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IN-MINE SEALING OF WATER INRUSHES

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ABSTRACT

Underground sealing of water inrushes from within the workings of a mine is applied when preventive measures have been inadequate. Effective sealing is necessary in order to minimise the costs and enviromental impact of mining.

During the past five years the author has directed four in-mine sealing operations in Hungary and one in Slovenia. All cases were characterised by weak rock conditions. The paper outlines each operation and presents their common and individual features. Investigations of the reservoir and natural protective layers were carried out first, included testing of stress conditions. In all cases, bulkheads with transferring pipelines were constructed and modification of the rock stress by hydrofrac grouting carried out. Holes bored from the surface have also been used, either for direct grouting or for supply of materials for in-mine grouting or bulkhead construction. Where the barrier was of insufficient length to accommodate a bulkhead, the area immediately around the inrush channel was treated. Emergency measures were taken only in cases where the capability for pumping, water delivery or solid control was inadequate.

Some important conclusions are summarised below.

a) In-mine sealing of water inrushes can be completed even under extremely difficult conditions, such as high flow rate, weak rocks, close proximity of water channel to workings. However, it is time-consuming and the cost is high. Effective preventive measures are preferable to a successful sealing.

b) Although all operations were successful, the application of 'Murphy's Law' created many problems.

c) Protection against spontaneous hydrofracing by proper modification of the rock stress successfully prevents water inrush, even where the thickness of natural barriers is insufficient.

IN-MINE SEALING AS A STANDBYE MEASURE

Highly mechanised mining involving extremely expensive equipment requires reliable protection against water inflows. Where the available information regarding local hydrogeological conditions is uncertain, control measures should be over-engineered. Whilst providing the required safety margin, this involves increased cost and environmental impact.

Karstification resulted in a high degree of variation in the properties of the reservoirs and natural barriers. Mineral exploration programs were not able to provide sufficient information on local parameters so that over-engineering was the only mine inrush *prevention* policy that could be safely applied.

Over-engineering of preventive measures has the following disadvantages.

a) Excessive water is drained from drinking water reservoirs.
b) To compensate for the uncertain thickness of the natural water barriers, the size of mineral barriers must be increased, resulting in sterilisation of reserves.

A combination of preventive measures such as use of natural water barriers, reservoir depressurisation and pumping sediment control and posterior measures, ie, sealing of inflows, may provide a feasible compromise. In any such compromise the costs and risks of sealing operations should be carefully considered.

During the last five years the author has directed five operations for the sealing-off of karst water inflows. The case examples and conclusions may provide useful information for dealing with similar incidents in the future.

CASE HISTORIES

All five sealing operations were related to the karstified fissured limestone or dolomite bottom reservoirs in coal mines. The incidents did not cause flooding of mines or mine fields. All sealings were completed under 'flowing water' conditions without having to halt production operations. The sealed water yield varied between 0.066 and 0.66 m^3/s. In four cases, inflows into roadways were sealed in close proximity to the inrush site and all operations were successful.

The presentation of the five cases focusses on those common and individual features which may be useful for decisions-makers involved in similar incidents in the future. The scope of this paper does not permit discussion of less significant but still important details of the practice. Earlier IMWA publications are available on the hydrogeology and mine water control of particular in-mine sealing sites [1,2,3,4,5,6]. The five cases are presented in chronological order.

Sealing water-solid inrush in Nagyegyhaza Coal Mine

The mine was designed to produce some 1200 kilotons of brown coal and 600 kilotons of bauxite per year. Danger from karst water was foreseen. Two fissured limestone layers of limited conductivity/recharge and a Triassic dolomite bedrock (covered by dolomite conglomerates with bauxite interbeddings, were indentified during exploration as the main source of danger. The mine was equipped for preventive drainage in the limestone layers and dolomite conglomerate and to deal with large spontaneous water/solid inflows. The nominal capacity of the two pumping stations was 1+2=3m^3/s. At the boundaries of the mine fields preventive grouting by clay slurry was also applied locally according to the know-how of Kipko.

