Bajtoš P, Pramuka S, Rapant S (2012) Impact of mineral extraction on the environment – Report for 2011, Report № ČMS Geological Factors 04–207–2012. Ministry of the Environment of the Slovak Republic | Section of Geology and Natural Resources | Dionýz Štúr State Geological Institute | Regional Centre Spišská Nová Ves, Spišská Nová Ves, 61 p

The chemical composition of groundwater exceeded the limit value for Sb by 0.009 mg·l^{-1} (OBÚ Spišská Nová Ves – Activity Report for 2011).

4.8 Nižná Slaná R8 site

The Nižná Slaná – Manó – Kobeliarovo metasomatic siderite deposit (DP Nižná Slaná) was mined underground by Siderit s.r.o. Nižná Slaná. However, due to insolvency, the company went into bankruptcy in November 2008 and mining was stopped. In the following years, unsuccessful attempts were made to resume mining, and the deposit was drained by pumping out mine water. Based on the decision of the District Mining Office No. 549-1709/2011 of 3 August 2011, SIDERIT, s.r.o. Nižná Slaná was granted a mining permit for the liquidation of the main mining works in the "Nižná Slaná" mining area. The District Mining Office in Spišská Nová Ves ordered this organisation to prepare a hydrogeological study of the flooding of the mine and subsequently also a Plan for the liquidation of the main mining works, which was to take this study into account. After the power supply was disconnected, the pumping of groundwater was terminated on 18 August 2011 at the XIII horizon and on 19 August 2011 at the XII horizon. Since then, the mine has been flooding spontaneously. The tailings pond in Nižná Slaná is classified as category A within the meaning of Act No. 514/2008 Coll. on the management of waste from the extractive industry and on amendments to certain acts, as amended. The District Mining Office in Spišská Nová Ves, as the first-instance authority for the exercise of state administration pursuant to Act No. 514/2008 Coll. , exercised state supervision in 2011 over the fulfilment of the requirements and obligations of mining waste storage operators established by Act No. 514/2008 Coll. and decisions issued on its basis.

Hydrogeological and geochemical aspects

The mining plant complex included an iron ore thermal treatment plant consisting of a crushing plant, two rotary roasting furnaces for ore decarbonisation and a thermal pelletisation plant. The ore processing plant was a long-term source of gaseous emissions and solid fly ash contaminating the air and surface of their catchment area, mainly with sulphur, iron, manganese and arsenic. The non-magnetic fraction of the thermally processed ore was stored in a tailings pond located near the mining and processing plant. During operation, the pumped mine water was used in the ore processing technology and its surplus was pumped to the tailings pond. Operational monitoring of the quantity and quality of mine water and seepage water from the tailings pond was carried out. In accordance with the programme in the approved handling and operating rules for the tailings pond, regular measurements of the groundwater level in the probes and geodetic measurements of the displacement of the tailings pond dam were carried out.

The results of our own measurements of the instantaneous drainage flow from the tailings pond, together with the water temperature and specific electrical conductivity values, are shown in Table 25.

Table 25 Results of hydrometric measurements of mine water and seepage water discharges at the Nižná Slaná site for the period 2008–2011.

Object	Qmin (l.s^{-1})	Qmax (l.s^{-1})	Qavg (l.s^{-1})	Water temperature (°C)	EC (mS.m^{-1})	n
Seepage from tailings pond	0.56	3.21	1.59	13.1 – 16.8	72.8-202.0	6
Gabriela shaft	Pumped yield 5 l.s-1 by the end of 2011			8.9 – 14.9	32.4-574	3

The mining organisation provided the ČMS GF VŤNŽP database with operational data on the quality of waste and mining water for the years 2005–2009. We conducted our own laboratory tests twice a year to determine the quality of drainage water from the tailings pond between 2009 and 2011. Table

26 shows the characteristic values of the monitored quality indicators, derived from laboratory analyses for the period 2007–2011. Increased concentrations of arsenic, sulphate anion, manganese and lead were found (Table 27).

Table 26 Characteristic values of indicators of mining and surface water quality from the Nižná Slaná site (2009-2010)

	pH	**EC** *$mS.m^{-1}$*	**SO_4** *$mg.l^{-1}$*	**Fe** *$mg.l^{-1}$*	**Mn** *$mg.l^{-1}$*	**Hg** *$mg.l^{-1}$*	**Zn** *$mg.l^{-1}$*	**Pb** *$mg.l^{-1}$*	**As** *$mg.l^{-1}$*	**Sb** *$mg.l^{-1}$*	**Cu** *$mg.l^{-1}$*
Sludge bed - drainage	5.79	115.9	597	0.469	2.14	<0.0001	0.006	0.0246	0.447	0.009	0.0078
Gabriela shaft	8.10	574.0	2519	0.15	0.29	<0.0001	<0.003	0.0684	0.013		0.0063

Table 27 Overview of the classification of groundwater and surface water quality at monitored sites in Nižná Slaná, 2009-2010

	Classification of groundwater quality				**Surface water quality classification**				
	-	**A**	**B**	**C**	**I**	**II**	**III**	**IV**	**V**
Sludge pond - drainage	Hg, Zn, Cu, Cd	Pb Sb		As	Fe, Hg, Zn, Cd	Cu	Pb, Sb	EC, pH	As, Mn, SO_4
Gabriela shaft	Cu, Zn, Hg, Cd	As	Pb, Sb		Al, Zn, Cr, Cd	pH, Hg, Cu	Fe, Mn, As	Sb, Pb	EC, pH, SO_4

The hydrogeological study of the flooding of the mine in Nižná Slaná, or rather the Manó – Gabriela deposit, was prepared for SIDERIT, s.r.o. Nižná Slaná by Ing. Marián Bachňák – ENVEX Rožňava. The study estimates that the mine will take 20 years to flood and that the amount of mine water flowing out will be 7–12 $l \cdot s^{-1}$. To prevent unwanted leaks in the built-up area between the shaft and the Slaná River, where the state road passes, it is proposed to excavate a drainage tunnel at the height of the local erosion base of 360 m above sea level.

Engineering geological aspects

The occurrence of signs of subsidence – cave-ins, sinkholes and ground subsidence at the Kobeliarovo deposit – was limited in 2004 to a section of the deposit measuring approximately 200 x 200 m. According to information that has not yet been verified, surface subsidence in the Kobeliarovo deposit area, on the north-western edge of the village, has been occurring since the mid-1990s. According to data from Siderit, s.r.o. Nižná Slaná, the first collapse occurred in 1995. From August 2002, repeated field surveys and detailed photographic documentation were carried out in the collapse zone, initially of the nine collapses that existed at that time, and later, at the end of the monitoring period (August 2004), of up to 19 collapses that had gradually occurred in the collapse zone. Due to the high safety risk resulting from the threat of sudden ground subsidence, the mining organisation minimised the geodetic monitoring of subsidence to a small number of peripheral subsidence areas and to two or three periods. According to the results of measurements at five points (KV-1, KV-12, KV-13, 4, 5), which were monitored from October 1996 to July 2004, it can be stated that only at two points was a more significant, but ultimately very slow, subsidence recorded (KV-1: -0.026 m; KV-12: -0.042 m), and at the other three points the decrease was negligible (0.000 – 0.008 m). The resulting cumulative vertical changes measured at two additional points monitored from June 2001 for a period of 3 years (0.004 – 0.013 m) can also be described as a very slow decline (Vrana, 2005).

Fig. 15 Temporal development of the extent of the landslide zone in Kobeliarovo with the status as of 2004, 2006, and 2009 based on an orthophotomap from aerial photography

The temporal development of the landslide zone in Kobeliarovo is documented in Fig. 15. Based on an orthophoto map from 2004, the contours of the landslides from 2006 and 2009, obtained from Google Earth satellite images, are shown. The situation in 2004 corresponds to that documented in the report by Vranu et al. (2005). Compared to this situation, it is possible to see the expansion of individual landslides and the formation of new landslides in the area above the mined siderite deposit. The sizes of the areas affected by landslides in individual years at the Kobeliarovo site are as follows:

2004	5,047 m^2
2006	10,451 m^2
2009	16,255 m^2

At the Manó – Gabriela deposit, the collapse zone is stable and no new surface manifestations of instability have been recorded. According to a 1:10,000 scale topographic map from 1991, there are 31 mostly smaller sinkholes with a diameter of up to 20 m along the Rimberg ridge in an area of 1 km x 300 m. We digitised their contours in 2011 and included them in the subsystem database. In connection with the termination of mining at this deposit, based on the decision of the District Mining Office No. 549-1709/2011 of 03.08.2011, the organisation SIDERIT, s.r.o. Nižná Slaná was granted a mining permit for the liquidation of the main mining works in the "Nižná Slaná" mining area.

4.9 Slovinky R9 site

This site contains the depleted copper ore deposit Gelnica – Gelnická žila (DP and CHLÚ) and the deposit Gelnica – Krížová žila (CHLÚ), both managed by ŠGÚDŠ Bratislava. Mining has been terminated since 1990, and liquidation and security work is carried out here by the organisation Rudné Bane š.p. Banská Bystrica, which operates the former ŽB plant.

Hydrogeological and geochemical aspects

The mining areas between Slovinky and Gelnica, where the following were mined in the past siderite-sulphide ore, and flooded.

Bajtoš P, Pramuka S, Rapant S (2013) Impact of mineral extraction on the environment – Report for 2012, Report № ČMS Geological Factors 04–207–2013. Ministry of the Environment of the Slovak Republic | Section of Geology and Natural Resources | Dionýz Štúr State Geological Institute | Regional Centre Spišská Nová Ves, Spišská Nová Ves, 61 p

The tailings pond in Markušovce is classified as category A under Act No. 514/2008 Coll. on the management of waste from the mining industry and on amendments to certain acts, as amended. The District Mining Office in Spišská Nová Ves, as the first-instance body for the exercise of state administration pursuant to Act No. 514/2008 Coll. carried out state supervision in 2011 over the fulfilment of the requirements and obligations of mining waste storage operators established by Act No. 514/2008 Coll. and decisions issued on its basis. When measuring the chemical composition of water seeping from the Markušovce tailings pond in the fourth quarter of 2011, the measured amount of insoluble substances exceeded the specified limit by 7 $mg.l^{-1}$ and when measuring the chemical composition of groundwater, the limit value for Sb was exceeded by 0.009 $mg.l^{-1}$ (Collective of authors, 2012).

4.8 Nižná Slaná R8 site

The Nižná Slaná – Manó – Kobeliarovo metasomatic siderite deposit (DP Nižná Slaná) was mined underground by Siderit s. r. o. Nižná Slaná. However, due to insolvency, the company went into bankruptcy in November 2008 and mining was stopped. In the following years, unsuccessful attempts were made to resume mining, and the deposit was drained by pumping out mine water. Based on the decision of the District Mining Office No. 549-1709/2011 of 3 August 2011, SIDERIT, s.r.o. Nižná Slaná was granted a mining permit for the liquidation of the main mining works in the "Nižná Slaná" mining area. The District Mining Office in Spišská Nová Ves ordered this organisation to prepare a hydrogeological study of the flooding of the mine and subsequently also a Plan for the liquidation of the main mining works, which was to take this study into account. After the power supply was disconnected, the pumping of groundwater was terminated on 18 August 2011 at the XIII horizon and on 19 August 2011 at the XII horizon. Since then, the mine has been flooding spontaneously. Due to the dangerous situation that arose after the liquidation of the surface part of the mining operation, as access to the underground via the main mining works was not prevented by any technical means, the District Mining Office in Spišská Nová Ves ordered the organisation Rudné bane, štátny podnik (Ore Mines, State Enterprise) Banská Bystrica to take measures to eliminate this dangerous situation and further ordered it to ensure compliance with the conditions of the decision on the liquidation of the main mining works in the mining area. Nižná Slaná. The tailings pond in Nižná Slaná is classified as category A within the meaning of Act No. 514/2008 Coll. on the management of waste from the mining industry and on amendments to certain acts, as amended. The District Mining Office in Spišská Nová Ves, as the first-instance body for the exercise of state administration pursuant to Act No. 514/2008 Coll. , exercised state supervision in 2012 over the fulfilment of the requirements and obligations of mining waste storage operators established by Act No. 514/2008 Coll. and decisions issued on its basis.

