

## Airborne laser scanning as a method of localisation and documentation of mining sites remains. Examples from Silesia

Letecké laserové skenování krajiny jako metoda lokalizace a dokumentace pozůstatků hornických lokalit. Příklady ze Slezska

PAWEŁ CEMBRZYŃSKI<sup>1</sup>, MARIA LEGUT-PINTAL<sup>2</sup>

<sup>1</sup>e-mail: pawelcembrzynski@op.pl; <sup>2</sup>Politechnika Wroclawska, Instytut Historii Architektury, Sztuki a Techniki, ul. Bolesława Prusa 53/55, Wrocław, 50-317-PL; e-mail: maria.legut@gmail.com

**Abstract:** Airborne Laser Scanning (ALS) as an archaeological prospection method is becoming increasingly popular. ALS enables clear identification of specific terrain forms, including remains of human activities, such as mining, even in forested areas. The aim of this project was to evaluate usefulness of ALS data gathered for ISOK project, as a source for verification of known Silesian gold mining centres. We selected some mining sites related to towns (Głucholazy, Lwówek Śląski), with the established history of gold mining from the Middle Ages to the early modern period. As most of the mining sites remains are situated out of the urban areas and mainly in forests, the results of ALS data analysis are highly promising. Also, the known results of direct field research of those objects were a basis for verification of ALS analysis methods.

**Keywords:** medieval gold mining, mining towns, Silesia, lidar, airborne laser scanning

### INTRODUCTION

Exploring archaeological remains of the medieval and early modern mining activities is both difficult and expensive. Mining sites are often situated on large forested areas, most commonly in mountainous regions. They also consist mostly of terrain forms - remains of mining shafts, adits, ore washers and piles of mined material, where artefacts are rare and their material value is usually low. Because of that, the mining studies are not particularly popular in Poland yet. On the other hand, thanks to modern methods of archaeological prospection, especially airborne laser scanning (ALS), we expect significant progress in that field to be done in the near future. The described methods are especially useful for identification and initial analysis of anthropogenic terrain forms, even in inaccessible, mountainous, damp or forested areas.

Airborne Laser Scanning (ALS) is a method that allows fast collection of data required for creating high resolution and accurate digital terrain model (DTM) for large areas, which makes it perfect for exploration of mining sites' remains. Lidar-based DTM was successfully used in studies of prehistoric and medieval mining in neighbouring lands - Saxony and Czech Republic (Falke 2013, 19–26, Gojda et John 2013, 21–37). Until recently, the method was not commonly utilized in Polish archaeology, because of the high costs of air raids and data processing. This situation changed after publishing the data acquired by ISOK project developed by CODGiK ([www.codgik.gov.pl](http://www.codgik.gov.pl)). The ISOK project - computer system for protecting the country from extraordinary threats - is aimed at creating accurate numerical terrain models for analysis of potential flood threats.

For the purposes of the project, about ⅓ of Poland have been scanned, mainly focusing on river basin areas. The data published by CODGiK are in form of point cloud of density of 4–6 points/m<sup>2</sup> for rural areas and 12 points/m<sup>2</sup> for selected urban areas. It is also possible to acquire ready-to-use numerical terrain models in form of grids. The majority of terrains expected to contain mining remains was scanned using lower density (4–6 pt/m<sup>2</sup>) which proves to be satisfactory for the purposes of mining site analysis.

For further analysis, we selected areas associated with gold mining in Silesia, with medieval chronology possible to establish and confirm, located on terrains scanned and published by CODGiK: Złotoryja, Lwówek Śląski, Mikołajowice, Złoty Stok and Głucholazy (Fig. 1). Those sites were also explored by archaeological surface surveys and, in some cases, small-scale excavations (Kaźmierczyk 1976, 1979, 1989, Firszt 1988, 1990, 1995, 1997). The current state of the art has recently been summarized by Tomasz Stolarczyk in his PhD thesis (Stolarczyk 2009). This created possibility for comparison and verification of the current state of the art with the results of analysis of digital terrain models acquired using lidar. The main goal of the research was to establish the range of mining sites with medieval origins and assess their preservation state. Additionally, an impact was made on defining and localising places related to different phases of acquisition process. The aforementioned areas were also selected due to the differences of deposit characteristics (primary deposits, gold veins - Złoty Stok, Głucholazy; secondary deposits, alluvial - Lwówek Śląski, Mikołajowice, Złotoryja). Such categorisation simplifies the classification of remains of mining activities characteristic to different mining techniques.

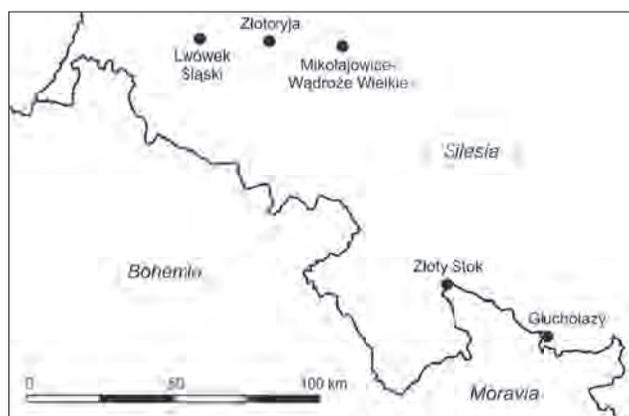


Fig. 1. Location of main medieval gold mining centres in Silesia (by L. Legut).

Obr. 1. Umieszczenie głównych średowiecznych ośrodków kopalnictwa złota w Śląsku (od L. Legut).

## ZŁOTORYJA

The town of Złotoryja is situated on a hill on the right bank of river Kaczawa, south to Legnica. Gold ore occurs here in alluvial deposits in glacial gravel layers located mainly on the heights east from the town, from Góra Mikołaja, heading east through Kopacz to Kozowo and Rokitki. Placer deposits lay mainly on the left river bank and on the height south to it. The other large deposits are located to the south-west from the town in the region of Jerzmanów Zdrój, Sępów and Nowa Ziemia (Kaźmierczyk et Grodzicki 1976, 208, Maciejak 1997, 16). Easy accessible outcrops are located to the east from the town in the valley of Złoty Potok, on the northern and eastern outskirts of the Kopacz village and on the plain on the left bank of Kaczawa river, to the north from Kopacz (Kaźmierczyk et Grodzicki 1976, 213). The whole gold-bearing area was 2.5 km long and 1 km wide. An average amount of extracted gold is estimated to 1–2 g per 1 tonne of sand (Dziekoński 1972, 108, Kaźmierczyk et Grodzicki 1976, 217).

The oldest phase of mining settlement in the Złotoryja area is related to a village called Kopacz. It was supposedly a servant village, specialised in gold mining. As an evidence to that fact, its typically Polish name is mentioned. It is presumed that the village appeared in 12<sup>th</sup> c. in the reign of duke Bolesław Wysoki (1162–1201) (Dziekoński 1972, 108–109, Gorzkowski 1997, 29, Zientara 2006, 139). Such dating is indirectly confirmed by pottery dated to 10–12<sup>th</sup> c. found in the area. There are also traces of earlier settlement activities found, from before 10<sup>th</sup> c. In the very village, on the river terrace and on Legnickie hills there are also evidence of mining activities discovered, yet difficult to establish precise dating (Kaźmierczyk 1974, 76). It is possible that duke Bolesław Wysoki brought some experienced miners from Meißen, for the purpose of further development of the mining in the region. A new settlement with St. Nicolas church was supposed to be established to the west of Kopacz, in the place called Góra Mikołaja. Some pottery dated to the end of 11<sup>th</sup> c. were found there (Gorzkowski 1997a, 29, Zientara 2006, 140).

What is also probable that the settlers were brought later by duke Henryk Brodaty while establishing a town.

The town of Złotoryja was established between 1211 and 1232. The first date is commonly considered as a foundation date, but not until 1232 was it referred to as a town (Gorzkowski 1997a, 36, Zientara 2006, 160). It appears in written sources as *de Aureo*, *Aureo Monte*, *Aurum*, *in districtu Aurij Montis* (Eysymontt 2009, 601). In a document by bishop Wichmann from 1211, regulating the law of Magdeburg mentions “guest from Gold”. Presumably at that time a reorganisation of the structure of Złotoryja was made. A document from 1217, related to an argument between priests from St. Nicolas church and a chapel of St. Mary, suggests moving the settlement before establishing the town. The chapel might be the origin of the church currently located near the town’s marketplace. Thus, there were two churches functioning in parallel - one in the old settlement and the other in the new town (Gorzkowski 1997a, 35).

It is difficult to find out what parts of the deposits were exploited at the time of the town being formed. The region to the north-east from the town was significant in 13<sup>th</sup> c. and the area to the south-west mainly in 14–15<sup>th</sup> c. (Firszt 1999, 277–278). The crisis of mining hit the region after the battle of Legnica in 1241, but the good times returned in 2<sup>nd</sup> half of 13<sup>th</sup> c., which can be inferred from donation of the incomes from mining to the Lubiąż monastery (Dziekoński 1972, 111, Gorzkowski 1997a, 52).

The mining works were held in the 1<sup>st</sup> half of 14<sup>th</sup> c. In 1342 dukes of Legnica, Waclaw and Ludwik established a code for mining works in Złotoryja. This may be interpreted as a trial of reactivation of mining activities in that area, which were gradually deteriorating due to depleting of the deposits (Dziekoński 1972, 111, Godzkowski 1997a, 52).

Along with the abandoning of the mining sites, the town’s economy changed. Craftsmanship and cloth manufacture developed at the time, replacing mining. In 15<sup>th</sup> century some attempts to exploit copper deposits and reactivate gold mining were made, unsuccessfully (Dziekoński 1972, 115). The copper was exploited still in 16<sup>th</sup> c. in Nowy Kościół, Prusice and Kondratów (Bogacz 1997, 69, Maciejak 1997, 17). Later, some exploration works were held in 18<sup>th</sup> and 19<sup>th</sup> century (Stolarczyk 2009, 68 – after Quiring 1914, 9). In 20<sup>th</sup> century there were mining works conducted on the southern field connected with digging a gallery. (Stolarczyk 2009, 69).

