SURFACE PROTECTION PROBLEM IN CONDITIONS OF WATER HAZARD IN DIAPIR SALT MINES

Kortas Grzegorz and Wilk Jan,
Development Center for Chemical Raw Materials, Kraków,
and Jasiński Zbigniew, "Solno" Salt Mine, Inowrocław, Poland.

A B S T R A C T

The basic problem in underground mining of diapir salt deposits is in Polish conditions, the water surrounding salt domes. The water hazard in salt mines is indirectly connected with danger to the surface and environment of mining areas in case of water inrush. The drastic proof of that was the biggest catastrophy in the history of Polish mining - the flooding of one of the diapir salt mines in 1977. The paper presents symptoms of water hazard gradually growing in the years 1972 - 1977, describes the water inrush into the workings, deals with the effects of drainage of mining area and the mining damages caused by water flow under the built-up area. The process has been presented of restoring hydrogeological equilibrum and settling down of surface displacements in the period from 1978 - 1985. The paper aims at pointing out the necessity of preventive surface protection in conditions of growing water hazard in salt mines.

INTRODUCTION

The water hazard in salt mines, particularly those located on salt diapirs, is one of the most important factors which must be taken into consideration in mines projecting, exploitation and at the stage of closing them down. As it has been shown by numerous experiences in salt mining gathered in Germany (Spackeler 1957, Gimm 1968), the USA (Kupfer 1979), Poland and other countries, the salvage of mine after water inrush is, in most cases, impossible. The action practically reduces to saving human lives and minimizing losses. In order to prevent such catastrophies, a controlled flooding of salt mines is considered advisable in certain cases (Brückner 1983). The drastic example of connection between water hazard in mine and danger to the surface was the flooding of diapir salt mine in Wapno. The paper presents processes which are characteristic of that type of hydrogeological conditions:

/i/ growing symptoms of water hazard,
/ii/ flooding of mine with drainage of overlay and all resulting effects,
/iii/restoring of hydrogeological equilibrum and stabilization of surface.

The case of flooding of the mine in Wapno is unique in literature of the subject, in view of the greatest mining damages being created on the surface, beyond the boundaries of salt diapir.

WATER HAZARD IN MINE

The mine in Wapno near Bydgoszcz carried on the exploitation of rock salt in salt diapir of a cross-sectional area 0,5 km^2, on the level of 380 - 540 metres, capacity of workings reaching 5,6 million cubic metres. Workings were insulated from waters surrounding the diapir in gypsum cap formations, as well as from lateral contacting the cap, a widespread aquifer of tertiary sands of regional propagation (fig. 1).

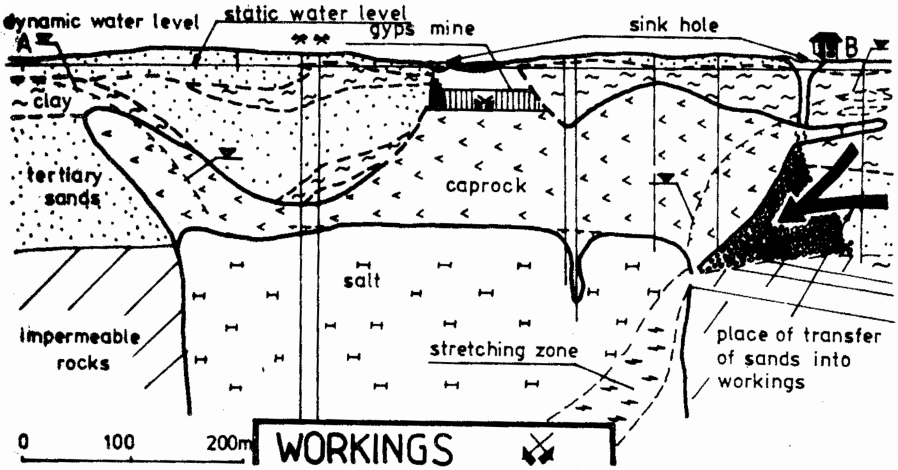


Fig. 1 Hydrogeological schema of Wapno Salt Mine

It should be added here, that the existence of the above aquifer, abounding in fresh water, had not been discovered until the break-down, because geological surveying, carried out during construction of the mine, resolved itself to formation of salt diapir. Water hazard in the mine was therefore connected mainly with fractures and cracks of gypsum cap; that point of view being supported by its hydrogeological examination and the following facts: water flow rate of 4,5 cubic meters per minute during shaft sinking, consumption of 30 thousand tons cement and exploitation of 100 thousand cubic meters gypsum in gypsum cap. Then it was found out that the contact zone of gypsum cap with salt mirror was the most flooded area in which opened joints typical for salt diapirs, were discovered and documentary evidence provided (Botsch and Klarr 1979)
The course of flooding of the mine showed that after drainage

