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# Non-invasive Investigation of Segment C of the Krzemionki Exploitation Field. Initial Research Results

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Non-invasive research has been undertaken in the southern arm of the archaeological area of the Krzemionki exploitation field, which is one of the least excavated of its regions. Geophysical prospection covered an area of 3.5 ha, and in addition, an area of more than 5 ha was examined by surface collection. The image of the underground structures was obtained thanks to a comprehensive comparison of the results of magnetic, earth resistance and GPR measurements, as well as the distribution of archaeological finds on the ground surface. The study was supplemented with data obtained from the analysis of archival aerial photos and Airborne Laser Scanning (ALS) derivatives. On the basis of these complementary data, it was possible to create a general image of the distribution of archaeological sources in the study area. When trying to determine the potential range of the exploitation field, the most legible results were obtained from earth resistance survey and magnetic gradiometry methods. In the most fully explored fragment of the area, anomalies suggesting the presence of prehistoric mining facilities are located in a strip 40–60 m wide, running in the NW-SE direction. Surface studies showed the presence of anthropogenic limestone debris in a zone of similar width (50–75 m) and the direction of its course, while the spread of flint and erratic stone finds turned out to be even greater (a belt 70–90 m wide). Geophysical surveys indicate the possibility of the existence of flint workshops and settlement facilities around the mining field. This can be confirmed in future by further systematic studies of its surroundings.

KEY-WORDS: Krzemionki, exploitation field, non-invasive research, striped flint

The Krzemionki striped flint mines are one of the most important monuments of prehistoric mining in the world. They functioned throughout much of the Neolithic period and at the beginning of the Bronze Age (3900–1600 calBC). Discovered

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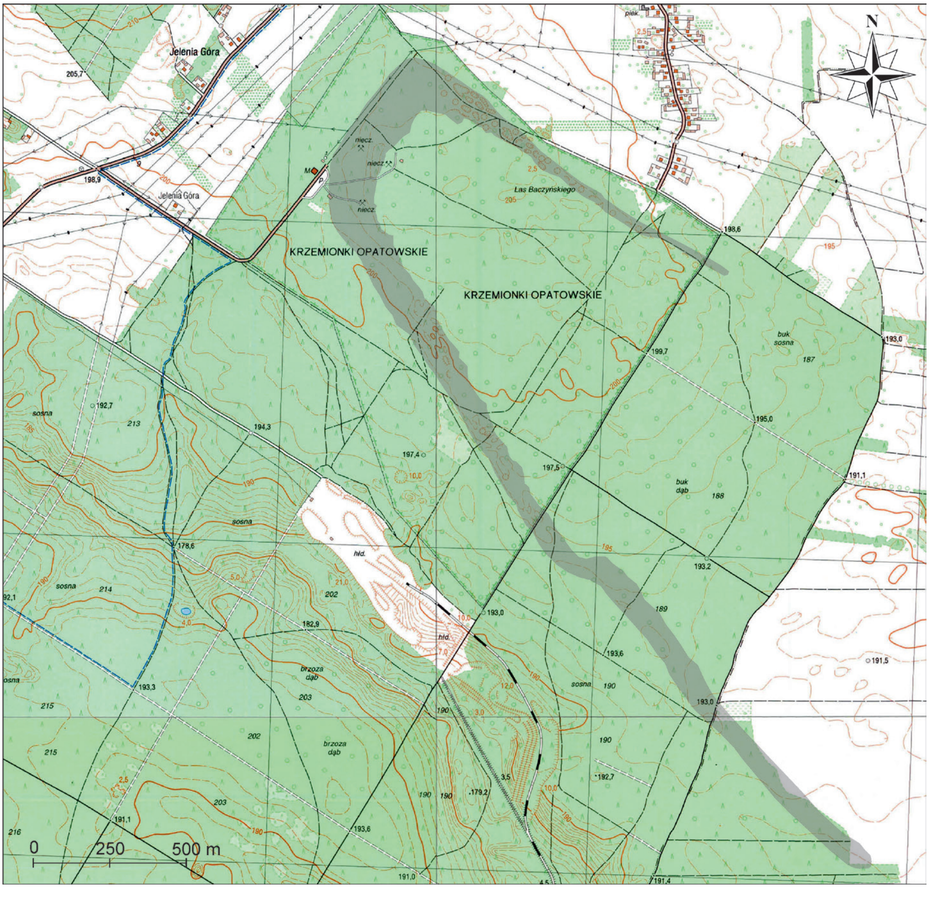


**Fig. 1.** Approximate extent of the Krzemionki exploitation field drawn on the basis of the Digital Terrain Model and previous interpretations (including Bąbel 2015 and Borkowski and Michniak 1992) on the basis of the topographic map 1: 10000, Sudół and Boria sheets, ed. Geokart-International Rzeszów 2002–2003.

in 1922, the exploitation field covers about 4000 mines, representing the majority of prehistoric flint extraction techniques. The largest of them, chamber mines, reached a depth of 9 m with several hundred square metres of underground workings (Bąbel 2008: 90–91). In the period of functioning of the Globular Amphora culture (3100–2400 calBC), the polished striped flint axes produced here were distributed to customers living in a large part of Central Europe. In addition to the distinctive size of the mining area and the state of preservation of the underground workings, other

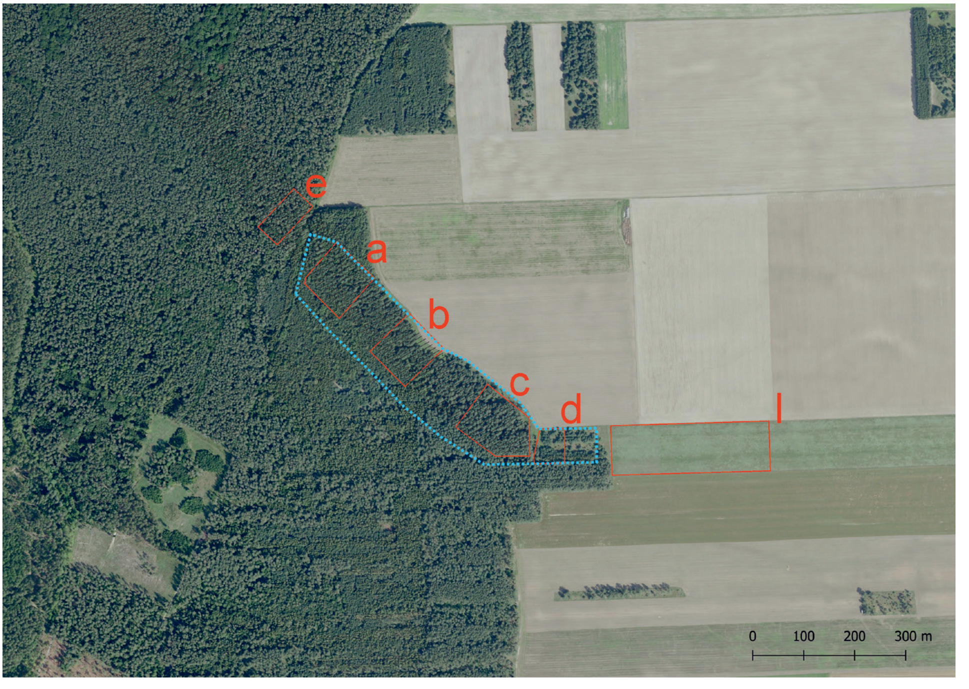


**Fig. 2.** Zones selected for geophysical research (red outline), surface survey (blue outline) and the approximate extent of the exploitation field (hatching) on the basis of a modern orthophotomap.