Hydrogeological and geochemical aspects

The mining plant complex included an iron ore thermal treatment plant consisting of a crushing plant, two rotary roasting furnaces for ore decarbonisation and a thermal pelletisation plant. The ore processing plant was a long-term source of gaseous emissions and solid fly ash contaminating the air and surface of their catchment area, mainly with sulphur, iron, manganese and arsenic. The non-magnetic fraction of the thermally processed ore was stored in a tailings pond located near the mining and processing plant. During operation, the pumped mine water was used in the ore processing technology and its surplus was pumped to the tailings pond. Operational monitoring of the quantity and quality of mine water and seepage water from the tailings pond was carried out. In accordance with the programme in the approved handling and operating rules of the tailings pond, groundwater level measurements were regularly performed in probes and geodetic measurements of the tailings pond dam displacement were performed.

The mining organisation provided the ČMS GF VŤŽP database with operational data on the quality of waste and mining water for the years 2005-2009. We conducted our own laboratory tests twice a year to determine the quality of drainage water from the tailings pond between 2009 and 2012. Table 37 shows the characteristic values of the monitored quality indicators, derived from laboratory analyses for the period 2007–2012. Elevated concentrations of sulphate anion, manganese and arsenic were found in the water from the tailings pond, which do not meet the requirements for surface water quality (Table 38). In terms of assessing the quality of drainage water from the tailings pond according to the criteria for assessing the risk of groundwater pollution (Methodological Instruction of the Ministry of the Environment of the Slovak Republic No. 1/2012-7), this risk is due to the content of As (exceeding the indicative criterion but complying with the intervention criterion, Tables 39 and 40).

Table 37: Characteristic values of mining and surface water quality indicators from the Nižná Slaná site (2009-2012)

Object	Date	Q *l/s*	EC *mS/m*	pH	SO_4 *mg/l*	Fe *mg/l*	Mn *mg/l*	Pb *mg/l*	As *mg/l*	Sb *mg/l*	Cu *mg/l*
sludge	2009 - 2012	1.40	110.6	7.45	374	0.491	1.510	0.0025	0.0981	0.0041	0.0013

Table 38: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with surface water quality requirements (2009-2012)

Object	Period	EC	pH	SO_4	Fe	Mn	Pb	As	Sb	Cu
sludge	2009 - 2012	1.01	V	**1.50**	0.25	**5.03**	0.35	**13.08**	0.81	0.11

Explanatory notes: The data represent the ratio of the measured characteristic value for the monitored period and the required value according to Slovak Government Regulation No. 269/2010 Coll. Values greater than 1 indicate that the required value has been exceeded and are highlighted in colour and bold font.

Table 39: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with indicative criteria (ID) for groundwater (2009-2012)

Object	Period	EC	pH	Pb	As	Sb	Cu
sludge	2009 - 2012	0.55	V	0.03	**1.96**	0.16	0.01

Explanatory notes: The data represent the ratio of the characteristic value determined for the monitored period and the required ID value according to the methodological guideline MŽP SR 1/2012-7. Values greater than 1 indicate that the ID value has been exceeded and are highlighted in colour and bold font.

Table 40: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with the intervention criterion (IT) for groundwater (2009-2012)

Object	Period	EC	pH	Pb	As	Sb	Cu
sludge	2009 - 2012	0.37	V	0.01	0.98	0.08	0.003

Explanatory notes: The data represent the ratio of the determined characteristic value for the monitored period and the required IT value according to the methodological guideline MŽP SR 1/2012-7. Values greater than 1 indicate that the IT value has been exceeded and are highlighted in colour and bold font.

The hydrogeological study of the flooding of the mine in Nižná Slaná, or the Manó – Gabriela deposit, was prepared for SIDERIT, s.r.o. Nižná Slaná by Ing. Marián Bachňák – ENVEX Rožňava. This study estimates the flooding of the mine to take 20 years and the amount of mine water flowing out to be 7–12 $l.s^{-1}$. To prevent unwanted seepage in the built-up area between the shaft and the Slaná River, where the state road passes, it is proposed to excavate a drainage tunnel at the height of the local erosion base of 360 m above sea level.

Engineering-geological aspects

In the Nižná Slaná deposit area, the manifestations of terrain subsidence are linked to older excavations of the Manó siderite lens and to more recent collapses above excavations of a smaller siderite lens near Kobeliarovo. The collapses above the Manó deposit are stable and are located in a rarely visited and relatively inaccessible area around the Rimberg hill between Nižnoslanská Baňa and Kobeliarovo. According to a 1:10,000 scale topographic map from 1991, there are 31 mostly smaller sinkholes with a diameter of up to 20 m in an area of 1 km x 300 m. Since 1995, dynamic changes have been taking place in the collapse zone of the Kobeliarovo deposit on the north-western edge of the village (Fig. 10), with the continuous expansion and merging of the original 19 sinkholes. The temporal development of the extent of this collapse zone in 2004, 2006 and 2008 is documented in Fig. 8. Based on an excerpt from a digital colour orthophoto map processed from aerial survey images from 2002 and 2003 (Orthophoto map © Geodis Slovakia, s.r.o.), the contours of the landslides are visible, highlighted by a blue line (status in 2003). The contours of the landslides from 2004 shown by lines were obtained from Google Earth satellite images, and the extent of the landslides in 2008 was documented in the field using a GPS device. The total area of the landslides was 5·047 m^2in 2004, 10·450 m^2 in 2006·and 16,255 m^2 in 2009.

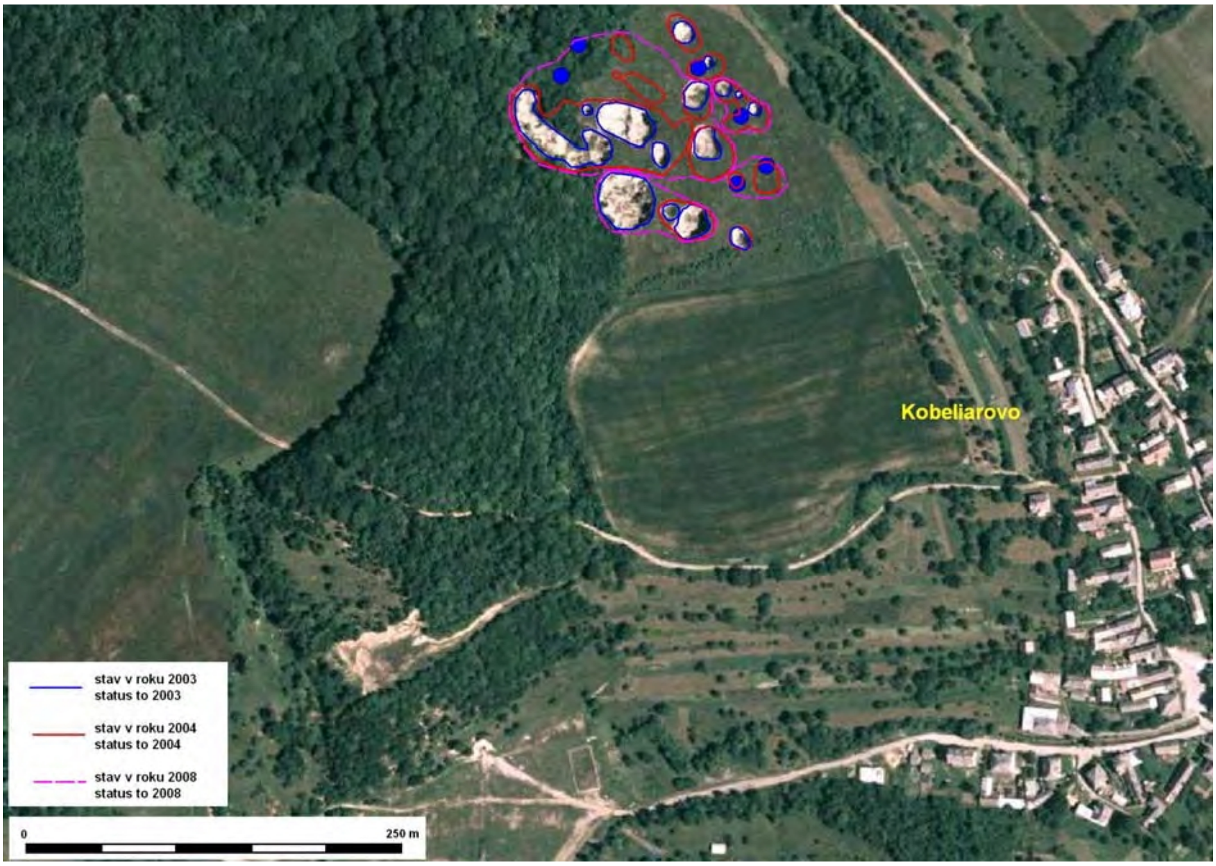


Fig. 10: Temporal development of the extent of the landslide zone in Kobeliarovo in 2003–2004–2008 based on a digital colour orthophotomap of the Slovak Republic (Orthophotomap © Geodis Slovakia, s.r.o.).

Bajtoš P, Mašlár E, Mašlárová I (2015) Impact of mineral extraction on the environment – Report for 2014, Report No. ČMS Geological Factors 04–207–2025. Ministry of the Environment of the Slovak Republic | Section of Geology and Natural Resources | Dionýz Štúr State Geological Institute | Regional Centre Spišská Nová Ves, Spišská Nová Ves, 77 p

assessments. These are most often sections of roads (the so-called new and old state road Rudňany - Poráč). Field reconnaissance monitored the manifestations of landslides and sinkholes in the area above the Zlatník vein north of the village of Poráč, extensive landslides and sinkholes in the Banísk area, and landslides on the slopes at the north-eastern edge of Rudnian and abandoned mouths of underground mining works. The monitoring includes measurements on numerous structures of the front and rear dams of the tailings pond in the Markušovská Valley and monitoring of faults on some structures in the Ždiarik area, retrospectively also on the structure of the now defunct 5RPI compressor station (Vrana et al., 2005).

Extensive undercutting has caused demonstrable damage and posed a threat to property on a large scale in the deposit area. Physical changes in the rock mass after long-term ore mining with the widespread use of open-pit mining methods and the subsequent creation of open spaces have caused subsidence with landslides over large areas: at the Baniská site, almost 1 km long, at the bottom and foothills between Rudňany and Poráč, in several places above Hrubá žila, several hundred metres north of the valley floor, and sporadically in the Zlatník vein area, about 1.5 km north of the village of Poráč. In the past, subsidence with continuous terrain deformation occurred along the entire length of the valley and adjacent slopes between the Mier pit and the Poráč pit. These phenomena have been monitored on 14 geodetic profiles, of which 4 are monitored, 3 of them at the eastern end of Baniská, south of the village of Poráč.

The organisation RIS a.s. Spišská Nová Ves is currently mining in a special mining area called "Poráč I". It mines barite using a mining method
"Inter-panel mining using short boreholes for caving" with spontaneous caving of the mined space, where no open excavated spaces of such a size are created that they could endanger the safety of operations and employees. The mining operation is defined on the surface by a collapse zone, in which the resulting terrain subsidence (sinkholes) is continuously filled with inert material – power plant ash – as a form of subsequent recultivation. Between 2012 and 2014, no new subsidence was recorded at this site, nor were there any significant changes compared to the previous period (Kolektív autorov, 2013, 2014, 2015). This is related to the reduction in mining operations due to stagnant sales of barite raw materials on the market.

The tailings pond in Markušovce is classified as category A under Act No. 514/2008
Z.z. on the management of waste from the mining industry and on amendments to certain laws, as amended. The District Mining Office in Spišská Nová Ves, as the first-instance body for the exercise of state administration pursuant to Act No. 514/2008 Z.z. , carried out state supervision in 2011 over the fulfilment of the requirements and obligations of mining waste storage operators established by Act No. 514/2008 Coll. and decisions issued on its basis. When measuring the chemical composition of water seeping from the Markušovce tailings pond in the fourth quarter of 2011, the measured amount of insoluble substances exceeded the specified limit by 7 mg/l, and when measuring the chemical composition of groundwater, the limit value for Sb was exceeded by 0.009 mg/l (Collective of authors, 2012).