Preventive drainage at the coal getting operations was quite successful but the total yield of water exceeded that which had been forecast. This was due to the higher-than-predicted in-mine conductivity of the faults in the dolomite conglomerate, caused by piping [6].

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In February 1987, a single roadway had been driven some distance away from the depressurised zone to open up a new coal field. The depth of operations was 360m, some 260m below the piesometric head of the bottom reservoir. During approach to the dolomite conglomerate, precautionary holes were drilled to detect faults and to achieve local drainage. The yield of water drained from five holes was around $0.05 m^3/s$. Despite the precautionary measures, water inflows occurred and increased up to $0.53 m^3/s$ from a faults just at the face. The water transported some 1000 tonnes of solids (dolomite gravel/powders) within the first two days. Later, smaller yields of dolomite sands/powders occurred occasionally. The piping in the bottom dolomite conglomerate caused extensive failures in the area around the face. The geological cross-section with the location of the inrush is shown in Fig. 1.

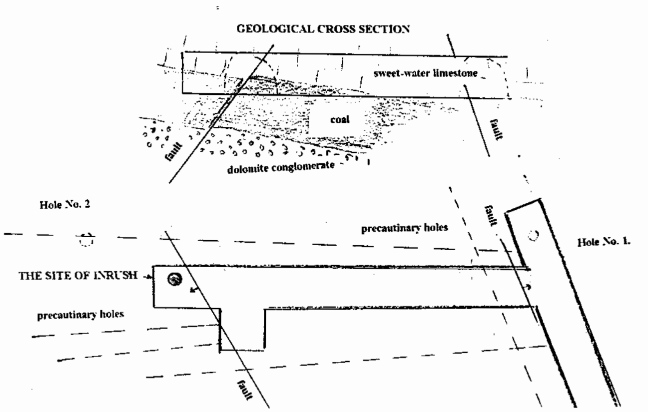

Fig 1. The site of water-solid inrush in Nagyegyháza Mine

The pumping/settling capacity was adequate but the risk of flooding remained due to the inadequate capacity of sediment removal from the settler to the surface. Also, water flowing down the inclined drivage damaged the roadway. To prevent further failure, increased water inrush and to protect the settlers from more solid inflow, emergency measures were taken.

The emergency staff of the mine built serially connected emergency settlers along the roadway. Quasi-clear water was transferred directly to the sump of settled water by Flygt pumps and low-pressure pipelines.

As the total water output of the mine exceeded the environmental limit, the inflow had to be sealed. Staff of the mine and the Institute (KBFI) examined a number of alternative plans. The selected plan included a bulkhead and conducting pipeline in close proximity to the inrush and two holes bored from the surface (Fig. 2).

Hole No. 1 served initially for supply of materials for bulkhead construction. It was also equipped with a high pressure pipeline for secondary grouting. Hole No. 2 was directed towards the fault on the dolomite conglomerate where the main channel of the inflow and caves due to piping were supposed, with the objective of sealing them. A grouting plant was established on the surface at the site of the boreholes. Temporary roads, water and electric supply were also established.

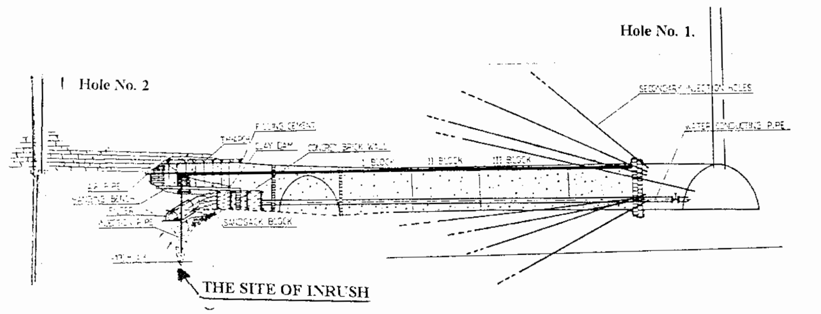

Fig. 2. The bulkhead for sealing in Nagyegyháza Mine

The emergency measures and the preparation for sealing took four months. The main stages of the sealing itself were as follows:

