Environmental problems related to the closing down of the Idrija Mercury Mine

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Abstract

The consequences of five hundred years of mercury excavation in the Idrija Mercury Mine are visible in the sinking and sliding of ground above the mine as well as in the pollution of air, water and soil. In addition to landslides on the slopes above the ore deposit, a large sinking crater has developed in the area above the mine. In the 70's, when the production of mercury reached its peak, the mercury concentrations in air were above MAC. In 1994, mercury exploitation and production was abandoned. Today, mercury concentrations in air are ten times lower. When the mine was in full operation, the closed technological water circuit was employed. However, during the phase of shutdown and flooding of the pit (four lowest levels), increased concentrations of Fe_{tot} and sulphates (above MAC) were found in the water being collected up to the XIth level. The Hg concentration did not exceed MAC. The analysis of sediments has confirmed the extreme pollution of the Idrijca and Soča rivers with mercury. Reports on rivers as heavily polluted as the Idrijca are very rare on a global scale.

INTRODUCTION

Idrija has one of the oldest and most important mercury mines in the world (figure 1). The ore deposit is situated below the center of the town of Idrija, and extends in the directions north-west and south-east. It is 1500 m long, 450 m deep and 400-600 m wide. The mine was comprised of 15 levels reaching a depth of 280 metres (36m below sea level). For economic, technical-technological and environmental reasons, the Long-term Programme for the Gradual, Complete and Permanent Shutdown of the Idrija Mercury Mine was prepared in 1986 and adopted in 1989. The Programme was prepared on the basis of the existing knowledge of the pit, stability conditions in the pit area, and the influence of the exploitation and production of mercury on the environment, taking into account the general mining problems related to shutdown works. The complete and permanent shutdown of mining activities calls for the adequate liquidation of all pit facilities in order to protect the town of Idrija, which lies directly above the pit, against sinking and other consequences of five hundred years of mining, as well as to ensure the sound rehabilitation of the environment. The results of studies and analyses of the effects of executed shutdown works (from 1988 onward) indicate that the concept of the mine's shutdown was properly selected, however, the new results and findings call for the adaptation of individual parts of the Programme. The mine will be shut down by the year 2006 (Bajželj 1996).

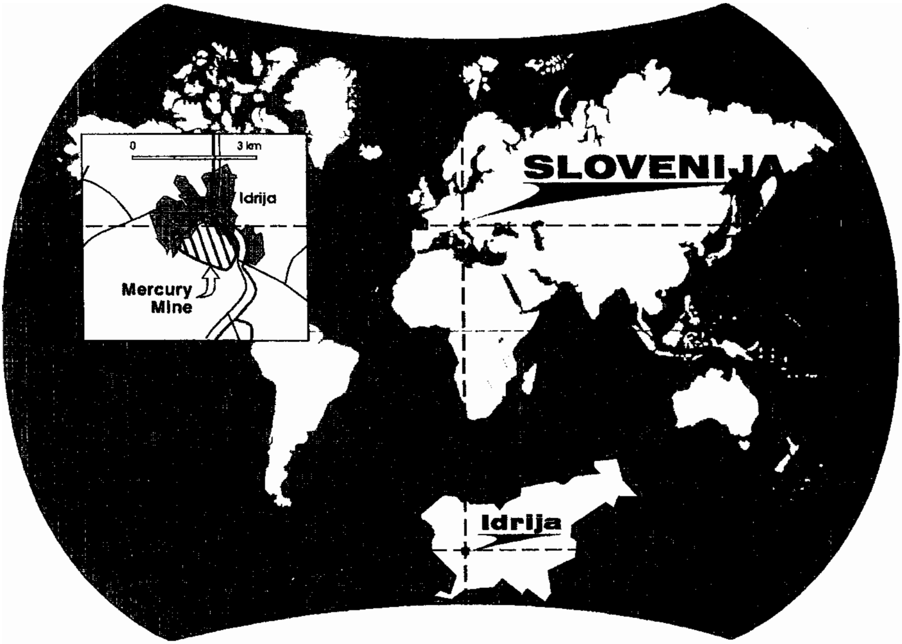
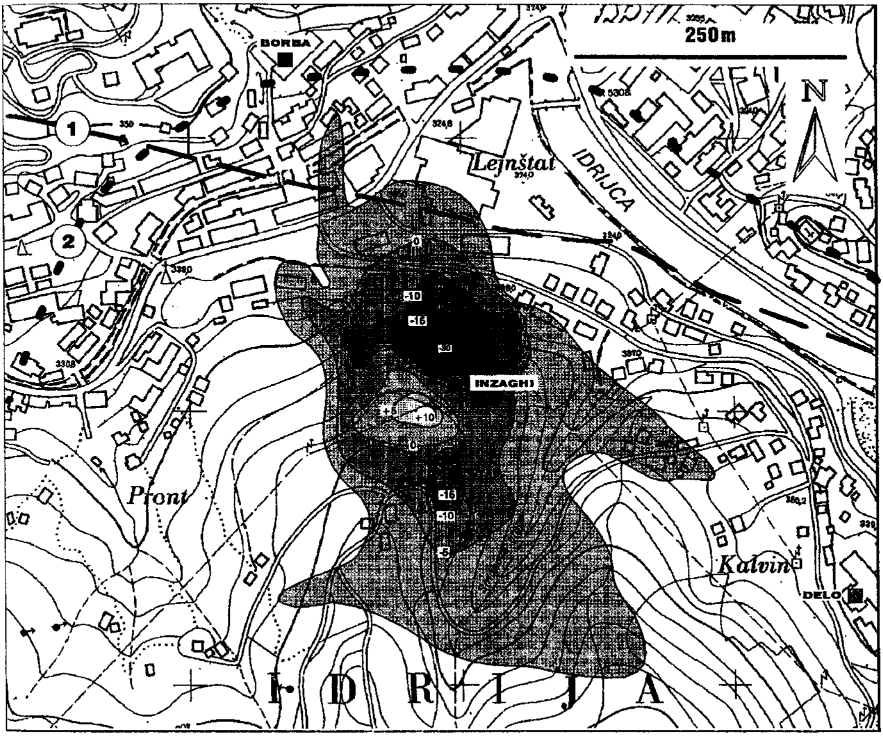


