RELIEF RELICS OF HISTORICAL MINING NEAR ĽUBIETOVÁ (CENTRAL SLOVAKIA) – POSSIBILITIES FOR MONTANISTIC (MINING) RESEARCH USING AIRBORNE LASER SCANNING (LIDAR)

Pavel HRONČEK[1], Karol WEIS[2], Dana TOMETZOVÁ [1], Miloš JESENSKÝ [3]
[1] Department of Geo and Mining Tourism, Faculty of Mining, Ecology, Process Control and Geotechnology, Institute of Earth Resources, Technical University of Košice, Slovakia
[2] Department of Geography and Geology, Faculty of Natural Sciences, Matej Bel University, Tajovského 40, 974 01 Banská Bystrica, Slovakia
[3] Miloš Jesenský Museum of Kysuce in Čadca, Moyzesova 50, 022 01 Čadca, Slovakia
E-mail: pavel.hroncek@tuke.sk

ABSTRACT

The study deals with the history of Cu (±Ag)- and locally Fe- ore mining in the locality Peklo near Ľubietová in central Slovakia. The emphasis is on the evidence of mining in the local landscape relief during the period of 16th to the 19th century. Anthropogenic landscape changes were examined on the basis of written archival documents, cartographic sources and field research. An important part of the investigation was the use of data obtained from aerial laser scanning (LIDAR) to research mining anthropogenic relics in the contemporary landscape. The study deals with the identification of these shapes in situ, their morphological and morphometric properties. The conclusion points to the positives, but also the negatives of the methodical use of LIDAR data in the mining research of historical relief relics.

Keywords: LIDAR, laser scanning, mining research, historical relief relics

1 INTRODUCTION

Nowadays, state-of-the-art computer technologies are gradually becoming established in all scientific disciplines, thus mining research is no exception. The study presents the possibilities of using LIDAR scanning for the research of historical relief relics after mining activities in local - scattered mining areas Slovakia. These locations can usually be found in inaccessible mountainous areas and are overgrown with dense forests that limit and, in many cases, make it completely impossible to explore mining relief forms.

Obviously, the older these shapes are (the Middle Ages and the beginning of modern times, as in the case study), they are more affected by weathering, and in many cases resemble natural or anthropogenic forms of other origin. It is LIDAR that provides for an unlimited view of the forms in the landscape and make them visible despite forest vegetation.

At present, the non-destructive archaeology, or, as in the case of our research, non-destructive mining archaeology. It can be characterized as... a set of techniques, methods and theories aimed at searching and evaluating archaeological [mining] sources without performing destructive interventions in the terrain...[1] Although, non-destructive archaeology is frequently understood as survey-generating knowledge of continuous, supporting or complementary nature, it is in fact an original research pursuing specific knowledge of archaeological sources.

The importance of non-destructive methods is constantly increasing and developing on the basis of new technologies, not only in the field of archaeology but also in mining research. The aim of the study is to identify historical relics of the mining relief using the LIDAR aerial scan. The mining relics were formed mostly due to Cu (±Ag)- and locally Fe ore mining in the period from 16th to 19th centuries in the local mining area Peklo, which belongs to the former mining town Ľubietová. The Peklo site has been specifically chosen as an example, as it is currently covered with dense forest considerably limiting ground field mining research.

2 POSITION AND DEFINITION OF THE HISTORICAL MINING AREA

The historical mining site Peklo that is subject to our research and belongs to the former free royal mining town Ľubietová (Fig. 1), is currently a part of the Banská Bystrica region, more precisely of the eastern part of the Banská Bystrica district. It is located about 22 km to the east from the town Banská Bystrica.

Figure 1. Location of the research area within the borders of Slovakia and Central Europe (Atlas krajiny Slovenska, 2002)

In the past it belonged to the northern part of the Zvolen county. Currently, Ľubietová is a rural settlement with a population of 1,200 inhabitants.

