POSITIVE AND NEGATIVE IMPACTS OF TECHNOGENIC DEPOSITS

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Abstract: The paper presents the results of research on several characteristic mine tailings in the World and in our country (Republic North Macedonia), in terms of their negative impact on the human environment, but also in terms of their eventual positive impact due to their industrial use and extraction of Rare Earth Elements, rare metals etc. Three characteristic mine tailings were treated in this paper that have clearly defined negative environmental impacts, some of which have catastrophic consequences. The first of them was the tailing dam in Baia Mare, Romania where tailings material from the gold mine had been deposited. During the tailing dam failure in 2000, up to 100 000 cubic meters of liquid and suspended waste containing about 50 to 100 tons of cyanide, as well as copper and other heavy metals went into the nearby stream and later into the Tisza and Dunav rivers. Much of the wildlife in the rivers in Romania, Hungary and Yugoslavia was extinct, and in particular 1240 tonnes of dead fish were found in Hungary. The second accident we studied was the Sasa tailing dam failure in 2003. During the accident from the Sasa tailing dam into the near Kamenicka river outflow 100 000 m^3 of material. Human casualties were not recorded during this accident, but all the wildlife in the Kamenica River was extinct and large material damages were reported, too. The big catastrophic dam failure occurred in 2019 at the Vale's Brumadinho mine in Brasil when over 12 million cubic meters of tailings material overflow after the tailing dam collapsed and 270 people died.
The positive impacts are seen in the examples of the studied lead-zinc deposit Toranica with approximately 3 Mt material and interesting contents of lead, zinc and especially indium, germanium, gallium, and in the As-Sb Lojane deposit containing over 1 Mt with 2% As and Sb withi 3Mt of tailing dam.
Keywords: technogenic deposits, mine tailings, environmental impacts

