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BLANK LENGTH RECONSTRUCTION ON THE BASE OF CIRCULAR SEGMENT METHOD – CORE REFITTING CASE STUDY

ABSTRACT: The "life" of a lithic artefact stays recorded in the palimpsest of flake scars on the surface of the retrieved object. Especially on cores we can find distal parts of flake scars that remained after the preceding processes of core reduction. Their more detailed characteristic (determination of the length, the direction of detachment, and identification of the striking point) can contribute to the reconstruction of technological processes. The new method for the calculation of the length of the flake scar is based on a more or less regular spreading of the strike strength that manifests itself in the raw material as concentric lines of force (waves) with the centre at the striking point (in case of using a hard hammer). By determining the radius of a certain wave we can also establish the length of the entire flake. Two methods have been tested in an experiment – a calculation of a selected circular segment, or measuring it using a template. The application of a template turned out to be more precise and less time-consuming, and we confronted the template with the waves on the preserved flake scar. At the same time we identified the cases, when the measuring was not precise due to external factors. The application of the method was tested on a discoid core with the respective flakes created in an experiment, and on two refittings of Aurignacian cores. In all of the cases it is evident that the method of reconstruction of the length of the flake can be widely used in the technological analysis of chipped stone industry.

KEY WORDS: Flake scars – Hard hammers – Circular segment method – Core volume reconstruction – Refittings of lithics

INTRODUCTION

Chipped stone industry still belongs to the most numerous and best preserved archaeological material that is available to us for the reconstruction of the behaviour of early human groups. However the retrieved artefacts (raw material blocs, cores, blanks, tools, and waste) are a rather heterogeneous group of products at

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various stages of transformation. This holds for tools and for cores alike (on the issue cf. Barton 1987, 1990, Brumm, McLaren 2011, Dibble 1987a, 1987b, 1995, Dibble, Rolland 1992, Eren *et al.* 2005, Jaubert 1993, Sackett 1982, Slimak 1998–1999, Wiśniewski 2012).

At the sites where raw materials were scarce due to various factors (i.e. absence of suitable resources or functional specialization of the site) this problem had often been resolved through an intense utilisation of a preferred lithic raw material. This is generally manifested in an extensive reduction of cores, tools, and secondarily also other constituents, and may result in erroneous interpretations (Neruda 2012). A typical example is e.g. the site Bojnice III – the Castle Moat: because of the small sizes of the retrieved items the chipped stone industry had been classified either as micro-Mousterian (Bárta 1967, 1972) or Taubachian (Valoch 1984, 1996) but a complex techno-typological analysis has revealed that the industry coming from layers VIII, IX, and X can be placed within the sphere of industries with backed bifaces (according to Debénath, Dibble 1994: 158), i.e. Micoquian *sensu lato* (Neruda, Kaminská 2013).

The study of the stone industry collections can be affected both by the taphonomy of the assemblage (Neruda 2012) that stems from the specific behaviour of archaic humans (and also the possible post-deposition influences) and the already mentioned static character of this archaeological source (comparing of items that capture different stages of processing). Bigger items that prove the original mental template applied in the manufacture of lithic artefacts were most probably taken away from the site, and the preserved remains either reflect the production processes that were in use only in part, or are found in such state of preservation that they cannot be used for the techno-typological analysis any more. The only option in resolving such a problem is to quest after the approaches how to reconstruct the production of stone tools over as long period of time as possible, i.e. like a dynamic process.

Currently there are two main directions of research employed that can be complementary, but simultaneously both can be rather significantly limited by the taphonomy of the studied assemblage. In the reconstruction of the "life" of stone artefacts one of the options is a complex technological analysis that takes into account a combination of a number of features, and endeavours at eliminating the problem of the static nature of this archaeological source on the grounds of such phenomena. Therefore it is not only a description of the individual artefacts, but also looking after combinations of various attributes. For instance, in the case of cores it is important to compare the dimensions of cores with the preserved blanks (the dimensions of the exploitation surface of core and the dimensions of blanks, the presence of cortex etc.), with the dimensions of the available raw material, or with the morphology of fragments of cores (the preserved traces of specific production processes). In the instance of tools it is necessary to analyse not only the item as such but also the so-called by-products or waste that resulted in the course of their production (Demidenko 2015, Lev *et al.* 2011). Only such a technological analysis is capable of differentiating certain anomalies, which may have a negative impact on the interpretation of the industry.

The second method increasing the quality of technological analysis is the refitting of stone artefacts. Provided that a suitably preserved site and a lithic inventory are available, in some cases we can refit complex technological sequences (e.g. Guilbaud, Carpentier 1995, Lamotte 1999, Neruda, Nerudová 2005, Škrdla 2003) that give us a much more dynamic insight into the manufacturing process, especially if the refitted sequence is combined e.g. with spatial distribution of artefacts (e.g. Aubry *et al.* 2012, Vaquero 2011). However this requires the relevant artefacts to be preserved at the site. Many times some items are found missing for whatever reasons, and this makes the interpretation of the acquired refittings and the reconstruction of the technological processes very complicated (Nerudová 2009).

Both of the mentioned methodical processes have been developed quite minutely, and they often employ various digital technologies (digitalization over raster images, measuring of artefacts based on their photographs or 3D images etc.), which enhance the quality of especially graphical and consequently presentation options (Bretzke, Conard 2012, Nerudová *et al.* 2011, Riel-Salvatore *et al.* 2002).

However one important source of information still not adequately utilised is available to us. It is the system of flake scars on the surfaces of artefacts. Although it has been used in various analyses targeted at manufacturing processes (e.g. Clarkson *et al.* 2006) or at the extent of reduction in the artefacts (e.g. Dibble 1987b, Kot, Richter 2012), it has not made the most of the whole potential of preserved scars. In the course of production a palimpsest of scars is formed on the surface of an item; it consists of both the flake scars with a visible striking point (a complete flake scar) and the remains of scars that capture the distal or the distal-medial part of the knapped-off piece. And exactly the incomplete flake scars after detached blanks reflect the preceding processes of handling the artefact and can help in the reconstruction of its volume (shape) over a longer period of time. An important feature we can use with success in various reconstructions and hypotheses is the original length of the artefact that had been extracted. If we succeed in the reconstruction of the length, then in combination with the force propagation vector (e.g. Clarkson *et al.* 2006) we can determine the point of strike, and thereby reconstruct the length of the item in the preceding stages of reduction/reutilization with a reasonable accuracy. The presented contribution offers one of the possible methods of reconstruction of the length of the detached blank based on the metric characteristics of waves in the remnant of the preserved flake scar.

