# THE EFFECT AND UTILIZATION OF PROTECTION LAYERS IN MINE WATER CONTROL

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## SUMMARY

Movement of water and rock is analysed in the system of aquifer and protection layer in order to reveal the behavior of the protection layer and to recognize new mater control possibilities.

The water inrush process in interpreted from energy aspect, and process identification is used for deriving the energy budget equation of water inrushes, and the operation of the protection layer. Dynamic properties of the water flow lead to the coefficients of reduction and sealing of the protection layer. The derived relationships are used for discussing the possibilities of protection layer utilization, the reinforcement of the protection layer, and the principle of the "instantan" water control method.

## 1. INTRODUCTION

Those rocks between aquifers and artificial underground openings, such as mining spaces are definied as protection layers which are capable of preventing or decreasing water flow. Their water control role is characterized by their sealing and reduction effects /Schmieder, 1972./.

The physical phenomena in the protection layer was almost uniformly explained by the initial condition of water flow in this layer. This was characterized by the necessary specific thickness of the protection layer /Vigh, 1949, 1952/, which can be interpreted as the reciprocal of the threshold hydraulic gradient /Schmieder, 1966, 1970/.

A growing mining depths and the resulting experience have shown that water flow in the protection layer can be induced by a change of state pertaining to another energy threshold, such as the hydraulic rock fracture or the hydraulic rock failure. As a result, practical conclusions based on the generalization of large-scale experience on the lower energy threshold may not be valid any more. Inrushes through the protection layer are studied now in order to attain a more general answer to the operation and water control effect of the protection layer. In such a way, new areas of process control will be a revealed.

## 2. ENERGY INTERPRETATION AND CHARACTERIZATION OF THE WATER INRUSH PROCESS

Mining inrush is called such water inflow which is stochastic and not artificially drained.

Mining spaces regardless to their technological function operate as drainage elements. This drainage effect can be direct if the openings are located in aquifers such as tectonically fractured karstic limestone, dolomite or ore body. The drainage effect may be indirect if the opening is located in an adjacent inpermeable rock such as coal or marl. Under such more frequent conditions water from the aquifer can enter the opening only if the resistance of these adjacent rocks, the protection layers is overcome. This would happen where the protection layer breaks, becomes fractured or its previous, smaller fractures expand.

In both cases, a new equilibrium is reached by self-regulation, a common property of free systems. Self-regulation is the spontaneous endevour of nature to restore the energy equilibrium distorted by mining openings in view of the smallest energy level.

In this process, state transition of material and energy transports results in minimum free energy of the system, while its entropy becomes maximum due to the dissipation energy.

Finally a steady-state energy balance is reached as expressed by the Bernoulli equation

$$s = h_D + \frac{v^2}{2g} \qquad /1/$$

where the first term means the dissipation energy and the second one is the kinetic energy.

In lack of protection layer equalization starts immediately at the smallest pressure gradient and lasts as long as the new equilibrium is reached or without drainage the opening is filled up and the piezometric head difference, $s_0$ is eliminated.

Such water inflows are called inrushes without reduction effect. Their empirical and statistical behavior /Fig. 1./ that is, their energy budget equation can be described for fractured and karstic rocks by the same general equation:

$$s_o = a_o\, q + b_o q^2 \qquad /2/$$

Terms in equation /2/ can be expanded /Schmieder 1972, 1975/:

$$s_o = \frac{q}{2\pi\ kM} \ln \frac{R}{X_o} + \frac{q}{\pi\,/km/} \ln \frac{X_o}{\Delta_o} + \frac{q^2}{/km/^{3/3}\Delta_o} \qquad /3/$$

where q: inrush yield; kM: average aquifer transmissivity; km: local laminar transmissivity of the conducting fault zone; R: radius of the cone of depression; $X_o$: half distance of fault zone; $\Delta_o$: equivalent radius of inrush.

In the presence of protection layer, conditions of water flow are modified: seepage starts if available energy, $s_o = H_1 - H_2$ is greater than the resistance, $E_o$ of the protection layer against seepage. If the difference

$$s_o - E_o < 0 \qquad /4/$$

in every point of the opening, no seepage can start, and the protection layer behaves as a perfect sealing structure. If the energy difference or its relative value

$$\mu(\nu) = \frac{s_o - E_o}{s_o} = 1 - \frac{E_o}{s_o} \qquad /5/$$

becomes positive either in a few points or along greater surfaces, state transition occurs, and seepage starts, leading sooner or later to an inrush.

Winkléner /1903/ analysed mining experience of the Esztergom coalfield, and showed that inrushes occur in tectonically fractured and weakened zones of faults. These findings were refined on morfologically bases by Vigh and Szentes /1952/ demonstrating that tectonics will denote zones of highest available energy, that is, boundary points of inrush configuration.

If these zones are approached or crossed by mining openings, inrushes take place and their frequency greatly depends on the protection layer.

In Hungary first Vigh /1950/ showed that the higher is the specific thickness of the protection layer.

$$\nu = \frac{m_o - h}{0{,}1\ s_o}\ \text{m/bar} \qquad /6/$$

the smaller is inrush frequency, and above a certain $_o$ no inrush would occur.