Given the mining history of Ľubietová, its position in relation to geomorphological units of a different geological structure is also interesting. The northwestern and southwestern part of the cadastral area is located in the volcanic field of Zvolen Basin and Poľana. The eastern part of the cadastral territory, to be more precise the right bank of the Hutná Brook, lies in the Veporské Hills. There, the most important historical mining sites (Podlipa, Jamešná and Svätoduška) can be found.

The Peklo site lies east of Ľubietová in the neighbouring valley of the Brusnianka Brook, i.e. in the widened area in which the Peklo Valley turns into the Brusnianka Valley from the left side.

3 METHODS AND MATERIALS

The in-situ research of relief relics after historical mining requires a comprehensive approach consisting of several basic methodological procedures. The first step is a comprehensive archival research on the history of mining in the mining site under research. The archival research must be complemented by systematic field mining survey focusing on anthropogenic field mining relics. Nowadays, however, the historical mining relief relics originated from the 16th century during the Cu (±Ag)- and Fe- ore mining are covered with dense forest, in many places with rich vegetation. The current state makes it much more difficult to perform in situ research. For this reason, the best option is to use methods of non-destructive archaeology, or in our case rather non-destructive mining archaeology aimed at identifying and analysing relief mining relics.

3.1 Historical and archival research

Our archival research of textual historical sources was based on the methods consisting of traditional steps of historical research [2, 3, 4, 5]. After setting the goal of the work, we collected, sorted and critically evaluated related historical documents and maps stored in archives. This was followed by their logical arrangement and preparation of a final textual synthesis [6, 7] reconstructing the historical development in the baseline of the 16th to 19th centuries. The sources used for the research came from the State Archive in Banská Bystrica, the Slovak Mining Archive in Banská Štiavnica, the Public Archive and the Public Museum in Ľubietová.

The 1827 mining map of the researched mining site Peklo was subjected to a detailed historical, geographical and cartographic content analysis. The map is held by the Slovak Mining Archive in Banská Štiavnica, the Map Collection of the Main Mint Chamber Counts Office in Banská Štiavnica, under no. 9225. The content of historical maps was, for instance, analysed by Olah [8], Boltižiar [9], Hronček and Jakubík [10] and Hronček and Turóci [11]. Of those, it was Hronček [12, 13] who focused on the content analysis of historical mining maps.

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3.2 Field research

A detailed field research using modern cartographic and computer devices and methodological procedures is a very important part of research, especially in the mining locations with no or minimal written and cartographic archival materials. The use of modern GPS devices or laser measuring tools is devoid of purpose or is significantly restricted if the mining sites are hidden in dense forests. Just like in the case of the researched site Peklo.

During the field research we used proven (traditional) methodological work procedures typical for geomorphological research [14, 15]. The methodology of mining anthropogenic relief form identification was based on the works of experts dealing with anthropogenic geomorphology such as Zapletal [16, 17], Z. Podgórský [18] or Čech and Krokusová [19]. Even more detailed methodology can be seen in the mining archaeology written by Hronček, Weis and Rybár [20]. However, the most comprehensive methodological work dealing with mining archaeological research is the work of Hrubý et al. [21].

3.3 Non-destructive mining research using LIDAR

Light Detection And Ranging (LIDAR) makes it possible to identify or verify relief relics in mining research, especially in areas where up to now only the forest has been seen from the plane, which is a problem of most historical mining areas not only in Slovakia.

The digital terrain model made by LIDAR technology can provide detailed information about the terrain forms even hidden in vegetation. It is possible to create high-quality materials for the creation of a detailed digital relief model (DMR) of individual mining relief shapes up to micro-shapes by classifying and filtering the point cloud obtained with aerial scanning. In these models it is possible to detect relief structures of approx. 10 cm in size also in wooded areas that otherwise cannot be noticed [22, 23, 24, 25].