METHOD OF RECONSTRUCTION

The basic concept of the method for reconstruction of the length of the detached blank from the preserved flake scar is based on the principle of propagation of force in the processed material. The force manifests itself by concentric waves with the centre at the striking point. This especially holds for the use of a mineral hard hammer, which comes into contact with the processed material at the point. Any of the waves is in fact an arc segment, and it can be employed for the calculation of the distance between its crest and the point of strike (radius of an individual arc), even in case when the proximal part of the flake scar has not been preserved. If we select one of the waves and connect two points determined on the arc of the wave, we create a circular segment, in which we can measure two values (*Figure 1*) – the width of the arc (chord length) and its height, whereas the height of arc is positioned on a straight line intersecting the point of strike, the ½ of abscissa defining the width of arc and the chord length. Using both height and width of the arc we can calculate the radius of the given arc (wave), i.e. the distance between the point of strike and the vertex of arc, and if we add the remaining part of the flake scar to this value (provided its terminal part has been preserved), we can reconstruct the entire length of the flake.

The first manner of the tested reconstruction of the blank length is based on a direct measuring of the chord length (c) and the height of the segment (h). Ensuing from these values we calculate the radius of the circular segment using the following formula:

$R = h + d = h/2 + c^2/8h$

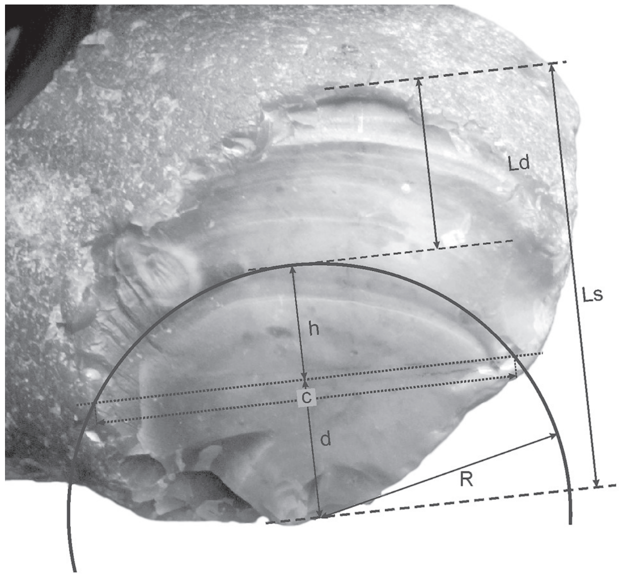


FIGURE 1. Main principles of blank length calculation based on the circular segment method. c – width of segment (chord length), d – apothem, h – height of segment (arc), Ld – length of a distal part of a scar, Ls – length of a scar, R – radius of an arc of the segment.

And the length of the entire flake is calculated as follows:

$Ls = R + Ld = (h/2 + c^2/8h) + Ld$;

Where *R* is the radius of arc, *h* – the height of arc, *c* – the chord lenght, *Ld* – the distal rest of the scar, and *Ls* – the length of the blank.

It is possible to utilise some web applications for the calculation of the required radius or the total length of the blank (e.g. Sunga 2014), or else the formula can be defined e.g. in an Excel table that will facilitate the collection of the data of all measured items in the form that suits the possible statistic analyses (cf. *Table 1*). However the measuring is rather demanding in terms of time and precision. Especially in small flake scars the height of arc of circular segment may be very small, mainly in the distal part of the scar.

For the above reason we have also tested another variant in measuring of the radius of arc of a circular segment (or the total length of the flake scar) based on the use of arc template (*Figure 2*). This is a transparent foil with arcs printed at a determined distance (e.g. 1 or 2 cm), which is applied to the flake scar during measuring. When using the template we try to find a conformity of some of the arcs printed on the template with some of the waves on the measured item. In this way we can reconstruct both the radius of arc and the total length of the flake scar at the same time.

TABLE 1. Comparison of the results of measuring a segment and a complete flake scar using two methods – mathematic calculation and applying a template.

Measu-rement number	RSg – radius of circular segment (mm)					LSc – length of scar (mm)					ID of scars
	reconstruction		real value (RSgR)	deviation		reconstruction		real value (LScR)	deviation		
	Calculation (RSgC)	Templa-te (RSgT)		Calculation RSgR-RSgC	Template RSgR-RSgT	Calcula-tion (LScC)	Tem-plate (LScT)		Calculation LScR-LScC	Templa-te LScR-LScT	
1	23.48	20	21.53	-1.95	1.53	32.56	30	30.7	-1.86	0.7	1
2	20.88	20	23.73	2.85	3.73	36.65	40	37.64	0.99	-2.36	2
3	33.52	30	30.38	-3.14	0.38	45.88	42	41.8	-4.08	-0.2	3
4	37.12	40	34.04	-3.08	-5.96	40.18	42	37.31	-2.87	-4.69	4
5	21.87	25	23.3	1.43	-1.7	31.77	32	32.25	0.48	0.25	5
6	33.51	35	26.73	-6.78	-8.27	36.7	38	30.11	-6.59	-7.89	6
7	34.58	30	37.59	3.01	7.59	52	48	54.49	2.49	6.49	7/1
8	31.78	30	44.21	12.43	14.21	43.3	42	55.08	11.78	13.08	7/2
9	43.13	40	36.28	-6.85	-3.72	48.65	48	42.55	-6.1	-5.45	8
10	24.49	30	37.21	12.72	7.21	32.82	40	53.03	20.21	13.03	9
11	18.05	20	30.23	12.18	10.23	23.75	28	34.45	10.7	6.45	10
12	23.84	25	17.34	-6.5	-7.66	28.97	30	22.95	-6.02	-7.05	11
13	28.12	30	31.51	3.39	1.51	37.84	40	42.23	4.39	2.23	12/1
14	11.51	20	54.16	42.65	34.16	23.68	33	63.52	39.84	30.52	12/2
15	11.21	15	19.29	8.08	4.29	21	27	28.7	7.7	1.7	13
16	28.07	40	39.34	11.27	-0.66	36.98	48	48.7	11.72	0.7	14
17	25.51	25	22.74	-2.77	-2.26	27.25	26	23.83	-3.42	-2.17	15
18	20.99	20	24.77	3.78	4.77	28.42	30	30.46	2.04	0.46	16
19	22.38	30	35.62	13.24	5.62	41.43	49	51.33	9.9	2.33	17
20	35.59	40	48.34	12.75	8.34	45.59	50	57.42	11.83	7.42	18
21	33.65	35	22.95	-10.7	-12.05	46.63	47	35.21	-11.42	-11.79	19
22	26.96	28	28.35	1.39	0.35	34.97	36	35.67	0.7	-0.33	20/1
23	19.51	20	28.35	8.84	8.35	36.33	37	35.67	-0.66	-1.33	20/2
24	16.85	30	48.7	31.85	18.7	31.95	47	61	29.05	14	21/1
25	22.2	30	33.43	11.23	3.43	53.91	62	61	7.09	-1	21/2
26	17.18	19	23.15	5.97	4.15	58.53	61	61	2.47	0	21/3
27	36.09	45	36	-0.09	-9	84.72	81	78	-6.72	-3	22
28	29.84	30	30.95	1.11	0.95	48.16	50	49.96	1.8	-0.04	23
29	40.91	40	38.04	-2.87	-1.96	44.91	42	40.11	-4.8	-1.89	24
30	40.55	50	51.39	10.84	1.39	56.02	67	67.9	11.88	0.9	25
31	54.06	55	61.85	7.79	6.85	83.4	85	92.31	8.91	7.31	26
32	20.88	29	25.2	4.32	-3.8	32.78	42	38.64	5.86	-3.36	27
33	20.46	20	22.24	1.78	2.24	31.55	32	32.89	1.34	0.89	28/1
34	26.79	30	28.37	1.58	-1.63	30.68	34	32.89	2.21	-1.11	28/2
35	23.83	18	15.88	-7.95	-2.12	49.97	44	41.29	-8.68	-2.71	29/1
36	28.69	30	33.25	4.56	3.25	38.07	40	41.29	3.22	1.29	29/2
37	16.03	20	19.3	3.27	-0.7	20.3	25	23.96	3.66	-1.04	30
38	28.49	30	30.86	2.37	0.86	31.52	33	31.22	-0.3	-1.78	31
39	28	30	26.58	-1.42	-3.42	40.38	43	40.2	-0.18	-2.8	32
40	15.74	30	30.2	14.46	0.2	51.46	68	71.7	20.24	3.7	33
41	24.79	35	35.02	10.23	0.02	42.04	48	48.86	6.82	0.86	34
42	18.76	17	17.35	-1.41	0.35	28.07	28	27.25	-0.82	-0.75	35
43	23.74	25	20.6	-3.14	-4.4	35.54	34	28.66	-6.88	-5.34	36
44	32.07	30	28.13	-3.94	-1.87	50.86	46	47.61	-3.25	1.61	37
45	23.22	38	25.57	2.35	-12.43	42.67	42	30.86	-11.81	-11.14	38
46	18.41	20	23.84	5.43	3.84	32.37	35	36.63	4.26	1.63	39