Spatial frequency of inrushes in the Dorog coal field

$$\bar{\mu}(\nu) = \frac{n}{n_o} \qquad /7/$$

decreases as specific protection layer thickness increases /Fig. 2./. In accordance with Vigh's early findings, the chance of inrush occurrence, or the average coefficient of cealing becomes negligible above a certain value of $\nu_o$ /Schmieder, 1972/.

At values lower than $\nu < \nu_o$, inrush yield first increases in time generally, then slowly or more rapidly decreases.

Most of the inrushes carry more or less sediment in the initial period. After a certain time, a new dynamic balance is formed, sedimentation is stopped, and the inrush yield becomes relatively stable.

After seepage starts protection layer acts as a front resistance, and, serially connected to the aquifer it may play an active role in energy dissipation. This effect of the protection layer is called the reducive effect and a reduced yield of inrush occurs, which can be described by the empirical or statistical energy budget equation similarly to inrushes without this reduction.

Observation data can be explained by the following regression equation

$$s_o = aq + bq^2 \qquad /8/$$

which is similar to the energy budget equation /2/. Curves start from the origo, and have varions slopes depending on the reducing effect. Different slopes pertain to the statistical curves.

Considering average stabilized yields of inrushes as plotted against the average depth below actual water level, and the effective thickness of protection layer, the curves start in increasing distance from the origo /Fig. 3.a./.

The regression equation, that is, the energy budget equation was expressed for the mentioned Dorog example /Schmieder, 1976./

$$\bar{s}_o = \bar{I}_o\bar{m} + a_o\bar{q} + b_o\bar{q}^2 + a_1\overline{mq} + B_1\overline{mq}^2 \qquad /9/$$

where $\bar{I}_o$: the average threshold gradient for seepage; $\bar{m}$: average effective thickness of the protection layer; $a_o$, $b_o$: regression coefficients depending on the protection layer.

It is to be emphasized that equation /9/ expressing the stochastic relationship holds for the general process and not an actual one. The average energy loss in the protection layer is the sum of protection layer resistance $E_o$ and dissipation energy in the zone of protection less than $\nu_o$.

In equation /9/ constant term $\bar{I}_o\bar{m}$ expresses that no seepage, consequently inrush can occur at depth below

$$s_o \lesssim \bar{I}_o\bar{m} \qquad /10/$$

or at specific protection higher than

$$\nu_o \gtrsim \frac{1}{I_o} \qquad /11/$$

This latter value for Dorog coalfield is 4 m/bar.

Where specific protection was less than $\nu_o$, seepage occured and further, in the Dorog coalfield, protection layer exerted both the sealing and reducing effects.

## 3. REDUCING EFFECT OF THE PROTECTION LAYER

The reducing effect is related to the dissipation energy in the protection layer. Since this energy cannot be measured directly, it can be characterized by the average yield reduction /Fig. 3.b./ or the average relative yield reduction, the reduction coefficient

$$\bar{\varphi}/\nu/ = \frac{\bar{q}/\nu/}{\bar{q}_o} \qquad /12/$$

for the same aquifer and depth /Schmieder, 1962./. The behavior of $\bar{\varphi}/\nu/$ /Fig. 3.c./ is the same as that of $\bar{q}/\nu/$. Thus, the reduction coefficent expresses for a given aquifer, the relative yield reduction which is attributed to protection layer resistance.

The regression equation /Fig. 3.c./ can be written as the ratio of average yields expressed from the energy budget equations /2/ and /9/.

$$\bar{\varphi}/\nu/ = \sqrt{\frac{b_o}{b_o+b_1\bar{m}} \left(1 - \frac{\bar{E}_o}{s_o}\right)\left[\frac{\lambda/\nu/}{\lambda_o}\right]^2}\ , \qquad /13/$$

where / / and $_o$ : coefficients of hydraulic interference for inrushes with and without reduction effects resp. /Schmieder, 1972./.

Equation /13/ shows that reduction coefficients are about the same for areas of the same depth, geologic and hydrogeologic conditions and effective protection layer thickness.

In such cares the expected value of the average reduced yield of inrushes can be calculated in an analogous way by multiplying the average yield $\bar{q}_o$ of inrushes without reduction effect and the average reduction coefficient.

$$\bar{q}/\nu/ = \bar{\varphi}/\nu/\bar{q}_o \qquad /14/$$

If the resistance of the protection layer is characterized by $\bar{I}_o\bar{m}$, the reduction coefficient can be used for the above analogous computation as long as dynamic conditions for the beginning of seepage do not change.

When dynamic conditions change such qualitative alterations are possible which may lead to the formation of inrushes without any reduction effect of the protection layer.

## 4. RELATIONSHIP BETWEEN DYNAMIC PROPERTIES OF SEEPAGE COMMENCEMENT AND YIELD REDUCTION

Most significant changes occur during hydraulic rock failure due to the seepage force in the protection layer.

In rocks with small or without cohesion seepage force from the underlying rock may reach the shearing resistance of the protection layer. This would cause piping failure.