Figure 1: Idrija, geographical position

SHIFTS AND SINKINGS IN THE PIT AND ON THE SURFACE

Upon the adoption of the Programme for shutdown of the mine, the development the consequences of mining activities on the surface was not entirely known. In view of the geological structure of the ore deposit, the spatial distribution of excavated areas and the configuration of the surface, it was expected that the sinking of ground would continue and the shifts in Permian Carboniferous shale and the overlying Carboniferous nappe, on which part of the town of Idrija is built, would intensify. On the basis of sparse data, yet a detailed knowledge of the mining and geological conditions in the Idrija pit, a combination of sinkings due to the continued compression of unconsolidated backfills in the pit and surface slides due to the unfavourable configuration of terrain was expected. The results of ten years of studies, measurements and observations showed that a large slide had not formed over the pit, but a large sinking crater was gradually forming (figure 2). For the purpose of monitoring developments in the pit and on the surface, cave surveying, surveying, inclinometric and geotechnical measurements are being performed. The cause of this phenomenon has not been established to this day. Another interesting phenomenon is the rise of some other measuring points on the surface along the edge of the ore deposit (along the Idrija fault), for which no acceptable explanation has been found to this day.



Legend: 1- Idrija fault, 2 – Area influenced by the Idrija Mercury Mine, (-15, +5) – crater contoure lines

Figure 2: Crater near the Inzaghi shaft formed by sinking

Measurements of Horizontal and Vertical Shifts above the Ore Deposit and in the Pit

A decreasing trend of horizontal and vertical shifts above the ore deposit was established. Before the commencement of shutdown works, the horizontal and vertical shifts of terrain above the pit were up to 25 mm/year and up to 14 mm/year, respectively. The same trend was found for the sinkings (vertical shifts) in the pit, as measured on levels 1 to XI. After shutdown works were intensified (injection of old, uncompressed backfills and filling of pit areas), measurements were begun in 1994 for the purpose of monitoring the stabilization of the pit. The measured shifts gradually decreased and, in the past year, horizontal shifts declined to 12 mm and vertical shifts to 4 mm, i.e. by almost 100% with respect to the initial measurements (figure 3). At the same time, the flooding of the pit was begun. After the bottom four levels of the pit were submersed in 1991, the shifts of measuring points on the XIth level (depth 283 m) first appeared as sinkings of completely local character, whereas in the past three years, rises of individual measuring points on this level were observed.