a) setting-up of the bulkhead high pressure pipeline to stabilise the close vicinity of the inflow and conduct water into the new pipe (cc 40 days);

b) contruction of the body of the bulkhead and filling of fissures in the surrounding rock (cc 40 days);

c) grouting of the surrounding rock, including hydrofrac. grouting in the coal and the dolomite conglomerate (cc 40 days);

d) preparation of the final operations, exercising safety measures and testing of machinery and material supply (7 days);

e) grouting in two stages with intermediate testing;
   - filling/grouting the main channel and caves from Hole No. 2 using cc 640 tonnes of cement slurry within ten hours,
   - testing the results, by re-boring the grouted hole and opening the bulkhead valve,
   - secondary grouting through the grouting pipes in the bulkhead (240 tonnes of slurry within 8 hours.

Having completed the secondary grouting, no seepage was detected either through rock or from the open pipelines.

The progress of this successful operation was interrupted by various incidents arising from operational problems and bad decisions. For example:

- boring tools were lost in both pipelines;
- Hole No. 2 passed within close proximity to the failed face;
- during case cementing the cement slurry ran out through the transfer pipe of the bulkhead. This was because oil well professionals applied light floated cement under a temporary closed valve.

These incidents caused a total delay of about one month.

Partial conclusions from the Nagyegyhaza Mine operation are listed below.

a) Due to the inhomogenity of the conglomerate the precautionary holes did not prevent a large inflow.

b) Due to the inadequacy capacity of water drainage in an inclined roadway and the lack of continuous sediment removal from settler to surface, a mine of enormous pumping and settling capability was endangered by flooding.

c) The elimination of an emergency situation takes the same time as the sealing of a large inrush.

Sealing a group of inflows in Mány Mine by closing a field with bulkheads

Geological conditions at Mány mine are similar to those of Nagyegyhaza Mine, although the transmissivity of the dolomite bottom reservoir is half that of the Nagyegyhaza site. Mining operations started at the same time as Nagyegyhaza Mine at the same depth and under the same water pressure but extension of the operations has been on a reduced scale. The system of mine water control is similar with water output at $0.66 m^3/s$. An emergency situation had not yet occurred but the total water output of the three mines of the Nagyegyhaza-Mány basin exceeded the environmental limit.

Amongst other environmental protection measures, the company decided to close the field and open a new one with a lower water inflow. Three bulkheads designed for 28-32 bar pressure and weak rock conditions were applied. Fig. 3 shows the situation.

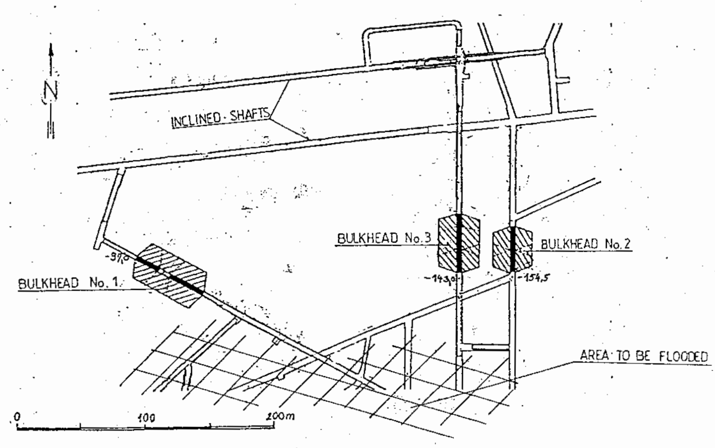

Fig. 3. The location of the bulkheads for closing a group of inflows in Mány Mine

