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Michał Jakubczak[1], Janusz Budziszewski[2], Michał Leloch[3], Natalia Gryczewska[4], Marcin Szeliga[5], Małgorzata Kot[6]

MINING FIELD „DĄBRÓWKA-I". NEOLITHIC JURASSIC FLINT MINE WITH VESTIGIALLY PRESERVED MINE RELIEF

ABSTRACT

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Neolithic flint mines are well-studied in the Kraków-Częstochowa Upland. However their spatial structure and diachronic history is still poorly understood especially due to the poor preservation of the mine relief on the surface. The paper presents results of ALS data analyses conducted on the Dąbrówka-I site which is the first Prehistoric flint mine in the region that has been studied recently on the basis of the surface relief. LiDAR analyses combined with technological analyses of collected cores gave us grounds to identify two phases of flint mining at the site dated to Lengyel-Polgar cycle and Late Bronze Age-Early Iron Age. The obtained results show the extent to which a multiproxy non-destructive approach may give ground for in depth studies of flint mines.

Keywords: Prehistoric flint mining, Kraków-Częstochowa Upland, LiDAR data analysis, knapping technology, Lengyel-Polgar cycle

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1 Institute of Archeology and Ethnology of the Polish Academy of Sciences, Solidarności avenue 105, 00-140 Warsaw, Poland; michal.jakubczak87@gmail.com; ORCID: 0000-0002-1655-7124
2 University of Cardinal Stefan Wyszyński in Warsaw, Institute of Archaeology, Wóyciciego 1/3, 01-938 Warsaw, Poland; budziszewski.janusz@gmail.com; ORCID: 0000-0002-6521-9973
3 University of Warsaw, Faculty of Archaeology, Krakowskie Przedmieście 26/28, 00-927 Warszawa, Poland; m.leloch2@uw.edu.pl; ORCID: 0000-0003-4916-7840
4 University of Warsaw, Faculty of Archaeology, Krakowskie Przedmieście 26/28, 00-927 Warszawa, Poland; n.gryczewska@uw.edu.pl; ORCID: 0000-0003-2299-8943
5 Maria Curie-Skłodowska University in Lublin, Institute of Archaeology, Pl. M. Curie-Skłodowskiej 4, 20-031 Lublin, Poland; marcin.szeliga@mail.umcs.pl; ORCID: 0000-0002-5185-073X
6 University of Warsaw, Faculty of Archaeology, Krakowskie Przedmieście 26/28, 00-927 Warszawa, Poland; m.kot@uw.edu.pl; ORCID: 0000-0001-5277-0283

INTRODUCTION

The southern part of the Kraków-Czestochowa Upland is widely recognised for the presence of prehistoric flint mines. Due to the long-lasting archaeological research in this area, a major phase of flint mining in the region can be connected with the Lengyel-Polgar cycle, *e.g.* on such sites as Sąspów or Bębło (Dzieduszycka-Machnikowa and Lech 1976; Lech 1980c, 1980d). Thanks to the increasing availability and significant reduction in the cost of airborne laser scanning (LiDAR), extensive prospecting of forested areas has become possible, including reanalysis of flint mines already excavated or surveyed (Budziszewski and Wysocki 2012; Czebreszuk *et al.* 2013; Budziszewski and Grabowski 2014; Jakubczak and Szubski 2015; Banaszek 2015; Budziszewski *et al.* 2019). The results show that the Neolithic flint mines in the region, even those where there already is a lot of information from archaeological investigations, are not preserved in the landscape. One of the very few exceptions is the Dąbrówka-I flint mine which was found and preliminarily studied by Jacek Lech (1980a).

The scope of the paper is to study the structure of the Dąbrówka-I flint mine, based on the LiDAR visualisation and the chronology of the site based on technological analyses of collected cores.

Dąbrówka I

The headland that rises above the Prądnik River valley at the level of Dąbrówka hamlet is entirely covered with forest (Fig. 1: C). This is probably how it looked throughout most of its history. It is similar to today's appearance on the Habsburg topographic map made in 1801-1804 by Colonel Anton Mayer von Heldensfeld (Fig. 1: A). According to Jacek Lech, attempts were made to farm here for several decades between 1864 and 1915 (Lech 1980a, 613; 1981, 51). However, the scale of this activity was probably not very large, as it is not included in any of the several Austrian and Russian 19th-century mappings at a scale of 1:100000. Only the New Topographic Map of Western Russia at a scale of 1:84000, published in 1914, attests to the deforestation of the northern part of the headland (Fig. 1: B).

This area is built up by Upper Jurassic limestones with flints. They are covered by Paleogene red and brown clay loams formed during karst weathering of the limestone. In many places, these clays contain rich concentrations of drusy flint nodules – so-called "krzemieńce" (Lech 1980b, 200-202, fig. 2a-b; 1981, fig. 4). They were usually exploited by prehistoric miners. They are covered by quaternary loess layers of various thicknesses.

The "Dąbrówka I" mining field was discovered in the spring of 1973 by Jacek Lech and the forester J. Glanowski (Lech 1980a, 613). The site was visible in the field in the form of heaps of flint consisting of more massive flint materials collected from ploughed land

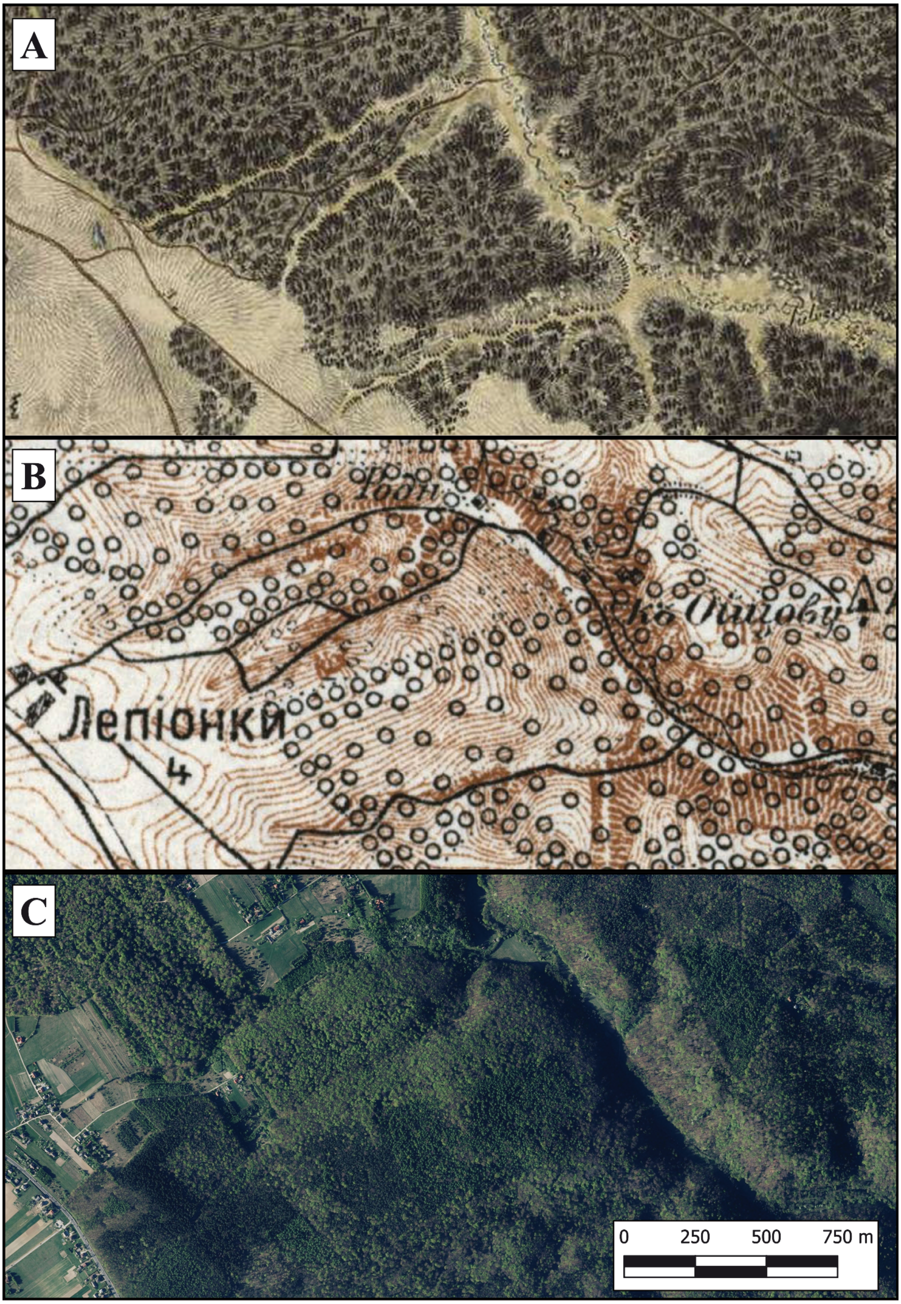

Fig. 1. A – Map prepared in 1801-1804 under the direction of Colonel Anton Mayer von Heldensfeld; B – New Topographic Map of Western Russia from 1914; C – Current aerial photography, after geoportal.gov.pl