The aim of non-destructive archaeological procedures is to identify traces of past settlement activities, classify them and locate them in space. Unlike archaeology exploring objects, non-destructive archaeology focuses on archaeological complexes that means: "structured sets of artifacts and ecofacts reflecting some kind of human activity" [26]. At the same time, we can talk about the research of areas of activity, or events during which "were created objects and complexes taking place in areas that were defined within the overall structure of the cultural landscape" [27].

One of the most dynamically developing areas of non-destructive archaeology is remote sensing, which, in addition to satellite imagery analysis, also includes a prospection of low-flying means (aircraft or drone) developed into a separate scientific field. The aerial survey is an integral part of the research focused on the knowledge of the regional settlement history, settlement dynamics, identification of prehistoric settlement network, as well as the analysis of relations between areas. The possibilities of aviation archaeology to address such topics are often crucial in the sense that sources collected by its methods create a data set (whose properties are mainly multiplicity and diversity), which, in a certain landscaped environment (for example, on well-developed river terraces), cannot otherwise be gathered [28].

At present, the most advanced technology is LIDAR aerial photography. It consists of evaluating the time interval during which the pulse reflected from the ground returns to the scanner on board of the aircraft. Since subtle differences of the Earth's surface can also be detected in this way, it is particularly suitable for mapping of the terrain relief in wide river valleys. LIDAR locates archaeological objects with an accuracy of 10 cm, measures their height, but does not map structures hidden under the surface.

Information obtained through aviation archaeology, and in particular through the use of the LIDAR system, effectively serves the study of the historical (prehistoric, medieval and modern) landscape, as well as evidence of human activity there. The main objectives of aviation archaeology include landscaping of the selected area from above to identify previously unrecorded archaeological monuments in relief, documentation of the cultural landscape, as well as subsequent recording, archiving and expert analysis of the obtained data, their use in scientific work and in the protection of cultural heritage [29].

The use of LIDAR technology has been documented in world literature enough to demonstrate its potential in archaeological research, including mining, and in the collection of spatial data for the creation of digital height models [30, 31, 32, 33]. This method of three-dimensional mapping, especially in Western Europe, becomes an integral part of the archaeological heritage registration and protection as well as the research of the historical landscape with the remains of former settlements [34, 35]. A similar trend can be observed in the neighbouring Czech Republic [36, 37, 38, 39, 40] or in Slovenia [41].

Automatically categorized images were used in format *.las, georeferenced in UTM34 coordinate system. We used the full LAS_ALL dataset as well as the filtered LAS_Ground data, which allowed us to use proper data and potentially incorrectly filtered data in complex relief with dense vegetation. Both datasets contained TILEs in

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*.las format with the size of 2000 x 2000 meters with a balanced density of about 5 points/m^2. Data were processed and visualized in 3DReshaper, ArcMap and ArcScene software environments (ArcGIS Desktop 10.5), DEM morphometric parameters were analysed in Surfer and Voxler (Golden Software). The resulting composition was optionally supplemented with ML5000_ortho RGB images [42].

4 RESULTS AND DISCUSSION

4.1 Brief history of mining on the site

Based on the current state of historical, montanistic (mining), geomorphological or deposit-mineralogical research, we cannot take a clear position on which main ores were mined in the Peklo site. Our historical research, based on original archival text and cartographic sources (stored in the archives in Banská Bystrica, Banská Štiavnica, Vienna and Budapest), show that iron ores were mined in the site and copper mining was marginal. On the contrary, deposit-mineralogical studies show in their conclusions that only copper-silver mineralization was mined in the Peklo site [42]. The authors themselves point out in this work that mining of Cu (± Ag) –ores was repeated exploration mining and not long-term mining. However, this does not preclude the possibility of occasional mining of local Fe-ore resources, to which our found archival sources point indirectly.

Since the aim of the paper was to point out the possibilities of using LIDAR aerial photography to investigate surface relicts of relief after historical mining, we will not discuss this issue in detail. We will work with the term ore mining.

