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Historical Outline of Iron Mining and Production in the Area of Present-Day Poland

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Abstract: The article presents the history of iron ore mining and production in present-day Poland and takes into account mining and production techniques and the influence of mining on the development of the surrounding areas. Examples of development are presented for the most important iron ore mining centers established since the period of the so-called Roman influences—Lower Silesia in the region of Tarchalice and the Świętokrzyskie region in the area of Góry Świętokrzyskie (Świętokrzyskie Mountains). The oldest traces of underground iron ore mining in Poland date back to the 7th–5th century B.C., and iron production dates back from the 1st century B.C. in the Częstochowa region where economically significant iron ore exploitation started in the 14th century and lasted until the 20th century. Studies showed that the development of iron ore mining in today's Poland was associated with significant events in the country's history, for example, with the expansion of a network of fortified castles in Silesia or with the industrial revolution. In each case, the increase in iron production resulted in the development and growth of the surrounding areas.

Keywords: mining; iron ore; iron metallurgy; mineral resources; history of mining; mine heritage

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1. Outline of the History of Iron Ore Mining in Present Poland

Iron has long been of economic importance. Archaeological research conducted in Egypt has uncovered a plate of iron located under the rolls of bandages on the forehead of one of the pharaohs. In 1925, archaeologist Howard Carter found two daggers next to Tutankhamun's mummy: one with a blade made of gold and iron [1]. The presented cases allow us to believe that the rulers of ancient Egypt already considered iron to be precious. It was then often obtained from lumps of meteorites. By the third millennium B.C., iron products of terrestrial origin were already known. The ability to produce iron reached Europe around 10th century B.C. In the areas inhabited by the Etruscans (present northern Italy), there were numerous iron production centers during 6th century B.C. The period from 750 BC to 500 BC is referred to as the Hallstadt period, originating from the village of Hallstadt in the Alps where a cemetery containing iron products was discovered. During this period, there is a rapprochement between the cultures of so-called barbarian Europe and the ancient civilization [2]. From the territories of present-day Italy, iron production reached the lands of present-day Poland around 700–500 BC [3]. Material from archaeological excavations allows us to conclude that in 5th century B.C. products from local iron deposits were already being manufactured on the territory of present-day Poland. The expansion of Celtic culture was accompanied by another Iron Age period called the Latenian (the name of the period comes from the archaeological site at La Tène in Switzerland), which lasted from 400 BC to the beginning of our era. During this period

in Poland, iron was already commonly smelted from ore in the Lower Silesia region and also in the Świętokrzyskie Mountains. Easily fusible bog ores mined from open pits were mainly used for iron production. The processes of digging the ore and its processing were not yet separated at that time, so the profession of ore miner and forge maker could not be distinguished. Simple single-use smelting furnaces called bloomeries were used for smelting. To treat iron for weapons and tool making, the method of re-melting and re-forging it several times was used, thus removing unnecessary slag [4]. Smelting was conducted manually using bellows [3]. The efficiency of smelting was not impressive. From about 10 kg of iron ore using the same amount of charcoal, about 1 kg of so-called iron shale was produced, which still had to be further processed. The beginning of our era saw the domination of Europe by the Roman Empire. In iron production, this period is called the Roman period or Roman influence. This period lasted until 4th century A.D. Iron ore mining was significant. The first deep mine appeared at Rudniki in the Czestochowa area in the current area of southern Poland where hematite was mined. The mine used wooden shoring, turnstiles, and vertical shafts as deep as 36 m [2,3]. During Roman influence, there was a development of iron production in the area of present-day Poland. It probably resulted from the possibility of selling iron to the Roman provinces. Iron production during that period was still carried out using bloomeries with manual bellows. In the next stage, called the period of migration of peoples (until 600 AD), the industry connected with the extraction of iron, and its ironworking collapsed. It is possible that barbarian tribes, coming from the east, contributed to the destruction of this industry. However, an analysis of iron smelting slag produced during the reigns of the first rulers of Poland—Mieszko I and Bolesław Chrobry—allows us to believe that the iron mining and metallurgy industries were present in Poland at the turn of the 9th and 10th centuries A.D. During the Middle Ages, iron mining in Poland did not belong to the mining regalia, i.e., no permission from the ruler was required for iron mining [5]. A significant change in iron production in the Middle Ages (early 13th century) was the use of flowing water energy for blowing in bloomeries and forging. From that time on, iron-producing plants became known as ironworks, and the efficiency of iron production began to increase. Manual bloomeries remained in use for several hundred years, but they were gradually replaced. Ironworks produced 50 kg of iron per day, which translated into the consumption of over 60 tons of iron ore per year [3]. Bog iron ores were no longer sufficient, so people exploited seam and nest ores using underground mining. During the reign of the Jagiellons in Poland, from the 14th to the 16th century AD. [6], the demand for iron grew. It was needed for the production of weapons, agricultural tools, or construction elements. Unfortunately, the growing number of ironworks began to negatively affect the environment due to the clearing of large areas of forest for charcoal extraction. In the 16th and 17th centuries, there were numerous quarrels between blacksmiths and Polish nobility over ironworks' ownership rights [3]. Slowly the mining plants and ironworks passed into the ownership of the sovereignty. According to Osinski [7], there were 34 blast furnaces, 83 iron refining furnaces, and 41 bloomeries in the lands of the Republic (Poland) at that time. In Upper Silesia, then outside the borders of the Republic, there were 14 blast furnaces, 40 iron refining furnaces, and 21 bloomeries. The total production of iron was then about 1300 tons per year. At the time of the partitions of Poland (1772–1795) and the Napoleonic Wars (1803–1815), iron mining and ironworking collapsed in most parts of Poland [8]. This decline did not affect the Prussian partition and Upper Silesia. New iron ore mines were created, both deep and opencast, in Bytom, Tarnowskie Góry, and Gliwice. In 1796, the first European steelworks, the Royal Cast Iron Foundry, was established in Gliwice, where coke was used as a fuel. This event, combined with the development of coal mining in the Upper Silesian region, resulted in the region's development, which continues to this day. In the first half of the 19th century, there was a revival of mining and ironworking in Poland. Stanisław Staszic, the founder of the Mining Academy in Kielce and educating personnel for the mining industry, had a significant contribution [9]. In the Zagłębie Staropolskie (central Poland), an iron combine was created. In the second half of the 19th century,

