COMBINED SYSTEM OF SEALING A MINE UNDER HEAVY KARSTIC WATER HAZARD

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ABSTRACT

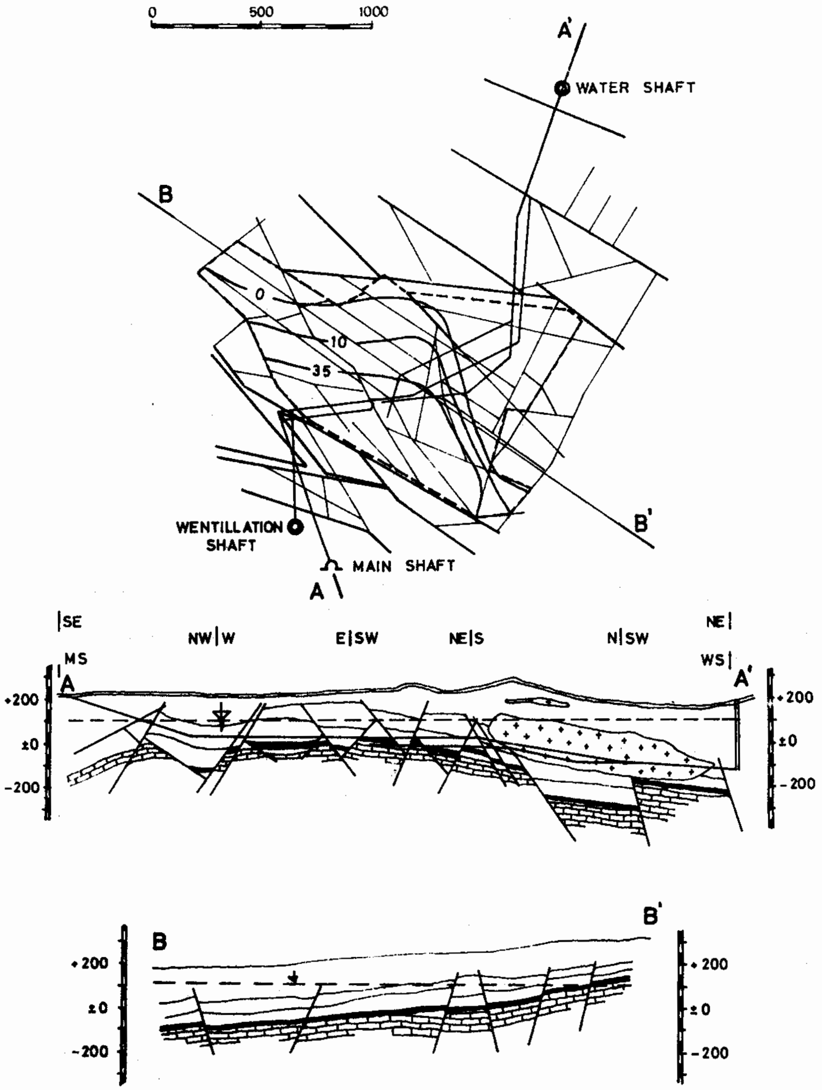
In a new coal mine under heavy karstic water hazard a combined way of mine water control is used for limiting the mine water /under 50 m³/min/ on account of environmental protection aspects. One subsystem of the combination is the preventive and "a posteriori" sealing. Large caves and small fissures will be sealed by surface and underground operations using hydraulic filling materials /sand/gravel/ and different grouting slurries as cement slurry /fly ash-cement slurry/ clay-cement slurry/ combined in space and/or in time sequence. The estimation of the sealing material demand and the selection of proper materials/technologies as well as the whole system and the sealing elements are presented in the paper.

1. INTRODUCTION

The Dorog Coalfield of Hungary under heavy karstic water hazard was the field of the first application of "a posteriori" sealing of spontaneous karstic water inrushes. During the last 60 years more than 150 inrushes were sealed successfully. /Schmieder 1978/ The combined preventive sealing technology discussed in this paper will be applied first in this coalfield in a new mine named "Lencsehegy II." The general designer of this new mine is the Central Institute for Mining Development.