Due to the lack of archival documents on the beginnings of mining activities in this area, the answer to this question is more than problematic. Sketchy information from written archival documents and cartographic materials was supplemented by comprehensive field research using the latest computer methods and thanks to this interdisciplinary approach to the issue, we were able to find out that mining of ore in Peklo started most likely in the first half of the 16th century.

Specific written document about the mines and smeltery located in the Peklo site is provided by a note of 1536 deposited in the State Archive in Banská Bystrica in the Zvolen County Fund (under No. 203). Another document confirming the intensive mining and metallurgical activity on the site is of 25th December 1555. It is held by the State Archive in Banská Bystrica in the fund Ľubietová town archive (ML - 46/a). Other evidence is of 1563.

Mines are also mentioned in the historical documents from the first half of the 17th century, for example in 1615 [44]. Similar are documents of November 1624, May 1631, January, May and December 1638, May 1639 (Black Valley) or of the end of 1639 [45]. The mines are documented in deeds from the second half of the 17th century and also the 18th century. These documents are deposited in the State Archive in Banská Bystrica in the Zvolen County Fund (under No. 162).

Despite many inaccuracies, the map of the first military mapping of 1783 is an important visual source for the topography research of the Peklo site [46]. The map is named after the German nomenclature in the form of Peklo *Eis. Schmeltz.* The fact that ore mines and iron smeltery were in the penultimate decade of the 18th century already in decline and possibly even out of service can be proved by the map of 24 July 1785 deposited in the Slovak Mining Archive in Banská Štiavnica in the Main Mint Chamber Counts Office (under No. 1469), since it does not depict them despite it is detailed.

The definitive abandonment of old ore mines is confirmed by the mining map of 1827 deposited in the Slovak Mining Archive in Banská Štiavnica in the fund of the Main Mint Chamber Counts Office (under No. 9225). The map shows the abandoned old ore mines because there was an interest in their recovery during this period. Based on this map, we know that these were old hand-mined mines (galleries and shafts), the origin of which can be estimated at least on the breakthrough of the Middle Ages and Modern Age, i.e. to the 16th century. These mines are located at the northern foot of the Valachovo Hill on the left side of the Brzáčka Valley (Welcky Czierny Peckla Grund). The old mines consisted of the hand-mined drainage adit (in Slovak „*kresanica*“), which is the lowest adit level accessible from the surface. They included an old hand-drawn shaft with a heap and several galleries as well. Lidar scanning also confirmed other old works represented by exploration adits and several lines of pingen (Fig. 8).

The shaft was hand-mined by a pick and a hammer in a square plan and reached a depth of 20 m. Short mine corridors came out of the shaft, spread out in two horizons. At the shaft was a slope heap facing the Brzáčová Brook, at that time called Veľké Čierne Peklo (Welcky Czierny Peckla Grund). Above the shaft was built a winch powered by a water wheel. The map does not record head-race channel and sluiceway, but a LIDAR scan revealed a well-preserved leading ditch in the field. The ditch was diverted from Brzáčová Brook and led its left side to the water wheel of the Ján shaft. Then it returned to the Brzáčová Brook by the shortest route (40 m). On the basis of

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LIDAR scanning, we also identified the presence of head-race channel relics in the field. Digital mapping determined the length of the sluiceway to 230 m when it was diverted off the brook at an altitude of 612 m and headed for a water wheel at an altitude of 608 m (Fig. 3, 4).