of gypsum cap, the mining damages were caused by violation of hydraulic equilibrum in sandy formations beyond the boundaries of diapir.
The first water leaks had appeared, in that region of the mine where the catastrophic inflow took place, 6 years before the break-down (Ślizowski and Kortas 1980). Complex, physico-chemical analyses of outflows, systematically carried out and in particular isotopic tests confirmed genetic connection of effluents with outside of diapir waters. The first symptoms of that contact appeared about 3 years before the catastrophy (fig. 2).

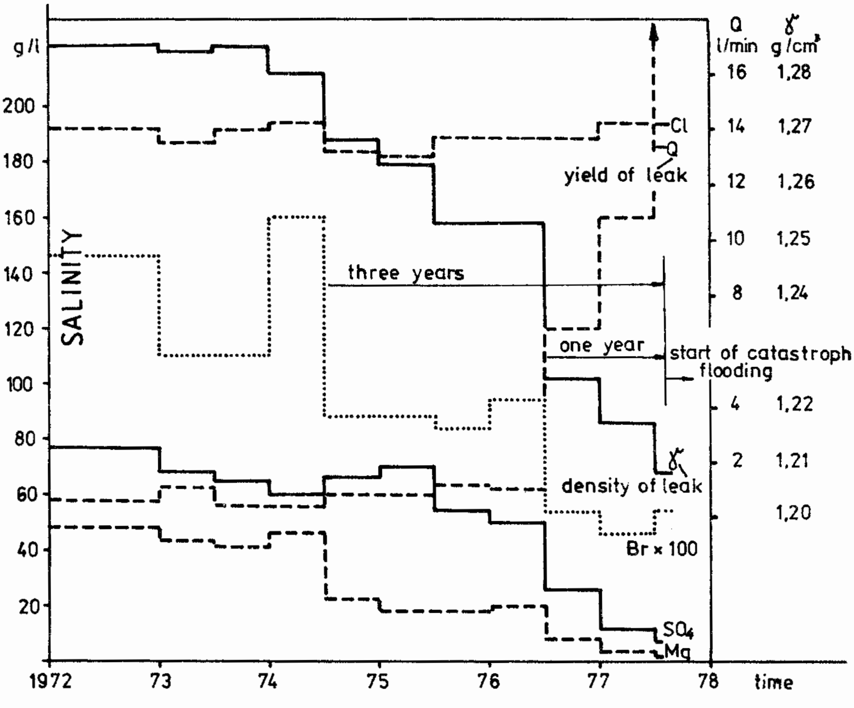


Fig. 2 Changeability of some physico-chemical datas of leaks before flooding of the mine

This was clearly shown by decrease in the content of magnesium and bromide ions, as well as in the specific gravity walue. Similar symptoms of a break-down were observed in German salt mines (Schwandt 1969).
The decrease in sulfate ions concentration was less sharp in the analysed effluents, while the analysis for the content of chloride ion did not show any danger at all. One year before the catastrophy, the results of analyses did not leave any doubt as for the origin of outflows. The similar estimation of the growth of water hazard was obtained on the grounds of isotopic composition of water analyses. (Zuber and others, 1979) thus making it possible to reduce consequences of onco-

ming catastrophy. The mining measures, undertaken 3 years before the catastrophy, aiming at sealing the rock-mass and mildening the possible effects of a break-down, caused only temporary decrease in the intensity of outflow. After the flow rate of 0,5 cubic meters per minute had been exceeded, i.e. on the 3rd August 1977, all mining crew was evacuated and two days later the abrupt inflow of 30 thousand cubic meters of water in time of 15 minutes started the process of out of control flooding of the mine.
The water inrush in a few hours time created the depression in gypsum cap area 160 meters deep and several meters lowering of water level in tertiary sands, while there was no reaction observed of quaternary water level. Such a big gradient (fig. 1.) created on the boundary of diapir was being explained by insulating influence of rock jacket between gypsum cap and sands. The degree of insulation, measured by theoretical inflow to not insulated diapir to actual inflow ratio, amounted from 2 to 5. Such a big hydraulic gradient caused the transfer of flooded sands from outside of diapir into it. Spontaneous water and sand inflow might have been reduced by additional controlled supply of water. Aiming at the above, the bore-hole was made in the central part of deposit, reaching the workings. Through the bore-hole the total amount of 3.15 million cubic meters of water was supplied from the lake situated 5 km away. It is estimated that the inflow of sands into diapir during half a year period starting from the moment of break-down amounts to 300 thousand cubic meters. The process of transfering sands was multiphased and comprised cyclic processes of inflow and flow retardation by rocks insulating the diapir. The course of flooding of the mine in time function is shown in fig. 3.