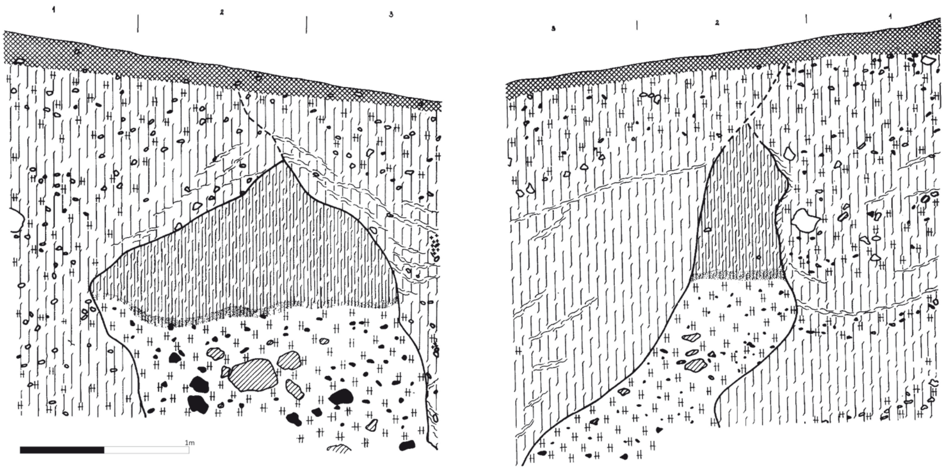

Fig. 2. Two opposing cross-sections of the 1974 test pits by J. Lech at the Dąbrówka-I site, showing the outlines of two shafts (Lech 1980a, Fig. 628)

during the agricultural use of the land and deposited on baulks between the fields (Lech 1981, 78). These allowed for the obtaining of a rich collection of blade cores (Lech 1980a, fig. 627, 1-4, fig. 629, 1, 3-4) and stone hammers (Lech 1980a, fig. 629, 2). These materials were technologically homogeneous and have analogies in the inventories from the mining fields at Sąspów and Bębło. This allowed them to be associated with the Lengyel-Polgar cycle (Lech 1980a, 615; 1981, 78). However, the forest overgrowing the site made it impossible to determine its size (Lech 1981, 51).

In autumn 1974, Jacek Lech together with Andrzej Leligdowicz and Zdzisław Skrok opened a 1 × 3 m test pit at the site (Lech *et al.* 1975). Unfortunately, the pit could not be fully explored. It was excavated to a depth of 2.3/2.4 m. The pit revealed fillings of two stratigraphically-related exploitation shafts (Fig. 2). Their fillings consisted of weathered clay with flints and loess. Relatively numerous nodules of limestone in one of the shafts and a discovery of a flint pick in the backfill (Lech 1980a, fig. 627, 5) suggest that the exploitation may have reached the top of the Jurassic limestone (Lech *et al.* 1975; 1980a, 613, 615; 1981, 76, 77).

The material from the research conducted at the site have never been fully published. However, it was mentioned in several studies of various types (*e.g.*, Lech *et al.* 1984, 233). At the beginning of the 1990s, the site was included in the Polish Archaeological Record (in Polish: AZP) system. It was then given the number AZP 99-55/107. It turned out that the site is currently located in Sąspów village and was described as the 21st site in this locality.

MATERIAL AND METHODS

LiDAR data analysis

LiDAR (Light Detection and Ranging) is a system of several interconnected devices-starting with an emitter that generates a laser beam, a system that distributes it over the scanned surface and a detector that records reflection of the laser beam, linked to a precise GPS system that determines the position of the scanner. Knowing the position of the plane, the speed of wave propagation and the angle at which the laser beam was sent, the algorithm is able to calculate with high accuracy points where subsequent reflections occurred and record them in a spatial coordinate system. This allows a cloud of all points recorded by the scanner to be obtained (Kurczyński 2014, 59, 60). The next step is point cloud classification, which is one of the most crucial elements of data processing. The data are divided into a number of classes, the most important for archeology is class 2 – points lying on the ground. Classification errors may lead to deterioration in quality of the digital terrain model (DTM) or even generation of false objects (Kiarszys and Szalast 2014).

For this study, data were obtained from the ISOK (IT System for the Country's Protection Against Extreme Hazards) project. This program initially assumed carrying out aerial scanning of the valleys of the main Polish rivers, but during the duration of the project, the area was increased and currently covers the whole country. Data for the analysed region were acquired in standard I, which provides a cloud density of at least 4 pts/sqm (Kurczyński and Bakuła 2013). The obtained point cloud was reclassified using the Axelsson algorithm in LAStools software. Proper execution of this operation allowed for a significant increase in the number of points classified as lying on the ground.

For further analysis, a digital terrain model of TIN (Triangulated Irregular Network) type was prepared. This is a vector model where the terrain surface is represented by a grid of triangles, with each vertex having an assigned attribute (Szypuła 2010, 116). The great advantage of this type of model is its high accuracy in representing complex terrain relief. It also gives the possibility to identify places where the quality of the model decreases.

Visualization of data is a crucial step during the processing of the digital terrain model and remote sensing of archaeological sites preserved in terrain relief. The change of the direction from which the model is illuminated allows to see terrain forms invisible at other angles. For example, linear structures that are arranged along the direction of illumination will be much less visible than when illuminated from the side (Devereux *et al.* 2005). In recent years, different ways and parameters of visualisation have become one of the most important issues in methodological discussion of the use of LiDAR in archaeology (Devereux *et al.* 2008), and the number of visualisations continues to grow (Yokoyama *et al.* 2002; Humme *et al.* 2006; Hesse 2010; Challis *et al.* 2011; Kokalj *et al.* 2011). It should be noted that each visualisation provides various capabilities and is suitable for remote sensing and analysis of different types of sites. For example, PCA (Principal Component

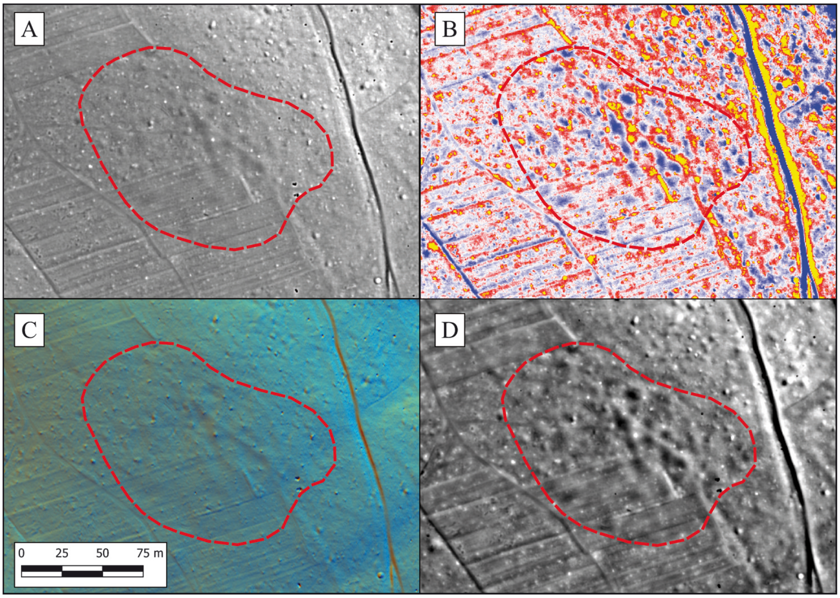

Fig. 3. DTM visualizations of the mining field; A – MSII (radius: 1-2, number of scales: 8, histogram: 1.3-1.6); B – CC_LRM (radius: 10, histogram: -0.2 – 0.15); C – Multi-Hillshading (illumination from 16 directions, h: 20); D – LD (radius: 5-10, observer height: 1.7; histogram: 0.85-1.2)

Analysis) performs better in analysing ridge and furrow than celtic fields (Kokalj and Hesse 2017,35). Visualisations and their parameters should be appropriate for the type of analysed site and local terrain relief (Kokalj and Hesse 2017, 34, 35). It is also possible to merge visualisations, the combinations of which often produce interesting results, especially for more complex or very poorly preserved features. Hillshading of the DTM, slope analysis, principal component analysis, local relief model, sky-view factor, openness, local dominance, accessibility, cumulative visibility, and multi-scale integral invariants should be considered basic visualisations.

Airborne laser scanning has already demonstrated its usefulness in remote sensing of mining fields (Budziszewski *et al.* 2018, 2019; Sudoł-Procyk *et al.* 2018) and in their analysis (Jakubczak 2012; Radziszewska 2015; Szubski 2016).

The Dąbrówka-I mining field is an excellent example of resuming the research of a site using modern methods. Thanks to the use of airborne laser scanning, it was possible to observe the remains of the preserved relief of mining field (Fig. 3). However, it is worth noting that it is very subtle. The following visualisations were prepared for detailed analysis: local relief model, multi-scale integral invariants, trend removal and local dominance. The latter is usually not applied in areas with significant slopes, but in this case, its application became most reasonable after some modifications. The best results were obtained using the local relief model with radius set to 10 meters and local dominance, where radius was also 10 meters, and observer height was 16 meters, the histogram was stretched between 0.85 and 1.2.