4.8 Nižná Slaná R8 site

The Nižná Slaná – Manó – Kobeliarovo metasomatic siderite deposit (DP Nižná Slaná) was mined underground by Siderit s.r.o., Nižná Slaná. However, due to insolvency, the company went bankrupt in November 2008 and mining was stopped. In the following years, unsuccessful attempts were made to resume mining, and the deposit was drained by pumping out mine water. Based on the decision of the District Mining Office No. 549-1709/2011 of 3 August 2011, Siderit, s.r.o. Nižná Slaná was granted a mining permit for the liquidation of the main mining works in the "Nižná Slaná" mining area. District Mining Office in

Spišská Nová Ves ordered this organisation to prepare a hydrogeological study of the flooding of the mine and subsequently also a plan for the liquidation of the main mining works, which was to take this study into account. The hydrogeological study of the flooding of the mine in Nižná Slaná, or rather the Manó – Gabriela deposit, was prepared for Siderit, s.r.o. Nižná Slaná by Ing. Marián Bachňák – ENVEX Rožňava (Bachňák, 2011). This study estimates the flooding of the mine to take 20 years and the amount of mine water flowing out to be 7–12 l/s. To prevent unwanted seepage in the built-up area between the shaft and the Slaná River, where a state road passes, the study proposes the excavation of a drainage tunnel at the elevation of the local erosion base of 360 m.

n.m. After the power was disconnected, drainage of the underground area by pumping was completed on 18 August 2011 at the XIII horizon and on 19 August 2011 at the XII horizon. Since then, this mine has been flooding spontaneously. Due to the dangerous situation that arose after the liquidation of the surface part of the mining operation, as access to the underground via the main mining works was not prevented by any technical means, the District Mining Office in Spišská Nová Ves ordered the organisation Rudné bane, štátny podnik (Ore Mines, State Enterprise) Banská Bystrica to take measures to eliminate this dangerous situation and further ordered it to ensure compliance with the conditions of the decision on the liquidation of the main mine works in the Nižná Slaná mining area. In 2013, the organisation Zamgeo s.r.o., Rožňava, excavated the initial section of the Marta drainage tunnel, the construction of which was proposed by the above-mentioned hydrogeological study, with a length of 53 m (Collective of authors, 2015). The tailings pond in Nižná Slaná is classified as category A within the meaning of Act No. 514/2008 Coll. on the management of waste from the mining industry and on amendments to certain acts, as amended. The District Mining Office in Spišská Nová Ves, as the first-instance authority for the exercise of state administration pursuant to Act No. 514/2008 Coll. exercises state supervision over the fulfilment of the requirements and obligations of mining waste storage operators established by Act No. 514/2008 Coll. and decisions issued on its basis.

Hydrogeological and geochemical aspects

The mining plant complex included an iron ore thermal treatment plant consisting of a crushing plant, two rotary roasting furnaces for ore decarbonisation and a thermal pelletisation plant. The ore processing plant was a long-term source of gaseous emissions and solid fly ash contaminating the air and surface of their catchment area, mainly with sulphur, iron, manganese and arsenic. The non-magnetic fraction of the thermally processed ore was stored in a tailings pond located near the mining and processing plant. During operation, the pumped mine water was used in the ore processing technology and its surplus was pumped to the tailings pond. The operator carried out operational monitoring of the quantity and quality of mine water and seepage water from the tailings pond. In accordance with the programme in the approved sludge pond handling and operating rules, groundwater level measurements were regularly taken in probes and geodetic measurements of the sludge pond embankment displacement were performed.

The mining organisation provided the ČMS GF VŤŽP database with operational data on the quality of waste and mine water for the years 2005-2009. We conducted our own laboratory tests twice a year to determine the quality of drainage water from the tailings pond between 2009 and 2014. Table 36 shows the characteristic values of the monitored quality indicators, derived from the results of laboratory analyses for the period 2007–2014. Elevated concentrations of sulphate anion, manganese and arsenic were found in the water from the tailings pond, which do not meet the requirements for surface water quality (Table 38). In terms of assessing the quality of drainage water from the tailings pond according to the criteria for assessing the risk of groundwater pollution (Methodological Instruction of the Ministry of the Environment of the Slovak Republic No. 1/2012-7), the seepage water from the tailings pond is risky due to its As content (it exceeds the indicative criterion and reaches the intervention criterion limit, Tables 39 and 40). In 2014, it was

The characteristic value of As content was found to be 14% lower than in the period 2009–2013, Mn by 21%, iron by 39%, ammonium ion by 17% and sulphate anion by 15% (Table 36).

Table 36: Characteristic values of seepage water quality indicators in Nižná Slaná

Period	Q *l/s*	EC *mS/m*	pH	SO_4 *mg/l*	NH_4 *mg/l*	Fe *mg/l*	Mn *mg/l*	Pb *mg/l*	Zn *mg/l*	As *mg/l*	Sb *mg/l*	Cu *mg/l*
2009-13	1.46	109.3	7.61	357	1.36	1.281	1.539	0.003	0.013	0.099	0.004	0.001
2014	1.72	104.7	8.23	304	1.13	0.782	1.210	-	0.003	0.085	0.004	-

Table 37: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with surface water quality requirements

Object	Period	EC	pH	SO_4	NH_4	Fe	Mn	Pb	Zn	As	Sb	Cu
sludge	2009 - 2014	0.99	V	**1.39**	0.99	0.60	**4.95**	0.35	0.17	**12.88**	0.78	0.13

Explanatory notes: The data represent the ratio of the characteristic value determined for the monitored period and the required value according to Slovak Government Regulation No. 269/2010 Coll. Values greater than 1 indicate that the required value has been exceeded and are highlighted in colour and bold font.

Table 38: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with the indicative criterion (ID) for groundwater

Object	Period	EC	pH	NH_4	Pb	Zn	As	Sb	Cu
sludge	2009 - 2014	0.54	V	**1.07**	0.03	0.004	**1.93**	0.16	0.01

Explanatory notes: The data represent the ratio of the characteristic value determined for the monitored period and the required ID value according to the methodological guideline MŽP SR 1/2012-7. Values greater than 1 indicate that the ID value has been exceeded and are highlighted in colour and bold font.

Table 39: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with intervention criteria (IT) for groundwater

Object	Period	EC	pH	NH_4	Pb	Zn	As	Sb	Cu
sludge	2009 - 2014	0.36	V	0.53	0.01	0.001	0.97	0.08	0.003

Explanatory notes: The data represent the ratio of the characteristic value determined for the monitored period and the required IT value according to the methodological guideline MŽP SR 1/2012-7. Values greater than 1 indicate that the IT value has been exceeded and are highlighted in colour and bold font.

Engineering geological aspects

In the Nižná Slaná deposit area, the terrain depressions are linked to older Manó siderite lens mining areas and newer collapses above smaller siderite lens mining areas near Kobeliarovo. The terrain depressions above the Manó deposit are stabilised and are located in a rarely visited and relatively inaccessible terrain around the Rimberg hill between Nižnoslanská Baňa and Kobeliarovo. According to a 1:10,000 scale topographic map from 1991, there are 31 mostly smaller depressions with a diameter of up to 20 m in an area of 1 km x 300 m. Since 1995, dynamic changes have been taking place in the landslide zone of the Kobeliarovo deposit on the north-western edge of the village, with the continuous expansion and merging of the original 19 sinkholes. We monitored the temporal development of the extent of this collapse zone until 2013 on the basis of an excerpt from a digital colour orthophotomap (Bajtoš et al., 2014) processed from aerial survey images from 2002 and 2003 (Orthophotomap © Geodis Slovakia, s.r.o.), Google Earth satellite images from 2004, and our own measurements the extent of the landslides in 2008 in the field using a GPS device. The total area of the landslides was 5,047 m^2 in 2003, 10,450 m^2 in 2004 and 16,255 m^2 in 2008.

Assessment of the current state of the landslides in Kobeliarovo

In order to monitor temporal changes in geodynamic phenomena in Kobeliarovo caused by mining activities and to predict their future development, it was necessary to carry out detailed mapping. Therefore, we carried out detailed GNSS surveying in the area of the cave-ins using a Trimble Geo7x device with a horizontal accuracy of up to 0.1 m (in areas without higher vegetation cover) and an accuracy of approximately 1.5–2.5 m (in areas with higher vegetation cover). In parallel with the GNSS measurements, written documentation of the recorded geodynamic phenomena and their photo or video documentation were carried out.

The positional surveying focused on all manifestations of morphological changes in the terrain surface due to mining at the deposit. The following geodynamic manifestations were defined:

- landslides,
- cracks of a subsidence, tensile and tensile-subsidence nature.

The result of the field surveys is an interpretation of the activity of landslides and other slope deformations caused by mining activities at the Kobeliarovo deposit in the form of a map. The map (Fig. 8) shows the location of landslides and cracks, where their activity or degree of stability is defined by colour, which may be stable, temporarily stabilised or stabilised phenomena. For cracks, the degree of subsidence or the degree of crack opening, as manifested on the surface of the terrain, was documented. For subsidence-type cracks, the directional orientation of the subsidence was documented.

The following facts emerge from the documentation of slope deformations. A total of 19 landslides were located. Some of them are also delimited groups of previously separate landslides (e.g. landslides Z5, Z12). The area covered by the landslides (excluding cracks) is approximately 200 m wide in the E-W direction (270 m including cracks) and approximately 170 m wide in the N-S direction (200 m including cracks).

The most active area in the monitored territory appears to be the south-western to north-western part. This is also where the largest and oldest collapse, Z10, is located, which began to form and expand into its present form from the first signs of the impact of mining activity, i.e. in April 1995. The collapse can still be considered active, as the walls of the collapse are exposed (Fig. 9). The course of the collapse is not uniform in shape, nor is the bottom of the collapse. Approximately in the middle part, there is a residual ridge that is actively subsiding. Transverse active open tensile cracks with a width of up to approx. 25 cm were found here.

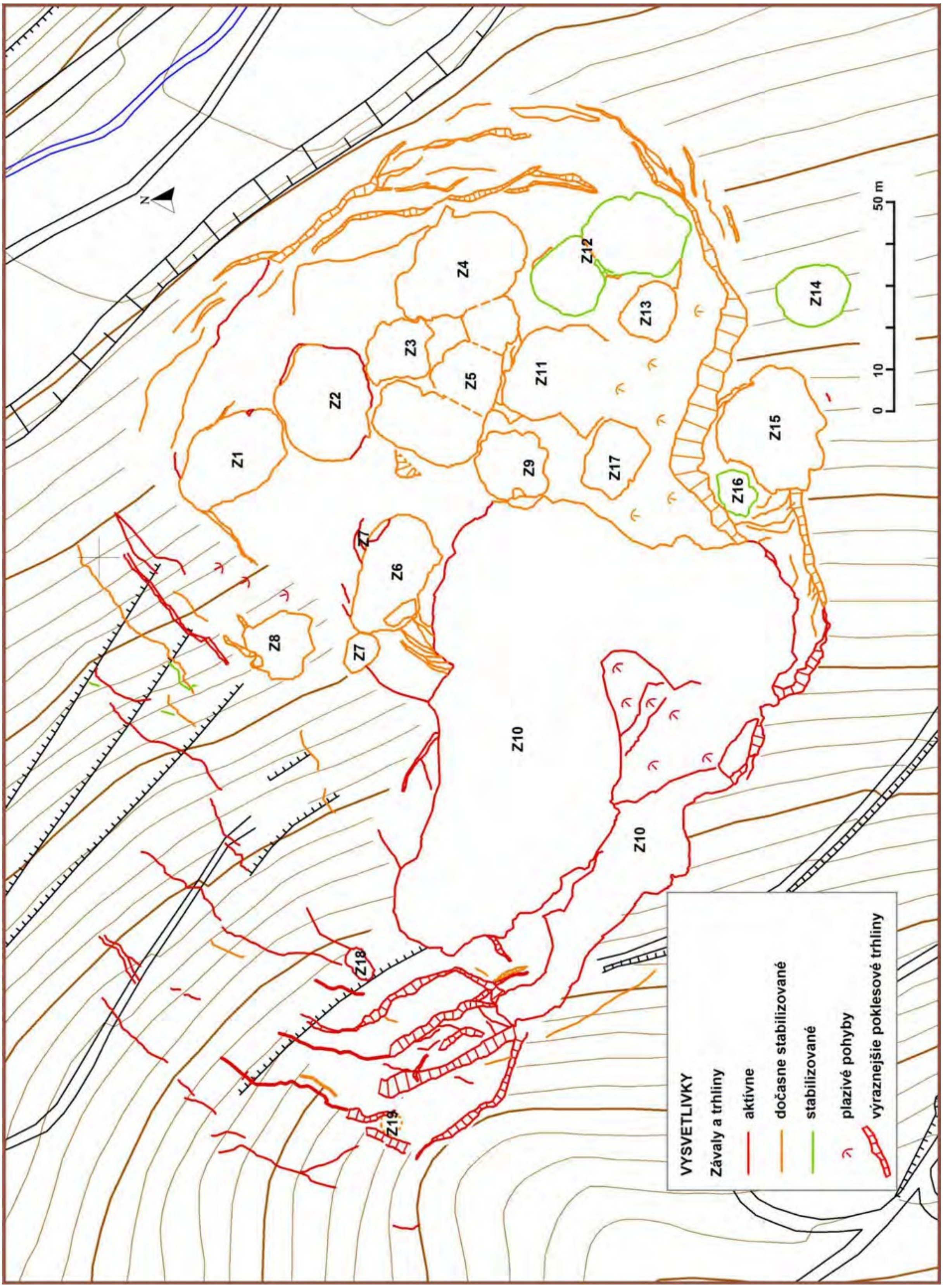


Fig. 8: Map of landslides and other slope deformations caused by mining activities at the Kobeliarovo deposit (Topographic base Ščuka et al., 1982).