DANGER TO SURFACE AND ITS DEFORMATION

Building development of miners'settlement in Wapno comprised complex of both one-storeyed and multi-storeyed houses, servicing facilities and public use objects as well as industrial, mining objects. Over the mine there were roads, railway and territorial development. The settlement is surrounded by arable lands. During exploitation of the mine a subsiding trough formed over the workings with depression of the centre $W_s = -0,7$ m. The results of geodesic measurments show that the maximum horizontal strains reached the value $\varepsilon_{max} = 1,2$ ‰ without causing any mining damages. In 20 years period before the break-down the rock-mass movement had been observed also inside the mine. There had been recorded both upheaval of lower levels and subsiding of upper ones with the maximum sinking $W_{max} = -1,4$ m. The Knowledge of disposition of rock-mass deformations allowed to localize the dangerous strains area. In this area the effluents localized, which had contact with outside of diapir waters (G. Kortas 1979).
At the beginning the outflows appeared near boundary of interbeddings of anhydrite and potassium salts, and directly before the break-down, waters were filtrating into the workings along the north arch of tensile strains area. The above confirms the hypothesis of a major role of geomechanic factor in water hazard in mine. As soon as a few hours after water had rushed into the mine, five collapses formed in gypsum cap

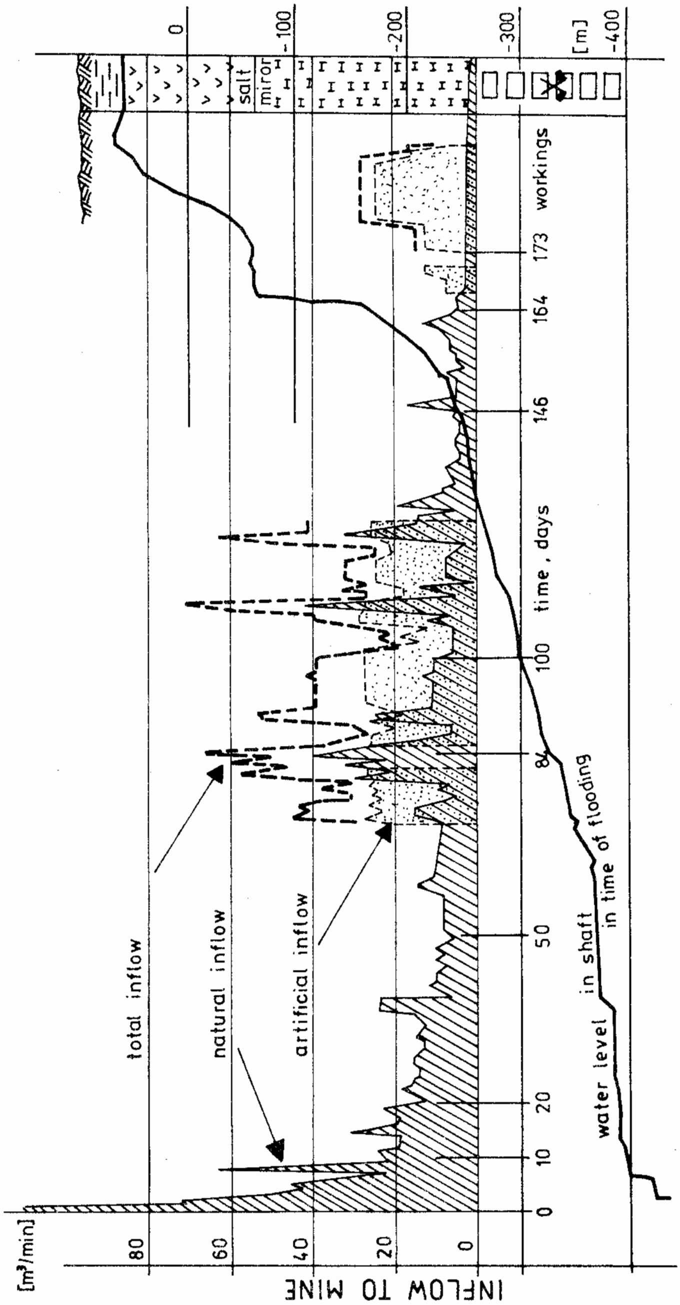


Fig. 3 Course of flooding

area caused by breaking down the excavations of a closed down gypsum mine, at the depth to 58 meters. (fig. 1). In time of five days the subsiding trough on the area of 1.5 km^2 reached capacity of 19,8 thousand cubic meters; which after a month amounted to 35,2 thousand cubic meters. A few days after the break-down, the sinking resulting from drainage was observed up to 60 mm deep and several times bigger over the area of suffosion wash-out of sands, beyond the boundary of the diapir. Main deformations of terrain concentrated over the widening area of suffosion, in four periods starting on days: 0,84, 146, 164 after the catastrophy and were revealing themselves within a few hours to a few days. It had been calculated that increases of subsiding trough resulting from capacity of collapses equalled in the above periods respectively: 46, 89, 96 and 117 thousand cubic meters Capacity of subsiding trough in time function illustrates fig. 4.

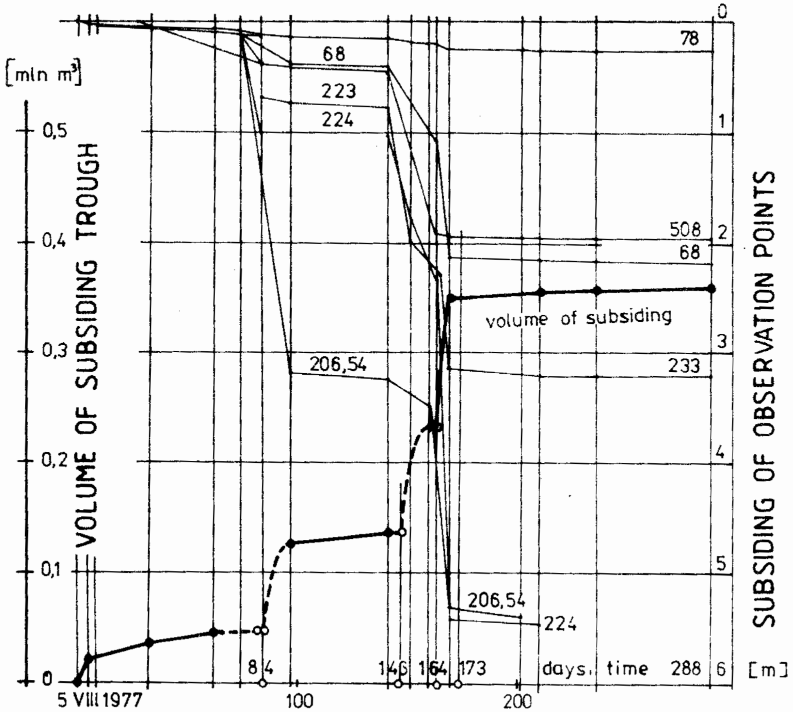


Fig. 4 Surface subsiding in time funktion

In a period of forming of discontinuous deformations there were recorded sudden swingings of water level in piezometers. In the centre of the trough situated beyond the diapir, close to its boundary (fig. 5) 66 days after the break-down, the collapse sink appeared of a diameter amounting to 30 meters and 19 meters deep. (fig. 7).