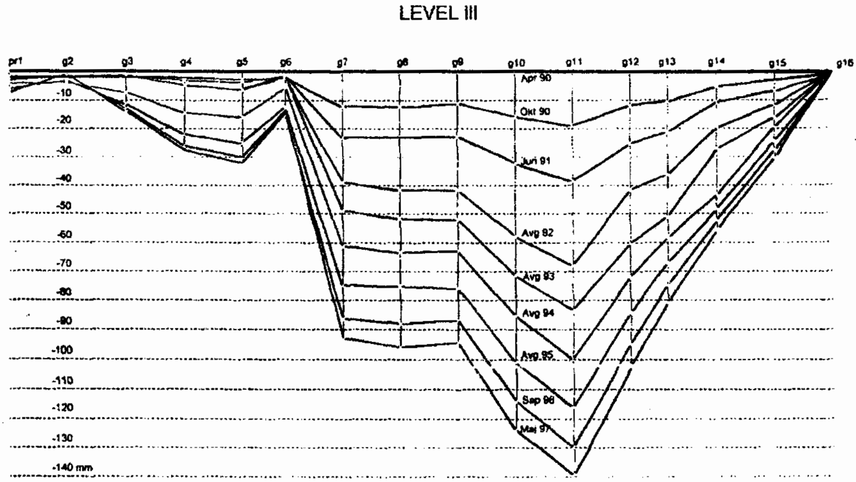


Figure 3: Diagram of craters forming on the IIIrd level of the Idrija Mercury Mine

Geotechnical Measurements and Observations

Geotechnical observations and measurements have been performed in some parts of the mine for six years or more. The deformation changes in rock masses are monitored by means of sondes and five-point extensometers installed on individual levels in the pit. Analyses of measuring results have shown that the submersed part of the pit is calm and stabilized. However, the measurements of strain states on higher, nonsubmersed levels indicate that the stresses caused by shifts due to the time development of sinkings are gradually concentrating in fortified areas, and thus do not present any major hazard.

Measurements of Inclinometric Borehole Shifts

In the period from 1989 to 1992, 14 inclinometric-piezometric boreholes were drilled and measurements conducted twice yearly. The boreholes are located in areas with the most intensive shifts. In the period from 1990 to 1993, the horizontal shifts attained values of up to 21 mm/year and vertical shifts up to 6 mm/year. However, measurements of inclinometric borehole deformations conducted in the period from 1994 to 1997 have shown that the shifting of terrain above the pit is continuing, but with a decreasing tendency (horizontal shifts up to 12 mm/year and vertical shifts up to 4 mm/year); which is undoubtedly the consequence of the abandoning of excavation works and the conduction of consolidation-fortifying works in the pit (figure 4).

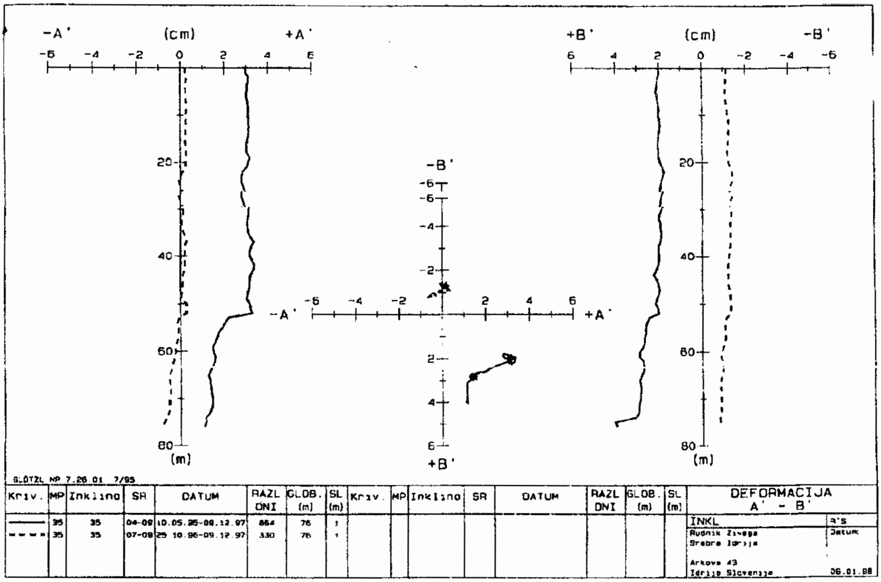


Figure 4: Deformation of G-2 inclinometric borehole in the period from 1995 to 1997