noteworthy components of the site include the post-mining landscape in the form of spoil heaps and shaft hollows, as well as the presence of relics of communication routes, flint workshops and wooden structures of mining infrastructure. These unique features were the basis for the inclusion of the monument on the UNESCO World Heritage List in 2019.

The Krzemionki mining field covers an area of 78.5 ha, 20 to 200 m wide and almost 4.5 km long. Its parabolic shape results from the location of the shafts at the edge of the Magonie-Folwarczysko Jurassic syncline and the outcrop of striped flint (Fig. 1). The post-mining topography is not visible everywhere, which makes it difficult to clearly define its boundaries. In many places, as a result of modern, intensive agricultural activity, the boundaries of the zone of spoil heaps and shaft hollows have disappeared. This applies especially to areas of the site characterised by shallow exploitation, i.e. the pit and niche mine zones located on the outer boundaries of the exploitation field and at its south-eastern end (Bąbel 2015: 16–17). One such area is the so-called segment C, i.e. a part of the southern arm of the exploitation field that extends from the line of a clear geological fault to its edge (Borkowski 1995: 51–53; 2000a: 128, Fig. 2, 186). It was its most eastern part, deforested and cultivated at least from the 18th century, that was covered by non-invasive archaeological research in 2021 as part of the Protection of Archaeological Monuments program managed by the National Heritage Board of Poland and co-financed from the budget of the Minister of Culture and National Heritage (Fig. 2).

## THE AIM OF THE RESEARCH AND ITS ENVIRONMENTAL AND ARCHAEOLOGICAL CONTEXT

The Krzemionki site is located in the area of the Iłża Foothills (Przedgórze Iłżeckie), an area built of Jurassic and Cretaceous rocks, covered with Tertiary and Quaternary formations, including loams, sands and, to a small extent, loess. The relief of the area is varied, the landscape is upland and submontane. There are also undulating plateaus and periglacial lowlands with eskers and kames. The area is crossed by the valleys of the Iłżanka and Kamienna rivers, the latter creating picturesque limestone gorges. There are also loess landscapes with ravines. The most common soils in the region are rendzinas and lessive, rusty and podzolic soils made of glacial sands, as well as lessive and black soils formed in loess, and marshy meadows. The potential vegetation cover consists of mixed pine-oak and pine forests, Central European oak-hornbeam forests, open lowland oak forests, riverside willow-poplar and ash-elm riparian forests. There are also semi-natural xerothermic steppe grasslands in the area. Today, forests cover over 40% of the area, and the remaining part is agricultural land (Strzyż 2021: 419–420).

The oldest, surface formations in the eastern part of the area of the Iłża Foothills, where the site of Krzemionki is sited (in Bodzechów and Ćmielów municipalities), are the rocks of the Upper Jurassic, arranged in two sets of beds. In those dated to the Oxfordian, there are platey limestones, shales and marly limestones with flints, above which there are compact limestones with flints, reef-coral limestones, and above them oolite limestones with striped flints. In the other set of beds, dating to the Kimmeridgian, there are mainly oolite limestones, marls and marl limestones, and numerous layers of shelly limestones. Tertiary formations (karstic clays and weathered sands) occur mainly south of the prehistoric mining field, in the area of the so-called Sudolska Valley, and are usually associated with karst forms that arose in the Miocene layer. Quaternary sediments are more common, among which the predominant element are layers associated with the Central Polish glaciation. These are tills as well as sands and

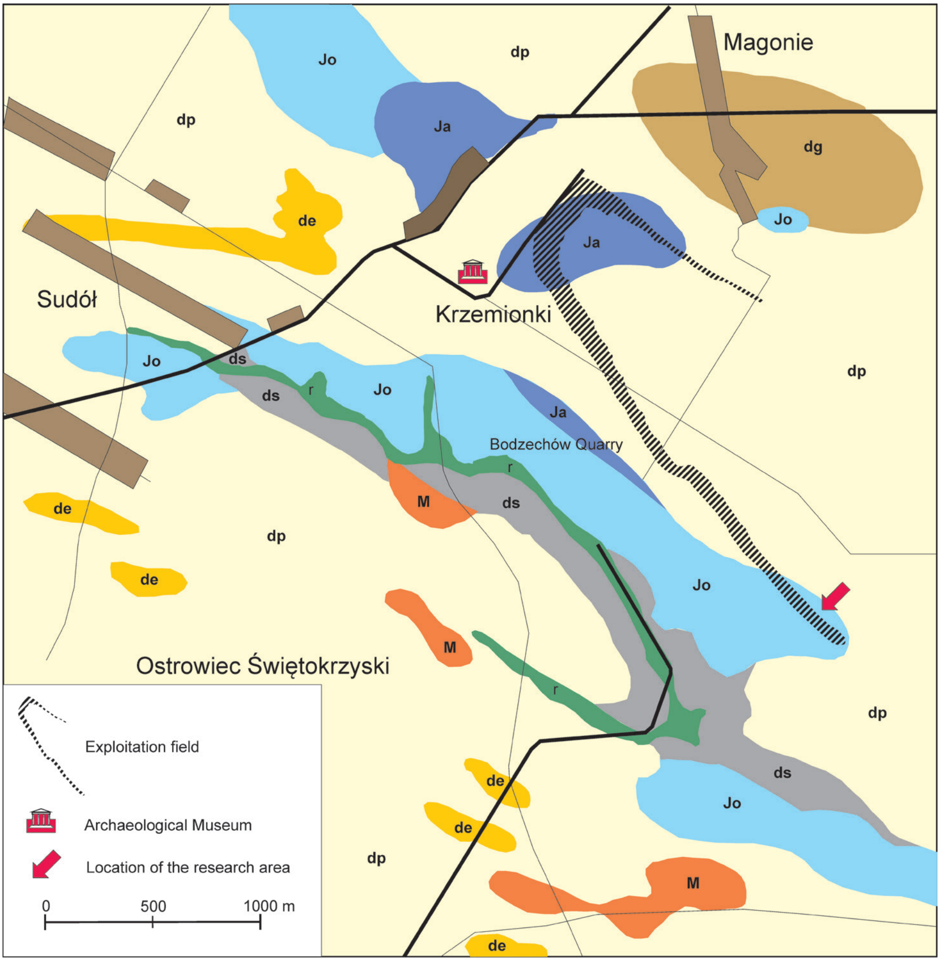


**Fig. 3.** Simplified geological map of the Krzemionki region: Jo, Ja – limestones, Jurassic, Oxford, dp – sands of glacial accumulation with boulders, Pleistocene, de – aeolian sands, Pleistocene / Holocene, ds – alluvial sands and silts, Pleistocene / Holocene, dg – glacial till, Pleistocene, M – karstic clays, Miocene, according to J. Fijałkowski 2000.