iron ore mining increased, e.g., from 1870 to 1890, it more than doubled, reaching almost 300,000 tons of output in 1897 throughout the Kingdom of Poland [3]. By the time World War I began, the annual output ranged from 120 thousand tons to 480 thousand tons. The underground mines were operated as multi-pit mines (a dozen or so shafts with a cross-section of 1 m by 1.5 m situated in a line) or with central shafts. The ore was brought to the surface in buckets that could hold up to 200 kg. After World War I, electric drives were introduced into the mines, which resulted in faster and faster mechanization of mining works—improvement of drainage works and improvement of ventilation in the mines. The use of explosives during mining was also widespread. The great economic crisis of the 1930s took its toll on iron ore mining, which declined sharply at that time. Starting in 1935, however, there was an increase in ore mining, which reached almost one million tons per year when World War II began. In the first 25 years after the war ended, iron ore mining and ironworking in Poland grew, and new mining and metallurgical plants were established. The 1970s and 1980s in Poland saw the decline of iron ore mining, which had lasted over 2000 years. In 1982, the last iron ore mine in the Czestochowa region in Wreczyca Wielka was closed. The last closed iron ore mine in the territory of present-day Poland was the mine near Łeczyca (Łódz Voivodeship), which was closed in 1989 [10]. Currently, in the 21st century, no iron ore mining is carried out in Poland.

The studies were based on a literature review including the following: technical and historical publications, geological documentation made available by Polish state units, and data from the Polish Central Statistical Office. The collected information was checked for data consistency. Moreover, interviews with the groups of old mining sites explorers and employees of museums were carried out, and sites were visited. The following chapters of the article detailed information on mining and metallurgy of iron ore for three regions of Poland: Świętokrzyskie, Lower Silesia, and Częstochowa regions. Traditions of the iron industry in Poland date back to ancient times (Świętokrzyskie region and Lower Silesia region) or the Middle Ages (Częstochowa region), and its history ended at the end of the 20th century.

2. Exploitation and Ironworks in the Świętokrzyskie Region

The Świętokrzyskie region is the area of the Świętokrzyskie Mountains. It is bounded on the west by the Pilica River, on the northeast by a line running from Nowe Miasto through Wierzbica and Iłża to Zawichost, on the southeast by the Vistula River, and on the southwest by the Nida River and the Przedborsko-Małogoskie Range. The Świętokrzyskie region thus defined includes, apart from most of today's Świętokrzyskie province, also adjacent fragments of Łódzkie and Mazowieckie provinces [11]. In the Swietokrzyskie region, iron ores from the Lower Cretaceous, Brown, and Black Jurassic are found in the rite and Palaeozoic deposits. These are mainly iron ore sedimentary deposits. They come in ferruginous sands, siderites, and clay siderites in the seam or lenticular form. They are pretty poor because they usually contain less than 30% Fe, and sometimes only Fe content reaches 40%. Igneous deposits were found only in the vicinity of Rudki. These are vein deposits of pyrite. Hematite and siderite are also found there [12]. The first exploited deposits in the Swietokrzyskie region were bog iron ores formed in swamps and other wetlands, i.e., meadows, bends of rivers, and lakes, where iron compounds precipitated from solutions and deposited under moderate climate conditions. The bog ores lay close to the ground surface under the soil layer. For this reason, opencast mining methods were used. The process itself was uncomplicated. It is presumed that after removing a thin layer of overburden (turf), the exposed ore surface was dried and then selected manually [13]. As the ancient sites uncovered by archaeologists indicate, the extraction of iron from bog iron ores was based on world-famous bloomery furnaces [14]. Briefly, their principle of operation was to reduce iron oxide ores at a high temperature with charcoal to obtain iron in a spongy form containing slag. The types, construction, and principle of operation of ancient bloomery furnaces have been widely described in the literature [15–17]. Somewhat deeper but easily accessible, siderite deposits were already exploited in the Middle Ages

by the underground method of digging mining pits in the deposit. As described in the works of Rybski and Kaptur [18,19], these pits were dug to a depth of several meters with the use of simple tools. Simple tools were used. Over time, a hollow mining system was used, enabling the penetration of deposits to a depth of 10–12 m. Vertical workings provided access to them (long stretches) and were partially encased and protected against rock collapses. A manually powered winch was installed over the vertical mining shaft, and with time, a treadmill was used to pull the excavated material. In the same manner, the miners working in it were lowered down the shaft. With time, the deposits at a depth of fewer than 30 m began to be exploited using shafts with full wooden housing. They were sometimes connected underground by mining galleries, thus creating larger mining complexes (Figure 1). Currently, only ground traces of the former underground mining activity are preserved [19].