The collapse area is also affected by active cracks occurring up to approximately 70 m from the edge of the collapse, which cause loosening of the rock mass into the wider collapse area. Cracks with the greatest degree of terrain subsidence occur on the south-western and western edges.
- up to approx. 2 m (Fig. 10). Their SE-NW direction is parallel to the direction of the edge of the collapse, with most of them practically starting from the edge of the Z10 collapse. Other (more distant) cracks in the north-western part more or less follow on from the cracks described, with their course turning in a SW-NE direction (Fig. 11). At the same time, their downward slope recedes or is even absent.

Fig. 9: Wall of the Z10 at its western edge.

Fig. 10: Detachment surface of a significant tensile-subsidence fracture in the western part of the collapse area.

Fig. 11: Tensile-subsidence fracture with a predominantly tensile character in the north-western part of the collapse area.


Fig. 12: SE wall of collapse Z2.


Fig. 13: Collapse Z5.


Fig. 14: Collapse Z6.


Fig. 15: Collapse Z7.


Fig. 16: Falling block on the Z8 landslide.


Fig.17:RockfallZ9.

Similar cracks continue eastward to north of the Z8 collapse and northwest of the Z1 collapse.

The eastern half of the collapse zone has the highest number of collapses, which are located relatively close to each other. Some collapses are a grouping of originally separate collapses. Collapse Z5 is a collapse formed by the connection of three original collapses, and collapse Z12 is a collapse formed by the connection of two original collapses separated by narrow sunken ridges. Most of the collapses can be considered temporarily stabilised. Although they currently show minor signs of activity, in the past they were affected by a continuous process of formation and expansion, which we will discuss later. Active to temporarily stabilised subsidence rock blocks have been observed at the edges of several landslides (Z1, Z2, Z6, Z8, Z9). The possible process of further expansion of individual landslides is indicated, among other things, by the occurrence of shorter cracks opening into the landslide with an attempt to bend in a direction parallel to the edge of the landslides. Such manifestations were observed in several collapses, namely in collapses Z1, Z2, Z6, Z8, Z11, and Z12. Given the position of the cracks between collapses Z5 and Z11, it is possible to assume that they will connect in the future. Photographs of some of the landslides are shown in Figs. 12, 13, 14, 15, 16 and 17.

The existence of active plastic subsidence, known as "creeping", which is visible in the gradual bending of the trunks of younger trees or in the occurrence of a series of parallel cracks, mainly of a tensile nature, also testifies to active terrain deformation processes in the areas between the landslides. "creeping", which is visible in the gradual bending of the trunks of younger trees or in the occurrence of a series of parallel cracks, mainly of a tensile nature (between landslides Z10 and Z6, between landslides Z1 and Z8).

Their manifestation is difficult to identify due to the dense growth of tall grass. They have been classified as temporarily stabilised. These are mainly cracks of a tensile-subsidence nature, less tensile in nature (Fig. 18), usually with a more pronounced separation subsidence (Fig. 19). These are mainly tensile-subsidence cracks, less tensile in nature (Fig. 18), usually with a more pronounced detachment subsidence edge. An interesting phenomenon is the presence of cracks with "reverse subsidence", i.e. away from the landslides.

Fig. 18: Open tensile crack on the eastern edge of the collapse zone.

The cracks on the eastern edge of the collapse zone are more or less connected to cracks of a subsidence, tensile-subsidence and tensile nature, which gradually turn in a NE-SW to NE-SW direction.

The most prominent crack, which takes on the character of a detachment edge of a shear surface, begins at the Z12 collapse. Its direction changes sharply from NE-SW to SE-NW and back to NE-SW. At the end, it connects to the orientation of the Z10 collapse wall. The height of the separation surface reaches a maximum of 2.5–3 m. It appears to be temporarily stabilised. Below this subsidence towards the collapses, there is an area with loose rock blocks and creep deformations.

A significant crack also connects the Z15 and Z10 collapses. The direction of the crack follows the course of the breakaway edge of the Z10 collapse, and when the orientation of the crack changes, there is also a change in character from a temporarily stabilised SVV-JZZ directional subsidence crack to an active V-Z directional tensile crack (Fig. 19) and then a tensile-subsidence open crack (JV-SZ direction) (Fig. 20), whose subsidence character increases towards the Z10 collapse to a height difference of approx. 1.6 m.

Fig. 19: Active tensile course of an open fracture at the southern edge of the Z10 collapse.

Fig. 20: Active tensile-compressive crack progression at the mouth of the Z10 collapse.

In the area between the crack and the collapse, there are several shorter cracks with a similar change in character as described for this crack.

Collapse Z14 shows no signs of activity and is probably stabilised. There is vegetation of older trees. The same applies to collapse Z16. However, the terrain near the collapse appears to be more active with a trend of gradual loosening. A series of parallel tensile and tensile-subsidence cracks was located here, positioned above collapses Z15 and Z16. Collapse Z15 appears to be active with temporary stabilisation. Frequent rockfalls on the walls and loose boulders and blocks are visible.

Historical development of rockfalls

Knowledge of the gradual development of the collapses in the past helps to estimate their further development. From this point of view, the approximate boundaries of the collapses at different times were plotted on a common map in Fig. 21.

The oldest photographs obtained are not precisely dated, but are approximately from the period 1995–2000 (Fig. 22). The extent of the rockfalls was roughly marked on the map according to the photograph (Fig. 21). It is clear from this that separate landslides occurred during this period, which are now combined into a single landslide marked Z10. Landslides Z14 and Z15 also occurred (almost to their current extent). Landslide Z3 and a small part of landslide Z5 also began to form.

The extent of landslides for 2006 was approximately interpreted from an orthophoto map from 2006. The map in Fig. 21 shows a significant increase in the number of newly formed landslides. A comparison of this situation with the current situation shows a slight tendency for the landslides themselves to spread, but there is also a noticeable increase in the number of landslides, namely the landslide that connected the current landslide Z5 and the significant expansion of landslides Z12 and Z17. The temporal development of the Z16, Z18, Z19 and, in part, Z10 landslides cannot be assessed due to their location in wooded terrain. The photographic documentation in Figures 22 to 25 shows the development of the landslide zone from 1995 to 2014.

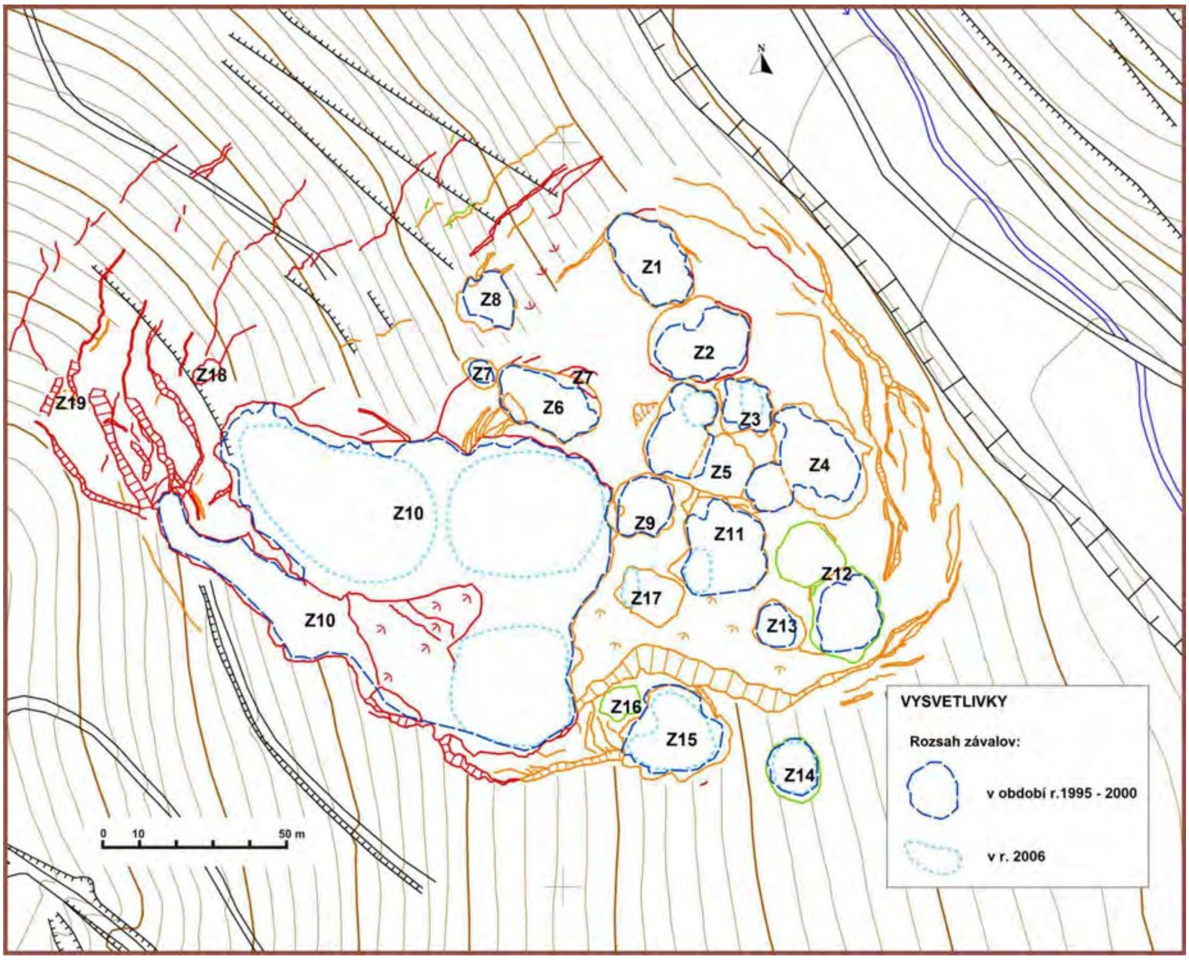


Fig. 21: Map of the development of landslides at the Kobeliarovo deposit between 1995 and 2014. (Topographic base Ščuka et al, 1982).

Fig. 22: View of the collapse area at the Kobeliarovo deposit sometime between 1995 and 2000. (photo: Dušan Vandrášik, Mining and Geological Exhibition in Nižná Slaná)

Fig. 23: View of the area of collapses at the Kobeliarovo deposit on 2 August 2005 (photo: Stanislav Lukáč).

Fig. 24: View of the area of landslides at the Kobeliarovo deposit on 21 August 2010 (photo: Stanislav Lukáč).

Fig. 25: View of the area of subsidence at the Kobeliarovo deposit on 8 September 2014.

Forecast of the development of landslides and slope deformations due to mining activities

In the past, more accurate methods of monitoring the development of slope deformations due to mining activity consisted only of monitoring fixed measuring points (Fig. 26). These points were mainly installed in the central and eastern parts of the current area of subsidence and in the wider vicinity to the south and east. Tabular data on the height measurements of these points are provided in the appendix to the report by Vrana (2005). The analysis of these data, the temporal development of the landslides and our own observations reveal the following facts. Height measurements of the measuring points began in October 1996. A large part of the points ceased to be measured in height after a short time – by June 1997, partly due to the collapse of the points (KV-5, KV-6) into emerging collapses or for reasons unknown to us (KV-4, KV-9, KV-16). Some points were probably not even initially surveyed due to their collapse into the cave-ins (points KV-7 and KV-11). Of the other points that were continuously monitored over a longer period, elevation measurements are available until September 2001 (points KV-1, KV-12, KV-13) as well as points 4 and 5. However, it has not yet been possible to determine the positional situation for these points.

