THE INFLUENCE OF SURFACE WATERS AND MINE WATERS ON THE CLOSING DOWN OF THE IDRIJA MERCURY MINE

Bojan Režun, Tatjana Dizdarevič

Rudnik živega srebra Idrija v zapiranju d.o.o. Arkova 43
SI-5280 IDRIJA

ABSTRACT

500 years of mining of mercury ore directly under the town of Idrija had a significant impact on the surface above the mine. In the beginning, the surface shiftings were treated as landslides. However, the measurements and observations conducted later on proved that the shiftings had been caused by the sinking of the area. In order to protect the town above the mine, the backfilling of the maj ority of galleries and shafts and the reinforcement of unconsolidated backfills by means of inj ection were foreseen in the Mercury Mine Glosing-Down Pxogramme. For this reason the mine dewatering concept was changed. The idea of dewatering the upper carbonate cover over the mine ore f eld was abandoned. Inj ections at the maj or water influx locations in the mine would reduce the quantity of water to be pumped out, and the water would accumulate in the pumping area below the IVth level. This would enable sampling of the mine water as pumped out and thus provide for good and efficient ecological monitoring.

IDRIJA ORE DEPOSIT

In the 500-year history of the mine (1490-1994), 4.7 million tons of ore was excavated and a total of 147,000 tons of commercial mercury was extracted, which represents over 13% of the entire world production to date. The Idrija deposit is situated below the center of the town of Idrija, and extends in the directions north-west - southeast. It is 1500 m long, 450 m deep, and 400 - 600 m wide.

The Idrija ore deposit is composed of Carboniferous, Permian, Scythian, Anisian and Ladinian rocks enriched with cinnabar. Ore appears in two forms: 70% as cinnabar (HgS) and 30% as native mercury (Hg). Cinnabar is the main ore mineral. In the entire ore-containing zone there are 141 cinnabar orebodies and 15 native mercury orebodies. Native mercury is mostly found in Carboniferous clay, shells and siltstones with lenses of quartz sandstone, Scythian siltstone and marlstone with lenses of oolitic limestone, as well as in various lithological components of the Skonca beds and tuffites of the Ladinian Age (Mlakar, Drovenik 1971). The quality of mineralization is extremely varied, ranging from extremely rich ores containing 78% Hg ("jeklenka" - steel ore) to poor ores with an average Hg content of 0.18 - 0.20%, prior to the mine's shutdown.

MERCURY MINE CLOSING DOWN PROGRAMME

The long-term programme of gradual, complete and definite termination of production in the Idrij a Mercury Mine, which as adopted and approved in 1987, served as a basis for the Law on the Prevention of the Consequences of Mining in the Idrija Mercury Mine. This law was conceived and prepared with the goal of ensuring that the closing down and consolidation works would be conducted in a manner eliminating any threat to the town of Idrij a as a consequence of mining in the past. The results of investigations and closing down works indicate that the concept of the mine's shutdown, based on the assumption that the processes on the surface were the consequence of the incomplete consolidation of backfl1s, was well chosen. The results of measurements and observations, which are being continuously conducted during shutdown works, have shown that, in addition to landslides on the slope above the ore deposit, a large sinking crater also develops in the area above the mine. On the basis of these results, the most emphasis during shutdown works is given precisely to consolidation works in this area, which include the backfilling of voids in the pit and the grouting of the inaccessible goaf that had been backf lled in the past. In the past, individual components of the shutdown programme have been upgraded and adjusted in accordance with the actual results of shutdown works, and this approach will also be practised in future.

Backfilling of Pit Areas

According to the long-term programme, closing down works shall be conducted gradually, from the lowest level upwards towards the surface. In the period from 1988 to 1992, all the blind shafts between the XVth and XIth levels were backfilled with gangue or poor concrete, while other pit facilities located in stronger or, as regards mechanical properties, more stable rocks were left unfilled. A new pumping area was created on the XIth level and the main pumping area on the XIVth level was abandoned. On 2nd October, 1992 the last pump was stopped, after which the gradual flooding of the pit began. The program of continued consolidation foresees the backfl1ing of unclosed galleries and shafts with poor concrete in the entire area between the XIth level and the surface characterized by softer, mechanically poor rocks which change their physical and mechanical properties in contact with water. This intervention will be followed by flooding of the pit up to the IVth level. The duration of flooding depends on several factors, the most important being the porosity of the rocks and the number of open, unfilled pit facilities (Fig. 1). Within the scope of these works, 20,512 m of galleries will be backfilled and 120,785 m^3 of poor concrete will be injected.