2. HYDROGEOLOGY

The schematic geological cross section is presented in Fig.1. The reservoir is a strongly karstified upper-triassic limestone tectonically ruptured. This reservoir rock is a part of a large reservoir discussed in two other papers of the Congress. /Szilágyi 1985, Havasy-Dusza 1985/



SHEMATICAL MAP AND GEOLOGICAL CROSS SECTION

Fig. 1.

According to the experiences gained in the Dorog Coalfield the karstified zones are strongly connected with tectonics /Willems 1973/. High water conductivity and large karstic caves were also indicated by different borehole tests even in this mine field.

The intensively karstified area is predicted in the upper area /3o-5o ms of the limestone bedrock/.

The major tectonic faults are indicated by the schematic mine map in Fig.1. The coal seams are located 3o-2oo ms below the karstic piezometer head. Between the coal seams and the reservoir eocennic clay protective layers and in small areas marls of cretaceaous age were detected by holes. Some isolinies of the protective barrier thickness are also shown schematically in the mine map /see Fig.1./. The protective effect of the clay barriers is sufficient only in a relatively small area. The average yield of spontaneous mine water is predicted as 6o-7o m³/min. The short time maximum may exceed 15o m³/min. Because of the inhomogeneities of the karstic reservoir, inrushes of 1oo-12o m³/min may also occur /according to the experiences in the Dorog Coalfield/.

3. THE SYSTEM OF MINE WATER CONTROL

Because of environmental control and water resource management aspects the maximum of mine water output is limited as 5o m³/min by the National Water Authority. This decision excludes the applicability of preliminary water level lowering methods.

A special combined way of protection is being used /Schmieder-Kesserü, Szilágyi-Bogárdi 1981/, which consists of

- passive protection /pumping/
- the instantaneous control /Kapolyi 1976, Kapolyi et al. 1978/ and
- the preventive and "a posteriori" grouting /Schmieder et al. 1977, Kesserü -Szilágyi- Honvéd 1977/

The way and feature of the combination depends on the protective effects of the clay barriers /Kesserü 1983/:

- In areas where the protective layer/barrier thickness is more than 35 ms the passive method of control will dominate. Only the large tectonic zones decreasing the protective barriers are planned to be grouted preventively. /This is called area 1./

- At a medium thickness of the protective layers /1o-35 m/ all known faulted zones will be pregrouted and the instantaneous protective effect of the roadways will also be utilised /Kapolyi et al. 1978/. The passive way /pumping/ is the standby control measure for this area. /This is called area 2./

- In areas where the clay layers have no significant protective effect, a grouted zone in the reservoir rock will serve as an artificial protective barrier. The pumping and "a posteriori" grouting in exceptional cases serve as stand-

by measures /this is called zone 3/.
The water delivery subsystem consists of water conducting roadways /located partly in the bedrock/, settlers with continuous sediment removal and a shaft equipped with submergible pumps /11x15 m³/min/ /Bagdy, Kocsányi 1982/.
The alarming and rescue subsystem is also carefully designed and organized.

As a standby control of environment and water resources a water reinjection system was also planned and designed. /Szilágyi 1985/.

This paper discusses the combined technology of sealing as the key subsystem of the mine water control system described above.

4. THE SUBSYSTEM OF SEALING

- The proper methods and materials are discussed first.
- The necessary volume and the input capacity are presented next.
- Sealing technology for different conditions/tasks.
- Finally the proper equipment parts and their system for material supply and for grouting are discussed.

4.1. Proper sealing methods and materials

Based on the experiences of the coal basin and of borehole tests, the presence of large karstic caves and small fissures were predicted/indicated.
For the purpose of sealing large karstic caves gravitational hydraulic filling with gravel/sand is planned to be used in the first stage. The filled material and the fissured rock will be grouted by clay-cement slurry according to the Kipko-method, /Kipko 1982/ or by cement-fly ash slurry to stabilize the loosen filled material by pressure.

At the near vicinity of the mining operations only solidifying grout materials as cement-fly ash slurry /Honvéd, Schmieder 1979, Du Bois 1978/ are allowed for the purpose of sealing even large karstic caves, but small caves and fissures are planned to be sealed by grouting of cheap clay-cement slurry according to the Kipko-method /Kipko 1982/.
As standby grouting material the more expensive fly ash slurry will be available.