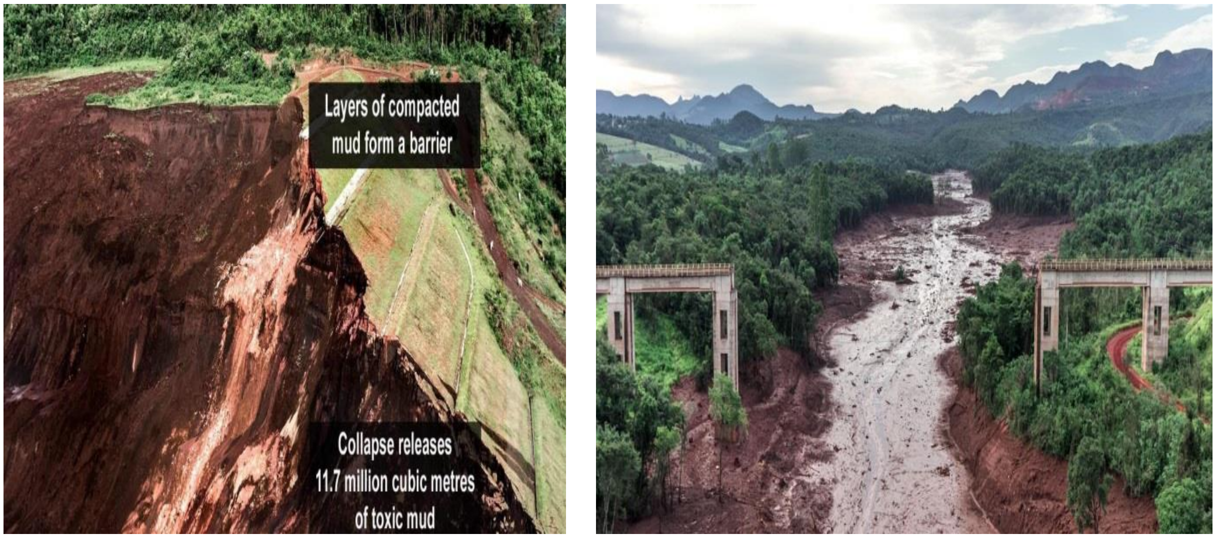
1. INTRODUCTION

Technogenic deposits date back to the 18th century when it was decided for the first time that waste material was exploited during the exploitation of polymetallic ores should be deposited near the mines themselves. Later this idea evolved into the formation of more classical dams. Already in the late 19th century and especially the 20th century, these dumps took their indivisible place from underground or surface mines that had a common name for tailings or mineral processing as a tailing dam. In particular, the materials were stored after flotation treatment where it was produced a liquid-fluid mixture that was deposited on the sediments or tailings dams, which usually contained significant concentrations of the essential minerals lead, zinc, copper and other attractive metals such as gold, silver, platinum, platinoids, REE etc. Nowadays more and more attention is being paid to these technogenic deposits because on the one hand they represent a potential hazard to the environment (Bes et al., 2014) and on the other they attract attention because they contain interesting concentrations of polymetals and precious metals. There are numerous examples in the World of catastrophe after tailing dam failures that resullted in major material damage, human casualties (Brumadinho, Brasil) and extremely contaminated human environment such as Balangen-Norway, Zletovo (1976), Baia Mare (2000), Sasa (2003) et al. Exploitation of such tailings by individual Chinese companies in the Balkans, such as in Romania, initiated a completely different view of tailings, as technogenic deposits that could have a positive impact on the economy and be used as potential deposits of useful minerals and numerous critical raw materials.

2. TECHNOGENE DEPOSITS WITH NEGATIVE INFLUENCE

Most of the old waste dumps and tailings dams have high contents of heavy metals which could represent potential risks to the environment or be an alternative source of some critical raw materials. Many mining sites, which are often abandoned, in Europe and worldwide have an old dam which has generated high impacts and presents several potential risks to the local community, contributing to a reduction in confidence in this industry. Deposited tailings originating from metallic mining, in particular, due to their sulfide content could result in the spread of this contaminant material through air or water to other regions. Sulfides when exposed to atmospheric conditions may be oxidized in a process known as Acid Mine Drainage (AMD), and this results in the successive formation of low pH effluents with several toxic metals.
Vale is Brazil's biggest mining company and the world's number-one producer of iron ore. Within Brazil, it produces 80% of the ore for export. On 25 January, 2019, at 12:28 local time, in Vale's Brumadinho mine tailing

dam, everything was destroyed. The 86m high mining dam close to the city of Brumadinho (state of Minas Gerais, Brazil) had collapsed (Figure 1; Pereira et al., 2019).



a) *b)*

Fig. 1. Illustration of mining dam collapse at Vale's Brumadinho mine (a); Tailling pollution material along the river with illustration of the railway bridge collapse, too (b)

Within seconds, 11.7 million cubic metres of liquid waste cascaded down the valley at more than 70km/h (43mph). The canteen building and everyone in it was buried beneath a torrent of mud. The mud destroyed two sections of railway bridge and about 100 metres of railway track. As of January 2020, 259 people were confirmed dead, and 11 were considered missing.Figures were later amended to 270 deaths. From the environmental point of view we would like to stress that iron ore railway bridge was destroyed by mudflow, 3 kilometres (1.9 mi) downstream from collapsed dam. The dam failure released around 12 million cubic meters of tailings. According to experts, the metals in the tailings will likely be incorporated into the river's soil and could go on to affect the region's whole ecosystem. The National Water Agency (ANA) stated that the tailings could pollute over 300 kilometres of river. Also, the economic impact should not be ignored. Namely, as a result of the disaster, on 28 January the Vale S.A. stock price fell 24%, losing US$19 billion in market capitalization, the biggest single day loss in the history of the Brazilian stock market. Also, economic effects reflected in facts that in the city of Brumadinho, many agricultural areas were affected or totally destroyed. The local livestock industry suffered damages, mainly from loss of animals such as cattle and poultry. The local market was also impacted due to the damages, with some stores and establishments remaining closed for a few days. Overnight 700 people of the neighboring were evacuated. There are at least 790 tailings dams across the Brasil, many of which are directly uphill from towns and cities (Davies and Martin, 2000). They have all been categorised by their "potential for damage". This rating scale does not measure how likely they are to collapse, but how much damage they would do if they did.