TABLE 1. Continued.

47	27	27	23.67	-3.33	-3.33	37.97	38	34.11	-3.86	-3.89	40
48	29.83	30	30.01	0.18	0.01	45.14	45	47.49	2.35	2.49	41
49	27.06	27	29.55	2.49	2.55	43.4	45	46.75	3.35	1.75	42
50	21.04	30	31.28	10.24	1.28	34.71	44	45.5	10.79	1.5	43
51	37.41	30	31.73	-5.68	1.73	52.49	44	45.75	-6.74	1.75	44
52	29.34	30	32.55	3.21	2.55	34.27	35	36.54	2.27	1.54	45
Median				2.7	0.9				2.1	0.4	

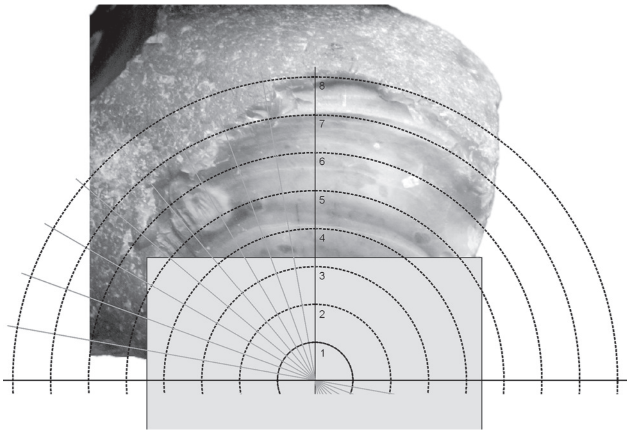


FIGURE 2. Using of the template for circular segment radius (scar length) calculation. Grey sheet of paper covers the proximal part of the scar to eliminate shifting of the template according to the position of the striking point.

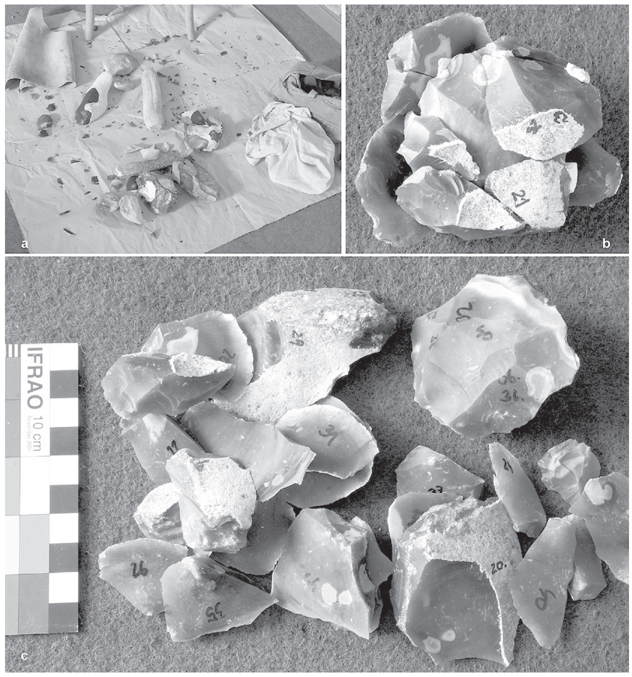


FIGURE 3. Knapping of experimental artefacts from erratic and "chocolate" silicites from Poland (a). Both core and flakes were designated (c) and then refitted all together (b).

Both methods have been tested on 52 samples created in an experiment. From the blocks of a fine-grained raw material (erratic silicites and "chocolade" silicite have been choose for the better visibility of scars) flakes had been knapped off using a hard hammer (mostly quartz, weight: 1/3 of raw material block in average), and the resulting flake scars were numbered (*Figure 3*). In some of the bigger scars or those of irregular shapes we have chosen more segments for measuring. The goal of the test has been to compare the reconstructed values obtained through both methods (the calculation and the use of template) with the real length (radius of the selected arc and length of scar). The difference in these values was the deviation of the measuring that can be used for the determination of accuracy of both methods (*Table 1*). In the instance of reconstruction using the calculation the values were measured with the digimatic caliper Mitutoyo (CD-15DCX) with two decimal points of accuracy. In the use of a template we have opted for 1 cm intervals between the arcs, whereas during the measuring a large piece of self-adhesive paper concealed the proximal part of the scar comprising the point of strike to prevent an unwanted correcting of the postion of the template according to the real state during the measuring (*Figure 2*, grey rectangle).

Our next step has been the testing of the practical possibilities in the application of the proposed method of the flake length reconstruction, or the reconstruction of the striking point position. In the first stage a block of the raw material had been chipped applying the volumetric concept of the discoid method (*Figure 3*), and the scars and flakes were numbered. Remnants of the distal parts of flake scars were retrieved on the core and a force vector (a perpendicular line to the arc of the segment) was defined, on which the striking point was supposed to be found. Our goal has been to determine, how many stages of exploitation we could reconstruct, and what would be the increase in the volume of the reconstructed shape as against the preserved core. Subsequently we have carried out refitting of the core and the respective flakes (*Figure 3b*) and prepared a graphic representation of the comparison between the resulting circle defining the plan view of the refitted core and the reconstruction employing the circular-segment method (*Figure 5*).