The analysis of the mining field surface also showed the dangers of over-interpretation of the data. After preparing the DTM and visualising it, the field surface showed lines running almost along the east-west axis, deceptively resembling ploughing traces. However, after closer analysis of the data, it seems that these should be interpreted as being due to a slight shift in the alignment of flight rows. This topic has been discussed more than once in the literature (Crutchley and Crow 2009, 27; Doneus and Briese 2011, 64; Banaszek 2015, 117). In this case, it is an issue that remains not without influence on the interpretation of the whole site because ploughing on the mining field significantly changes its relief.

Stone assemblage analyses

A significant amount of flint artefacts can be found on the surface of the site, in addition to the delicately delineated pit relief. The material is scattered throughout the site, but it is found in larger concentrations in some places. The material uncovered is mainly debitage from the processing of flint nodules. In order to analyse the chronology of the site and verify its contemporaneous character, it was decided to collect 16 core forms found scattered on the surface of the site.

Cores were subjected to morphometric and scar pattern analyses. In the former case, a set of 16 basic metric and descriptive features were analysed. Scar pattern analysis, on the other hand, was directed primarily at determining the interrelationship of the chronology of the individual negative reflections visible on the core in order to reconstruct a fragment, visible on the tool surface, of the chain of operations (Pastoors and Schäfer 1999; Pastoors *et al.* 2015; Richter 1997; 2001). Seven core forms bearing traces of primary knapping and initial orientation of the nodule in the direction of core formation were included in this analysis. Comparison of the results of the two analyses makes it possible to determine a reproducible pattern of processing of the core forms and to observe, each time, certain aberrations resulting from the specific nature of the raw material.

RESULTS

LiDAR data analysis

Based on LiDAR data, the size of the Dąbrówka-I mining field can be estimated to be about 1.30 ha. The minefield area is located on the valley border and the slope descending towards the Sąspów valley (Fig. 4). The relief of the mining field area is diversified, and it can be divided into three parts (Fig. 5).

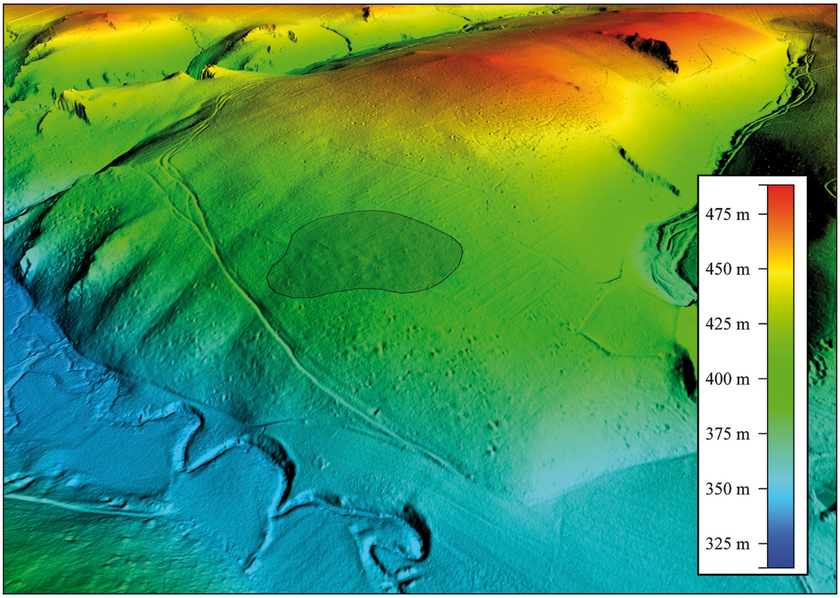

Fig. 4. 3D model with the site area marked, based on the digital terrain model. View from the north-eastern side

Part A is probably the original surface of the mine field associated with its use in the Neolithic period. It is covered by a scatter of irregularly shaped hollows, and it is impossible to indicate the remnants of mining objects or shaft heaps. Most likely, this type of relief covered the entire mine area. Part B covers an area of about 0.18 ha and is located in the central part of the minefield. The remains of mining hollows can be discerned using the local dominance visualisation. At least eleven shafts can be seen. They have spoil heaps, usually on the northeast side in line with the slope. This type of quarry-like mining has its analogues in the striped flint mining field "Skałecznica Duża" (Jakubczak 2012, 32), Mników (Budziszewski *et al.* 2019) and at the Rybniki-"Krzemianka" site (Zalewski 2000, 262). However, in the case of Dąbrówka I, the relief of the site is much more subtle. The depressions have a diameter of up to 7 m and a depth of up to 20 cm, so they are hardly visible in terrain. It is most likely that this part is related to the younger exploitation of the mining field and levels the remains of a Neolithic mine.

Part C located in the eastern part of the mining field consisting of at least four depressions with no visible spoil heaps. It is difficult to say whether these should be connected with part A or B of the mining field or represent another third episode of its use.

In the southern part, there is an area of about 0.37 ha, which was partly levelled by ploughing (Fig. 6). The shape and layout of the field indicate that it is a trace of modern plough cultivation. Baulks separating individual plots are visible, and flint material can be

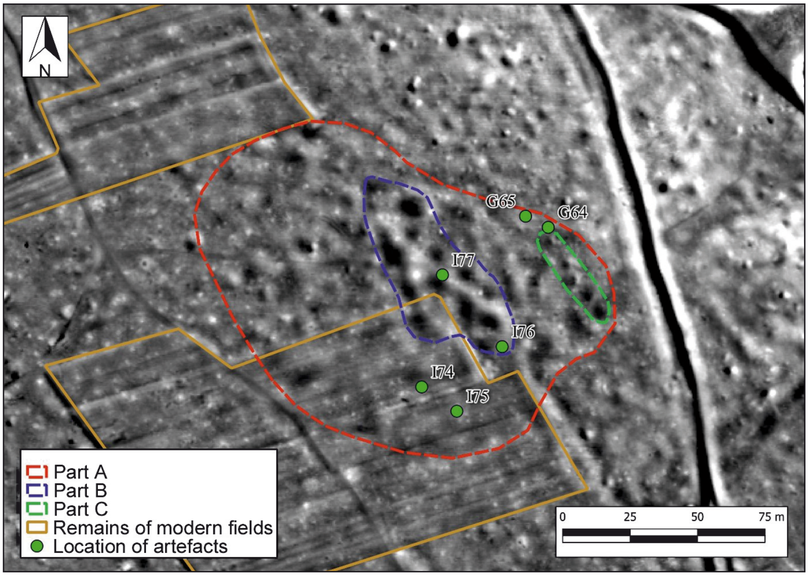

Fig. 5. Interpretation of the pit relief at the site, including the location of the flint cores described in the paper

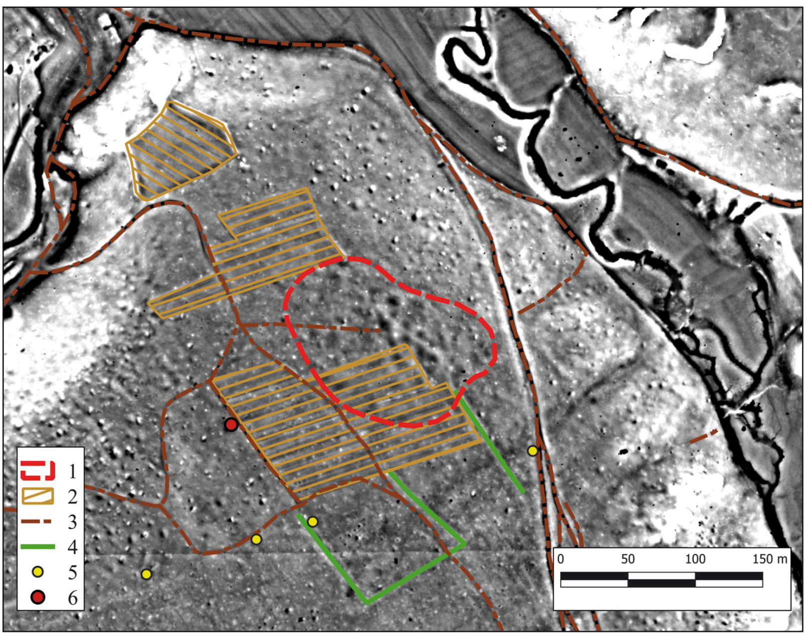

Fig. 6. Interpretation of the landscape in the vicinity of the site.
1 – mining field area; 2 – remains of modern agricultural fields; 3 – traces of roads and road indentations; 4 – remains of old baulks; 5 – boundary mounds; 6 – charcoal pile

seen accumulating on them. During the land use, farmers probably threw the larger forms onto the baulks so that they would not interfere with cultivation. The field division is consistent with the current land records. The age of the forest at this site based on the Forest Data Bank is estimated at a minimum of 70 years, indicating that the episode of cultivation of this area was short. This is supported by the fact that mining relief is still visible at this site.