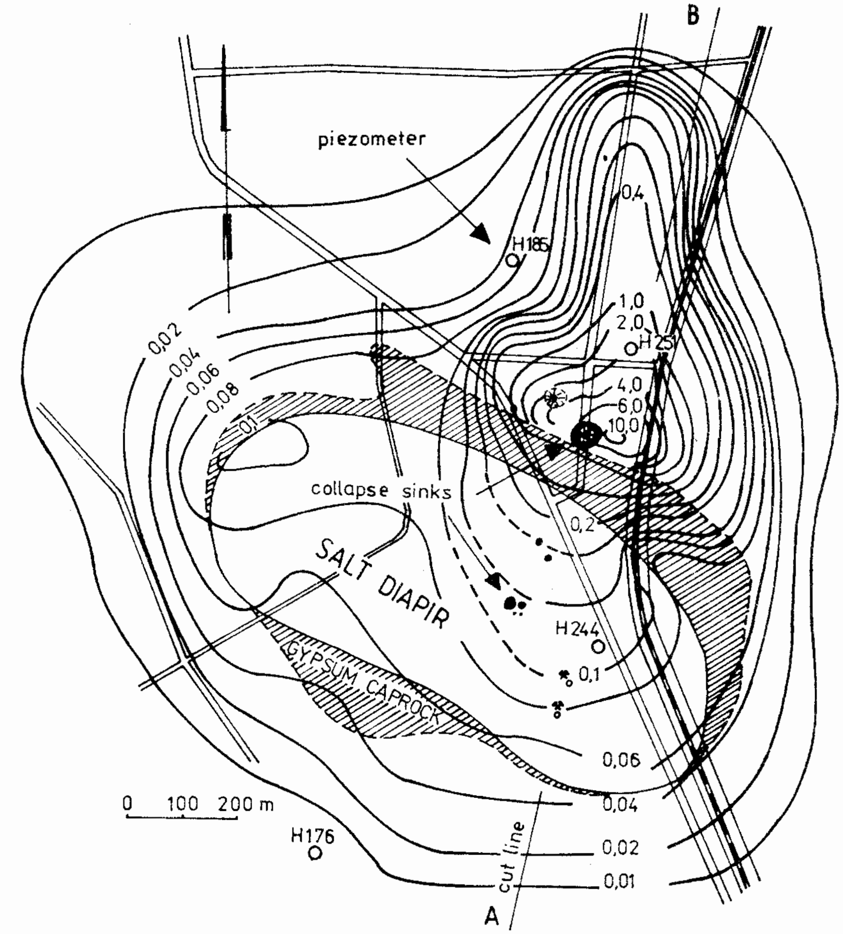


Fig. 5 Surface subsiding during 260 days and siting of piezometers

The bottom of the trough has lowered lately to 10 meters in the railway region (A. Kosikoń, 1980) and a group of discontinuous, fault-like deformations (fig. 8) as well as fractures have appeared along directions of water run-off. Main terrain inclinations in the centre of the trough exceeded 15 % . Final earth movements took place 173 days after the break-down, increasing the capacity of subsiding trough finally to 353 thousand cubic meters. Disposition of the subsiding trough is illustrated in fig. 6.

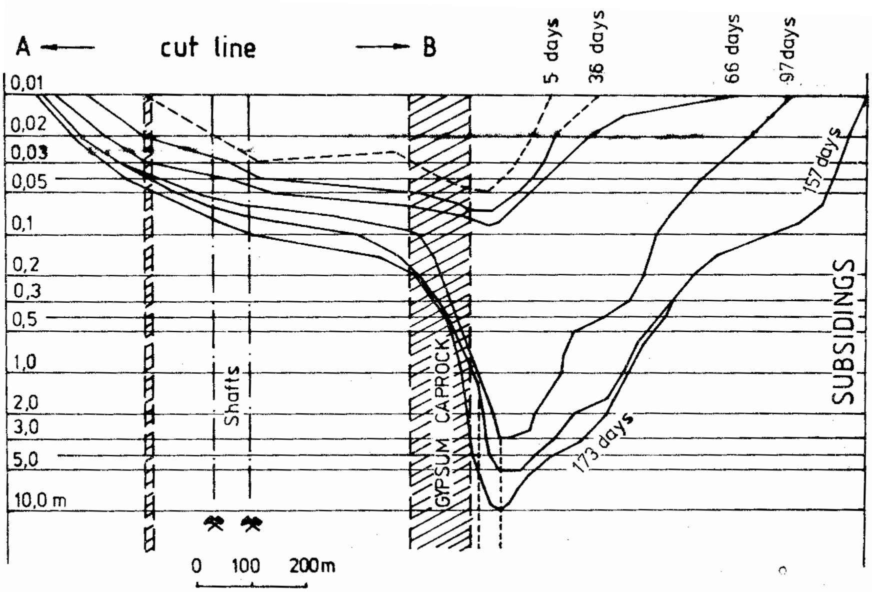


Fig. 6 Increases of subsiding trough in logscale

In the course of flooding of the mine the actual state of drainage was daily observed in 42 piezometers placed in both tertiary and gypsum cap formations and 16 piezometers installed in quaternary formations. The observation of surface movements was carried by recording the measurments in 300 bench-marks in monthly intervals, or once a week for chosen traverses. Wide and complex, geodesic and hydrogeological observations, systematically carnid out and succesively analysed made possible to evacuate safely 1340 people from 55 houses and stop both road and railway traffic in the right moment. In spite of great building damages (fig. 9) no one of inhabitants of Wapno had been injured. Main mining damages came out on the area of 1,4 km^2, mostly beyond the salt diapir, where the inclinations exceeded 10 % . 47 building were predestined for demolition. The restaration of hydrogeological equilibrium was proceeded by the reconstruction of railway and roads until the terrain was reconditioned. Buildings had been renovated and normal life in a housing estate had been restored.

