INTRODUCTION

Open-pit mining at the Thorez mine affects 3-8 confined aquifers consisting mostly of fine sand. Piezometric levels were as high as/or sometimes higher than/ the proximity of the ground surface prior to mine opening. A drawdown of 40-90 m is necessary for mining. There is considerable inhomogeneity both vertically and horizontally in the aquifers.

Dewatering started by the help of roadways in the middle of 1960, but the resulting high costs led to the application of deep wells in 1963. However, the high requirements of manpower and equipment of this latter method called for more advanced solution. In this line, the study of foreign examples and home research resulted in a decisive change,
the development of the intermediate-layer dewatering method.

THE INTERMEDIATE-LAYER DEWATERING AND ITS APPLICABILITY

Intermediate-layer dewatering can be applied if several aquifers are to be drained or their piezometric levels are to be reduced. If such an aquifer/s/ can be found below the deepest mining level of an open-pit or an underground mine — in an economically accessible depth — from which more water can be drained than from all upper aquifers, this aquifer is an appropriate intermediate /sink/ layer. Piezometric level in this layer is decreased until it is lower than those in the other aquifers. Next, layers are connected by wells and water from the upper aquifers is conveyed through these intermediate wells into the intermediate layer. Water is transported in the intermediate layer to pumping wells. Principles of the method are, thus, the development of an intermediate layer and the communication among the layers. It may be called as a dewatering method by artificial communication.

It is sufficient to bring about head difference for initiating the process. In a favourable case, this may be given already before mine opening. In order to maintain the process one has to maintain this head difference. In this respect, recharge to layers must be caught outside the mining boundary. After that, within the mining boundary, one has to drain only the static water resources.

Principles of intermediate-layer dewatering are illustrated in Fig. 1, and alternative well networks can be seen in Fig. 2. Spacing and configuration of pumped and intermediate wells are determined by the prescribed ratio of discharges from the various layers.

The simplest case corresponds to the following inequality:

\[ q_{vny} > \sum_{l}^{n} q_{vl} + \ldots + q_{vn} \]  /1/

where \( q_{vny} \) is the discharge from the intermediate layer and \( q_{vl}, \ldots, q_{vn} \) are discharges from the aquifers to be drained.

If inequality /1/ holds even before mine opening, dewatering can be affected according to Fig. 1B. The corresponding well network /Fig. 2A/ consists of intermediate wells /12/ conveying natural recharge to pumped wells, while static water resources are sunk by drilled intermediate wells /11/ into the intermediate layer and through that water arrives in the pumped wells.
If
\[ q_{vny} \neq \sum_{l=1}^{n} q_{vl}^+ + \sum_{m=1}^{n} q_{vm} \] 
holds, then the natural recharge of the aquifer cannot load the intermediate layer. In that case, dewatering is effected according to Fig. 1A. Natural recharge of layers 1 ... 4 is drained by the pumped wells /10/. Discharge ratios within the closed area can be analyzed by known well formulae. Discharge of a single well in a confined aquifer can be calculated as
\[ q_v = 2.73 \frac{kM_s R}{1gR} \]
where  \( k \): the seepage coefficient
M: aquifer depth
s: drawdown
R: radius of the cone of depression
r: well radius.

Discharge of an inner intermediate well decreases quickly since \( R_k \) is small:
\[ R_k = 0.5 \text{ L} \]

Drawdown in time \( t_i \) is interpreted also in a different way within the closed boundary:
\[ \Delta S_i = H_m - h_0 \]

Notations can be seen in Fig. 1.

Thus, discharge of an intermediate well is, under still confined conditions in time \( t_i \)
\[ q_{vl} = 2.73 \frac{k_{vl} M \Delta S_{vl}}{1g_{vl} R} + \cdots + k_{vn} M_n \Delta S_{vn} \]

On the other hand, pumped discharge from the intermediate layer will increase, since piezometric head \( H \) increases by \( \Delta H \), as a result of the discharge through intermediate well /Fig. 1/. Probably, only 50-60 % of the filtered part /facing the open-pit/ of the pumped well receives water from the intermediate layers. This limitation is, however, balanced by the decrease of \( R \), leading to higher discharges. It is not clear yet which \( R \); 1-2-3 /Fig. 1/ is the real one but this information is not inevitably necessary for practice. As shown, the initial high discharge from the aquifers sharply decreases.
Initial higher discharges are, then "pushed" into the intermediate layer, as an effect of the relatively great head difference $\Delta H$. In order to decrease the harmful effects of the initial high discharges, intermediate wells are drilled in series, one protected by the drawdown of the previous one.