Injection

In addition to the pit facilities to be backfilled with poor concrete, there are also extensive goaf areas which had primarily been backfilled manually in the past. The consolidation of these backfills (up to 50%), which reach a height of twenty or more metres in some areas, has caused the formation of voids in the upper levels of excavated oref elds. In addition, the rock mass above the compressed backfills is also collapsing, thus increasing the possibility that the effects of sinking will spread.

In order to prevent sinking effects, we have decided to form supporting columns by inj ecting grout into the fissured rock above the pit facilities. The incorporation of supporting columns by injection is technically, technologically and financially the most demanding part of the shutdown process in the mine. Until the completion of works in 2006, injection works will be conducted on all levels from the VIIth level upwards, including inj ection from the surface. Drilling and inj ecting will be performed from previously selected chambers on individual levels, which are located in the areas of most extensive excavations in the past and sinking processes at present. 43,856 m of boreholes will be made from 37 locations and 70,177 m^3 of grout (mixture of cement, fine dolomite sand with a fineness of up to 1 mm and water) will be injected. The results of extensive investigations, studies and experiments (1987 - 1995) have led us to the project of injection works. Individual chambers are located directly above the known or suspected voids in the upper levels of excavated ore bodies. The boreholes are arranged in the form of a fan and will gradually be drilled downwards towards the suspected voids. When a borehole reaches a crack in the rock mass or a larger void area, injection is begun. After the void is `illed, the drilling and injecting procedures are continued until the foreseen length of a borehole is reached. When the entire series of boreholes is completed at one location, the area is reinforced and in this way prepared for safe flooding.

