EXPLORATION AND EVALUATION OF THE HYDROGEOLOGICAL CONDITIONS OF COAL DEPOSITS, WHERE THE WATER DANGER STRONGLY DEPENDS ON MINING METHODS

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ABSTRACT

A coal deposit was explored where large karstified reservoirs are in the roof and in the floor strata as well. Because of environmental requirements, this century no mine drainage has been allowed. For this reason the exploitable part of the coal resources strongly depends on the hydrogeological conditions and on the possible ways of the mine water control. Therefore some special methods were used for measuring and for evaluating the hydrogeological conditions and the impact of mining on the reservoirs.

INTRODUCTION

In West Hungary the Ajka Coalfield, which has traditions for a century in mining activity, will be totally exploited till the end of this milleneum. A new neighbouring coalfield of hundreds of million tons of estimated reserves may provide the last chance to continue the mining activity in the region. In this new coal basin reserves of more than one hundred metric tons were detected by detailed borehole exploration. This is the "Ajka II" coalfield.

Because of the coal demands and for the sake of the continuous employment of the miners in this area the exploitation of the Ajka II field should start in the last decade of this century. At the same time all environmental requirements have to be fulfilled. The water balance of the main karstified reservoir of West Hungary has been strongly damaged by the mining activity (Szilágyi, Kisgyörgy et al 1987). Consequently the exploitation of the Ajka II coalfield may be started only under the following conditions:

- no drainage is allowed till 2010
- from 2010 the drainage must not exceed the recharge of

the region (see Schmieder, Szilágyi 1976) and a certain quantity of drink water should be provided for the municipal water supply system.

It means that the evaluation of the exploitable coal reserves strongly depends on a set of requirements regarding mine water control, environmental control and mine water utilization.

These conditions require an extremely complex and carefully performed hydrogeological study, where new approaches and methods are also applied. This is the reason for the presentation of this paper.

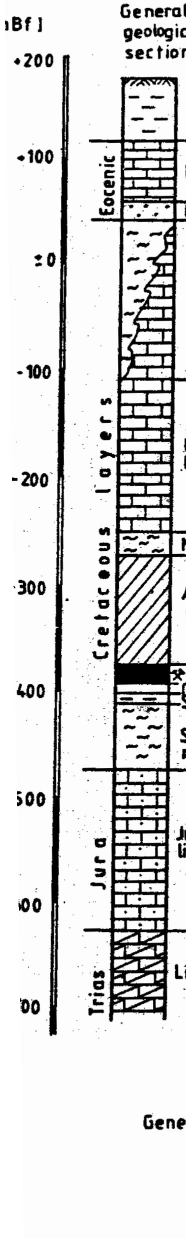
2. THE GEOLOGY IN NUTSHELL AND SOME HYDROGEOLOGICAL CONSEQUENCES

The regional geological conditions are presented on a "stripped" geological map and in two geological sections (see Fig. 1). The sediment collector basin was tectonically preformed after the erosion of an ancient anticlynar structure. As a consequence of this geological structure the bedrock is Jurassic silicatized limestone and marl. According to the experiences these formations are not karstified. No important water conductivity was detected in the exploration holes.

More attention should be paid to the cretaceous limestone (of 200 m thickness) in the overburden of the coal seam, contacting Triassic dolomite at the boundary of the basin, although direct hydraulic connection exists partially in the area of the "windows" (Szantner, Hegedüs 1986). High water conductivity (including karstified caves) was detected by almost all exploration holes in the cretaceous limestone. The stratigraphy is presented in details in an average geological profile of the coalfield (see Fig. 2) where the key mechanical parameters of the rocks are also marked.

On the basic of the geological conditions presented above two consequences can be drawn:

- The reservoir bedrock of low permeability is separated from the coal seams by protective barriers. Consequently the water danger from the roof will probably not disturbe the exploitability of the coal reserves. Later preliminary statement was proved even by more detailed studies.
- Although the upperlaying karstified reservoir is very dangereous, the 100-150 m thick series of impermeable beds between the exploitable coal seam and the upperlaying reservoir may provide good chance for partial coal extraction, (using e.g. panel and pillar method).