The most severe condition of hydraulic rock failure is that the effective main stress becomes zero as an effect of the seepage force

$$\bar{\sigma}_z = 0, \qquad /15/$$

or the piezometric head reaches the value

$$E_o = /1-n/ \frac{\varrho_k - \varrho_v}{\varrho_v} \; m \qquad /16/$$

In this Terzaghy criterium n is pore volume and $\varrho_k$ and $\varrho_v$ are mass densities of rock and water resp.

If piezometric head gradually reaches the above critical value, hydraulic failure and ensning inrush occur relatively slowly. This is the case in deep foundations, or flood level. If piezometric head is large, as typical to mining operations, hydraulic failure and the resulting inrush occure suddenly as an explosion with great deformation velocity. Such inrushes carry large-amount of sediment, cause considerable cavity and soil erosion.

Similar process takes place not only in cohesionless soil but in clay too.

In cohesive soils, the condition for soil failure is again the diminishing shearing resistance which prevails if actual piezometric head equals the critical value

$$E_o = c \, \frac{\operatorname{ctg} \phi'}{\varrho_v g} + /1-n/ \frac{\varrho_k - v}{\varrho_v} \; m \qquad /17/$$

where c: chesion; $\phi' \gtrsim \phi$ : angle of friction; g: acceleration of gravity.

As an effect of the flow, pipes formed in the clay are expanding as long as shearing forces occur on the wall of the pipes.

An equilibrium is reached when the shearing stress is stopped again and consequently water erosion is also stopped. This corresponds to the state, when the reduction coefficient for the soil pipe is unity /Schmieder, 1977./.

$$\varphi/\nu/ = \sqrt{1 - A\tau} \qquad /18/$$

As a consequence, if hydraulic rock failure causes inrush, this would flow without yield reduction.

In the above care, sand inflow coincides with water inrush if the aquifer consists of loose sedimentary rocks.

Empirical data of 240 inrushes in the Várpalota coalfield are now used for supporting the above principles.

In this area, there is 5-20 m thick plastic clay layer with cohesion of 0,2-0,5 MPa, underlying the coal seam. This clay layer acts as protection layer between coal seam and a 8-10 m thick porous media aquifer.

As a preindicator of inrush, clay swells. Next show, then stronger seepage occurs and sand inrush takes place. After a time, inrush yield decreases, water is gradually cleaning, and the dynamic equilibrium between rock and water is reached.

Observation data of inrush yield show that average seepage coefficient calculated from inrushes equals with great accuracy the areal average values derived from pumping tests. This demonstrates that inrush yield has no reduction effect.

Simultaneous total areal yield of inrushes is proportional to the energy $\bar{s}_0$-$E_0$ /Schmieder, 1976./

$$Q/\nu/ = \frac{2\pi kM \,/\bar{s}_0 - \bar{E}_0/}{\ln \frac{R}{\rho}} \qquad /19/$$

The head difference $\bar{E}_0$ equals with good approximation the threshold value calculated from equation /17/. Since this equation does not consider stresses increasing with depth, result of the analysis may be explained that compression stresses increasing with depth and tensile stresses caused displacements due to the openings compensate each other through superposition.

Since the reducing effect of clay protection layer in the Várpalota coalfield was not noticable, the protection layer acted as a sealing structure, decreasing discharge according to the ratio

$$\bar{\mu}/\nu/ = \frac{Q/\nu/}{Q_o} \qquad /20/$$

or the average sealing coefficient:

$$\bar{\mu}/\nu/ = 1 - \frac{\bar{E}_o}{\bar{e}_o} \qquad /21/$$

Equation /21/ shows that the sealing coefficient, in accordance with /5/, expresses the ratio of the free energy to the total energy.

In case of protection layers with higher cohesion as clays or marls /Fig. 4.a./, the critical head pertaining to hydraulic soil failure is higher with orders of magnitude than the critical value for soft clay. In general, the critical value is considerably greater than the one corresponding to the expansion of protection layer fractures, which become permeable through this hydraulic rock fracturing.

This can be experienced in rock fracturing applied with grouting and in every case when pore pressure opens rock fractures and modifies stress conditions.

The process was in-situ investigated in Csordakut and the Dorog coalfield /Kesserü et al., 1980./, further developing earlier laboratory analyses /Kesserü, 1976./. An important result of these experiments is shown in Fig. 4.b. According to the observations seepage started in the marl or clay protection layers when head difference reached the value

$$E_o = \frac{\sigma_\alpha}{\rho_v g} + I_o m \qquad /22/$$

Here,

$$\sigma_\alpha = \frac{1}{2}/\sigma_1 + \sigma_2/ + \frac{1}{2}/\sigma_1 - \sigma_2/\cos 2\alpha \qquad /23/$$

is the normal stress closing fractures of angle $\alpha$, $\sigma_1$ and $\sigma_2$ are resp. the vertical and horizontal main stresses.

The experiment showed that it available energy is less than the value corresponding to hydraulic rock failure but greater than the one corresponding to hydraulic rock fracturing, existing fractures in the protection layer are opening, and may lead to inrushes, depending on their conductivity.

There is some amount of sediment in the period between rock fracturing and the new equilibrium as a consequence of erosion in the initial part of the process.