gravels with hydro-glacial and glacial boulders that cover most of the area in question and shape the present-day landscape (Fijałkowski 2000: 3–5, Fig. 2, 3; Fig. 3).

The project discussed in this paper was conducted in the area of the "Krzemionki Opatowskie Nature Reserve" and in its vicinity. Prehistoric flint exploitation had shaped not only the surface relief of the landscape, but also the stratigraphy of the shallowest geological layers that differed from the natural pattern. The weathered clay and limestone rubble taken from deeper seams caused a change in the humidity and the abundance of minerals in the area of the exploitation field, and thus favoured the development of certain plants and animals. In the post-mining areas, a subcontinental oak-hornbeam forest with xerothermic grasslands has developed. However, in their surroundings, in post-agricultural areas, there is mainly a subboreal mixed coniferous forest (Barga-Więcławska 2016; 28–34). The research area was mostly forest areas and overgrown former farmlands, hence there was a great difficulty in carrying out the work, especially with the use of measuring equipment. The main goal was to investigate the least studied part of the exploitation field, and in particular to answer two basic questions:

– what is the actual extent of the area covered by prehistoric mining works?
– are the mines themselves accompanied by other types of archaeological features related to the prehistoric flint mining or other structures on the Krzemionki site?

Obtaining more complete archaeological knowledge about the south-eastern edge of the site would also facilitate the conservation protection of this fragment of the monument, especially in the context of emerging threats in its vicinity in the form of plans for the location of large mining investments nearby (Jedynak 2020).

For the first time, an indicative outline of the mining area, identical to the extent of limestone outcrops with striped flint, was presented by Jan Samsonowicz on the Opatów sheet of the General Geological Map of Poland that he compiled (Samsonowicz 1934). Subsequent researchers, including Stefan Krukowski, Zygmunt Krzak, Tadeusz Żurowski, Wojciech Borkowski, and Jerzy Tomasz Bąbel, copied the shape of the southern fragment of the exploitation field (Krukowski 1939: 1, Fig. 1; Krzak 1961: 31, Fig. 2; Żurowski 1962; Borkowski 1995: 58, Fig. 38; Bąbel 2015). W. Borkowski and Ryszard Michniak, authors of a study devoted to the geology and methods of flint mining, devoted more attention to this part of the Krzemionki mines. They divided the entire area into zones that differed in terms of the type and depth of the extraction carried out there. In Segment C, which coincides with part of the current research area, they saw a shallow exploitation through the use of pit and niche mines analogous to the neighbouring part of Segment B (Borkowski and Michniak 1992: 31).

Unfortunately, we do not have any geological and archaeological profile of the studied area because no excavations have ever been carried out here. The nearest excavated features (5/1416 and 10/1441) are located approximately 1150 m to the north-west, in segment B2. The profile of the 10/1441 trench shows the stratigraphy of the geological deposits lying here up to a depth of 7.5 m. Jurassic limestones appear here already at a depth of about 1.8 m. The upper parts are humic

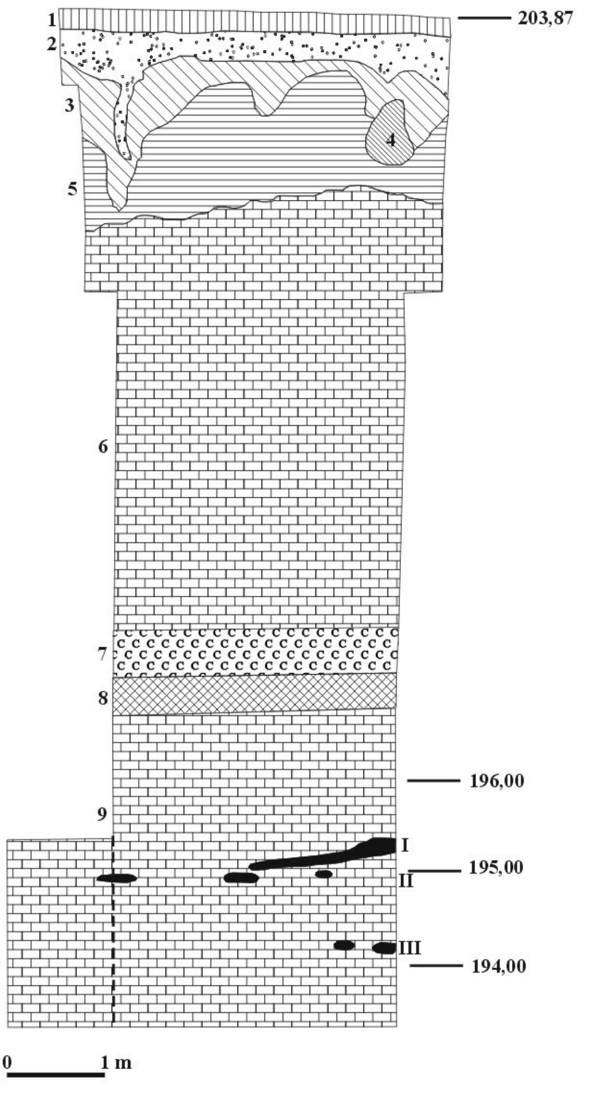


**Fig. 4.** Geological profile characteristic for the Krzemionki region: 1 – forest humus, 2 – sand, 3 and 4 – clay, 5 – limestone weathering, 6 – pelitic limestones, 7 – limestones with benthic fish burrows, 8 – oolitic limestones, 9 – pelitic limestones, fine-grained, I-III – flint beds according to J. Bąbel 2015.

layers (depth 0 – 0.25 m), sand (depth 0.25 – 0.5 m) and moraine clay gradually turning into calcareous weathering (from 0.5 to 1.8 m). The first flint bed occurs at a depth of 7.5 m (Borkowski 1995: 52, Fig. 36). This is the typical image of the stratigraphy of the Krzemionki exploitation field, and the individual profiles differ mainly in the thickness of the Pleistocene and Holocene layers (cf. Borkowski 1995: 48–49, Fig. 26–29, 31, 32; Bąbel 2015: 47, Fig. 39; Fig.4).