From the data mentioned above, provided by Vrana et al. (2005), we have compiled graphs showing the temporal development of the declines at these measuring points (Fig. 27). The graphs show that a minimal decline in ground level was observed at almost all measuring points, with the most significant decline occurring at points KV-1 and KV-12. Noteworthy is the decline observed at point S-1, which is located at a distance from the landslides where ground decline would not be expected. Due to the short monitoring period (June to September 2001), it is not possible to evaluate the time trend and rate of decline.

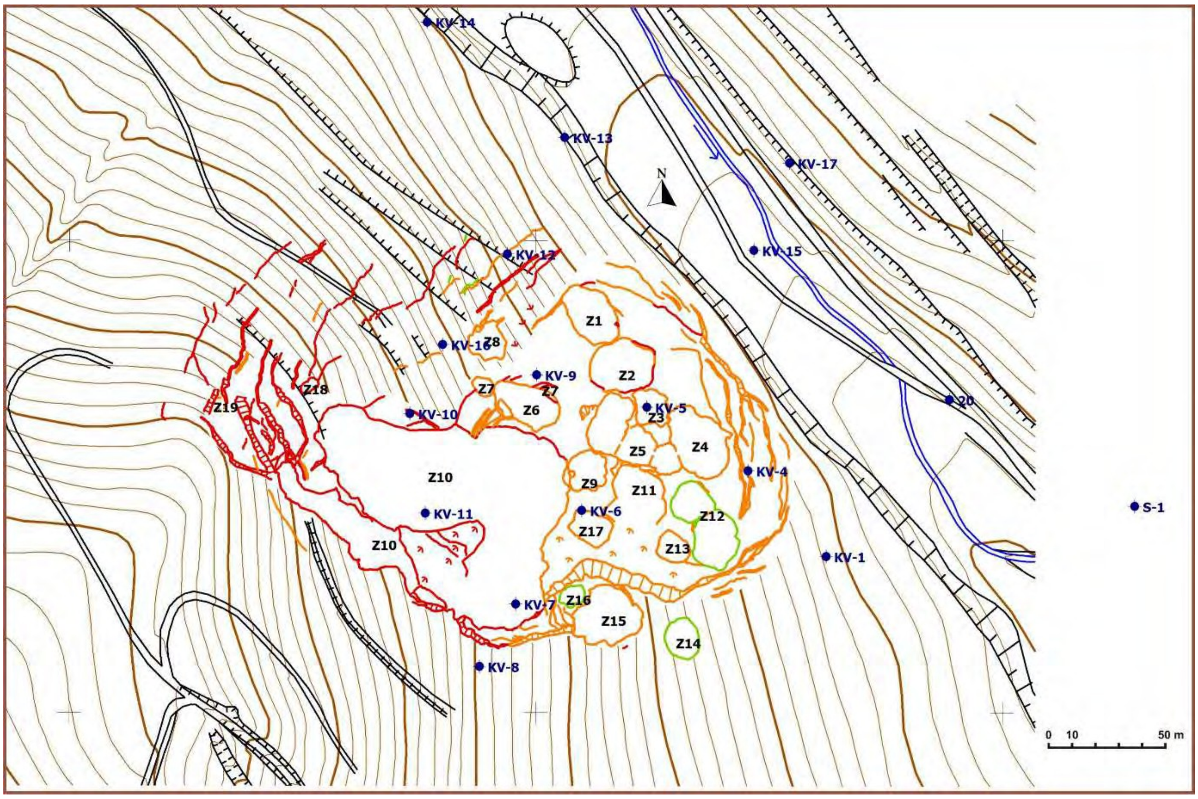


Fig. 26: Location of monitoring points (topographic base Ščuka et al., 1982).

Fig. 27: Graphs showing the time course of subsidence at measuring points in the Kobeliarovo deposit.

Due to the difference in the monitoring period and the absence of measuring points in the western part of the monitored area, it is not possible to determine the prognosis for the subsidence of the area. Only two measuring points have been found so far during the reconnaissance of the terrain, namely KV-4 (Fig. 28) and KV-8 (Fig. 29).

Fig. 28: Observation measuring point KV-4.

Fig. 29: Observation measuring point KV-8.

The following ***forecast of the area-wide spread of subsidence*** is based primarily on the results of our own documentation of terrain manifestations following mining activity. Research at the Kobeliarovo deposit site has shown that the process of slope deformation is active, with a trend towards temporary cessation.

The development of signs of undermining in the Kobeliarovo deposit is expected to take two basic forms, namely:

- the process of completion – widespread expansion of individual collapses,
- further activation of existing cracks and the formation of new cracks in the vicinity of the collapses.

As can be seen from the map in Fig. 30, the most significant active form of cracks occurs around the western edge of the Z10 collapse, where significant cracks of a predominantly subsidence nature were located a subsidence nature. In the area of expansion of these cracks, there is a reasonable assumption of further possible expansion of the main Z10 collapse in the future.

Further relatively minor expansion of the collapses can also be expected on the southern edge of collapse Z10 and on the northern edge of collapse Z10 in the direction of collapse Z6. Minor development (with the possibility of larger rock blocks being released into the collapses) is also expected in the near future in the vicinity of other collapses with shorter cracks parallel to the breakaway edge of the collapses (collapses Z1, Z2, Z5, Z6, Z8, Z9, Z11, Z12, Z15).

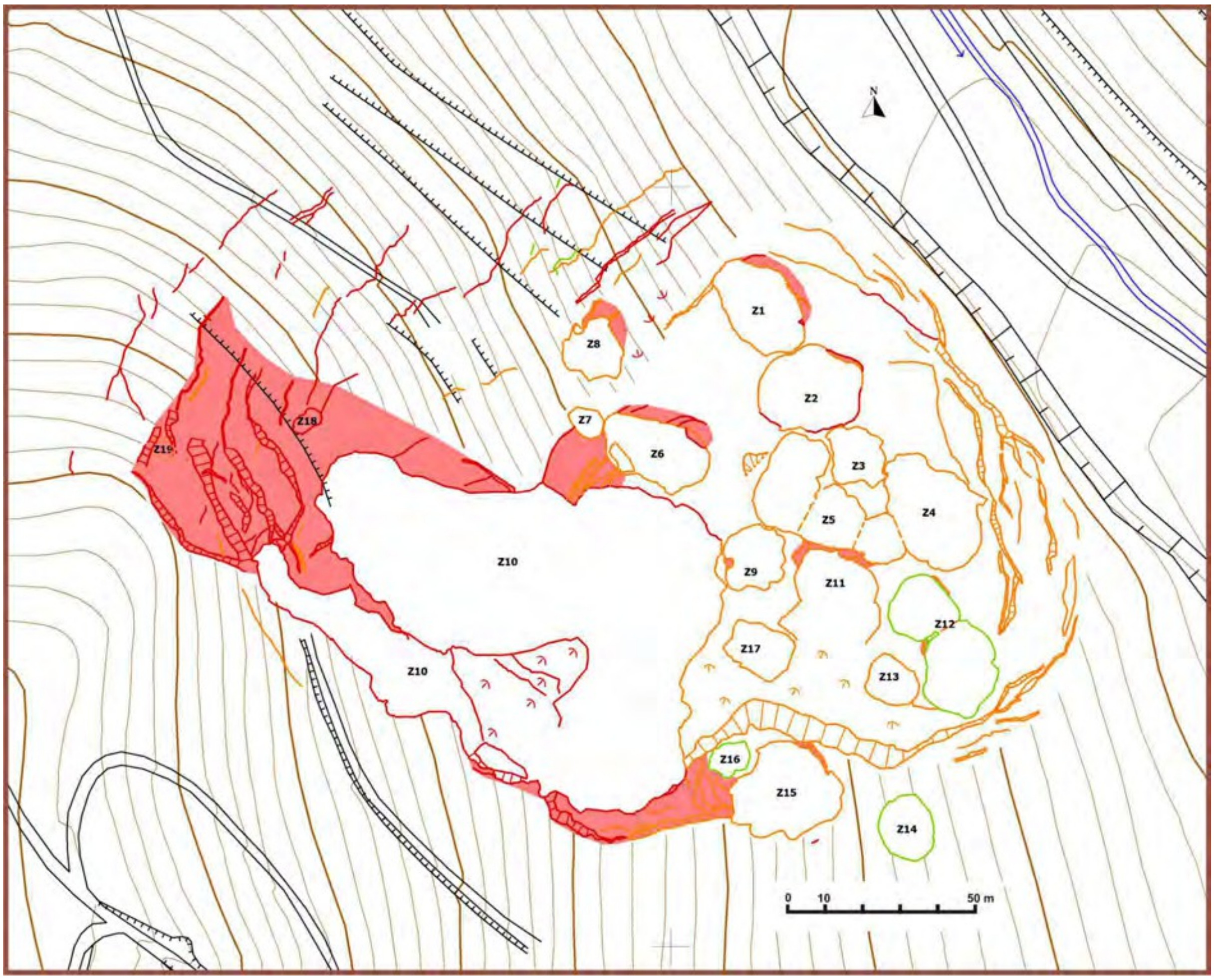


Fig. 30: Forecast expansion of landslides at the Kobeliarovo deposit marked with red areas (topographic base Ščuka et al., 1982).

The activation of existing cracks with the possible formation of new ones in the vicinity of the landslides is expected in the western to northern part of the area, especially in the area of active cracks, and also on the southern edge of the area near landslide Z10. The entire area of collapses at the Kobeliarovo deposit can be defined in terms of fracture activity as only temporarily stabilised to active.

As already mentioned, the above forecast is based primarily on the results of our own documentation of field manifestations of undercutting. The forecast did not take into account the latest status of the Kobeliarovo deposit (mining tunnels, excavations, etc.). The reason for this is that the latest status of the deposit's mining is currently only available from the results of the report on the calculation of the deposit's reserves - Final Report Kobeliarovo Fe PoP above VI. horizon from 1995 (Mihók, Jančura, 1995). Given that mining at the deposit has been terminated and the mining organisation has ceased to exist, the documentation on the mining of the deposit is stored in the State

Central Mining Archive in Banská Štiavnica. According to Ing. Mária Mihóková, head of the older collections department, the documentation is not yet available as it has not yet been processed.

4.9 Slovinky R9 site

This site contains the mined copper ore deposit Gelnica – Gelnická žila (DP and CHLÚ) and the deposit Gelnica – Krížová žila (CHLÚ), both administered by ŠGÚDŠ Bratislava. Mining has been terminated since 1990 and liquidation and security work is carried out here by the organisation Rudné Bane, š. p. Banská Bystrica, which operates the premises of the former Železorudné Bane plant. In 2011, this organisation repaired the mining water drainage system from the Alžbeta adit in Slovinky, along the state road to the drainage canal carrying water from the Bodnárec tailings pond. In 2013, the consequences of former mining activities and their effects on the surface in the cadastral area of Gelnica were eliminated, where the Jozef, Mokré pole and Štefánia tunnels were secured. In Slovinky, a retaining wall for the Slovinsky stream was built and regular maintenance of the Bodnárec tailings pond was carried out (Collective of authors, 2014). In 2014, the Rudné Bane organisation secured the old mining works of the Barbora and Geburda tunnels in Slovinky (Collective of authors, 2015).

Hydrogeological and geochemical aspects

The mining areas between Slovinky and Gelnica, where siderite-sulphide ore veins were mined in the past, are now abandoned. From a hydrogeological point of view, the situation here is stable. The flooded mining areas are drained by the Alžbeta adit into the Slovinský potok river basin and several other adits (Slovinský prekop, Krížová adit, etc.) into the Hnilec river basin. On the Gelnica side, there are several abundant outflows from the tunnels, the most significant being the Stará Krížová and Jozef tunnels. The regime of mine water outflows is closely linked to the precipitation and climatic conditions of the locality. The mine water from the Alžbeta tunnel has long contained elevated concentrations of As, Sb, Mn and SO_4 , and together with seepage from local tailings ponds and heaps, it causes deterioration in the water quality of the Slovinský potok stream.