Flint assemblage

The preliminary analysis of the flint material indicated that the core forms were abandoned at the site at various stages of their reduction. The collected assemblage lack only fully exploited cores. The obtained forms can be divided into three groups.

The first group consists of irregular nodules or chunks of raw material with negatives of single removals, difficult to unambiguously interpret. This group is represented by two specimens not exceeding 13 cm in size. Such may be accidental or connected with testing the raw material.

The second group consists of the pre-cores, represented by seven specimens (Fig. 7). They have partially or fully formed ridges, usually on the narrower side. Three of them are almost entirely covered with cortex. The others are either partially cortical, covered partly with natural, patinated surfaces or completely decorticated. They show a high degree of variation in their size and weight, ranging from 7.6 to 15.5 cm in length, 4.5 to 12.7 cm in width, and 6.9 to 11.7 cm in thickness, with weights ranging from 351.8 to 2031.7 g. It seems that the primary reason for abandoning most of them was internal cracks (*e.g.* Fig. 7, G69), or the impossibility of forming/correcting the core angle, making it impossible to remove blades. Only a single preform (Fig. 7, I76c) with a bilateral ridge forming the apical part and the knapping surface, located within the narrower side of the nodule (Fig. 7), deviates from this. It has a striking platform formed by a single removal, inclined to the flaking surface at an acute angle. The core was abandoned for an unspecifiable reason.

The last group consists of cores abandoned at an initial or advanced stage of the exploitation, also represented by a total of seven specimens (Figs. 8-14). They manifest varying sizes, including heights ranging from 6 to 13 cm, widths ranging from 7 to 10 cm, thicknesses ranging from 6 to 10.6 cm, and weights oscillating from 261.7 g to 1039.8 g. The vast majority of the cores have circular striking platforms (five specimens) located on the narrower sides of the nodule (four specimens). All cores in their initial form were single-platform forms, and in the case of three of them, there were also remnants of a change in orientation (Fig. 8). The remains of primary flaking can be seen on the analysed forms, analogous to those observed within the pre-cores. Apart from remnants of crest formation or ridges in the apical parts, most of the collected specimens also show clear traces of core preparation on their back, including the formation of single- or double-sided ridges covering part or even all of their length (Figs 9, 10). Only one of the analysed specimens has the back of the core left unprepared (Fig. 11).

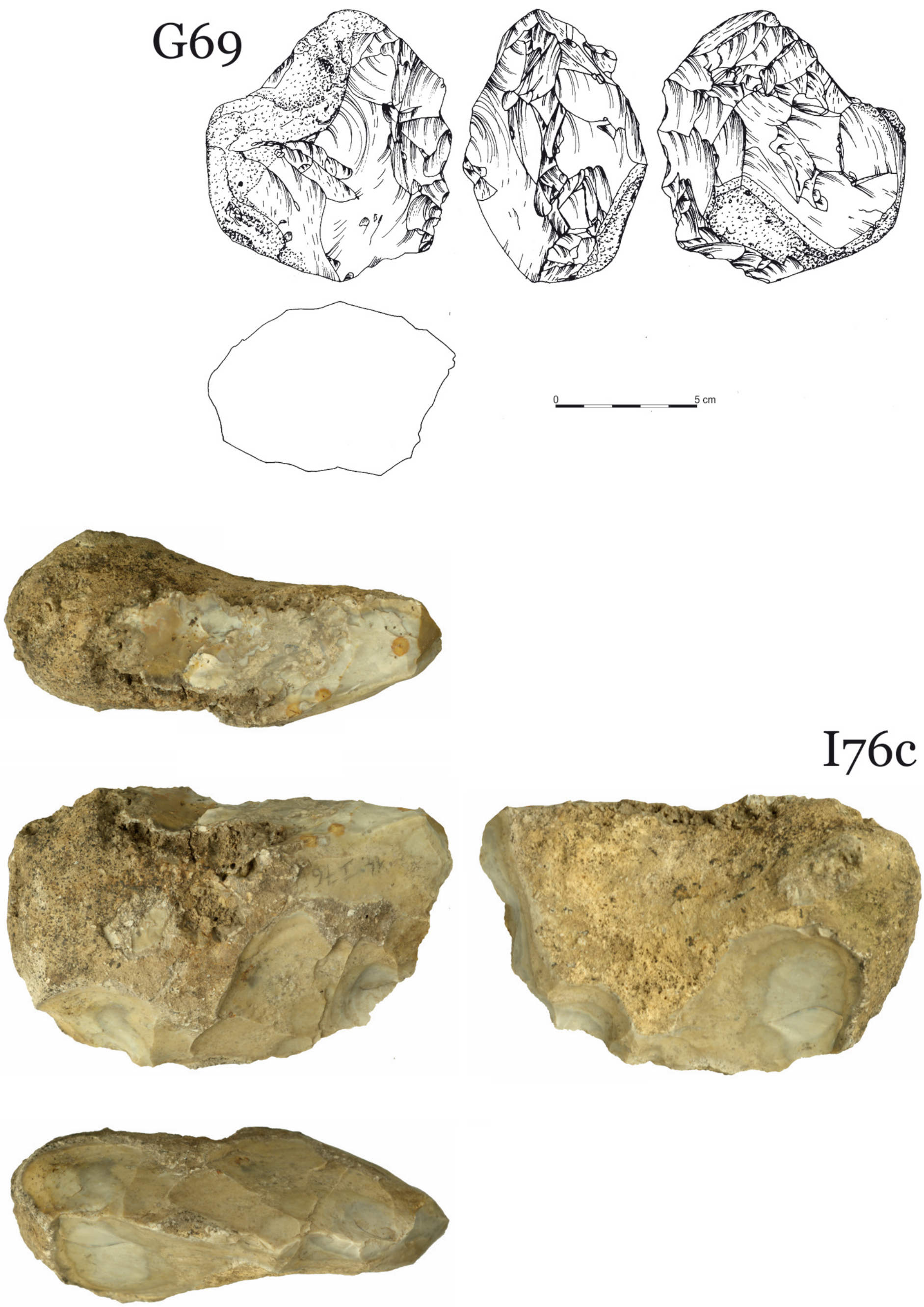

Fig. 7. Initial cores found on the surface
(drawn by Ewa Jurzysta; photo: Natalia Gryczewska)

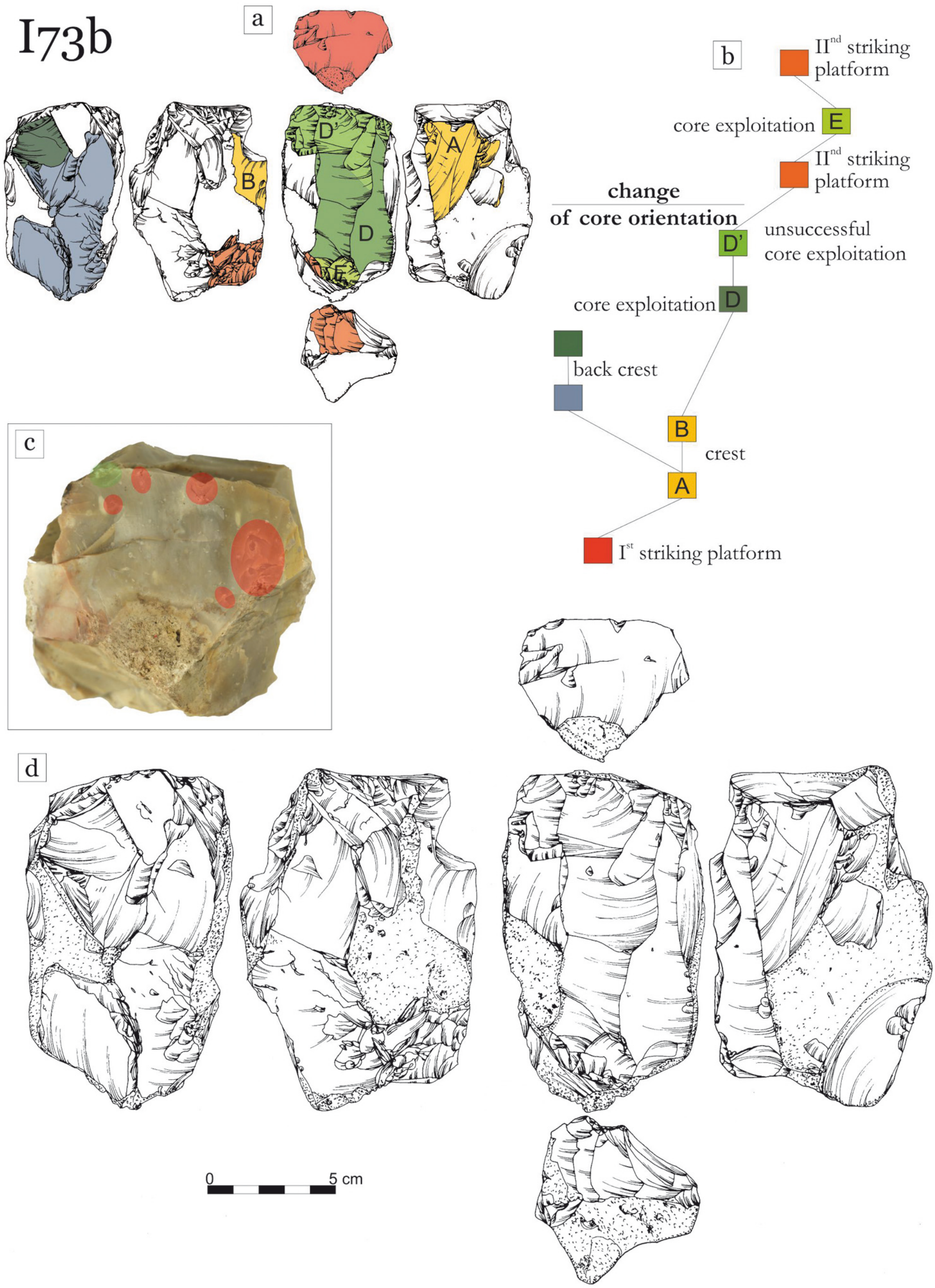

Fig. 8. Scar pattern analysis of the core.
A – visualisation of the analysis results; B – graph showing mutual chronological relations of particular knapping sequences; C – drawing of the artefact (drawn by Ewa Jurzysta, Małgorzata Kot)