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Design and in-situ measurements commenced in March 1987 and construction of the first bulkhead started in December 1987. Coal getting continued until June 1988 and the closing of the field was completed in June 1989. No unforeseen incidents occurred. The repeated testing and treatment of the rock around the bulkheads occupied about two-thirds of the total construction time.. During pressurising of the extremely weak clay by hydrofrac-grouting, strong visco-plastic movements of the clay were observed at all three bulkheads

Control measurements and observations around the bulkheads continued until the end of 1990, with special regard to the status of the weak clays. Depressurisation due to long term deformation may have occurred. During the operating period, no movements, seepage of reduction of the shut-in pressure were detected.

Details on the special structures of the bulkheads and the testing and treatment of the surrounding rock have been published previously [3,4]. The common and individual features of this case compared with the previous one are listed below.

a) The weak clay aroud the bulkheads necessitates a special bulkhead structure which enables continuous testing and grouting of the rock along the whole length of the bulkhead to be carried out.

b) In weak rocks the balance between the actual water pressure and the status of rock stress (fissure re-opening pressure) must be preserved. If the water pressure exceeds the fissure re-opening pressure, the water will create its own channel.

c) In spite of the extremely weak clay surroundings (σ_B < 4 MPa). the bulkheads and surrounding clays even now in good condition. Direct sealing of each inflow channel was not necessary. The safe pathway in the properly-pressurised clay is much shorter than the empirical value. This fact also validates the failure theorem of the author [3].

Contribution to the sealing of an inflow at Kanziarica Mine, Slovenia.

Kanziarica Mine, Slovenia, is a small brown coal mine working a medium-thick seam in a tectonically-formed sedimentary basin. The bedrock is a karstified limestone under water pressure. The major parts of the mine fields are protected by geological barrers of marl/clay at the karstified reservoir- bottom, along large faults and a the boundaries of the basin. In May 1976, the mine was flooded due to an inflow of some 0.46m^3/s which exceeded the its pumping capacity. Co-operation between the mine staff, the Geological Service in Ljubljana and the Hungarian Mining Institute (as chief designer), the inflow was sealed in three months by three grouting holes from the surface. The author also contributed to this operation.

In January 1990. two parallel roadways were driven 300 m below the surface, 260 m below the piezometric head of the bottom reservoir. Precautionary/drainage holes were applied into the fissured bottom marl to modify the water pressure in the fissures (as a special "Instantaneous" drainage in the protective barrier). This method has been implemented into the country's practice by G. S. of Slovenia.

On the 12th .January along one of the lined, cemented holes water inflow started and increased up to 0.13 m^3/s. Impact of an earthquake was also supposed due its time coincidence with the inflow. The water flow caused failures in the surrounding area of the face. The solids transported by water endangered the pumps.

The staff of G. S. and of the mine, well experienced in sealing had already prepared the conception of in mine sealing by applying two bulkheads and two grouting holes from the surface, when the author was requested to contribute the operations as an invited consultant of the advisory board commissioned by the government of Slovenia. The Board was chaired by Prof. R. Ahcan, The project leader was Prof. M. Veselic, the mine mangers: V. Breznik, A. Lugarich. The site and the conception of the sealing is presented in Fig. 4.