For a practical demonstration of the application of the method in the archaeological practice we have chosen 2 refittings of Aurignacian cores from the site Vedrovice Ia, Moravia, which had been uncovered by M. Oliva of the Anthropos Institute of the Moravian Museum in Brno (Oliva 1993). On these examples we could demonstrate that the circular segment method can reveal such technological steps (phases), which do not ensue from even quite complex refittings; thus the method makes the reconstruction much more precise regarding both the system of exploitation and the specification of the volume of the original block of raw material.

RESULTS

Accuracy of measuring

Prior to the practical application of the method of reconstruction of the blank length it was necessary to find out whether the chosen methods of reconstruction (i.e. the calculation and the use of a template) were adequately accurate. The main criterion has been the deviation of measuring from the real length of the blank determined as the distance of the striking point from the distal edge of the scar (measured according to the vector of force issuing from the striking point). For a more detailed checking we also observed the deviation between the radius of arc of the selected circular segment on the flake scar and the values established using both methods (*Table 1*). In this way we were able to compare 4 deviations:

1. The real circular segment radius (RSgR) – the calculated segment radius (RSgC);
2. The real circular segment radius (RSgR) – the radius determined using a template (RSgT);
3. The real length of scar (LScR) – the calculated length of scar (LScC);
4. The real length of scar (LScR) – the length of scar determined using a template (LScT).

For the assessment of accuracy of both methods of reconstruction we used the Student's *t*-test (*Table 2*), through which we have verified the hypothesis that both methods were relevant for the reconstruction of length (the so-called null hypothesis). This hypothesis is statistically valid only in case of using the template (P = 0.14 for segment and P = 0.36 for scar). When applying the method of calculating lengths from the measured values the null hypothesis cannot be corroborated; hence from the statistical point of view this method is not adequately precise at the 0.05 significance level (P = 0.002 for segment, and P = 0.02 for scar).

This is basically in correspondence with the comparison of both methods and their accuracy through box plots (*Figure 4*). The median of the deviation of scar length from the real length of flake is a mere 0.4 mm (the determined value is lower than the real value), whereas with the calculated flake scar it amounts to 2.1 mm. Much more important is the greater scatter of percentile points (25%–75%) evident in the method of calculation (11 mm as against 4 mm with the template).

The scatter of extreme values (min–max) amounts to more than 50 mm with the calculation and to 42 mm with the template. This clearly shows we have to take into account the negative impact of external factors that stem both from the accuracy of the method of measuring and

TABLE 2. One-sample t-test for four types of deviation. RSgR – real radius of a circular segment, LScR – length of a scar, RSgC – calculated circular-segment radius, RSgT – circular segment radius by template, LScC – calculated length of a scar, LScT – length of a scar by template.

Deviation	Average	Standard deviation	N	Standard error	Confidence interval -95.000%	Confidence interval + 95.000%	Reference constant	t	SV	p
RSgR - RSgC	4.109038	9.259609	52	1.284077	1.531147	6.68693	0	3.199994	51	0.002365
RSgR - RSgT	1.532308	7.41783	52	1.028668	-0.532829	3.597445	0	1.489604	51	0.142487
LScR - LScC	3.178462	9.580204	52	1.328535	0.511316	5.845607	0.00	2.392455	51	0.020458
LScR - LScT	0.835962	6.578849	52	0.912322	-0.995602	2.667525	0	0.916301	51	0.363822

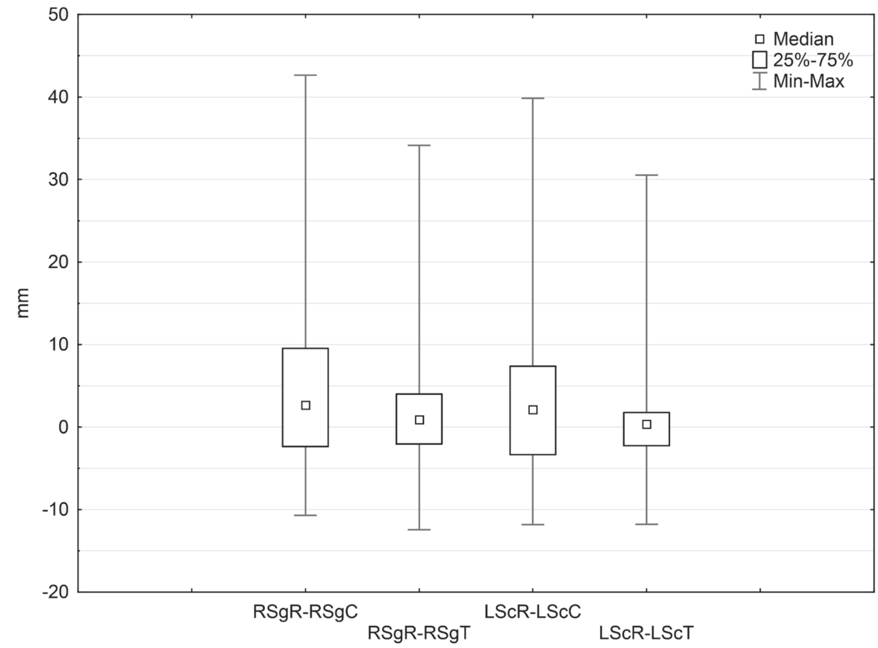


FIGURE 4. Box-plot charts demonstrated deviation of both methods of the reconstruction within the real value of a circular segment radius (RSgR) and length of a scar (LScR). RSgC – calculated circular-segment radius, RSgT – circular segment radius by the template, LScC – calculated length of a scar, LScT – length of a scar by template.

from the anomalies of the spreading of force in the lithic raw material.

Testing on the experimentally reduced discoid core

A discoid core with a volumetric concept is an ideal type of object for testing the options, how to utilise the studied method of reconstruction of the length of blanks on the grounds of flake scar remains. In the Middle Palaeolithic humans exclusively used hard hammer for this type of reduction; therefore the lines of force on the surface of a flake scar should have their centre at the striking point. Under normal circumstances the striking point is precisely defined, since hard hammer comes into contact with the processed item at points. At the same time, in the course of such exploitation (reduction) reshaping of a core through preparation of its distinct part occurs minimally and enhances the possibility of preserving older flake scars.

Both complete flake scars with visible striking points and flake scars coming down only in their distal parts were preserved on the core created in our experiment (*Figure 5*). The studied core enabled the use of 7 incomplete flake scars, 3 on one exploitation surface, 4 on the other (*Table 3*). To a certain extent it was possible to base the reconstruction of two preceding sequences of flake extraction on these flake scars (*Figure 5*, *S1 and S2*), not only on the front side (*Figure 5a–b*), but also at the side view (*Figure 5d*). This increased the peripheral area of the core by more than two times (roughly from 110 cm^2 to 250 cm^2) and the volume by more than 40 cm^3 (the values are only approximate; the shapes of the core have been simplified into basic geometric shapes). The periphery of the chronologically oldest sequence S3 graphically determined as an oval linking of the reconstructed flake scars 19, 22, and 34 has been

TABLE 3. Overview of reconstructed flakes on the experimentally knapped discoid core.

