# PROTECTION AGAINST UNDERGROUND WATERS OF BAUXITE MINING AT NYIRÁD, HUNGARY, AND ITS IMPACT ON THE ENVIRONMENT

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## SUMMARY

The "main karst water system" stored in Mesozoic carbonate rocks in the Transdanubian Hills of Hungary is a hazard to brown coal and bauxite mining in the region. The hazard is greatest in the Nyirád bauxite mining area. There, the karst water table is being depressed prior to mining by pumping out of drilled wells with submersible pumps. Pumping, whose current rate is 300 $m^3$ per minute, has been pursued for more than two decades now: it has depressed the head of the original karst water table by 100 to 110 metres.

Pumping has created a depression of some 2500 $km^2$ in the karst water table, affecting thereby many springs and wells within that area and draining some karst moors. Within the systematic monitoring of the environmental impact of pumping, the focus has in recent years shifted onto the interrelationship between pumping and the discharge of the Héviz Lake spring with its temperature of 39 $^oC$ and its medicinal properties. In this context, the geology of the recharge area of the lake spring and the geothermal situation have been studied; pressure distribution in the subsurface waters, their natural isotope content and chemical composition have been monitored, as well as the changes in the discharge rate and temperature of the lake spring. The spring cavern has been explored; the pathways of water and heat recharge to the spring have been established.

An evaluation of the findings has permitted to fix the maximum permissible rate of pumping at the mines that is still tolerable from the viewpoint of environmental protection at 350 $m^3$ per minute. This is the limitation that has to be reconciled with the necessity of winning the bauxite from a

dry mine. With a view to that end, the following combinations of methods of protection against subsurface waters have been examined: regional depression of the karst water table, local dewatering, partial sealing of the karst aquifer and water injection.

## INTRODUCTION

The Transdanubian Hills of Hungary contain significant deposits of brown coal and bauxite /Fig. 1/. A "main karst water system" constituting a single contiguous, communicating hydraulic system is stored in the carbonate rocks of the hills. Coal mining first came up against karst waters breaking into the mining spaces early in this century; bauxite mining encountered them in the 1950s /Fig. 2/. Protection against karst waters has been and continues to be a grave worry in bauxite mining above all, what with the bauxite overlying the karsted-eroded surface of the carbonate aquifer direct, with no impermeable formation in between.

The main karst water system is stored predominantly in fissures and cavities of the Dachsteinkalk Limestone and Hauptdolomite formations of the Upper Triassic. In its undisturbed state /prior to the impact of mining/, the rate of infiltration of precipitations used to be at equilibrium with the rate of discharge of karst springs and karst moors in the foothills; subsequently, pumping at increasing rates at the mines upset the water household of the system more and more and depressed the original karst water table.[±] The depressurizing /depression/ of the karst water table within the area of influence of large-scale pumping affects the springs fed by and the wells sunk into the karst water system. The mining enterprises are obliged to prevent or make good any damage due to pumping and to make up for water lost in this way to the rightful users.

Some of the drinking-quality water that the mining enterprises are compelled to lift goes to satisfy the water demand of nearby communities and industries.

In the mines menaced by the karst waters of the Transdanubian Hills, the main trend of progress in the methods of protection under the given hydrogeological conditions has been from passive protection - pumping out the inflow and sealing off the aquifer - to active protection, the depression of the karst water table prior to mining. Early on, there were attempts to seal off inrushes also in bauxite mining, but it became obvious soon enough that the only economical protection at Kincsesbánya /in the Eastern Bakony group of hills of the Transdanubian Hills/ and, later on,

[±] Throughout this paper, the term "karst water table" is used to denote the head /potential/ surface of karst water, regardless of whether it is confined or unconfined.

also at Nyirád /in the Western Bakony/ was karst water table depression by pumping preceding deposit development.