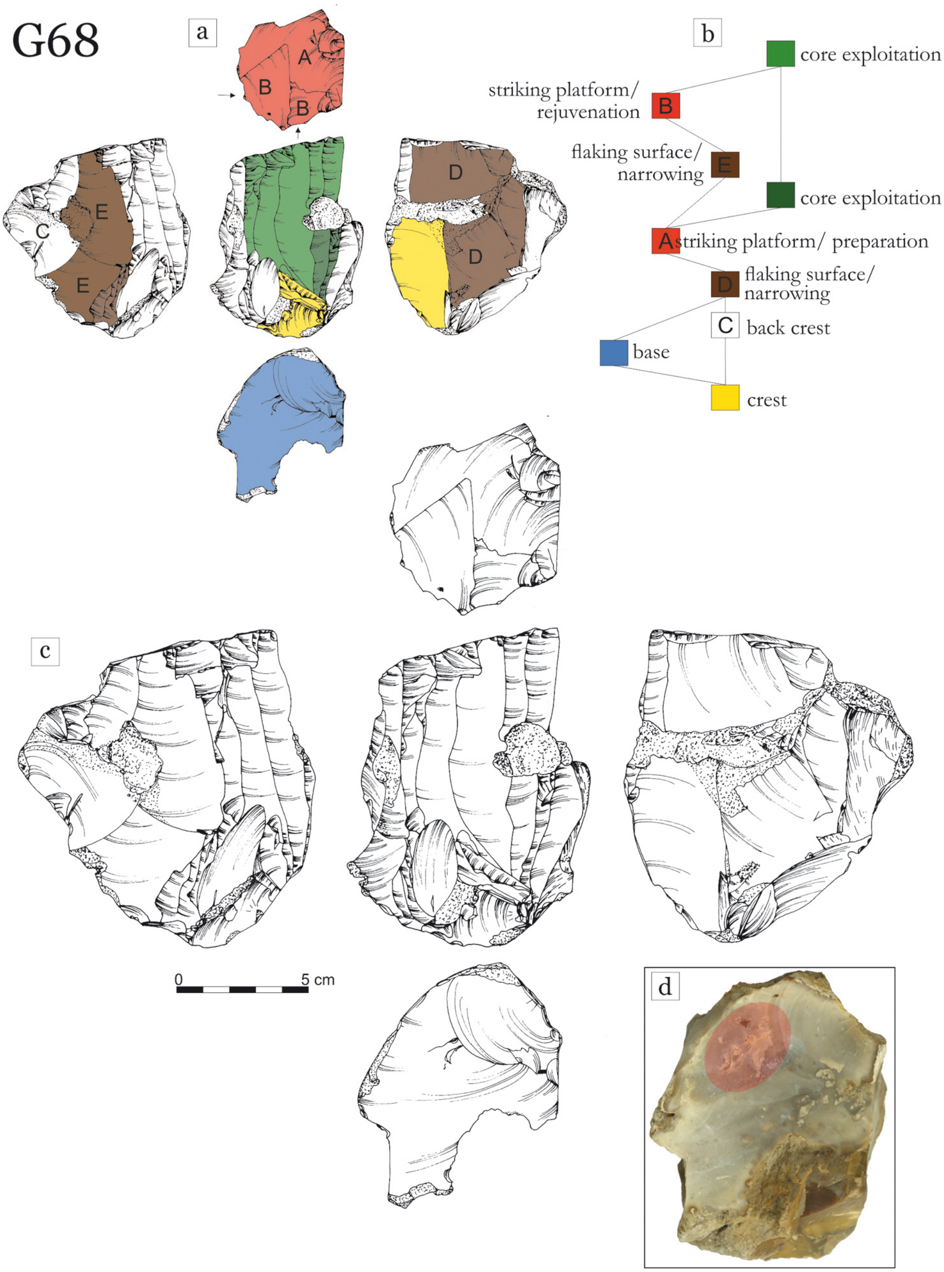

Fig. 9. Scar pattern analysis of the core.
A – visualisation of the analysis results; B – graph showing mutual chronological relationships of particular knapping sequences; C – drawing of the artefact; D – crushes visible on the base of the core (drawn by: Ewa Jurzysta, Małgorzata Kot; photo: Natalia Gryczewska)

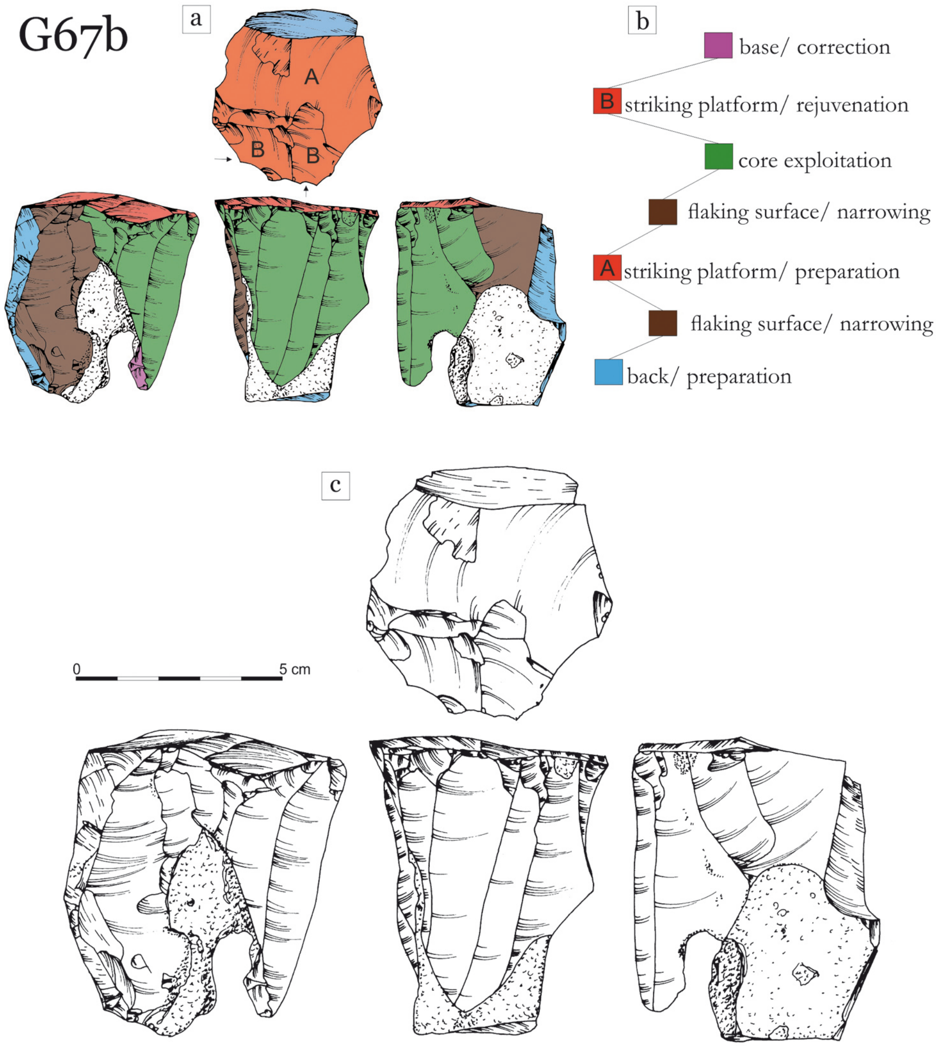

Fig. 10. Scar pattern analysis of the core.
A – visualisation of the analysis results; B – graph showing mutual chronological relationships of particular knapping sequences; C – drawing of the artefact (drawn by Ewa Jurzysta)

The values of core angles of the discussed cores show a small range of variation, oscillating each time around a right angle (80-90°). The planes of the initial striking platforms were formed by a single removal from one of the sides (Figs 9, 10). Throughout the core exploitation, they were successively rejuvenated with finer removals from the side of the flaking surfaces or sides of the cores allowing correction of the core angle (Figs 9, 10). In addition, the surface of one specimen (Fig. 12) retained traces of a secondary crest formed to cap the flaking surface and extend the blade exploitation to the left side of the core (Fig. 11). The analysis of the length of the blade negatives preserved within the flaking surfaces of individual cores indicates that blades 6.5-10 cm long and 2.0-3.3 cm wide were obtained in the last phase of their exploitation.