Flake number	Calculated length of flake (mm)	Real length of flake (mm)
19	33	39
21	33	39
22	40	41
34	54	48
35	33	30
36	43	42
38	30	28

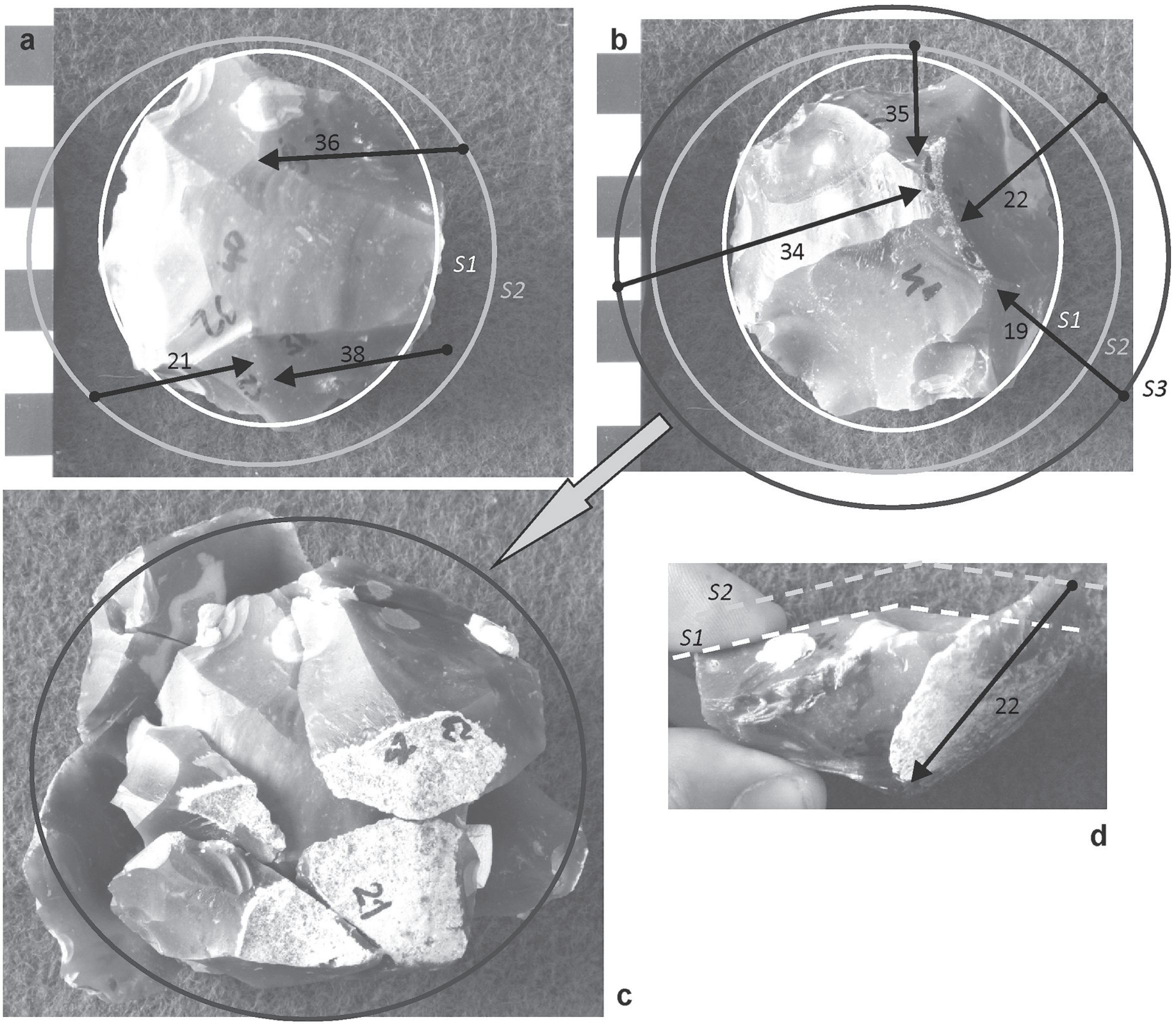


FIGURE 5. The principle of reconstruction of the discoid core using arc template. Lengths of the individual scars were projected within the core (a and b) and hypothetic striking points define the perimeter of the core (S1–S3). The perimentr S3 of the core was confronted with the refitting of the core to compare the accuracy of the reconstruction (c). Several flakes defined the reduction of the core thickness (d).

overlapped by a photograph of a refitting. It came to light that the periphery is in a quite precise correspondence with the periphery of the refitting, or with the striking points at the mentioned flakes 19, 22, and 34, which were attached as an outcome of the reconstruction of sequence S3. The scars on the preserved core did not allow the reconstruction of the preceding sequences.

Application on original materials

Refitting No. 1 consists of a core with a single striking platform and 3 preparation flakes (*Figure 6*). Two of them (F2 and F4) modify the striking platform (*Sp1*), the third one (F 10) forms the crest shape of the distal part of the core. The target products (e.g. F14) are not attached; these have apparently been taken away and consumed beyond the site. If we apply the method of reconstruction of the flake lengths on the scars preserved on the surface of the refitting, we can also assess the initial preparation steps and make a more relevant comment on the original dimensions of the processes lump of raw material. The distal part of the core is defined by a natural frost surface on the left side of the core and also two scars (F7 and F9); on plotting of the vector and the reconstructed length these connect ca 3.5–4 cm behind the preserved distal part of the core. The most recent evident modification of this part of the core