This sediment movement causes expanded soil pipes /Kesserü, 1976, 1978./, but the reducing effect reflected in the energy budget equation /9/ will still exist due its resistance against flow, that is, the dynamic interaction in the rock-water system /Kapolyi, 1976./.

Thus, if inrush is caused by hydraulic rock fracturing, the protection layer acts with reducing and sealing effects as well. In this state flow conditions correspond to fracture flow.

If through expanded fractures the protection layer is soaked and both its cohesion and shearing resistance decrease, pipes will be formed in the layer, characteristic to hydraulic rock failure. Now the earlier reducing effect may gradually cease, leading to increasing discharges.

If this experience is compared to the stochastic balance equation /9/ for the Dorog inrushes, one can note that the expression does not include the deformation effort necessary for fracture opening.

According to equation /9/, stress closing fractures in the protection layer was on the average zero at the inrush point. Thus, water flow started on the average at the energy threshold.

$$E_o = Y_c\bar{\bar{m}} \qquad /24/$$

The large amount of observations from Várpalota and Dorog mainmously demonstrat that inrusues whitin the fracture zone are attached to low-stress zones due to the highest available energy there.

Accordingly, the empirically known sealing coefficient expresses the ratio of maximum free energy to the whole energy.

## 5. SEALING COEFFICIENT

This coefficient expresses the chance of inrushes, as related to the inner resistance $E_o$ of the protection layer. This can be justified through the high-energy Dorog type system of aquifer-protection layer where the total yield $\bar{Q}/\nu/$ of inrushes is approximately proportional to the surface area due to the quasi homogeneous tectonic fracturing /Szabó and Székely, 1968.; Willems, 1969, 1973.; Kesserü and Willems, 1970./.

Because of this surface proportionality the total yields of inrushes stemming from various protection are compared for constant energy $\bar{E}_o$ and surface area. Let us denote $\bar{Q}_o$ the average yield and $\bar{n}_o$ the average number of inrushes under given conditions for $\nu = 0$, and $\bar{Q}/\nu/$ and $\bar{n}/\nu/$ the same for $\nu = \nu_i$. Now the discharge decreasing coefficient $\eta$ can be expressed as

$$\eta = \frac{\bar{Q}\,/\nu/}{\bar{Q}_o} = \frac{\bar{n}\,/\nu/}{\bar{n}_o} \cdot \frac{\bar{q}\,/\nu/}{q_o} = \bar{\mu}\,/\nu/\ \ \bar{\varphi}\,/\nu/ \qquad /25/$$

that is, as the product of the average coefficients of sealing $\bar{\mu}\,/\nu/$ and reducing $\bar{\varphi}\,/\nu/$.

From equation /25/ follows

$$\bar{Q}/\nu/ = \bar{Q}_o\,\bar{\mu}/\nu/\ \ \bar{\varphi}/\nu/ \qquad /26/$$

the general hydraulic model of inrushes whose solution can be found under different boundary conditions in earlier papers /Schmieder, 1972; 1976; 1979./.

Comparing equations /26/ and /20/, it can be seen that for $\varphi/\nu/ = 1$ the two functions are the same, and the sealing coefficient

$$\bar{\mu}\,/\nu/ = \frac{\bar{n}\,/\nu/}{\bar{n}_o} \qquad /27/$$

expresses the probability of inrush occurrence.

If resistance $E_o$ of the protection layer lacks, that is, the sealing coefficient equals to one, then there is an equal chance of inrush occurrence in every point of fault zones in fractured rocks. The average areal inrush density is

$$\bar{n}_o = \frac{/kL/}{/k\bar{m}/} \qquad /28/$$

Equation /28/ follows from the energy balance euqation, and k is the average seepage coefficient, L is the measure of specific tectonic fracturing /Willems, 1973./ and km is the average local transmissivity of fault zones.

The higher is the resistance $E_0$ of the protection layer, the smaller is the chance of inrushes. The empirical frequency curve /Fig. 2./

$$\mu/\nu/ = \exp - \left(\frac{\nu}{a}\right)^2 \qquad /29/$$

has a parameter "a" depending on protection layer properties.

A more exact interpretation of the sealing coefficient is possible if we consider equations /21/ and /27/ and use Taylor-series of $e^{-x}$ for small values of $E_0/s_0$

$$\mu/\nu/ = \exp - \frac{\bar{E}_0}{\bar{s}_0} \qquad /30/$$

Equation /30/ is similar to the Boltzmann distribution of statistical thermodynamics. According to this analogy, sealing coefficient expresses the ordering of energy conditions in the system of aquifer-protection layer, that is, its entropy. From this follows that state transition takes place during self-regulation in such a way that entropy, that is, ratio $\bar{E}_0/\bar{s}_0$ increases in a maximum degree.

Equalization occurs when the sealing coefficient pertaining to stable state becomes zero, or the ratio will be 1:

$$\frac{\bar{E}_0 + \Delta \bar{E}_0}{\bar{s}_0 - \Delta \bar{s}_0} = 1 \qquad /31/$$

After rearranging equation /31/

$$\Delta \bar{E}_0 + \Delta \bar{s}_0 = \bar{s}_0 - \bar{E}_0 \qquad /32/$$

the general mathematical model of self-regulation, that is, the control of aquifer-protection layer system is reached.

