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## Historical residues of iron ore mining in environs of the Holy Cross Mountains (the Góry Świętokrzyskie) are recognizable on the Digital Terrain Elevation Model (DEM) derived from the LIDAR data

### Introduction

The acquirement of iron ore on the territory of today's Poland has a long tradition derived, and due to, the transfer of iron smelting abilities from Asia Minor to Europe. According to archaeological research, iron was smelted in Europe since the 1st c. BC in many areas of Poland (Radwan 1963; Bielenin 1964). Initially, the Quaternary bog iron ore (meadow ore, morass ore, marsh ore, swamp ore) fast regenerating and quite common in the Polish Lowlands, was the main source of raw material for smelting iron, especially in the areas just released from the ice sheet cover (Ratajczak and Skoczyła 1999). Extensive zones of bog iron ores with many clusters of “dymarkas” (old, iron smelt furnaces) occur west of Warsaw in the vicinity of the town of Pruszków, in the other regions of Poland – in the

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Lublin region, in Warmia, Masuria, and in the Podlasie provinces. With time, or synchronically, an iron smelting of other raw materials containing iron ore begun. The Lower and Upper Triassic, and the Lower and Middle Jurassic siderites outcropping on gentle slopes or under the relatively thin weathering Quaternary cover were located on the outskirts of the Holy Cross Mountains. One of the greatest mining centers was located in the Holy Cross Mountains at Rudki, where about 50,000 metric tons of limonite-hematite ore was excavated between the I<sup>st</sup> and the III<sup>rd</sup> centuries AD in open pits and underground.

Many other iron furnaces have probably not yet been discovered. This conclusion is upheld by observations made in the north-eastern outskirts of the Holy Cross Mountains, where archaeological research of ancient metallurgy was carried out particularly intensively. Initially, according to Bielenin approximates (Bielenin 1964, 1992; Figure 1) it was assessed that during the Przeworsk culture period, under the Roman impact as many, as 1,500 furnace clusters in an unordered pattern, and approximately 4,500 furnace clusters in an ordered pattern could have been operating in the Holy Cross Mountains. The number of all furnaces probably exceeded 400 thousand units. According to newer data, covering approximately 80% of the metallurgical activity areas, the total number of individual furnaces could range up to 555 thousand units but could count 600 to 650 thousand smelts (Orzechowski 2012). For construction of furnace about 1-meter-high of the “kotlinka” kind in the Holy Cross Mountains about 100 kg of construction clay or other similar materials as needed. Approximately 200 kg of iron ore was smelted using 220 kg of charcoal in each of the furnaces. This means at least 130 thousand metric tons of iron ore smelted and 1.2 million cubic meters of solid wood burned during the Roman period. However, contrary to earlier understandings (Bielenin 1964), during the early Medieval time (500 to 1000 AD), the iron industry in the Holy Cross Mountains ceased to exist (Piaskowski 1986, 1995).

The iron smelting industry was probably revitalized around the XI<sup>th</sup> century (Samsonowicz 1928; Janiec 1993). The mining of iron ore on a greater scale has only started in the XVIII<sup>th</sup> century. The golden age of ore mining in the Holy Cross Mountains was XIX<sup>th</sup> century. Up to 1840, the annual ore mining amounted to 145 thousand metric tons. In 1885, in a period of the greatest prosperity, the mining amounted to 1.053 million metric tons. Before World War II, 942 thousand tons of iron ore mined in 1938, however, 80% of the crude material came already from the Częstochowa region, and only 20% from a region called the Old Polish Industrial Area in the Holy Cross Mountains. In 1939, a total of 38 ore mines operated in Poland. During the German occupation, the exploitation of ore continued, resulting in the recovery of about 400 thousand tons. After 1945, most of the mines were devastated and flooded (Barczyk 1967). Only seven mines remained able to operate, and these were gradually closing down up to 1969.

The natural effect of the Iron Age and the known historical growth of the metallurgical industry was a permanent improvement of processing operations, and the development of new, easy-to-apply technologies of mining, smelting, and handling of iron ores – the bog ores and the rocky siderites. The bog iron ores – a mixture of goethite and lepidocrocite, are common in wetlands, easy to spot and regenerate in a geologically short time. Another

commonly occurring raw iron ore, of relatively low smelting temperature is siderite, in Poland present mainly in various Jurassic sedimentary layers; these siderites often appear as weathered (limonitized). Such type of ore was processed in the Starachowice metallurgical plant. Archaeological traces of mining brown limonite turf iron ores were discovered in groups of furnaces. Within the areas of siderite occurrences, apart from occasional furnaces, iron ore mining fields, visible on the LIDAR DEM images of the terrain surface, as densely grouped mining waste heaps with typical past-mining shaft shallow depressions are very common. These mining fields are the main study subject in the presented paper.



Fig. 1. An ancient steel-mill industry map overlapping a map of the Old Polish Industrial Area (by Orzechowski and Suliga 2006, after Bielenin 1992); reproduced from an exhibition board (drawing by Przychodni 2006 with small changes) in the Muzeum Starożytnego Hutnictwa Mazowieckiego im. Stefana Woydy (The Museum of Ancient Mazovian Metallurgy), in Pruszków. Orange: A Physiographic Extent of the Holy Cross Mountains; Brown-red: An area of the highest concentration of ancient furnaces (dymarka); Brown: An extent of a furnaces and ancient still-mill enclaves area

Rys. 1. Plansza prezentowana przez Orzechowski i Suliga 2006 (za: Bielenin 1992). Zasięg występowania starożytnego hutnictwa świętokrzyskiego. (Rys. Przychodni 2006 z małymi zmianami). Reprodukcja z wystawy w Muzeum Starożytnego Hutnictwa Mazowieckiego w Pruszkowie. Pomarańczowy: zasięg fizjograficzny Gór Świętokrzyskich; brązowo-czerwony: obszar największej koncentracji starożytnego hutnictwa dymarkowego; brązowy: zasięg występowania starożytnego hutnictwa

## 1. Methodological notes

The Digital Terrain Elevation Models (DEM) derived from LIDAR data were the basic analytical material for remotely detecting, identifying, and locating traces of historic mining. LIDAR is an English acronym for Light Detection and Ranging, and all the same, the name of the device for it. It works in a similar way as radar, but emits a dense array of laser pulses of light instead of radar microwave beams. The used LIDAR data is characterized by high resolution. Some of the laser light arrays of pulses penetrate partially through the canopy of trees and other vegetation, reaching up to the ground surface. Reflections of the latter pulses from the terrain reach the receiver the latest, thus becoming a basis for determining the real morphology of the terrain surface (Fryskowska 2011). The advantage of the LIDAR method for creating a digital terrain model (DEM) is the ability of data acquisition regardless of the natural light

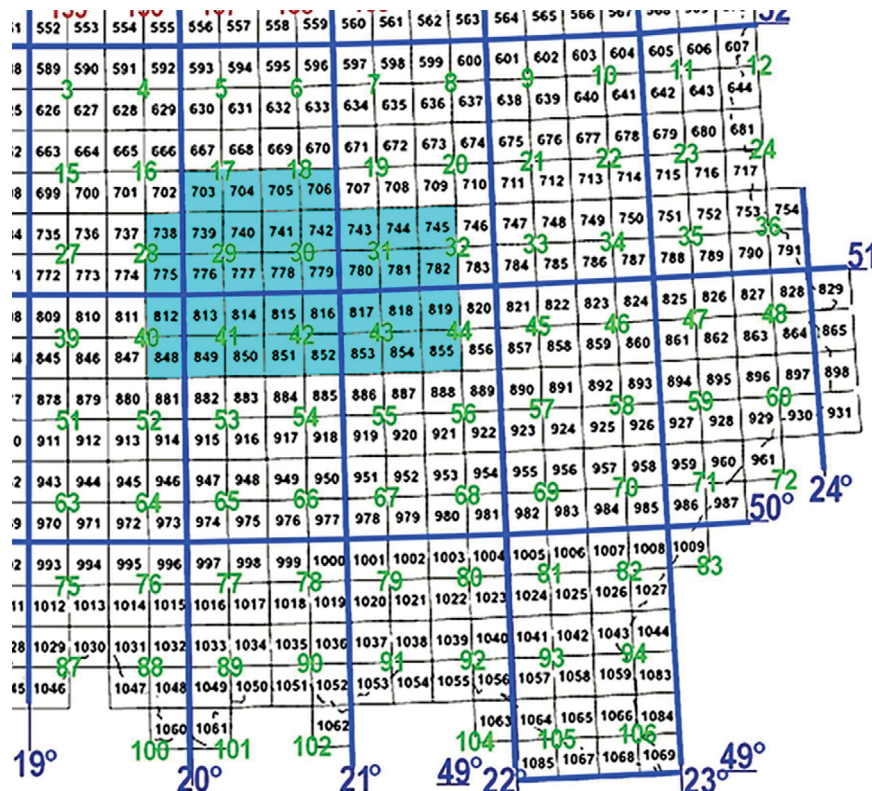


Fig. 2. Location of the area in SE Poland subjected to DEM analysis; topographic map sheets on a scale of 1: 100,000 are marked with green numbers; boundaries of 10'×15' sheets of the SMGP on scale 1: 50,000 are marked with black numbers; 1° geographical grid is outlined in blue

Rys. 2. Lokalizacja obszaru w południowo-wschodniej Polsce poddanej analizie WMT; arkusze map topograficznych w skali 1: 100 000 oznaczone są zielonymi numerami; granice arkuszy SMGP o wymiarach 10'×15' w skali 1:50 000 oznaczono czarnymi numerami; siatka geograficzna 1° jest zaznaczona na niebiesko



condition, significant independence from the weather condition except for fog and low clouds, the high accuracy as the estimated error of the average height does not exceed 0.2 m, and the short time of data processing, under a relatively low cost of data acquisition.