The accident at the Baia Mare occurred on January 30 at 22:00, with a break in a dam encircling a tailings pond at a facility operated by Aurul SA Company, northwest Romania. The result was a spill of about 100,000 cubic meters of liquid and suspended waste containing about 50 to 100 tonnes of cyanide, as well as copper and other heavy metals. The break was probably caused by a combination of design defects in the facilities set up by Aurul, unexpected operating conditions and bad weather (Csagoly, 2000; Figure 2).

a) *b)*

Fig. 2. Illustration of the failed gold-tailing dam in Baia Mare, Romania (a) and illustration of negative influence after the spill of cyanide flow throught the Tiscza river with dead fish.

The contaminated spill travelled into the rivers Sasar, Lapus, Somes, Tisza and Danube before reaching the Black Sea about four weeks later. Some 2,000 kilometres of the Danube's water catchment area were affected by the spill. Romanian sources said that, in Romania, the spill caused interruptions to the water supply of 24 municipalities, and costs to sanitation plants and industries, because of interruptions in their production processes. Romania also reported that the amount of dead fish was very small in Romania. Hungary estimated the amount of dead fish in Hungary at 1,240 tonnes. Yugoslavian authorities reported large amounts of dead fish in the Yugoslavian branch of the Tisza River and no major fish kills in the Danube River.
The active production of lead-zinc ore from the Sasa mine that began with active exploitation in 1962 and has been operating to date has enabled the formation of tailings dump in which approximately 18-18.5 Mt of tailings has been accumulated. On the 30. 08. 2003 during the afternoon hours one part of the the Sasa Mine tailings dam collapsed, discharging 70 000 - 100 000 m^3 of material along the Kamenicka River valley (Figure 3).

a) b)

Fig. 3. Illustration of the collapsed "crater" in the tailings dam at the Sasa Mine, Republic North Macedonia (a) and tailing flow contaminates Kamenicka River and its valley, view from valley level (b)

As can be seen from the accompanying pictures the material from the tailings covered a larger area of the riverbanks and was transported at a 12 km distance up to the Kamenichka River estuary in the Kalimanci artificial lake. During 2011, the remains of the material along the Kamenichka River were examined for toxic metal (Ag, As, Cd, Cu, Mo, Pb, Sb, Bi, Zn, Ni, Al, Fe, Mn) and sulphur (S), and the results are presented in Table 1.

***Table 1.* Concentrations of different elements and pollution index values in Sasa surficial tailings dam material (Vrhovnik et al., 2011).**

Samples	**Mo** mg kg^{-1}	**Cu** mg kg^{-1}	**Pb** mg kg^{-1}	**Zn** mg kg^{-1}	**Ni** mg kg^{-1}	**As** mg kg^{-1}	**Cd** mg kg^{-1}	**Sb** mg kg^{-1}	**Bi** mg kg^{-1}	**Ag** mg kg^{-1}	**Al** %	**Fe** %	**Mn** %	**S** %
H – 1	2.9	188	3752	6092	28	54	53	2.5	6.7	2.8	4.6	12	1.6	4.4
H – 2	3.4	164	4573	3709	29	64	32	7.9	5.9	2.9	4.7	112	1.6	4.2
H – 3	2.7	244	5657	9747	32	49	81	3.6	12	3.7	4.9	11	1.5	4.8
H – 4	3.0	641	>10000	>10000	35	72	234	5.0	15	8.2	4.6	14	1.8	6.8
H – 5	2.7	213	4775	5761	29	85	48	3.0	6.0	3.1	4.9	12	1.5	4.2
H – 6	2.9	226	4995	6512	30	91	58	3.0	10	3.7	4.8	12	1.6	4.7
Mean	2.9	279	3975	5320	30	69	84	4.2	9.4	4.1	4.8	12	1.6	4.9

