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Solution Mining of Miocene Salts in Poland and its Environmental Impact

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ABSTRACT

The Wieliczka salt mine located near Kraków is one of Poland's top tourist attractions. The western part of the Wieliczka deposit, called Barycz, has been exploited since 1923 by leaching salt with water through boreholes from the surface. As the result of lengthy exploitation at Barycz, there are numerous sinkholes and ponds filled with saturated brine. The prevailing part of the area became unusable for agricultural purposes and, for several years, some parts of the mine field have been turned into the main municipal dumping-ground for Kraków.

Another Miocene salt deposit at Leżkowice on Raba is situated about 20 km east of Wieliczka. In 1968 exploitation began using the method of solution mining from the surface. The exploitation has been carried out much longer than initially designed, resulting in severe surface damage and pollution of the natural environment. Examination of ground salinity from 1976 to 1984 showed a remarkable increase of NaCl content within soil. Surface surveys in the same years indicated the occurrence of widespread subsidence. In addition, some deep sinkholes developed between 1984–1990.

INTRODUCTION

The main production of brine in Poland comes from the solution mining carried out in Zechstein salt deposits in Middle Poland. Two mines operate there, situated over salt domes at Góra and Mogilno.

In the southern part of Poland, where the Miocene salt deposits occur (Poborski and Skoczylas-Ciszewska, 1963; Garlicki, 1968, 1974, 1979), demand for brine started as early as 1920–1925, when the soda plant was established in Kraków. From the western part of the Wieliczka deposit, the solution mining division at Barycz has been delivering brine since 1923, for the Kraków soda plant as well as for a vacuum salt plant at Wieliczka. After almost 50 years of continuous production, the Barycz mine field could not deliver the necessary quantity of brine.

Exploration works carried on by the Geological Institute (State Geological Survey) from 1956 to 1960 led to a discovery of a new Miocene salt deposit at Leżkowice (Garlicki, 1971). This made it possible to design a new site of solution mining, situated about 20 km east of Wieliczka, and to construct one uniform pipeline system connecting the Soda Plant in Kraków with Wieliczka, and with the newly discovered salt deposit at Leżkowice on Raba.

SOLUTION MINING AT BARYCZ

Barycz, the western part of the Wieliczka salt deposit (Fig. 1), is exploited by leaching salt with water through boreholes from the surface. The mine field at Barycz is over 2 km long, covers an area of over 1 km^2 and is separated from the underground galleries of Wieliczka by the boundary pillar 300 m wide.

Exploitation of the Barycz deposit started in 1923 (Windakiewicz, 1927); the brine was used for soda production at the Solvay Plant in Kraków. In almost 70 years of continuous mining activity, about 10 million tons of NaCl have been mined. Solution mining took place at a depth of 230–280 m, in a fairly regular network of boreholes, located in equal-sided triangles with sides 50 m long. An average thickness of deposit is about 30 m, and the minimum thickness for mining operations is 12 m. The total number of boreholes in the Barycz field exceeded 900 (including the prospecting ones). Apart from the above-mentioned boundary pillar, no roof protecting pillar has been established.

Mining operations at Barycz have caused severe damage to land and plants, and considerable changes in the hydrogeological conditions (Batko, 1973, 1975). In 1926–1934, surface subsidence as high as 100–300 mm had already been registered. The prolonged exploitation at Barycz has resulted in the occurrence of a so-called "moon landscape" with numerous sinkholes and ponds filled with saturated brine. A total of thirty-three sinkholes have been recorded (Batko, 1973; 1975). Some have appeared suddenly and have been accompanied by the outbursts of overburden rocks and several thousand cubic metres of brine. The largest sinkhole originated in 1974. During that collapse, as well as considerable alteration of the ground surface, brine totally filled the channel of the local creek Malinówka.

From the numerous measurements and aerial photographs taken between 1953 and 1976, it was discovered that the most extensive areas of subsidence even contained some 9–11 m deep depressions, and the maximum depth of some sinkholes reached 27 m. Moreover, many landslides situated close to the Carpathian margin have become more active, additionally changing the Barycz landscape (Batko, 1973, 1975). The brine is squeezed out of many abandoned boreholes and occupies local morphological depressions.