If entropy /31/ increases in a spontaneous way without human activity self-regulation corresponds to passive control. Otherwise active control will take place such as stress reduction, gronting, water protection pillars, instantan or combined protection.

## 6. POSSIBILITIES OF INRUSH CONTROL

a./ One of the most generally used methods is stress reduction /Fig. 5.a./. Conditions of equilibrium are that the amount of stress reduction equals to the available energy, that is, equation /32/ holds for every point.

$$\Delta s_o = s_o - E_o \qquad /33/$$

the necessary amount of discharge to be pumped is $\bar{Q}_o \bar{\mu}/\nu/$.

b./ Another widely applied control method is gronting /Fig. 5.b./. Its principle is to increase the resistance of the protection layer

$$\Delta E_o = s_o - E_o \qquad /34/$$

for the increase of entropy corresponding to the equilibrium. In the limit case, energy will not change on the average, thus $\bar{Q}/\nu/ = 0$.

Not only local gronting but control of whole blocks are possible with cement, flyash or clay, but a small chance of inrush occurrance will stay in that case /Schmieder et al., 1976./.

As a consequence, in addition to gronting a pumping station should also be constructed for the capacity of the expected maximum inrush yield $q_{max}/\nu/$. Subsequent control of inrushes in spite of gronting may be also necessary. Such methods are known in passive protection.

A preventive form is the water control pillar along faults, boundaries etc., aiming at eliminating the possibility of inrushes, or, as Fig. 5.c. shows, giving equal chance for the fault and the underlying aquifer. This condition is satisfied if the sealing coefficient, or consequently the protective layer resistance is isotrope.

If the condition of water movement beginning is connected to the threshold gradient, for multilayer rocks of various quality, the equivalent thickness from sealing aspect can be expressed by the help of the ratio of threshold gradients

$$\beta_i = \frac{I_{oi}}{I_{oe}} \qquad /35/$$

as a product /Schmieder, 1970/.

$$m_e = \sum_{1}^{n} \beta_i \, m_i \qquad /36/$$

If a higher energy threshold governs water movement beginning, the equivalent thickness, or the protection of the water control pillar can be determined only by rock-mechanical tools.

c./ A new, less known control method is the instantan protection /Kapolyi, 1975, 1976, Kapolyi, Schmieder et al. 1976/, which utilizes the simultaneous change of protection layer resistance and aquifer energy conditions by a planned inducing of inrushes in advance.

The principle of passive control is that the drainage network corresponds to producing mining spaces. Thus, the aquifer energy reduction, $\Delta s_0$ and the higher resistance, $\Delta E_0$ result in inrushes into mining openings. The equilibrium is expressed by equation /32/.

The increase of protection layer resistance is caused by a change of the set $E_0$. As a result of actual inrushes the smallest values of $E_0$ will be dropped from the set. Consequently, except singularities where inrushes occurred the resistance relatively increases. Available energy is gradually diminishing, and inrushes occur as long as the equilibrium as expressed by equation /32/ is restored.

This natural process is utilized by the instantan control through the formation of a drainage system independently from mining openings /Fig. 5.b/.

Between the aquifer and mining openings to be protected, in the coal seam or the protection layer, a drainage system is constructed prior to mining activity from water cuts and drillings. This drainage system below mining activity aims at a controlled provoking of inrushes which would occur by all means.
As a result, available energy conditions will gradually approach the equilibrium corresponding to naturally in occurring inrushes. Chance of further inrushes decreases, that is, the higher mining operation can be accomplished without considerable extra yield. This control system is being planned for the new Nagyegyháza and Mány mines /Schmieder and Kesserü, 1978/.

The name "instantan" refers to the simultaneous process of stress transformation during drainage system construction then the subsequent exploration and mining.

d./ An important element of instantan protection if the post-gronting of inrushes. This method became a control method in Hungarian mining after Schmidt /1926/, and used mostly for closing high-yield inrushes /Ajtai et al., 1962./. Some data illustrate its effectiveness.

In the Dorog coalfield the inrush yield was higher than the average in 16% among 700 events. This 16% conveyed some 80% of the total flow. By post-gronting the small number of inrushes of excess yield, only 8-10% of the total flow had to be pumped.

Past-gronting can be effected from the surface /Schmidt, 1932; Kassán, 1948; Albel, 1950; Kálmán, 1950; Honvéd and Schmieder, 1978./ or from mine openings. This method changes the state of equilibrium, but does not increase considerably the chance of further inrushes since the other points of the protection layer have larger resistance $E_0$.

e./ Economic control of the highest reliability can be achieved by a proper combination of the former methods. This combined protection aims at pumping minimum amount of groundwater for the necessary safety level.

Water table lowering requires the highest amount of pumping. If water level equals mining level, the expected total flow is $Q_0$ with a relative value of $\eta = 1$. Under the same conditions, discharge reduction coefficients, expressing the role of the protection layer for the other methods are: $\bar{\mu}/\nu/$ for stress reduction, $\bar{\mu}/\nu/\ \varphi/\nu/$ for instantan protection, $\bar{\mu}/\nu/\ \bar{\varphi}/\nu/ > \bar{\mu}/\nu/'\ \bar{\varphi}/\nu/'$ for combined instantan and subsequent gronting, and $\eta = 0$ for combined instantan and regional gronting.