If the average concentrations of examined elements from Sasa tailings dam are compared with average concentrations from Barroca Grande (Ávila et al., 2008; Candeias et al., 2015) tailings dam (Ag 16 mg kg-1, As 7.1 mg kg-1, Cd 56 mg kg-1, Cu 2.5 mg kg-1, Mn 730 mg kg-1, Ni 29 mg kg-1, Pb 172 mg kg-1, Sb 62 mg kg-1, Zn 1.7 mg kg-1 and Fe 8.7 %), it can be seen that concentrations of almost all toxic metals are much higher in surficial material from Sasa tailings dam. However, in both cases, toxic metals concentrations exceed the permissible levels (MDK) adopted by the National Environmental Protection Agency of Republic North Macedonia. The majority of the streams located near Barroca Grande (Avilla et al., 2008) indicates that were exceeded at severe levels for As, Cu, Cd, and Zn and are ‘‘grossly polluted’’, which strongly reflects the situation around the Sasa Mine tailing dam even after 8 years.

3. TECHNOGENE DEPOSITS WITH POSITIVE INFLUENCE

New mining industry based on the use of alternative sources of energy and raw minerals, can consider the reprocessing of the active and former mines tailings. Literature reports some pieces of work, obtained satisfactory results in metal recovery from mining tailings. Tailings reprocessing can be considered as a solution that minimizes social and environmental impacts, recovers some essential minerals, such as Zn, W, REE, Ga, In, Ge, Au, Cu etc., which can help to offset investments made. Particular project designs involve several stages of metal concentration, determined by experiments, as well as a model of the process.

The Lojane deposit is located in the north of Macedonia and between the villages of Lojane and Vaksince (Fig. 2). The mine exploited As, Sb and Cr during the period 1923-1979. Sb and As were mined from steeply dipping, NW-SE trending veins, often located at the junction of the andesite and serpentinite (Jankovic 1960; Antonovic 1965). The main ore minerals were the sulphides of As and Sb (orpiment, realgar, stibnite), but bravoite ($(Fe, Ni, Co)S_2$), vaesite (NiS_2), cattierite (CoS_2), pyrite, marcasite, molybdenite and pitchblende (UO_2) also occur in minor quantities. The gangue consists of quartz and minor dolomite. Some oxidation of the primary sulphides has resulted in the formation of secondary oxides and hydroxides (Tasev et al., 2018; Djordjevic et al., 2019).

The mined ore was transported by rail from the underground workings to the mill and flotation plant and then exported by rail. These former workings are spread over a large area (10 km^2) and are currently in a very poor state of maintenance (Figure 4).

a)

b)

Fig. 4. Illustration of position of the Lojane As-Sb tailling dam (a) and sampling locations along depth of the Lojane's tailing dam (b)

Waste material is estimated at 20 000 t at the mine site and 15 000 t (50% As) of arsenic concentrate and 3 000 000 t of tailings (1-2% As and Sb) at the concentration facility (Antonovic 1965; Tasev et al., 2018). The tailings dam is completely unprotected and its orange colour (clearly visible from satellite images) suggests a high concentration of arsenic sulphides (Alderton et al, 2014). Our most recent Lojane study was carried out in 2018 (Kolitsch et al., 2018) and lately in 2019 as part of the RIS-RECOVER (EIT-Raw Materials) project, and the results for this deposit's tailings dump are presented in Table 2.

Table 2. Elemental analyses of the Lojane's tailing material, ICP-AES (mg/kg)