From 2002 to 2009, the amount of mine water flowing through the Alžbeta adit was measured four times a year by employees of Rudné bane, š.p. Banská Bystrica, and its quality was also monitored once a year within a limited range of parameters. The amount of drainage water from existing tailings ponds was not monitored by this organisation. Since 2008, the ČMS GF VŤŽP has been conducting its own monitoring at the following observation sites (Fig. 31): Sl4 – mine water from the deposit flowing through the Alžbeta adit, Sl5 – drainage water from the Bodnárec tailings pond, Sl1 - Slovinský potok above the deposit, Sl2 - Slovinský potok before its confluence with Poráčsky potok, Sl3 - mouth of Poráčsky potok and Sl6 - Slovinský potok below the deposit. Since 2009, seepage from the Kalligrund tailings pond (Sl7) has also been monitored. The characteristic values of risk components derived from the results of laboratory analyses of water samples taken between 2008 and 2014 are shown in Table 40.

In the period 2007–2014, monitoring detected high concentrations of As and Sb in the profile of the Slovinský potok stream below the area affected by mining activities (profile Sl6), which did not meet surface water quality requirements (Table 41). The Slovinský potok stream has satisfactory quality at the entrance to the deposit area (Sl1), but the antimony content is already unsatisfactory in the profile before the confluence with the Poráčsky potok stream (Sl2). The quality of the Poráčsky potok stream at its confluence with the Slovinský potok stream (Sl3) is satisfactory. In terms of assessing the quality of mine water from the Alžbeta adit and drainage water from tailings ponds according to the criteria for assessing the risk of groundwater pollution (Methodological Instruction of the Ministry of the Environment of the Slovak Republic No. 1/2012-7), only the adit is considered risky.

Liščák P, Bajtoš P, Mašlárová I, Slaninka I (2020) Impact of mineral extraction on the environment – Report for 2019, Report № ČMS Geological Factors 04–207–2019. Ministry of the Environment of the Slovak Republic | Section of Geology and Natural Resources | Dionýz Štúr State Geological Institute | Regional Centre Spišská Nová Ves, Spišská Nová Ves, 124 p

The revisions are listed in the partial report for 2018 – ČMS Geological Factors, subsystem 04: Impact of mineral extraction on the environment.

The latest measurements of vertical subsidence in the area *of the relocation of the III class road (Spišská Nová Ves – Poráč)* were carried out in 2016. Jakubek (2016) states that, based on a comparison of the results of long-term observation measurements and the fact that more than twelve years have passed since the end of mining activities in this location, it can be assumed that the monitored area is stable with a minimal probability of vertical movements of the area itself and of road No. III/3244. For these reasons, it was proposed to carry out a control geodetic observation of vertical movements in this location after five years, i.e. in 2021.

Since mining operations at the Poráč mine were terminated in 2018, the results of the latest measurements from *the Poráč mine courtyard area* are from 2017. Land subsidence has been monitored at geodetic points set on existing structures (social building, shaft building, engine room, tower strut base) since April 1990, when the initial measurements were taken. The total subsidence for the period April 1990 – May 2017 (according to the source: SABAR, s. r. o., Markušovce archive) ranged from 24.0 to 68.0 mm. The maximum rate of subsidence (68.0 mm) was recorded at point XIII (a point located on the warehouse building). The downward trend of the monitored points indicates that the slow subsidence of the monitored area of the Poráč Pit courtyard may continue. The subsidence is accompanied by deformation of the pit equipment caused by continuous deformation of the rock mass affected by mining. A more detailed evaluation of the measurement results in the area of the Poráč Pit courtyard is provided in the ČMS GF partial report for 2017.

4.7 Nižná Slaná site

The Nižná Slaná – Manó – Kobeliarovo metasomatic siderite deposit (DP Nižná Slaná) was mined underground by Siderit, s.r.o., Nižná Slaná. However, due to insolvency, the company went bankrupt in November 2008 and mining was stopped. In the following years, unsuccessful attempts were made to resume mining, and the deposit was drained by pumping out mine water. Based on the decision of the District Mining Office No. 549-1709/2011 of 3 August 2011, Siderit, s.r.o., Nižná Slaná was granted a mining permit – liquidation of the main mining works in the "Nižná Slaná" mining area. The District Mining Office in Spišská Nová Ves ordered this organisation to prepare a hydrogeological study of the flooding of the mine and subsequently a plan for the liquidation of the main mining works, which was to take this study into account. The hydrogeological study of the flooding of the mine in Nižná Slaná, or rather the Manó – Gabriela deposit, was prepared for Siderit, s.r.o., Nižná Slaná by Ing. Marián Bachňák – ENVEX Rožňava (Bachňák, 2011). This study estimates the flooding of the mine to take 20 years and the amount of mine water flowing out to be 7–12 l/s. To prevent unwanted leaks in the built-up area between the shaft and the Slaná River, where a state road passes, the study proposes the excavation of a drainage tunnel at the elevation of the local erosion base of 360 m above sea level. After the power supply was disconnected, the pumping of underground water was terminated on 18 August 2011 at the XIII horizon and on 19 August 2011 at the XII horizon. Since then, this mine has been flooding spontaneously. Due to the dangerous situation that arose after the liquidation of the surface part of the mining operation, as access to the underground via the main mining works was not prevented by any technical means, the District Mining Office in Spišská Nová Ves ordered the organisation Rudné bane, štátny podnik (Ore Mines, State Enterprise) Banská Bystrica to take measures to eliminate this dangerous situation and further ordered it to ensure compliance with the conditions of the decision on the liquidation of the main mine works in the Nižná Slaná mining area. In 2013, the organisation Zamgeo, s.r.o., Rožňava, excavated the initial section of the Marta drainage tunnel, the construction of which was proposed by the above-mentioned hydrogeological study, with a length of 53 m.

(Collective authors, 2015). The organisation Rudné bane, š.p. Banská Bystrica, Spišská Nová Ves centre, as part of the measures ordered by the OBÚ in Spišská Nová Ves in DP Nižná Slaná, completed the excavation of the Marta adit – a drainage mining structure from the surface to the Gabriela pit with a total length of 110 m. In 2017–2019, water management facilities were constructed in front of the Marta adit entrance on the basis of a water management decision, and the portal of this adit was constructed (Zvrškovec, 2020).

The tailings pond in Nižná Slaná is classified as category *A* under Act No. 514/2008 Coll. on the management of waste from the extractive industry and on amendments to certain acts, as amended. The District Mining Office in Spišská Nová Ves, as the first-instance authority at for the performance of state administration, pursuant to Act No. 514/2008 Z. on the management of waste from the extractive industry and on amendments to certain acts, as amended, the state supervises the fulfilment of the requirements and obligations of mining waste storage operators established by Act No. 514/2008 Coll. on the management of waste from the extractive industry and on amendments to certain acts, as amended, and decisions issued on the basis thereof.

Between February 2014 and July 2015, a detailed geological survey of the environment was carried out at the Nižná Slaná site (Pramuk et al., 2016), focusing on the tailings pond and heaps as probable environmental burdens. The work carried out confirmed the environmental burden posed by the Nižná Slaná tailings pond and waste dumps. A total of six contaminated areas were identified: the tailings pond, waste dumps at the mining plant and in the Gampeľ valley, and two smaller areas with high contamination near roads. The current environmental risk – the spread of pollution to receptors in the biological contact zone – was confirmed only in the case of the slag heap in the Gampeľ valley. Based on the assessment of the carcinogenic risk from soil ingestion, there is a potential risk to both the adult and child populations. A non-carcinogenic risk through accidental soil ingestion has also been demonstrated for the child population. Therefore, remediation of the dump in the Gápeľ valley is proposed.

Hydrogeological and geochemical aspects

Since mining operations at the Manó deposit ceased in August 2011, the mine has been spontaneously flooding. The RB Banská Bystrica organisation monitors the rising water level through occasional measurements in the Gabriela pit. In October 2019, the water level was measured at 143 m below ground level.

The mining plant complex included an iron ore thermal treatment plant consisting of a crushing plant, two rotary roasting furnaces for ore decarbonisation and a thermal pelletisation plant. The ore processing plant was a long-term source of gaseous emissions and solid fly ash contaminating the air and surface of their catchment area, mainly with sulphur, iron, manganese and arsenic. The non-magnetic fraction of the thermally processed ore was stored in a tailings pond located near the mining and processing plant. During operation, the pumped mine water was used in the ore processing technology and its surplus was pumped to the tailings pond. The mining organisation carried out operational monitoring of the quantity and quality of mine water and seepage water from the tailings pond. In accordance with the programme in the approved sludge pond handling and operating rules, groundwater level measurements were regularly carried out in probes and geodetic measurements of the sludge pond embankment displacement were performed.

The mining organisation provided the ČMS GF database with operational data on the quality of waste and mining water for the years 2005–2009. We conducted our own laboratory tests twice a year to determine the quality of drainage water from the tailings pond between 2009 and 2019. For the period 2014–2015, these data are supplemented by the results of laboratory analyses carried out as part of a geological survey of the environment (Pramuk et al., 2016). Table 41 shows the characteristic values of the monitored quality indicators of drainage water from the tailings pond, derived from the results of laboratory analyses for the monitored period. The following have been found

Increased concentrations of sulphate anion, ammonium ion, manganese and arsenic, as well as EC values in the tailings pond water, do not meet the requirements for surface water quality (Table 42). In terms of assessing the quality of drainage water from the tailings pond according to the criteria for assessing the risk of groundwater pollution (Methodological Instruction of the Ministry of the Environment of the Slovak Republic No. 1/2015-7), the seepage water from the tailings pond is risky due to its As content (approximately twice the indicative criterion and approaching the intervention criterion limit) (Tables 43 and 44). It also slightly exceeds the indicative criterion for ammonium ion content. In 2019, the characteristic value of As content was found to be 73% higher than in the period 2009–2018, ammonium ion content was 19% higher, and sulphate ion content was 12% higher. Conversely, a decrease in concentration was found for Sb (18%) and Cu (31%).

Table 41: Characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond

Object	Date	EC mS/m	pH	SO4 mg/l	NH4 mg/l	Fe mg/l	Mn mg/l	Pb mg/l	As mg/l	Sb mg/l	Cu mg/l
Sludge	2009 – 2018	114.1	7.81	344	1.52	1.01	1.48	0.0027	0.1001	0.0033	0.0015
	2019	132.2	8.17	386	1.81	1.01	1.50	0.0003	0.1727	0.0027	0.0010

Table 42: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with surface water quality requirements

Object	Period	EC	pH	SO4	NH4	Fe	Mn	Pb	As	Sb	Cu
Sludge	2009 – 2018	**1.04**	V	**1.37**	**1.18**	0.50	**4.92**	0.37	**8.70**	0.66	0.13
	2019	**1.20**	V	**1.55**	**1.40**	0.50	**4.98**	0.03	**15.02**	0.54	0.09

Explanatory notes: As in Table 5.

Table 43: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with the indicative criterion (ID) for groundwater

Object	Period	EC	pH	NH4	Pb	As	Sb	Cu
Sludge	2009 – 2018	0.57	V	**1.26**	0.03	**2.00**	0.13	0.001
	2019	0.66	V	**1.50**	0.003	**3.45**	0.11	0.001

Explanatory notes: As in Table 8.

Table 44: Comparison of characteristic values of drainage water quality indicators at the Nižná Slaná tailings pond with the intervention criterion (IT) for groundwater

Object	**Period**	**EC**	**pH**	**NH4**	**Pb**	**As**	**Sb**	**Cu**
Sludge	2009 – 2018	0.38	V	0.63	0.01	1.00	0.07	0.001
	2019	0.44	V	0.75	0.001	**1.73**	0.05	0.001

Explanatory notes: As in Table 9.

According to observations from 1968 to 2015, the flow rate of the Slaná River in Vlachovo (about 6 km above Nižnoslanská Baňa) ranges from 0.110 to 72 m^3/s, with an annual average of 3.643 m^3/s for 2016[3] /s and monthly averages of 1.393–8.343 m^3 /s (Blaškovičová et al., 2017). At such flow rates, the contaminated water from the tailings pond is sufficiently diluted in terms of the required surface water quality. In 2019, as part of the national surface water quality monitoring programme (www.shmu.sk), the contents of Hg, Cd, Pb and Ni were monitored at the Slaná River monitoring site in Vlachovo – all of them met the surface water quality requirements. The content of As was not monitored here. When calculating according to the mixing equation, we consider a concentration of As = 4 µg/l (background value for this section of the Slaná River) and a flow rate of 110 l/s in the profile above Nižnoslanská Baňa, with a concentration of As = 172 µg/l and a yield of 2 l/s for seepage from the tailings pond, we obtain a value of As = 5.3 µg/l for the profile of the Slaná below the inflow from the tailings pond. This indicative calculation shows that even at the lowest flows of the Slaná, the inflow from the tailings pond does not increase the As content in river water above the limit for surface waters.