The flint raw material exploited at the site occurs in various-sized nodules with spherical shapes, covered by a thin (2-4 mm) cortex with a rough texture. The individual concretions have a lot of internal cavities and irregularities, which could have been exploited by their users during the processing (Fig. 10), but more often were a significant impediment to the full and effective exploitation of the cores (Fig. 9). The raw material is highly fractured internally, which appears to have been the main reason for the widespread abandonment of cores during exploitation. Of the collected specimens, only one core (Fig. 10) showed no signs of internal cracking and was abandoned due to its high degree of exploitation. Reduction of all other cores was abandoned due to an error occurring at some stage of exploitation, resulting from internal cracking of the nodule.

The average height of the analysed cores is 10 cm, which indicates a specific metric preference in the selection of flint nodules for production. At the same time, pieces up to 7 cm in length could also be found at the site. This confirms the exploitation of forms with a slightly smaller initial size, allowing the production of shorter and narrower blades (Fig. 10). It also corresponds with the length of the prepared flaking surface of the pre-core (Fig. 7).

The analysis of scar patterns has shown that six out of seven analysed cores were exploited according to a similar technological scheme, based on three primary stages of core preparation, preceding the phase of blade exploitation. As far as it can be determined based on this type of analysis, these stages followed a specific order, from which, however, some deviations occurred. The first stage was forming the sharp edge of a double-sided ridge, covering the initial flaking surface and the top and/or back of the designed core. This ridge was used as a crest for further processing. With one exception (Fig. 7, I76c), it was made within the longest edge of the nodule. The next stage was to form the initial striking platform by removal of one or a series of large flakes at one end of the oblong nodule. The striking platforms of the cores analysed are inclined at approximately right angles to the striking surfaces. The only exception is core I76a (Fig. 14), which will be characterised separately later.

After the preparation of the striking platform, and before the further blade exploitation, the third stage of core preparation was executed; namely, the flaking surface narrowing by series of blades/flakes removed from both sides of the preform, either transverse or longitudinal to the axis of the future core. This aimed to regulate the sides of the cores and reduce the width of the future flaking surfaces by removing the cortex and the natural unevenness of the nodule. Only after such preparation of the sides of the flaking surfaces, the main exploitation of the cores and obtaining blades was commenced. The traces of striking platform rejuvenation in the place of the planned removal of the next blade, by correcting the angle of coring using small flakes, were preserved on three forms (Figs 8-10).

They indicate that the platform edge was prepared each time in the place selected for the future strike, not its whole length. The edges do not bear traces of intensive abrasion. There are also no traces of reduction in the area of the striking platform lines. In general, a tendency toward sequential action is evident with blade exploitation. Major core repair was undertaken only after several blades had been removed, and core angle correction became necessary. Repair of cores was the same as their initial preparation, but the stage of crest forming was usually omitted. First, the repair procedures were undertaken in the striking platform areas, involving the removal of several tiny flakes derived from the side of the flaking surfaces and especially the sides of the cores (Figs 9, 10). The next step in the repair was to reshape the sides of the core. After these steps, it proceeded to its exploitation again.

The three cores show remnants of a change in their initial orientation, made when it was impossible to continue the blade exploitation and repair a functioning or prepared flaking surface.

An example of a change in orientation is the form of core I73b (Fig. 8), in which internal cracking and the very high hinges formed at the first blade removal prevented further exploitation. The reorientation consisted of using the already prepared crest and creating a striking platform at its opposite end. Unfortunately, here too, internal cracks stopped exploitation already at the stage of narrowing the future flaking platform. This core is also interesting because of an error that occurred during blade exploitation. The removed blade did not wholly separate from the core, but its outline is visible on the surface. A further two hinged removals have partially fallen out from underneath it, further highlighting it on the nodule (Fig. 8). In this case, we can observe the only example of a very thorough preparation of the area for the blade impact. It was connected with a strenuous attempt to separate it from the nodule. The future impact point was isolated on the flaking surface by a series of small flakes on both sides of the blade, but there are no traces of preparation of the striking platform, which remained plan. There are distinct crush marks at the point of failed impact (Fig. 8: c). In addition, there is a series of crushes near the point of force application, presumably created by flaking with a hard hammer to deflect the unchipped blade visible on the flaking surface. The final blow occurred in the centre of the striking platform in the line of the internal crack line visible on the platform surface, which provided a chance for complete removal of the flaking surface and its renewal. The impact left a circular mark on the platform and a grid of radially spreading resulting cracks (Fig. 8: c), testifying to its strength.

An interesting example of an attempt to bypass an internal crack is core I73a (Fig. 11), with a lateral crest. The crest was not removed during blade exploitation due to the internal crack adjacent to it along the entire body. The flaking surface was therefore moved to the side of the core. After it had become too flattened, an attempt was made to radically shorten the core by removing several thick flakes from the striking platform. The core was shortened by about 1/3 of its height, but the cracking along the initial crest remained visible.

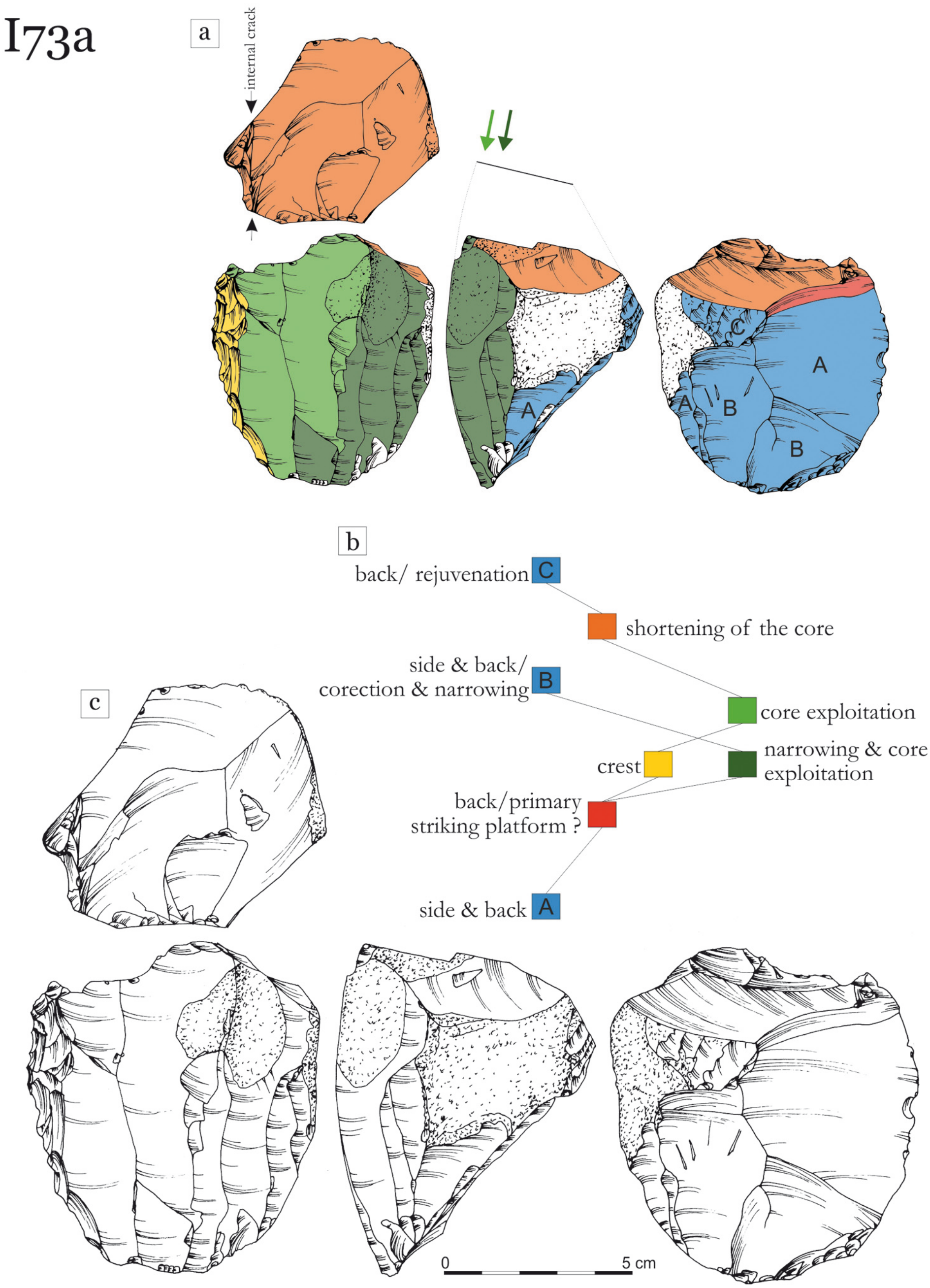

Fig. 11. Scar pattern analysis of the core.
A – visualisation of the analysis results; B – graph showing mutual chronological relations of particular knapping sequences; C – drawing of the artefact (drawn by Ewa Jurzysta)

Fig. 12. Core with changed orientation (photo: Natalia Gryczewska)

The crack caused the series of hinges at the striking platform. At this point, the core was abandoned without attempting to use the newly prepared flaking surface.