## KARST WATER PROTECTION IN BAUXITE MINING AT NYIRÁD

Most bauxite at Nyirád is found under Eocene and/or Miocene cover, in lenticular deposits filling depressions controlled by structural features and karst processes in the Upper Triassic Hauptdolomite formation /Fig. 3/. The bauxite lenses are of varying size, the size group containing 50 000 to 100 000 tons of ore being the most frequent. The Mesozoic "basement" /dolomite/ underlying the bauxite crops out to the surface in the south, whereas in the north it descends to depths of several hundred metres. Bauxite explored so far ranges in depth from surface exposures to 200 m below the surface /i.e. practically down to the sea level/. The area has undergone strong deformation, predominantly faulting. The Triassic carbonate rocks have a high water storage capacity and permeability, as revealed by effective /gravity-drained/ porosities of 3 to 4 % and filtration coefficients on the order of 0.0001 m/s on average.

Prior to pumping, the karst water table used to fluctuate between 175 and 179 m above the sea level, depending on the abundance of precipitations /or, to be more precise, on the rate of infiltration/. Ever since bauxite mining had to penetrate under the karst water table /that is, since 1956/, systematic pumping has been a major feature in the area. Early on, attempts were made to seal off the inrushes of karst water: these attempts, however, were doomed to defeat because the dolomite is so strongly fissured and karsted at and near its surface and along the faults. Mining the bauxite by simply pumping out the spontaneous inflow was not feasible, either; not only were the inrushes provoked, on the order of 10 $m^3$ per minute, a menace to life and property, but even the dispersed inflow was sufficient to soften up the bauxite enough to prohibit any mechanisation, technological progress and the creation of tolerable on-the-job conditions. Such passive protection was rendered unacceptable also by the fairly large tonnages of bauxite that should have been tied down in safety pillars. This is why a decision was taken to install a pumping system permitting to depress the karst water table prior to the development of the mines and to the winning of their ore.

All attempts at tapping the karst water reservoir by mining methods /by driving water shafts and galleries in the dolomite/ were frustrated one by one by the tremendous inrushes provoked /one of which, e.g., silted up deep the workings with the masses of debris and silt of altered dolomite that it swept in/. This is why, since 1964, dewatering by pumping out of drilled wells gradually gained the upper hand. These wells are 200 m deep, more or less; they have at the bottom a drilled diameter of 2000 mm and a casing diameter of 1400 mm; they are pumped, depending on their yield, by one to four EMU brand submersible pumps of 7.5 $m^3$ per minute output each.

A quarter of a century of pumping has removed some 21 thousand million $m^3$ of water from the karst reservoir, giving rise to a comparatively flat depression of large horizontal extent. At its centre, where the mining is going on, the water table was lowered by 108 m on average, to the + 68 m level /reckoned from the sea level/ /Figs. 4 and 5/. The 22 dewatering wells currently in operation permit the lifting of some 300 $m^3$ of water per minute. Doing so will, in the two to three years to come, depress the karst water table under the + 60 m level to permit the dry working of the entire bauxite reserve of the mines that have already been developed.

Bauxite prospecting, however, has turned up a further substantial reserve of high-grade bauxite bordering on the developed areas, largely under the + 60 m level. To make up for the output of the mines that are now being worked out, the development of new ones is being envisaged. In order to protect the new mines against the karst water hazard, the depresssion has to be further deepened and horizontally extended. Simply carrying on with the regional dewatering now being practised, however, is not feasible because the direction and extent of the incremental depression generated thereby would result in intolerable environmmental damage.

## ENVIRONMENTAL IMPACT

The bulk of mining's impact on the environment is due to the active method of protection against subsurface waters, although some other effects also enter into play. In sum,

/1/ Extraction by caving results in failure in the overlying rocks, in phenomena of surface subsidence and collapse. These reduce significantly the time it takes for the precipitations to filter down into the aquifers. Rain collecting to form ponds in the surface depressions is apt to locally boost rates of infiltration. The two phenomena combine to greatly increase the hazard of contamination of the subsurface aquifers.