HYDROGEOLOGICAL INVESTIGATIONS AND PIT FLOODING

Owing to the relatively few difficulties encountered with underground water during five hundred years of mining in the Idrija mine, there were practically no extensive hydrogeological investigations in the mine prior to the decision on its shutdown, except for those aimed at explaining the basic hydrogeological conditions in the pit and its surroundings. Not until 1989 was a more extensive hydrogeological study conducted within the scope of the mine shutdown project. Historical data on waters was collected, a register and a map of water sources in the pit and on the surface were made, chemical analyses of important waters were conducted in order to determine their source, the hydrogeological structure was analyzed in detail, hydrogeological maps and cross-sections were drawn, and the sourcing and discharging conditions of individual aquifers were determined. Old piezometric boreholes were activated and new ones drilled, so that hydrogeological measurements are now conducted in a network of 18 bores on the surface, and on a permanent basis at two water collection locations in the pit and occasionally at 11 measuring points at the locations of water inflows into the pit. This network will allow us to monitor the conditions and changes even after final shutdown of the mine. The first findings after flooding of the bottom part of the pit are in good agreement with forecasts. Special attention was devoted to the study of hydrogeological conditions in surface aquifers above the Carboniferous shale nappe due to the influence of underground water on surface stability. In view of the fact that high underground water levels are particularly critical, the drainage possibilities were investigated. By means of flooding tests it was established that the coefficient of imperviousness of surface aquifers is very low. Due to the small impermeability of dolomite in the rock strata above the ore deposit, the drainage ability of the existing pit facilities (shafts) is poor. The fluctuating underground water levels also cause changes in the geotechnical conditions for stabilizing the carbonatic nappe above the pit. The high underground water level in the tectonically raised carbonatic rocks above the Delo shaft has a considerably negative influence on stability. The possibility of draining this block is minimal. The results of hydrological studies will, to a considerable extent, determine the further course and manner of the mine's shutdown.

The mine shutdown programme foresees, in the final phase, the flooding of the pit up to the IVth level (depth 161m) and thus the wetting of backfills and sliding contact areas between the nappe and the ore deposit. This may considerably worsen the situation as regards slides and shifts of rock masses above the pit. Consolidation and injection of backfills as well as the backfilling of remaining underground facilities should be performed in a manner preventing the shifting of rock blocks in the pit after flooding. For this reason the flooding of the pit will have to be performed gradually and the installed measuring devices and eventual movements of rock masses continuously monitored. If observations indicate any critical shifts of rock masses triggered by pit flooding, the further flooding of the pit will have to be stopped. At present the pit is flooded up to the XIth level (depth 283m). Flooding of the pit above the XIth level will only be possible after the completion of all consolidation works up to the IVth level, as these will be the foundations on which the stability of the entire pit structure will be built. In the first phase, the pit will be flooded up to the IXth level (depth 235 m). If observations and measurements do not indicate any negative consequences of pit flooding up to the IXth level, the pit will be flooded up to the VIIth level (depth 206m) or up to the IVth level. As a precaution, it is foreseen in the project that the pit may only be flooded up to the IVth level, where a pumping station will operate on a permanent basis. Once the measurements in the pit and on the surface have undeniably proved that the shifting of rock masses has completely stopped, individual pit facilities above the IVth level will rehabilitated and adapted for extended operation (water pumping and maintenance), thus ensuring the safety of the town above the pit.

ENVIRONMENTAL POLLUTION

More than 147,000 tons of Hg were produced in the 500 years of operation of the Idrija Mine. More than 27% of this mercury has been dissipated into the environment. In view of man's growing ecological awareness in the 70's, when mercury production reached its final peak, systematic measurements of total mercury in water, soil, air, plants, animals and humans were introduced.