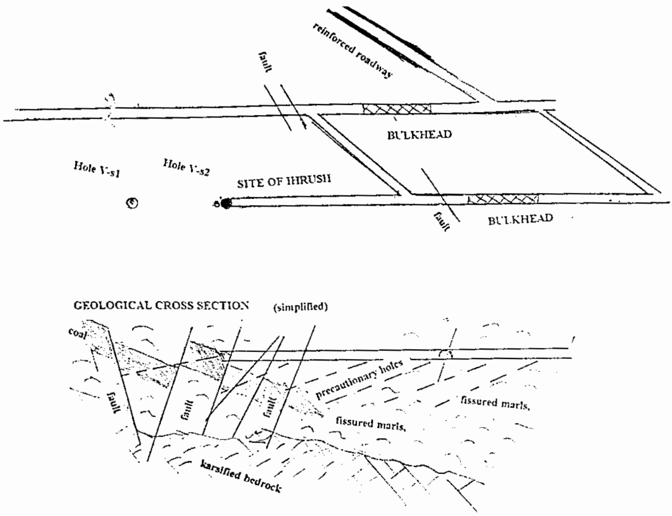

Fig. 4. The site and the conception of sealing in Kanizarica Mine Slovenia

Hole No V1s directed to the fault (just to the boundary of the marl and of the limestone) to grout the channel at the bottom-reservoir. Hole No. V2s served to fill the caves in and around the roadway and to stabilise the failured zone. The two bulkheads were sited into medium hard marls, at equal distance from the closest roadways.

The author has been asked on the proper form of the bulkhead's body and on preventing against the risks due to the close location of roadways. The summaries of the answers are as follows:

— Special form for the body is not necessary because the pipings of the seepage-pathways in the surrounding rocks are the weak elements. Systematic grouting is necessary to fill the fissures and to modify the rock stress properly. It will require same time as in Nagyegyháza.
— The surrounding rock between the bulkhead and the road of close location should be filled/pressurised properly. Against 26 bar water pressure cc 23 bars of shut in pressure is necessary according to the experience in Mány.

After one month the two bulkheads and the two holes were completed, although the mine transport facilities to the site were poor ones.

During the next meeting of the board the proper sequence of the grouting was discussed. The author preferred to start with grouting the mine caves in hole V2s. because this grouted area allows to apply high pressure grouting (up to 36 bars) in the hole V2s Without any risk of overloading the bulkhead's surrounding rocks.

The sealing was absolved within three month from the date of inrush. According to the author's knowledge, this is the "Guinness record" of in-mine sealing .

In comparison with the former cases the conclusions are as follows:

- In medium hard coal, marls bulkheads with grouting can be absolved within two months. (Nagyegyháza, & Kanizarica cases)
- The proper modification of the status of the rock has been absolved around a roadway supported by steel arch and shotcrete. The seepage pathway (15 m.) between the flooded area behind the bulkheads (26 bars) and the roadway is much shorter than the empirical safe thickness. This fact looks to support the theorem of the author [3].

Sealing water inrush (2 m³/s) in Lencsehegy Coal Mine in close vicinity of operating roadways

Lencsehegy mine is the last operating one in the historical Dorog coal field. This coal basin is known as the case example of strong karsic water hazards. A thousand karsic water inrushes occurred, from the karstified bedrock through the insufficient bottom barriers (weak and medium marls, clays sweet water- limestone interbeddings). Fifty mines/mine fields were flooded, and many of them were reopened by applying sealing from the surface.(cc. 50 cases.) [1]. Basing on the experience the new mine (called Lencsehegy) was equipped with pumping and sediment settling/removal plant of 2.5 m^3/s output capability [1]. Local drainage in combination with preliminary grouting was planned as a preventive measure [5]. The coal getting operations started in the area of sufficient protective barrier. Having extended the exploitation, water inrushes occurred. Due to the powerful pumping plants and to the low (non-market) prices of electric energy the operation and the economy of the mine were not disturbed by the inflows. Most of inflows were in close vicinity of openings under operation, therefore the engineering staff of the mine was full of doubts on the chance of sealing.

The conditions changed strongly. The Environmental Authority determined new output limits for better protecting the thermal wells/springs of Budapest. Market governed prices are ruling. The new Private owner of the mine: DOSZÉN RT considered the sealing of one or more inrushes. The Central Institute for Mining offered their sevice for sealing. Due to the strong doubt on the success the Institute had to hold all responsibilities as chief contractor of design and operations.