Over the past several years, LIDAR data has been circulated in archaeological, geomorphological, agricultural and forestry sciences, and various specialized processing programs have been invented. In geology, LIDAR DEM data is already used in geomorphological analyses. This applies primarily to pursuing the development dynamics and distribution pattern of river channels, sand dunes, and their complexes. This new research tool also seems very promising in studies and assessments of erosion and landslide areas, both in registering the extent of existing features and in determining the potential risk of their further development. Up to now, however, there are generally fewer reports regarding the application of DEM in geological studies. Nevertheless, the DEM becomes sporadically applied into studies of land's geodynamical phenomena, their history, and, foreseeable, changes in their surficial intensity (Ostaficzuk 2019).

Awareness of the advantages and possibilities of using LIDAR DEMs inspired the author's interest in the bit traces of former mining activity in the northern outskirts of the Holy Cross Mountains. The main objects of interest were the terrain historical manifestations of the iron ore mining works for, supposedly, local needs. The DEM representation of the area covered by 36 sheets of the Detailed Geological Map of Poland in scale 1:50,000 (SMGP, Figure 2, Table 1.) was analyzed in enlargement up to 1:3,000 scale.

Table 1. Summary of analyzed terrains covered by SMGP sheets on a scale of 1:50 000 from the northern periphery of the Holy Cross Mountains

Tabela 1. Zestawienie zanalizowanych arkuszy SMGP w skali 1:50 000 z północnego obrzeżenia Gór Świętokrzyskich

	703 Sławno –	704 Opoczno ***	705 Przysucha *	706 Przytyk –			
738 Lubień *	739 Żarnów **	740 Końskie ***	741 Niekłań *****	742 Szydłowiec **	743 Wierzbica –	744 Skaryszew –	745 Ciepielew –
775 Przedbórz –	776 Czermno ***	777 Radoszyce **	778 Odrowąż ****	779 Skarżysko- -Kamienna ****	780 Starachowice ***	781 Sienno –	782 Lipsko –
812 Włoszczowa –	813 Oleszno *	814 Piekoszów –	815 Kielce –	816 Bodzentyn –	817 Nowa Słupia ***	818 Ostrowiec Świętokrzyski ***	819 Ożarów *
848 Secemin –	849 Nagłowice –	850 Chęciny –	851 Morawica –	852 Daleszyce –	853 Łagów –	854 Opatów –	855 Sandomierz –

Each cell contains the serial standard sheet number and name.

Marks: – no signs of iron ore mining fields within the area covered by the given sheet;

\* up to 2 mining fields; \*\* from 2 to 5 mining fields; \*\*\* from 5 to 10 mining; \*\*\*\* above 10 mining fields.

The terrains of SMGP sheets on the following scale 1: 50,000, were geologically mapped over 60 years, the oldest (78 Odrowąż was mapped in 1955 by Krajewski (Krajewski 1955) and verified in 2017 by Złonkiewicz (Złonkiewicz 2017)), the newest (777 Radoszyce verified in 2009 by Kwapisz et al. (Kwapisz et al. 2009)). The formal mapping instructions and guidelines for authors obviously changed with such a long passage of time. Different stratigraphic units and lithostratigraphic profiles became defined in a different way, which is exemplified by comparing the geological units of the archival Odrowąż sheet with the newest study by Złonkiewicz (Złonkiewicz 2019). The authors of maps treated the traces of historical mining with special care. Some neglected, much older publications, which contained notes on the localization of abandoned mines (Samsonowicz 1928, 1929; Kleczkowski 1970). That was partly due to the usual exclusion of past-mining areas from agricultural use, thus overgrown with bush and trees seemed less interesting, and were less accessible for standard mapping procedures. Such obstacles are insignificant for the remote sensing geological cartography based on the detailed DEM derived from LIDAR data.

## 2. Traces of historical underground iron ore mining detectable on DEMs

The iron ore mining operations in the Holy Cross Mountains were carried out either open-cast or underground. Underground mining was implemented for many years with gradually deepening shafts. The oldest underground mining, up to 30 m deep, dated I<sup>st</sup>–II<sup>nd</sup> century AD was documented in Rudki (Bielenin 1992). However, the oldest Medieval traces of underground mining (about XI<sup>th</sup> century) are known from the environs of Żarnów and Skrzynno on the terrain of SMGP sheet Żarnów. More consistent historical data came from the XVI<sup>th</sup> century (Krajewski 1947). It was, however, only in the XX<sup>th</sup> century that extraction galleries with central shaft become functional in iron ore mining. The “Multi shaft” method was applied in different variants, with accompanying short galleries (Maciejasz 1954).

On LIDAR DEMs, each shaft place is marked by surrounded, clearly perceptible piles of dug leftovers – a waste of mining spoil. Mining fields with clusters of heaps with post-shaft hollows differ in the size of individual heaps and their spatial arrangement within the mining field and around former shafts. Their classification was made by analyzing DEM images by covering the terrain area of 36 SMGP sheets, enlarged linearly up to 1: 3,000. The Global Mapper program used by authors allowed for a presentation of the mining fields in a variable graphic manner. Due to need of analyzing, some were imaged in hypsometry colors, while others in shadows of gray varying with height and azimuth of light direction. Some portions of the DEM were presented in a combination of both color and grey shadows. Finally, the four types of mine heaps with remnants of former shafts were identified on the base of their shape, size, and distribution pattern upon the minefield.

**Type I heaps and shaft hollows:** they are small heaps surrounding central depressions remained after the mine shaft; type I objects are usually grouped in several dozens to

several hundred, and in places up to several thousand gatherings. Precisely, 1,720 objects were counted on one of the minefields covering an area of 16 ha. These heaps are less than 1 m high and their diameter varies from 10 to 15 m (Figure 3). In places, heaps of individual shafts overlap. Based on sizes, it can be assumed that the shafts were relatively shallow, not exceeding 7 m in depth. Elsewhere an increase of heaps size upslope was noted, which became the basis for distinguishing Ia and Ib subtypes (Figures 4 and 5). The overlap of

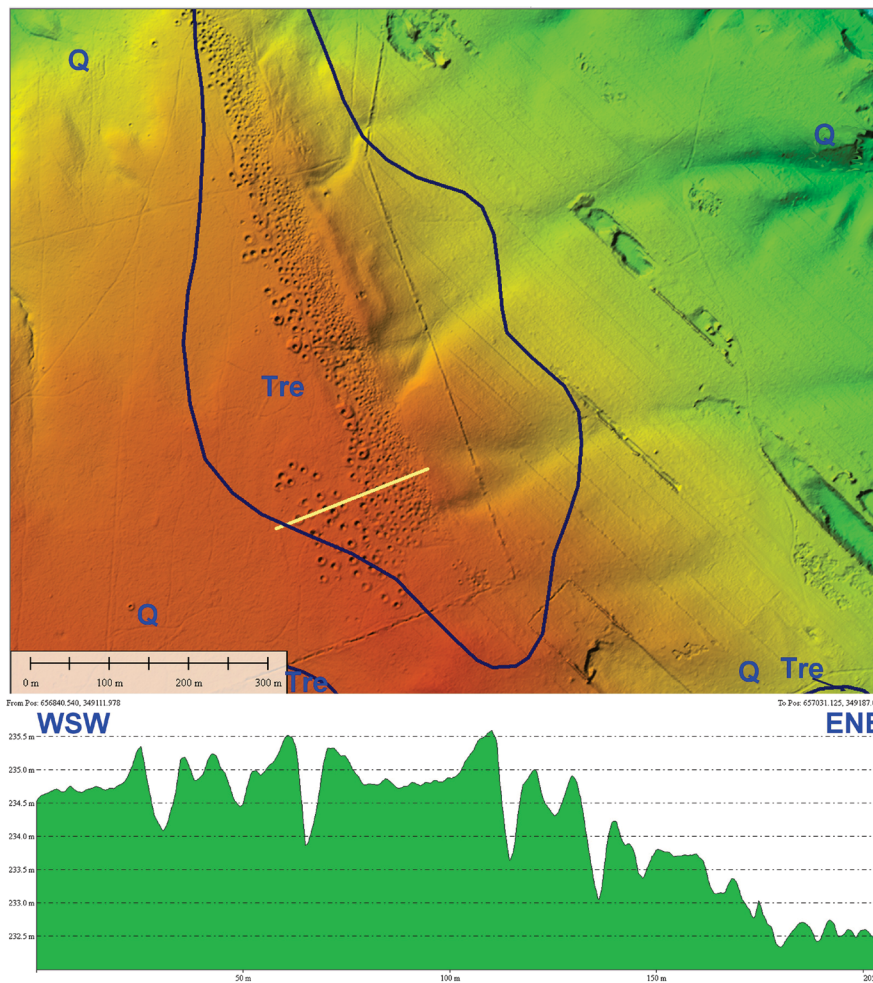


Fig. 3. The DEM of a terrain portion of the SMGP Nowa Słupia sheet bearing a minefield with type I heaps and post shaft hollows within the outcropping of Upper Triassic – Rhetian formations between the villages Rudnik and Nietulisko Duże; (Tre – Rhetian) clays, conglomerates, and sandstones; (Q) Quaternary deposits; below: morphological profile along a yellow line marked on DEM