Firstly, the exploration on the plains around Kaczawa river was done in open pits, but later mining shafts were built. As the open casts were getting deeper, it was necessary to dig drain ditches to the river (Dziekoński 1972, 122). Later, as the works moved further away from the river, where the deposits were covered by a layer of clay, it became necessary to dig shafts to access the placer. In a horizontal plane the highest part of a shaft was circular. The walls were timbered, enforced by willow stretchers (Dziekoński 1972, 123).

During the archaeological research in 1973, the relics of mining shafts, visually similar to wells, were discovered on

Kaczawa river terraces, but their chronology was not established (Kaźmierczyk 1974, 74–75, Kaźmierczyk et Grodzicki 1976, 226). In the horizontal plane, they were square, timbered and enforced with clay. The shafts might be 7 to 9 m deep, but their bottom was never excavated. In the late Middle Ages the shafts might be larger (Gorzowski 1997a, 50–51). The output was most probably transported to ore washers. Their remains found in the river valleys were dated to 13<sup>th</sup>–14<sup>th</sup> century (Kaźmierczyk 1974, 75, Kaźmierczyk et Grodzicki 1976, 231). They had a form of troughs made of tree trunks and covered by laths. They were connected to channelled recesses of unknown size lined with clay. Similar devices were found in 1995, during archaeological inspection in the north of Kopacz (Firszt 1997a, 473–474). During surface surveys in the area to the south-west from the town, numerous remains of piles of output and shafts recognised as exploration digs were found (Stolarczyk 2009, 74–75). It is estimated that within 200 years of mining activities in this region, since 13<sup>th</sup> c., over 150 000 digs and shafts were made (Gorzowski 1997a, 50–51).

Basing on comparison of numerical terrain model of Złotoryja area with mining maps and plans from 18<sup>th</sup> century and results of archaeological research, we observe vast transformation of the former mining areas (Fig. 2). The traces of

exploration of gold from gravel in the valley of Kaczawa, also known as Sieben Bötten were blurred by agricultural activities, melioration and probably river erosion and accumulation of sands. The potential heaps resulting from ore washing might have met the same faith. For that reasons there are no clear trails of ore washing activities in form of piles, although some washers are placed on modern mining maps.

The progressing urbanisation of the river valley area also significantly influenced the mining relics. The main centre of exploration in Kopacz regions was urbanised without any archaeological supervision. Although the remains of open pit exploration on the slopes of river terraces on the Kopacz height are clearly visible, it is possible that the trails of exploration of gold dust were obliterated by exploration of the aggregate for the construction purposes. During the field research for the purpose of verification, we encountered a problem of dense vegetation in the area, which covered trails of mining activities recognised on DTM and made precise measurements impossible. The only area, where the relics of mining shafts in form of pits are recognisable on numerical terrain model and possible to be verified by field works are northern slopes of Górká Mieszczáńska (Fig. 3). This area was transformed in relatively slightest way into a recreational area.

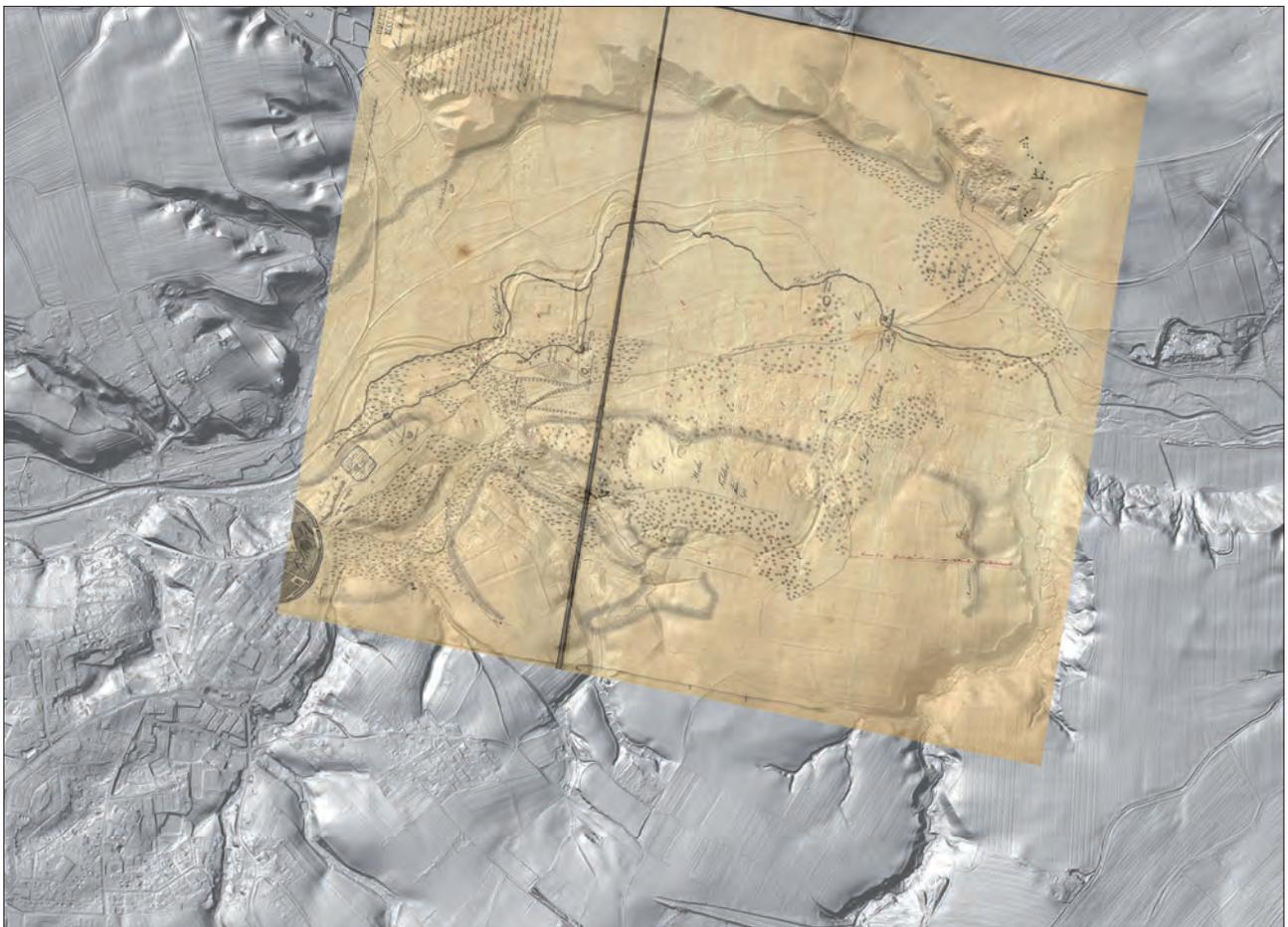


Fig. 2. Comparison of DTM and historical map of mining area near Złotoryja (by M. Legut-Pintal).  
Obr. 2. Porovnání DTM a historické mapy těžební oblasti blízko Złotoryja (od M. Legut-Pintal).

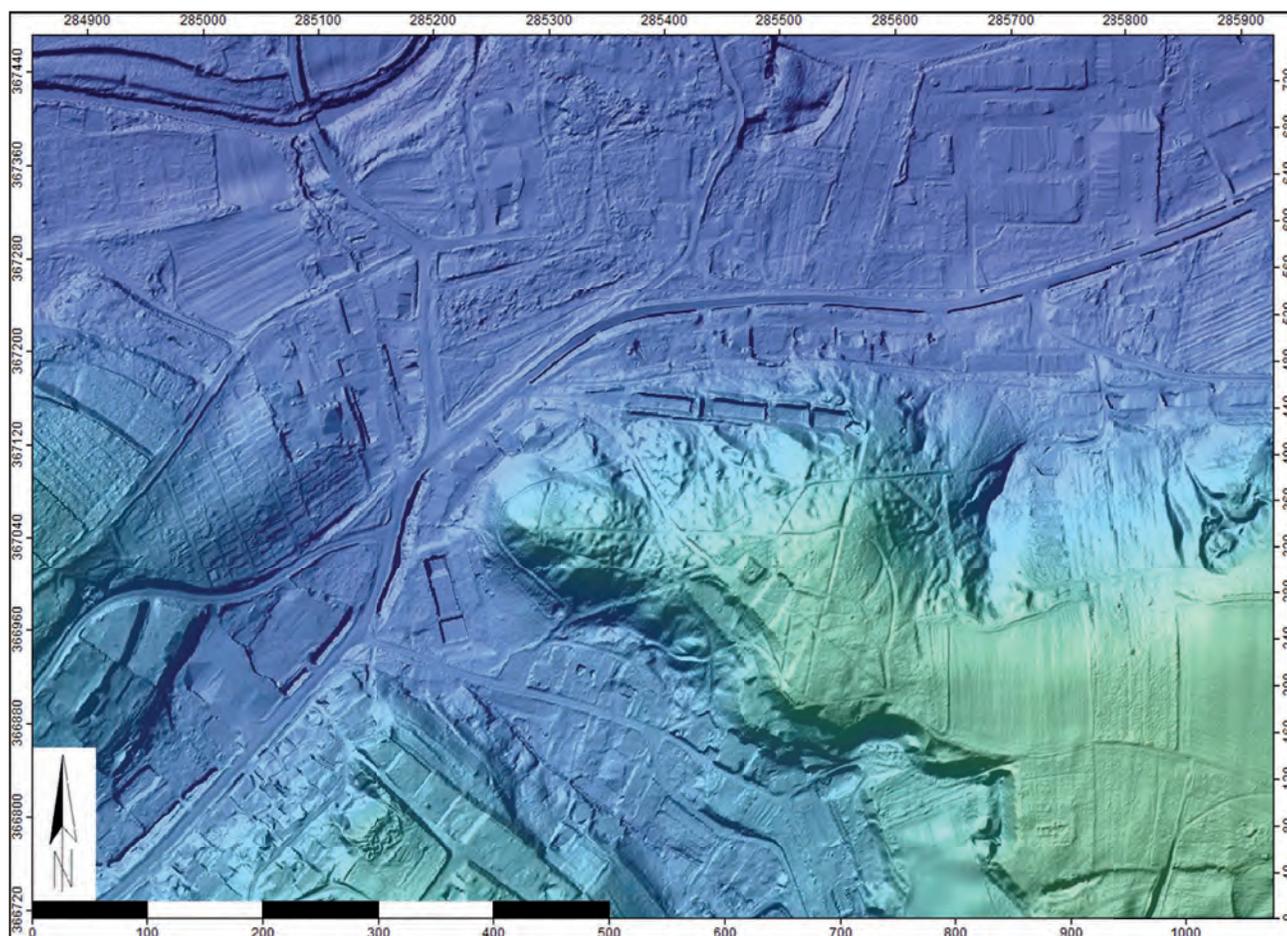


Fig. 3. Former mining area near Złotoryja - Górka Mieszczkańska. Only preserved relicts of shafts. Lidar-based DTM (by M. Legut-Pintal).  
Obr. 3. Bývalá těžební oblast blízko Złotoryja - Górka Mieszczkańska. Pouze zachovalé reliktý šachet. Lidar DTM (od M. Legut-Pintal).