Engineering geological aspects

In the Nižná Slaná deposit area, terrain depressions are linked to older Manó siderite lens mining areas and newer collapses above smaller siderite lens mining areas near Kobeliarovo. The terrain depressions above the Manó deposit are located in a rarely visited and relatively inaccessible terrain around elevation Rimberg between Nižnoslanská Baňa and Kobeliarovo. In 2015, we conducted field research to determine the current state of surface stability near surface and subsurface mining areas. Since 1995, dynamic changes have been taking place in the collapse zone of the Kobeliarovo deposit, located on the north-western edge of the village of Kobeliarovo, which we assessed in detail in our 2014 annual report. Between 2015 and 2019, we conducted field reconnaissance to investigate changes in the extent of landslides and their accompanying manifestations. The following text presents an evaluation of the monitoring results at the Kobeliarovo deposit.

The Kobeliarovo deposit is located near the village of Kobeliarovo, about 150 m northwest of the northern edge of the village. The deposit is formed by carbonate bodies – metasomatic siderites, with dolomites and crystalline limestones representing the other carbonates. The deposit strikes NW-SE with a 50° dip to the NE. The siderite filling and other carbonates are not layered; the rocks are compact, with considerable tectonic disruption. The directional length of the balance mineralisation at the VI horizon is 350 m with an average thickness of 70 m. At

The deposit has a strike length of 200 m and a false thickness of 30 m. The bedrock of the deposit has a relatively steep slope with a northward inclination. The balance body is tectonically bounded by a layer of black phyllites 1–5 m thick, under which there is a relatively thick layer of unbalanced carbonates – dolomites and crystalline limestones (Fig. 39). The overburden of the body consists of black phyllites with lydites and sericitic-chloritic phyllites (Mihók and Jančura, 1995).

The Kobeliarovo deposit is characterised by the occurrence of a concentrated group of collapses. Mihók and Jančura (1995) already pointed out the reasonable assumption that the collapses were caused by mining in connection with the calculation of reserves at the deposit. As they state, the ore body of the main location is located 25–50 m (E-W) below the surface, which is a realistic assumption for surface subsidence when a certain amount of reserves are extracted. This was confirmed in April 1995, when the previously uncollapsed mined area on levels II and I suddenly collapsed due to the collapse of the overburden (black and greenish phyllites) with manifestations reaching the surface, creating a crater approximately 20 x 15 m. It follows from the above that, with further mining using caving methods, the surface above the deposit will gradually collapse as the deposit is exploited. The caving zone, after being brought to the surface, has an area of 5.6 ha (mining of reserves to the level of the VI horizon; Mihók and Jančura, 1995).

As part of our own work at the Nižná Slaná R8 – Kobeliarovo deposit site, detailed GNSS surveying was carried out in 2014 in the area of rockfalls using a Trimble Geo7x device with horizontal accuracy ranging from 0.1 m to 1.5 – 2.5 m (depending on the vegetation cover). Several types of geodynamic phenomena were recorded as a result of undercutting, such as landslides (or subsidence depressions), cracks subsidence, tensile and tensile-
-subsidence, creeping movements of rocks, etc.

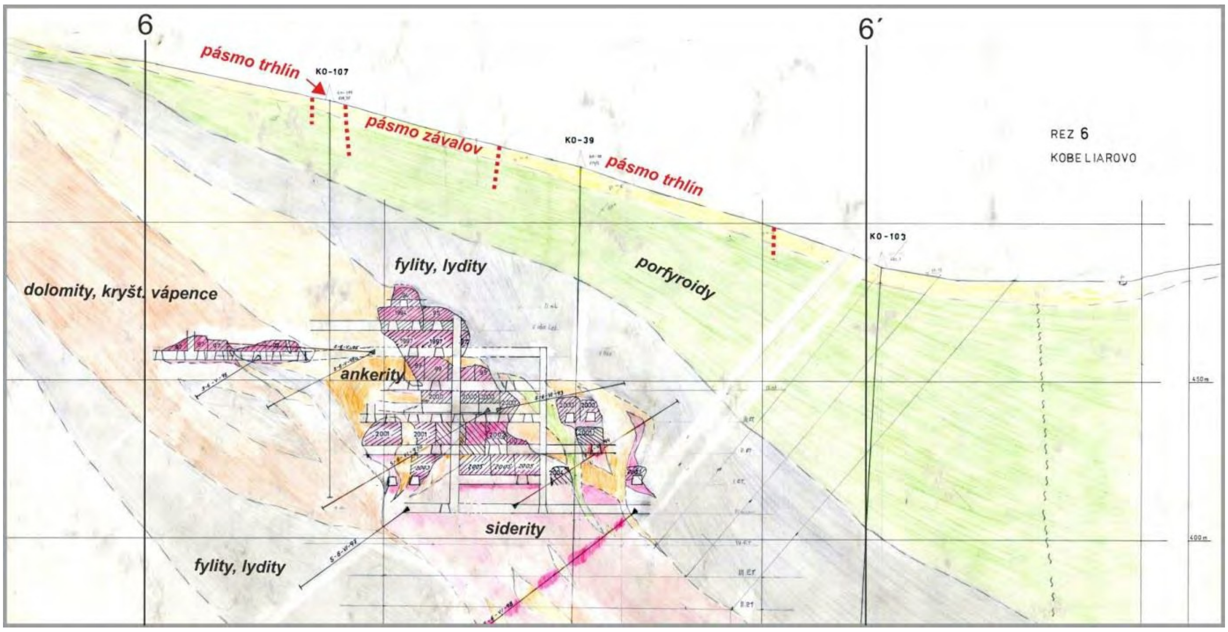


Fig. 39: Section 6 – 6´ of the Kobeliarovo deposit.
Source: Slovak Mining Archive in Banská Štiavnica, file GJ11 (modified and supplemented).

A total of 19 collapses were located, as shown in Fig. 40, which also shows the gradual spread of collapses in the deposit. Some of the collapses are also bordered by groups of previously separate collapses (e.g. collapses Z5, Z12). The area of the collapses (without cracks) reaches a width of approximately 200 m in the V-Z direction (270 m including cracks) and approximately 170 m in the S-J direction (200 m including cracks).

As can be seen in Fig. 41, the most extensive collapse Z10 is located in the mining area.
V. horizon and its levels. This is the area where mining took place closest to the surface of the deposit. It is the oldest mined area, exploited in the 1990s. Mining at the deposit gradually moved deeper and at the same time northeast towards the Kobeliarsky Creek valley. The north-eastern part of the collapse zone, with more or less separate collapses Z1 – Z9, Z11 – Z13 and Z17, developed above the mining area of the VI horizon and its levels. Further expansion of the collapses into the valley is prevented by the protective pillar of the Kobeliarsky stream.

The western to north-western part of the collapse zone is active. The reason for this activity is probably the interconnection of mined areas from the V horizon towards the depths – to the VI horizon levels, with the aim of expanding the collapses in the form of the creation of significant active tensile-subsidence cracks oriented S-N to NE-SW. Noteworthy is the southwestern area of the collapse zone, where no collapses have yet been observed on the surface above the mined areas.
V. horizon, which is probably related to the greater depth of the overburden of the mined areas. There is greater activity on the southern edge of the collapse zone, where the level of the V horizon is closer to the surface and the mined areas are also in the first stage of the V horizon and, towards the north, in the Z10 collapse zone, also in the second stage of the V horizon. The south-eastern edge of the mined part of the deposit at the level of the second stage of the sixth horizon is closest to the village of Kobeliarovo. Despite the relatively shallow mining depth (around 40 m), no significant morphological manifestations of land subsidence (visible to the naked eye) have been observed here so far.

In 2019, work focused on reconnaissance of the area in question, aimed at recording changes in the extent and activity of landslides and related secondary geodynamic phenomena compared to the previous period. Due to the reduced availability of the GNSS measurement signal (due to forest cover) and limited access to the edge of the landslide (for personal safety reasons), the possibility of monitoring the spread of landslides and accompanying geodynamic phenomena using GNSS surveying (especially on a smaller scale) is is significantly limited. Therefore, it is advisable to evaluate morphological changes in the landslide zone by comparing time-lapse photographs taken from designated locations. However, due to the dense vegetation cover, this method of monitoring is also very limited in terms of tracking changes in the spread of the landslides themselves.

In order to observe changes in the landslide zone, seven observation points were marked in 2017 with the designations F1, F5, F7, F8, F10 – F12 (marked as A to G in 2017), from which "zero imaging" was performed. In 2018, the first series of comparative photographic imaging was carried out from these stations, and in 2019, the second series. In addition, eight more sites (labelled F2 – F4, F6, F9, F13 – F15) suitable for comparative photographic imaging were marked out in 2018. A
In 2019, the F6A site was added. In total, comparative photographic imaging is carried out at 16 sites (Fig. 41). Fig. 40: Map of the development of landslides at the Kobeliarovo deposit in the period from 1995 to 2014.

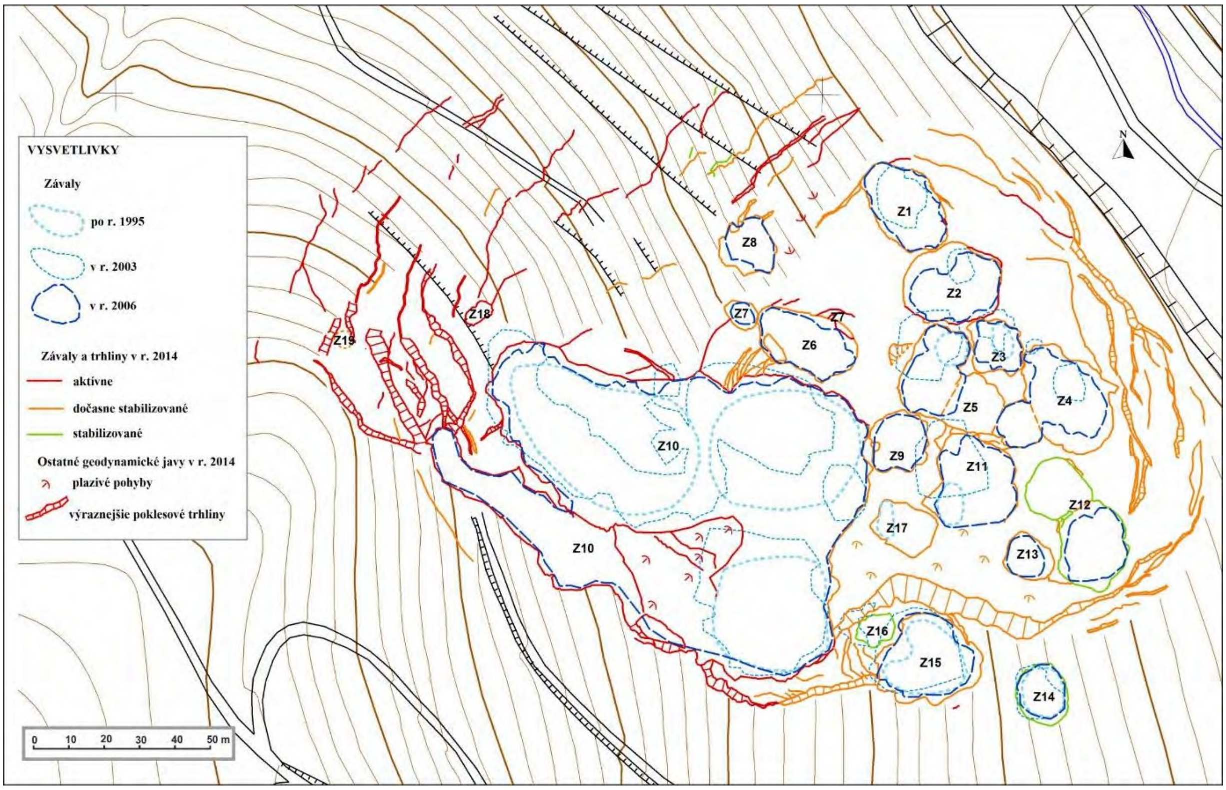


Fig. 40: Map of the development of landslides at the Kobeliarovo deposit in the period from 1995 to 2014. (Topographic base: Ščuka et al., 1982.)