Pollution of Pit and Surface Waters

While the mine was in operation, the closed circulation of technological water was employed in the smelting plant, but pit water was discharged directly into the Idrijca River. Analyses were made only for Hg content in discharged pit water (0.2 - 80 ng/l). After the abandoning of production and the commencement of shutdown works and flooding of the bottom part of the pit, the concentrations of iron (Fe_{tot}) and sulphates (SO_4) also began to be monitored. Their values increased considerably in 1994, when the pit was flooded up to the XIth level and the pumping of water was recommenced. Mercury concentrations ranged from 2.0 to 547 ng/l (MAC for waste waters: 10000 ng/l), iron concentrations ranged from 0.02 to 15 mg/l (MAC: 0.2 mg/l), and sulphate concentrations ranged from 16 to 6400 mg/l (MAC: 300 mg/l) (Ulrich-Obal 1997). It was established that the increased iron content in water was the consequence of washing the oxidation products of pyrite and metallic iron present in the ore. The oxidation process was primarily the consequence of burning ore in the smelting plant, from where the burned wastes were returned to the pit as backfilling material. After a certain period the concentrations of iron and sulphates in the discharged pit water began to decrease; today these values are within allowable limits, with the exception of sulphates, whose content is still above the allowable limit, probably due to the leaching of $FeSO_4$ from old backfills. Problems with the pollution of pit water, and indirectly also surface water, may be expected in future during the further flooding of the pit up to the IVth level. So far, an adequate solution for the purification of leachate from the pit has not yet been found, but can be expected during the course of further studies.

The discharge of pit water into the Idrijca River has also polluted our surface waters. After the production of mercury was stopped, the pollution of surface waters with mercury did not decrease as expected. The results of monthly measurements of Hg in water samples from the Idrijca River below the pit water outlet ranged from 36 to 1146 ng/l, whereas mercury concentrations in unpolluted surface and underground waters ranged from 0.02 to 0.1 μ ng/l (Rose et al. 1979).

Mercury in Sediments

A significant burden on the environment was caused by the smelting plant, as in the past poorly burnt ore residues (0.004 - 0.007 % Hg) were deposited at dumps along the Idrijca River, and consequently some of them were also carried off by the river. This created conditions for the uncontrolled penetration of various mercury compounds into water flows and indirectly into the sediments along the Idrijca River, the Soča River, and all the way to the Adriatic Sea in the Bay of Trieste. Within the scope of a studies conducted from 1991 till 1997 (Hess 1991, Gosar 1997), samples of sediments and water samples from the Idrijca River were studied and found to contain 1.8 to 885 mg Hg/kg and 0.0004 to 0.0031 mg Hg/L, respectively. According to Slovene legislation (Official Gazette 1996), the alerting value of mercury content in soil is 2 mg/kg and the mean value for flood sediments in Slovenia is 0.05 mg Hg/kg (Bidovec et al. 1994).

Mercury in Air

Measurements conducted in the 70's, when the mine and smelting plant were in full operation, showed very high mercury concentrations in air. An average concentration of 2000 ng Hg/m^3 was measured in the town of Idrija, and concentrations of up to 30000 ng Hg/m^3 were measured in the smelting plant area (Byrne & Kosta 1970, Kavčič 1974). In the period from 1986 to 1993, when the mine and smelting plant operated with reduced capacity, the results of measurements showed a considerable decrease of mercury content in air, whose values were below 300 ng Hg/m^3 (Pirc 1991, Lupšina-Miklavčič 1994). After 1995, i.e. after ore excavation and its processing in the smelting plant were discontinued, mercury concentrations ranged from 8 to 2950 ng/m^3 of air. The increased concentrations measured after this year were primarily the consequence of local mercury sources (discharges of pit air, old dumps of ore residues). WHO regulations specify 1000 ng/m^3 as the limit value of mercury content in air for residential areas (WHO 1991).

The high mercury content in water, air and sediments is not only due to anthropogenic sources such as the smelting plant, ventilation shafts and riverside dumps, but may also be caused by natural sources such as outcropping rocks containing mercury and located in the town itself.

CONCLUSIONS

The closing down of the Idrija Mine is a very complex project, which needs to provide solutions for various factors which, if not properly addressed, could produce serious effects on the town of Idrija and its nearby surroundings. An unprofessional approach to the closing down of the Idrija Mine and the inadequate performance of shutdown works could have far-reaching consequences for the town itself in the form of sinking ground. For this reason, shutdown works are accompanied by observations and measurements aimed at monitoring their effects, as well as by measurements and studies within the scope of environmental monitoring of pollution with mercury. Measurements and studies are primarily focused on monitoring the quality of discharged pit water and air, and indirectly on the effects of mercury on plants, animals and humans. The results obtained will serve as guidelines for the further planning of shutdown works, which should ensure the safety of the town of Idrija and its surroundings as well as the rehabilitation of the environment.

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