## LWÓWEK ŚLĄSKI

Lwówek Śląski is located in a valley between steep hills in an estuary of a left tributary of river Bóbr. Near the town there are two secondary deposits. Gravels containing gold ore are concentrated in a north to south stripe situated several kilometres east from the town, between Dworek, Sobota, Pieszków, Bielanka and Plakowice. The other deposit is located north from town, between Zbylutów, Chmielno, Żerkowice, Skała and Ustronie (Stolarczyk 2009, 37 – after Grodzicki 1979, 168).

It is not entirely clear, when the mining activity in Lwówek started, as well as when the town was founded. Many researchers state that the town was founded by Henryk Brodaty in 1217 (Zlat 1961, 6, Zientara 2006, 160). It is certain though, that the town location happened before 1233 (Eysymontt 2009, 392–393). Some researchers claim that urban layout of Lwówek Śląski originated from an older trading settlement established on a route to Łużyce (Zlat 1961, 10). B. Zientara states that the town originally was a regional market supplying new settlers grubbing the forests (Zientara 2006, 161). Along with the city rights,

Lwówek acquired a ducal privilege to exploit the mining area, forests and meadows (50 mining lans) around the settlement called *Gorensiffen* (Górczyca, south-east from Lwówek), as well as in the area between Plakowice, Dworek, Pieszków, Bielanka and Chmielno. Another mentioning, in a document from 1241 is related to the mining sites in Górczyca and Pławna and indicates continuity of the works. In 1323 duke Henryk of Legnica confirmed his ownership of the mining areas east from town, Between Chmielno, Plakowice, and Pieszkow, and in the region of Sobota. In 1479 some mining freedom is granted to miners operating in Płuszczyna near Jelenia Góra by the major and city council of Lwówek. In the 2<sup>nd</sup> half of 15<sup>th</sup> century the town was an administrative centre for the mining in this region, but there were no more mining works held in the close proximity to the town (Dziekoński 1972m 104–105).

The techniques used in the Lwówek area were similar to those utilized in Złotoryja. For the shallow deposits, if it was profitable, open pits were dug. If the deposit was located deeper, a shaft was built (Stolarczyk 2009, 43, Kaźmierczyk 1976, 78). According to archaeological research conducted in the areas in the proximity of Lwówek,

near Płakowice the pits were shallow (up to 4 m) and wide (70 × 25 m). As the works in the pit were done, it was buried using output from other pits (Każmierczyk 1976, 78). In this region, the gold placer was found 1.5 to 3.5 m below current ground level. As the open pit method was only profitable in areas where a layer covering the placer is minimal, e.g. in the river valleys (Stolarczyk 2009, 43), the basic method of gold exploitation was digging shafts. Due to the lack of knowledge about the structure of the deposit and minimising the losses of material, the shafts were dug very closely to one another (Stolarczyk 2009, 44). During excavations in 1975 a few of such objects were discovered in Płakowice. In horizontal plane they were circular, oval or square, over 1 m in diameter. The shaft walls were timbered, enforced with stretchers made of young wood. The depth of the shafts was over 6 m (Każmierczyk 1976, 79, Stolarczyk 2009, 45–47). The output of the mines was transported to washers located near watercourses. A dugout and bonfires remains indicating the presence of temporary dwellings for miners were also discovered near the shafts (Każmierczyk 1976, 80).

The remains of mining activities in Lwówek Śląski region are much better preserved than in Złotoryja. This is most probably because of the distance from settlement area and low agricultural terrain transformations. The area of dense occurrence of pits and heaps covers over 600 ha and is located on the forested terrain between Sobota, Dworek, Płakowice, Bielanka, Pieszków, Zbylów and Chmielno villages. The number of shafts in this region is of tens of thousands (Fig. 4). Basing on the analysis of airborne photos we assume the former gold mining area to be even wider than that, covering up to ½ more terrain now occupied by fields and meadows. The exact number of mining shafts in the region is extremely difficult to obtain but possible to be estimated. The average density of the shafts number per 1 ha is about 35, which gives the overall number of shafts in the Lwówek Śląski area over twenty thousand (Fig. 5). There are outcrop exploration trails visible on the terraces of river Widnica crossing the mine fields. Near Widnica and Bukowica streams there are also clearly visible heaps of washed output and remains of ponds, some of which might have been used as settlers. There is also clear grid of drain ditches, which was possibly a part of the washers system.

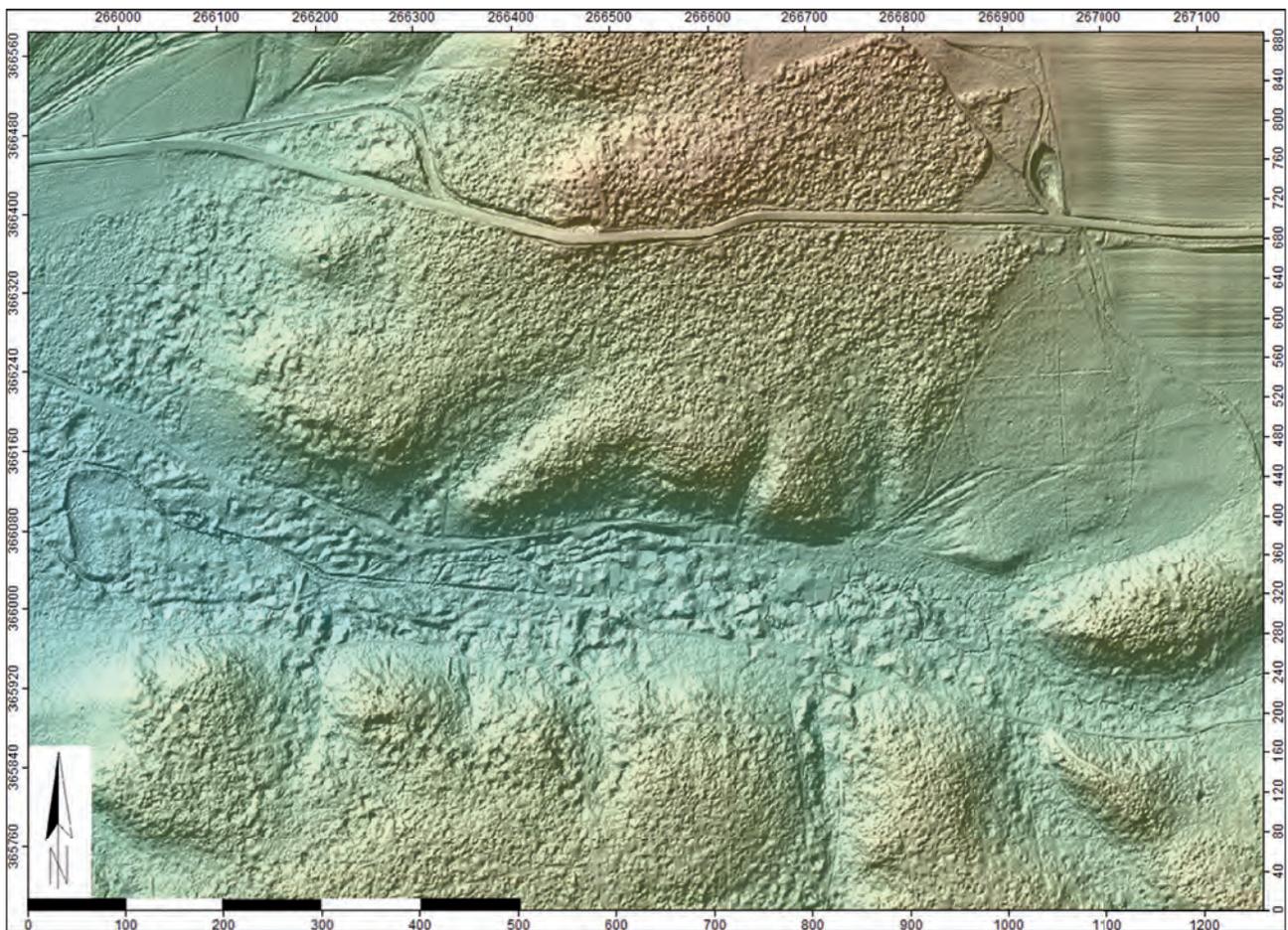


Fig. 4. Mining and washing area near Lwówek Śląski – Płakowice. Lidar-based DTM (by M. Legut-Pintal).

Obr. 4. Těžební a mycí oblast blízko Lwówek Śląski – Płakowice. Lidar DTM (od M. Legut-Pintal).

