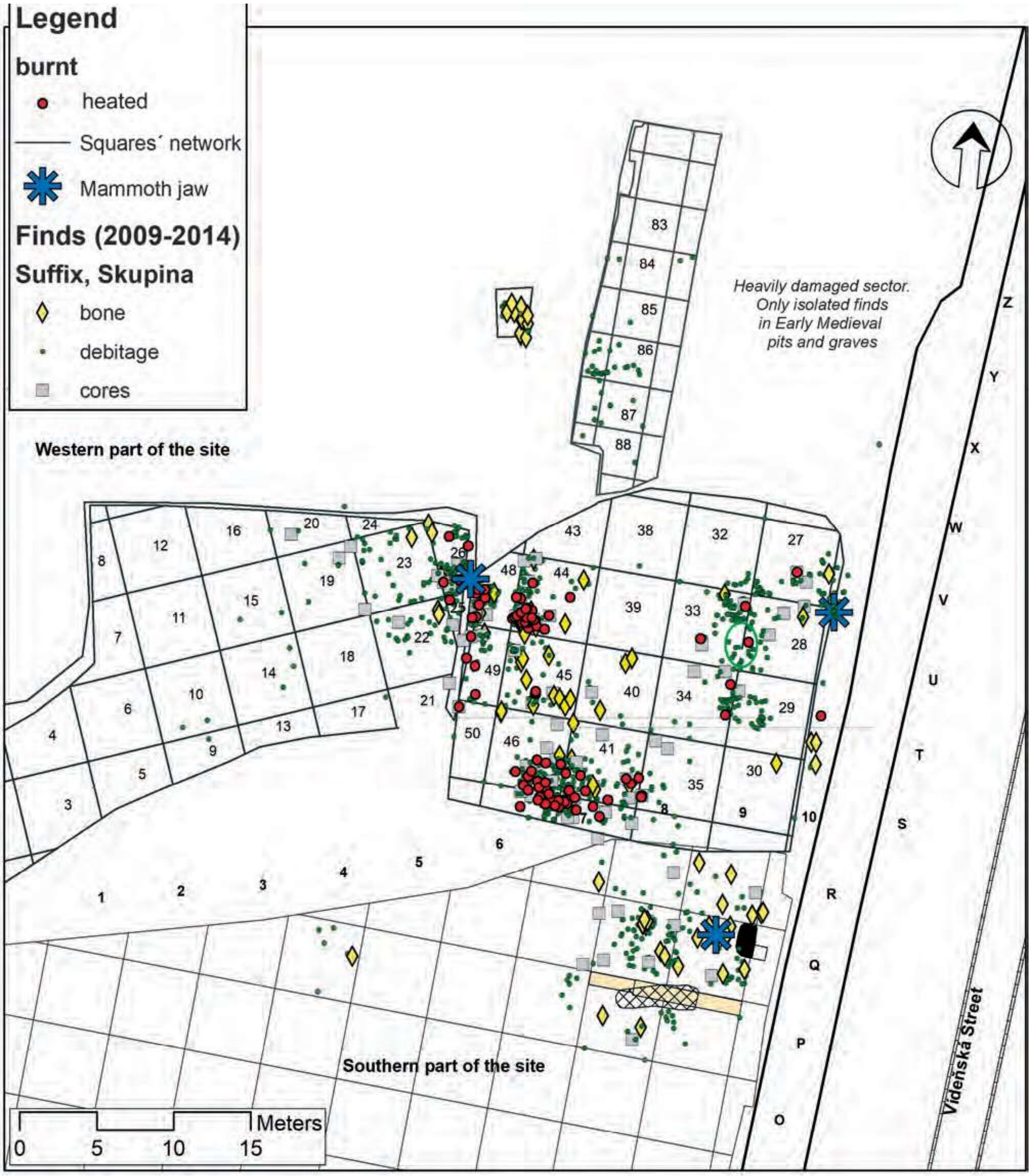

FIGURE 8: Brno-Štýřice III; exact spatial distribution of heated lithics, animal bones and black (or reddish) spots with burned fragments of charcoals and animal bones. The burned sediment is indicated by a green circle. The artefacts without coordinates are not shown. Digitalization by P. Neruda and Z. Nerudová. Heated artefacts are marked red.