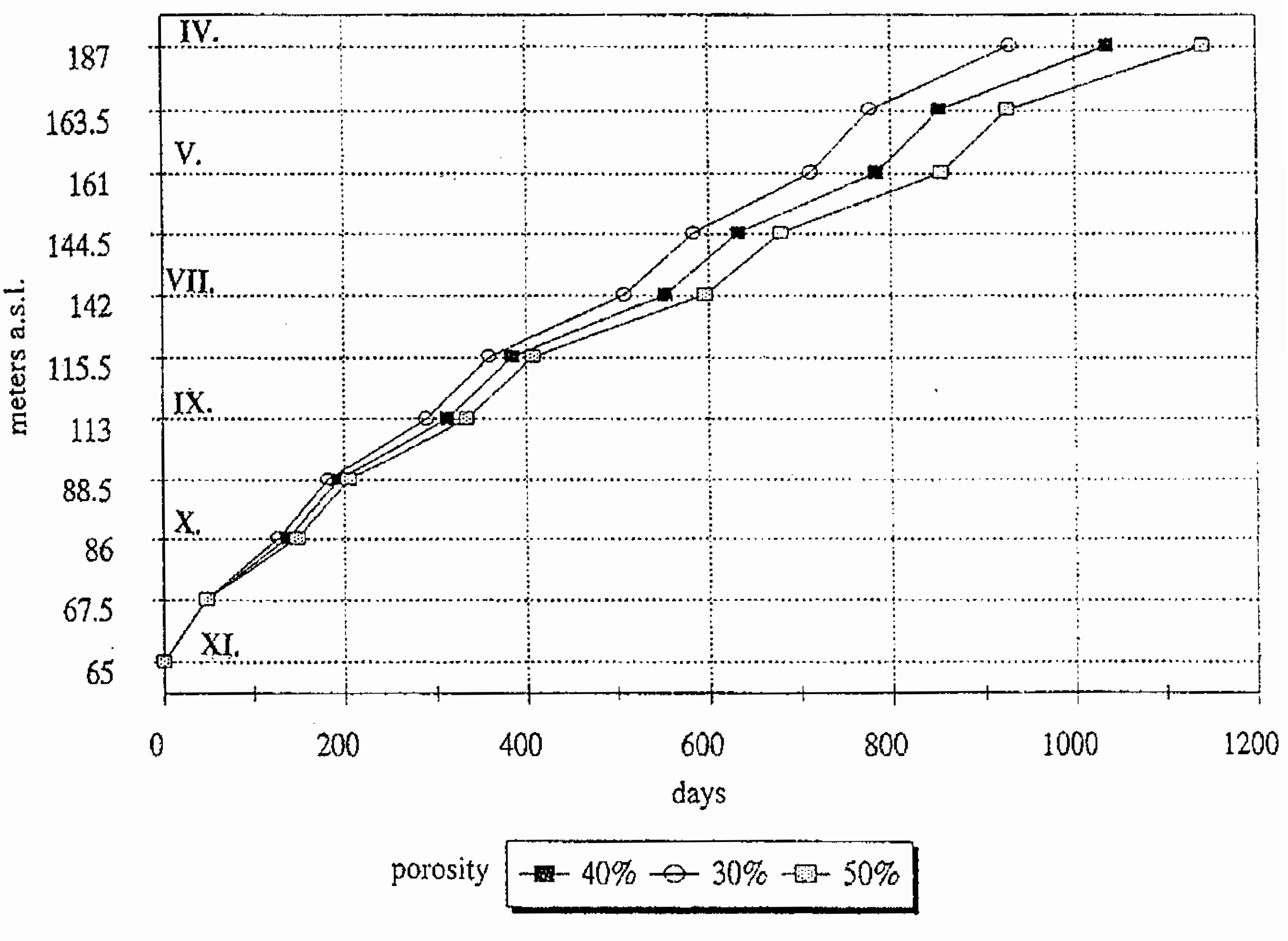


Figure 1: Forecast diagram of flooding the pit between the XIth and IVth levels

Flooding of the pit without previous consolidation works and the resulting wetting of backflls and unstable areas may increase the danger of sliding and shifting of rock masses. For this reason, consolidation with backfilling and the grouting of backflls and voids above the backflls must be performed in a manner preventing the shifting of rock blocks in the pit area even during flooding of the pit. Flooding of the pit will be performed gradually. The fnal pumping depth will be determined in the last phase of shutdown works on the basis of the conditions developing in the flooded part of the pit. For this purpose, Gl"tzl's probes were installed in the backfills and surrounding rocks on the XIVth and XVth levels prior to flooding of the bottom part of the pit. The probes enable the constant monitoring of pressure changes occurring after the submersion of this part of the pit.

In addition to the main shutdown works, special attention was also devoted to the inflows of water into the pit, whose influence should be taken into account during shutdown works.