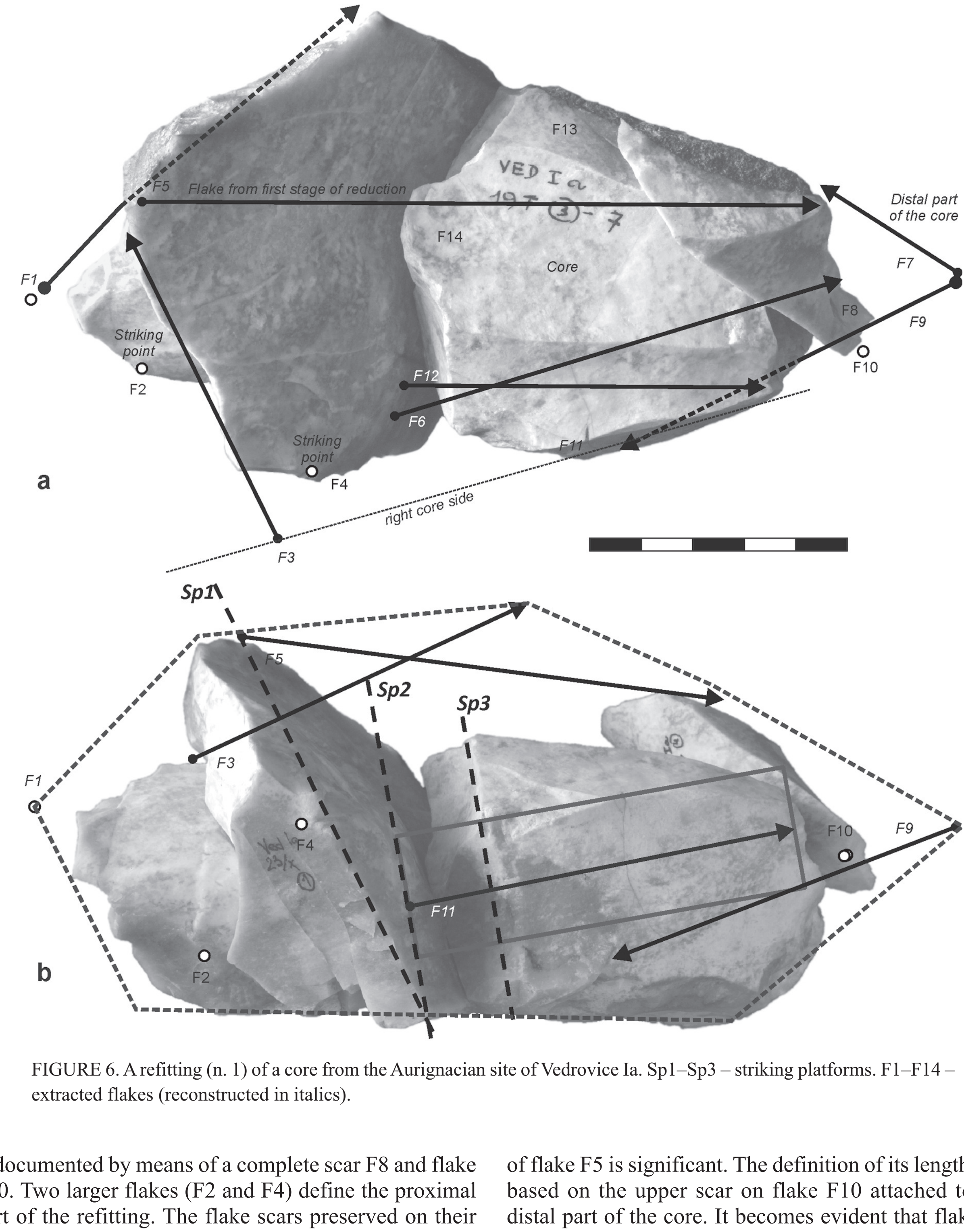


FIGURE 6. A refitting (n. 1) of a core from the Aurignacian site of Vedrovice Ia. Sp1–Sp3 – striking platforms. F1–F14 – extracted flakes (reconstructed in italics).

is documented by means of a complete scar F8 and flake F10. Two larger flakes (F2 and F4) define the proximal part of the refitting. The flake scars preserved on their surface enable a reconstruction of other two detached flakes F1 and F3, whereas flake F3 is defined by the position of the right side of the core. The reconstruction of flake F5 is significant. The definition of its length was based on the upper scar on flake F10 attached to the distal part of the core. It becomes evident that flake F5 must have been knapped off the striking platform (*Sp1*), which was defined by flake F4. Another striking platform (*Sp2*) is defined by reconstructed flakes F6, F11 and F12.

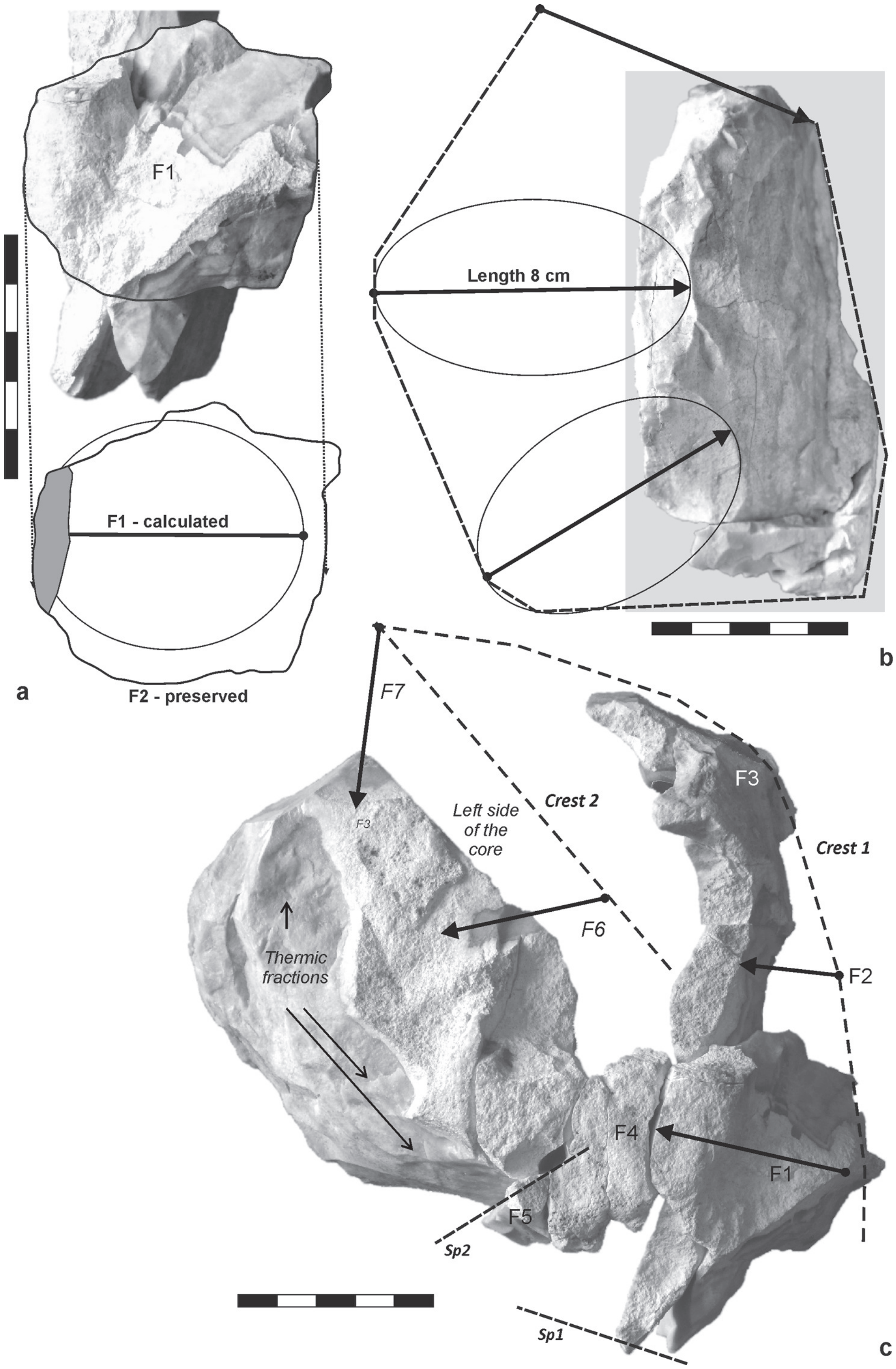


FIGURE 7. Refitting (n. 2) of a core from the Aurignacian site of Vedrovice Ia. SP1–3 – striking platforms. F1–F4 extracted flakes. a – comparison of reconstructed length of the flake (F1) and its real value (grey polygon shows the area of the flake F4 used for calculation of the length); b – a view of the back of the core with reconstruction of the width; c – a view of the left side of the core with localisation of the core crest 1 (defined by striking points of flakes F1–F3) and crest 2 indicated by two flakes on the core side (F6 and F7). Sp1 – first striking platform, Sp2 – second striking platform defined by the flake F5.