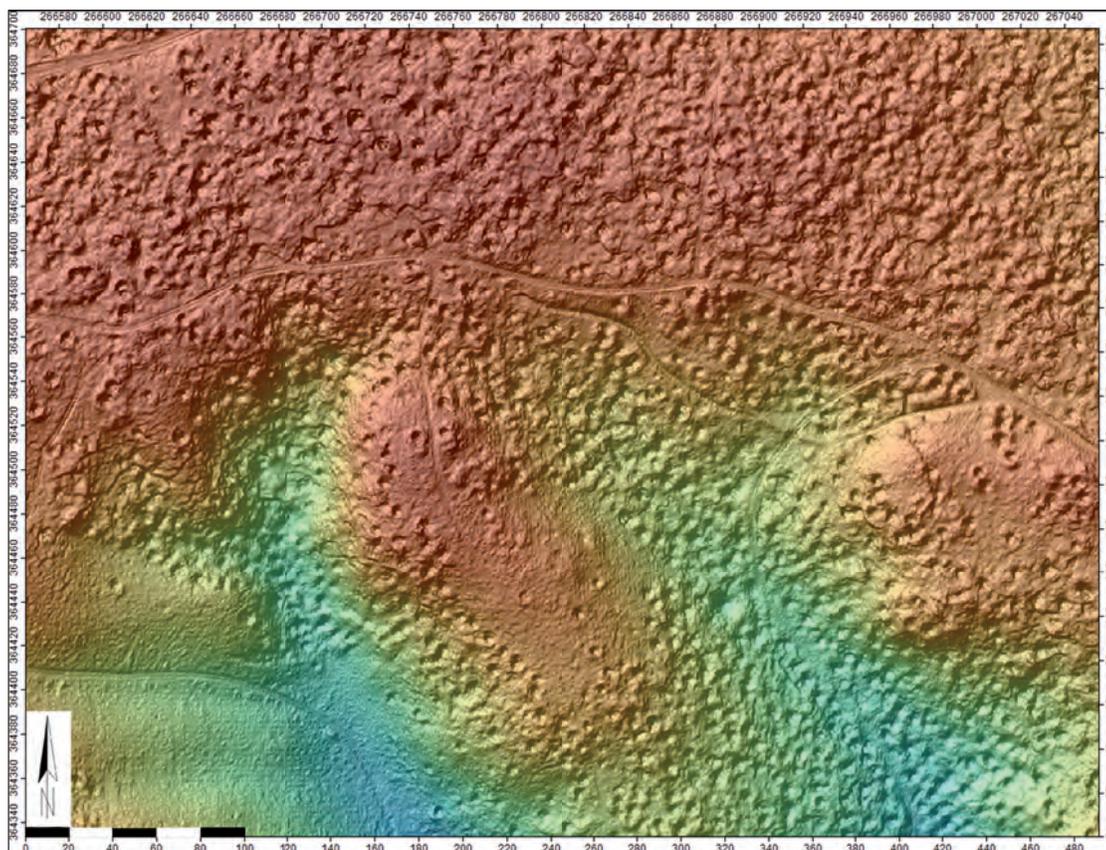


Fig. 5. Lwówek Śląski mining area - concentration of shafts relicts. Lidar-based DTM (by M. Legut-Pintal).

Obr. 5. Lwówek Śląski těžební oblast - sousředění reliků šachet. Lidar DTM (od M. Legut-Pintal).

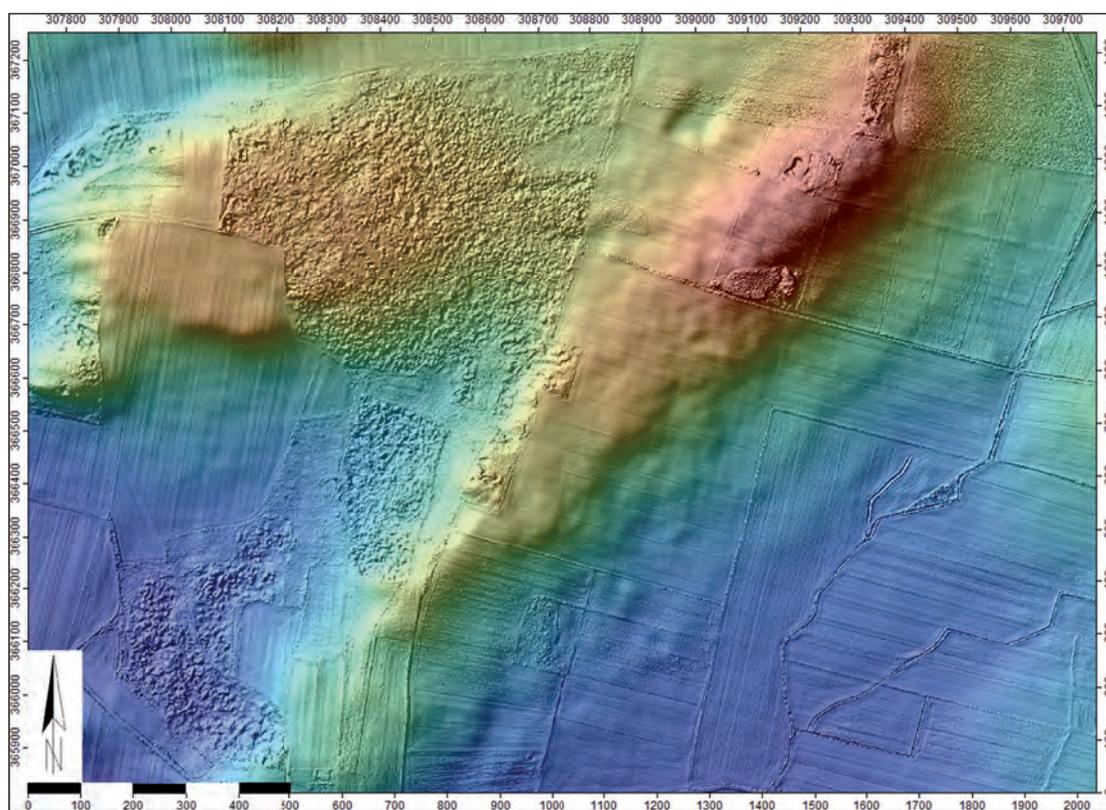


Fig. 6. Mikołajowice – mining area. Lidar based DTM (by M. Legut-Pintal).

Obr. 6. Mikołajowice – těžební oblast. Lidar DTM (od M. Legut-Pintal).

## MIKOŁAJOWICE

Mikołajowice is a small village located 12 km south-east from Legnica. Gold deposits occurred in the region between Legnickie Pole, Strachowice, Mikołajowice, Wądroże Wielkie and Wądroże Małe in form of gravel pits placed between tertiary and quaternary forms (Stolarczyk 2009, 102). Those deposits had different characteristics than previously described and required crushing rocks and gravel (Dziekoński 1972, 112).

The deposits were discovered in 1335 (Molenda 1963, 89). Shortly afterwards, a village inhabited by 130 grew to the size of a major mining settlement. Thus, in 1345 the dukes of Legnica established a town in the place of the settlement. The deposits run out in the 2<sup>nd</sup> half of 14<sup>th</sup> century and were abandoned in 1364. There were several unsuccessful attempts of resuming the exploration in later years (Dziekoński 1972, 112–114, Firszt 1987, 111–112; 1997, 197–200).

The techniques used in the area were based mostly on digging shafts and no open pits were found (Stolarczyk 2009, 105). During archaeological research conducted in 1984–88 in woods between Legnickie Pole and Mikołajowice, several shafts, as well as ditch system and ponds, being remains of ore washers were discovered in a site

Legnickie Pole 19 (Firszt 1987, 113–114; 1988, 80–81; 1990, 244; 1995, 239–43).

The remains of mining shafts in form of pits are clearly visible in the area of a forested hill located between Legnickie Pole and Mikołajowice (Fig. 6). Establishing the primary shape and size of this mining area is not possible because of transformations related to agricultural works and field melioration system. There are also several traces of open pit exploration visible on DTM.

## GŁUCHOŁAZY

The town of Głucholązy is located in the northern part of Opawskie mountains, in a valley on the right bank of Biała Głucholąska river. The town was established on the northern edge of the mining area covering Zlaté Hory and Jeseník region (Krawczyk 2002, 16). There were rich alluvial gold deposits in the close proximity to the town, in the valley of Biała Głucholąska and its tributaries (Stolarczyk 2009, 89, after Grodzicki 1979, 172–173).

The origins of the town are strongly related to an argument between bishop of Wrocław and Moravian settlers about domination over the gold-bearing areas. A boundary

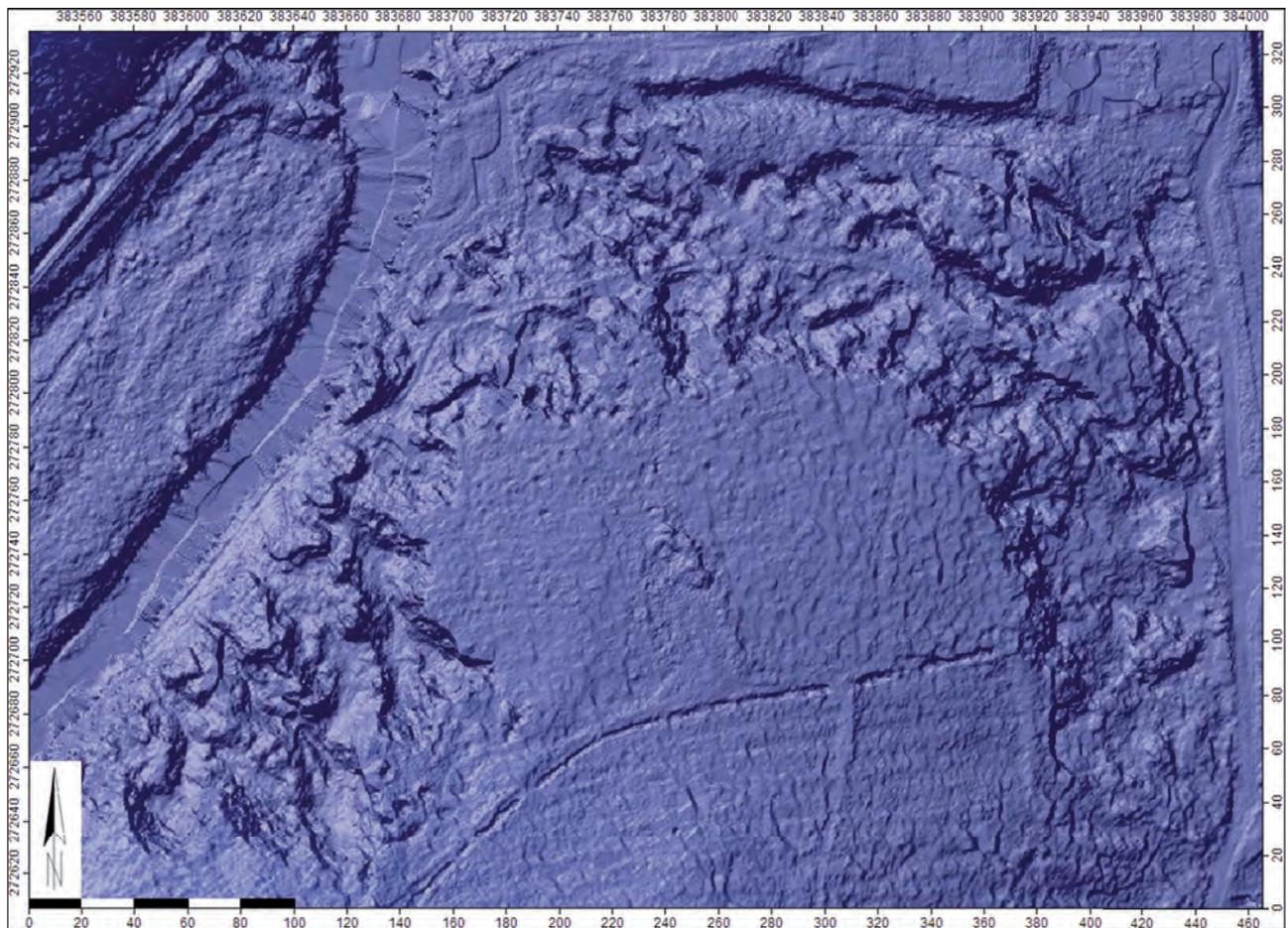


Fig. 7. Głucholązy, mining area near Biała Głucholąska river – remains of open pits. Lidar-based DTM (by M. Legut-Pintal).  
Obr. 7. Głucholązy, těžební oblast blízko řeky Biała Głucholąska – zbytky otevřených jam. Lidar DTM (od M. Legut-Pintal).