In view of the fact that the reserves of the Barycz deposit are fairly exhausted, limited exploitation currently takes place in marginal parts of the deposit only. Brine from Barycz is used at the Wieliczka vacuum salt plant.

The prevailing part of the mine field was unusable for agricultural purposes again, and for several years some parts of the Barycz area have been turned into the main municipal dumping-ground for the more than 800,000 inhabitants of Kraków.

MINING OPERATIONS AT LEŻKOWICE ON RABA

In 1968 solution mining was established in the Leżkowice mine field, as a division of the Bochnia salt-work. The depth of the salt occurrence is 40–450 m. Exploitation began within the eastern part of the mine field, close to the boundary of the 300 m wide protecting pillar, separating the mine field from the Raba river. Boreholes were drilled from the surface and placed in equal-sided triangles with sides 35 m long. Mining operations were designed for a short period, some 8–10 years, with roof protection from the surface to a depth of 120 m, with underground cavity control by means of echosounding measurements. Unfortunately, exploitation of the deposit has been carried on for over 20 years, resulting in severe surface damage and pollution of the natural environment. The results of that prolonged mining activity are: underground connections of caverns, broken pipelines, soil impregnated with salt, the Raba river polluted with brine and, lastly, widespread subsidence of the mine field area and its vicinity.

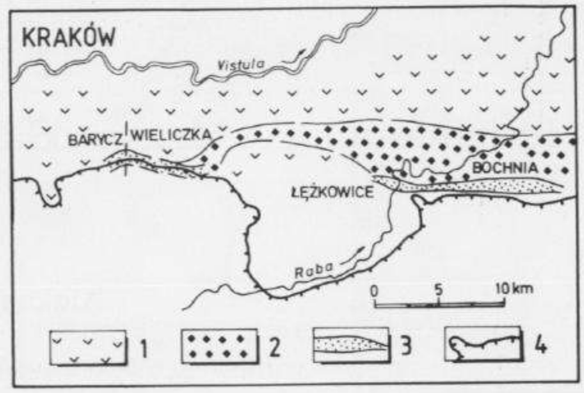

Fig. 1. Map of salt deposits in the Wieliczka-Bochnia region. 1, Sulphate facies; 2, chloride facies; 3, salt deposits in the overthrust unit; 4, margin of the Carpathians.

As from January 1986, exploitation using the pressure method of leaching stopped at Leżkowice. The brine was pumped out and the carverns filled with mine-filling materials: loam, sand, gravel, clay, anhydritic claystone, salty clay, and ash from the power station.

In January 1988 mining activity at Leżkowice came to an end. During the whole period of exploitation, the total output of rock salt was about 5,100,000 t of NaCl (or about 17 million m^3 of brine). The total volume of caverns exceeded 1,450,000 m^3; the total volume of mine-filling materials introduced into the deposit exceeded 1,100,000 m^3.

SOIL SALINITY

A few years after the start of exploitation at Leżkowice, ground salinity analyses were initiated by the students of the Academy of Mining and Metallurgy, Kraków. During the summer of 1976 systematic sampling of the soil was performed in the whole mine field area, followed by chemical analyses for NaCl content determination (Grabski, 1976). The results presented in Fig. 2 reveal that soil in the central part of the mine field is almost free of salty contamination. In the western part of the mine field NaCl content is generally between 0.1 and 2 wt %. In one place salinity of only 5% has been determined. In the eastern part of the mine field the same values of between 0.1 and 2.0% were measured, but there were four separate areas with an NaCl content exceeding 5%.

After 8 years the same examination took place at Leżkowice (Batko, 1984) and revealed a remarkable increase in the soil salinity (Fig. 3).