The third striking platform is preserved on the core. From this primarily flake F14 had been detached; judging by the scar and the formation of its proximal part it resembles a Levallois point.

The method for reconstruction of the lengths of flakes was applied to good effect in revealing the existence of one striking platform (*Sp2* – not preserved in the refitting), but on top of that also in refining the volume and form of the original piece of raw material, especially as regards its distal part and right side. We can also see that the shape of the preserved refitting still more or less respects the original form of the raw material.

The second example of the application of the method can be presented on refitting No. 2 (*Figure 7*); apart from the remnant of the core it contains a sequence of flakes that model the crests of the core (e.g. F1–F3) and one flake (F5) that modifies the striking platform (Sp2). In this case as well the target blanks were probably carried away from the site.

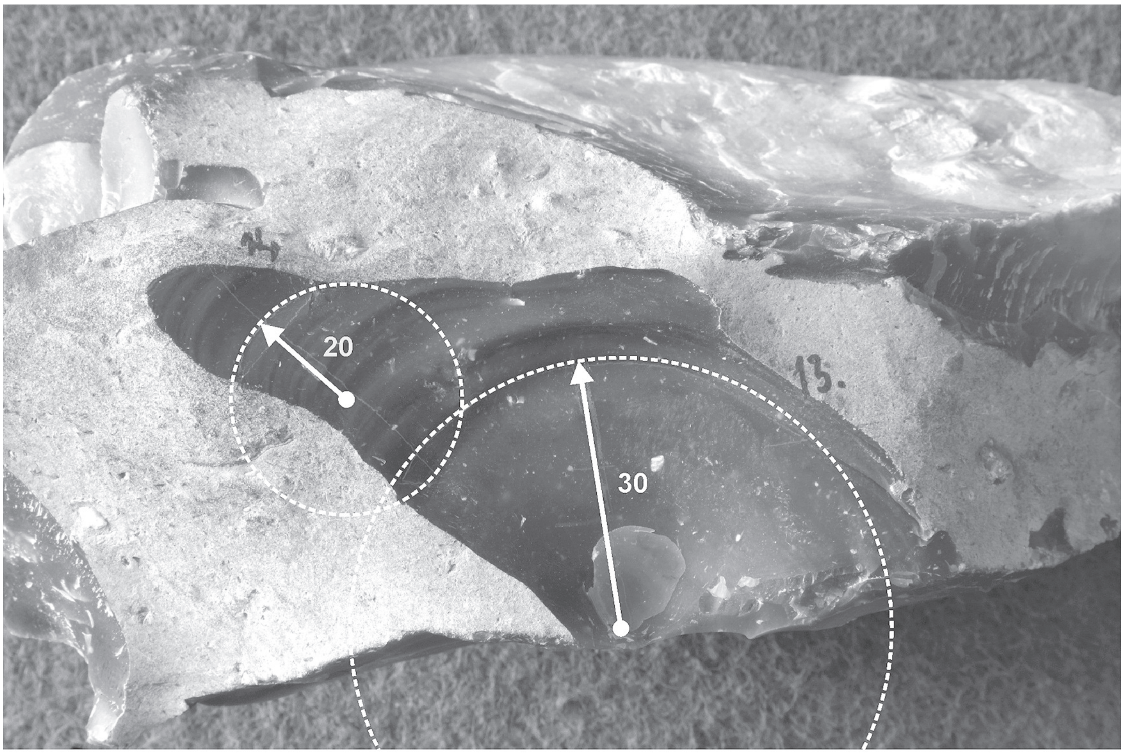
If we first take the preserved core without the sequence of flakes defining its crest, we can state that the original block of raw material that had been used was quite markedly bigger. Three flake scars that can be reconstructed increase the width of the core by ca 8 cm (*Figure 7b*). The volume of the preserved core is ca 700 cm^3, however if we connect the striking points of the reconstructed flakes, the volume of the core will expand to ca 1,750 cm^3.

For the testing of accuracy of the flake length method of reconstruction (a template was used) the distal remnant of the scar on flake F4 (*Figure 7a*: grey area) rendered an interesting option, because it was possible to attach preparation flake F1 to it (*Figure 7b*), which was a part of the sequence of flakes that form the first crest of the core (C*rest 1*) related to the striking platform *Sp1*. Since the mentioned flake F1 is available and the rest of the scar on flake F4 is small (decreasing the possibilities of a precise reconstruction), this part was ideal for the testing of precision. If we overlap the ascertained length of the flake with its real shape (*Figure 7a*), we can see that the difference amounts to just ca 5 mm, and this is an acceptable error during a reconstruction. Moreover, the angle between the dorsal part and the rest of the striking platform is quite acute (the dorsal side is longer than ventral), which makes the real difference even smaller. We can obtain a similarly satisfactory outcome for the reconstructed flake *F2;* the striking point calculated for this is located on the connecting line of the striking points of flakes F1 and F3 (*Figure 7c*). Also flake *F7* slightly extends the length of the refitting; it is situated in the distal part of the core (left side), and together with flakes F1–F3 (+ other without numbers) determines the curvature of the longitudinal convexity of the core. In the middle part of the left side of the core it is possible to reconstruct flake *F6*, which is apparently connected to the secondary forming of the core crest (*Crest 2*) or to the modification of the side of the core. If we link the striking points of flakes *F6* and *F7*, we create a line that is parallel with the preserved side of the core and makes a suitable angle with the striking platform *Sp2*, which can be defined in the refitting on the grounds of preserved flake F5. These components describe the stage of core reduction that virtually has not come down to us in the refitting, and we would not be able to provide its unique identification if it had not been for the method of reconstruction of flake length.