forest was overtaken during the colonisation of Nysa and Otmuchów regions, that belonged to bishops. As a result of that action, two settlers groups met, one of bishops and the other brought by the earl of Moravia. It is probable that discovering gold in the regions owned by bishops brought a vast number of settlers and inflamed the border conflict. A mining settlement called Zlaté Hory (Cukmantel) was established and shortly after, in 1220 taken over by the Moravians. In order to stop Moravian expansion, after failing to reclaim Zlaté Hory, the bishop founded Ziegenhals (Glucholazy) castle nearby.

The actual town was established in 1220–232 (Chrobak 2002, 36, Zientara 2006, 228, Eysymontt 2009, 302). Numerous small open settlements were located in the close proximity along with castles built in order to guard them: Lichtenstein on the southern slopes of Kopa Biskupia and a ducal stronghold on Zamkowa Góra (Krawczyk 2002, 16). There are documents directly referring to and confirming gold exploitation in the region in 1224 and 1263. The mining works were performed at intervals until 16<sup>th</sup>–17<sup>th</sup> century. At that time the bishops of Wrocław reclaimed Zlaté Hory and moved the centre of exploration there after exhausting the Glucholazy deposits (Krawczyk 2002, 16). Most of the mining and washing works in Middle Ages were

concentrated on northern slopes of Przednia Kopa, in the valley of Sarni Potok and Potok Zdrojowy, around Jarnołtówek, Pokrzywna, in the valley of Bystry Potok and Złoty Potok and in the region of Kondratów, between Glucholazy and Zlaté Hory (Krawczyk 2002, 17–19). Unfortunately, due to the lack of necessary data, it is impossible to establish a precise dating of works conducted in particular areas. According to J. Kaźmierczyk, the mining works were performed using shaft-based methods, not depleting whole deposits due to security reasons. In the later periods the shafts were dug out, forming open pits. The area of open pit exploration is significantly smaller than the shafts area. On the other hand, the mining works at Przednia Kopa sites were firstly performed by using open pit techniques and the shafts were dug only for survey purposes (Kaźmierczyk 1979, 113). Later, the deeper deposits were explored by draining shafts and adits. In 1550 a Three Kings' tunnel was started, running south from Glucholazy Zdrój region (Večeřa et Večeřová 2002, 22–23). During archaeological excavations made on Przednia Kopa in 1978, two similar shafts were found. The first one was circular in horizontal plane, 2.83 m in diameter. It consisted of three distinctive parts: the top part, roof-covered, bell-mouthed, 2.2 m deep, leading to the actual shaft; the internal part, 0.87 m deep and

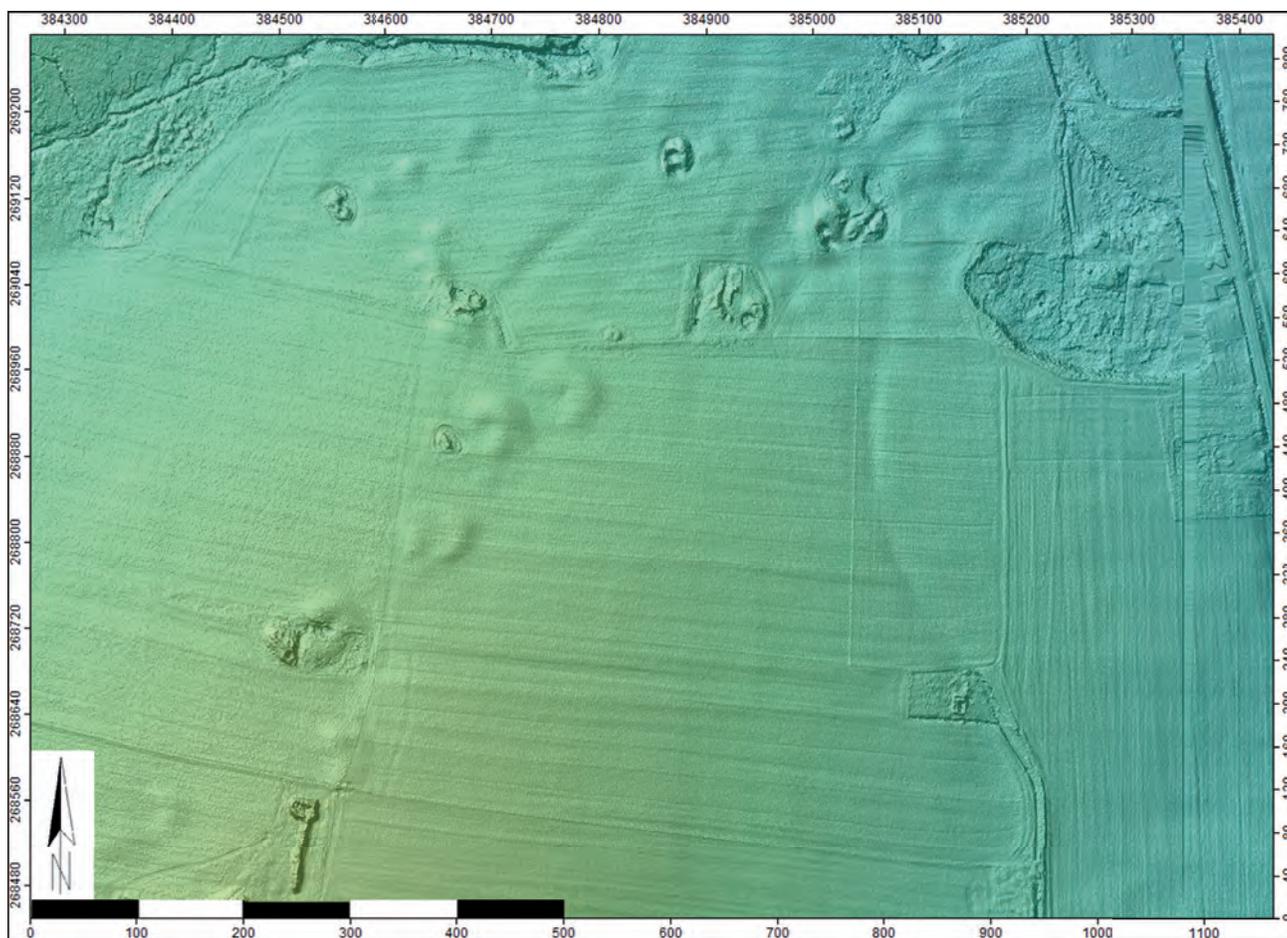


Fig. 8. Mining area between Glucholazy and Zlaté Hory - remains of shafts connected with "Three Kings' tunnel". Lidar-based DTM (by M. Legut-Pintal).  
Obr. 8. Těžební oblast mezi Glucholazy a Zlatými Horami - pozůstatky šachet spojených s tunelem „Tří králů“. Lidar DTM (od M. Legut-Pintal).