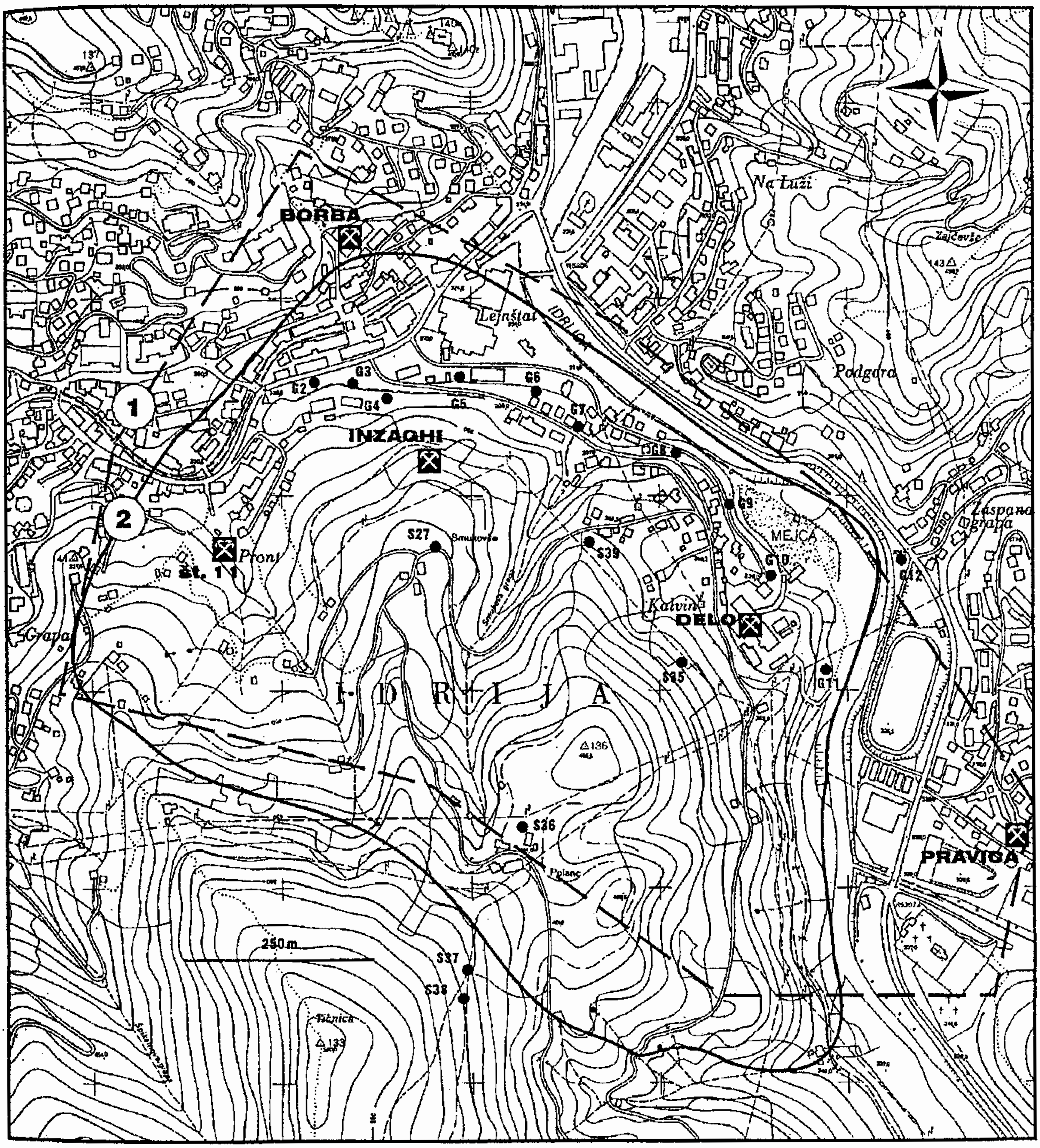
WATER FLOWS INTO THE PIT

Prior to the decision on the shutdown of the mine, extensive hydrogeological investigations, except for those which explained the basic hydrogeological conditions in the ore deposit and its surroundings, were not performed since no major problems with underground water were encountered during fve hundred years of mining in the Idrija mine. In 1989 an introductory hydrogeological study was prepared within the scope of the mine closing-down proj ect (Jane` 1989). Archival data on waters was collected, a register of pit and surface water sources was made, chemical analyses of significant water flows were conducted in order to determine their source, the hydrogeological structure was analysed, hydrogeological maps and cross-sections were drawn, and the sourcing and discharging conditions of individual water flows were determined.

Due to the geological stnzcture of the Idrija ore deposit, water flows into the pit facilities are relatively small. Approximately half of the water comes from the carbonate cover above the ore deposit, while the remainder comes from indirect sources in the periphery of the pit structure (Upper Triassic "main" dolomite and karsted cretaceous limestone). The surface water flows above the ore deposit are separated from the pit structure by Carboniferous layers due to the overthrust structure of the area. Within the scope of activities involving the monitoring of shiftings in the carbonate block on the surface, 16 boreholes with a length of 30 - 100 m were drilled along the periphery and in the most critical areas of the pit in the period from 1988-1992. Inclination pipes were pla.ced inside the boreholes. In addition to being used for measuring the shifts on the surface and in the cover above the ore deposit, the inclinometers may also serve as piezometers for monitoring the ground water level in the cover above the ore deposit. In addition to inclinometric/piezometric boreholes, older piezometers above the ore deposit were also activated, so that an entire network of 18 boreholes is available for hydrogeological measurements on the surface (Fig. 2).