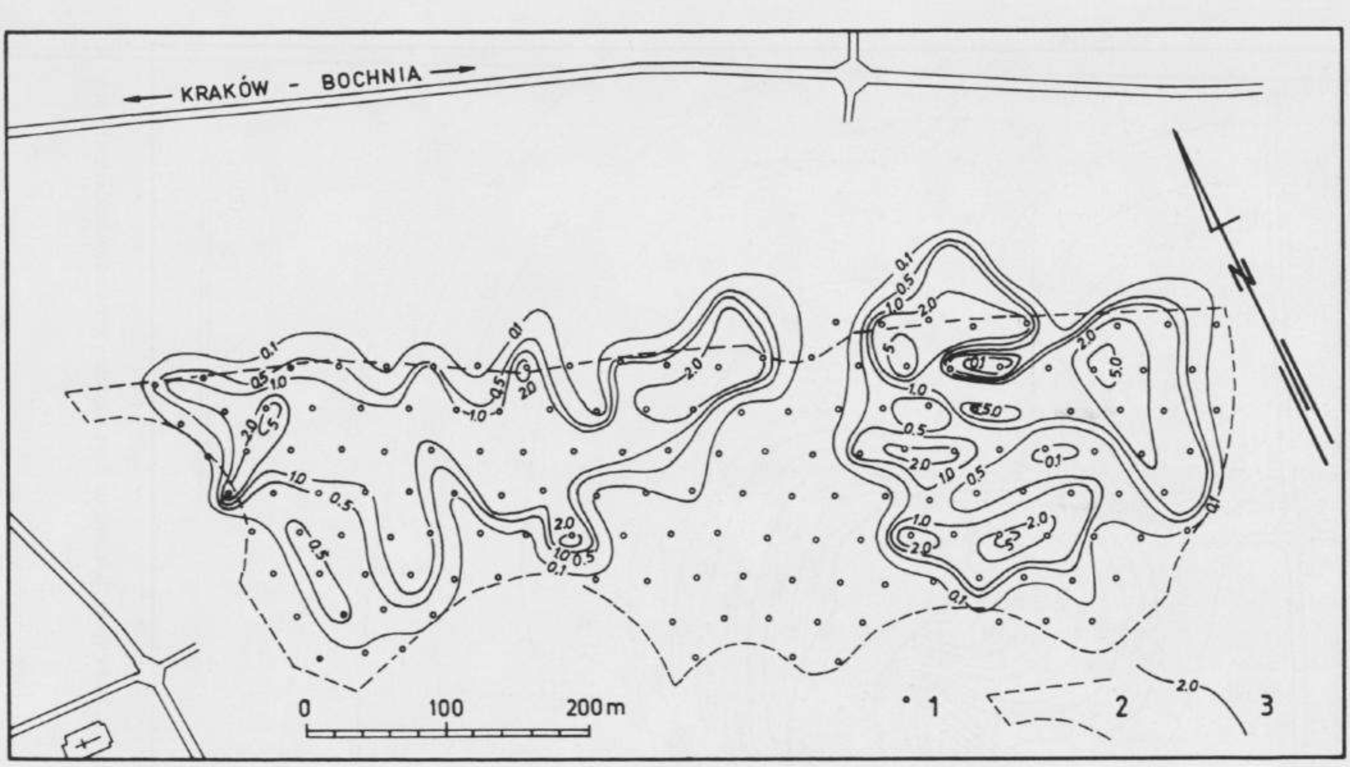

Fig. 2. Distribution of NaCl on the surface of the solution mining division Leżkowice in 1976. 1, borehole; 2, mine field; 3, contour line showing NaCl content in wt.%.