Rys. 3. Wysokościowy model terenu fragmentu arkusza Nowa Słupia, pomiędzy wsiami Rudnik a Nietulisko Duże, typ I hałd i zagłębień poszybikowych na wychodniach utworów górnego triasu – retyku (Tre – ły, zlepierce i piaskowce), wokół utwory czwartorzędowe (Q), niżej profil morfologiczny wzdłuż zaznaczonej żółtej linii na WMT

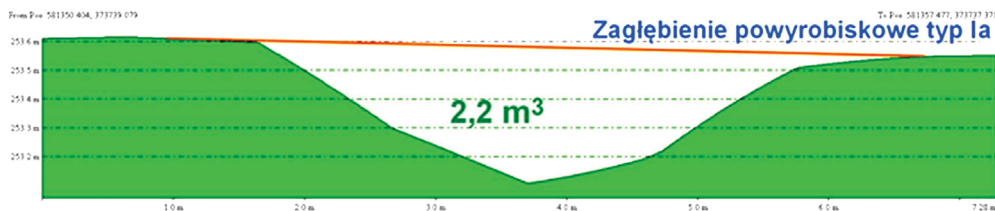


Fig. 4. Morphological profile of the type Ia hollow of 2.2 m<sup>3</sup> in volume, 6 m in diameter, and 0.5 m in depth

Rys. 4. Profil morfologiczny zagłębienia typu Ia o wymiarach 2,2 m<sup>3</sup> objętości, 6 m średnicy i 0,5 m głębokości

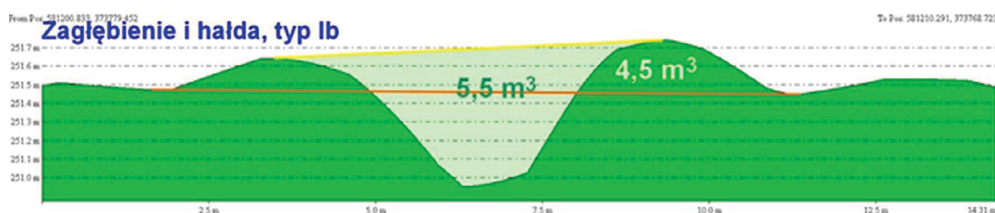


Fig. 5. Morphological profile of the heap and hollow of type Ib of 5.5 m<sup>3</sup> in volume, 4.5 m<sup>3</sup> of heap volume, heap diameter 8 m on average, and hollow depth of 0.6 m

Rys. 5. Charakterystyka morfologiczna hałdy i zagłębienia typu Ib o objętości 5,5 m<sup>3</sup>, kubaturze 4,5 m<sup>3</sup>, średnicy pryzmy średnio 8 m i głębokości urobku 0,6 m

a SMGP image upon the DEM exposes the relationship between the location of mining fields of shafts of all types with the productive strata outcrops in the Mesozoic formations. In many places, the type I shaft area is significantly degraded, the outline of individual objects blurred. The morphological profile sections with metric dimensions of type I heaps and hollows are shown in Figures 4 and 5.

**Type II** represents of relatively fresh morphology of heaps and post-shaft hollows of variable sizes, display arrangement, as well. These were, undoubtedly, deeper shafts than that of type I shafts, which reached up to several meters depth. In type II the centrally located shafts were surrounded by greater heaps, as their today's remnant dimensions are of several dozen centimeters to about 2 m in height, and a dozen to 30 m in diameter. The central location of the post-shaft hollows indicates the extraction mining spoil – the waste and ore to the surface by containers transported manually by miners or, at most, by a windlass sited above the shaft (Figure 6). These type II shafts and heaps often occur together with the type I heaps and shafts. They seem to be the continuation of ore exploration and extraction in ore level zones at a greater depth but, still at a short distance from the shaft. In places, single shafts with heaps of type II overlap the type I heaps zone, which clearly indicates their younger age. Usually, the arrangement of type II objects is chaotic, but in places, they seem



sited along the intentionally positioned lines (Figure 6); according to morphological profiles the shafts were interconnected underground by galleries, because from the morphological profiles it follows that the shafts were connected to the pavements because there is more waste material than the supposed volume of sole shafts. After-shaft terrain hollows bottoms are located well above the terrain surface, as marked by the yellow line in Figure 7.

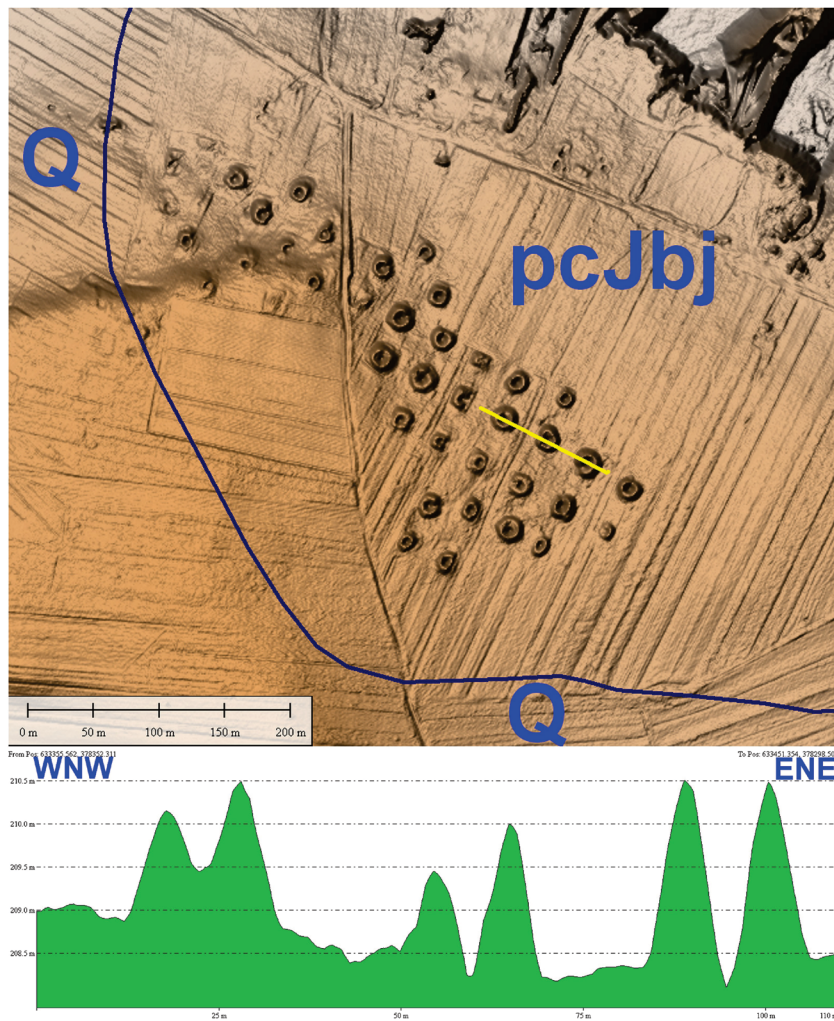


Fig. 6. The DEM of a terrain portion of the SMGP Szydłowiec sheet near village Chustki, showing the orderly distribution of type II heaps upon the subcropping Bajocian (pcJbj) sandstones, mudstones and claystones; blue line – geological boundary; (Q) – Quaternary deposits; below: morphological profile along the yellow line marked on DEM

Rys. 6. Wysokościowy model terenu fragmentu arkusza Szydłowiec SMGP, okolice wsi Chustki, hały szybików typu II, na wychodniach utworów bajosu (pcJbj) – piaskowce, mułowce i iłowce, (bajos) oddzielone niebieską linią od utworów czwartorzędowych (Q), niżej: profil morfologiczny wykonany wzdłuż żółtej linii zaznaczonej na WMT

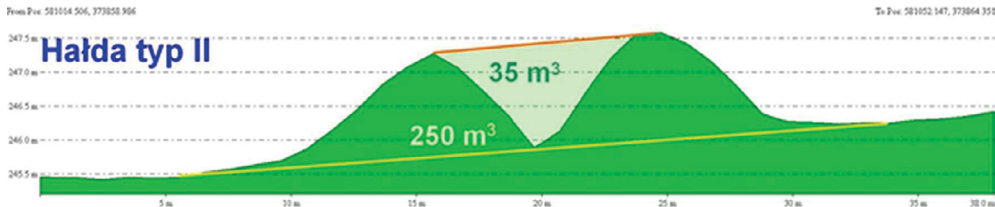


Fig. 7. Type II heap and post-shaft hollow; a volume of mining waste heap is  $250 \text{ m}^3$ , a volume of the hollow is  $35 \text{ m}^3$ , a total volume of mining waste material without extracted iron ore was at least  $285 \text{ m}^3$

Rys. 7. Hałda typu II i zagłębienie poszybowe; kubatura hałdy  $250 \text{ m}^3$ , kubatura niecki  $35 \text{ m}^3$ , oraz  $285 \text{ m}^3$  ogółem odpadów górniczych bez wydobytej rudy żelaza