General geological section	Avg thickn.	(km)a	σ_c	σ_t	ϕ_c	τ	E	W_L	Ip	n
	m	m³/sec	MPa	MPa	°	MPa	10 MPa	%	%	%
Limestone, marl	60	$4{,}3 \cdot 10^{-5}$	35		45		25			6
Conglomerate	10									
Marl with/or limestone	150		20 - 80		50		20	3		
Ugodi limestone	150	$2{,}3 \cdot 10^{-3}$	40 - 80	5	35	12	45			2
Marl	30		25		35		3			
Aleurit mixture	100		35-12		35	7	10 - 20			
☆ Seam	8									
Clay	10		10	0,7	33	1,7	15			
Soft clay	15				15		0	75	40	
Sümegi marl	0 – 150		45		34	10	15			
Jurassic limestone	150	$3{,}5 \cdot 10^{-5}$	35		35		70			
Limestone										

General geological section with mean values of the rock parameters

Fig. 2.

Under impermeable beds of similar thickness water bodies (including the sea) were undermined successfully applying proper mining methods to preserve the protective effect of the undermined impermeable layers (Mohr 1965, Hohlov 1971, CCMRI 1976, Kesserü 1976, Loofborough 1976, Babcock and Hooker 1977, Gviroman 1977, Singh 1986).

Attention should be paid to the presence of an extremely soft clay bed in the roof layers with special regard to the subsidence of the pillars.

As a consequence of the above conditions the investigations on the quantity of the exploitable reserves should be focused on the water danger from the upperlaying karstified reservoir.

3. THE KEY QUESTIONS

When evaluating the exploitable coal reserves two main questions had to be answered:

- Whether there is any proper mining method which allows to extract a part of the coal reserves without any drainage of the upperlaying reservoir. (This part of the reserves should be enough for 2 - 3 million tons of yearly production in a 20 - 25 years period.)
- Whether there is any drainage method, which requires only a limited yield (less than 200 m^3/min) to protect the exploitation of the remained reserves after 2020.

4. THE POLICY AND METHODS OF THE INVESTIGATIONS

4.1. The possibility of utilizing analogous experiences

Experiences in connection with undermining water bodies are available for the following geological conditions:

- The undermined layers were all soft rocks (e.g. clay, week clayey marl and sand) (Kesserü 1976, 1979.CCMRI 1976, Kesserü, Havasy 1984, Shaji Ihi 1962).
- Hard rocks were undermined (Hohlov 1971, Gviroman 1977, Babcock and Hooker 1977, Singh 1986, etc .).
- The undermined sea bed was covered with soft layers, the soft layers and the coal seams were interbedded by a series of hard rocks. (Loofborough 1976, Whittaker, Aston 1982).

According to Fig. 2 the upperlaying series in the Ajka II coal field consists of hard beds of 500 m and week layers of 100 - 150 m between the hard rocks and the exploitable coal seam. The reservoir to be undermined is located in the upper zone of the hard series. There is a very soft clay bed in the roof of the coal seams. Although experiences relating to analogous conditions are not available, the requirements on the reliability of investigations were extremely high to exclude any risk of human life loss and flooding or any damages of the natural environment.

The policy and methods of the investigations were selected with special regard to these requirements.

4.2. The policy of the investigations

- During the preliminary study for the evaluation of the uncertainties of decision making:
  - -- Regarding the model uncertainties of the modul, more different models, approaches were applied to study the same process.
  - -- Regarding the uncertainties of the parameters, the parameters were taken into account with intervals instead of one medium value.

During the mining operation in order to exclude any failure caused by unfitted models the following measures are planned:

- -- The first mining operations will be started under "super safety conditions" (e.g. applying "super safety size" of pillars determined by the preliminary studies).
- -- All possible measurings should be carried on during this first operation to get the necessary parameters for fitting the models of sizing.
- -- The next operation will be sized by fitted models.
- -- Measurings and the models fitted better and better to the natural conditions will be the everyday tools for the operative management of mining.

Additional safety measures (standby measures) are also planned to protect the human life for any unforecasted case.