Figure 2. Preserved water-bearing relic of Ján shaft (left) and relic of collapsed mouth and slope heap of the main adit (right). These relics are still significant and can be identified in the field without LIDAR scanning. (photo by P. Hronček)

Another important part of the ore mine Peklo was the nameless adit located lower (605 m above sea level), described as an abandoned adit with a vein. At the end of its mine corridor was a large extracted chamber. Due to the relatively large dimensions of the slope dump (height 3.5 m, width 23 m and length 34 m) it had to be a larger underground space. A wooden mining dormitory - barrack (*HäuerKram*) (Fig. 2), covered with a gable roof stood on the platform of the dump in front of the entrance to the gallery. There was a collapsed pinge (mining pit), which formed the buried mouth of the old shaft situated at the foot of the slope of Valachovo Hill. The diameter of the pinge, including the spoil bank, is currently 15 m. In the given time horizon, it was already covered with mature fir forest. The map also shows the drainage adit described above, as well as a small exploratory adit on the right side of the brook. LIDAR scanning and field research revealed the relics of six more exploratory galleries with slope heaps and plenty of pingen and pingen lines, respectively.

4.2 The use of LIDAR scanning for research of historical mining site

Laser scanning of the Earth's surface or the terrain relief using LIDAR technology also brings significant simplification of the micro-shapes identification of natural or anthropogenically modified relief in the field of mining research. These advantages result from the relatively high density of the measuring points, by which we are able to cover the relief in short time. The technology is able to detect objects or subjects of different nature and composition theoretically up to the level of individual molecules. The laser beam thus enables aerial mapping of the landscape with a very high resolution.

LIDAR images from the NLC (National Forestry Center) in Zvolen, the Institute of Forest Resources and Informatics, which has its own images of selected areas in suitable resolution, were used for the purpose of relief micro-shapes identification.

Detailed information on the course of line terrain relics created after historical ore mining during the 16th to 19th century covered under dense forest vegetation were obtained in the mining area of Ľubietová surroundings in the Peklo site by using suitable visualization techniques and by creation of digital terrain model using LIDAR technology. With no major problems, we have identified anthropogenic mining relics, represented by pingen, sinkholes, heaps, ditches, exploratory adit lines, etc. (Fig. 6), with proper morphological analysis of the digital relief created from LIDAR scanning. The obtained results had to be verified by detailed and systematic field research, which we managed to do.

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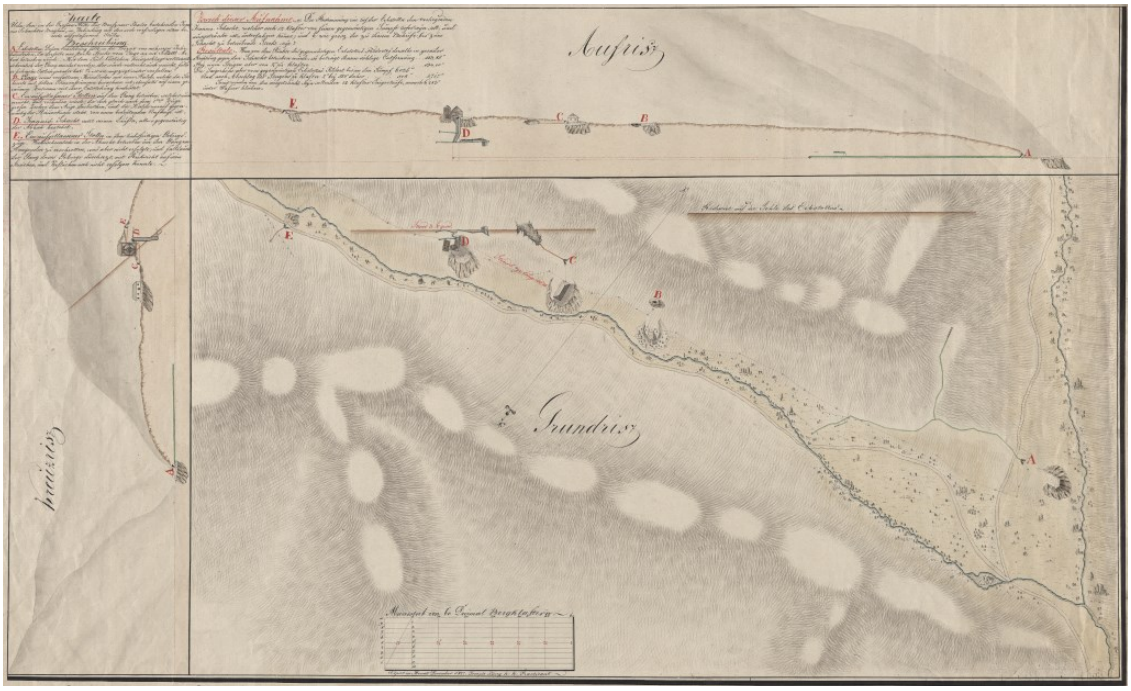