The first job has been the biggest inflow (0.2 m^3/s) at a dead end of a roadway surrounded by operating roadways as presented in Fig. 5. The price, the cost of sealing was a fixed one!

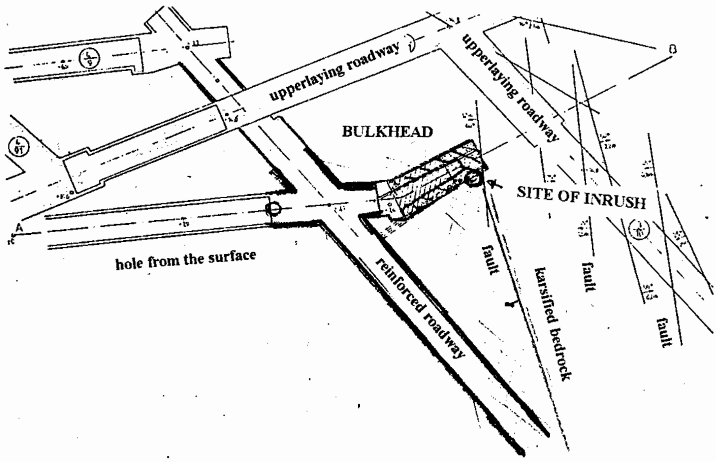

Fig. 5. The site, the geology and the structures for sealing in Lencsehegy Mine (0.2 m³/s)

The water inrush occurred in January 1990. The contract entered into validity in March 1991. Due to the impact of the water the vicinity of the inflow and the road crossing were ruptured and swelled strongly. Small water inflows were discovered even in those areas which must not be closed.

The first items of the operations were as follows:

— In mine holes have been bored for surveying the location of the karstified reservoir and for testing the rock conditions (including the shut in pressures).
— Reconstructing the supports
— Applying new water transferring pipe of high pressure.
— Stabilising the close surroundings of the inflow.

The main findings of the first operations are drafted below:

— The bottom barrier is sufficient, but a fault lifted the bedrock.
— The measurement on the depression cone shows zone of limited conductivity around the channel of the inflow. The virgin water head was estimated 100 m above the operations.
— The measurements on cave detection [5] have discovered cave of estimated volume: 3000 m³.
— Between the site of the inrush and the upper roadways (cc 10 m distance) the shut in pressures detected inside the barrier is sufficient ones. In spite of the ruptures at the inflows the limestone interbeddings (0.5~2 m. each) limited the extension of depressurised zone!

The next operations were based on above information:

- Treatments in the barrier of the upper roadways were not necessary, except occasional observations.
- Only in-mine grouting was allowed to apply gentle injection-pressures.
- Hole was bored from the surface to serve first the material supply of constructing the bulkhead and for the last in-mine grouting.
- Due to the cost limits our effort was to form a sealed zone just under the barrier layers in the fissured zone of the limestone, instead of filling a cave of 3000 m³.
- Special bulkhead, (similar to the bulkheads in Mány) was built in (see Fig. 5.)
- The surviving roads were reinforced by shot concrete and by the grouting pipes working also as rock bolts.
- The treatment of the barrier consists of systematic grouting/hydrofrac grouting and of step-by step detecting the shut-in pressure. The distance between the channel of the inrush and the closest point of the reinforced roadway has been 7 meter. The zones of proper stress have to be formed even in this thin barrier, taking into consideration the limited loading capability of the reinforced road-support.
- Due to cost limits the length of the reinforcement of the supports and the extension of barrier treatment was undersized. Hoping the good luck of miners a closing test was absolved in September 1991. During rebuilding the water pressure strong noise of rock fracturing, and sudden increasing the small seepage from the fissures of the coal detected the starting an inrush. We opened the valve and decided to extend the reinforced length and to complete the hydrofrac grouting as planned before.
- The final closing was absolved in 9 December 1991. The gentle groutings of the limestone require 80 m³ cement-fly ash slurry (with swelling additive) The final operations take two days including some incidents due to the cold weather.