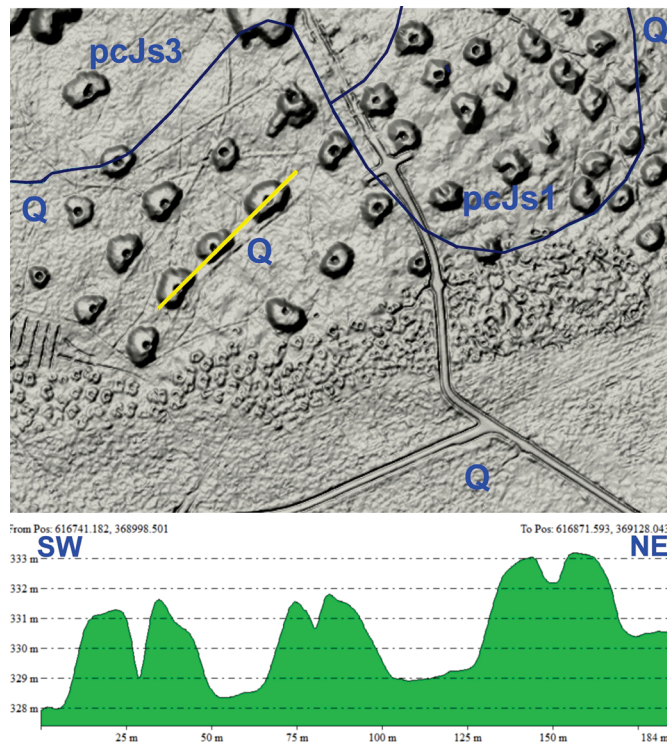


Fig. 8. The DEM of a portion of the SMGP Niekłań sheet, the “Piekło” mine, forest area on the East of Niekłań Wielki, covered with type III heaps and hollows in the upper part of the image; on the right, behind the road are heaps and hollows of type II and III of, probably, an older period of mining activity; lower part of the presented DEM image is covered by the oldest part of mining activity traces; blue lines separate the outcrops of Lower Jurassic (pcJs3 – Ostrowiecka Formation, pcJs1 – Przysuska Ore Formation) and Quaternary deposits (Q); below: morphological profile along a yellow line marked on DEM

Rys. 8. Wysokościowy model terenu fragmentu arkusza Niekłań, kopalnia „Piekło”, teren leśny na E od Niekłań Wielki, hałdy i zagłębienia typu III w lewej górnej części, za drogą w części prawej hałdy i zagłębienia typu II i III, prawdopodobnie ze starszej fazy eksploatacji, w dolnej partii najstarsze hałdy typu I, zdegradowane, na utworach dolnej jury (pcJs3 – formacja ostrowiecka, pcJs1 – przysuska formacja rudonośna) oddzielonych niebieską linią od utworów czwartorzędowych (Q), poniżej: profil morfologiczny wykonany wzdłuż żółtej linii na WMT

**Type III** heaps and shaft hollows represent the deepest mining, exceeding 30 m (the Piekło mine, [Krajewski 1947](#)). Heaps of this type surround the after-shaft hollows from three sides in most cases. The height of these heaps is within a range of 3 m above the natural ground surface, their terrain extent is up to 50 m. The arrangement of the heaps and shaft hollows is mostly ordered along the given lines (Figure 8). This indicates competence in designing the mining works and their consistent implementation. The type III units co-occur with heaps and shaft hollows of type II and type I occasionally. They are often located at the culmination of the hills, the lower parts of which are occupied by type I shafts, currently heavily degraded.

The type III heaps and post shaft hollows differ significantly in size, depending on their location in a specific field, or due to physiographical differences within mining fields (Figures 9, 10, and 11). Type III heaps are, usually, settled on three sides around the after-the-shaft hollows. The customary leaving one side free of a waste heap can be explained by the necessity of providing easy access to an active shaft. It should be assumed that this involved the use of mechanical hoisting devices. Some of the mining areas with heaps and hollows are, sporadically, supplemented by the outside heaps, which may evidence a greater depth

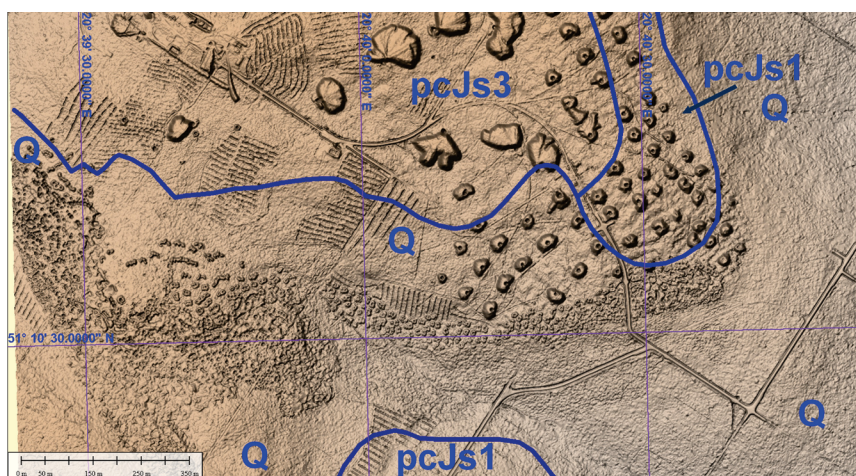


Fig. 9. The DEM of mining field with type III heaps and post shaft hollows of variable sizes, accompanied with rosette heaps, and a type Ia, and Ib heaps with shaft hollows; the differences in the diameter and the shape of heaps are clearly visible; next to and below the type III objects are older, heavily degraded the type Ia and Ib heaps and shaft hollows; in the upper part of the image are the youngest waste heaps piled up by conveyor belts nearby the Niekłań Wielki, the terrain of SMGP Niekłań sheet. Blue lines separate the outcrops of Lower Jurassic (pcJs3 – Ostrowiecka Formation, pcJs1 – Przysuska Ore Formation) and Quaternary deposits (Q).

Rys. 9. Wysokościowy model terenu z hałdami i zagłębieniami poszybikowymi typu III, wyraźnie widoczne jest zróżnicowanie średnic hałd i ich kształtów; obok i poniżej na tym samym polu są inne, starsze, mocno zdegradowane hałdy i zagłębienia poszybikowe typu Ia i Ib, a u góry obrazka widoczne są znacznie młodsze hałdy, sypane z taśmociągów.

Arkusz Niekłań SMGP, okolice Niekłania Wielkiego. Niebieska linia oddziela wschodnie dolnej jury (pcJs3 – formacja ostrowiecka, pcJs1 – przysuska formacja rudonośna) i osadów czwartorzędowych (Q)



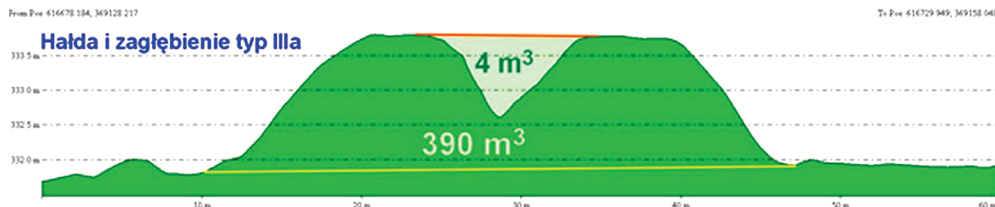


Fig. 10. Profile showing the type IIIa, a typical mining waste heap with small post shaft hollow, the volume of heap 390 m<sup>3</sup>, 30 m in diameter and 3 m height, the volume of the hollow is 4 m<sup>3</sup> and diameter 7 m at top opening; yellow line marks original terrain surface

Rys. 10. Profil przedstawiający typ IIIa, typowa hałda górnicza z niewielkim zagłębieniem poszybowym, kubatura przyzmy 390 m<sup>3</sup>, średnica 30 m, wysokość 3 m, objętość zagłębienia 4 m<sup>3</sup> i średnica 7 m w górnym zagłębieniu; żółta linia wyznacza oryginalną powierzchnię terenu

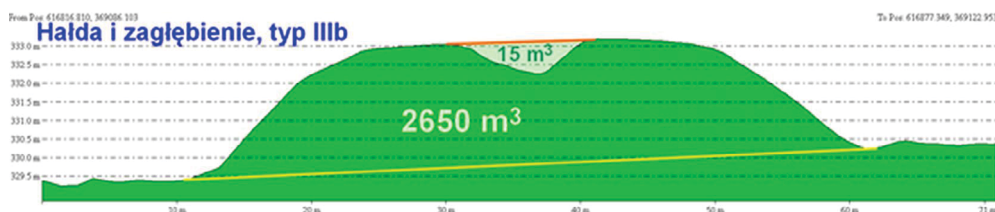


Fig. 11. Profile crossing the type IIIb, large heap with relatively small post shaft hollow; heap volume 2650 m<sup>3</sup>, 55 m in diameter and 3.5 m height, a hollow volume is 15 m<sup>3</sup>, diameter 10 m, and about 1 m depth

Rys. 11. Profil przecinający typ IIIb, duża hałda ze stosunkowo niewielkim zagłębieniem poszybowym; objętość hałdy 2650 m<sup>3</sup>, średnica 55 m, wysokość 3,5 m, kubatura 15 m<sup>3</sup>, średnica 10 m, głębokość około 1 m

of mining and/or bigger galleries dug down underground. Mining waste heaps of a rosette shape, greater and freshly looking than oval ones, appear rather rarely. This may be the result of mining with direct accessible dip-heading galleries; the height of the heaps near the openings of such supposed galleries reaches 4 m.

Heaps and shaft hollows of the uncommon structure were discovered, and tentatively named **Type IV** shafts (Figure 12) were found in the Stąporków area, in the vicinity of the Błotnica village, and close to Osicowa Góra on the terrain of the SMGP Odrowąż sheet. Heaps of up to 1.5 m high surround double shaft hollows, a greater axis of oval-shaped heaps are about 20 meters long.