4.3. The main steps of the preliminary investigations

4.3.1. Procedure to determine the possibility and feasibility of partial extraction without any water from the roof.

The following subsequent investigations were performed:

- The proper method and criteria for evaluating the protective effect of the undermined layers was selected first with special regard to the given conditions. (For more details see Chapter 5.1).

- The mechanical status of the undermined protective layers was analysed using reversal models (numerical simulations: as finite element models. Everling models, two dimensional and spherical ones, equivalent material models of different sizes) under conditions of different methods and sizes of coal extractions (panel and pillar methods of different sizes, slicing etc.). (For more details see Gajári and Machalek and others 1987).

- In accordance with the mechanical status and with the criteria for evaluating the protective effect of the undermined layers the safety versions of exploitation were determined. These versions of exploitation (e.g.the sizes of pillars and panels) were the bases to determine the exploitable coal reserves for the first period (till 2020).

- The proper methods and ways of measurements for the first mining operations were designed next. All planned ways, methods and the devices necessary for these measurements are in use in the mines of Veszprém Coal Company.

- Additional safety measures were also designed to protect the human life and to increase mine safety against flooding for any unforecasted conditions.

4.3.2. The possibility and feasibility of the drainage of the upperlaying karstic reservoir was studied for determining the exploitability of the coal resources of the remained pillars.

The steps of the study were as follows:

- More exact data and parameters of the upperlaying karstified reservoir were obtained first:
  - -- The water conductivity and storage parameters were determined by using not only conventional methods, but new ones, like pulsation interference test, were also applied. This method is cheap and gives more information under unisotropic conditions of conductivity (for more details see Tóth and Megyeri and Szilágyi 1987).
  - -- More exact knowledge of the boundary conditions is given by bauxite explorations at the boundary area (Szantner and Hegedüs 1986).

- Using these more exact parameters finite difference model studies were carried on to compare more versions of drainage regarding the drinking water demands and environmental aspects. The parameter uncertainties were also taken into account.

- As a result of these studies a drainage version was offered which meets all requirements of mine water utilization and of environmental limits. It means that the whole coal reserve can be considered as exploitable under the given environmental protection requirements.

5. SOME DETAILS OF THE ABOVE STUDIES

Some of the studies listed in subchapter 4.3. are discussed in details in other papers of these symposium (see Gajári and Machalek 1987, Tóth and Megyeri 1987). Only one main question is discussed herein.

This is :

- the proper criteria for undermined protective barriers

5.1 Selection of the proper evaluating method and the criteria of protective layers

This is the key question of the exploitability of coal reserves if the upperlayin g karstified reservoir must not be drained. In subchapter 4.1. the absence of analogous geological conditions was pointed out. For the above reason s more sophisticated con siderations were taken in this respect.

5.1.1. General considerations on evaluating the protective layers/barriers

The protective layer/barrier should be evaluated simultaneously in two respects. These are:

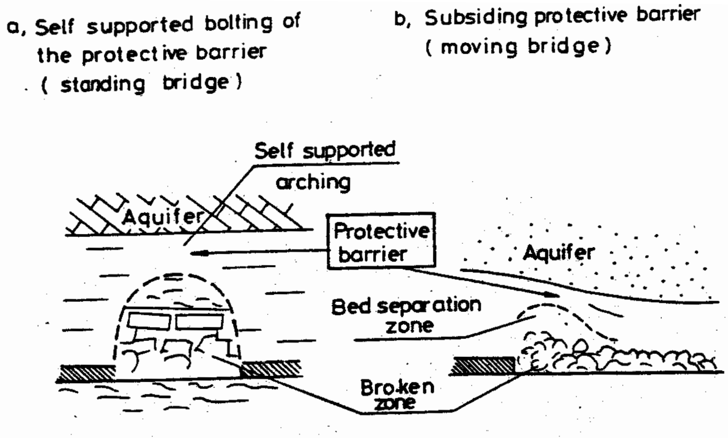
- The "mass stability" of the undermined protective layer.
- The stability of the local zones against starting the in rushes.

5.1.1.1. The "mass stability" of undermined protective barrier can be evaluated like a "dam" or a "stone bridge".

This "bridge" is quite visible in case of forming a stone arch (see Fig.3/a) over the broken area and the zone of bed separation (e.g. Singh 1986). These conditions are present in most of the cases of partial extraction (e.g. panel and pillar methods).