The most information about the geology of the reserve is provided by the work of Jerzy Fijałkowski, who described the profiles of a dozen or so outcrops and quarries located to the west and south of the study area. Their analysis shows that the Quaternary layer, made of humus, sand and weathered clay mixed with limestone rubble, has a thickness here of up to 2 m, but more often it is thinner and is from 1 to 1.5 m. Below, there are different types of Oxford limestone (Fijałkowski 2000: 11).

The key work undertaken in the area in question during the present project consisted of an earth resistance survey conducted by Tomasz Herbich and the accompanying excavation sampling survey (trial trenching) carried out by the Team for the Study of Prehistoric Flint Mining of the State Archaeological Museum in Warsaw in 1989. These surveys were carried out in an area where the relief features of the post-mining landscape were unpreserved. The multi-level profiling of the area covering both the exploitation field itself and fragments of the surrounding area showed differences in the electrical resistance of the layers that had not been disturbed by human activity compared with the places where mining had taken place. This made it possible to define the approximate extent of prehistoric flint mines and to select sites for the excavation survey test pits. The excavations located on the edge of the defined mining zone revealed the backfills of two mining shafts (Herbich 1993). Based on the positive results of these studies, further exploration of the southern part of the Krzemionki exploitation field is planned.

## RESEARCH METHODS, SCOPE AND RESULTS

In 2021, archaeological work was carried out using several non-invasive methods. These were geophysical methods (earth resistance, magnetic and Ground Penetrating Radar GPR) combined with surface prospection and the analysis of the Digital Terrain Model made on the basis of airborne laser scanning and archival aerial photos. The results obtained by each method were compared. The proposed techniques of prospection have already been applied with positive results to research on prehistoric flint mining landscapes, including at Krzemionki (cf. Herbich 2000; Misiewicz 2000; Borkowski 2000b; Welc *et al.*, 2014; 2016; Mieszkowski *et al.*, 2014). However, this project was the first time that these several methods were used simultaneously and the obtained results integrated into a GIS project.

In the preliminary stage, 6 zones with the designations from a to e and l were designated for geophysical exploration. Finally, four (b, c, e and l) with a total area of 3.5 ha were selected for fuller study. Only in zone e had the prehistoric post-mining landscape survived. Measurements within this segment of the site were carried out to compare the results with other zones, where heaps and shaft hollows have not survived. An area of 3.5 ha was examined by GPR and magnetic methods, while the electrical resistance method was employed over an area of 1 ha. The surface collection prospection covered an area exceeding 5 ha. Zones a, b and c, which were located in a forest, required to a different degree, additional preparation for research (removal or thinning of the undergrowth). Zone l was located in the meadow area of a forestry aircraft landing site (Fig. 2).

*Geophysical Investigations*

The part of the site covered by the research included both forest and open areas (the latter comprising that grass strip of a landing field), which made accessibility to both the measuring devices together with their operator very varied (Fig. 5). In general, it can be assumed that the terrain was very difficult to research, which was reflected not only in the field activities, but also in the quality of the measured signal of geophysical measurements. Nevertheless, efforts were made to conduct the measurements in such a way as to obtain the most uninterrupted, long measurement profiles, which is favourable for the readability of the results. Three geophysical methods were used in the research, including GPR, magnetic measurements and earth resistance. Geophysical surveys were performed along with geodetic measurements, so all measurements and results were integrated by GIS for the purpose of data management, creation of site plans and data interpretation.

Geophysical surveys as a set of non-invasive archaeological prospecting techniques enable the recognition of the natural features of subsurface layers without interfering with the soil structure. Based on the results of the prospection, it is possible to indicate the places of potential presence of archaeological features related to past human activity and the transformation of the landscape as a result of these activities. The selection of methods and their specifications, including the accuracy of geophysical and geodetic measurements during the work, aimed at obtaining the fullest possible set of data presenting disturbances caused by subsurface structures. The interpretation of this information is based on the analysis of the contrast between the natural geological background and the visible changes in the values of the measured features (cf. Aspinall *et al.*, 2008; Conyers 2013; Schmidt 2013).

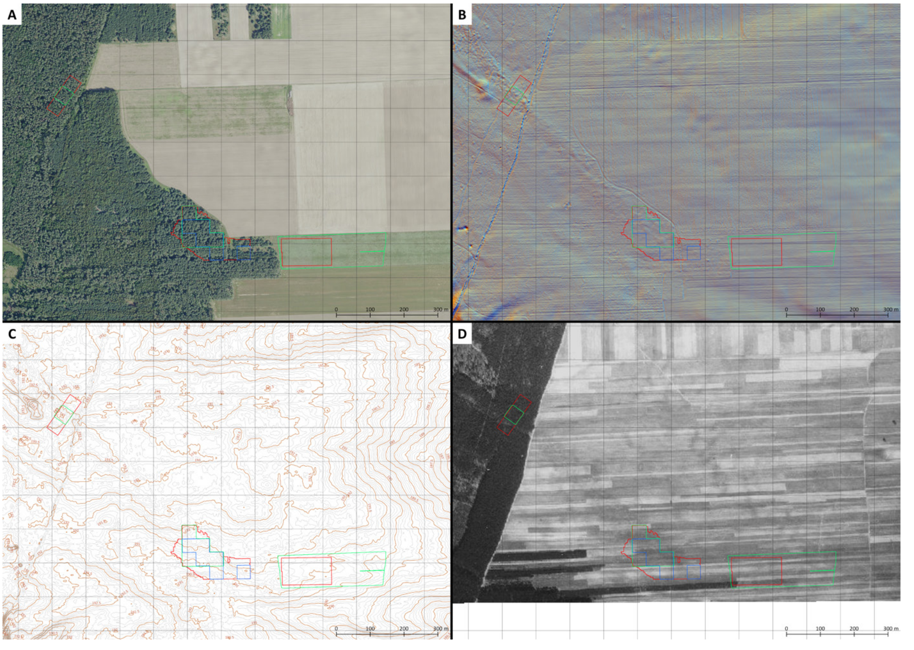


**Fig. 5.** Location of geophysical research, red outline – magnetic research; blue outline – earth resistance survey; green outline – GPR surveys, superimposed on various backgrounds, A) contemporary orthophotomap; B) hillshaded terrain model based on ALS; C) contour plan; D) archival orthophotomap from 1964.