Analogue type IV heaps with doubled hollows were found in Stara Góra within the SMGP Niekłań sheet only. The purpose of drilling two shafts close one to another is unclear. One may guess that the pair played a role, split into the spoil extraction purpose shaft, and the ventilation, drainage, and communication shaft.

The four type of remnants of iron ore mining presented above reflect the prevailing ways of obtaining raw materials for the iron industry. There are, however, various intermediate



terrain forms of historical connotations, dependable of physiography, geological settings, and iron ore properties and the last but not least, local state of mining technology i.e. social conditions and development of technical civilization. Mining shaft assemblies of varying sizes grouped tightly without an apparent order, and some heavily degraded, are present. Apart from the four types of heaps with hollows representing obvious exploitation entities, some of such objects found were sited quite apart from each other, along straight lines. These regularly displayed shafts with heaps respond to lines of reconnaissance and exploratory drillings (Figure 13) appropriate to the work order applicable up to the middle of the XX<sup>th</sup> century.

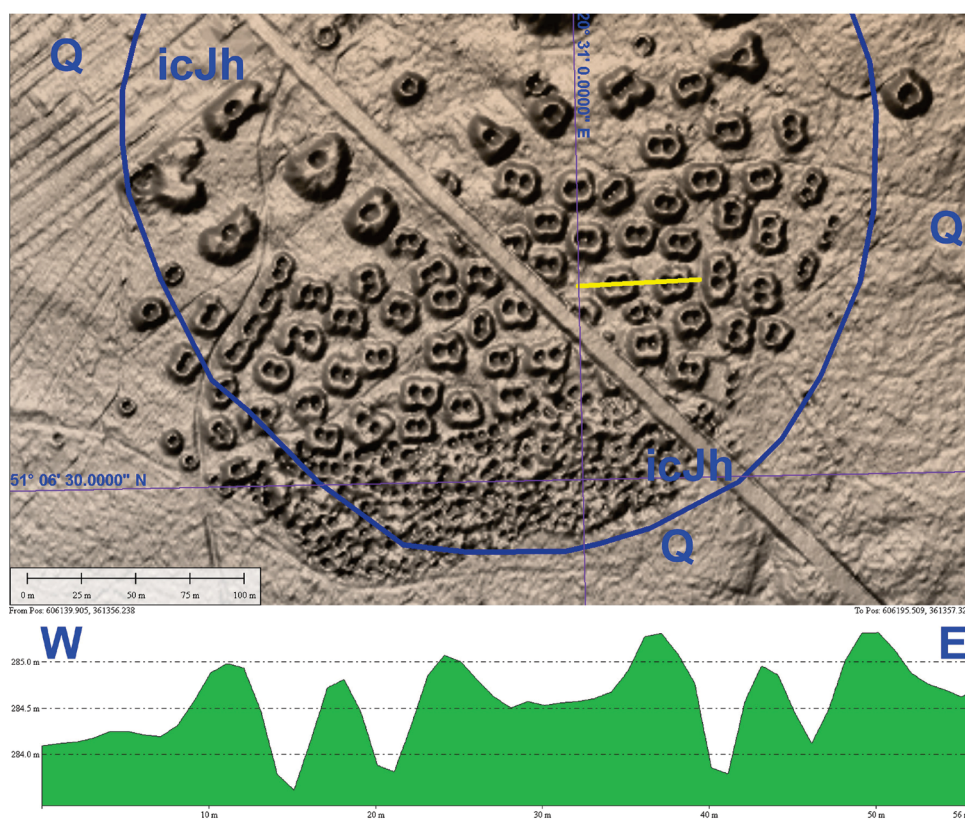


Fig. 12. A DEM of a portion of the terrain covered by the SMGP Odrowąż sheet, nearby the Błotnica village; an array of heaps of type IV, with doubled “composite” shaft hollows in the mining field is accompanied downslope by a cluster of type I heaps with hollows, and upslope by numerous type II heaps and hollows, visible on the left at the top of the picture; outcrops of the Lower Jurassic deposits (icJh – Przysuska Ore Formation) separated by a blue line from Quaternary deposits (Q); below: morphological profile crossing over two typical type IV objects along a yellow line marked on DEM

Rys. 12. Wysokościowy model terenu fragmentu arkusza Odrowąż SMGP, okolice wsi Błotnica; w centrum hałdy i szybiki typu IV „zespolone”, wokół szybiki typu I (na dole) i II (powyżej), wychodnie osadów dolnej jury ( icJh – przysuska formacja rudonośna) oddzielone niebieską linią od osadów czwartorzędowych (Q), niżej: profil morfologiczny przecinający dwie typowe hałdy typu IV wzdłuż żółtej linii zaznaczonej na WMT

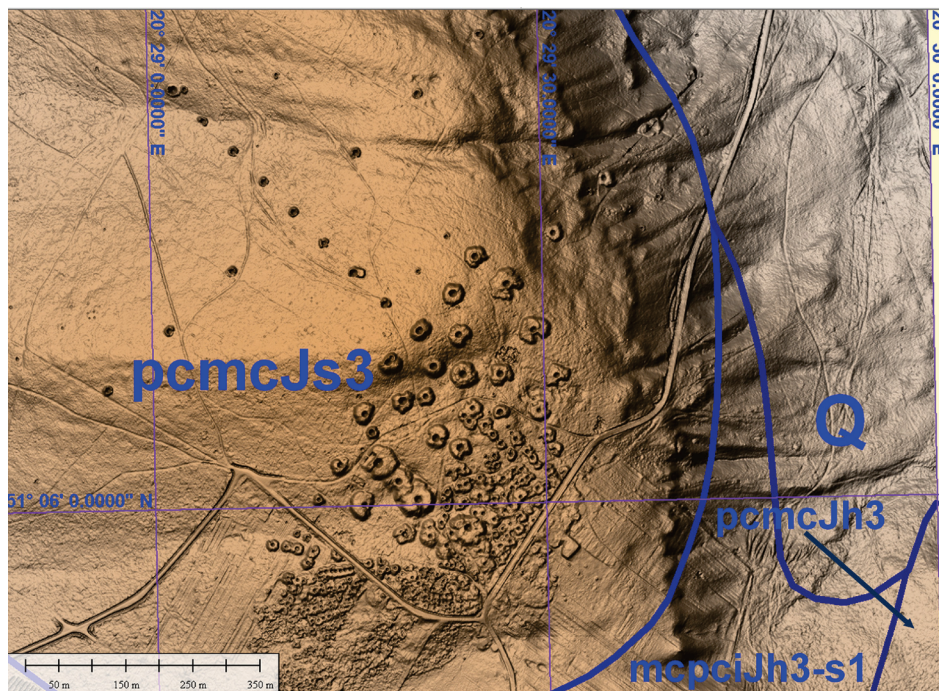


Fig. 13. DEM covering part of the SMGP Radoszyce sheet area, in the vicinity of the village Kamienna Wola; strips of reconnaissance shafts in the NW part of the image, next to the mining field with heaps and hollows of type I and II within the outcrops of Lower Jurassic deposits (pcmcJs3 – Ostrowiecka Formation, mcpclJh3-s1 – Przysuska Ore Formation) separated by a blue line from Quaternary deposits (Q)

Rys. 13. Wysokościowy model terenu fragmentu arkusza Radoszyce SMGP, okolice wsi Kamienna Wola, szybiki zwiadowcze w NW części modelu, obok pola górniczego z szybkami typu I i II na wychodniach utworów dolnej jury (pcmcJs3 – formacja ostrowiecka, mcpclJh3-s1 – przysuska formacja rudonośna) oddzielonych niebieską linią od osadów czwartorzędowych (Q)

### 3. Comparison of the geological setting of iron ore bearing formations in the Mesozoic peripheries of the Holy Cross Mountains with the DEM manifestation of historical mining activities

The detailed description of ore deposits geology by Krajewski (Krajewski 1947, 1960) and Kleczkowski (Kleczkowski 1970) still remains a reference base for the recent authors of geological maps of the Holy Cross Mountains region. According to the analysis of the detailed geological maps, mostly of SMGP series sheets, the iron ore mining works, in general, carried out in the Mesozoic formations at the northern peripheries of the Holy Cross Mountains, where the siderites ( $\text{FeCO}_3$ ) outcrop. They occur in many stratigraphic levels, primarily in the layers of the Lower Jurassic, although, to a lesser extent, also in the Middle Jurassic, and in the Lower and Upper Triassic (Table 2). Siderite iron ores form, both,

Table 2. Mesozoic formations with ore horizons at the northern peripherals of the Holy Cross Mountains

Tabela 2. Utwory mezozoiczne z horyzontami rudnymi w północnym obrzeżeniu Gór Świętokrzyskich