In case of full extraction the "stone bridge" of the protective layer is subsiding and moving continuously.

Many case examples of soft roof layers are known, where the protective effect of the undermined protective barrier



The protective barrier as a "stone bridge"

Fig. 3

was served even under the conditions of extreme subsidences (30 - 50 m) (e.g. Kesserü 1976).

The way of evaluation of the mass stability is the rock mechanical analysis of the undermined layers. As a result of this analysis the broken zones, areas of bed separation and open fissures are determined which zones must not be regarded as protective barriers. For determining these zones experiences of analogous conditions (Mohr 1965, Fides and Valkovič 1965, Harsányi and Staudinger 1968), simplified mechanical models (Gviroman 1977, Singh 1986), numerical simulations, like finite element model studies (Kesserü 1977, CCMRI 1976), equivalent model studies (Gviroman 1977, Whittaker 1985) been are used. The estimations are also compared with and fitted in the data of measurements (Hohlov 1971, Ahcan, Hrasnik 1974, Kesserü 1976, Gviroman 1977, Whittaker 1978, etc.).

5.1.1.2. Considerations on the protective effects at local zones

The possible ways of local failures in the protective layer strongly depends on rock properties as discussed below:

- Even open fissured zones of hard rocks are able to limit the water yield because of their permanent hydraulic resistance.

- In soft rocks, after the water starts to flow through, the permanent hydraulic resistance of the fissures cannot be quaranted (e.g. because of piping). Consequently: the risk of starting any water throughflow has to be excluded (Kesserü 1976, 1979, 1982).

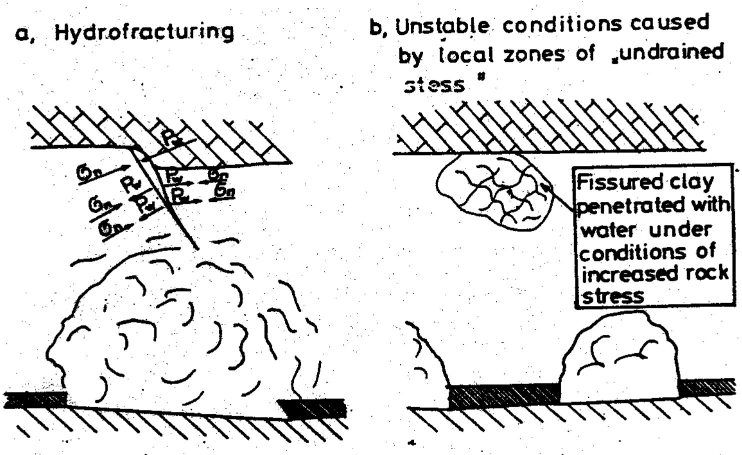
In the Ajka II coalfield the interbedding layers between the upperlaying karstified reservoir and the exploitable coal seams are mostly week rocks, although hard beds also occur. Consequently the risk of starting any water throughflow should be excluded.

The risks of water throughflow were studied in all possible ways of local failures. These are is follows (see Fig.4):

a/ spontaneous hydrofracturing through the impermeable bed (Fig.4/a);

b/ critical stability of fissured zones in impermeable beds (Fig.4/b);

c/ sandy lenses in the impermeable layer (Fig.4/c; Fig.4/d).



Ways of local failures in the impermeable protective barrier.

Fig. 4

a/ The spontaneous hydrofracturing

is quite the same process as the hydrofracturing, which is well known and thoroughly studied in the petroleum reservoir engineering practice as a well-treatment method or as a spontaneous failure (Radzev and Navlyutov 1970, Mahoney Stubles 1981, Waprinski, Clark 1982, Waprinski Schmidt 1982) and even in the high pressure grouting practice (Kassai, Solymos 1981).

According to the references mentioned below hydrofracturing starts, when the fluid pressure (p_w) is less than the initiating pressure of hydrofracturing (p_{hf})

$$p_w < p_{hf}$$

The initial hydrofracturing pressure depends strongly on the minimal rock stress component (Waprinski, Clark 1982).