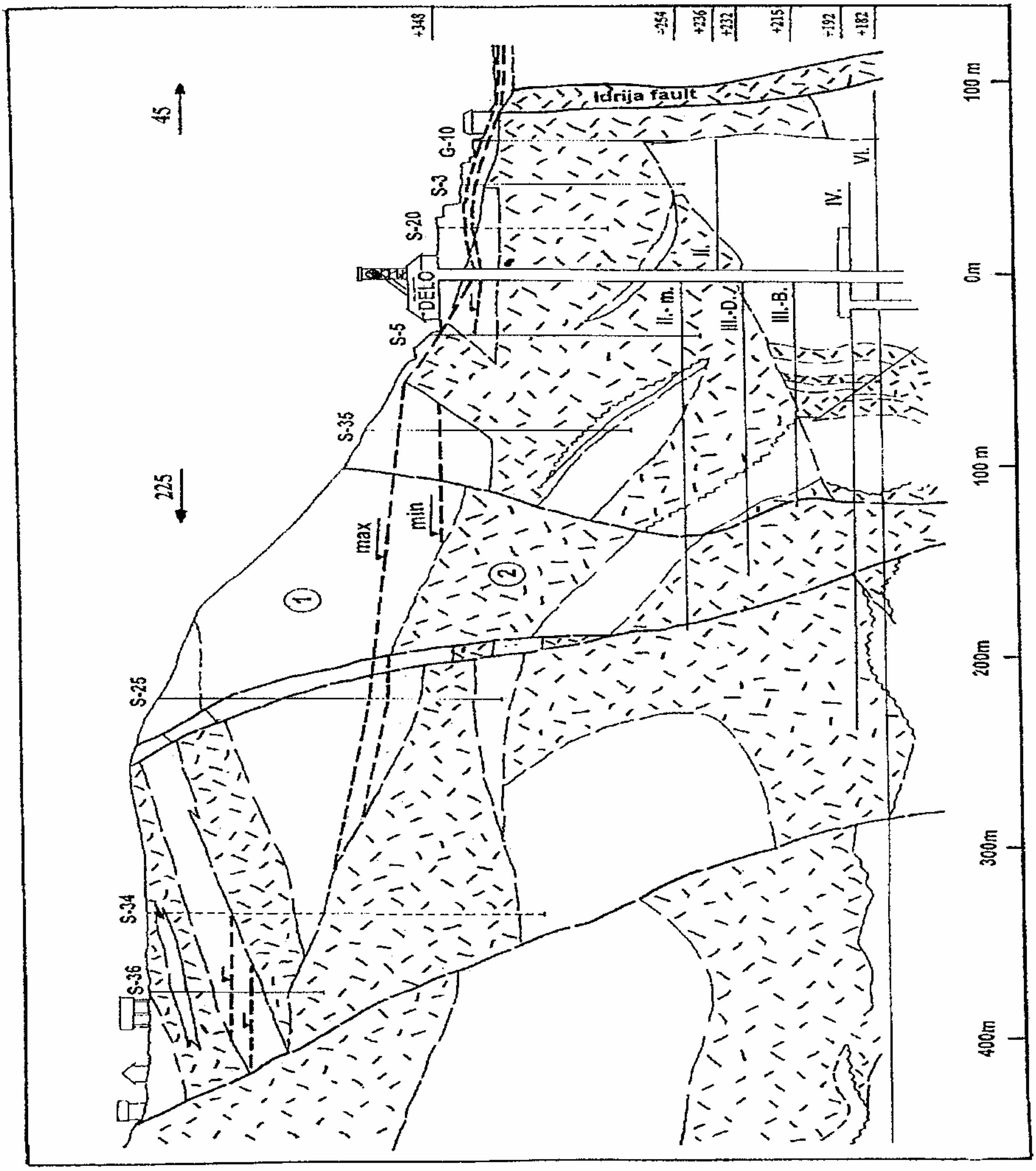
On the basis of the above measurements and most recent hydrological investigations, the water delivery area in the carbonate cover is divided into three separate regions: the surroundings of the Inzaghi shaft, the area along the Idrijca River to the Delo shaft, and the area of Poljanec hill behind the Delo shaft (Jane` 1991) (Fig. 3).