The right angle of core reduction, accurate preparation of the striking platform before the individual blades removal, traces of well pronounces bulbs visible at the scars of previous blade removals, and their regular edge delineation indicates the use of the indirect percussion.

Finally, it is worth noting the Hertzian cones visible on the surface of the striking platforms, which are traces of unsuccessful impacts. These Hertzian cones were formed at the last stage of the core's life when the flaking surface required radical rejuvenation. They appeared during the attempt to detach massive blades/flakes with the use of a hard hammer. Unsuccessful rejuvenation ended in reorientation or abandonment of the core. In the case of core G68 (Fig. 9), the crushes are visible on the core base formed by a single removal. The crush marks are located far enough away from the edge that it is difficult to see any evidence of attempts to remove flakes/blades. These marks may be the result of leaning the core against a hard surface. Impacts brought out on the striking platform may have

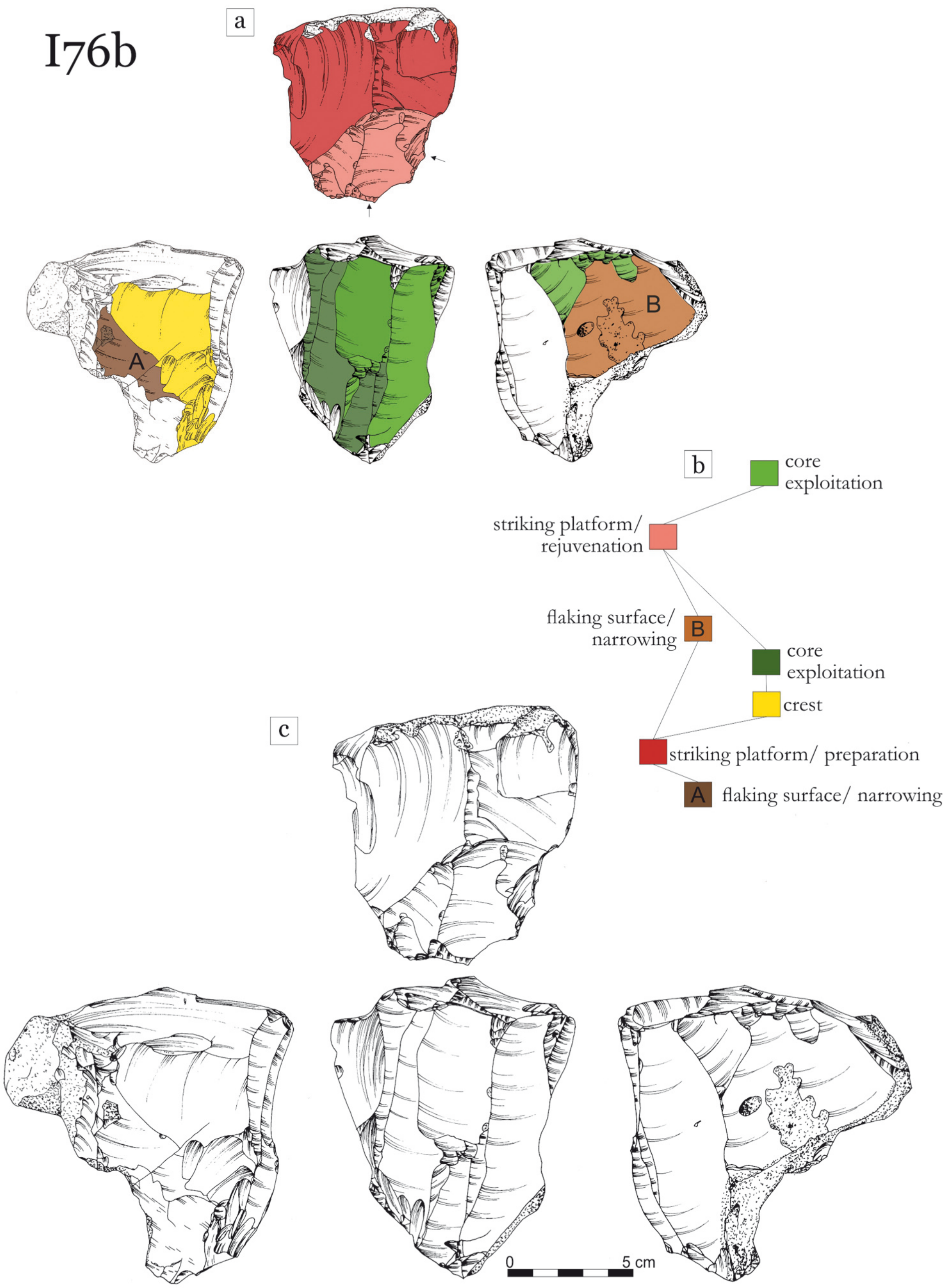

Fig. 13. Scar pattern analysis of the core.
A – visualisation of the analysis results; B – graph showing mutual chronological relationships of particular knapping sequences; C – drawing of the artefact (drawn by Ewa Jurzysta)

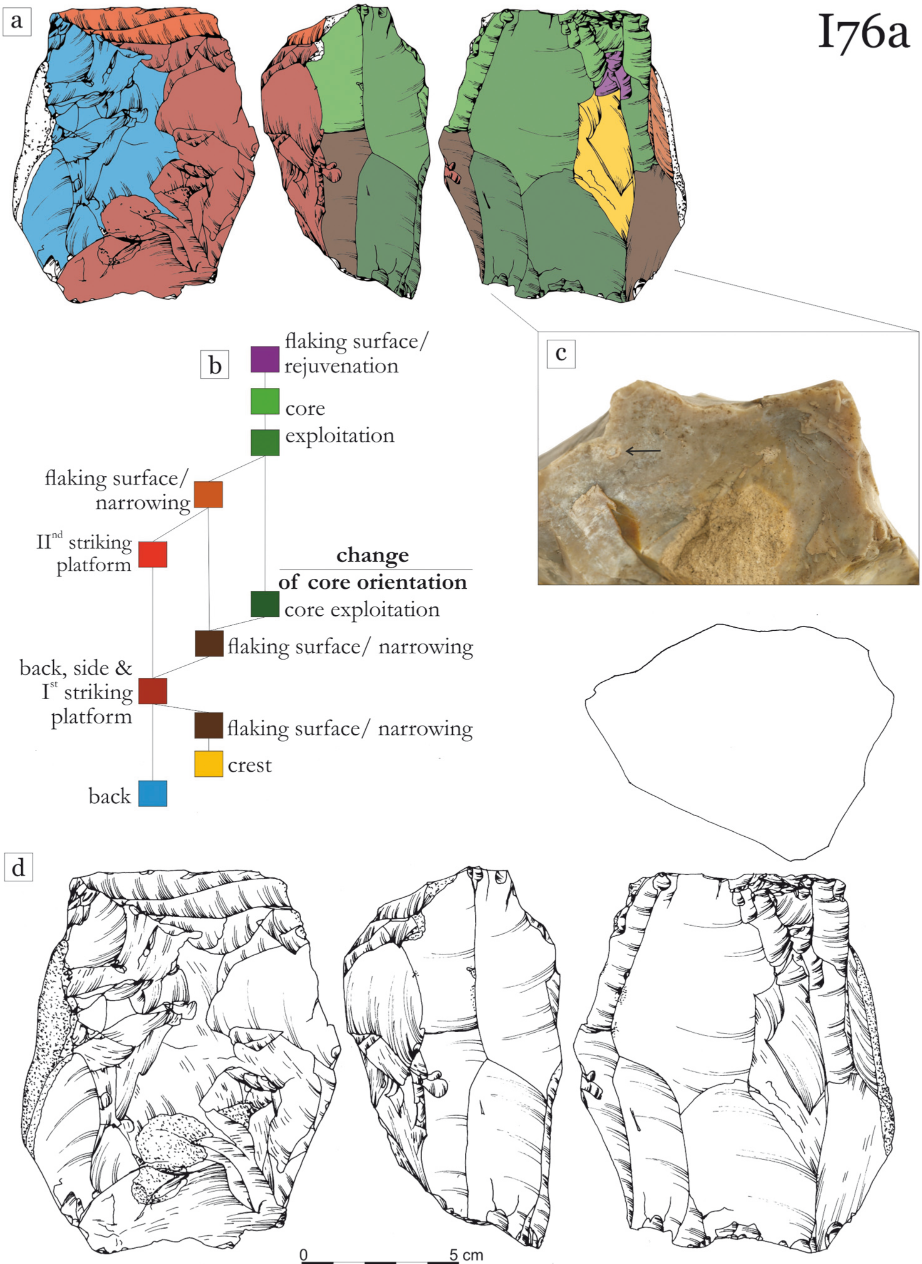

Fig. 14. Scar pattern analysis of the core. A – visualisation of the results of the analysis; B – graph showing mutual chronological relationships of particular knapping sequences; C – drawing of the artefact; D – course of the edge of one of the striking platforms and visible hard hammer impact points (drawn by Ewa Jurzysta, Małgorzata Kot; photo: Natalia Gryczewska)

caused the transfer of force and the formation of crush marks from the underside of the core. However, these conclusions should be verified by traseological analysis. The literature indicates that immobilising the cores using an anvil enables the detachment of straighter blades (Budziszewski and Grużdź 2013, 168).