Field research conducted in 2019 revealed changes in the geodynamic activity of the monitored site in the form of new active cracks identified in the vicinity of the landslides marked 1 to 10 (Fig. 41). The area of landslides Z1 to Z17 is gradually becoming more and more overgrown with shrubs and trees and is increasingly difficult to observe. No expansion of the landslides due to undercutting was observed. Geodynamic activity on the landslides manifests itself only in the form of deluvial soil horizons or rocky to boulder fragments from the pre-Quaternary bedrock. These manifestations were recorded during reconnaissance, especially in the area of the northern wall of landslide Z10 (Fig. 42).

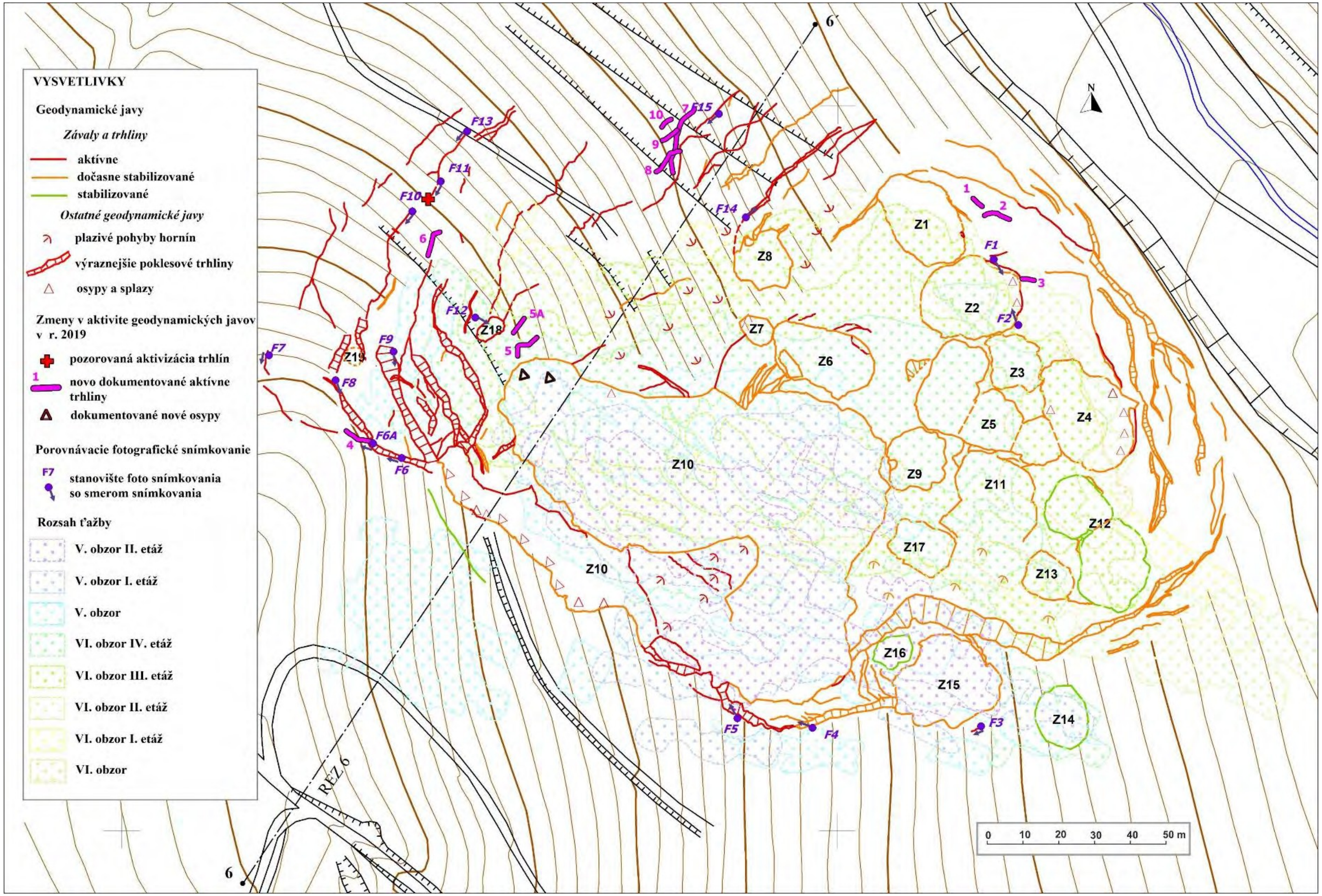


Fig. 41: Map of landslides at the Kobeliarovo deposit showing documented changes in 2019 and the extent of mining obtained by processing map data from the Slovak Mining Archive in Banská Štiavnica (topographic data: Ščuka et al., 1982).

Fig. 42: Active landslides on the Z10 landslide. Fig. 43: Fracture 1 at the Z1 landslide.

In the eastern part of the landslide zone, east of the edge of landslide Z1, geodynamic activity was documented in 2019 in the form of tensile *crack 1* with a local opening depth of up to 0.7 m (Fig. 43) and *crack 2* with a reverse dip (or dip in the direction of the landslide) of approximately 0.2–0.3 m. However, no expansion of the Z1 landslide itself was observed. Comparative imaging from stations F1 (Fig. 44a) and F2 (Fig. 44b) shows that the eastern edge of the Z2 landslide continues to expand slightly due to debris falling from the upper part of the landslide wall (Fig. 44a). No significant changes in the expansion of the landslide were observed here. However, geodynamic activity was observed in the fracture zone. On the eastern edge of the Z2 collapse, *a 3* V-Z oriented tensile *crack* was documented in 2019, with a slightly deep depression with a depth and width of approximately 0.1–0.15 m.

No observable changes in geodynamic activity were detected in the further eastern to south-eastern course of the edge of the collapse zone (collapses Z3, Z4, Z12, Z13, Z14, Z15 and Z16). Near collapse Z15, an active tensile crack with a width of approximately 10–15 cm and a continuous length of approximately 1.8 m has been observable for a long time. Comparative imaging of this crack from location F3 shows no visually observable changes in its dimensions (Fig. 44c). Comparison of images of crack branching from location F4 showed no signs of observable activity (Fig. 44d).

The location where the significant downward crack ends in a collapse, photographed from observation point F5, showed no activity, as can be seen from a comparison of photographs from 2018 and 2019 (Fig. 44e) (including the preservation of the tree root connecting the upper and lower edges of the crack).

Reconnaissance in 2019 in the area of the south-western wall of the Z10 landslide confirmed the occurrence of active rockfalls with the formation of overhangs on the edge of the landslide.

An active subsidence-tension crack was photographed from location F6, and a comparison of the images from 2018 and 2019 (Fig. 44f) shows that there has been no observable change in the activity of the crack. During reconnaissance in 2019, *a* new tensile-subsidence *crack 4* was observed and documented (Fig. 41). The crack connects a significant subsidence crack and a less significant tensile-subsidence crack in the V-Z direction. The degree of subsidence is approximately 0.2–0.4 m (Fig. 44g). Its openness is also observable intermittently. Another imaging station marked F6A (Fig. 41) was set up to monitor this crack. Comparative imaging of the tensile-

- The subsidence crack from location F7 (Fig. 46h) did not show any observable activation. Comparative imaging was performed at site F8 of a significant subsidence-tension fracture with presumed active character (Fig. 44i) with a subsidence rate of approx. 1–2 m and a width on the terrain surface of up to approx. 1 m (from the opposite direction of its course as from site F6). The terrain depression as a manifestation of the openness of the crack continues to be filled with debris and deluvial soil from the upper part of the crack's separation surface. Imaging of the active subsidence-tension crack from site F9 did not show any change in its activity compared to 2018 (Fig. 44j). According to comparative imaging of its SV end from site F10 (Fig. 44k), no observable progression in its activity was recorded on the significant tensile crack. East of this fissure, sporadically open sections of *a* new tensile *fissure 6* were observed during reconnaissance in 2019 (Fig. 41). It is sporadically open up to 0.4 m along its course. The fissure has an S-N orientation. The tensile fissure photographed from location F11 (Fig. 44l) is directionally connected to the fissure photographed from location F10. Comparative imaging and field reconnaissance revealed an observable deepening of the opening in the crack, approximately 0.3 m wide at its southwestern end, with an observed depth of approximately 3 m.

a)

b)

c)

d)

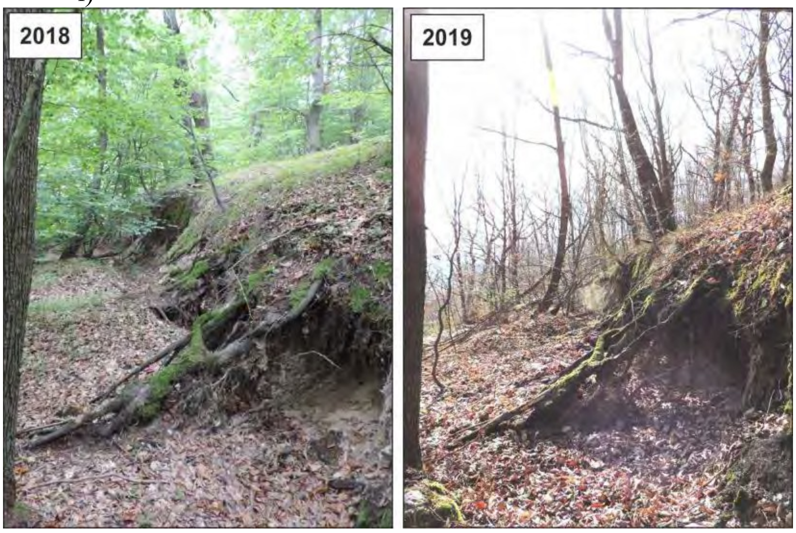
e)

f)

g)

h)

i)



j)

k)

l)

m)

n)

o)

p)

Fig. 44: Comparative photographs of the landslide zone in Kobeliarovo from 2018 and 2019 2019 from the following locations: a) F1 with the location of debris fall marked, b) F2, c) F3, d) F4, e) F5, f) F6, g) F6A, h) F7, i) F8, j) F9, k) F10, l) F11 marking the location of the crack opening and detail, m) F12, n) F13, o) F14, p) F15.

Fig. 45: Fracture 5 at the Z10 collapse with marked locations of visible fracture openings.

Landslide Z18 was documented by comparative imaging from location F12 (Fig. 44m). No expansion of the landslide was observed. Geodynamic activity is manifested only in slight rockfall at the edge of the landslide.

In the area between the Z18 and Z10 collapses, two continuously open cracks were recorded during a terrain reconnaissance in 2019 (Fig. 45), the course of which is parallel to the course of the edge of the Z10 collapse in these locations. *Fissure 5* (closer to the Z10 landslide) is tensile-subsidence in nature and approximately 10 m long. The subsidence of the terrain at the crack is approximately 0.2 m. Tensile *crack 5A*, further away from the collapse, probably runs mostly hidden under the surface of the terrain, with its observable section on the surface being approximately 2–3 m long.

No observable changes in activity were recorded on the prominent tensile crack photographed from location F13 (Fig. 44n). Similarly, no changes in activity were recorded on the tensile fracture photographed from location F14 (Fig. 44o) and the tensile-subsidence fracture photographed from location F15 (Fig. 44p).

In the northern edge of the fracture zone (near site F15), active *fractures 7, 8, 9, and 10* were recorded during reconnaissance in 2019 (Fig. 41). Tensile *crack 7,* with a longitudinal depression of 0.5–1 m, is sporadically open and connects to crack 8. Crack 8, with a reverse dip of 0.2–0.5 m (in the direction of the landslides), connects to *crack 9*. With little visible manifestation on the surface, tensile *crack 9* and tensile-subsidence *crack 10* are probably secretly connected to crack 7.

Fig. 46: Bent and tilted tree trunks in the fracture zone north of collapse Z10.

Monitoring of the Kobeliarovo deposit site in 2019 shows that the observable activity of geodynamic phenomena caused by mining continues to manifest itself primarily in the fracture zone, especially in the contiguous area in the western to northern region. The ongoing geodynamic activity in this area is also confirmed by creeping subsurface deformations of the rock environment. These are visible on the surface, as documented not only by directly observable changes in crack activity (documentation of new cracks) but also by bent and tilted tree trunks (Fig. 46).