Thus, the applicability of the method is not constrained by inequality /1/. If natural recharge is caught by a line of properly operating wells, intermediate-layer dewatering can be effective even if inequality /1/ is the opposite. A well system as shown in Fig. 2B can also be helpful under extremely adverse hydrogeologic conditions. Greater initial discharges of the static resources are pumped by wells /13/, the operation of which are stopped when discharges decrease.

**TYPE OF WELLS FOR INTERMEDIATE-LAYER DEWATERING**

**Triggering well**: Its function is to establish and maintain the intermediate layer effect. It is filtered only within the intermediate layer. Its radius fits the dimension of a submersible pump. It needs electric energy and water conveyance.

**Pumped terminal well**: It drains the intermediate layer and all the other aquifers. It has filtered parts along every aquifer, fits the dimension of a submersible pump and requires electric energy and water conveyance.

**Intermediate well** drains aquifers within mining boundary and conveys drained water into the intermediate layer. No pumping is necessary; it has a smaller radius with PVC casing to prevent rupture of mining machinery. It becomes shorter and shorter according to mining strips. After reaching the first strip, the well is filled with gravel or closed with a permeable packer and continues to operate under the mining level.

**Intermediate terminal well** has the same construction as the previous well. Its function is to direct natural recharge arriving in the mine into the intermediate layer.

**Observation wells** are drilled among well lines. Piezometric heads are to be measured separately, thus layers are separated in an impermeable way.

**OPTIONS OF REALISATION**

A number of realisations is possible, depending on the form, magnitude, production, schedule and hydrogeologic conditions of the mine. Dewatering of single or adjacent mines is also different. More important options are as follows:
Simultaneous dewatering of a bounded area [2] may be used during mine opening when e.g. the area of the opening pit is encircled by triggering wells or terminal wells. Intermediate well system is also sunk. Pumping starts when all the wells are completed. The drainage of aquifers and triggering of the intermediate layer is simultaneous. Its advantage is to minimize pumped water from recharge, however this option is not flexible.

Advancing line of laterally closed wells

Lateral slopes are protected by terminal wells. Lateral wells are longer, corresponding to a lead time of dewatering period /3 years in the Thorez mine/. Intermediate wells are completed in several lines in front of the mining face. No terminal wells are prepared parallelly with the face in the direction of mining. Terminal wells are substituted by intermediate wells /Fig. 2.C/. Outcropping part of the mine can be protected from backward by the inner dump if it is sufficiently impermeable. According to the advancement of mining, terminal wells become shorter and shorter.

Subsequent operation[2] is justified if some layers of less conductivity near the surface can be drained only by a dense network of wells. If, however, the next layer is a leaky aquifer, it can receive water from the upper layers. Adjacent wells convey water from the leaky aquifer into the main intermediate layer /Fig. 3./. Such option is used in the Keleti-II open-pit mine of the Thorez mines, leading to a 30 % reduction of drilling activity.

TECHNO-ECONOMIC ADVANTAGES

Drainage efficiency is high since the remaining parts of intermediate wells cut by stripping are still operating. Dewatering period becomes longer just in the most efficient time of removing water left in the aquifers.

The decrease of pumped wells simplifies the operation /e.g. in the Thorez mine every sixth or seventh pumps are pumped/. Application of highly efficient pumps is possible in the fewer wells of higher discharge. The smaller number of pumped wells results in savings in the energy supply network and equipment.

Additional sinking of wells is easy since the intermediate layer exists under the whole mining area. No energy supply and water conveyance are necessary. Intermediate wells can be drilled even subsequently from mining levels.

The number of checking points is higher. By using water level observations in intermediate wells the dewatering process can be controlled and less observation wells are necessary. Intermediate wells are cheap since requirements...
due to submersible pump operation are eliminated. The inner -

core layer can be maintained even under the inner -
core of it is also to be dewatered.

Economic advantages of the method are illustrated by the -

following numbers:

100 $ is the cost of dewatering by roadways

82 $ is the cost of dewatering by deep wells

40 $ is the cost of dewatering by intermediate wells.