Sample	Mg	Al	P	S	Ti	V	Cr	Mn	Fe2	Ni	As	Sb	Tl
LO 1/1	14589	15320	93	11847	1533	33.3	314	922	53240	1853	8816	5040	58.5
LO 1/2	11432	31275	247	2626	3127	36.4	190	889	37663	904	4117	422	32.8
LO 1/3	9309	38789	321	3084	3615	39.4	209	741	31476	1338	2006	382	32.6
LO 1/4	11147	50729	1609	2259	5749	72.5	258	584	44365	1083	1801	476	<1
LO 2/1	22941	36272	403	12246	6212	133	125	338	44570	563	3478	371	18.2
LO 2/2	8440	26808	291	3104	9760	86.7	226	740	45180	958	4257	397	33.9
LO 2/3	10180	20257	212	13500	6440	63.2	181	835	47585	1186	5035	362	33.4
LO 3/1	<100	5557	36	129826	324	21.2	104	2.58	9445	188	175665	17608	132.7
LO 3/2	<100	13372	64	120917	378	49.8	191	21.4	14903	327	128990	11467	188.2
LO 3/3	<100	5600	27	145188	249	3.2	32	9.09	11162	864	228807	23420	127.5
LO 4	<100	1064	12	148077	210	1.8	34	<1	2569	49.0	263218	8705	44.4
LO 5	8927	13363	103	13633	761	27.9	259	563	79883	6029	29783	10754	257.8
LO 6	114	6979	22	933	213	15.1	83	35.1	10742	588	188009	82477	164.1

The results presented in the table above show that from the analyzed ICP-AES 40 elements package a total of 14 elements representative of the As-Sb Lojane deposit with high concentrations were selected, as expected, As, Sb and Tl which of course gives a clear signal that the material in the tailings may be interesting for further treatment and extraction of aforementioned metals on one side and the rest of material to be used as building material.
The Toranica mine is located roughly 18 km south-east of the town of Kriva Palanka (northeastern part of the Republic North Macedonia) and 2 km west of the Bulgarian border. The mine started commercial production in 1987 (at its peak it accounted for ~20% of Macedonia's total Pb-Zn output). There are elevated concentrations of Cd, Cu, Mn, Ag, and Bi in the ore, also (Serafimovski et al. 1997). Milling and flotation, for the production of Pb and Zn concentrates, are situated close to the mine and there is a tailings dam below the mine site with a culvert directing the River Toranica beneath the dam (Figure 5).

a) *b)*

Fig. 5. The position of the Toranica mine tailing dam with the water mirror (a) and view from the tailing dam along the Kriva River valley (b)

So far with the operation of the Toranica mine was deposited at the tailing dam flotation material in amount of 3.2 Mt. This fact motivated us in our research to sample part of the tailing dam during 2019, and the results of the analyses are given in Table 3.

Table 3. Elemental analyses of the Toranica's tailing material, ICP-AES (mg/kg)

Sample	Mg	Al	Fe2	Zn	Ga	Ge	As	Se	Ag	Cd	Sn	Sb	Pb
TO 1/1	16040	51716	91249	861	46.3	1.5	79.6	3.2	7.0	17.3	5.1	10.4	2226
TO 1/2	15849	50263	92842	1592	44.8	1.4	88.3	4.3	<1	32	5.0	10.1	269
TO 1/3	16815	53683	96715	732	47.5	1.6	88.3	2.9	<1	13.1	5.4	10.7	2560
TO 2	24842	60845	86175	1934	58.4	1.7	91.7	3.7	35.0	35.2	5.4	13.5	989
TO 3	27814	64402	86182	1018	57.7	1.5	72.7	5.5	<1	18.5	5.3	11.2	2522

The table above shows the synthesized results for the 13 representative elements of lead-zinc deposits such is the Toranica deposit and production of lead-zinc ores in which occur Ga, Ge, Se, Ag, Sn, Sb etc. These data point to the fact that the Toranica tailing can be treated as a technogene deposit with an eventual positive impact in future research and eventual metal extraction.
We would like to emphasize that there are several other important technogene deposits in the Republic North Macedonia that may be of significant interest for future processing, including Zletovo with about 10 MT, Sasa with 18 MT, and Bucim with over 130 MT tailing materials in which of particular interest are Cu, Ag, Au and REE.

4. CONCLUSION

Technogenic deposits are definitely significant objects that must be paid attention, both, from an environmental and economic point of view.
Significant are the catastrophes of the tailing dam collapses of the Baia Mare (Romania), Brumadinho (Brasil) and Sasa (R.N. Macedonia) with human casualties (Brumadinho), destruction of wildlife and major material damages. However, technogenic deposits are also attracting attention from an economic point of view as they contain significant amounts of polymetals, critical raw materials and Rare Earth Elements etc, which are not only economically significant but also important for future industrial development on a global scale.