In summarizing, phenomena of rock and water were analyzed in the system of aquifer-protection layer. A uniform physical view was used for considering the operation of the protection layer, and its active utilization and control.

It is clear that protection layer effect can be utilized in a complex manuer according to mining experience. An increased utilization is warranted by frowing mining depths, and more stringent economic and environmental constraints /Schmieder and Kesserű, 1978; Schmieder 1978./. In this respect greatest demands are posed to combined instantan protection and subsequent gronting, and the reinforcement of the protection layer to be applied in new mines of the Eocene Program. Consequently, higher imphasis should be given to understanding all important process and in-situ observations verifying theoretical results based on the above physical view.

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## LIST OF FIGURES

Fig. 1.: Typical performance of karstic water inrushes without discharge reduction

Fig. 2.: Change of frequency of Dorog inrushes as plotted against the specific thickness of the protection layer

Fig. 3.: Stochastic performance /a/ of Dorog inrushes with reduction effect and the coefficient of reduction as plotted against the specific thickness of protection layer

Fig. 4.: Failure curve /a/ of clay, marl protection layers affer Asszonyi and Kapolyi /1976/ and results of gronting experiments /b/

Fig. 5.: Principles of water inrush control

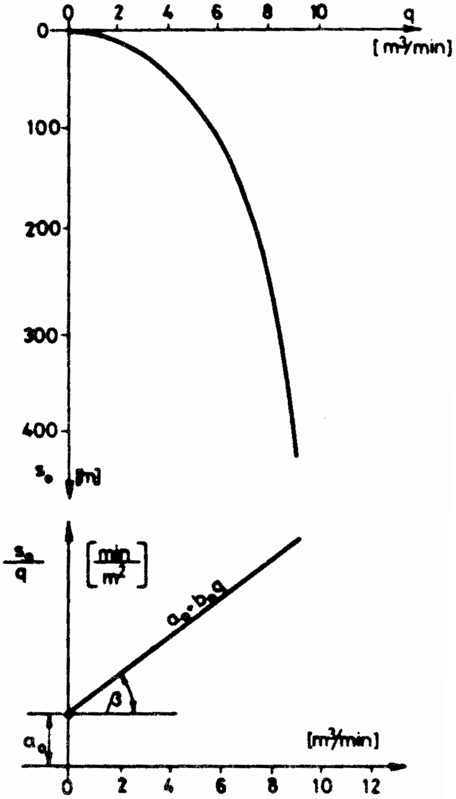
0
2
4
6
8
10
q
[m³/min]
0
100
200
300
400
$s_o$ [m]
$\frac{s_o}{q}$
$\left[\frac{min}{m^2}\right]$
$a_q + b_q q$
β
$a_q$
[m³/min]
0
2
4
6
8
10
12

Fig.1 ábra

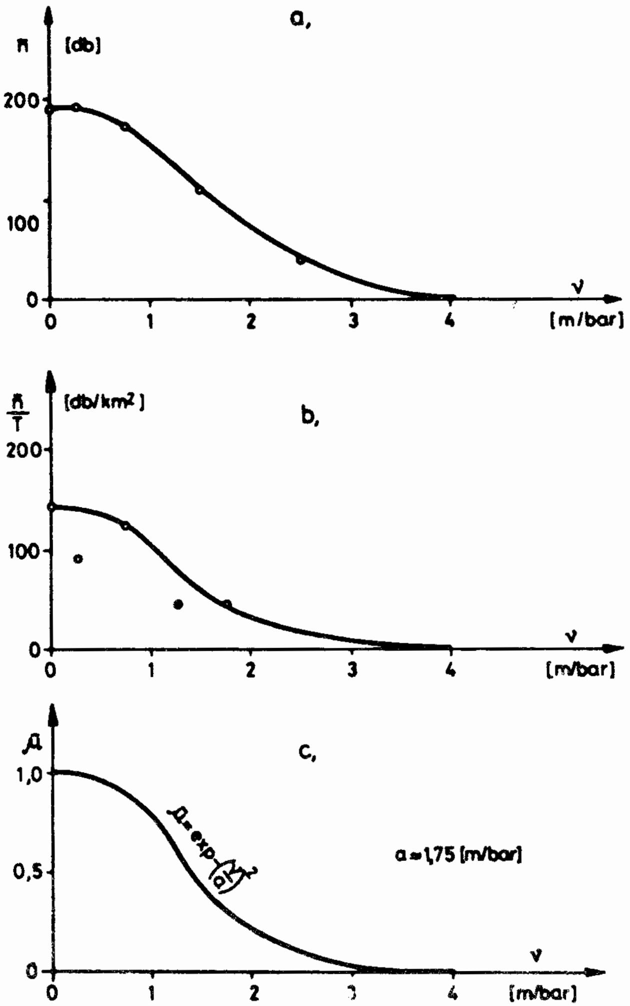
a,
ñ
[db]
200
100
0
0
1
2
3
4
v
[m/bar]
b,
ñ/T
[db/km²]
200
100
0
0
1
2
3
4
v
[m/bar]
c,
μ
1,0
0,5
0
0
1
2
3
4
v
[m/bar]
μ=exp-(v/a)²
a≈1,75 [m/bar]