Surface water enters the pit primarily through three main shafts (Delo shaft, Borba shaft and Inzaghi shaft) and two ventilation shafts (Pravica shaft and shaft No. 11). Due to the poor permeability of dolomite rock above the ore deposit, the drainage capacity of shafts is small. The water entering the pit primarily drains off from the upper carbonate cover and its quantity depends on rainfall in individual periods of the year. Due to fluctuations in the ground water level, the geotechnical conditions for ensuring stability in the carbonate cover above the ore deposit also change.



Legend: 1 - Extraction area of the Idrij a Mercury Mine, 2 - Area influenced by the Idrij a Mercury Mine, • G, S - Piezometric/inclinometric boreholes

Figure 2: The Mercury Mine area with inclinometric and piezometricborehole locations



Legend: **1**- ervious layers with karst and fissured porosity; **2** - impervious layers; **max, min** - piezometric level of ground water; **S,G** - piezometric/inclinometric boreholes

Figure 3: Section across G and S boreholes - max and min ground water levels (Janež 1991).

The high ground water level in tectonically raised carbonate rocks above the Delo shaft has a pronounced negative influence on the stability conditions. Observations over a period of several years and the measurements of inflows are presented in Table 1.

Table 1: Measurements of pit inflows (average values in the period from 1979-1996)

Location	Surface Inflows (l/s)	Pit inflows (l/s)	
Inzaghi shaft	1,6		
Shaft No.11	0,25		
Borba shaft	0,8		
Pravica shaft	0,4		
Delo shaft and shaft No.10	0,8		
Nadvojvoda shaft (IIIrd level)		0,4	
Maver shaft (VIth level)		1,1	
Bizjak shaft (VIIth level)		4,2	
Pekel shaft (IXth level)		1,5	
Pekel shaft (XIth level)		0,5	
Rop shaft (XIVth level)		1,0	
SW of Delo shaft (XVth level)		0,7	
Ljubevč (XIVth level)		0,1	
Total	3,85	9,5	13,35

Water inflow measurements are performed continuously at two measuring locations and occasionally at 11 measuring locations. Larger water inflows are mostly limited to areas where mining works have penetrated the impervious layers of Carboniferous shale which practically enclose the ore deposit from all sides. There are also small water flows into existing routes on individual levels, which, primarily in the upper part of the pit, include inflows of surface water as well as of pit water, and for this reason we were unable to precisely determine their source. In addition to the measured inflows, we also proved the existence of other inflows, which, however, cannot be measured due to their inaccessibility. The largest quantity of water (average 25 l/s) had flowed into the pit from the Ljubev~ orefield, which was connected to the old pit facilities by the route on the XIVth level. In October 1988 this largest inflow of water was stopped by the closing of the wa,ter gate. This drastically decreased the flow of water into the mine facilities, which is now only 0.1 l/s.

During the measurement of water flows into the pit at selected locations, it was found that the water flow into the pumping area considerably exceeds the sum of monitored inflows, which is the consequence of unmonitored, inaccessible inflows. This is why we began to measure the total water flow into the pumping area. Prior to closing the water inflow from Ljubev~, the total water flow into the pumping area on the XIVth level was 36.5 l/s. Following the closing of the water gate on the route between the Ljubev~ ore deposit and the old part of the ore deposit on the XIVth level, the water inflow dropped to 16.8 l/s. After flooding of the bottom part of the pit and the submersion of inflows below the XIth level, the total water flow into the pumping area also declined. The latest measurements of water flows into the pumping ground on the XIth level have shown an average inflow of 15.1 l/s. This reduction is believed to be the result of the submersion of lower lying sources in pit.