Figure 3. Map of the Ján shaft in Veľké Peklo with existing adits (SBA Banská Štiavnica, Fund HKG-IV., under. No. 9225, Jozef Taug 1827)

Figure 4. 3D DEM composition, as a result of the interpretation of LIDAR and RGB photographs OrthoImage in scale 1:5000 (Geodetic and Cartographic Institute Bratislava), the view of the orthophoto-mosaic is approximately south-oriented

The DEM micro-shapes identification was performed by combining the results of a detailed visual evaluation of LIDAR 3D images and comparing them with the results of DEM morphometric analysis (orientation, slope, horizontal & vertical curvature) in Surfer environment. Finally, due to the high-quality LIDAR images and consistent DEM analysis results was sufficient to visually compare imagery with archival research and field mapping results. The situation is documented by the section oriented into the valley of the Brusnianka Brook above its confluence with the Peklo Brook (Fig. 4, 5). In addition to the access roads to the individual mining works, the mining ditches and the remains of the shaft collar heaps, or the cuts of already mentioned collapsed galleries, are clearly visible.

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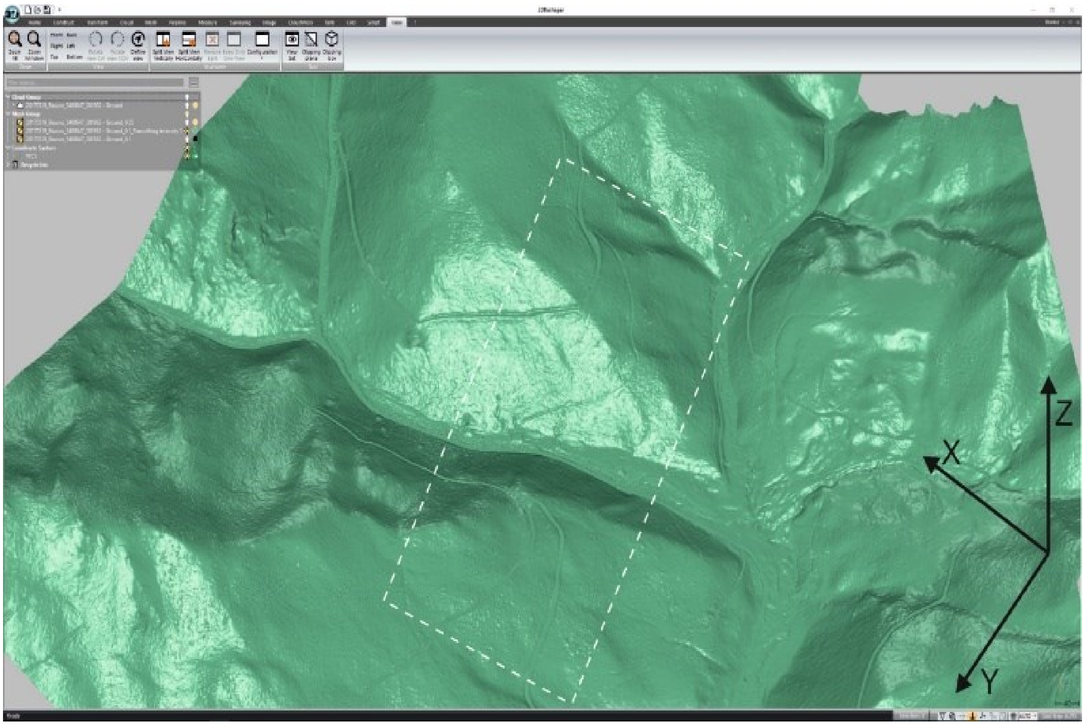