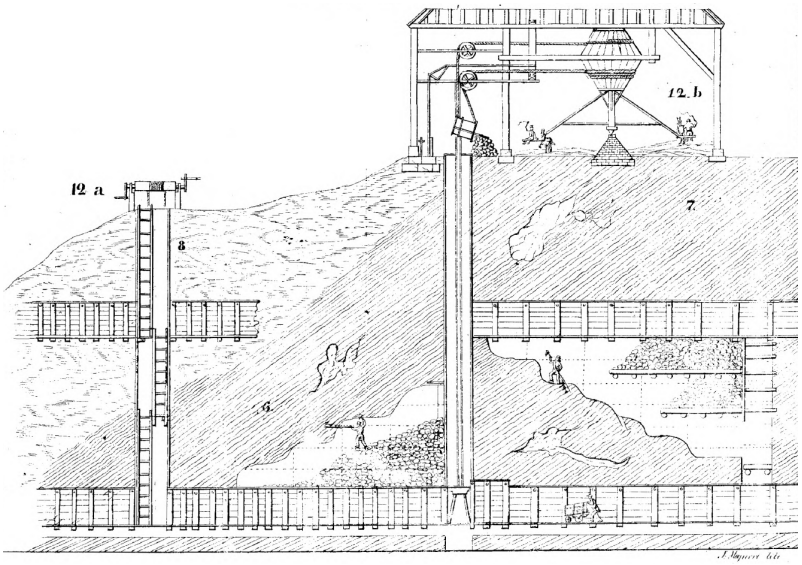

Figure 1. The treadmill mine (first half of the 19th century) [20].

As in the other areas of Poland, the beginnings of the Iron Age can be traced back to the Latenian or even the Hallstadt period, referred to as the Early Iron Age in the prehistory of Central Europe. While according to the literature [21,22], only a few traces of iron products have been found from the Hallstadt period. The Latenian (pre-Roman) period already brings clear traces of the extraction and processing of iron. Therefore, the beginnings of iron smelting in the Świętokrzyskie region can only be traced to the Latenian period, and the turning point was the last century B.C. From that time, it is possible to talk about the uninterrupted functioning of the so-called ancient mining and metallurgical complex until the 10th–11th century A.D. Rudki was the capital of the basin, and it was the mining center; the area around Nowa Słupia was considered a well-known center as well. Iron ore mining also occupied large areas in the region of Ostrowiec Świętokrzyski, Starachowice, and Końskie. In the middle of the 3rd century in Rudki, the only known deep iron ore mine from ancient times in Central Europe was outside the borders of the Roman Empire [14]. Dating the oldest monuments related to iron mining was a significant problem in historiography. The development of iron ore mining simultaneously fueled the growth of ironworking in the region, and its traces were usually found by archaeologists and analyzed by historiographers. The slags and charcoal used in the process were the basis for dating in the Świętokrzyskie region of the first smelting sites used to smelt iron. A series of radiocarbon analyses for C14 carbon content was carried out [23]. The most accurate of these studies were performed in the 1980s at the C14 Laboratory of the Silesian University of Technology in Gliwice. A numerous series of dates was obtained for selected bloomeries, which are summarized in Table 1. In the Nowa Słupia site, the time of work—mining and metallurgical activity—is dated the longest because it dates to modern times, up to the

11th century A.D. All the presented research cycles confirm the connection of the ancient mining and metallurgical activity of the Świętokrzyskie with the period of the Przeworsk culture (dated from the 3rd century B.C. to the 5th century A.D.). People associated with this culture contributed to the formation of numerous settlements. The settlement of the Przeworsk culture developed in the younger pre-Roman period and the Roman influence period on the western side of the Vistula River. Many sites associated with this culture were discovered in the Kamienna, Opatówka, Koprzywiarka, and Czarna river basins [24].

Table 1. Dating of charcoal and slag samples from localities: Łysa Góra, Grzegorzewice, Nowa Słupia, Łazy, Rudki, Jelenów, and Częstocice [23].

Sites	Dating
Łysa Góra	75 A.D. (50 B.C.–200 A.D.)
Grzegorzewice	25 A.D. (90 B.C.–140 A.D.)
	200 A.D. (150 A.D.–250 A.D.)
Nowa Słupia	65 A.D. (20 B.C.–150 A.D.)
	220 A.D. (140 A.D.–300 A.D.)
	1020 A.D. (970 A.D.–1100 A.D.)
	540 A.D. (470 A.D.–590 A.D.)
Łazy	230 A.D. (110 A.D.–340 A.D.)
	15 A.D. (110 B.C.–140 A.D.)
	100 A.D. (30 B.C.–230 A.D.)
	300 A.D. (180 A.D.–400 A.D.)
Rudki	280 A.D. (220 A.D.–330 A.D.)
	280 A.D. (230 A.D.–320 A.D.)
Jeleniów	1 A.D. (30 B.C.–30 A.D.)
	280 A.D. (45 B.C. (85 B.C.–5 B.C.)
Częstocice	210 B.C. (300 B.C.–160 B.C.)

In the first half of the 1st millennium A.D., the Świętokrzyskie mining and smelting industry reached significant development on a European scale. This activity extended in the area from the Vistula River almost to the Pilica River. The range of the ancient Świętokrzyskie metallurgy is shown in Figure 2.