4.2. Evaluating the sealing material volume.

In 3rd Chapter 3 areas of different control measures were presented. In area 1 and 2 only the tectonic faults are planned to be sealed. In area 1 the major tectonic faults detected by exploration holes are planned to be grouted. The length of tectonic faults is given by the map of tectonics according to the exploration by drilling.

In area 2 all tectonic faults /even small ones/ are planned to be grouted. The length of all tectonic faults were estimated by Willems' method of estimation. /Willems 1973/

In area 3 a zone of thickness of 25 ms should be grouted in the reservoir rock. For this case the average pore volume of the triassic limestone evaluated by Schmieder /1975/ was the basis of evaluating the volume of grouting material.

The result of this evaluation is summarized in Table 1.

Table 1.

Areas of different protective measures according to Chapter 3	Area km^2	Length of faults km	Volume of grouting material: for 1 m of a tectonic fault m^3/fm	for 1 m^2 of a grouted zone /thickness of 25 m in the reservoir rock	m^3
Area 1	0,3	high faults 4,2	15		63000
Area 2	0,22	all faults 3,3	15		55000
Area 3	0,70			0,25 m^3/m^2	175000
					293000 ~ 300000

According to Table 1 the average yearly demand of grouting material for a 15 years operation period of the mine is estimated as 20000 m^3/year. For the last 9 years /when area 2 and 3 will be exploited, the average demand is 25000 m^3/year.

Because of the inhomogeneities and quasi-random distribution of the volume of karstic caves, estimations were also made on volumes of the grouted caves on the basis of experiences gained in the Dorog Coalfield /see Fig.2/ and on the number of grouting operations. Based on these estimations the maximum slurry output capacity of grouting was designed as 400 m^3/day and the maximum hydraulic filling capacity was designed as 800 t solid filling material/day. This filling output capacity requires 4000 m^3/day water supply for hydraulic filling.

4.3. Technologies for sealing

For hydraulic filling large caves with gravel/sand slurry holes bored and filled from the surface can be used most effectively according to the 60 years practice obtained in the Dorog Coalfield /Schmieder 1978/.

For grouting /with cement/fly ash/clay slurries/ holes bored from the surface and from the mine openings can also be used, although the quasi-horizontal location of the grouting holes surely provides higher efficiency.

According to the above considerations filling operations from the surface and grouting operations from the surface and from mining openings are planned.
The proper combination of different materials and methods in space and in time sequence are planned to be used, depending on the task and on the rock conditions.
Four main types of preliminary sealing operations are predicted. These are as follows:

- Sealing the tectonically faulted zones in the limestone bedrock in order to protect the exploitation.

- Sealing the tectonic faults and other water conducting zones to be crossed by water conducting tunnels in the limestone reservoir bedrock.

- Sealing large zones in the limestone reservoir bedrock to form an artificial barrier /Schmieder et al. 1977/ in order to protect the exploitation.

- "A posteriori" sealing of large spontaneous inrushes.

Although each case will have individual feature, the sealing policies for different types of operations are summarized hereunder:

4.3.1. Sealing tectonic faults

Holes were/will be bored first from the surface to the crossing points of large faults where large caves/zones of high conductancy are forecasted according to the former experiences. Conditions /transmissibility, sizes of caves/ in the near vicinity of the holes were/will be detected by conventional pumping and/or injection tests and by geophysical logging as well.
Zones between these holes were/will be surveyed by a special pulsation-interference test method. This method used commonly in the petroleum reservoir engineering practice was applied succesfully in the mine water control practice as well.
A patented computer based evaluating method is used for eliminating the background noise. /Megyeri et al. 1979/

If the pulsation interference tests indicate large caves and/or zones of high conductance, several other holes will be bored from the surface and all tests mentioned above will be carried on.

Based on these tests, the large caves will be hydraulically filled with sand/gravel slurry from the surface. Grouting for the solidification of the fillers material will be the next operation in the same holes. Finally each hole will be carefully cemented between the bedrock and the coal seam.