/2/ The purpose of active dewatering is the lowering of the water table /the reduction of its pressure/. As a result,

- karst moors will dry out,
- springs in the beds of watercourses will disappear,
- other springs will also dry up or suffer a substantial reduction of discharge,
- the output of waterworks based on springs or wells fed by the affected aquifers is reduced or cut off,
- flow patterns change, and so does the tempera-

ture distribution in the aquifers,

- the recharge of stratiform aquifers out of the karst water system gradually declines; after a while, flow is reversed, so that the stratiform aquifers begin to feed into the karst aquifer;
- as the upshot of all this, the karst water reserve stored in the karst is substantially reduced.

The present paper is not concerned with the details of the processes under /1/. As regards the impact of active protection as outlined under /2/, on the other hand, one must be, in order to appreciate it, reasonably familiar with the pre-depression water household of what today is the Nyirád depression area.

Nyirád is situated near the western end of the Bakony Hills, one of the hill groups making up the Transdanubian Hills. In its original /natural/ state, the area fell into five natural water household units. /These do not include the Balaton Highlands, the hills looking down on Lake Balaton, which are separated from the Bakony Hills by an impermeable barrier./ The long-term average natural discharge of each of the five natural units is shown in Table 1.

The depression created by pumping at the Nyirád mines affects the natural water household units III, IV and V.

In 1980, the total discharge of the still active springs was 65 000 $m^3$ per day, as against pumping at Nyirád at the rate of 432 000 $m^3$ per day. The water household balance of the Nyirád region is presented below.

| | | |
|---|---|---|
| Reduction of outflow from: | | |
| - springs in the open: | 220 000 $m^3$/d | |
| - springs in the beds of brooks: | 25 000 " | |
| - karst moors: | 41 000 " | |
| - stratiform aquifers: | 35 000 " | |
| Recharge from: | | |
| - stratiform aquifers: | 10 000 " | |
| - karst reservoirs: | 101 000 " | |
| Available for pumping: | 432 000 $m^3$/d | Pumping: 432 000 $m^3$/d |

The more sizeable dried-up karst springs and the dried-out karst moors are shown in Fig. 6. The dried-up springs include the Tapolcafő spring cluster /marked I in the figure/ which, at an average discharge of 62 500 $m^3$ per day, used to supply several neighbouring communities. The Tapolca spring cluster /not to be confused with the Tapolcafő one, and marked II in the figure/ had an even greater yield at 72 000 $m^3$ per day. Of the springs of this latter cluster, the one feeding the underground lake at Tapolca used to be a fine tourist attraction. Fourteen karst moors have dried out in the neighbourhood. Flow in the brooks was significantly reduced by the impact of dewatering on the head-springs and on the springs in the brook beds. Inflow into Lake Balaton was reduced as a result by 120 000 $m^3$ per day.

In the systematic monitoring of the effects of pumping on the environment, the focus of interest has over the last five to six years shifted onto the interrelationship between pumping rates at the mines and the yield of the "lake spring" feeding the Héviz Lake, with its temperature of 39 °C and its medicinal properties. In 1969 or 1970, the discharge of the lake spring started to decline, a worrying development since the Héviz Lake as the largest medicinal-lake of Central Europe is an object of outstanding environmental, medicinal and touristical value. This is why, between 1975 and 1979, systematic research was done into the nature and functioning of the tie-up between pumping at Nyirád and the behaviour of the Héviz lake spring. Research covered, among other things, the geology of the recharge area of the lake spring, by a survey that encompassed an area of some 20 000 $km^2$ and evaluated almost 3000 drill logs. In structural analysis, low-altitude air photos were used together with satellite imagery. The geothermal situation, pressure distribution in the subsurface waters, the natural isotope contents /Tu - tritium -, $C_{14}$, $C_{13}$, $O_{18}$, U, Th, Ra/ and chemical compositions of those were studied in depth. Ten new monitoring wells were drilled within a radius of five to six kilometres about the Héviz Lake for the purpose of acquiring detailed information on pressure and temperature distribution and on the interaction between hot and cold waters. In order to learn more about the discharge of the lake spring, more than 300 discharge measurements were executed within one year.