Fig. 2. ábra

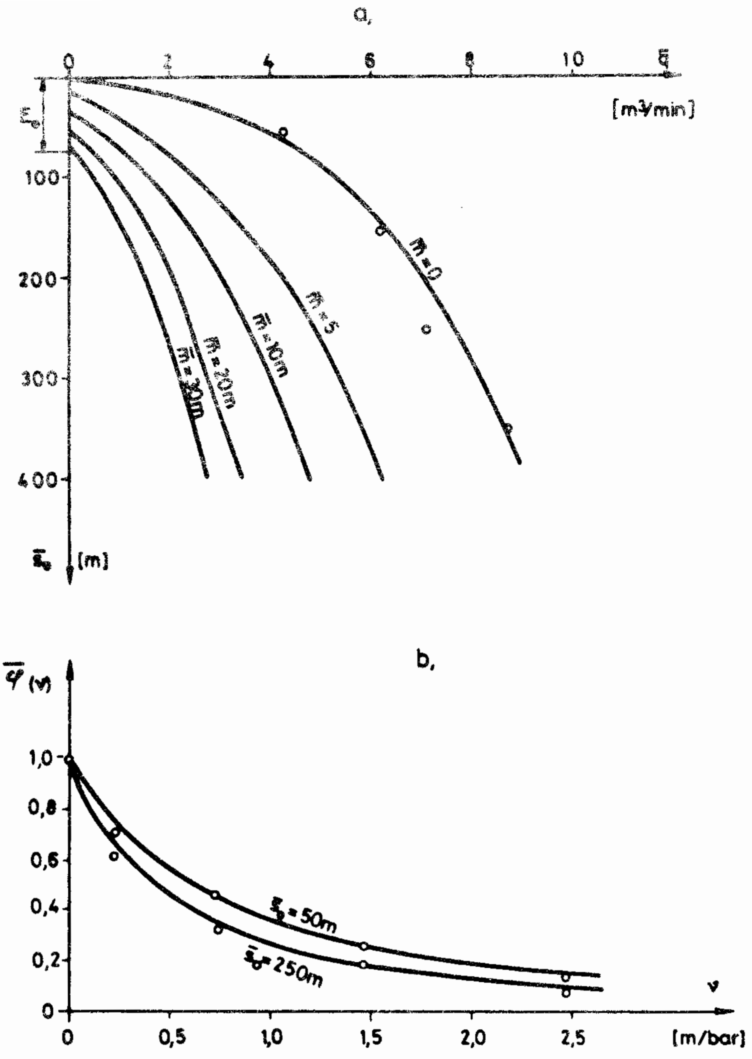
a,
0
2
4
6
8
10
ξ
[m³/min]
$\xi_0$
100
200
300
400
$\bar{s}_0$ [m]
$\bar{m}=0$
$\bar{m}=5$
$\bar{m}=10m$
$\bar{m}=20m$
$\bar{m}=30m$
b,
$\bar{\varphi}(\nu)$
1,0
0,8
0,6
0,4
0,2
0
0
0,5
1,0
1,5
2,0
2,5
ν
[m/bar]
$\bar{s}_0=50m$
$\bar{s}_0=250m$

Fig 3 ábra

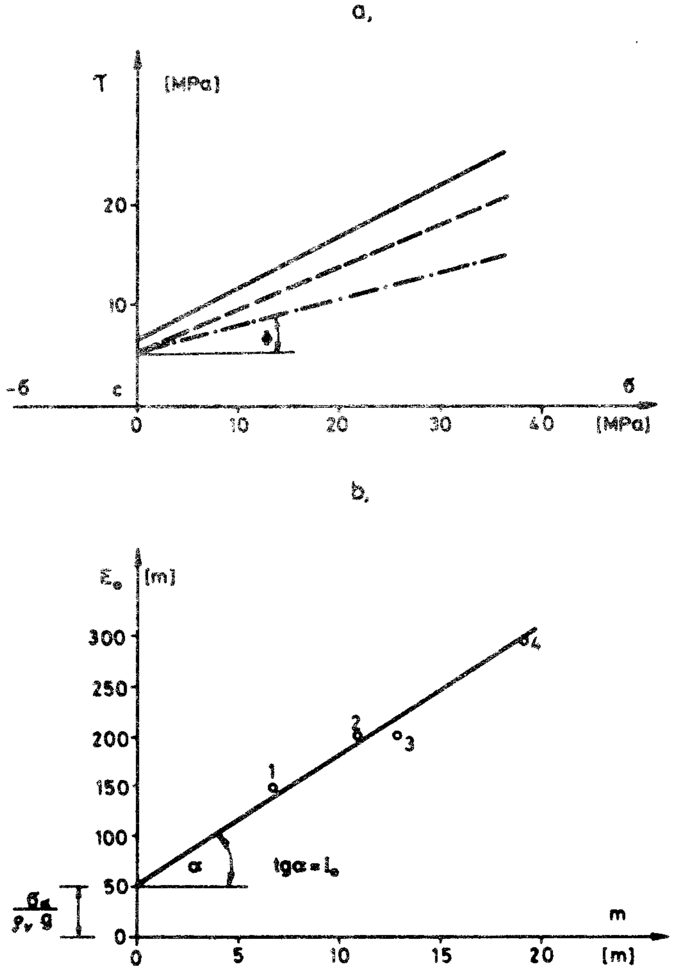
a,
τ
[MPa]
20
10
φ
-6
c
σ
0
10
20
30
40
[MPa]
b,
E₀
[m]
300
250
200
150
100
50
0
σc / ρv g
1
2
3
4
α
tgα = L₀
m
0
5
10
15
20
[m]