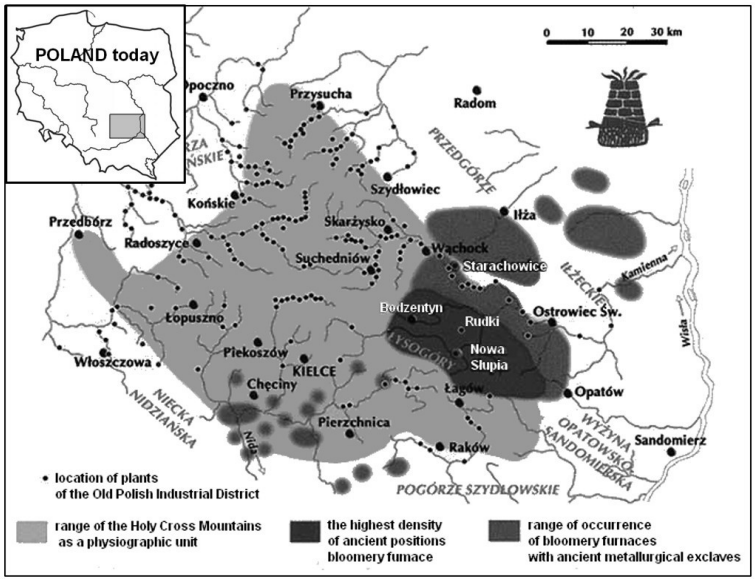

Figure 2. Range of the ancient Świętokrzyskie ironworking. Reproduced with permission from Orzechowski S., Suliga I. (eds.), 50 years of research on ancient Świętokrzyskie ironworking. Archeology—Metallurgy—Education (K. Bielenin, Przychodni A.—Świętokrzyskie ironworking in school education); published by KTN Kielce, 2006 [25].

The exact boundaries of metallurgical regions shown in Figure 3.

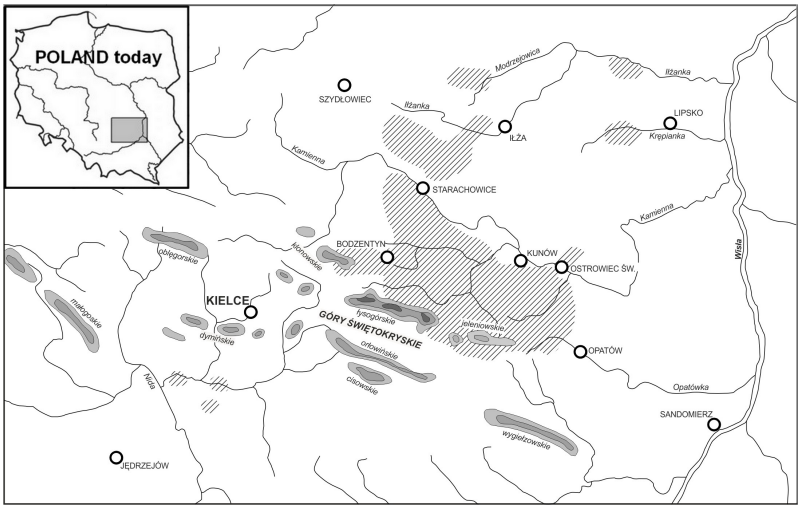

Figure 3. The range of densely occurring slag sites in the Świętokrzyskie Mountains and its potential exclaves. In the north are the basins of the Iłżanka, the Krępianka, and the Modrzejowica rivers. In the south is the basin of the lower and middle Nida river. Reproduced with permission from Orzechowski S., Region żelaza. Centra hutnicze kultury przeworskiej published by Wydawnictwo Uniwersytetu Jana Kochanowskiego, 2013 [26].

In 1964, while researching the ancient metallurgy of the Świętokrzyskie region archaeologist, K. Bielenin took a series of aerial photographs of selected mines in the Ostrowiec area. In this manner, he documented the relics of old mining works in this region. These photos are available in the archives of the museum in Ostrowiec Świętokrzyski. According to the inventory of bloomery sites between the Kamienna River and the Łysogóry completed in 1989, their numbers in this area amounted to approximately six thousand [14].

After the 3rd century A.D., metallurgy and mining in the Świętokrzyskie region experienced a particular recession. It was probably related to the invasion of the Goths and the subsequent migration of the Huns [27]. In the early Middle Ages, known as the era of migration of peoples, iron production in the region of the Świętokrzyskie Mountains was significantly reduced, and according to some researchers, disappeared altogether [28]. In the 10th–11th centuries A.D., together with the settlement of migrating tribes in new areas, an economic boom took place in Europe that was accompanied by gradual technical development in mining and ironworking.

The increasing demand for iron for weapons production caused significant changes in this field at the beginning of the 13th century. Reusable ground furnaces replaced Earth furnaces, and manual bellows were replaced by mechanical ones moved by water power, etc. It increased the demand for iron-containing ores [4]. The subsurface resources became insufficient. Underground mining techniques developed. The separation of the mining and metallurgical professions also occurred at that time [8]. The beginning of the first water forge implementation is assumed to be the year 1261, i.e., the launch of such a forge in Rudniki Jędrzejowskie. At that time, monks from Cistercian monasteries played an essential role in developing iron technology [29]. At the end of the 15th century A.D., the Cistercians owned the largest complex of 22 forges in the Republic of Poland in the vicinity of Wąchock. It is this fact, together with the complex of 142 forges in the Sandomierz Province at that time, that caused the area to be called the Staropolski Okręg Przemysłowy (SOP) region in the second half of the 16th century. In turn, this period was called the era of blast furnaces. The first was built in 1598 on the Bobrza River in Samsonowo by an Italian named Jan Hieronim Ciaccio, a gunsmith from Bergamo. Improvements in blast furnace technology continued until the turn of the 19th and 20th centuries [30,31]. From the mid-16th to the 1870s, SOP was the leading mining and metallurgical district in Polish lands. At the beginning of the 19th century, Jan Jakub Graff, a professor of the Mining Academy

in Kielce, estimated the resources of Świętokrzyskie iron ore in the government property at 16 million tons, which was supposed to be sufficient for 135 years [11]. In the 1930s, thanks to the metallurgist M. Radwan [32], the Świętokrzyskie slag from the ancient period became the subject of research and re-use of the then still developing metallurgical industry. The iron content of about 50% made the slag a sought-after raw material for steelworks. Smelting of Świętokrzyskie slag lasted continuously from 1930 to 1939. The amount of slag smelted at that time can be estimated at hundreds of thousands of tons [23]. This probably resulted in the irreversible destruction of many well-preserved archaeological sites. The opening of the Krzywy Róg mine in Ukraine in 1881 somewhat diminished the importance of domestic resources. Increasing imports of Krzywy Róg ores and a policy of special railroad tariffs were responsible for the economic collapse of most mines in the early 20th century. The last iron ore mines in the Świętokrzyskie region (near Starachowice) were not closed until the 1970s [11]. In 1994, the deposits of sedimentary iron ore were definitely removed from the national balance of mineral resources. The exploitation of 313 million tons of documented resources of sedimentary iron ore in the Świętokrzyskie region was considered to be completely unprofitable now and in the future due to the low quality of the mineral and unfavorable geological-mining conditions. This deposit was no longer a mineral resource [11].