Research included the exploration of the spring cavern. It was found that some springs of temperature 17.2 °C surge on the eastern side of the spring-cavern hall, whereas hot waters at 40 to 41 °C surge on the western side. It is the mixing of the two kinds of water that produces the medicinal water of 38.8 °C temperature filling the lake "crater" /Fig. 7/.

An analysis of discharge measurements revealed that, prior to the start of dewatering at Nyirád, the mean annual discharge of the lake spring used to be 600 to 610 litres per second. On rising to the surface some 30 metres up, the temperature of the water in the lake declines by less than one degree Centigrade, depending on the heat content of the water, on air temperature, wind direction and strength, precipitation and insolation. The annual mean temperature of water in the lake, as established by measurements recorded since 1790, was 30.4 °C, with extremes, depending on the season and on the weather, of 22.2 °C and 37.1 °C.

A study of the subsurface catchment area of the spring has shown that 45 % of its discharge comes from the Western Bakony Hills /Units III and IV/, 32 % from the Keszthely Hills /Unit V/, and 23 % from non-karstic aquifers in the region of Zala County hummocks. The heat content of the hot waters was revealed by a geothermal analysis of the conditions to be picked up in its bulk by the down-plunging branch of the recharge coming from the Bakony Hills /Fig. 8/, which dives down to substantial depth before reaching Hévíz.

A North-South line running close to the Hévíz Lake separates the zone of cold waters /temperature less than 20 °C/ from the zone of hot waters. The places where the hot waters surge up are indicated by temperatures exceeding 50 °C in the monitoring wells. In these surge zones, the hot waters pass into the sediments overlying the Mesozoic karst basement: that is, above the top of that basement, a body of higher-temperature water is moving towards the lake, as revealed among other things by inverse temperature distributions, with temperatures rising down to the top of the Mesozoic and sinking below it /Fig. 9/.

One of the research findings was that, over the last 15 years, pumping in the region, at the mines and elsewhere, has reduced the pressure head of the springs above the lake surface by some 30 % /by s = 1 m of water column/ and their discharge by some 17 % /q = 100 litres per second/. For all this, pumping at Nyirád has been co-responsible. The reduction in discharge must have affected the cold and hot springs feeding the Hévíz Lake about equally, because outflow temperature at the aperture of the spring cavern has remained unchanged and so has the chemical composition of the outflowing water.

The reduction in discharge has increased the turnover time /the time it takes for the water in the lake to be fully exchanged/ by some 20 % /it is 69 hours at present/. As a result, water temperature in the lake has declined by one to two degrees Centigrade on average over the critical winter months.

In view of the outstanding value, already referred to above, of the Hévíz Lake, pumping at the Nyirád mines has to be adjusted so as not to cause any harm intolerable from the medicinal point of view. In forecasting the limit of tolerable harm, the observation that the reduction of the lake-spring discharge is at any given time one to two per cent of the pumping rate at Nyirád has been taken as a basis.

A study of the biological factors revealed that the minimum turnover time required is 7 to 10 days, the minimum spring discharge needed to ensure it being 300 litres per second. The lowest medicinally permissible discharge, on the other hand, is 450 litres per second: it is required to maintain the mean monthly temperature of water in the lake, over the critical month of January, at or above the 24.5 °C recorded so far, assuming an average air temperature of - 1 °C.

An analysis of the time sequence of events permits to infer that the influence of pumping at Nyirád /the onset of the pressure drop/ reaches Héviz with a time lag of four months and that, given a constant pumping rate, a quasi-steady state sets in after about four years. However, some of the flow pathways being rather longer, adjustments may continue for four more years. In the Héviz area, a high percentage of the depression due to the current quasi-steady-state pumping has already established itself, so that the current pumping rate of 300 $m^3$ per minute at Nyirád is unlikely to reduce the discharge of the Héviz lake spring by more than 10 to 20 litres per second over and above the reduction so far: that is, the average discharge of the year 1978, 500 litres per second, would not be reduced to less than 480 litres per second.