A set of inclined or quasi-horizontal grouting holes bored from the mine roadways will serve for the testing and seal-

ing of all the other parts of the tectonic zone. Individual and interference tests will be carried on in this set of underground holes. After evaluating these tests the proper grouting material and operation will be selected/designed.
In case of indicating a large cave, additional hole/s/ from the surface will be taken into consideration.

The result of grouting will be checked by individual and interference tests in the grouting holes rebored and in special checking holes as well.

4.3.2. Sealing zones of high conductance for protecting roadway driving in the limestone reservoir bedrock

A system of water conducting tunnels will serve to conduct water inflows to the main water treatment and pumping station. A part of these roadways should be driven through the limestone reservoir bedrock. Because of the limitation of the maximum mine water inflow /see Chapter 3/ major inflows / 2-5 m³/min/ must be excluded even during driving these water conducting tunnels.
For this reason these tunnels will be driven under protection of pilot holes /see Fig 2./ to detect zones of high conductance.

In case of detecting zones of high conductance pregrouting of pilot holes will be used with fly ash-cement slurry. For extremely large caves holes from the surface may also be considered in order to decrease the time period of sealing operations. Because of safety aspects fly ash-cement slurry will be used even for extremely large caves.

4.3.3. Forming artificial barriers in the limestone reservoir bedrock

The main goal of forming protective barrier in the dolomite bedrock is to limit the mine water inflow according to the permitted maximum yield /see Chapter 3/. Therefore total water exclusion is not required.

The system of large tectonic faults will be surveyed and sealed by holes from the surface as discussed in Para 4.3.1 Testing of holes bored from the surface and tests/experiences in connection with water conducting roadways will provide information for designing the network of quasi-horizontal holes bored from the water conducting roadways to form protective barriers of proper efficiency by grouting. /See Fig.2/

4.3.4. "A posteriori" sealing of spontaneous inrushes

Because of the extremely high costs of the preliminary sealing total water exclusion is not required, but the maximum yield produced must not be over 5o m³/min during a long period. Consequently spontaneous mine water inflows of limited yield will be permitted, but inflows over the limit have to be sealed.