The GPR method (Figs. 6c and 6d) allows creating a three-dimensional image of what is underground up to the maximum measurement depth of the antenna employed. During the research, an antenna with a frequency of 400 MHz was used, allowing measurement to a depth of approx. 3.5 m. The results are presented in the form of radar profiles, which are most often visualized in the greyscale convention. They show the result of the depth measurement in the form of XYZ, where Z is the reflection of the electromagnetic wave below the ground surface. Properly prepared by means of specialized filtration, the radarogram is processed into the form of time-slices that show the distribution of anomalies on a plane, depending on the depth, in a manner comparable to magnetic or electrical resistance maps. In total, 236 profiles with a total length of just over 34,574 metres (34.57 km) were made. The GPR profiles were made at least every 1.5 m (on average every 1 m).

Magnetic measurements were also used in the project (Fig. 6a). Measurements of the distribution of the magnetic field values allow the indication of the distribution

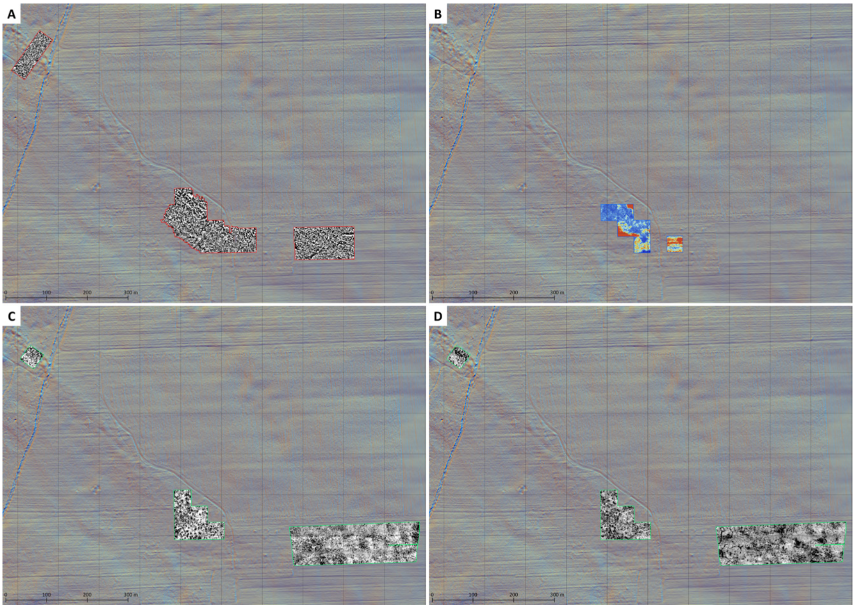


**Fig. 6.** Compilation of the results of various research methods used during the research in 2021, A) visualization of greyscale gradiometric data, negative readings in white, positive readings in black; B) visualization of earth resistance data, 0.5m Wenner array, low readings in blue, high readings marked in red; C) visualization of radar measurements converted to a time-slice at a depth of about 40 cm; D) visualization of radar measurements processed into a time-slice at a depth of about 120 cm.

of geophysical anomalies and to estimate the range and nature of the archaeological characteristics of the site. Measurements were taken using a Bartington Grad 601–2 dual probe fluxgate magnetometer in parallel profiles with a measurement density of 1m x 0.25 m.

Earth resistance measurements were also made in the profiling mode (Fig. 6b). This technique complementarily enriches the image of subsurface structures with information on approximate depth, constituent material and thickness. Measurements are recorded in a regular, dense grid, thanks to which it is possible to examine multi-layer objects as well as to conduct wide-area prospecting. Based on the results, high- and low-resistance zones are distinguished, which can be associated with backfills, ditches and any stratigraphic disturbances, as well as with the existence of non-conductive structures. Electrical resistance measurements were carried out using the network of polygons designed for the magnetic measurements. Data were recorded using the Geoscan Research RM–15D Advanced device in a Wenner electrode configuration with a depth profile of up to 0.5 m and a measurement density of 1 x 1 m.

The research area was divided into polygons, the tops of which were fixed in the field with wooden pegs. For this purpose, a GPS RTK instrument and a robotic laser total station were used, which allowed for embedding the points of the designed measuring grid with an accuracy of 3 cm. The tops of the polygons were measured into the National Geodetic Coordinate System (PUWG 92; EPSG: 2180).

The GPR surveys detected anomalies of various nature throughout the surveyed area. The eastern area - the landing site - is characterized by a large number of small, larger circular and more complex examples of GPR anomalies, especially at its western end. Undoubtedly, the identified features look very promising and require further individual investigation. The central area (zone c) is also characterized by a rich set of anomalies, in this case of rather small size. It cannot be ruled out that the source of some of these are natural features, e.g., the root system of trees, but attention is drawn to the mapped groups of anomalies arranged in a circular pattern around a central anomaly and anomalies that coincide with the magnetic data. Despite its small size, the western area, which occupies the area of this part of the site with the visible relief of the post-mining landscape ( zone e), includes a number of anomalies among which are two circular features that are located at the foot of small terrain unevenness related to the remains of mine spoil heaps.

The magnetic survey revealed numerous anomalies that can be attributed to anthropogenic activities and require further investigation. Among the disturbances probably caused by archaeological structures are increases in the value of the magnetic field. In the northern part of the central area (zone c), a complex of anomalies of this type was registered, which shows similar spatial and morphological features to those known from other studies and features related to Neolithic flint mining. It can therefore be assumed that they determine the real range of the area covered by the flint mining. In the eastern part (zone l), a large number of anomalies of various types were also noted, with particular intensity at the northern and western borders. Undoubtedly, in many cases they are potential archaeological features and they require further exploration both in terms of obtaining new information about the registered anomalies and the investigation of the wider landscape context. On the other hand, as noted above, the study of the western area (zone e) was aimed at obtaining data for a comparative analysis of newly detected features with known and existing ones. The visualizations of the survey results show the correlation of magnetic anomalies with some topographic anomalies, demonstrating clearly that the cavities of mining shafts generate changes in the magnetic field. However, in the case of the potential mining facilities detected in the levelled central part of the study area, the differences are small and most probably result from the poorer state of preservation. No earthworks of spoil heaps have survived in the central part, so it can be