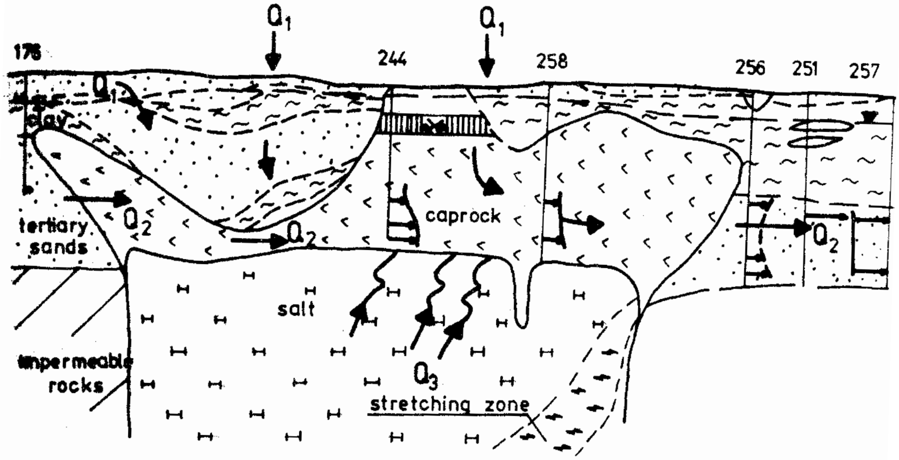
SURFACE BEHAVIOUR AFTER THE RESTORATION OF HYDROGEOLOGICAL EQUILIBRIUM

The hydrogeological equilibrium in diapir area was restored within 10 months after the break-down. During the following 2 years, the observations were carried out of a slow settling of a new hydrogeological regime, which, in comparison with the previous one, characterizes with forming of "a hydrogeological window" inside the diapir, where quaternary and precipitation waters migrate through gypsum cap to tertiary formations (fig. 10).

Fig. 7 Photography of a collapse sink

Fig. 8 Photography of discontinous dislocations

Fig. 9 Photography of damaged building



-depth of measurment of salinity, value of salinity

Q_1 – natural recharge /app. 100 .000 m³/year /

Q_2 – regional ground water flow /app. 1500 m³/year /

Q_3 – recharge of ground water as effect of convergence of workings /app. 2500 m³/year /

Fig. 10 Hydrogeological schema of salt diapir after flooding of the mine

This may result in the leaching of gypsum cap rocks and salt (Q_1). Moreover, the spoiling of the insulating jacket dividing the diapir from surrounding rocks causes probably the leaching of salt level by regional flow (Q_2). The saturated brine (Q_3) coming out of the flooded mine, as a result of convergence of workings, is the third factor which influences the hydrogeological regime. (Kortas G. and Kolanko M. 1984). Those three factors cause the increase of salinity of fresh tertiary waters around the diapir area and subsequent terrain dislocations. The hitherto obtained results of observations of salinity are presented in fig. 11. Up till now we have not been