REFERENCES

Alderton, D., Serafimovski, T., Burns, L. and Tasev, G., (2014). Distribution and mobility of arsenic and antimony at mine sites in FYR Macedonia. *Carpathian Journal of Earth and Environmental Sciences*, Vol. 9, No. 1, 43–56

Antonovic, A., (1965). *Geology, tectonic structure and genesis of the arsenic-antimony ore deposits in the Lojane and Nikustak district (Skopska Crna Gora Mts)*. Geological Institute, Skopje, Special Issue 1, 77 pp. (in Macedonian).

Ávila, P. F., Ferreira Da Silva, E., Salgueiro, A. R. and Farinha, J.A., (2008). Geochemistry and Mineralogy of Mill Tailings Impoundments from the Panasqueira Mine (Portugal): Implications for the Surrounding Environment. *Min. Wat. Env.*, 27: 210-224.

Bes, C. M., Pardo, T., Pilar Bernal, M., & Clemente, R. (2014). Assessment of the environmental risks associated with two mine tailing soils from the La Unión-Cartagena (Spain) mining district. *Journal of Geochemical Exploration*. Volume 147, Part B, 98-106. doi:10. 1016/j.gexplo.2014.05.020. in press

Candeias, C., Ávila, P. F., Ferreira da Silva, E., Ferreira, A., Durães, N. and Teixeira, J.P., (2015). Water–Rock Interaction and Geochemical Processes in Surface Waters Influenced by Tailings Impoundments: Impact and Threats to the Ecosystems and Human Health in Rural Communities (Panasqueira Mine, Central Portugal). *Water Air Soil Pollut*, 226:23

Csagoly, P., (2000). *The Cyanide Spill at Baia Mare, Romania: before, during and after*. Regional Environmental Center for Central and Eastern Europe, 8 p.

Davies, M. P. &. Martin t. e. 2000: *Upstream constructed tailings dams – A review of the basics. Tailings and Mine Waste*. A.A. Balkema, Rotterdam., 3-15.

Djordjevic, T., Kolitsch, U., Serafimovski, T., Tasev, G., Tepe, N., Stoger-Pollach, M., Hofmann, T. and Boev, B. (2019) Mineralogy and weathering of realgar-rich tailings at a former As-Sb-Cr mine at Lojane, North Macedonia. *The Canadian Mineralogist*, 57. pp. 1-21

Jankovic, S.R. (1960). Allgemeine Charakteristika der Antimonerzlagerst ätten Jugoslawiens. *Neues Jahrbuch für Mineralogie Abhandlungen* 94, 506–538 (in German).

Kolitsch, U., Djordjevic, T., Tasev, G., Serafimovski, T., Boev, I. and Boev, B., (2018). *S*upergene mineralogy of the Lojane Sb-As-Cr deposit, Republic of Macedonia: tracing the mobilization of toxic metals. *Geologica Macedonica*, 32 (2). 95-117. ISSN 0352-1206

Pereira, L, F., Cruz, dB, G., and Guimarães, F. M. R., (2019). Impacts from the tailings dam rupture of Brumadinho, Brazil: an analysis based on land cover changes. *Journal of Environmental Analysis and Progress*, V. 4, No. 2, 122-129

Tasev, G., Serafimovski, T., Boev, B. and Gjorgjiev, L., (2018). *Morphological types of mineralization in the Lojane As-Sb deposit, Republic of Macedonia.* 18th International Multidisciplinary Scientific GeoConference SGEM 2018, 13. pp. 601-608. ISSN 1314-2704

Vrhovnik, P., Rogan Šmuc, N., Dolenec, T., Serafimovski, T., Tasev, G. & Dolenec, M., (2011). Geochemical investigation of Sasa tailings dam material and its influence on the Lake Kalimanci surficial sediments (Republic of Macedonia)-preliminary study. GEOLOGIJA *54/2*, 183–190, Ljubljana 2011; doi:10.5474/geologija.2011.000