The flow stops if the fluid pressure is less than the closing pressure (p_c), which closing pressure is quasi equal with the minimal normal rock stress component (σ_{min}).

$$\sigma_{min} \approx p_c < p_{hf}$$

Consequently a more safe criterion against hydrofracturing is:

$$p_w < \sigma_{min}$$

Under intact conditions, the liquid-phase pressure (e.g. p_w) never exceeds the hydrofracturing pressure in intact rocks, but forming and abandoning the mine openings the minimal rock stress component is less than the original one, consequently the hydrofracturing pressure (p_{hf}) also decreases, which stress status may form the conditions necessary for spontaneous hydrofracturing.

As a consequence of the above considerations the conditions necessary for spontaneous hydrofracturing may occur only in "changed rock stress zone" around mine openings but for safety reasons their risk is excluded if $p_w < \sigma_{min}$.

Earlier the general criterion used in Hungary for evaluation of the soft impermeable layers was the threshold value of specific thickness of the protective layer (ν) (Vigh and others 1946) or its inverse the threshold hydraulic gradient (Schmieder 1970, 1976, 1982). This approach was used even abroad (Kesserü 1976, Ahcan 1977).

According to our approach of evaluation (Kesserü 1984) the threshold value of the protective layer represents also the criterion of spontaneous hydrofracturing. Some phenomena at the start of the inrushes (increased rock pressure, etc.) are also very similar to the phenomena, which occur during grouting over the hydrofracturing pressure around mine openings.

b/ Unstable conditions of the fissured zones

in impermeable beds (e.g. in clay breccia in tectonic faults) may occur under all those conditions if the rate between the pore (fissure) water pressure and rock pressure change (see Fig.4/b). These critical conditions can be tested experimentally, too. (Kesserü 1976)

If $p = \sigma_{max}$ local failure should occur, because the fissurized system will lose their inner friction. Depending on the anizotropy of strength parameters (e.g. inner friction and cohesion)

$$p_w > \sigma_{min}$$

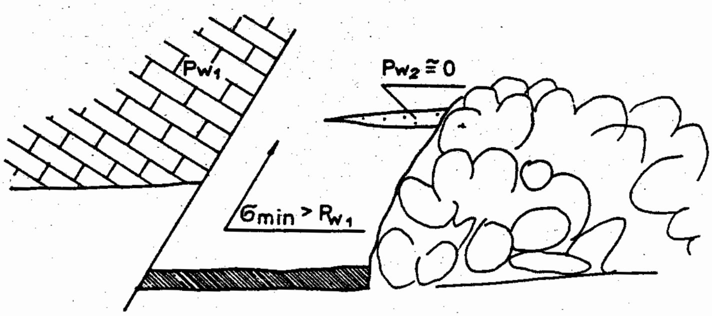
may also cause local failures.

It means, that for cases a/ and b/ the same criterion $p_w < \sigma_{min}$ of safety can be applied.

c/ The sandy lenses in the impermeable protective barrier may also cause local failures.

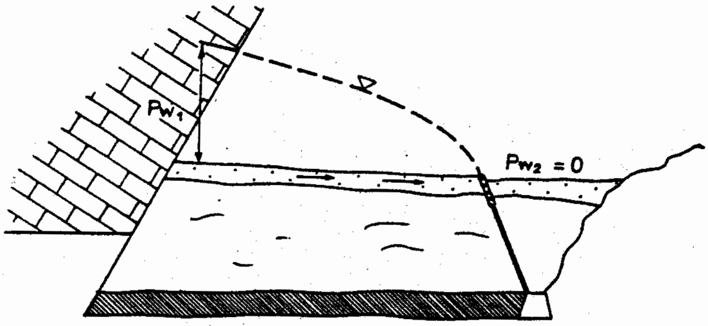
Two typical cases should be considered:

- closed sandy lenses (Fig.4/c);
- lenses laterally con nected with the karstified reservoir (Fig.4/d).



Case c, Sandy lenses without lateral contact with the karstified reservoir

Fig. 4.