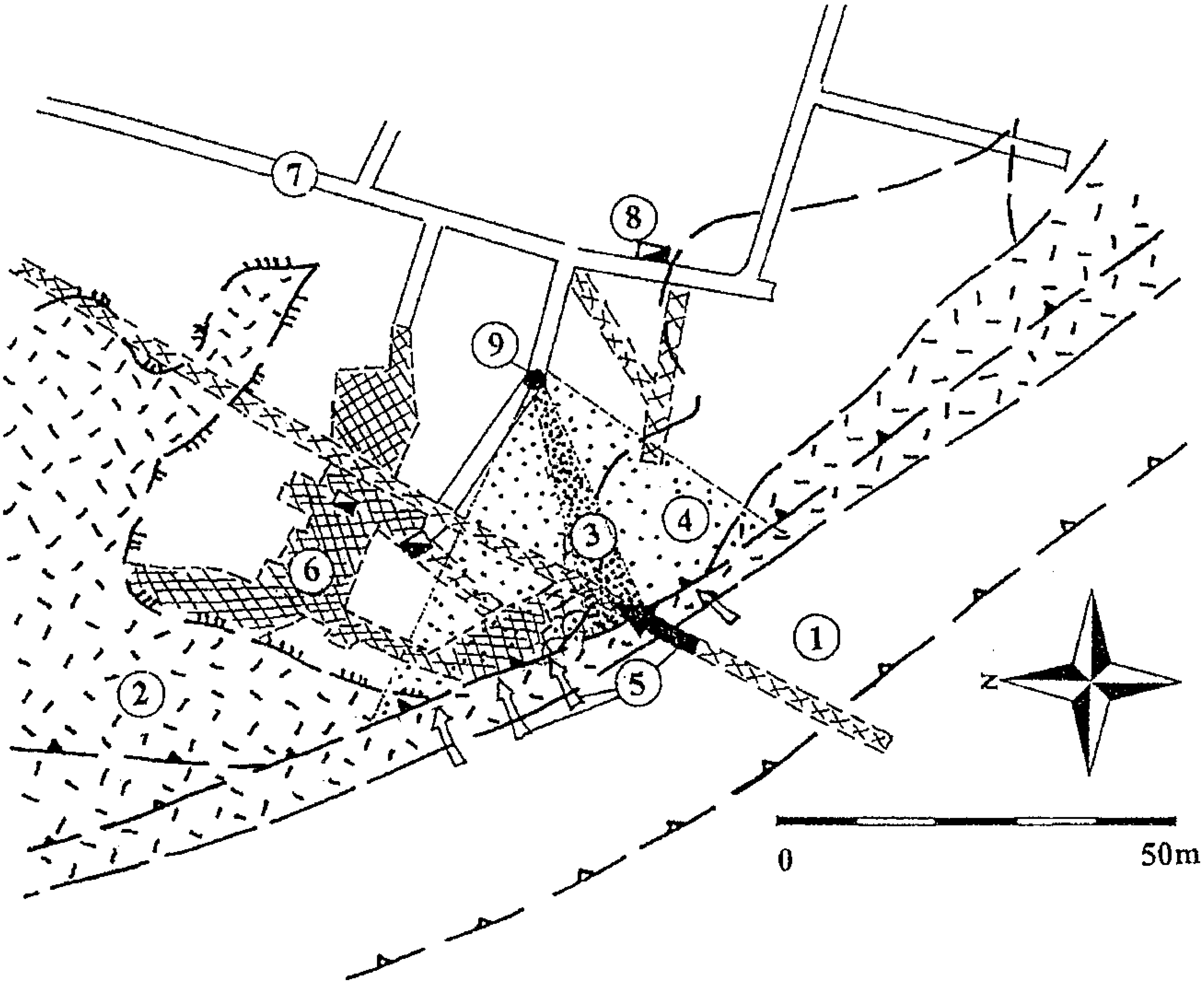
PIT WATER DRAINAGE FACILITIES

The Idrija Mine Closing-Down Project foresees the direction of all main water sources in the pit through the pipes into the pumping area on the IVth level. In accordance with the "Regulations on Technical Measures and Safety during Underground Mining Works" (Offcial Gazette), all sources of pit water must be accessible and controlled. The same applies for the pit areas along which the water will be directed to the pumping area.