3. Exploitation and Ironworks in Lower Silesia

The first documented historical traces of iron ore mining and metallurgy in the Lower Silesian region are dated from the middle of the Latenian period (between the 3rd and 1st century B.C.). In the last few decades, there has been a significant increase in knowledge about this period due to the rise in archaeological sites in the Lower Silesian and Opole provinces [13,33–36]. It should be noted here that exploration in this historical period is based primarily on identifying traces of ancient metallurgy from findings of slag and lumps of roasted ore from surface surveys or fragments of smelting furnace walls [35,37]. It is perfectly illustrated by the numerical comparison of identified settlement sites belonging to several cultures with traces of metallurgy (Table 2).

Table 2. Identified settlement points with traces of metallurgy at archaeological sites (MS—Manufacturing settlement; MW—Metallurgical workshop; STM—Settlement with traces of metallurgy; TM—Traces of metallurgy; U*—Uncertain cultural affiliation) in Lower Silesia within the cultural units: Ł—Łużyckie; PM—Pomorskie; LT—Latenian; J—Jastorskie; P—Przeworskie; LB—Luboszyckie [35].

Culture	MS	MW	STM	TM	U*MS	U*MW	U*STM	U*TM
Ł	-	-	-	-	1	-	1	-
PM	-	-	-	-	1	-	-	-
LT	4	-	3	-	-	-	-	1
J	8	-	3	-	-	-	-	-
P	65	12	16	2	13	2	4	-
LB	2	1	-	1	4	-	-	-

Most of the excavations in this region indicate the migration of peoples from southern directions to these areas during the 1st–2nd centuries A.D. Moreover, there are preserved traces of iron ore exploitation and metallurgical centers along with the progressive concentration of settlements [33,35,38]. Bog iron ores were used to produce iron. Their exploitation was carried out in a manner consistent with what is described in Section 2. The spread of technology for smelting and processing these ores is attributed to the Celts, whose influence increased significantly during this period [13]. The area of Lower Silesia is hilly and marshy, which favors the precipitation of iron compounds and their deposition. Their exploitation was carried out in a manner consistent with what is described in Section 2. Originally, it was estimated that the total number of bloomeries in the area was 30–40 thousand, but

later studies showed that their number exceeded 70 thousand [13,39]. In the literature, one can find claims that ore exploitation and metallurgy influenced the improvement of the population's living conditions and cultural significance. In addition to individual small production centers, regions with a significant concentration of extraction and production of iron raw material and finished products have also been identified. The occurrence of these areas partly coincides with the identified traces of intensified settlement, particularly of the Przeworsk culture, indicating that the emerging settlements were concentrated around the extraction and processing of iron ore [13,35,38–40]. Based on the traces of ancient mining and metallurgy in the Lower Silesia region, a publication [35] proposed dividing the region into 12 smaller zones related to settlement in the basin areas of individual rivers. Of the areas indicated, the largest number of sites comprised the following regions: dolnobarycko-odrzański (II), bystrzycko-oławski (VI), brzeski (VIII), strzelecko-opolski (X), and oraz głubczycki (XI) (Figure 4), i.e., the regions of today's large urban centers of Opole and Lubin.