GRAPHICAL PROGRAMMING OF DEWATERING

Dewatering plans of the Thorez mine have been prepared by -

analytic tools in the KBFI [6]. Main outputs of the plans -

are: necessary discharge for the planned drawdown, spacing, -

dewatering time. Plans generally cover 5 year periods. -

Plans referring to well-explored areas properly fits rea -

lity. The greatest problem of this method is that hydro -

gological exploration is not detailed enough. Detailed ex -

ploration takes time and is expensive, thus engineers are -

often bound to use estimated values. As a result, over -
some part of the inhomogeneous mining area there is a dif -

ference between planned and observed dewatering states. -

Dewatering faster than planned is ineconomic, slower one -
hinders production. Economic and reliable dewatering op -
eration would need the knowledge of the drawdown function -
in advance for every aquifer in each observation well. In -

this case, overdesign and underdesign could be checked. -

However, these functions could not be determined due to -

the above reasons [4].

Technological and economic importance of the problem re -

quired a better solution. The study of long-ago observed -

water level functions of observation wells in the Thorez -

mine led to the following conclusion in 1973: Drawdown -

function can be fitted well by a straight-line over a hyd -

raulically closed area, using advancing dewatering and -

normal operation schedule [5].

Linearity does not hold in the initial dewatering period -

and in case of considerable changes of discharge. This -

conclusion has made possible to apply a very simple sche -
duling and supervision method.

Scheme of graphical programming is illustrated in Fig. 4. -

Water level diagrams /y, t/ of observation wells are used, -

containing also the mining schedule. A strip of level dif -
fERENCE Z -Z, reaches the observation well in time t, as -
given in the mining schedule. The period T, of pre-dewate -
ering is substracted from t, /T, is 3 years in the Thorez -

mine/ and the resulting t, and the corresponding water le -
vel give the initial state of programming.
The second strip $Z_2-Z_1$ reaches the observation well in time $t_0$. By this time, only a permitted water level $h_0$ (about 3.0 m) can remain in the aquifer. This value $h_0$ above the underlying layer yields the final point of programming. Between the initial and final points a straight-line approximates water level. Programming is to be completed for each observation well and layer.

### Supervision of Dewatering

The graphical programming line $y, p$, and the actual water level can be compared to supervise the state of dewatering. The difference $\Delta S_i$ of programmed and actual levels are calculated for each control point and layer.

$$\pm \Delta S_i = b_{si} - p_{si} [m] \quad /7/$$

The efficiency of dewatering programming can be measured as

$$\tau_i = \frac{b_{si}}{p_{si}} \cdot 100 \quad /8/$$

Values of $\tau_i$ for many points of a layer inform on possible delay or "over-dewatering". Average $\tau$ according to layers permits to evaluate the density of wells. Values of $\Delta S_i$ and $\tau_i$ are, however, of static character, not showing any tendency. Consequently, dewatering intensities are compared.

**Programmed dewatering intensity** is

$$i_p = \tan \alpha_p = \frac{D}{m} \quad [\text{cm/day}] \quad /9/$$

**Actual intensity** is, after linear fitting:

$$i_b = \tan \alpha_b = \frac{\Delta S}{\Delta t} \quad [\text{cm/day}] \quad /10/$$

The ratio of intensities informs on the tendency of the process.

Mapping of control data $\Delta S_i, \tau_i, i_p/i_b$ may contribute to process control aiming at minimizing the difference between planned and actual dewatering. Control possibilities are: changing of pumping rate, areal pumping distribution, pumping network, dewatering time.

Only properly scheduled and systematically supervised dewatering system can lead to an economic optimum and to sufficient safety.
References

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11 intermediate well
12 intermediate terminal well
S₁...S₅ drawdown
Rᵣ radius of the cone of depression for intermediate well
ΔS₄ drawdown left
h₀ piezometric head left
hᵣ drainage head
Rₙ radius of the cone of depression for the triggering well
L distance between wells

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B basic line
/y, t/ water level diagram
τ₀ time
τ₀ start of water level observation
τ₁ time of programming
τ₁ time of supervision
τ₁, t₂ time of mining fronts arriving to the observation well
Tₑ period of pre-dewatering /3 years/
Tv programmed dewatering time
h₀ planned head left
D₀ programmed total drawdown
/y, p/ programmed dewatering
\( p \) programmed drawdown in \( t \)
\( b \) actual drawdown in \( t \)
\( \Delta S \) drawdown difference in \( t \)
\( \alpha \) angle of programmed dewatering
\( \beta \) angle of actual dewatering
p provisional observation well