Prior to fnal shutdown, it will be necessary to ensure the controlled discharge of all sources in pit areas which will not be flooded. All inflows which will not be accessible due to the backfllling of routes (particularly in Carboniferous shale) will have to be caught and directed along the pipes to the main pumping area, while the sources accessible by pit routes will be directed to outfall channels.

After fnal shutdown of the mine, the pit water will have to be pumped on a continuous basis, which shall require considerable funds. In order to provide a cost-effective solution, several measures for reducing the costs of pumping pit water have been foreseen in the closing-down programme. In this first phase, it will be necessary to prevent the penetration of surface water into the pit facilities. For this purpose all those shafts which will no longer serve their purpose after shutdown of the mine will be backfilled, and surface draining will be ensured for those shafts remaining open. Attempts shall also be made to reduce the continuous inflows of underground water. Attempts will be made to eliminate or reduce, to a maximum extent, the inflow of water from one of the largest sources by means of inj ection. The largest water inflow is on the VIIth level and is the consequence of the construction of the route to the said level through the impervious surface layers to the water-carrying cretaceous limestone. The current inflow from this source contributes almost half of all water flowing into the pit facilities. By means of inj ection, we shall attempt to plug the inflow area that is no longer accessible, and with a series of inj ection drillholes we shall additionally isolate from the pit facilities the broader area of the old entrance of water inflow (Fig. 4).

If it will not be possible to completely prevent water inflows in the pit areas, we expect to at least considerably limit them and therefore reduce pumping costs after shutdown of the mine.



Legend: 1 - pervious layers with karst and fissured porosity, 2 - impervious layers, 3 - narrower injection area, 4 - broader injection area, 5 - foresen water inflows, 6 - backfllls, 7 - galleries, 8 - blind shafts, 9 - fan arrangement of injection boreholes

Figure 4: Injection area on the VIIth level of the Idrija Mercury Mine.

POLLUTION OF PIT WATER

In the period from October 1992 until September 1994, the lower part of the pit between the XVth and XIth levels was flooded. However, the creation of a new pumping area on the XIth level of the pit brought a new, unexpected and priznarily ecological problem. The pumped out pit water discharged directly into the Idrijca River had a strong orange-brown colour. An analysis of the water performed by the water inspection authority has shown increased iron and sulphate concentrations in pit water discharged into the Idrij ca River after the flooding of level XI. The Mercury Mine ordered, on its own initiative, a study to be conducted by IRGO Ljubljana in order to determine the cause of pollution and propose rehabilitation measures.

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 smeltery, from where the burned wastes were returned to the pit as backfilling material. The increased Fe_{tot} content caused the colouring of the Idrijca River in a length of approx. 100 m from the outfall and the settling of orange-brown Fe-precipitate on the riverbanks (pH>6).

On the basis of laboratory tests, the following technological solution was proposed: the treatment of primary water with lime in the frst phase, and the precipitation of sulphates with barium chloride in the second phase (Obal 1996). The proposed procedure ensures the high quality of pit water discharged into the outfall channel and the Idrij ca River, but at very high costs.

CONCLUSIONS

The water flowing into the mine area is one of the main factors decisively influencing the final closing-down programme of the Idrij a mine. In addition to inj ection and reinforcement works, the flows of water into the permanently closed mine are of key importance and will require continuous monitoring in future. The final decision on the permanent location of the pumping area, currently foreseen on the IVth level, will depend on the quantity of inflowing water and its influence on flooded backfills. The results of studies and investigations obtained so far indicate that the wetting of Carboniferous shale at the contact point between the pit facilities and the carbonate cover could cause greater shiftings in the cover layers and thus pose an additional threat to overlying town of Idrija. The continuous pumping of pit water also means the constant control of water sources in the unfilled part of the pit.

During the shutdown phase of the Idrija mine and the flooding of its underground facilities, sudden increases in concentrations of metals and accompanying anions present in pit water can also be expected in future.

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