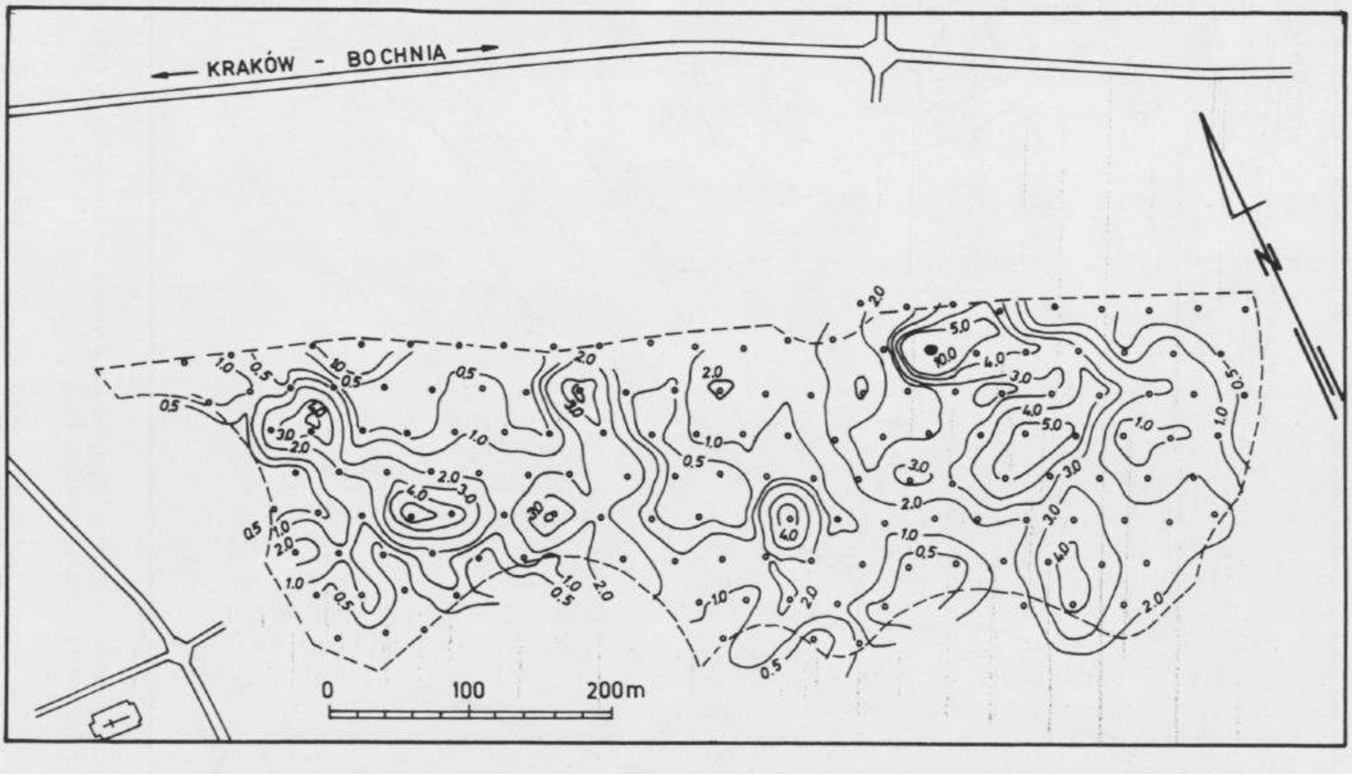

Fig. 3. Distribution of NaCl on the surface of the solution mining division Leżkowice in 1984. (Explanation as in Fig. 2.).