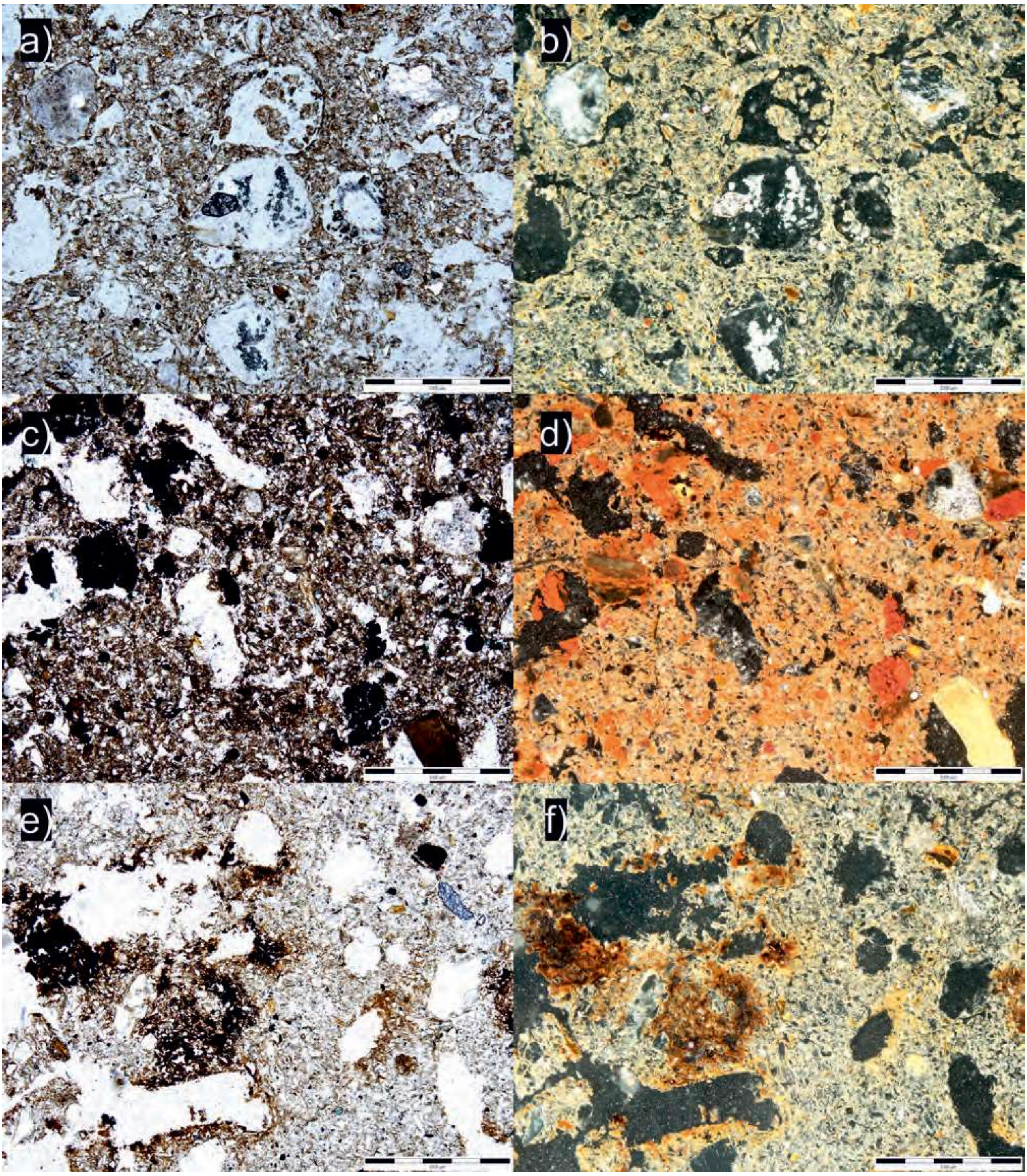

FIGURE 9: Brno-Štýřice III, micromorphology of a possible hearth: orange B-horizon (a, b), reddish smudge (c, d) and black sediment (e, f). Plane polarized (a, c, e) and oblique incident (b, d, f) light. Microphoto: L. Lisá.

sections show calcite hypocoatings typical for ash layers (Karkanas *et al.* 2007), and the amounts of phosphorous, calcite, magnesium and potassium are also elevated here.