In view of the above, the maximum permissible pumping rate at Nyirád has been calculated to be 350 $m^3$ per minute, implying that, if none of the other pumping installations in the region will exceed their pumping rates of 1978, pumping 350 $m^3$ per minute at Nyirád will not reduce the discharge rate of the lake spring below the medicinally critical 450 litres per minute, and that with a margin of safety of 10 to 20 litres per second still in hand.

It is not only at Héviz, however, that bauxite mining strives to prevent or reduce any unfavourable impact on the environment. To make up for the waters of the dried-up spring-fed water supply systems, dug and drilled wells, a regional water supply system providing first-rate karst water was established, an improvement on the earlier means of supply both technically and as to water quality. To supplant the springs that used to feed Lake Balaton, karst water of drinking quality is being discharged into the lake, at rates exceeding the 120 000 $m^3$ per day of the original rate of recharge.

Mining has no interest at all in any further raising of the pumping rate of dewatering. On the contrary, it would be better served by a drastic reduction in the cost of dewatering per ton of bauxite mined, provided such a reduction is feasible using some other method than large-scale pumping.

## METHODS APT TO REDUCE THE ENVIRONMENTAL IMPACT OF DEWATERING

The tonnage- and gradewise distribution of the bauxite reserves of Hungary and the long-term plans of bauxite mining both prescribe the development of the known and surmised industrial-grade bauxite deposits of the Nyirád Basin. More than 50 % of those deposits is still below today's depressed karst water table. The limit of economic viability of bauxite mining, with expenditures /to which the cost of de-watering makes a crucial contribution/ calculated at the national economy level, is about the zero-metre level /the sea level/. The task of the future, then, is to provide a protection against subsurface waters in such a way as to ensure

- the development of dry mines and the dry winning of bauxite, a process sensitive to wet conditions,
- a dewatering rate not exceeding 350 $m^3$ per minute, so as to avoid any substantial environmental damage,
- the economic viability of bauxite mining.

These conditions can, under the hydrogeological conditions of the Nyirád area, be satisfied by the following methods of dewatering, applied jointly or severally.

Regional depression of the karst water table

Preventive regional depression of the karst water table by means of drilled wells is the only dewatering method being employed at Nyirád at present. Its technical feasibility is proven, and so is its economic viability, provided bauxite is being mined at a fast enough rate; its realisation is a fully developed, smooth-running, routine process. The objection to its exclusive use for the dewatering of the deeper levels at Nyirád is the foreseeable extension of the depression and the resulting seriously enhanced environmental impact.

It is, on the other hand, indicated to stick to this method up to the maximum permissible pumping rate of 350 $m^3$ per minute because

- the dewatering system currently in operation is economically viable and the technical conditions for expanding it are there,
- calculations using a mathematical model of depression as a function of time and pumping rate have shown that pumping from the available wells can be controlled so as to create a subsurface water-table relief that is optimally helpful to mining,
- even the envisaged flat-out pumping rate of 350 m /min will cause no further significant environmental harm.

A computer analysis performed at the Bakony Bauxite Mines, the enterprise running the Nyirád bauxite mines, has revealed that pumping at a rate of 350 $m^3$ per minute will depress the karst water table to the + 30 metre level soon enough for the purposes of ongoing mine development.

Local dewatering

The method is essentially a preventive depression of the karst water table, but one that is limited in both space and time. It may serve to boost the regional depression in two distinct hydrogeological situations:

/a/ In places where insufficient permeability prevents the regional depression from forming a funnel of the depth and shape required. This is the case in the Rákhegy II bauxite mine at the eastern end of the Bakony Hills, where local dewatering through boreholes drilled from underground galleries has been used with success to broaden an overly steep funnel of depression.

/b/ In situations where a high permeability entails a rapid sinking of the karst water table, creating an extensive flat depression. The high rates of pumping connected therewith cause damage to remote areas if continued long enough, as is the case at Nyirád. This is why it is helpful to create beneath the regional depression smaller, local depressions limited in space and time, by pumping at much enhanced rates. This method permits to reduce the total volume of water to be pumped owing to the fact that the improductive flat outer part of the local cone of depression des not have the time to develop.