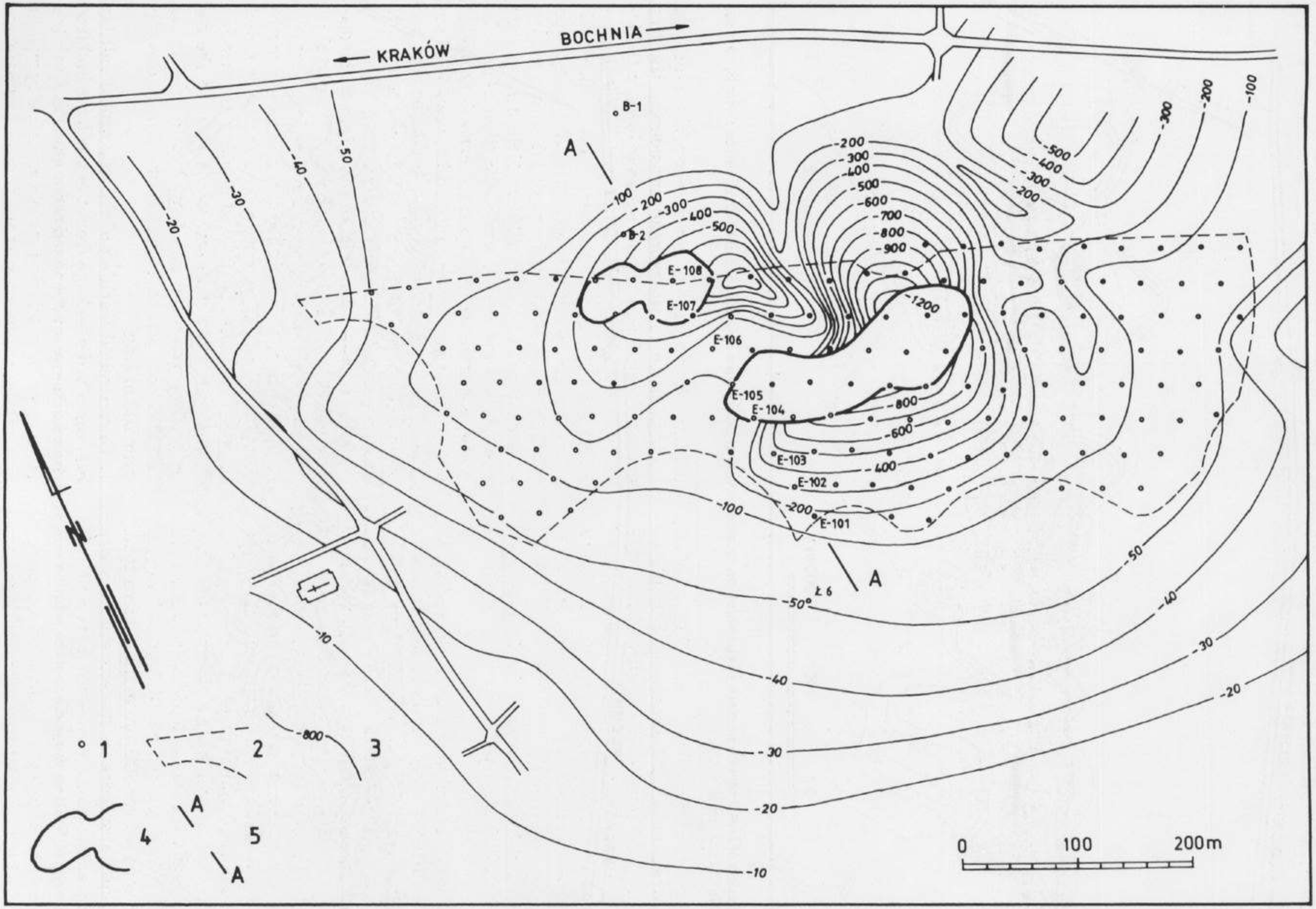

Fig. 4. Surface subsidence of the solution mining division Lezkowice during 1974–1988. 1, borehole; 2, mine field; 3, contour line showing ground subsidence in mm; 4, collapsed sinkhole area; 5, line of geological cross-section.