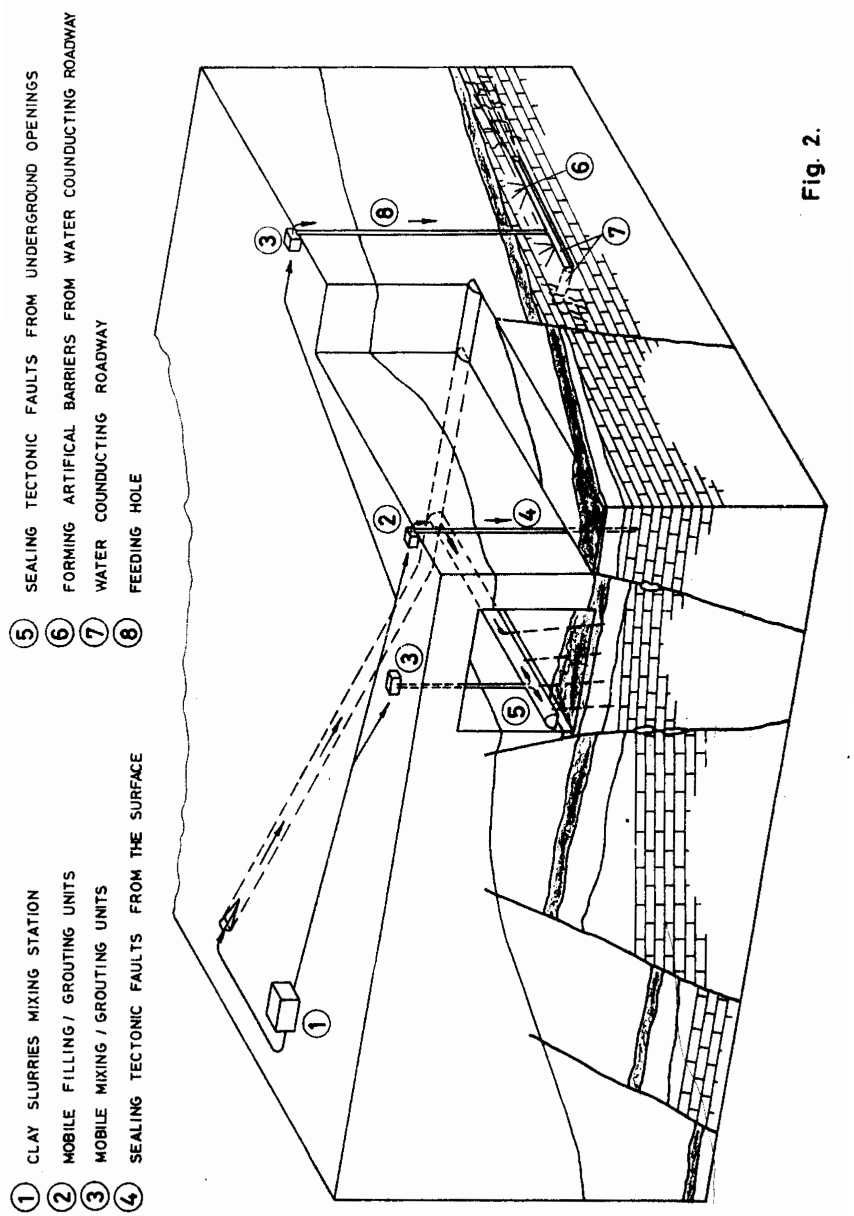

① CLAY SLURRIES MIXING STATION
② MOBILE FILLING / GROUTING UNITS
③ MOBILE MIXING / GROUTING UNITS
④ SEALING TECTONIC FAULTS FROM THE SURFACE
⑤ SEALING TECTONIC FAULTS FROM UNDERGROUND OPENINGS
⑥ FORMING ARTIFICAL BARRIERS FROM WATER COUNDUCTING ROADWAY
⑦ WATER COUNDUCTING ROADWAY
⑧ FEEDING HOLE
1
2
3
3
3
4
5
6
7
8

Fig. 2.

Although the sealing of mine water inrushes under flowing water conditions will surely be a difficult job, a set of newly developed methods /patent pending/ are available.

4.4. Equipment for sealing and for material treatment and supply

The sealing operations are planned to be applied from the surface using hydraulic filling and grouting with different slurries. The grouting operations using different slurries /cement/fly ash/clay/ are planned to be applied from mine openings. The surface and underground operations of sealing will be combined. Materials will also be combined in space and in time sequence as well.

Due to special conditions the surface is suitable for surface sealing operations only in some months of the year. It means that continuous grouting material supply is necessary through the inclined shaft.

The necessary output capacity of the sealing system is estimated according to subchapter 4.1 Estimations on ratios of different sealing materials were as follows:

hydraulic filling material /gravel, sand/	3o - 6o %
clay slurry with cement /according to Kipko-method /Kipko 1982/	6o - 3o %
fly ash-cement slurry	1o %

The proper equipment was selected and the system was designed according to the above listed requirements.

Although the clay-cement slurry is a cheap sealing material, the proper clay quality and a proper treatment are strongly recommended. To meet these requirements several clay deposits located in the vicinity of the mine were explored to select the proper one.

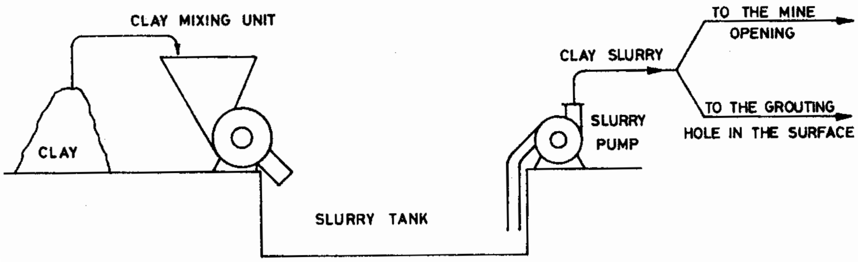
Because of the output capacity requirements the clay treatment plant is located at the upper gate of the main haulage shaft.
The clay treatment plant was designed according to the Kipko technology /Kipko 1982/ /See schematically in Fig.3/.