Only core I76a (Fig. 14) does not fit in the consistent core structure described above. It has two striking platforms. One of them forms a right angle with the flat flaking surface located on the broader side of the nodule. While the other is inclined at an angle of 50°. Such a knapping angle is not found in other cores. In addition, at the initial stage of core reduction, a long crest was prepared at the back of the core. The crest smoothly transitions into removals which form both striking platforms. Such a pattern of striking platform preparation is not similar to the way they are prepared in other cores. After preparing the back of the core along with the striking platforms, the exploitation of the core started with slightly narrowing it and then removing two big flakes from the striking platform of a sharp core angle. Both flakes had prominent butts with an almost triangular shape in the cross-section, which can be observed in the form of deep, triangular notches on the edge of the striking platform.

After these two wide, rectangular flakes, the exploitation was transferred to the second striking platform. One very wide flake was removed at this stage. Then after an attempt to move exploitation to the other side of the flaking surface and after it had narrowed, a series of hinges halted further exploitation of the core.

At this point, it should be emphasised that the flint raw material exploited in the Dąbrówka-I mine was of poor quality and bore numerous internal cracks, which made blade exploitation difficult and prevented the acquisition of a long series of regular blades. We may assume that this was a reason for conducting not only the nodules testing, preform preparation at the site, but also core exploitation and blade production. The small number of blades extracted from each nodule probably made it more economical to transport the finished selected blades from the site than to haul the pre-cores, which could later prove to be suitable for production of only a few blades. It is possible that better quality nodules and pre-cores, without internal cracks, were taken out from the site as a whole, but this can only be confirmed after a detailed debitage analysis.

DISCUSSION

Despite the small series of collected and analysed preforms and cores, the obtained results distinguish two independent episodes of exploitation of the Dąbrówka-I flint mine. The quantitatively dominating group are artefacts connected with blade-production characteristic for the Neolithic, represented by 15 specimens in total, including eight pre-cores and seven cores abandoned at different stages of exploitation. These forms constitute a collection standardised in technological and conceptual terms, reflecting uniform preferences in raw material selection and a repetitive scheme of technical solutions applied during the adaptation of their surfaces for blade production. The uniform character of the collection is also supported by very similar morphometry of the obtained blade blanks. It is visible in the negatives of blade scars preserved on cores and similar values of the core angle oscillating in the 80-90° range each time, indicating the use of the indirect percussion technique for blade exploitation. The commonly observed narrowing of the cores by reducing the side of the core and striving for their rectangular shape in the longitudinal section may also indicate the necessity to immobilise the cores during the use of the indirect percussion technique.

The analysed materials also show strong morphometric correspondences with blade cores recovered at the site during earlier work conducted by Jacek Lech and associated with the "Lengyel-Polgar complex" (Lech 1980a, figs 627, 629). Of particular note is the analogous orientation of cores by locating the flaking surface on the narrow side of the nodule (Lech 1980a, fig. 627, 4 and fig. 629, 3) or narrowing the flaking surface (Lech 1980a, fig. 627, 3 and fig. 629, 4). The near-right angle of coring is also analogous, as are the rejuvenation removals at the striking platform. One of the cores presented by J. Lech (1980a, fig. 629, 1) furthermore bears traces of reorientation, analogous to the forms described above (Fig. 12). These concordances indicate at least the partial chronological contemporaneity and cultural homogeneity of the majority of artefacts collected to date from the surface of the Dąbrówka-I mining field.

The cited technological and metric properties of the presented pre-cores and cores fit very clearly into the pattern of blade production of younger, post-linear Danubian communities developing during the 5th millennium BC. At the same time, they find numerous and very close analogues among such dated assemblage recovered from the nearby, well-studied mines of the Jurassic-Cracow flint in Bębło (Lech 1980d) and Sąspów (Dzieduszycka-Machnikowa and Lech 1976; Lech 1980c, 619). Particularly numerous and apparent similarities to the forms from "Dąbrówka-I" can be seen in the case of the richest and best-studied inventory from the flint mine in Sąspów. They manifest themselves very clearly at the level of formal and metric criteria of selecting flint nodules used for further core reduction. Analogies can also be seen in the orientation of exploitation itself and the location within them of the basic core surfaces, *i.e.* the striking platform and flaking surface, and the closely related scope of adaptation of natural surfaces for the further blade exploitation. It is confirmed by analogous preparation of narrow-flaking surface cores with the use of a crest (Dzieduszycka-Machnikowa and Lech 1976, 117). Clear analogies are also visible during blade exploitation itself, initiated at the flaking surface located on the narrower side of the nodule and sometimes – with the progress of exploitation – undergoing an extension to one of the sides of the core, leading to its flattening (I73a; see Fig. 11). This knapping scheme was commonly used in Sąspów (Dzieduszycka-Machnikowa and J. Lech 1976, 118). Along with other techno-morphometric similarities, it may argue for a similar chronological and cultural position of the presented materials from the Dąbrówka-I flint mine.

The features mentioned above justify the identification of the most intensive phase of exploitation of the Dąbrówka-I mining field with the post-linear groups, including most probably the Pleszów and/or Modlnica groups of the Lengyel-Polgar cycle (Dzieduszycka-Machnikowa and Lech 1976, 151; Lech 1981, 185). The radiocarbon dates obtained for the flint mine in Sąspów (Lech 1980c, 619) do not exclude the possibility of exploitation of the Dąbrówka-I mine also by the communities of the older Lengyel cultural groups or the Malice culture. Intensive penetration of the area by communities of these cultural groups is documented among others by numerous cave sites associated with seasonal stays of human groups (*e.g.*, Kamieńska 1973, 72-74, 100-102; Rook 1980), including intensive processing of local flint (*cf.* Lech 1981, 109-115). High activity of the Malice culture community within the Jurassic-Cracow flint outcrops is also indicated by the rich inventories discovered in recent years at the open-air sites at Modlnica and Targowisko. The narrow- and broad-flaking surface blade cores from these sites, abandoned at various stages of exploitation (Wilczyński 2011, tables I-V, 2014, tables 8-16), show relatively high similarity to some of the cores (Figs. 9-11) and pre-cores (Fig. 7) from "Dąbrówka-I". The mining activity of these communities is also indirectly indicated by the presence of tools in the type of picks (Wilczyński 2014, Pl. 21: 6, 7).

The presence of a second, later phase of mine utilisation is indicated by the presence of core I76c (Fig. 14). Both the morphology of its striking platforms and the morphometric features of the debitage are characteristic for the hard hammer technique. Also, the different structures of the core, the different core angle, the exploitation of two opposite striking platforms, and the location of the flaking surface on the broader side of the nodule, point to its different chronology from other specimens collected from the mine surface. In the materials published by J. Lech, there are no forms analogous to this core.

The mentioned morpho-technical attributes of the discussed core show certain analogies to the so-called "declining knapping traditions", characteristic for the Bronze Age and early Iron Age (Kopacz and Valde-Nowak 1987; Libera 2005). They find morphological analogues among flint materials, including cores known from sites of the Mierzanowice culture near Kraków (*e.g.*, Kopacz 1976; Wilczyński 2011; Stefański 2015), the Trzciniecka culture (Budziszewski 1998), and finally the Lusatian culture (*e.g.*, Kruk 1994; Trela-Kieferling 2013; Wilczyński 2015). Such a cultural classification of the mentioned core in question may be indicated primarily by the remnants of the para-blade, 'Clactonian-type' technique of core exploitation, characteristic for the Lusatian flint production (*e.g.*, Libera 2005, table 1). However, it should be noted that the presence of two striking platforms and the presence of core preparation sequences is unusual in this context. Before assigning a more detailed cultural affiliation to the discussed core, we should wait until a more numerous collection of cores of similar technological features is gathered.

The analysis of LiDAR data also suggests at least two stages of mining field utilization. The only core that can be associated with the later exploitation horizon of the site was found in zone B, which is characterised by a less eroded pit relief.

Our results suggest that the Dąbrówka-I mining field has at least two mining horizons: the first, more intensive one, is connected with the Neolithic period and the second one, covering a smaller area and is connected with the Late Bronze Age/Early Iron Age. Neolithic cores found throughout the site indicate that mining related to the later horizon was carried out within an area already exploited in the Neolithic period.

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