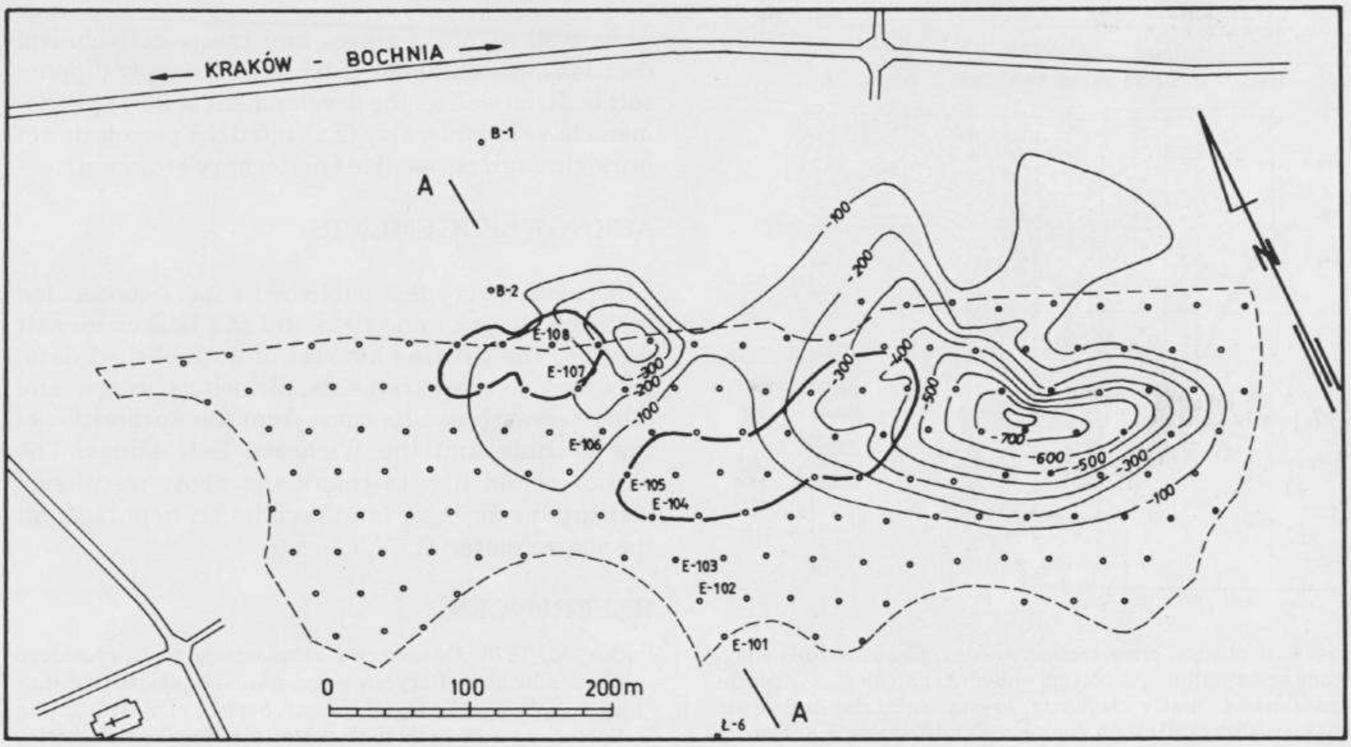

Fig. 5. Surface subsidence of the solution mining division Leżkowice during August 1988–June 1991. (Explanation as in Fig. 4).

In 1984 the majority of the mine field showed salinity between 1 and 3%, exceeding 4 or 5% in many places. In the north-eastern part of the mine field, there was a large area with an NaCl content of between 5 and 10%. The main sources of soil salinity are broken pipelines and damaged borehole casings.

SURFACE SUBSIDENCE AND OTHER ENVIRONMENTAL CHANGES

From the very beginning of mining operations at Leżkowice, a surface survey was established for surface subsidence control. Measurements taken over longer periods, e.g. 1974–1988 (Fig. 4) show an area of subsidence spreading far from the central part of the mine field. Two main areas of subsidence could be distinguished, both with subsidence exceeding 800 mm. In the larger area, situated east of boreholes nos. E-104 and E-105, subsidence exceeding 1200 mm (up to 1800 mm in places).

In the same two central areas and during the next, shorter, period between August 1988 and June 1991 (Fig. 5), the subsidence increased from 400 mm in the western zone to over 800 mm in the eastern zone. The maximum subsidence in the eastern zone was elongated in shape along west–east axis and was displaced about 150 m eastward.

Measurements take over quite a short period (March 1991–June 1991) revealed subsidence exceeding 160 mm in the eastern zone of the mine field.

In addition to widespread subsidence, the first extended and deep sinkhole began to form in 1984 in the vicinity of boreholes E-107 and E-108 (Figs. 4 and 5), and continued westward until 1986. Within a few months both sinkholes, up to 22 m deep, were filled by clayey and sandy material with a volume exceeding 250,000 m^3. In 1988– 1989 east of boreholes E-105 and E-104, another shallow depression was recognized (with a depth not exceeding 3 m). A few other sinkholes were formed between 1988 and 1090. The total volume of nine sinkholes was estimated at about 303,000 m^3. All have been totally packed with mine-filling material.