This plant consists of
- a platform for clay storage
- clay dispergators
- slurry pumps
- slurry tank

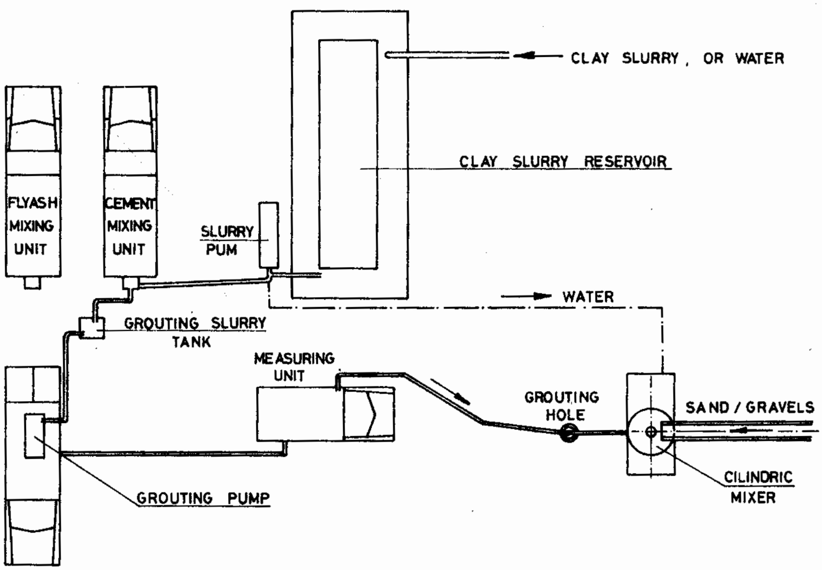
The proper clay mixture forms a stable dispersed system, which can be stored without the settling of solids for weeks.

The clay slurry grouting operations are supplied through pipeline both on surface and in mining openings.

The structure-forming additives as cement and water glass have to be added to the slurry before it reaches the grouting pump.



Clay slurry mixing station



MIXING / GROUTING / SEALING UNITS AT THE GROUTING HOLE

Fig. 3.

At surface operations of grouting with clay cement slurry, other tanks for storing clay slurry should be made forming a simple reservoir in the ground.

For hydraulic filling from the surface a mobile set of equipment will be used. /Fig.3/
This set consists of

- a water supply system based on mine water
- a mobile cylindrical mixer with feeding belt conveyer for the gravel and with a regulator for water input adjustment
- a gravitational feeding pipeline into the borehole or a gravel pump /Worman type/ if it is needed.

For grouting from the surface a mobile set of equipment used commonly in the oil well cementing technology is used
Each set consists of
- two mobile cement/fly ash mixing units,
- one/two mobile grouting pumps /Type 9T/
- a mobile laboratory and a dispatcher unit equipped with instruments for measuring/recording and regulating the parameters.

Each of the above set can operate at holes bored from the surface and at the upper gate of the main haulage shaft in a covered hall.

For grouting from underground openings the clay slurry or fly ash slurry will be prepared in the surface plant /presented above/ and supplied through a pipeline. The cement slurry will also be prepared on the surface but a separate pipeline will serve for supplying the underground grouting set.

For mixing of the structure forming additives and for the purpose of injection mobile sets will operate. Each set consists of

- a mobile mixing and feeding unit
- a mobile grouting plant

Grouting operations by the use of holes bored from mine openings can also be carried on by sets operating on the surface. In this case connection holes between the surface and mine openings will serve for conducting the grouting pipeline. Some holes of former filling operations will most probably be used for this purpose.

The system discussed above is drawn schematically in Fig.3
This system includes also the raw material sources, which are not marked in Fig 3.

In the vicinity of the mine a hydromechanized gravel/sand open pit is operating which will supply the filling material for the hydraulic filling operations.

A small coal fired power station operates also in the vicinity area, from which the fly ash is supplied in cement cars.
An open pit for producing clay of proper quality will enter into operation soon.

Several major cement factories are located near this mine

forming the background of the cement demand.
The whole system described will be put into operation next year, although many holes from the surface were bored in the last year already and many tests mentioned in this paper were also completed and evaluated.

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