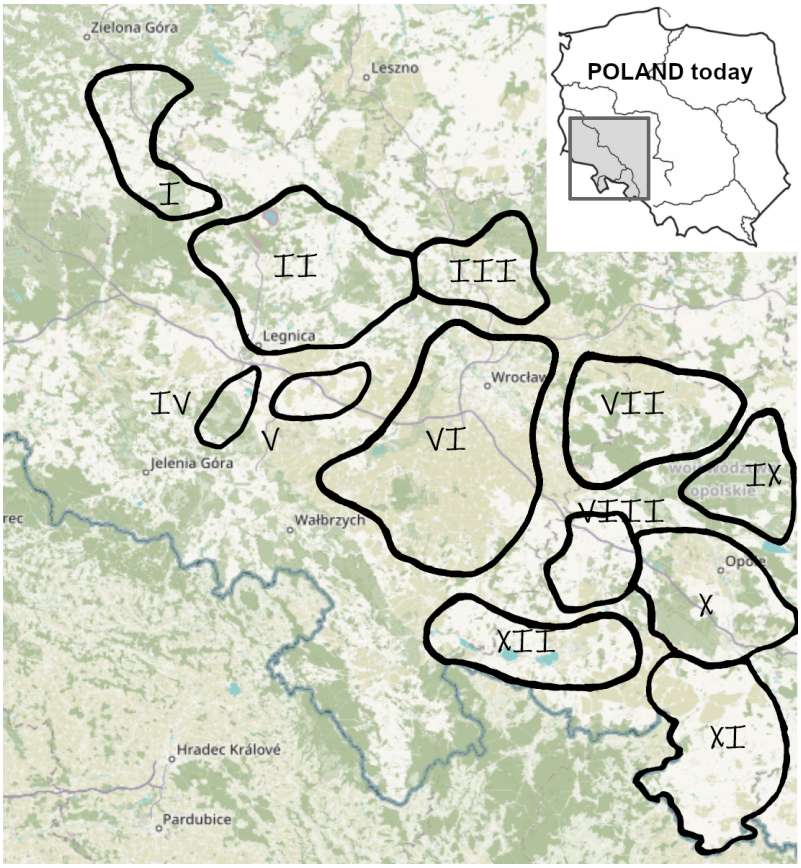

Figure 4. Location of sites with traces of ancient iron ore mining and metallurgy in the regions proposed by P. Madera: I—głogowski; II—dolnobarycko-odrzański; III—górnobarycki; IV—kaczawski; V—średzki; VI—bystrzycko-oławski, VII—widawski; VIII—brzeski; IX—stobrawski; X—strzelecko-opolski; XI—głubczycki; XII—nyski (own elaboration).

Significant development of iron ore mining in Lower Silesia dates back to around the 12th–16th century A.D. At that time, mining and metallurgy constituted one profession. The introduction of the so-called servile mining system meant that the local population had to provide non-agricultural work, including mining work, for the duke. One such center is the mining settlement established by order of Duke Bolesław Kędzierzawy in 1158 in the area of the present-day municipality of Kowary. The activity of the settlement is indicated by many documents later found in local museum collections and archives. The skills and experience of the Kowary miners were highly valued in the duchy, as evidenced by the records of their participation in many historical events, such as the Battle of Legnica in 1241

or blowing up Rubritter Talkenstein's castle in 1479. A documented breakthrough in ore mining in these areas was the use of wheels moved by falling water in the 14th century, which gave rise to new types of ironworks (i.e., old forges). Along with the development of this technology, a new law was introduced, based on which there appeared to be the first grants of ore-bearing fields to the so-called ore-miners, whose only duty was to exploit the deposits and develop mining centers [41,42]. Changes came to Kowary in 1513, when the King of Bohemia and Hungary, Władysław Jagielończyk, granted settlement town rights and the right to use the coat of arms "Sigillum Civitatis Metallica 1513". Due to the increased importance of the settlement, the mining industry developed rapidly. In the peak period of exploitation, between 1558 and 1560, Kowary exported nearly 1500 cetnar of iron to Poland. Historical records indicate that the ores mined here were used for the quickly expanding infrastructure of that period; it has been documented, among others, that the raw material from Kowary was used for building a part of the structure of the first bridge in Warsaw. There are also historical records indicating the development of the arms industry in this region; the area was particularly famous for its excellent gunsmiths. However, Kowary was not the only mining center in the Sudeten foothills in the 12th–16th century. In the case of the latter, there are preserved documents of the sale of mines dating back to 1483, also indicating the existence of a forge or granting rights to the "Sankt Paul" and "Sankt Jacob" adits from 1521. The development of industry and inflow of people resulted in the establishment of many settlements and communities on these lands, among others in Kletno and Bolesławowo. The period of decline of the mining and metallurgical industry in Lower Silesia falls on the first years of the 17th century. It was caused by the collapse of the economy and decline in population as a result of the so-called Thirty Years' War [5,42,43]. It should be noted that many historical sources from this period are incomplete, and only the most significant centers are known and investigated. In recent years, many of the former mining sites are being rediscovered by groups of passionate explorers. Unfortunately, in most cases, no records of these sites have survived. In the 18th century, mining was resumed. Polymetallic deposits in the form of long lenses and non-regular, steep shapes were mined. Among the ore minerals extracted were magnetite, maghemite, martite, pyrites, galena or sphalerite, and chalcopyrite [10]. This was to a large extent connected with technological development and the introduction of a new method of constructing mines, mining, and transporting the ore, as well as the development of processes for enriching the ore consisting in the thermal removal of harmful residues of admixtures accompanying the ore (it was roasted in piles of slack wood). During this period, access to the ore was introduced in the regular grid system, making shafts at uniform, regular distances. One of the newly established mines was the Bergfreiheit-Grube mine, which operated intermittently until 1962, and the Carl Friedrich Gustav mine that operated until 1944. The stoppages were related to the crisis caused by the influx of cheaper iron ore from Sweden and Spain in the late 19th century and the two world wars. In these mines, the roof mining system was used due to the significant slope of the vein deposits. In the Góra Wolności mine, the ore was mined at floor level, which was 2 m over the entire length of the mining field; therefore, this system was more similar to the longwall systems used today. Figure 5 shows the surviving diagram of the mining technique used at this site [41,44].

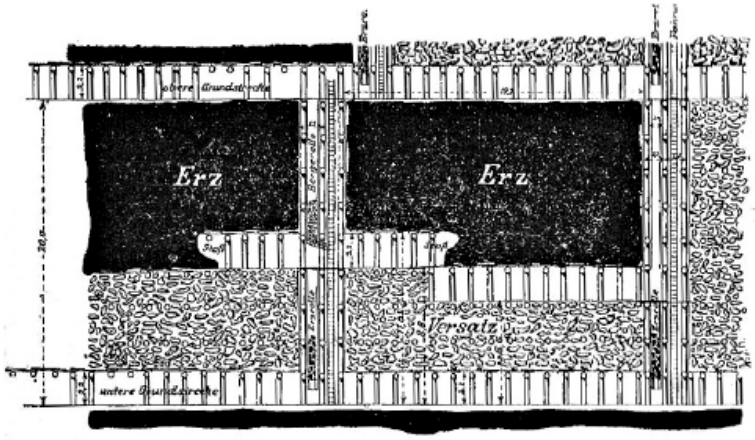

Figure 5. Floor-and-wall mining system [44].