In the cross-section (Fig. 6) the origin of the deep sinkhole in the vicinity of boreholes E-107 and E-108 could be explained by uncontrolled leaching of a steeply-dipping rock salt bed occurring a few metres below the Quaternary strata. The shallow sinkhole between boreholes E-104 and E-105 is the result of the existing high chamber, which entered the roof protecting pillar and penetrated an overlying salt bed. This took place along the strike of beds, in a zone over 200 m long.

Uncontrolled leaching of the uppermost salt layers, some brine leakage from the pipelines and from the borehole casing, caused the high salinity of Quaternary sediments. In many places brine percolated through sands and gravels and thus formed seepages

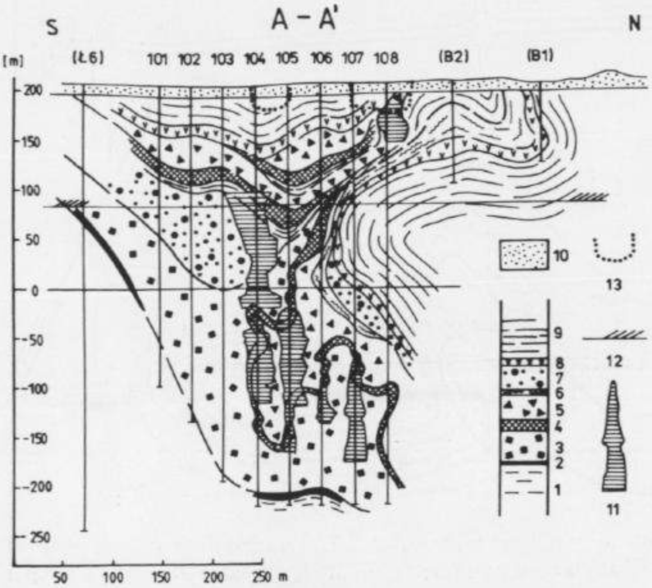

Fig. 6. Geological cross-section A–A'. 1, Skawina beds (claystone and siltstone); 2, bottom anhydrite; 3, complex of southern salts; 4, marly claystone, crystal salt, clay–anhydrite shales with crystal salt; 5, complex of middle salts; 6, anhydrite claystone; 7, complex of northern salts; 8, top anhydrite; 9; Chodenice beds (mainly siltstone); 10, Quaternary (loams, sands, gravels); 11, cavern shape determined by echo sounder; 12, roof protection pillar; 13, sinkhole.

on the western bank of the Raba river. An average content of NaCl in the river water was: 1976, 45 mg/l; 1980, 51 mg/l; 1983, 206 mg/l. Since 1983 the salinity of the Raba has decreased considerably, due to the introduction of a drain borehole barrier, which directed saline waters back to the boreholes in the mine field (Batko, 1984).

FINAL REMARKS

The last years of mining activity at Barycz, and particularly those years of extended exploitation at Leżkowice, point to the fact that political reasons prevailed over technical and economic ones. Despite numerous warnings by engineers and mining authorities, the governmental management of the salt industry forced those mining operations to continue resulting in evident damage and destruction of the natural environment. Examination of soil salinity, measurements of surface subsidence, hydrogeological and geological study and other research carried out simultaneously with mining operations, turned out to be an insufficient warning of possible danger.

Even now, it is very difficult to estimate the total costs of mine filling, replacement of soil, renewal of groundwater, and other long-term efforts which still need to be undertaken.

As well as any failures and incorrect technical decisions, the shallow occurrence of steeply dipping salt beds, as well as the development of karst phenomena have considerably facilitated the percolation of brine through permeable Quaternary sediments.

ACKNOWLEDGEMENTS

There are very few published papers concerning both the Barycz mine field and the Leżkowice salt deposit. The existing amount of unpublished data, documents, measurements, drawings, maps and other research results come from the authorities of the Bochnia and the Wieliczka Salt Mines. The author would like to thank the above-mentioned institutions for their kind permission to publish all the source material.

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