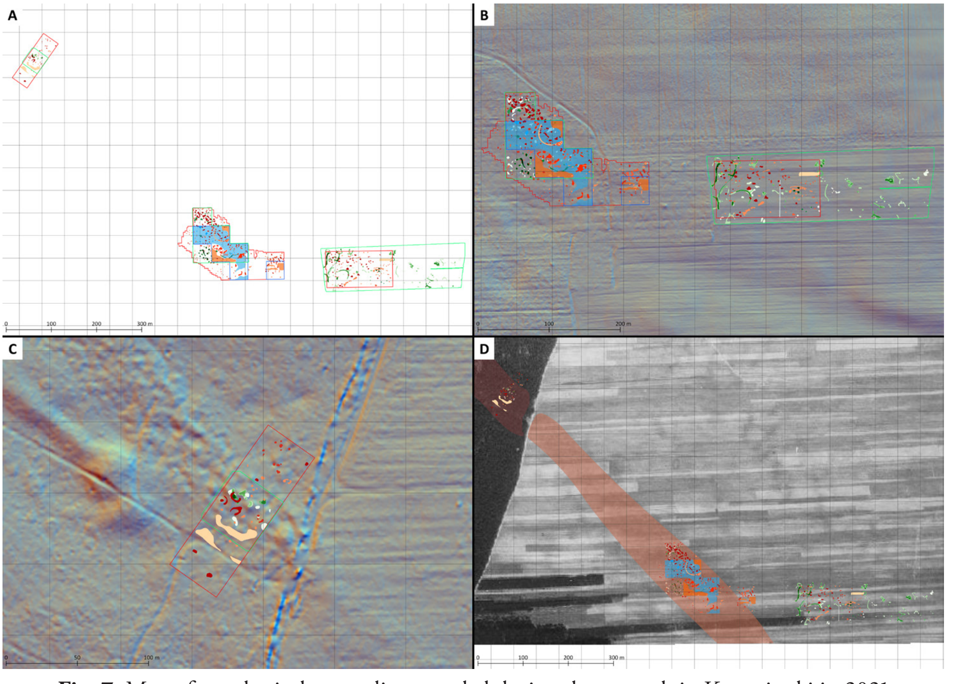


**Fig. 7.** Map of geophysical anomalies recorded during the research in Krzemionki in 2021 overlaid on various basemaps, A) 50 m grid; B) hillshaded terrain model based on ASL; C) hillshaded terrain model based on ASL; D) archival orthophotomap from 1964.

assumed that the sources of magnetic anomalies are shallower than in zone e. This has a positive effect on the detection of this type of objects.

The electrical resistance method found a background with low apparent soil resistance in the middle of the western part of the research area (zone c). This is surrounded on the south and north-east by parts of high resistance zones that extended beyond the investigated area. Within the low-resistance zone, there are clusters of magnetic anomalies interpreted as potential remnants of prehistoric mining features. The small eastern research area (zone d) is characterized by linear disturbances of the apparent soil resistance. They can be associated with contemporary forestry or agricultural activities rather than with potential archaeological features.

Each of the methods used produced a lot of information about the properties and nature of the detected anomalies that could be interpreted as potential anthropogenic structures of different natures, shapes and depths (Fig. 7). The magnetic and electrical resistance methods produced information about the position of anthropogenic structures and stratigraphic disturbances as well as their physical properties (that is the values of their magnetic susceptibility and electrical resistance). The GPR survey revealed the underground structure of anomalies causing disturbances and their depth of occurrence. In this case, anomalies were recorded at a depth of 0.3–0.5 to approx. 1.8 m. The comparison of the results of these methods allows for the mutual complementation of information about the disturbances detected, which is an undoubted advantage of each program employing the integrated use of geophysical methods in the non-invasive determination of the archaeological potential of the area studied.

*Surface Collection Survey*

The fieldwalking surface survey covered a strip of land approx. 600 m long and 75 to 100 m wide. The research area was difficult to access, due to the fact that it is covered mostly with dense undergrowth and pine thickets with a large number of windbreaks. These conditions meant that it was necessary to apply a survey method that was more precise than the standard survey method (*Archeologiczne Zdjęcie Polski* [English: Polish Archeological Record]) employed in Poland (Oniszczuk *et al.*, 2019). The method of work consisted of dividing the entire research area into parallel strips of land, approximately 30 metres wide, and crossing them several times while examining the ground surface precisely. The position of the finds were logged using hand-held GPS devices. The artefacts were divided into two categories: flint and stone finds and limestone fragments with anthropogenic features (sharp-edged related to mining operations).

The spatial registration of relics related to flint production was to determine the range of flint processing sites and possible clusters that could be interpreted as areas of flint workshops. If a find was spotted, the area within a few meters around it was searched more carefully. Not all the artefacts were collected and a selection was made in the field with the focus on the forms giving chronological clues.

In the case of finds of limestone debris, this material was not collected, and only its presence and spatial distribution was documented. Information was recorded on the size of the rock fragments (3 categories) and the amount of mining debris (4 categories) present at the site. Efforts were also made to register the presence of till on the surface. In principle, such observations were to allow for the precise determination of the range of mining activities, and, under favourable circumstances, also for a general assessment of the depth of the mine.

The surface work conducted yielded information on the dispersion of finds and other traces related to prehistoric mining activities. During the survey, 60 points of occurrence of archaeological finds and 58 findspots of anthropogenic limestone debris were recorded. In the work, 157 items were collected, mainly flints, and a small group of glacial pebbles with traces of use. The material had been unevenly distributed throughout the area covered by the project. There were clear areas where they were denser on the ground and other areas where they were largely absent. Undoubtedly, this state of affairs is the result of unequal access to the research area. Most of the material was obtained in the central part of the research area (zones b and c and their vicinity). When observing the distribution of the finds, certain regularities can be noticed. The finds were located in a strip 70–90 m wide. This largely coincides with the range of the exploitation area known from the literature in this part of the Krzemionki mining field, and is even larger. Numerous pieces of worked flint were also observed in the arable fields directly adjacent to the survey area to the north, which may indicate the presence of flint workshops in this area too.

Flint and stone artefacts define the zone of mining and production activities, while the extent of anthropogenic limestone debris is important to determine the extent of the mining area itself. It is grouped into two distinct zones with a width between 50–75 m and determines the location of the mine workings in this place (Fig. 8).

The obtained flint material, including fragments of concretions, allows for a general description of the raw material found in this region. Apart from three small fragments of chocolate flint (plus one indefinite one), the finds consisted of fragments of striped flint. Pieces of nodules with preserved opposite outer surfaces are 4 to 10 cm thick, but single fragments of flint suggest the presence of larger and more massive raw materials. The discovered finds were mostly heavily covered with a light patina, which is typical for material from flint mines. The cross-sections show striped and non-striped zones typical of this material, the often thick (from 4 to 8 mm) white outer halo and the clear presence of a grey, non-striped inner zone are noteworthy. The flints from the south-eastern edge of the Krzemionki mining field are therefore similar to concretions occurring in the area of the "Ostroga" mine in Ruda Kościelna (Budziszewski and Michniak 1989: 170–175). In the study area, there were also fragments of concretions with a dominant striped zone, with a thin white halo and a small, inner grey zone. They resemble the finds from Segment A of the Krzemionki mining field. The collected flints mostly show a high degree of cracking. It is waste material that showed its shortcomings at the first processing attempts and was rejected. It cannot therefore be used to assess the quality of the material in the original deposit.