Historical data indicate a significant increase in iron ore mining during World War I and the interwar period due to increased demand from the arms industry. It was again a period of considerable development of mining communities and settlements. After the war, the mining industry in the Lower Silesia region was gradually phased out, but due to the geopolitical situation and the simultaneous exploitation of uranium ore deposits, the number of available sources is limited [5,41,45].

4. Exploitation and Metallurgy in the Częstochowa Region

Iron ore deposits in clayey siderite were mined in the area between Wieluń and Zawiercie using open pit and deep mining methods. A diagram of the Częstochowa Ore-bearing Area is shown in Figure 6. The Częstochowa Ore-bearing Area comprises an iron ore occurrence stretching from Zawiercie to Wieluń in a belt about 120 km long and 2 to 20 km wide (Figure 6). The ore mineralization in the described area was connected with the so-called ore-bearing series, which covered the floors from Aalene and Bajos to the upper Bathonian. The basis for iron ore mining was the siderites of the thill and middle levels. According to [10], the total thickness of the ore at the 1.8 m high mining gate was 0.15–0.37 m. The middle level occurred at a depth of 30–50 m below the roof level, characterized by variable thickness. Three ore layers could be distinguished in it.

At a depth of 75 m below the middle level, there was a thin seam, the most important in terms of mining, which consisted of several layers with a thickness of up to 0.4 m. In the archives of the Jasna Góra Monastery, there are documents concerning the exploitation of iron ore and iron production in the area under consideration. During the Middle Ages and during the reign of Kazimierz Wielki, a network of masonry fortifications was created. The castles performed various functions at that time and mainly performed defensive functions [46,47]. At the same time, there was a development of urban centers in the area [48]. It has even been stated [3] that the inhabitants of these buildings contacted each other due to iron ore extraction issues and created communication routes coinciding with the course of the exploited deposits. As early as before the 14th century, shallow bedded siderite and spherosiderite layers were mined there. At that time, ten forges were established in the area of Częstochowa to smelt iron. Since the 15th century, the number of forges has increased, and their location corresponds to the diagonal course of iron ore outcrops shown in Figure 6. The development of metallurgy in the Częstochowa area coincided with the development of urban centers such as Częstochowa itself and Krzepice and Panki.

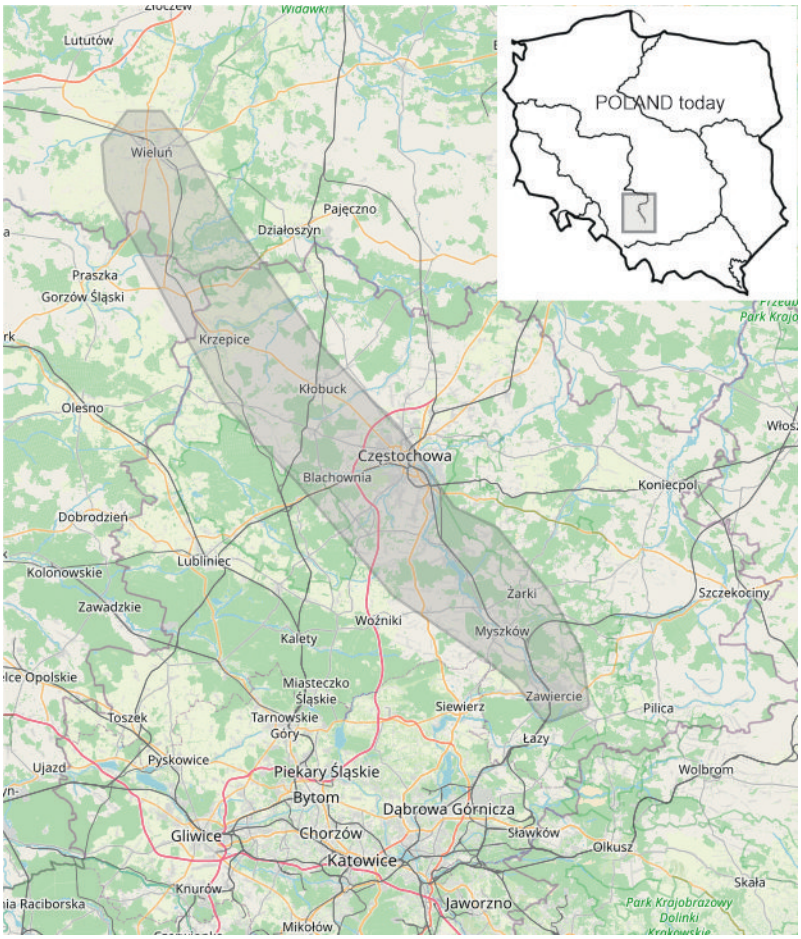

Figure 6. Czestochowa Ore-bearing Area (own elaboration).

In the 16th century, the development of iron ore mining in the region regressed due to the progressive destruction of forests. Still, at that time, forges in the area of Klobuck gained importance. The importance of the industry connected with the extraction of iron ore and metallurgy in the region in the 14th–16th century is evidenced by the names of settlements that were transformed into towns and larger centers. In Polish, these include the following: Rudy, Rudniki, Huty, Hutki, Blachownia, Kowale, etc.