Figure 5. 3D visualization of DMR around the confluence of the Brusnianka Brook with Peklo Brook in 3DReshaper environment (archive of the village Brusno, compiled by K. Weis)

The identified relics of the mining relief micro-shapes are clearly visible on a detailed section, oriented east-north-east into the valley of the Brusnianka Brook, about 350 m above its confluence with the Peklo Brook. To enhance the embossed micro-shapes, the point cloud was folded with a regular mesh with a cell size of approximately 10 x 10 cm, filtering and smoothing was done to form a tight mesh. The original map section contained 41504823 unfiltered ground points. For display purposes, 2530276 points were used at filtering intensity 1, which created a total of 5057785 triangles (Fig. 7, 8, 9).

Figure 6. The mining dumps on the stream flood-plain Brzáčová brook (photo by P. Hronček)

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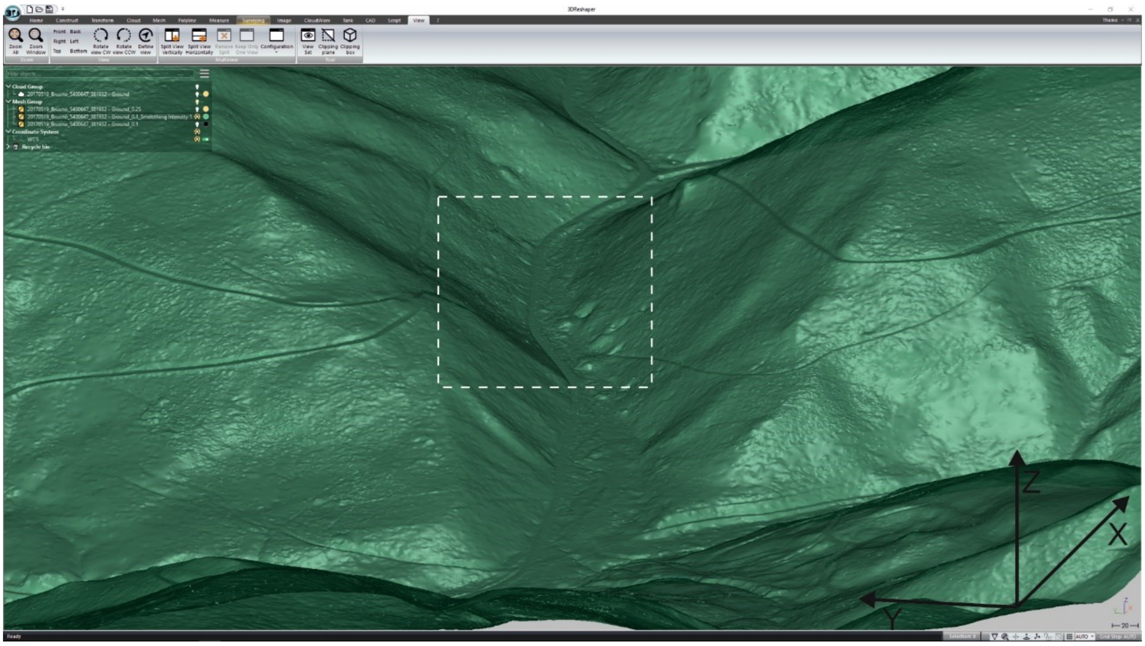

Figure 7. View of the Brusnianka Brook valley (east-north-east) above its confluence with the Peklo Brook (archive of the village Brusno, compiled by K. Weis)