Flint objects constitute approximately 95% of the collected artefacts. During the analysis, they were divided into basic categories. The breakdown is as follows: 22 fragments of nodules, 67 flakes, 60 fragments of industrial waste and 8 pieces at the early stages of creating cores, the so-called roughouts. This is typical material from

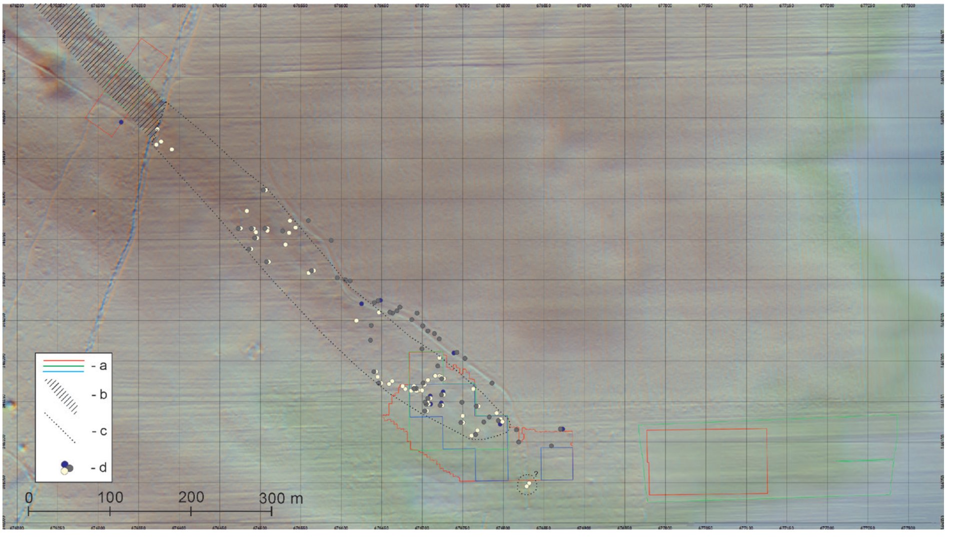


**Fig. 8.** Area of surface survey with the spread of finds: a – the boundaries of the geophysical research areas, b – the extent of the preserved post-mining landscape in the mining field, c – the hypothetical range of the levelled fragment of the exploitation field determined on the basis of the spread of archaeological material and the DTM analysis, d – the location of archaeological finds and anthropogenic limestone debris (grey – flint finds, blue – erratic rocks, white – limestone fragments).

mining flint workshops. The most interesting group of artefacts are the roughouts, which are mostly of tetrahedral forms, obtained by dividing concretions into smaller fragments created in the form of parallel slices. Usually, in their case, the extent of processing is very small and is limited to a few flakes removed from one or two faces. Most of the finds from the group in question have material defects in the form of tectonic cracks, which prevented further, effective processing to obtain a tool (axe). One of the items in this category can be described as a very early stage in the shaping of a bifacial axe. It shows the multidirectional processing associated with an attempt to form a blade and the preliminary knapping of one of the side edges. Unfortunately, due to a raw material defect, the roughout disintegrated in the early stage of the tool's production (a large part of the butt side had fallen off) and was abandoned.

The most numerous category in the collection of flint relics are flakes. Most of them are so-called flakes of the first series, or struck from concretions at the earliest stage of work. On the upper surface they have fragments of the cortex that originally covered the raw material. The remaining finds show individual negatives of earlier removed flakes, and in a few cases a few such flake scars. Characteristics of the use

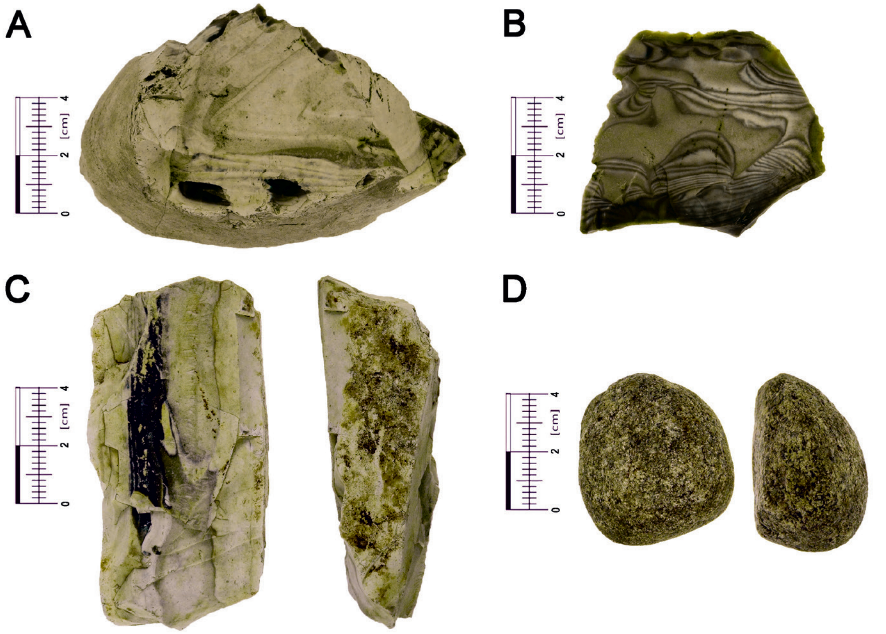


**Fig. 9.** Examples of raw material, flint and stone tools from the area of surface survey carried out in 2021: A – fragment of concretion; B – flake; C – roughout of a tetrahedral core tool; D – hammerstone and smoother made of granite glacial pebble.

of a hard hammerstone are visible on a significant part of the flakes: clear bulbs of percussion and erailleur scars on the underside. Individual finds have traces of further processing in the form of retouched edges. Usually this is an irregular, often toothed retouch, which was probably created accidentally as a result of rubbing the edge of the flake with a hard object. Only in two cases is it a more regular retouching, indicating the intention to make a tool.

The group of nine erratic rock relics consists of granite, quartzite and other pebbles with surfaces with visible traces of grinding or crushing arising when using them to prepare flint tools. On the basis of macroscopic observation, three of them were defined as hammerstones and smoothing stones. The others require closer observation. At this stage of the research, it can only be stated that their presence in the exploitation field is not accidental, because this type of erratic rocks is typical material for making flint tools in mining workshops (Fig. 9).