Case d, Sandy lenses laterally contacting with the karstified reservoir

Fig. 4

In case of closed sandy lenses two ways of local failures should be considered. One of them is the risk of hydrofracturing between the nearest lense and the mine opening. This hydrofracturing may cause sandy water inflow with piping or caving in the sandy lense. Because of this piping and caving process the stress conditions of the rock-water system change in the far area from the opening, which may iniciate water inrush from the karstified reservoir. The second way of local failure may be caused by the decreasing the rock pressure below the water pressure of the lense, which is equivalent with case b/.

In order to protect against both ways of failures the same criterion $\sigma_{min} > p_w$ has to be fulfilled.

Consequently to prevent against local failures in cases a/, b/ and c/ the same criterion should be used for evaluation .

c2/ The case of lenses connected laterally with the karstified reservoir is an exceptional one, because the risk of water flow cannot be excluded.
For this case the realistic goal is to preserve the mechanical equilibrium of the rock-water system even under water seepage conditions by applying special measures as preventive drainage, or water barrier pillars.
To select the proper measures the lenses should be explored and tested by holes bored from the mine openings (before undermining).
If a quasi-stationary depressurized condition can be reached the broken zone or the zone of bed separation can contact the totally depressurized area of this lense. If this condition cannot be reached, water barrier pillars should be applied.

As a consequence of the above considerations the safety criteria can be summarized as follows:

Between the undermined reservoir and the mine openings (including abandoned area: broken zone, bed separation zone, etc.) 15 - 25 m of effective protective barrier of impermeable beds are necessary, where the criterion against local failures

$$\sigma_{min} > p_w$$

has to be fulfilled (see Fig.5).

In cases of sandy lenses connected laterally with the reservoir, expectional measures should be taken, as discussed before.

The mechanical status of undermined protective barrier for more versions of total and partial exploitation was analysed using several models (as mentioned before). As a result of comparing the stress conditions and the criterion of the local failure, the proper version of partial extraction (sublevel caving with longwall faces: max. face with 100, and minimum 100 m pillars between faces) was selected (for more details see Gajári and Machalek 1987).

Since the stress conditions at the undermined roof of the proper version is already known, the deformations are also given.

The maximum tensile strength is:

$$\varepsilon_{max} = 3 \cdot 10^{-3}$$

According to the British practice relating to hard rocks, the permitted limit is 8 - 10 . 10^{-3} (Singh 1986).

The maximum value of torsion (the inverse of the minimal radius of deformation) is:

$$\frac{I}{R_{min}} = 2,\ 3.10^{-3}\ (m^{-1})$$

According to the measurements made in 17 mines of four coalfields of carboniferous age in the USSR, the above value of I/R_{min} was safety for all cases (under conditions of argillite-aleurolite type of sandstones) (Gviroman 1977). The stress criterion, which excludes the risk of any water throughflow seems to be more rigorous even for deformations. Let us point out, that a criterion relating to one or more deformation parameters is theoretically unsufficient against local failure in soft rocks, because the risk of failure depends on the relation between the reservoir pressure and the absolute value of rock pressure (as discussed before). But a deformation criterion refers only to a given stress difference. Let us mention, that the application of the stress criterion $\sigma_{min} > p_w$ even for conditions of hard rocks may also provide some advantages, e.g.

- σ_{min} or p_{hf} can be measured, detected in boreholes quite easily, but the deformation criterion parameters (as ε_{max}, I/R_{min} cannot be measured directly.
- Experiences of analogous conditions are not very necessary.
- It provides more safety criterion against local failures.

6. CONCLUSIONS

From the viewpoint of evaluating the exploitable coal reserves, the investigations provided all of the necessary information. Among these some more generalized conclusions can also be summarized. These are as follows:

- For the evaluation of coal deposits under heavy water danger (regarding also the strong requirements of environmental control) the conventional hydrogeological exploration and evaluation are not sufficient. More detailed studies, including the comparison of realistic technical versions for mine water control and for mine water utilization should be carried on simultaneously with the last phase of geological exploration.

  The Ajka II case presented herein is not the only one in Hungary in this respect.

- The approach and criteria for the evaluation of the protective water barriers/layers may also be applicable for more other cases.

These general conclusions were the main purposes to present this paper.

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