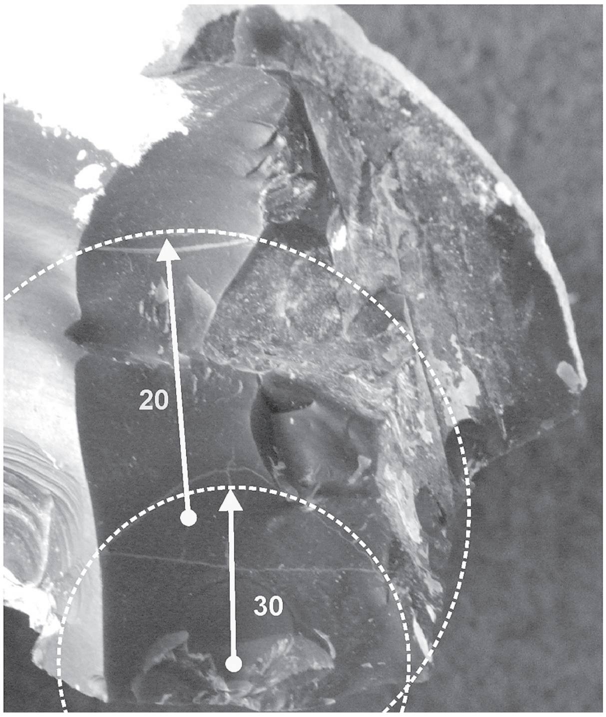
DISCUSSION

The main issue relating to the reconstruction of the lengths of blanks that have been knapped off is the accuracy of the method, and hence its utility for the practise. The statistical assessment of the values acquired from experimental items indicates that the best results (the smallest deviations of measuring) have been achieved using arc-template despite the fact that the arcs are printed on the template in 1 cm interval, which theoretically enables the selection of half values as well. A finer grid on the template would obscure the waves on the scar and make their comparison with arcs on the template more difficult. The statistical assessment of the file of measured deviations (the real length – the length defined by the template) indicates the statistic relevance of the method for the determination of lengths. Its other advantage is the possibility of comparing the grid on the template with more lines of force (waves), and this makes the work much easier. Simultaneously we can determine the length of the entire flake scar and refine the measuring on one millimetre, provided we mark out a more accurate division. In addition to that the work with the template is much quicker than the lengthy process of measuring and calculating the data, although the calculation can be suitably automatised using some of the web applications (Sunga 2014) or the modification of an Excel file into which the data can be entered using a digital measuring instrument.

On the other hand the tabulated experimental measurements (*Table 1*) reveal a significant deviation of some of the taken measures from the real values – these are beyond acceptability. From the viewpoint of the



a



b

FIGURE 8. Examples of irregularities than can affect the measurements. a – a small scar process indicates very thin flake and waves have shorter radius; b – inhomogeneity of the raw material affects spreading of energy within the material and can cause an unexpected radius of waves.

practical application of this method of reconstruction it is certainly essential that some measures differ from the real values by more than 3 cm and 4 cm using the template and the method of calculation respectively, and most frequently the established values are lower than the real ones (*Figure 4*). Therefore we have to ask the question whether it is possible to make an estimate of the relevance (precision) of measuring according to some attribute in advance. Judging by the experimentally assessed items it seems that the morphology of the flake scar and the routes of the lines of force have to be considered before the measures are taken. The best results have been obtained by measuring of the lines of force roughly in the centre of the flake scar or in its distal part as the case may be, provided we had to do with a more or less regular fan-shaped or oval flake. We were confronted with some problems in the instances of narrower, very thin tongues projecting from the main mass of the blanks towards the edges. In such cases the lines of force clearly have a smaller radius as against what we would expect, and if we plot their centre, the point of strike is located in the middle of the processed lump (scar) of raw material (*Figure 8a*).

A similar situation may occur if an inhomogeneity or failure appears within the mass of the raw material, and this exerts an effect on the propagation of force within the material. In such cases the radius of lines of force also happens to be smaller than it should be, and as a result the point of strike appears within the surface of the scar (*Figure 8b*). This observation is supported by another measurement that has been taken on the same scar, albeit before the evident inhomogeneity (frost fraction), and this measuring more or less corresponds to the reality. In all of the above instances we have to bear in mind that the measurements may not be adequately precise; it is therefore necessary to "read" the character of the lines of force first, and to seek the possible deviations from the spreading of force, since this can at least prevent the analysis of extreme cases and make the overall outcome of the reconstruction more accurate.

The described method also has its technical limits. First of all, so far it has been tested only on flake scars, which were formed using a hard mineral hammer. That is to say only in such cases the points of strike are so small that they can be considered centres of the concentric waves that propagate through the material during transmission of force. When soft hammers (both organic and mineral) are used, the force is transferred to the processed item through a much larger area; hence the radius of the waves on the flake scar is bigger than the real distance between the crest of the arc of a circular segment and the point (area) of strike. In future the propagation of the force in other specific cased, that result to bended flakes, should be tested.

Another problem is an adequate readability of the waves that define the circular segment. In coarser materials (cherts, quartzites) these waves are not so clearly visible because of the physical properties of the materials or the taphonomy of the surface. This causes an increase in the measuring error, especially when applying the method of reconstruction using calculation since during measuring of the height of arc even errors in the range of tenths of millimetre exert a significant influence on the result. Application of the template is more precise as we can level the template with some more conspicuous wave in the material, or check the correlation against other arcs on the template with more waves on the scar.

In the reconstruction of the core volume the success rate (i.e. how many sequences we are able to retrace) is in a direct proportion to the number of scars preserved on the core. This method seems to be applicable to good effect e.g. on cores of the discoid type, since these have been knapped using a hard hammer throughout their volume; thus the quantity of the preserved scars after the detachment of the target blanks tends to be relatively high. On the other hand the detached flakes reach even to the half of the exploitation surface, and the older traces of exploitation of blanks quickly become wiped off. In the experimentally formed core we managed to reconstruct two sequences knapped off prior to the third and last sequence represented by whole scars with preserved striking points.

CONCLUSION

The described method of reconstruction of the blank length from the remnants of scars by means of measuring a selected segment on a certain line of force has proven to be of adequate precision for the technological analysis of stone industry. Its application (mainly the variant using a template) substantially enhances our options during the analysis of chipped stone industry (this especially regards cores). In the description of cores or the reconstruction of the technological processes of reduction we can reveal more sequences, thereby acquiring a much more dynamic source of information that captures a longer period of the "life" of the artefacts. To a certain degree the projection of the directions of percussion and the length of flake can substitute for the absence of refittings.

Using this method we can acquire a greater quantity of metric data, and we can employ these in the comparison of the sizes of cores and those of the preserved blanks. This comparison is extremely important for the evaluation of the degree of core reduction at the site, or for establishing of the distribution strategies, i.e. in what form and size had the lithic raw material been brought to the site. Only a limited quantity of complete flake scars tends to be preserved on the cores. If we are able to ascertain the dimensions of flakes through which the core had been reduced in the preceding sequences, the outcomes of the comparisons of the dimension of cores and debitage can be much more precise.

The described method for reconstruction of the lengths of blanks can also serve as a powerful supporting tool for the assessment of refittings of stone industry, especially refittings of cores and flakes. Applying this method we can not only achieve a greater precision in establishing the original shape of the raw material in some instances but also reveal some technological processes that cannot be identified from the preserved objects.

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