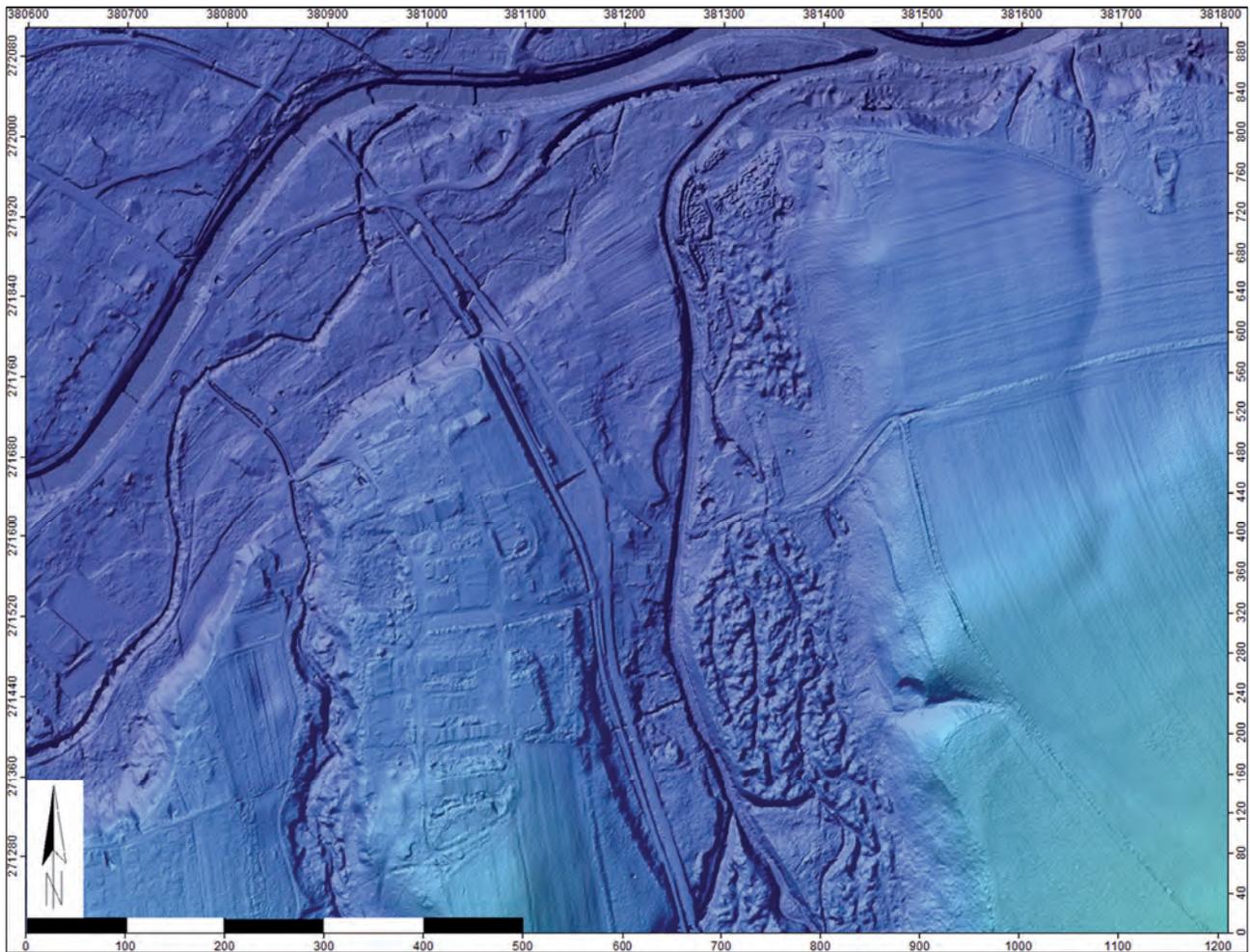


Fig. 9. Washing area along Olešnice river. Lidar-based DTM (by M. Legut-Pintal).  
Obr. 9. Mycí oblast podél řeky Olešnice. Lidar DTM (od M. Legut-Pintal).

about 1 m wide, was cylindrical and enforced with wood. The bottom part was inside the gold-bearing layer and in form of a chamber. There was no dating material inside the shaft, but its chronology was established to 12–13<sup>th</sup> century (Kaźmierczyk et Wachowska 1980, 98–100). There were also remains of borders of mining areas on the site, in form of shallow ditches (Kaźmierczyk 1983, 173).

The remains of mining activities related to exploration of secondary deposits are focused mainly in stream and river valleys and on river terraces. It is visible especially in the valley of Biała Głucholaska, east from the town. The relics of outcrops can be seen on the north slope of Przednia Kopa (Fig. 7), on a terrace in a bend of the river and further to the west, by the Czech Republic border (Kaźmierczyk 1979, 111–112; 1986, 46–48, Krawczyk 2002, 17–18). On the edge of Biała Głucholaska terrace, there are several pits, including relics of shafts dug for the penetration purposes (Kaźmierczyk 1979, 114–115). In the valley itself, there are clear trails of ore washing activities, such as piles of washed output and a grid of ditches. In so called Paradise Valley there are two, probably medieval, adits, and a third one further to the west, directly by the river (Kaźmierczyk

1986, 51, Krawczyk 2002, 17). Unfortunately, those objects are not possible to be located and recognised using ALS methods if no piles of outcrop appeared near them. The area near Zdrojowy Stream is highly transformed by urbanisation processes (Fig. 8). Few trails of shaft exploration can be found in the upper reaches of Sarni Potok (Fig. 9). Next to the relics of the shafts there are also remains of ditches, probably washers. The region between Zlaté Hory and Głucholazy is also interesting - an accumulation of secondary deposits from the massif of Góra Poprzeczna (Příčný Vrch) occurs there. Numerical terrain model shows numerous pits which can be a basis for establishing the course of the 'Three Kings' tunnel (Fig. 10). Numerical terrain model allowed identifying vast number of structures, impossible to recognise during field research. There are no places in the region of Jarnoltówek, that could be unambiguously connected with gold exploration. Several mining shaft relics can be seen on the western slope of Zamkowa Góra. The trails of exploration areas between Przylesie and Gęstwina are much more ambiguous. A ditch, interpreted by Kaźmierczyk as a washer is visible on numerical terrain model. The pits located on the edge of river valley can also

be related to gold mining. The ISOK project also covered a small area located outside Polish borders, along the Olešnice river. (Fig. 9) In its lower reaches one can spot heaps

of washed material which may indicate ore washing activities. Further up the river, there are parts of a mining fields with numerous shaft relics visible.

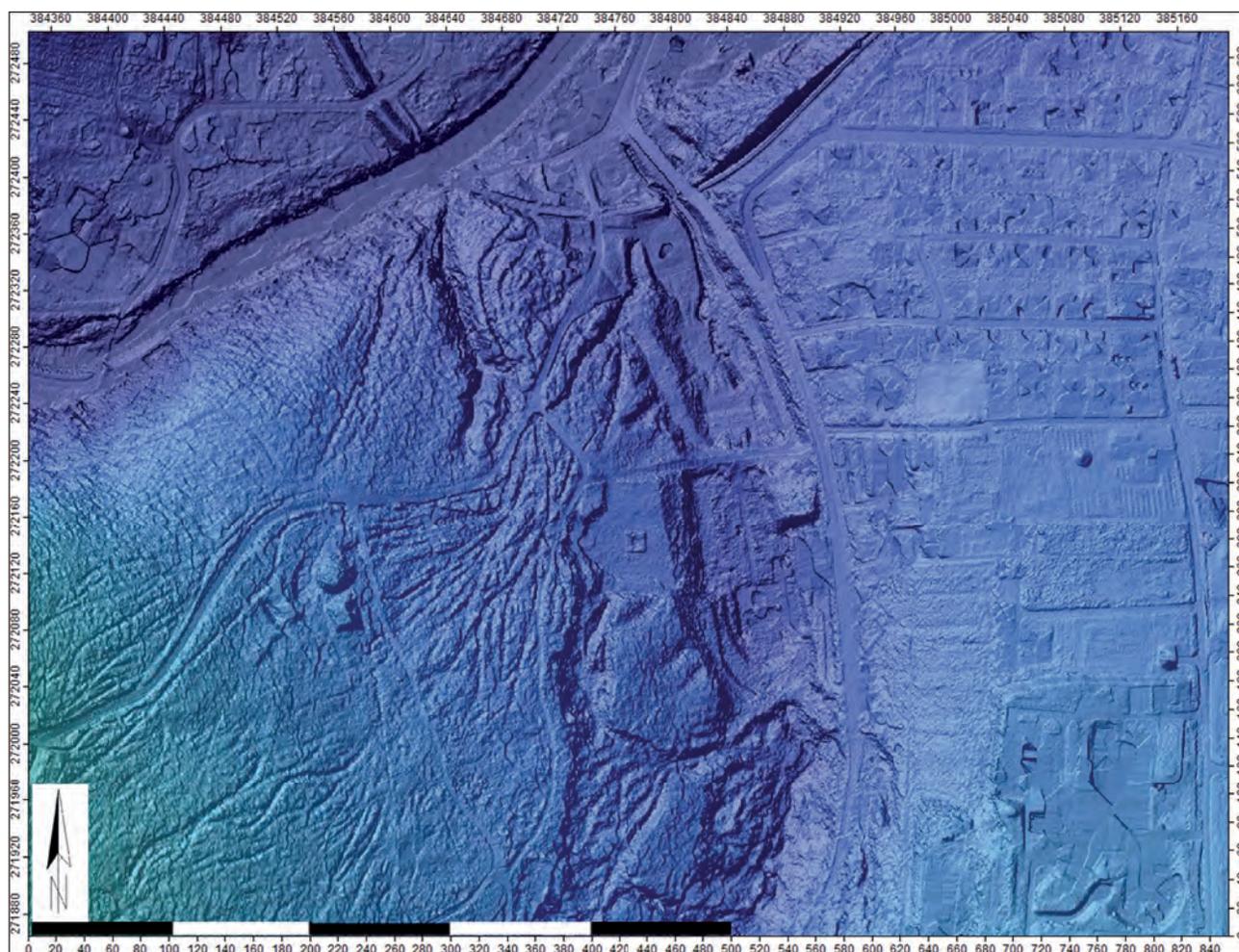


Fig. 10. Former mining area near Glucholazy-Zdrój - relics of open pits and sunken ways. Lidar-based DTM (by M. Legut-Pintal).

Obr. 10. Bývalá těžební oblast blízko Glucholazy-Zdrój - pozůstatky otevřených jam a potopených cest. Lidar DTM (od M. Legut-Pintal).

## ZŁOTY STOK

Złoty Stok is situated in the northern foothills of Góry Złote on a long platform heading east to west, on the left bank of Złoty Potok. The primary deposits of arsenic ore containing gold were located in 3 km<sup>2</sup> area in Góry Złote. The largest amount of gold ore occur in the eastern area and decrease as the deposits go deeper. The mining areas were on south-east slopes of Góra Haniak, in the Góra Krzyżowa massif and on the slopes of Góra Sołtysia in Złoty Jar (Mikoś et al. 2009, 28–44).

The establishment of the town may be related to the mining privilege for the Cistercians in Kamieniec Ząbkowicki from 1273. In 1341 the town belonged to the house Haugwitz and to this year a document confirming selling a mine called 'Montana' is dated. In 1344 the town was described as *oppidum aurifodiorum in Reychinstejn* and claimed city rights, but the rapid development period came

later (Dziekoński 1972, 137–138, Kornecki 1980, 11, Eysymontt 2009, 607, Mikoś et al. 2009, 50–52). Thus, the beginnings of mining in this region can be dated to 2<sup>nd</sup> half of 13<sup>th</sup> century (Stolarczyk 2011, 206). Probably at first the alluvial deposits in river valleys or easily accessible eroded outcrops were explored. Secondary deposits were located in the sands of streams coming out of Złoty Jar and Wąwóz Kłodzki. The outcrops were located on mounts Haniak and Krzyżowa, where some mining works are confirmed in 14<sup>th</sup> and 15<sup>th</sup> century (Dziekoński 1972, 133, 137, Mikoś et al. 2009, 38). There is not much information about mines working at the time. During the Hussite Wars the town was burned down. We can only presume that the mining infrastructure was also destroyed then. In 1429 the town was owned by the king of Czech (Dziekoński 1972, 139).