Stratigraphy			Lithostratigraphic or lithological units	Form of iron ore occurrence	Map sheets covering an area of iron ore mining studies	
Jurassic	Middle	Bajocian	Middle + Upper (Kujawian)	Sandstones, claystones, mudstones and shales	Siderite insets and nodules	Końskie, Szydłowiec
			Lower	Sandstones, clays and shales	Siderite insets and nodules	–
		Aalenian + Lower Bajocian		Sandstones, claystones and shales	Siderite insets	Końskie, Żarnów
	Lower	Toarsian	Upper	Borucicka Formation	Siderite spherulites and siderite impregnation	Żarnów
			Lower	Ciechocińska Formation	Siderite insets	Czermno, Końskie
		Pliensbachian	Lower	Gielniowska Formation	Siderite insets	Końskie, Opoczno
		Sinemurian	Upper	Ostrowiecka Formation (former Żarnowska Series)	Siderite insets, ferruginous concretions	Końskie, Niekłań, Odrowąż, Przysucha
			Lower	Przysuska Ore Formation, (former Zarzecka Series, Ores Series)	Two (locally three) siderite seams	Czermno, Końskie, Niekłań, Odrowąż, Opoczno, Ostrowiec Świętokrzyski, Przysucha, Radoszyce, Skarżysko-Kamienna, Starachowice, Szydłowiec, Żarnów
		Hetangian	Upper	Skłobka Formation (f. Gromadzicka Series)	Siderite insets, sphaerosiderites	Końskie, Opoczno, Radoszyce
			Lower	Zagajska Formation (f. Coal-ores Series)	Siderite insets	Odrowąż, Starachowice
	Triassic	Upper	Rhetian	Motley claystones and mudstones	Siderite insets	Skarżysko-Kamienna, Słupia Nowa, Starachowice
		Lower	Upper (Rot)	Dalejów Beds – former Ores Level	Siderite insets locally siderite seams	Odrowąż, Skarżysko-Kamienna, Słupia Nowa, Starachowice

According to: (Krajewski 1947, 1960; Kleczkowski 1970), with later modifications in the explanations to the SMGP.



the pay ore strata, the nodules, or brown panes concentrated in clayey beds. In weathering zones, siderites are accompanied by limonite i.e. amorphous or a cryptocrystalline mixture of iron hydrous ferric oxides, mainly goethite and lepidocrocite, of the generalized formula  $\text{Fe}_2\text{O}_3\text{nH}_2\text{O}$ . Beds containing siderites deposited under specific conditions, partially in small marine basins, separated embayments, and lagoons. Others were formed on coastal floodplains, in swampy lakes and marshes. Hence, most of the ore the occurrence is of a local nature, while extensive ore-bearing beds are scarce. Growing import availability of much richer iron ores, and continuing change in the economic criteria, the ore deposits of a limited extent gradually become eliminated from the formal Resource Balance Sheets and ceased to exist in the late 1990s (Niec 2001). Only traces of the old mining of iron in the Mesozoic formations at the peripheries of the Holy Cross Mountains have been recorded in various lithostratigraphic units by Samsonowicz (Samsonowicz 1928, 1929), Krajewski (Krajewski 1947) and Kleczkowski (Kleczkowski 1970).

In the Triassic, siderites were mined in the Rot (informal, local name for the uppermost part of the Upper Bunter Sandstone, the upper part of the Olenekian). Kleczkowski (Kleczkowski 1970) divided the Rhetian profile into four parts. In the upper part, he selected a siderite ore horizon, now called the Dalejow beds (Zlonkiewicz 2019). The Rot forms a discontinuous lenticular packet, with iron ores occurring in two stratigraphic levels. The lower ore level, 0.15 to 0.90 m thick contains partially oxidized sideritic iron ore, and the higher, 0.15–0.20 m contains limonite ore. Up to three pay plays of iron ore: the lower 0.6 m thick, the middle 0.2 m thick, and the uppermost 0.4 to 0.6 m thick may appear even locally (as e.g. in the vicinity of the village Jastrzębia). Type I and II heaps with shaft hollows in the area covered by the SMGP Odrowąż sheet, where about a dozen mining fields were found on DEM images, especially in the Świnia Góra and vicinity are associated with these Rot Formations. Excavating was equally intensive in the SMGP Skarżysko-Kamienna sheet area. Few post-mining fields were located on the Nowa Słupia sheet near the Jabłonna village, and in the southern part of Starachowice town. It should be emphasized that only type I and II heaps with shaft hollows, mostly degraded, appear upon the Rot outcroppings.

The Upper Triassic (Keuper) pay iron ore strata appears in, probably Rhaetian, Formations of claystone, and mottled clays with alternate inliers of sandstone, mudstone and sandy mudstone, pseudoolites and siderites (Studencki 1993; Zlonkiewicz 2019). Traces of mining of the Upper Triassic deposits in the form of type I heaps with shaft hollows were found on the terrain of the SMGP Nowa Słupia sheet within the Kamienna River Valley, on the terrain of the SMGP Skarżysko-Kamienna sheet in the vicinity of the Wielka Wieś village, and on the terrain of the SMGP Starachowice sheet in the vicinity of the Adamów the Second (Drugi) village. As in the Lower Triassic strata mining, the all historical mining traces spotted on DEM images of the Upper Triassic outcropping area are mostly type I, and sporadically type II mining objects.

Krajewski (Krajewski 1947, 1960) has synthesized a litho-stratigraphic profile of a higher part of the Lower Jurassic sediments in the North and North-Eastern margin of the Holy Cross Mountains. That profile was detailed in the following years and formally adjusted



according to the current nomenclature, which was reflected in explanations to the Detailed Geological Map of Poland (SMGP) in scale 1:50,000 of that area. A few traces of iron ore mining were found on DEM images covering outcrops of the Zagajska (Hettangian) Formation on the area of the Lower Jurassic Formations outcrops, earlier known as the Coal-Ore Series (Krajewski 1947). Type I heaps with shaft hollows on the outcrop of this series were spotted only on the terrain of the SMGP Starachowice sheet within the Adamów village area and just ten type II shafts on the SMGP Odrowąż sheet terrain near the Adamów Drugi village (Mniów borough) remain. Hettangian deposits within the Skłobska Formation (former Gromadzicka Series) of sandstone with mudstone and claystone inliers, siderite panels and sphaeroiderites in roof parts (Cieśla et al. 1999) were mined more often. Mining activity on the Radoszyce sheet terrain near Straszów town, where several hundred type I shafts were spotted on DEM images was mainly intensive. These oldest objects were accompanied, and at places overlaid, with type II heaps with shaft hollows (Figure 14).

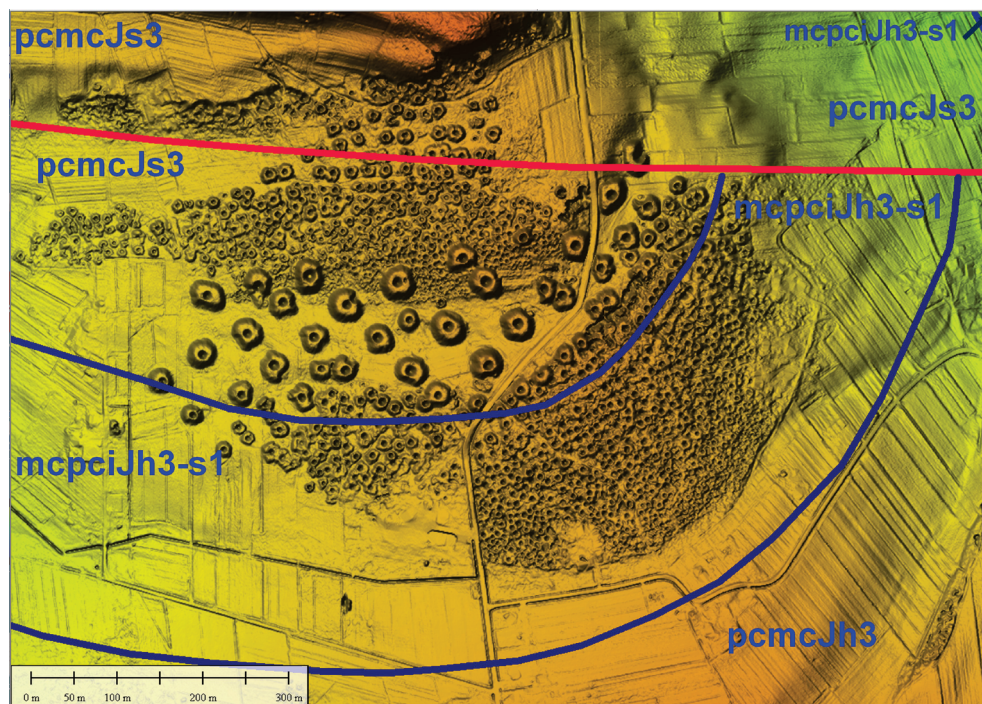


Fig. 14. DEM of a portion of the SMGP Radoszyce sheet territory; type II shafts are superimposing the type I shafts near the Gliniany Las village; outcrops of the Lower Jurassic (pcmcJs3 – Ostrowiecka Formation, mcpciJh3-s1 – Przysuska Ore Formation and pcmcJh3 – Skłobska Formation), separated by a blue line from Quaternary deposits (Q), red – fault line.