Figure 8. Many exploratory pits – pingen or line ditches only marginally resemble mining relief shapes, they are more similar to pit of a rootwad. Their identification in LIDAR and their terrain layout allows them to be clearly identified with historical mining on the site (photo by P. Hronček)

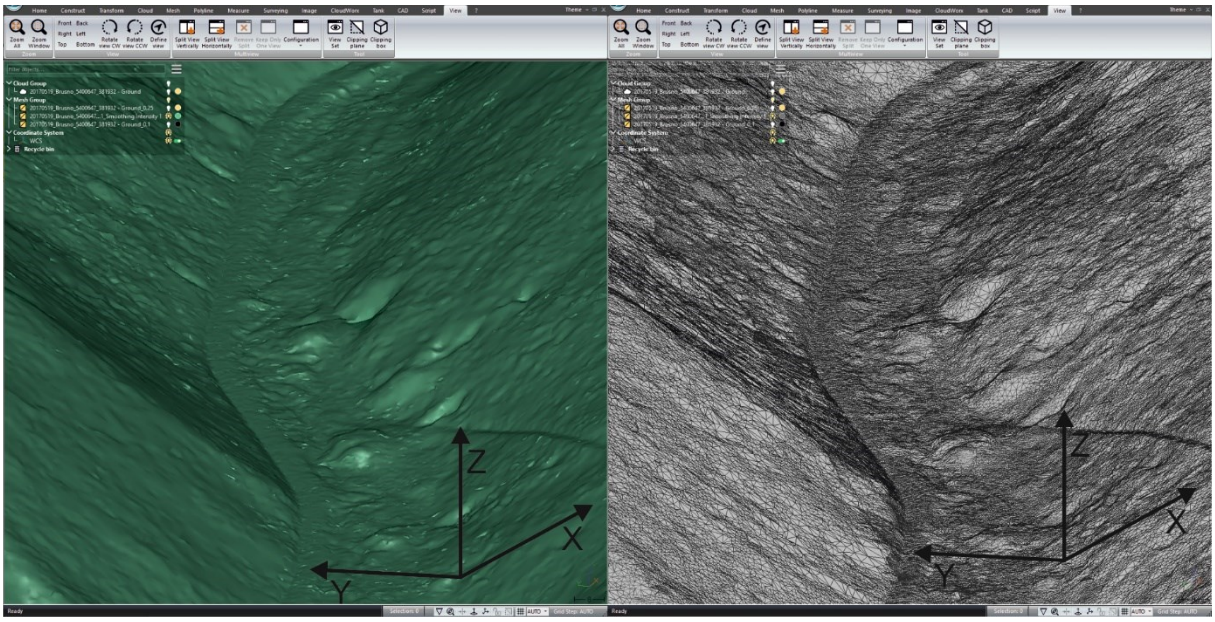

Figure 9. Detail of map section with identified micro-forms of mining relief in Brusnianka Valley (left) and representation of mining relief using triangular mesh without rendered surface (right) (archive of the village Brusno, compiled by K. Weis)

5 CONCLUSION

So far, mining anthropogenic geomorphology in Slovakia has focused its research on 'traditional' methodological procedures of field research based on geomorphology and partly also on geography. The use of LIDAR aerial photography in mining anthropogenic geomorphological research helped us to identify in the dense forest such relief elements that we could not define in our country despite our nearly 25 years of field research experience. After the digital removal of forest vegetation, the digital relief model revealed invisible pingen lines with dimensions of individual pingen up to 2 m in the terrain. The head-race channel supplying the wheel of Ján shaft by water also appeared in a plastic representation. The paper documents the innumerable advantages of using LIDAR aerial scanning in detailed anthropogenic mining geomorphological research. However, at the very end it should also be mentioned the disadvantage of this technical research and that is its high price, which has a major impact on its unique use in science.

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