In 1465 the duchy of Ząbkowice and Ziębice and earldom of Kłodzko, along with Złoty Stok was claimed by Henryk Starszy (Jindřich Starší), son of Jiří of Poděbrad. The

duke reorganised mining works in the region. In 1483 Złoty Stok gained privileges of a mining town basing on the law of Jihlava and Kutná Hora. It also established own mining department, being a city council at once (Dziekoński 1972, 139–140). By the end of 15<sup>th</sup> century, an intensive exploration started in this area and lasted till the late 16<sup>th</sup> century. The mines were mainly owned by private investors; in 1510 the representatives of Welser and Imhoffs from Nuremberg and in 1513 the company of Turzons and Fuggers invested in the area and lasted for about 50 years (Dziekoński 1972, 142). In that time the primary deposits were explored, by digging shafts and adits. On the slopes of Góra Haniak the works started in Goldener Esel deposit, which had its outcrops on the south-east side. The mining works were held there in 15<sup>th</sup> and 1<sup>st</sup> half of 16<sup>th</sup> century. The deposits went deeper in the north-west direction. The shafts dug there were about 70 m and later about 100 m deep. On the can be split as follow Krzyżowa Góra site the digs went to 70 m below ground level (Dziekoński 1972, 157). In 16<sup>th</sup> c. the works were conducted also on the slopes of Sołtysia Góra (Mikoś et al. 2009, 47). During the prosperous period numerous adits were dug, the first appearing in 2<sup>nd</sup> half of 15<sup>th</sup> c. (Dziekoński 1972, 161). In 1509 duke Karol Podiebradowicz, owner of

the town, established another code to regulate organisational issues and maintain continuity of mining works (Dziekoński 1972, 141). In the 2<sup>nd</sup> half of the 16<sup>th</sup> century, the exploration gradually slowed down, until 17<sup>th</sup> c. All the richest deposits were exhausted in 16<sup>th</sup> c. After that the mining works were moved to some minor deposits in Haniak, Góra the same as below (Krzyżowa) and Góra Sołtysia massifs (Mikoś et al. 2009, 39). All attempts to uplift the mining in the area were stopped by a crisis caused by Thirty Years' War (Dziekoński 1972, 149). From the beginning of 18<sup>th</sup> century, the production of arsenic exceeded the gold mining, and the investments were mainly in smelting (Dziekoński 1972, 150–151). Nevertheless, there had been mining works performed in the area continuously until 1961 (Dziekoński 1972, 152–55).

The mining works were firstly conducted using open pit method in the river and stream valleys. Later, the pits were transformed into shafts of indeterminate depth. In 15<sup>th</sup> century drain adits were dug. Among with increasing depth, the function of different shafts clarified (transportation, ventilation) and the whole process moved underground. The output was transported to water powered ironworks located near Złoty Potok and in the mouth of Złoty Jar (Dziekoński 1972, 134)

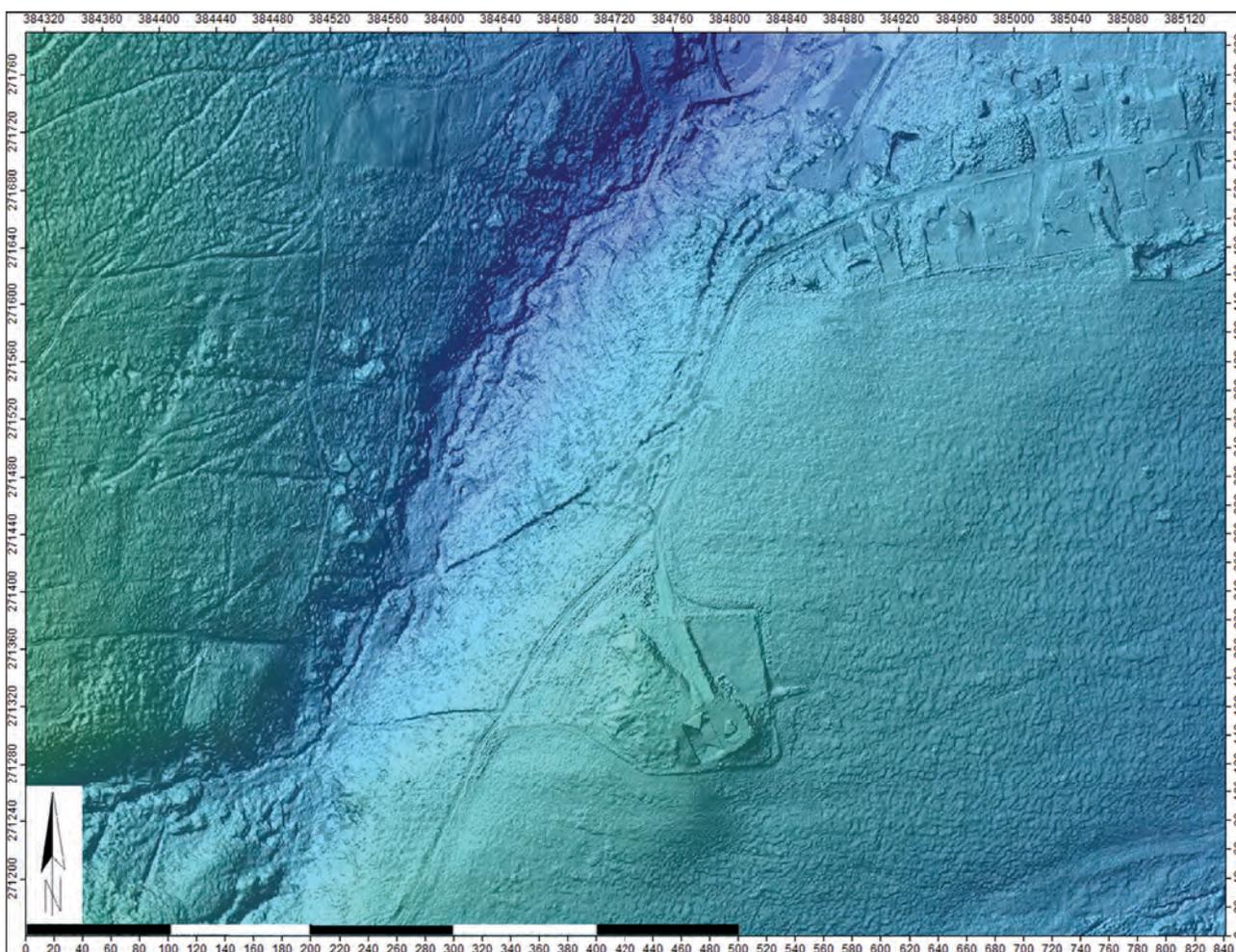


Fig. 11. Valley of Sarni Potok - relicts of shafts and washing area. Lidar-based DTM (by M. Legut-Pintal).

Obr.11. Údolí potoka Sarni - relikty šachet a mycí oblast. Lidar DTM (od M. Legut-Pintal).

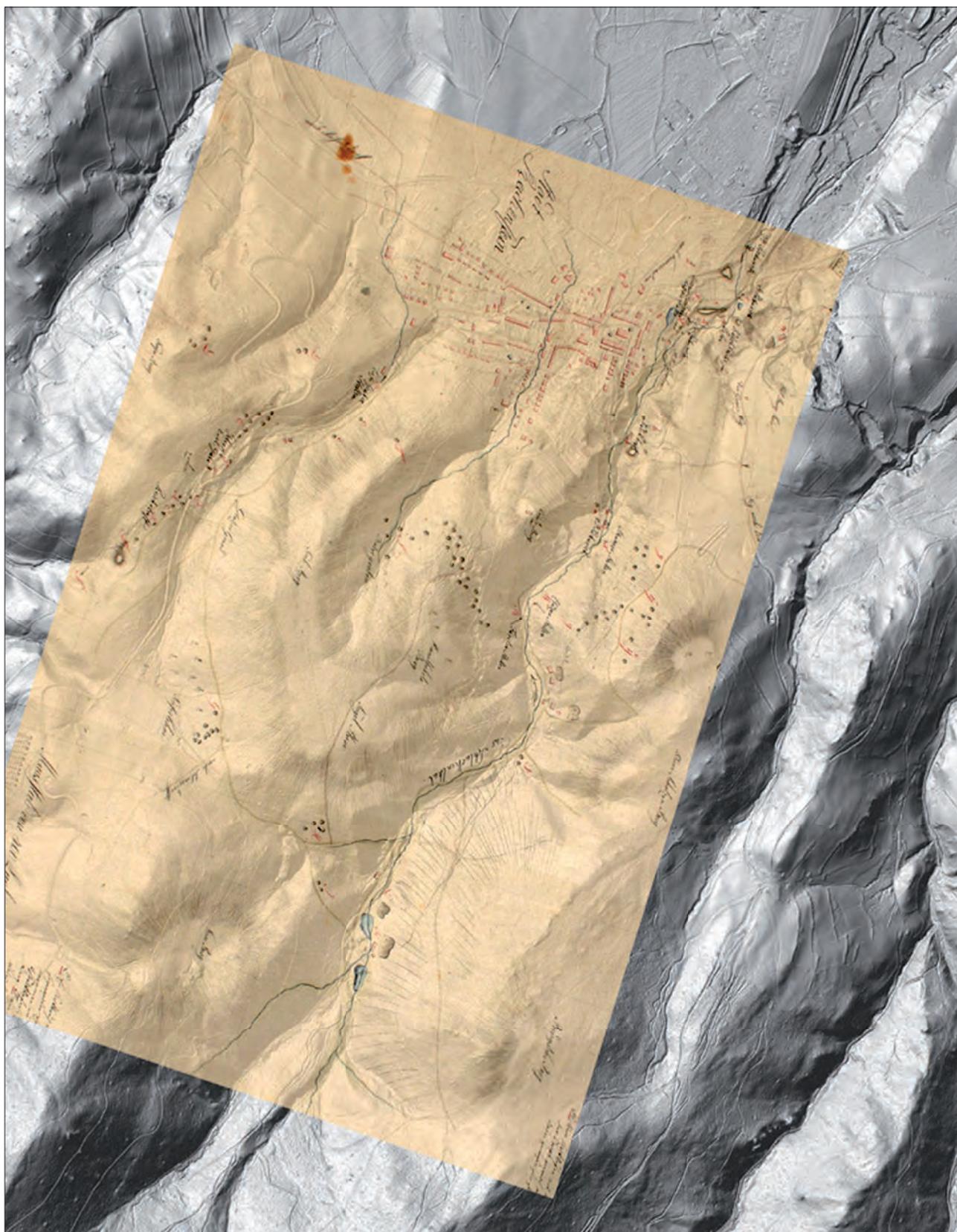


Fig. 12. Comparison of historical map and DTM of Złoty Stok mining area (by M. Legut-Pintal).  
Obr. 12. Porovnání historické mapy a DTM těžební oblasti Złoty Stok (od M. Legut-Pintal).