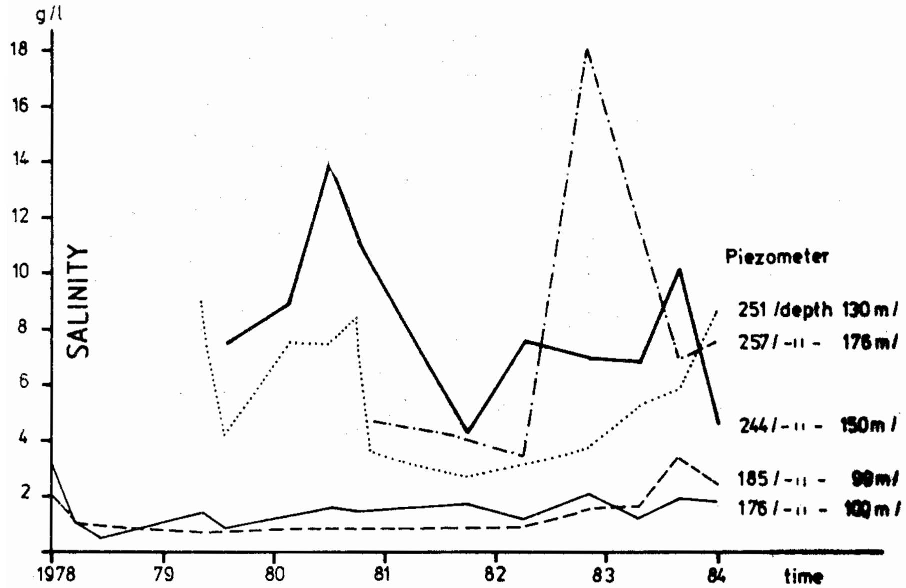


Fig. 11 Changeability of salinity of ground water

successful in gathering documentary evidence that would explain reasons for salinity fluctuations observed in particular holes. The restoration of hydrogeological equilibrium did not stop terrain movements, subsidings not exceeding 15 mm per year, though, the global reaction comprises further forming of subsiding trough with external belt of uplift (fig. 12). In a period from 1978 to 1984 the capacity of 5, 6 thousend cubic meters underwent uplift as a result of elimination of depression in the area, while 14,7 thousand cubic meters underwent subsiding. The present annual increase of capacity of subsiding trough equals 2,81 thousand cubic meters that makes 43 % of pre-catastroph annual increase.

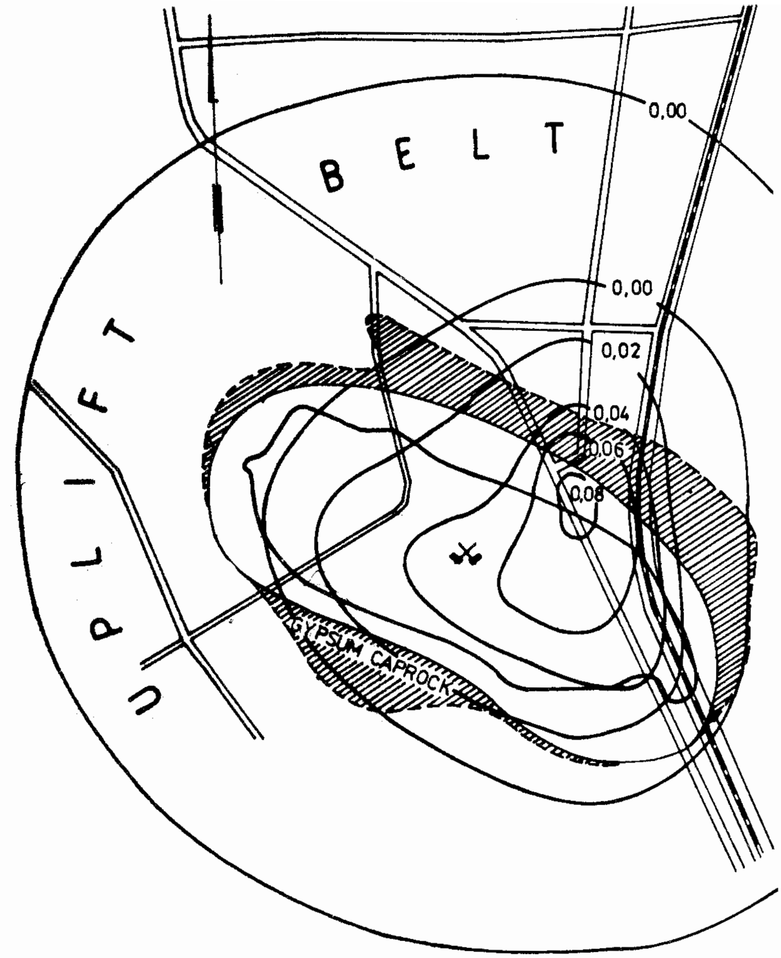


Fig. 12 Surface subsiding during 6,5 years after flooding of the mine

HOW TO PROTECT SURFACE FROM EFFECTS OF WATER INRUSH?

Flooding of the mine in Wapno attracted people's attention in Poland to the problem of danger to the surface over underground salt mines. The new category of potential hydrogeological damages limits the possibilities of construction, exploitation and closing of mines in hydrogeological condidions which are unfavourable to the surface. The risk of such damages increases with the growth of water hazard in mine and capacity of workings. The result of the above is the necessity of gathering documentary evidence of hydrogeological conditions endangering the surface at the stage of deposit examination, as well as taking into consideration costs of surface protection while the estimation of industrial value of deposit is being done.