Rys. 14. Wysokościowy model terenu fragmentu arkusza Radoszyce SMGP, szybiki typu II nałożone na szybiki typu I, na północ od wsi Gliniany Las, wychodnie utworów dolnej jury (pcmcJs3 – formacja ostrowiecka, mcpciJh3-s1 – przysuska formacja rudonośna i pcmcJh3 – formacja skłobska) oddzielone niebieską linią od osadów czwartorzędowych (Q), czerwona linia – uskok

The type I heaps with shaft hollows occurs on the terrain of the SMGP Opoczno and Końskie sheets, close to the Budki village (Chlewiska borough). The upper layering Przysuska Ore Formation, previously classified as the Zarzecka Series, also called the Ore Series, represents Sinemurian. This is a lithostratigraphic unit characterized by the steadiest appearance of the ore-bearing horizons within the Mesozoic margins of the Holy Cross Mountains. That regularity was at the foundation of many iron ore mines, and the metallurgy development over several centuries. This is a regular iron ore bearing sequence of layers sandwiched between a base and a top of iron ore bearing beds. Clays, clay shales, and mudstones with siderite inliers (the “Cherry ores” Horizon according to [Krajewski 1947](#)) are at the base. The upper ore layer is composed of mudstone-clayey sediments with clayey siderite inliers ([Jurkiewicz 1968](#)). There are known three ore-bearing horizons found on the terrain of the SMGP Niekłań, Końskie, and Starachowice. The third appears in the middle of the Zarzecke Series, called “The Pearl Ore Horizon” ([Krajewski 1947](#); [Cieśla and Lindner 1991](#); [Studencki 1993](#); [Cieśla et al. 1999](#)).

Mining traces of iron ore from the Przysuska Ore Formation are visible on the DEM images of the terrain of eleven SMGP sheets. The outcrops of each ore level there associated mainly with the type I heap and shaft hollows zones, show a characteristic increase in heap dimensions upslope. The higher parts of the terrain are covered by heaps and shaft hollows of type II and IV, while crestal parts of the terrain are covered with the type III heaps and shaft hollows ordered along the parallel lines. At places, these objects are situated outside outcrops of iron ore bearing formations, sitting on younger geological formations, as e.g. the Ostrowiecka Formation (called “The Sandstones of Hell” according to [Krajewski 1947](#)), on a loessial terrain cover, or even on fluvio-glacial Quaternary sands. No doubt, the purpose of digging up these shafts were iron ore horizons within the Przysuska Ore Formation lying below the covering, younger formations.

The dominance of type I and II heaps with shaft hollows is significant in areas covered by the SMGP sheets Skarżysko-Kamienna, Czermno, Radoszyce, Opoczno, and Szydłowiec. Apart from type I and II heaps and shaft hollows, poorly ordered type III heaps and shaft hollows also appear on terrains covered by the SMGP Końskie and Żarnów sheets. Particularly numerous, large and orderly situated type III heaps and shaft hollows are found on terrains covered by the SMGP Starachowice, Odrowąż, Niekłań and Ostrowiec Świętokrzyski sheets. Two horizons of beds bearing siderite ores with ferruginous concretions ([Szajn 1984](#)) are locally developed in the roof sequence of strata in the Ostrowiecka Formation, earlier known as the Żarnowska Series, also representing Sinemurian. It should be stated, however, that often shafts were dug throughout the Ostrowiecka Formation (the “Hell’s Sandstones”, [Krajewski 1947](#)) and were continued down to the ore-bearing horizons in the underlying Przysuska Ore Formation. That certainly applies to several known mining fields on the SMGP Odrowąż sheet (as e.g. Osicowa Góra, Ostrocin in the Stąporków borough) and mines located on the terrain of the SMGP Niekłań sheet (as e.g. the “Piekło” and “Bieliny” mines). Two subsequent lithostratigraphic levels representing Pliensbach occur locally. The older, Gielniowska Formation are sandstones and mudstones with mollusk fauna and places with

clay siderites (Cieśla and Lindner 1991; Warmuzek 1991). A small number of type I shafts were found at DEM from the Opoczno and Końskie sheet area.

The top strata of the Lower Jurassic – Toarcian, is represented by the Ciechocińska Formation, containing sandstones with siderites (Janiec 1993; Studencki 1993). In the vicinity of the Wąsosz village on the terrain covered by the SMGP Czeremno sheet, there are two type I shaft belts with a type IIIa shaft line in between them. An analogous striped arrangement of type I and type II shafts is located near Kuraszaków village (Białaczów borough) on terrain covered by the SMGP Końskie sheet.

In the Middle Jurassic Formations, in Lower Bajocian were mined mudstones with pyrite and, sporadically thin, irregular inliers of clay siderite occur (Studencki 1993). Some traces of iron ore exploitation from these deposits were found on DEM images in the vicinity of the Białaczów and Zakrzów villages on the area covered by the SMGP Końskie sheet, and in the vicinity of Nadole village (Opoczno borough) on an area covered by the SMGP Żarnów sheet, where intensely degraded type I heaps with shaft hollows and, also, traces of opencast mining were identified.

Generally, in the Middle Jurassic the outcrops of Upper Bajocian sandstones and calcareous sandstones with siderites in the weathered zone are sands with interbedding of brown iron ore – limonitic “żelaziak brunatny” (yhr “brown iron ore”) were mined (Studencki 1993). Traces of these mining operations are manifested on DEM images as type II heaps with shaft hollows seen around the Orłów district on the terrain of the SMGP Szydłowiec sheet and, near Parczów village on the terrain of the SMGP Końskie sheet.

The outcrops of the Middle Jurassic Batonian formations are characterized by sandstones, calcareous and dolomitic sandstones with siderites, with inliers of claystone and conglomerates; siderites in a weathering zone, are altering into ferruginous sands with limonitic brown iron ore deposits (Studencki 1993). No heaps, shaft hollows, and any other significant traces of historical mining were found in the DEM images of Batonian outcrop zone. The iron ore concentration in the area of Rudka village, north of the Nowa Słupia town is genetically different. It is the largest accumulation of sulphide iron ore in the Holy Cross Mountain region. Thick vein of mostly marcasite (iron sulfide ore), accompanied by irregular accumulations of siderite, hematite, and local nests of uranium-bearing polymetallic ore, within the Łysogóry N-S fault zone result from hydrothermal processes (Rubinowski 1966; Nieć 1968, 2007). Limonite was also found in the near-surface weathering layer. The “Rudki” Mine exploiting the “Staszic deposit” is the oldest known underground iron ore mine in Poland, operating from the I<sup>st</sup> to the III<sup>rd</sup> century AD (Bielenin 1992, Jochemczyk et al. 2006; Orzechowski 2007). The pyrite deposit in the Rudki was exceptionally important for the iron industry during the Roman impact times. However, according to archival data collected by Nieć (Nieć 2007), the Rudki iron ore deposit mining was surprisingly scarcely documented, despite its importance in the history of mining in the Holy Cross Mountains.

#### 4. Historical aspects of iron ore mining in the Holy Cross Mountain region

The development of iron ore mining powered concurrently emerging iron metallurgy. It can even be said that the demand caused the development of both metallurgy and mining. In the studied area, the age-related metallurgy of the Roman times (I<sup>st</sup> century BC – IV<sup>th</sup> century AD) is already documented by archaeological excavations. Most of the geologists believed that the then-contemporary metallurgists were Cotyns, a Celtic-language people, who smelted iron from mined ore, as Tacitus stated in his masterpiece work “Germania” (after Piaskowski 1995). There is also a recent opinion that the metallurgical center of the Holy Cross Mountains was related to the people under the Przeworsk Culture, identified as Vandals. The following recess of metallurgy and related mining after the IV<sup>th</sup> century AD was the result of the Goth invasion and the subsequent migration of people caused by the invasion of the Huns (Niec 2007). During the Early Middle Ages, called the migration era, the iron production in the Holy Cross Mountains region disappeared completely. Archaeologists have suggested earlier that iron smelt activity could have been significantly reduced, however, at present archeologists believe in the complete cessation of mining and metallurgical activity (Piaskowski 1986, 1995).

The iron industry and, consequently, ore mining revived in the Middle Ages; traces of mining in the XI<sup>th</sup> century are known from the Żarnów area, near Opoczno (Janiec 1993). According to Samsonowicz (Samsonowicz 1928, 1929), the mining of iron ore began in the XV<sup>th</sup> century in the Dalejowo Beds, the SMGP Starachowice sheet, representing the highest part of the Upper Bunter Sandstone (Rot), and lasted until the mid-XIX<sup>th</sup> century. The remnant traces of mining activity are preserved and observable on DEM images in a form of chaotic arrangement of small type II heaps and shaft hollows near Krynki village.

Much intensive mining in the Holy Cross Mountains lasted from 1865 to the end of the XIX<sup>th</sup> century. The increasing import of the Krzywoskie ores, and a special railway tariff policy were a cause of the economic collapse of most mines at the beginning of the XX<sup>th</sup> century. A temporary better economic situation for the iron ore mining in the Holy Cross Mountains region occurred after World War I, until 1925 when the mines were successively liquidated. Re-interest in the Holy Cross Mountains iron ore raised in the years 1937–1939, a series of exploration and documentation drillings were carried out, resulting in the opening of two mines named “Edward” and “Stanisław” in Czarniecka Góra. World War II has ruined the plans of reactivation of the mining and metallurgy industry; the already existing mines were becoming overexploited and robbed of valuable gears during the occupation (Krajewski 1947). As it was already stated, several mines were still active after World War II.

There seems to be a reasonable opinion that the higher the level of technology, the deeper the sinking shafts are drilled and the higher and the larger is the surface of the waste material around the shaft. Undoubtedly, mechanized methods of mining output were advancing continuously. The use of horse treadmills and later also electric hoisting devices resulted in stacking heaps from three sides of the shaft, and the fourth served as the location



of the winch and other technical devices, and allowed miners easier access to the shaft. Unfortunately, the archive and published material resources are modest in relation to the deep mines operating in the past, documenting their operating time, mining techniques used, staffing, ventilation methods, drainage methods, and dredge transport. Recent attempts to connect contemporary discoverable shafts with the historical periods, based on both archival queries and field research, concern small fragments of the area (Kaptur 2014; Młodawski 2017; Kuszta et al. 2020), and to a small extent only refer to earlier works of Samsonowicz (Samsonowicz 1928, 1929), Krajewski (Krajewski 1947) and Kleczkowski (Kleczkowski 1970).