Although the laboratory report (Lisá 2015) does not specify the origin of the iron oxides present, it seems likely they originated here through the burning of the sediment. A hearth was most likely situated between squares 28 and 33. Unfortunately, it was not recognized or photographed in the process of rescue excavation.

Apart from this feature, burned bones were very frequent and some dispersed charcoals also occurred in archaeological layers (Nerudová *et al.* 2016) but these did not have clear borders and it was impossible to distinguish these spots within the sediment during excavation. According to the results of anthracological and osteological analyses, the micro-remains are generally from animal bones rather than charcoals; for more discussion see (Nerudová *et al.* 2016).

DISCUSSION

Once heated to at least 300°C, Olomučany cherts are easier to distinguish, as regards colour change, than in the case of erratic flints. The latter show a much larger variability among the geological (unheated) sample (*Figure 5*). This is because Olomučany chert is darker in its unheated state than most Moravian materials (i.e., erratic flints; Krumlov cherts, varieties I and II; spongolites of western Moravia and cherts of Stránská skála types etc.) used in the Late Glacial (*Figure 10*). It only partially overlaps with the spongolites of western Moravia and erratic flints in PCA when (all three) CIEL*a*b* coordinates are

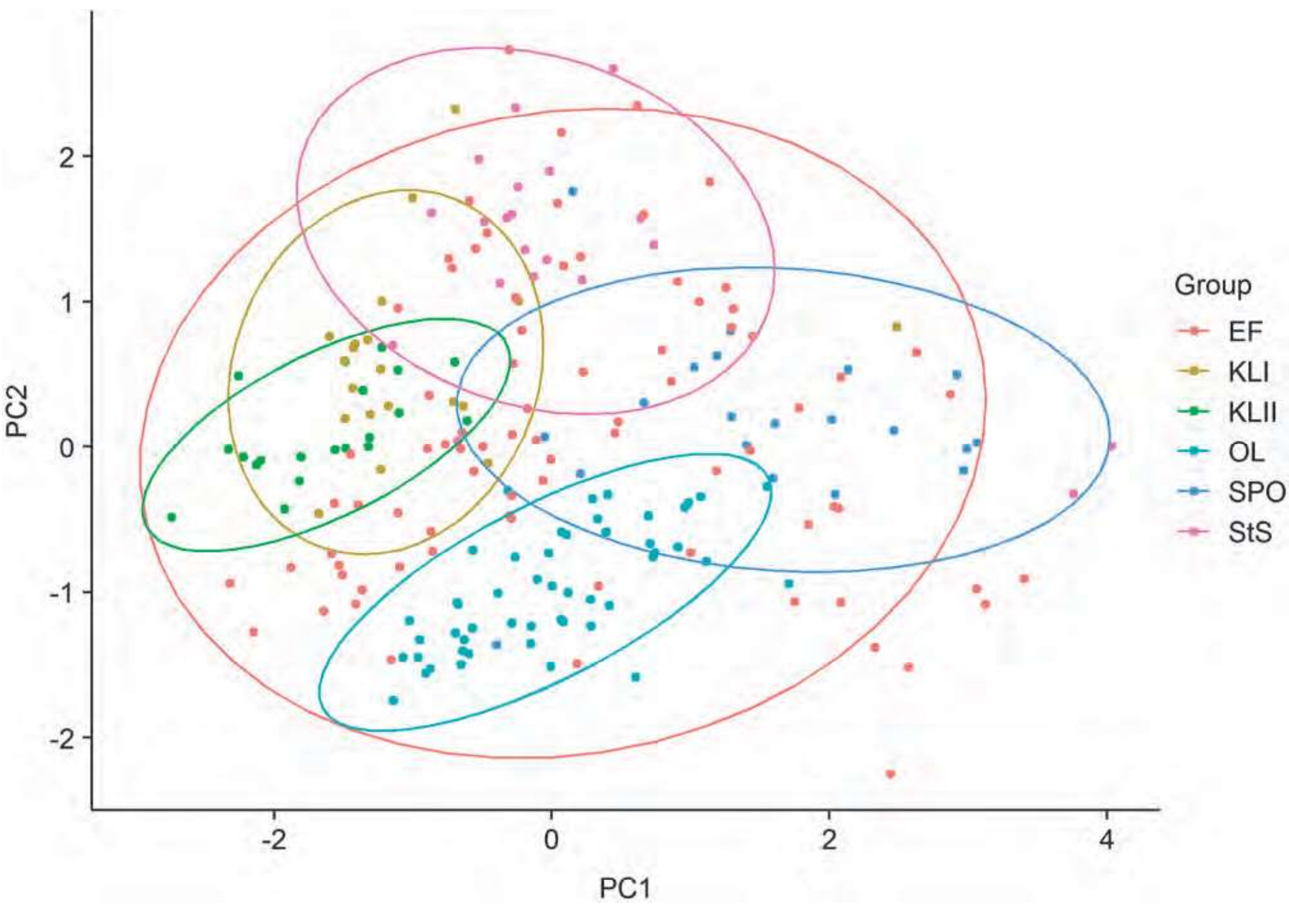

FIGURE 10: Colour variability among Moravian cherts and erratic flints in PCA. EF, erratic flints; KL I, II = Krumlov cherts, varieties I and II; OL, Olomučany chert; SPO, spongolite of western Moravia; StS, chert of Stránská skála type.