## DIGITAL TERRAIN MODEL ANALYSIS AND AERIAL PHOTOGRAPHY

An important element of the non-invasive research that was used to verify the data obtained during geophysical research and surface exploration was the use of Digital Terrain Model analysis. The surface relief model shows the almost complete levelling of the land by agriculture. The boundaries between different arable plots are even visible. Inequalities that could be interpreted as remnants of the post-mining relief survived only in the central part of the study area, currently poorly accessible for surface research. What is visible, however, is a longitudinal structure running along the extension of segment B of the mining field with preserved spoil heaps and shaft cavities. It forms a gentle "step" in the surface relief, less than 1m tall and running along the axis of the research area in the NW-SE direction, almost completely invisible in the field, but very clear in the cross-sections. The step is no longer visible over about half of the length of the surface surveyed area. The location of the discovered fragments of sharp-edged limestone debris is consistent with the position of this structure, but the spread of other finds on the surface seems not related to it. Its presence probably reflects the course of the limestone outcrop with striped flint around which the mining was focused. Looking south-east, it disappears under younger settlements. In the literature, it is precisely the submergence of the outcrops under the increasingly thicker Quaternary cover that has been referred to as the main reason for the gradual narrowing and disappearance of the mine belt (Borkowski and Michniak 1992: 31).

Also analysed were aerial photographs available from the resources of the Central Office of Geodesy and Cartography. Those of most use were taken in 1964, e.g., before the expansion of the forest to the south-eastern edge of the mining field, and show a darker strip of land with lighter spots in the area of the former arable fields, east of the dense forest cover. It stretches along a NW-SE line and is 700 m long and 90–100 m wide. Further to the south-east there are lighter and darker linear soil features, which most likely reflect the outcrops of the Jurassic strata of the border of the Magonie-Folwarczysko syncline. They almost exactly mark the line on which the prehistoric striped flint mines are located: Księża Rola Mała and Duża and Ostroga (Fig. 10).

## CONCLUSIONS

The implemented project was undertaken in the field of heritage protection. The registration of archaeological and potentially archaeological structures, both in the area

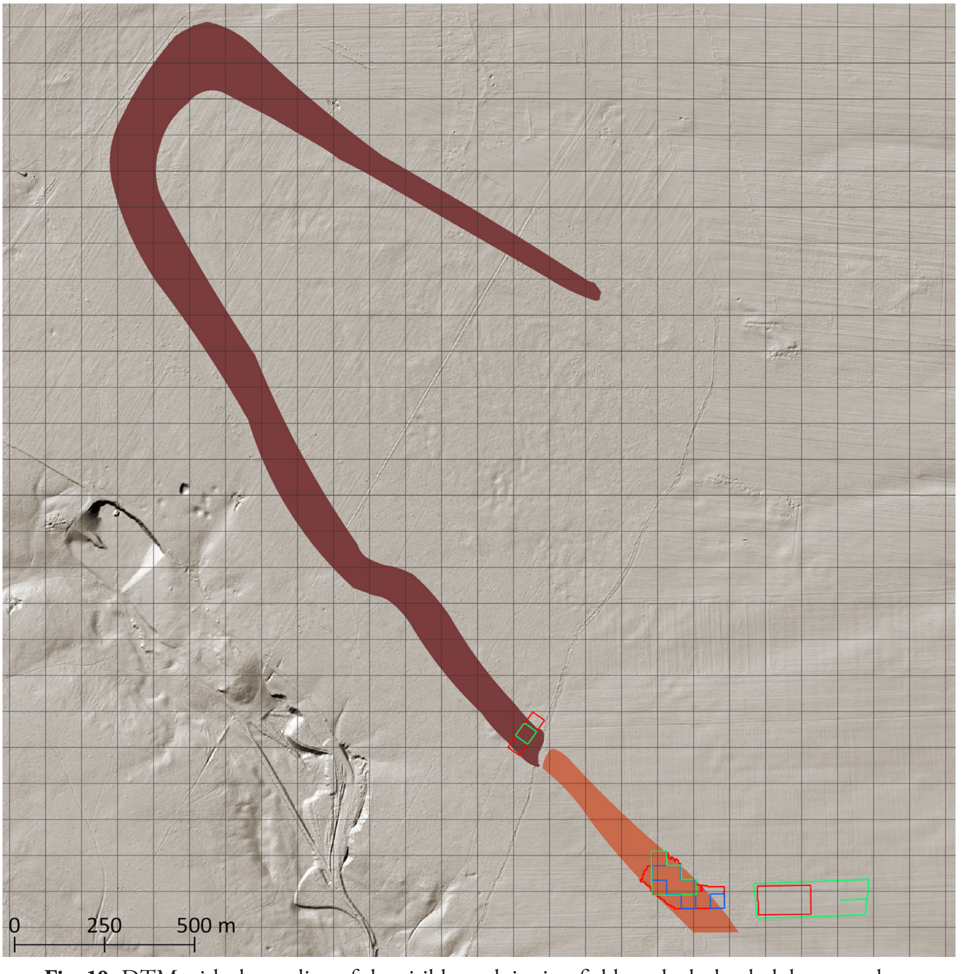


**Fig. 10.** DTM with the outline of the visible exploitation field marked, the dark brown colour indicates the extent of the field based on the ASL data; the light brown colour was used to mark the extent of the field based on the interpretation of soil discriminants visible on the archival orthophotomap from 1964 and the geophysical measurements.

previously defined as an exploitation field and outside, will allow for planning activities aimed at strengthening the protection not only of this part of the Krzemionki monument but also its landscape. One of them will be the currently proceeded extension of the entry in the register of monuments to the so-called buffer zone (surroundings) of a World Heritage property.

The fieldwork and analytical work using all the applied prospection methods reported here have resulted in the identification of a number of potential archaeological structures. An image of the subsurface structures was obtained through a comprehensive diagnosis of the archaeological sources. These can be distinguished on the basis of the mutually complementary results of the analysis of aerial photos (including archival photos), ALS images, magnetic gradiometry and earth resistance measurements, GPR measurements and surface surveys. An important aspect is the repeatability of registration of the same subsurface structures using several methods, thanks to which there are indications that the subject of the analysis are actual archaeological structures. On the basis of these complementary data, it is possible to initially create a general picture of the distribution of archaeological sources in the study area. When trying to determine the potential range of the exploitation field, the most readable results were obtained from earth resistance and magnetic investigations. In the most fully explored area (zone c), anomalies suggesting the presence of prehistoric mining sites are located in a strip 40–60 m wide, running in a NW-SE direction. In the remaining zones, they did not provide such a clear picture, however, changes were recorded that can be interpreted at this stage of the research as archaeological features. The surface studies showed the presence of anthropogenic limestone debris in an area of similar width (50–75 m) and the direction of its course, while the spread of flint and erratic stone finds turned out to be even greater (70–90 m). At this stage of work, it is not yet possible to determine the exact extent of the exploitation field in the southeast segment of the mining complex. The distribution and nature of the surface finds and the results of geophysical research indicate the possibility of the presence of flint workshops and settlements around it. This can be confirmed by expanding the area of non-invasive research combined with the integration of data from other activities, including excavations.

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