Preventive action against effects of water inrush applies to mining works and a limitation of surface development. The choice of optimum strategy as a praxiological problem depends on recognition of hydrogeological conditions, risk valuation and potential gains and losses. Minimization of potential hydrogeological mining damages can be achieved by reducing either the risks or the effects of a break-down. Reducing chances of a break-down can be achieved by controlling the water hazard in a way which lessens rock-mass movement, detaching and insulating of water migration area and sealing the rock-mass, particularly drill-holes, shafts, water dams and regions of active outflows. In order to reduce the effects of a break-down, first of all the capacity of workings endangered with water inrush should be reduced by carrying such a spatial development of mine which makes possibly a successive flooding of lower, closed down levels. This can be obtained by exploitation from the bottom to upper parts as well as by tight damming of worked out mining fields. It should be pointed out here, that a principle is being implemented in Poland of installing in endangered salt mines the equipment suitable for quick, controlled flooding of mines. Prophylaxis in surface development should base on qualifying which area is endangered with water inrush and excluding it from building development, on the strength of the Mining Law. In case of adverse balance of potential gains and losses the mine should be flooded in a controlled way. Such a decision was made in 1982 in case of a working salt mine situated under the town of 70 000 population. In the rest of mines the additional, complementary hydrogeological investigations were made including wider regions of deposits as well as surrounding rocks.

CONCLUSION

The present knowledge of water hazard symptoms in mines, ways of their interpretation, estimation of the risk of excavations being flooded, methods of counteraction and minimization the effects of such catastrophies - is scattered and scanty. That is why we consider it advisable, that on the grounds of experiences of the countries where such catastrophies took place, all the relevant materials should be collected and scientifically worked out in order to create better conditions for getting water hazard in mines under control.

The above problems could be the subject for a separate symposium.

REFERENCES

1. Batsche Hans und Konrad Klarr, 1979, Beobachtungen und Gedanken zur Gipshutgenese, Fifth Symposium on Salt, Vol. I, Hamburg.
2. Günther Brückner, Gerhard Knitzschke, Martin Spilker, Johannes Pelzel, Arno Schwandt, 1983, Probleme und Erfahrungen bei der Beherrschung von Karsterscheinungen in der Umgebung stillgelegter Bergwerke des Zechsteins in der DDR, Neue Bergbautechnik, H 8.
3. Gimm W., 1968, Kali- und Steinsalzbergbau, Bd I, Deutsch. Verl. Grundstoffind. Leipzig.
4. Donald H. Kupfer, 1979, Problems associated with anomalous zones in Louisiana salt stocks USA, Fifth Symposium on Salt Vol. I, Hamburg.
5. Kortas G., 1979, Ruch górotworu przed wdarciem się wód do wyrobisk kopalni soli w Wapnie, Ochrona Terenów Górniczych, 49, Katowice.
6. Kortas G., M. Kolonko, 1984, Górotwór po zatopieniu kopalni soli im. T. Kościuszki w Wapnie, Ochrona Terenów Górniczych, 69/3.
7. F.F. Prugger, 1979, The flooding of the Cominco Potash Mine and its rehabilitation, Fifth Symposium on Salt, Vol. I, Hamburg.
8. Rosikoń A., 1980, Mozliwości i skutki uruchomienia linii kolejowej na terenie powstałych odkształceń nieciągłych, Ochrona Terenów Górniczych, 52
9. Schwandt A., 1978, Zusammenhänge zwischen Geologie und Zuflüssen von Salzlösungen und Wässern in Kali und Steinsalzgrubenfeldern des Saale-Unstrut- und Nordharz-Kaligebietes, Jb. Geol. Bd. 9/10, Berlin.
10. Spackeler G., 1957, Lehrbuch des Kali- und Steinsalzbergbaues, Knapp Verl., Halle.
11. Slizowski K., G. Kortas, 1980, Zagrozenie powierzchni spowodowane eksploatacją wysadów solnych na przykładzie Kopalni Soli im. T. Kościuszki w Wapnie, Ochrona Terenów Górniczych, 51, Katowice.
12. Zuber A., J. Grabczak, M. Kolonko, 1979, Environmental and artificial tracers for investigating into salt mines, Isotope Hydrology, Vol. 1, Vienna.