Using this method, then, fast pumping is of the essence: it can be realised most readily by driving a gallery or a system of galleries in the rock underlying the bauxite lens or cluster of lenses and drilling tapping boreholes from those. Needless to say, in the light of what has been expounded above, this method is applicable in the Nyirád region in certain favourable lithological and structural configurations only.

Sealing of the rock

The physical-hydrological conditions do not prohibit the sealing of the rocks accompanying the bauxite or the reduction of their permeability. Sealing by means of a plastic-based additive has been experimented with, and sealing with a clay pulp has been employed full-scale in Hungarian coal and ore mining. Rock sealing as an exclusive measure of protection in bauxite mining with a water hazard is not, however, economically viable, owing first and foremost to the extensive drilling and the masses of sealing materials required. Since sealing tends to remain imperfect in any case, there is a risk of the bauxite staying soaked: to dry it out, additional pumping from the mine and additional time would be required.

In view of all this, rock sealing should be applied only as a supportive measure in combination with other means of protection. A case in point may be local dewatering combined with rock sealing, two varieties of which may be envisaged:

/a/ The winze out of which the galleries tapping the karst water under a bauxite body to be extracted are to be driven can be sunk under the protection of a seal /a mantle surrounding the winze/.

/b/ In cases where the galleries driven under the depressed regional water table tap an inflow that can be handled only by exceeding the top permissible pumping-rate limit or by slowing down the extraction of the bauxite reserve to be protected by the local depression, the sealing off of the zones of highest permeability, of the faults above all, may permit the required depression to be attained while staying within the permissible pumping-rate range.

## Water injection

Forestalling environmental damage due to dewatering may be achieved by injecting karst water into or upstream of the menaced area /that is, by boosting its natural recharge/. In the Nyirád bauxite mining area, improving the pressure distribution of the karst water system by this means has been examined with a view to preventing damage to the Hévíz lake spring. The studies carried out so far have not, however, come down on the side of this method because

/a/ in the area where the injection would have to be made, the karst aquifer is so deep that the objects required /shafts, etc./ would be exceedingly costly,

/b/ operating the system would also be costly and energy-consuming, both for the above reasons and owing to the short-circuiting of part of the reinjection stream.

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Table 1

Long-term average outflows of the natural water household units I to V in the Bakony Mountains prior to the onset of large-scale pumping at the bauxite mines

| Number and designation of unit | | Outflow through | | | Outflow into | | Total |
|---|---|---|---|---|---|---|---|
| | | springs | brooks | karst moors | stratiform | other karst | |
| | | | | | reservoirs | | |
| | | THOUSAND CUBIC METRES PER DAY | | | | | |
| I | Tés | 218 | 34 | 3 | 3 | - | 258 |
| II | Northeastern Bakony | 6 | - | 7 | 15 | 86 | 114 |
| III | Northwestern Bakony | 96 | - | 3 | 15 | - | 114 |
| IV | Northern Bakony | 135 | 19 | 35 | 20 | - | 209 |
| V | Keszthely Hills | 35 | 6 | 3 | 2 | - | 46 |
| I-V | altogether | 490 | 59 | 51 | 55 | 86 | 741 |
| | In per cent | 66 | 8 | 7 | 7 | 12 | 100 |

LIST OF FIGURES

: boundary of Palaeozoic deposits

a b : Mesozoic deposits: a/ exposed,
b/ underground

: impermeable structure

: karst spring whose outflow has ceased

town waterworks

large spring

spring-based waterworks

: dried-out karst moor

Fig. 7.: Hévis Lake: the crater and the spring-cavern hall

1 : peat muck
2 : debris
3 : sandstome
4 : crater
5 : spring-cavern hall
6 : spring outlet
7 : clay, silt
8 : hot springs
9 : silt divide
10 : cold springs
11 : hot springs
12 : spring outlet