According to the authors, there is no doubt that type III shafts are associated with the late XIX<sup>th</sup> and early XX<sup>th</sup> centuries. This is indicated by the fact that only these types of shafts occur in the area of mines, whose period of operation is formally documented (Krajewski 1947; Kaptur 2014; Młodawski 2017). These are, for example, the “Zygmunt”, “Edmund”, “Janusz”, “Giełdawy” and “Łączki” mines from the Ostrowiec Świętokrzyski SMGP sheet operating at the beginning of the XX<sup>th</sup> century, the “Cecylja”, “Stanisław” and “Edward” mines within the worksheet Odrowąż, and the “Piekło” and “Stara Góra” mines from the Niekłan sheet area.

It can be stated without any doubt that the type I and II shafts represent an older historical period than type III shafts. The latter, in general, are located in known mining areas, with existing written documentation, while the documentation of the former did not survive or did not exist, and in many places are covered by heaps of type III shafts. It, however, is problematic to associate them with a strictly defined historical time, especially since the substantial part could be carried out by artisan and even moonshine methods even at the beginning of the XX<sup>th</sup> century (Maciejasz 1954). Observations of clusters of type I and II shafts indicate their evolutionary development. In many places, type I shafts increase in size towards higher parts of slopes. It can be assumed that the exploitation was started in the outcrop zone and continued until the then technical possibilities allowed for penetration with a shaft of only a few meters of rock overburden. In turn, type II shafts are located a short distance from the outcrops found, which was associated with the necessity of sinking shafts to a depth of at least several meters. Type II shafts with heaps in many places are located in areas previously penetrated by type I shafts (Figures 8 and 14), which clearly indicates their younger age than that of type I shafts. While some evolution in planning and leaving heaps of waste is seen within the mining fields with objects of type I and to some extent type II shafts, then the gap between the period of mining technologies relating to type I and the later mining technologies seems dramatically huge.

Considering the extent of the metallurgical activity conducted there since ancient times, thus iron ore demand, one may suppose that, despite a lack of written documentation, the beginnings of ore mining date back to the Roman period. The views on specialized underground mining in the area of Holy Cross Mountains during the Roman period is supported by a general need for raw iron for the production of weapons at that time and, the state of degradation of some exploitation remnants is decidedly more advanced than others within

a type I facility. Thus, these heavily degraded type I heap and shaft hollows could be as old as the late Roman period. The Roman shafts discovered in Rudki were  $110 \times 175$  cm (Bielenin 1964), but no data is available as to the depth of type I shafts in the areas of siderite ore occurrence and in the area of the functioning of the smelting industry. Assessing mine depth based on the geological intersection and dip is rather unreliable because of the significant local differentiation of deposits. The assessment of shaft sizes based on the size of the shaft wells is difficult and uncertain. It seems that to clarify the issues raised, it would be necessary and highly advisable to carry out archaeological and mining research by teams of researchers from both specializations.

### Summary and conclusions

The preliminary results of remote sensing work based on images of DEM derived from high-resolution LIDAR data may be applied effectively to solve various geological, geomorphological, and mining problems, including a chase for blurred, historical traces of human earthworks. The LIDAR DEM may complement with high precision the standard direct research methods of geological mapping (Ostaficzuk 2019).

Using the Global Mapper program in the construction of DEM of hilly terrains surrounding Paleozoic center of the Holy Cross Mountains, it appears possible to locate areas rich with traces of mining works in the long historical period from the early Medieval times to the 1970s. Whether some of the localized surficial traces of underground mining may be associated with the Roman time period remains debatable. It would be important to extend the presented research data on archeological discoveries of industrial historical complex gatherings of historical iron smelting sites, miners and smelters historical settlements, their communal infrastructure, communication, and transportation overall ways, and the communal dump sites.

The authors classified surface traces of historical mining activity both in terms of their size, location, and arrangements of mining facilities on the basis of estimation of penetration depth of mining works. On this basis, four types of mining facilities were selected in the form of typical heaps and shaft hollows (types I, II, III, IV). It was found that, along with progressing technologies, the technique of sinking shafts and their achievable depth changed. Generally, it can be stated that type II and IV shafts reflect the technical capabilities of older mining, until the mid-XIX<sup>th</sup> century. Type III shafts are associated with the use of more complex devices, as e.g. horse-drawn trolleys and lifts, and later electric treadmills for extracting spoil during the heyday of the Holy Cross Mountains mining activities. Type II and III shafts chosen by the authors have intermediate varieties called “a” and “b” in both types.

The age-related affiliation of type I heaps and shaft hollows still remains controversial. It is difficult to state, which historical period they belong to, based on observation of DEM images only, regardless of their accuracy. Prevailing items of type I should be dated to the

Middle Ages, but some of the type I items are so time-devastated, that it seems supportive to relate them to ancient times. Moreover, the recent appearance age of ancient mining remnants could be affected by artisanal mining activity between World War I and World War II. The final opinion regarding the time of the beginning of type I shafting and the time of replacement of type I shafting technology by type II must be formulated after comprehensive research in cooperation with archeologists specialized in the history of mining. Another problem concerns double shaft heaps. The purpose of digging or drilling two type IV shafts side by side and confirming their function also requires further studies, either by historians of mining technologies or by on-site research work earthworks.

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**HISTORICAL RESIDUES OF IRON ORE MINING IN ENVIRONS OF THE HOLY CROSS MOUNTAINS  
(THE GÓRY ŚWIĘTOKRZYSKIE) ARE RECOGNIZABLE ON THE DIGITAL TERRAIN  
ELEVATION MODEL (DEM) DERIVED FROM THE LIDAR DATA**

**Keywords**

iron ore, LIDAR, digital elevation terrain model, mining shafts, waste heaps

**Abstract**

Based on the analysis of the LIDAR terrain Digital Elevation Model (DEM), traces of opencast and underground mining of iron ore mining were located and classified. They occur in the zone of ore-bearing deposits outcropping on the north-eastern and north-western bounds of the Holy Cross Mountains. The DEM of an area covered by thirty-six (36) standard sheets of the Detailed Geological Map of Poland on a scale of 1:50,000 was thoroughly explored with remote sensing standards. Four types of ore recovery shafts with accompanying waste heaps were classified. The acquired data on the extent of former mining areas, covered with varying shafts and barren rock heaps could make a basis for distinguishing, according to historical data and in cooperation with archaeologists, the historical development stages of today's steel industry. According to general knowledge, the iron industry in Europe instigate dates from the Roman times, in the I<sup>st</sup> century BC to the IV<sup>th</sup> century AD, throughout the earlier and the late medieval times, up to the most recent the 1970ties. The usefulness of the LIDAR method has already been amazingly confirmed in archaeological researches worldwide. Many discoveries of long forgotten, even large entities resulting from human activities in Asia and Central America especially were discovered owed to the LIDAR DEM. Also, traces of human settlements from various historical periods were discovered that way in Poland. The applicability of DEM based on LIDAR data is, in geological studies of surficial geodynamic processes and in geological mapping in Poland, rather contested.

**HISTORYCZNE ŚLADY GÓRNICICTWA RUD ŻELAZA W OBRZEŻENIU  
GÓR ŚWIĘTOKRZYSKICH NA LIDAROWYCH WYSOKOŚCIOWYCH MODELACH TERENU**

## Słowa kluczowe

LIDAR, hałdy, wysokościowy model terenu, rudy żelaza, szybiki eksploatacyjne

## Streszczenie

Pozyskiwanie rud żelaza na terytorium dzisiejszej Polski ma długą tradycję, sprzężoną z transferem z terenów Azji Mniejszej do Europy umiejętności wytapiania żelaza. Według danych archeologicznych żelazo było wytapiane w Europie i na terenie Polski od I wieku p.n.e. Na podstawie analizy lidarowych modeli wysokościowych terenu (WMT) zlokalizowano i sklasyfikowano ślady naziemnej i szybikowej eksploatacji rud żelaza na obszarze występowania rudonośnych utworów wschodniego i północnozachodniego obrzeżenia Gór Świętokrzyskich. Badaniami objęto 36 arkuszy Szczegółowej Mapy Geologicznej Polski w skali 1:50 000. Wyróżniono cztery typy szybików eksploatacyjnych, którym towarzyszą hałdy materiału płonnego. Zebrano dane na temat rozprzestrzenienia obszarów dawnego górnictwa, na podstawie których można będzie podjąć we współpracy z archeologami próbę powiązania odmian szybików eksploatacyjnych z historycznymi etapami funkcjonowania rozwoju hutnictwa żelaza, począwszy od czasów rzymskich (I w. p.n.e.–IV w. n.e.) do lat siedemdziesiątych XX wieku. Użyteczność metody lidarowej została już spektakularnie potwierdzona w badaniach archeologicznych. Pozwoliła na odkrycie zapomnianych, nawet dużych obiektów będących efektem działalności człowieka, zwłaszcza na terenie Azji i Ameryki Środkowej. Także w Polsce odkryto w ten sposób ślady osadnictwa ludzi z różnych okresów historycznych. Przydatność lidarowych wysokościowych modeli terenu w geologicznych badaniach procesów egzodynamicznych i w geologicznej kartografii jest obecnie raczej kontestowana.