Fig.4.ábra

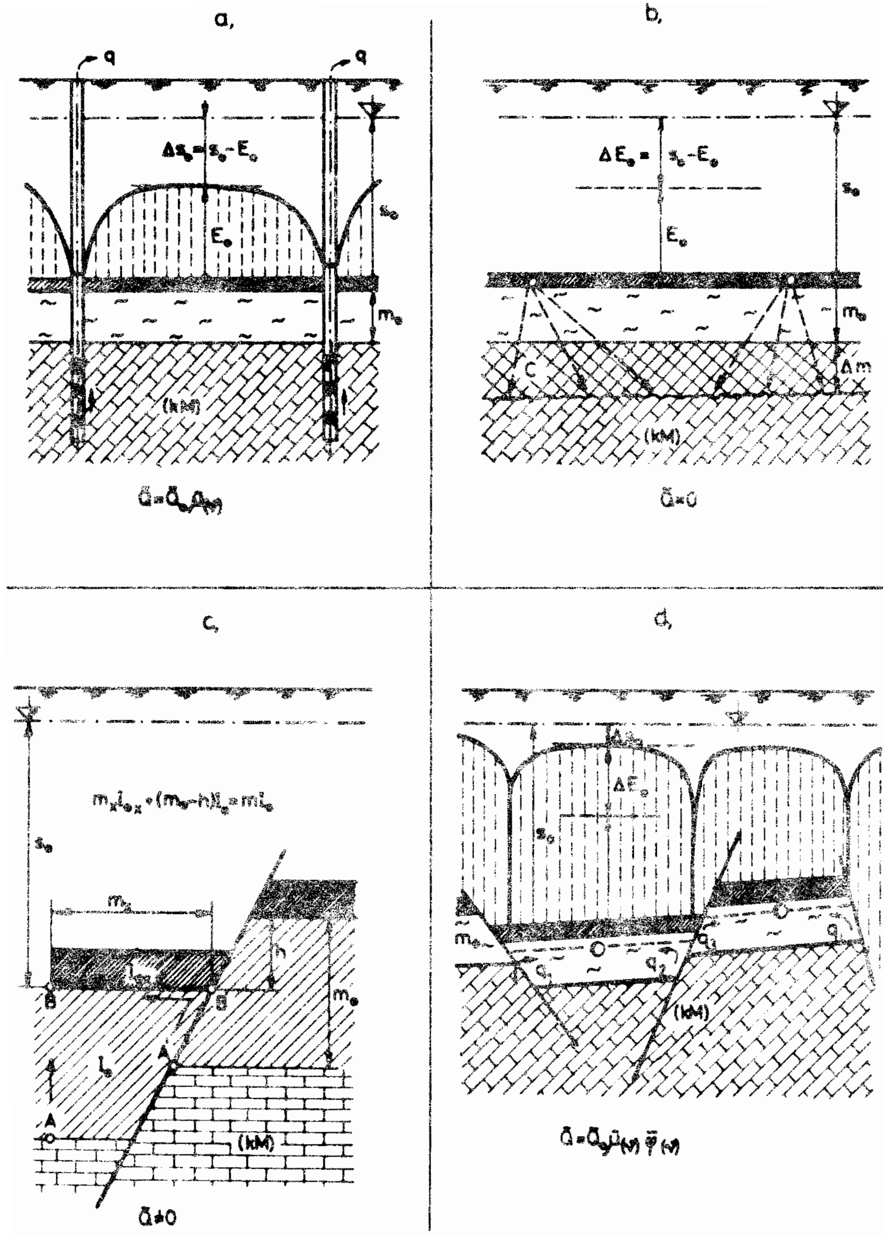
a,
q
q
Δs_o = s_o - E_o
E_o
s_o
m_o
(kM)
Q̄ = Q̄_o A(M)
b,
ΔE_o = s_o - E_o
E_o
s_o
C
m_o
Δm
(kM)
Q̄ = 0
c,
m_x I_ox + (m_o - h) I_o = m I_o
s_o
m_x
I_ox
h
m_o
B
B
I_o
A
A
(kM)
Q̄ ≠ 0
d,
Δs_o
ΔE_o
s_o
m_o
q_1
q_1
q_2
q_1
(kM)
Q̄ = Q̄_o μ(M) φ̄(M)

Fig.5 ábra