plotted together (it should be stressed that higher amounts of erratic flints (80 pcs.) and Olomučany chert (50 pcs.) were used in PCA than other Moravian cherts (20 pcs. each) due to the focus of our research on the former two materials, and specialized research on the colour variability of Moravian cherts is yet to be conducted). Even so, there is a large overlap between geological samples, experimentally heated pieces, and artefacts (macroscopically estimated as) heated in the past (*Figures 5b, 6*) so that colour measurements must be always accompanied by other methods and by macroscopic estimation, however subjective the latter it may be. Factors like granularity or sediment freezing (Michel *et al.* 2019) may also influence the susceptibility of SiO_2-materials to cracking, similar to that caused by heating, and their colour is undoubtedly modified in the course of post-depositional processes. Analysis of bone material, which shows significant colour changes after heating (Lebon *et al.* 2015), from within the same layers (e. g. from Balcarka Cave) should be conducted in future to verify our conclusions.

Although there is little doubt about human control of fire in the Magdalenian, verification of settlement features from older excavations is problematic and information about large-scale, thick ash layers comprising stone artefacts from the Kůlna and Balcarka caves (Kostrhun 2005, Valoch 2010), or bone and antler artefacts from Balcarka Cave (Moník *et al.* 2019, Valoch 2010), are not supported with evidence. One possible reason for this is that the temperature necessary to modify stone or bone is relatively low (Inizan, Tixier 2001) give values between 250 and 300°C for fine-grained materials) and is not necessarily evidenced in archaeological sediments. Another reason may be the ephemeral nature of fires within the sites (see Valoch 2010 for discussion).