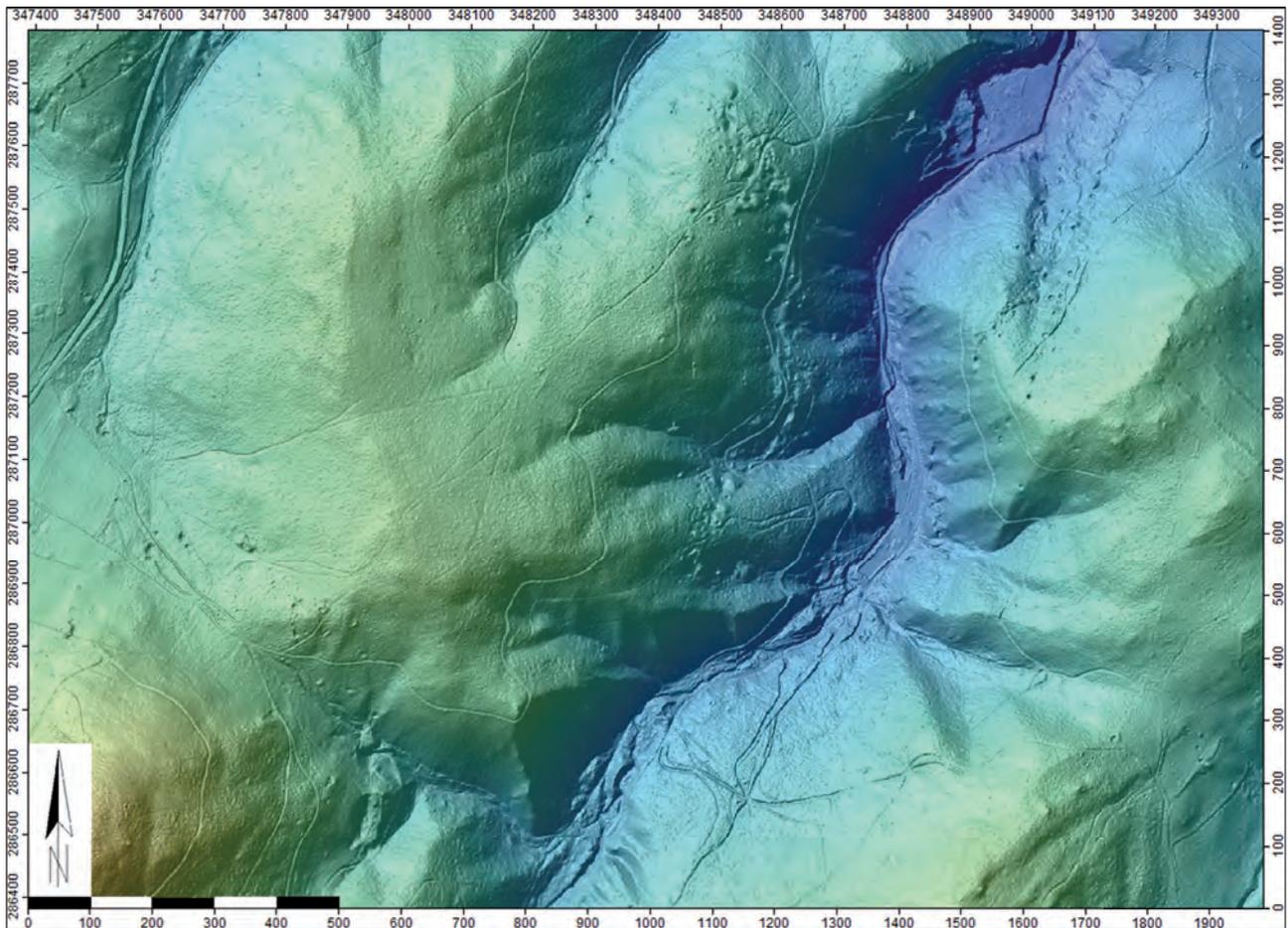


Fig. 13. Złoty Stok – mining area. Remains of shafts located along gold veins. Lidar-based DTM (by M. Legut-Pintal).

Obr. 13. Złoty Stok – těžební oblast. Pozůstatky šachet umístěných podél zlatých žil. Lidar DTM (od M. Legut-Pintal).

Correct interpretation of numerical terrain model may be difficult due to the long term mining activities in the region and continuous degradation of old mining sites by establishing new ones in their place. As the river and stream valleys were highly transformed, the remains of ore washing are impossible to be recognized. Comparison of historical maps with numerical terrain model allowed identifying and verification of the state of all significant mining sites in the region south from Złoty Stok (Fig. 12). The areas of high density of shaft relics are visible on the terrain model of the eastern slopes of mount Haniak, on a strip of land between Pustelnik and Krzyżnik, concentrated on the top of Krzyżnik and along the Złoty Jar on the slopes of Pasieka (Fig.13). Singular pits, probably dug for exploration purposes can be found on all the hills around the valley. There are also cinder tips located in Trująca valley, related to smelting.

## CONCLUSION

ALS is an accurate prospection method, allowing identification of structures difficult or impossible to be recognised by field research. It also enables looking at the archaeological site and its surroundings from different and wider

perspective. The method makes acquiring information about large scale areas easier and, because of the published, ready-to-use terrain models, it is a low cost research. The main advantage of the method is the possibility of creating numerical terrain models under the vegetation. The models are priceless source of information about terrain transformations, such as agricultural changes, urbanisation or erosion. 3D models and profiles generated from the data are clear visualisation methods. For regions of high density of archaeological sites (such as mining fields) this is the only way of creating an accurate and clear map of the area. On the other hand, as an archaeological prospection method, ALS analysis may lead to severe interpretation errors. There is still need of field research for verification and confirmation of functions and chronology of identified structures. The method also does not provide any information about structures below ground level, as it does not penetrate soil.

Although ALS seems to be a perfect method for identification of the remains of the mining activities, it does not provide any information that could help establishing their chronology. Such information can only be obtained by analysis of written sources related to mining works or by excavation. Thus, ALS can and should be utilized as a prospection method, while verification of conclusions stated basing on

numerical terrain model analysis still require verification. ALS data is an excellent starting point for further research.

## SUMMARY

Dissemination of a new method of archaeological prospection – airborne laser scanning (ALS) – enables a re-look on remains of medieval mining sites in Silesia. Digital terrain models (DTMs) based on data obtained from ALS allowed us to identify and document terrain forms related to mining. Sites selected for the research were mainly important medieval centers of gold mining with mining fields situated near the towns – Złotoryja, Lwówek Śląski, Mikołajowice, Głuchołazy and Złoty Stok. Basic archaeological research were conducted on those mining sites to confirm their medieval chronology and to discern the technique of exploitation.

ALS-based high resolution DTMs reveal enormous scale of exploitation of gold placer deposits, especially between Lwówek Śląski and Mikołajowice. Remains of tens of thousands shafts and open-pits were detected on a surface of few hectares. Comparison of DTM with historical maps allowed us to determine the preservation state of mining and washing (sluicing) areas near Złotoryja. The most important destructive factors are urbanization, agriculture and forestry.

The different types of mining works' remains were possible to identify basing on DTM. The easiest to recognize was concentration of mining shafts (Lwówek Śląski, Mikołajowice) and traces of open-pits exploitation of placer layer (Głuchołazy). DTM analysis enables identification of washing areas located along rivers or streams – piles of washed output, levees, sediment ponds and channels (Lwówek Śląski, Głuchołazy). Although ALS does not enable a documentation of underground structures, investigation of ventilation shafts remains can help in reconstruction of the course of the tunnels, as it was possible in case of Three Kings' tunnel between Głuchołazy and Zlaté Hory. In Złoty Stok, ALS analysis helped discovering previously unknown shafts and precise a positioning of gold veins.

Aforementioned examples proved that the usage of ALS data in mining research allows making high accuracy documentation of large-area sites and also identification of new objects. The method does not allow establishing precise the chronology of preserved relicts and requires further verification in surface survey and archaeological research.

## SHRNUTÍ

ALS umožňuje i v lesnatém terénu jasnou identifikaci specifických terénních útvarů včetně pozůstatků hornictví. Cílem tohoto projektu bylo vyhodnocení užitečnosti ALS dat získaných v rámci projektu ISOK za účelem ověření doposud známých center těžby zlata na území Slezska. Pro účely výzkumu bylo vybráno několik hornických lokalit se

vztahem k městům (Złotoryja, Lwówek Śląski, Głuchołazy, Mikołajowice, Złoty Stok) s dlouhou tradicí dolování zlata sahající od středověku až po raný novověk.

ALS je metoda prospekce s vysokou přesností, s jejíž pomocí je možné identifikovat i struktury, které jsou během klasického terénního výzkumu rozpoznatelné jen stěží nebo vůbec ne. Umožňuje také nahlížet na archeologickou lokalitu z odlišné a širší perspektivy. Zmíněná metoda ulehčuje získávání informací o velkoplošných areálech a díky publikování použitelných modelů terénu představuje i nízkonákladový typ výzkumu. Hlavní výhodou této metody je možnost vytváření číselných modelů terénu pod vegetačním porostem. Tyto modely jsou neocenitelným zdrojem informací o změnách terénu způsobených například zemědělskou činností, urbanizací či erozí. V případě území s vysokou hustotou archeologických nalezišť je to jediný způsob vytvoření přesné a přehledné mapy dané oblasti. V případě využití ALS jako jediné archeologické prospekční metody však může analýza dat vést k závažným interpretačním chybám. Nevyhnutelná je proto verifikace takto získaných dat terénním výzkumem, který potvrdí funkci a datování identifikovaných struktur. Metoda také neposkytuje žádné informace o podpovrchových strukturách, jelikož neproniká půdou. Ačkoli ALS se zdá být perfektní metodou pro identifikaci pozůstatků hornické činnosti, neposkytuje informace potřebné pro jejich chronologické zařazení.

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