Only one short but serious incident occurred during closing test. Having reopened the valve the solid sediment sealed the valve. The quick manual cleaning made by the mine managers own hands heroically stopped the rebuilding of water pressure and the approaching inrush.

Some experience, observations in comparison with the previous cases should be summarized below:

- In the strongly fissured medium weak coal of proper rock stress conditions seepage did not cause any risks, but under inappropriate stress the inflow started immediately.
- By applying gentle grouting the zone of proper stress can also be formed at some meter distance from the roadway of limited loading capability (steel arch, shot concrete and bolts).

Sealing water inflow in an operating roadway in Lencsehegy Mine

After the first successful actions the management believed the success. In March 1993 the Institute was requested to design and to command the next operations. The contractor was the mine itself.

The site of the inflow has been in the bottom of a settling basin located in ventilation-roadway. The time of occurrence was unknown. Only the difference between the inflow and outflow rates (0.04 m³/s) have detected the presence of a new "spring" in the basin.

The new in mine holes detected a small "horst "of the karstified bedrock. Except for this small surface the thicknesses of bottom barriers are sufficient. The virgin water head was estimated as 100 m above the operations. The medium weak marls with small limestone interbeddings provided quite favourable conditions for sealing.

The staff of the mine enlarged and supported the channel of the inrush down to the bedrock by applying Flyght pump in the bottom face of this small shaft.

Thick steel concrete tube equipped with injecting pipes served to carry all loads of hydrofrac grouting. The site and the sealing structures are presented in Fig. 6. Comments are not necessary.

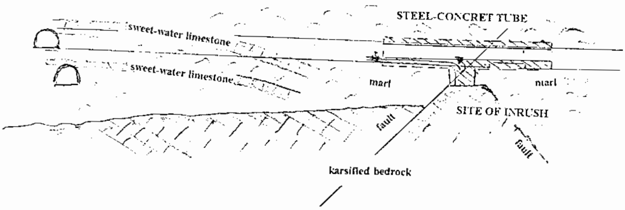

Fig. 6. The site and the structures for sealing an old inflow in operating ventilation drift

MAIN CONCLUSIONS

1. The in-mine sealing water inrushes can be absolved even under extremely difficult conditions (high flow rate, weak rocks, openings in the close vicinity). During surveying the site the rock stress conditions inside the natural barriers should also be measured.

2. The success of the operations and direct observations demonstrated, that by modifying the rock stress conditions properly even thin natural barriers prevents against water inrushes.

3. Weak rock surroundings require special structures that give possibility to modify the stress of the rocks properly; this treatment of the rock often requires some months.

ACKNOWLEDGEMENTS

Results of teamwork have been presented . The permanent team of these five jobs has been the Dept of Mine Water of the Central Institute for Development of Mining of Hungary. Due to a governmental decision the Institute has already stopped with its professional activity. The author as one of staff member and as the last research director of the Institute addresses his last thanks to Mr. I. Bagdy, L. Mr .G. Kovács, Mr L. Szentirmay. They are the inventors of the new bulkheads the designers and the supervisors of site operations. Dr. A. Schmieder world wide known scientist in karstic reservoir engineering and inventor of many sealing methods managed, and backgrounded all operations.

The art of sealing in flooded mines from the surface has been developed by mine managers 70 years ago. Due to this tradition the mine management was innovative partner, co-inventor in implementing, developing the new art of sealing as well. The project leader of Nagyegyháza and Mány has been Mr. F. Benyöcs, The mine

Nagyegyháza and the sealing has been commanded by Mr J. Stüber. Mr. M. Szikrai commanded Mány Mine. Mr E. Fehér is the manager of Lencsehegy mine. Thanks for giving us challenges.

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