The spatial distribution of artefacts from the analysed sites probably indicates redeposition of artefacts as there is no clear correlation between supposed hearths (if present) and heated materials. This is probably caused by post-depositional deluvio-fluvial disturbances in both cave (Balcarka and Kůlna caves) and open-air (Loštice I site) sites. The predominant orientation of artefacts in the Loštice I site has been mentioned earlier (Neruda *et al.* 2008, Fig. 7) and is equally indicative of partial redeposition of artefacts. The depth of archaeological layers or position of artefacts may be especially influenced by post-depositional processes within the floodplains of major rivers (e.g., the Morava, Dyje or Odra rivers). Intensive deforestation in the Middle Ages (in the 13th century) induced a distinct increase of gradation in flatland regions with low inclination. Sediments have buried the original varied floodplain of the lowland rivers and, with them, also possible relics of prehistoric settlements (Pokorný 2011: 194). It is possible that this process, which is captured, for example, in the Morava River valley around Strážnice (Kadlec *et al.* 2009), may have secondarily influenced some sites which lie close to the river and barely overtop the stream. Intensive changes have also occurred in karstic areas where Pleistocene and Holocene fall-off from cave ceilings has significantly affected archaeological situations (cf. Kůlna Cave). The only exception seems to be the Brno-Štýřice Epigravettian site where (mostly macroscopically estimated) heated artefacts form clusters, one of which is linked to a structure filled with iron oxides and remnants of ash layers (*Figure 9*; Appendix 2). Late Glacial hearths were thus probably preserved here without major disturbance.

CONCLUSION

In thus study, we have focused on the identification of heated artefacts within Moravian Late Glacial sites by comparing them with experimentally heated chert and flint samples. We have subsequently attempted to reconstruct the position of hearths within those sites. All analyses based on colour measurement of silica-rich materials, however, can only serve as a rough approximation for distinguishing heated pieces, and macroscopic observation based on professional experience is indispensable. This is because of the high variability within outcrop samples and the relatively large area measured by the spectrophotometer used. This leads to a possible "swamping" of colour anomalies. Colour is undoubtedly also modified during post-depositional processes, the role of which, however, was not the focus of our research. Isothermal remanent magnetism is useful in that it identifies unheated cherts and flints as these often (but not always) comprise only of magnetite in their matrix. Magnetite can also predominate in pieces heated at elevated temperatures (>500°C) which are, however, mostly destructive for silica materials.

By plottting the (mostly macroscopically estimated) heated artefacts in a plan, it becomes clear they do not cluster in three of the analysed sites and can hardly be used for verification of the position of Magdalenian hearths. In the Brno-Štýřice Epigravettian site, on the

APPENDIX 1: Micromorphological protocol from Brno-Štýřice site (based on Lisá 2015).

Štýřice-squares 28/33: micromorphological description	
Microstructure	Vughy
Pores	Voids; (1000 – 2000 μm; 10 %; 200 – 500 μm; 10 – 30 %), channels (<10 %), interpedal pores (20 %)
Granularity	C/F (250 μm) = 5:95; C/F (50 μm) = 10:90; C/F (20 μm) = 50:50; = clay-silty loam
Coarse fraction	Angular clasts of quartz (< 250 μm, cca 5 %); silt fraction made of mostly semiangular and semi-rounded quartz (40 %), weathered mica (15 %); feldspars (5%), opaque minerals, semi-angular, semi-rounded, clay and silt fraction (40 %).
Matrix	Brown to red-brown, crystalline, made largely by opaque matter
Organic component	Microcharcoals (<5 %); dark decomposed organic matter – Problematic differentiation from concentrations of FeOH minerals, probably around 30 %
Pedofeatures	Hypocoatings of fine-grained carbonates around channels and voids – not frequent but present, zones bioturbated by microorganisms and plant roots
Summary	Summary: Sediments rich in Fe-rich minerals can be encountered at nearby-located Červený kopec hill, in Devonian basal clastics. These are, however, concretions and coatings of larger dimensions, not fine-dispersed matter. Clasts larger than 250 μm were not identified in the studied sample. Apart from archaeological finds, the sample also comprises of micro-charcoals and is strongly bioturbated. We deal here probably with an anthropogenic sediment and the presence of opaque minerals, which colour the sediment red, are probably result of anthropogenic activities.

other hand, three clusters of heated artefacts, most likely hearths appeared. This interpretation was corroborated by micromorphological analysis at the place of one of these clusters. Thus, the Brno-Štýřice site probably did not experience the kind of redeposition of artefacts witnessed by the three other sites.

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