The development of iron ore mining and metallurgy in the Częstochowa area collapsed in the 18th century due to the partitions of Poland and the disappearance of the country. The renewed development of the region coincided with the industrial revolution, i.e., at the end of the 19th century. Additionally, the development was aided by the concentration of capital in mining and metallurgy and the construction of the Warsaw-Vienna railroad. The neighborhood of the Upper Silesian Industrial Area was also significant. At that time, the deposits in the Częstochowa region were significant on the European map. When Poland regained independence in 1918, the Częstochowa region accounted for 43% of the country's recognized iron resources. Between 1918 and 1939, iron mines increased from 7 to 28 [3]. This period coincided with the development of other centers such as Konopiska. After 1945 there was the last period of development of iron ore mining in the region. Many smaller centers were established, e.g., Włodowice [49] or Rudniki. There was also the development of the already existing centers, e.g., Zawiercie. Zawiercie became an important city on the map of today's Silesian province, and its importance decreased with the liquidation of the iron industry in the area, which was decided in 1970. The first to be liquidated was the Rudniki mine in Rudniki near Zawiercie in 1970 and the last was the Wręczyca mine in Wręczyca Wielka in 1982 [50]. In the years 1903–1968, the deposit was exploited on the site of 68 km^2. In 1939, the population of Zawiercie amounted to 34,000. In the 1970s, it reached 61,000. At the beginning of the 1980s, it was about 63,000 according to Statistical Yearbooks

of GUS [51], and then it systematically fell despite ten years of prosperity relative to the heavy industry in the Silesian Province. Today, it amounts to 49,000. It is assumed [3] that almost every locality in the Czestochowa Ore-bearing area has experienced a positive impact from the mining industry. Several dozens of kindergartens and schools have been built. Many roads were constructed, or the existing tracts were paved. A entire system of power lines was created. Sports and cultural centers were established near housing estates, and a network of health care centers developed. In Częstochowa, the Museum of Iron Ore Mining was established. In the village of Raków (currently a district of Częstochowa), housing estate for workers was built near Bernard Hantke's steelworks; electrification was carried out, streets were paved, and a school and church were built. After World War II, estates for workers were built with schools, kindergartens, and the characteristic Aleja Pokoju. Workers' housing estates were built in Huta Stara, Dźbowa, Blachownia in single blocks in Piłsudskiego Street or Wolności Avenue in Częstochowa. Enterprises of the Iron Ore Mines built educational institutions. In 1979, on the Konopka River, the Barbara Iron Ore Mine in Dźbów built the Pająk Reservoir in Konopiska. The mine water pumped out in the "Dębowiec" mine in Dębowiec was used to create a lagoon in Olsztyn (now dried up) [3]. The mining companies sponsored sports clubs, e.g., "Lot" Konopiska, Górnik Dźbów; the Częstochowa smelter sponsored the Raków Częstochowa club.

Table 3 shows the volume of iron ore extraction in the Częstochowa Ore-bearing Area over the years.

Table 3. Size of iron ore mining in Czestochowa Ore-bearing Area over the years (based on [3]).

Year	Mining (Mg)
1390	920
1475	3600
1580	9800
1785	5500
1820	530
1840	2300
1905	90,000
1945	73,228
1950–1960	max. 200–250 thousand

At present, the traces of former exploitation of iron ore deposits in the Częstochowa area are waste dumps. Exploitation and processing of iron ore were connected with depositing waste on the ground's surface in heaps. In the Częstochowa region, there are 41 heaps located between Częstochowa, Konopiska, Kłobuck, and Zawiercie. The heaps cover the area from 0.4 ha to about 20 ha. Wastes measuring 18,000 Mg to 5.3 million Mg were deposited on the heaps. The studied heaps, due to their genesis and petrographic composition, can be divided into the following: created from post-mining waste—they are rocks coexisting with iron ore—dogger clay, claystone, sandstone, and siderite; and arising in the course of processing—these are mainly raw siftings, associated with ore enrichment and processing plants (roasting furnaces). These type of heaps accumulate roasted siftings, slags, and post-hydrocyclone loams [52].

5. Summary

1. Mining and metallurgy of iron ore on the territory of present-day Poland lasted from the 7th–5th century B.C. until the end of the 20th century A.D. The oldest traces of iron ore mining were located in the Świętokrzyskie region and the Lower Silesia area.
2. Initially, mining was carried out by using open-pit methods, and bog iron ores were mainly exploited. Since the Piast and Jagiellonian dynasties, the increase in demand for iron resulted in a shift from opencast to underground mining. There was also a development of iron smelting technology from the sub-period of ore mines, which fell on the Latenian period, to he sub-period of forges (around 1200) and charcoal

(around 1500) to the sub-period of coke use. The first blast furnace operated on coke was started up in Gliwice in 1796.

3. In the 19th century and the first half of the 20th century, the iron industry developed well despite the partitions of Poland and the world wars. This development coincided with the industrial development of both the country and all of Europe. Many urban centers were created or developed, e.g., towns in today's Upper Silesian Industrial Region and workers' settlements (e.g., Blachownia). Iron ore mining ended in Poland in the seventies of the 20th century and ended with the closure of the last mine near Łęczyca, in 1989.
4. Iron ore is not currently exploited in the regions presented in the article due to the large scattering of the deposits, low metal content in the ore, and a high degree of depletion of the deposits. In addition, iron ore has been identified in Poland in the north-eastern part of the country, which is the Suwałki region. However, due to the depth of the deposit (up to 2300 m) and the location of the deposit in the vicinity of the national landscape park, its exploitation is not currently planned.
5. According to the list presented by the Polish Geological Institute, Poland has iron ore deposits of over 1.3 billion tons [53]. These resources are qualified as off-balance, which forces Poland to import iron from other countries. Imports of iron ore and concentrates amounted to almost 7 million tonnes. The leading suppliers were Russia and Ukraine [54].
6. Currently, former iron ore exploitation traces include post-mining waste dumps, post-mining basins, and residual relics of iron ore processing. Mine heritage of the region is presented in museums of the following: The Historical and Archaeological Museum in Ostrowiec Świętokrzyski, the Museum of Nature and Technology "Ekomuzeum" in Starachowice, and The Museum of Iron Ore Mining in Częstochowa.

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