Fig. 8.: Proposed flow pattern

: area of poor permeability

: karst water

: water from stratiform aquifers

: mixed water

: boundary of Mesozoic deposits

: Upper Triassic exposed

Fig. 9.: A hydro- and thermodynamic profile across Héviz Lake

: hydrostatic level of original karst water table

: isopotential line

: flow line

30 : isotherm, °C

— 1 — : locus of unity specific gravity

: Upper Pannonian /Lower Pliocene/ sand, sandstone

: Miocene and Cretaceous clay, clay marl

: Upper Triassic marl

: Upper Triassic Dachsteinkalk limestone

: Upper Triassic Hauptdolomite

H 1 : borehole

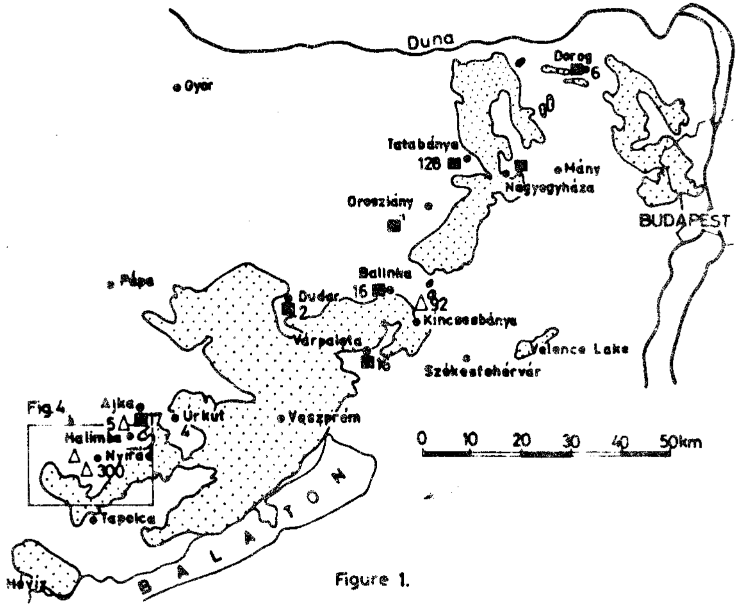



Figure 1.

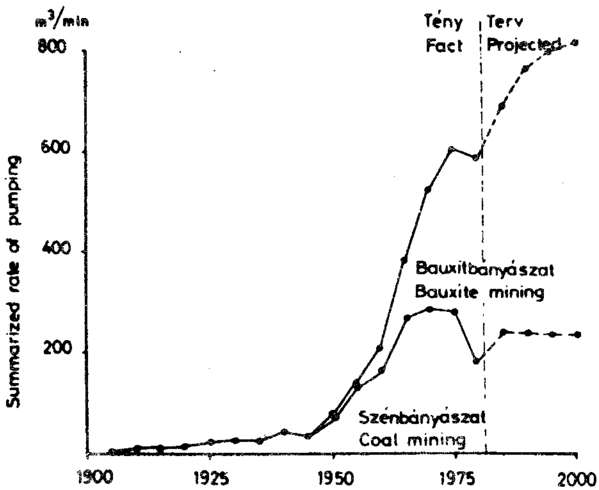
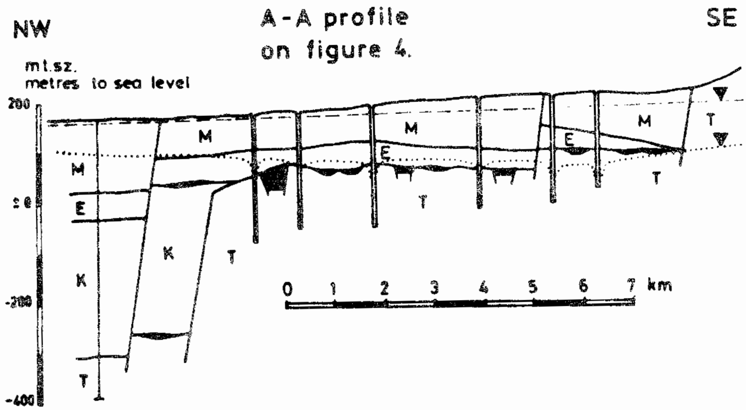



Figure 2.

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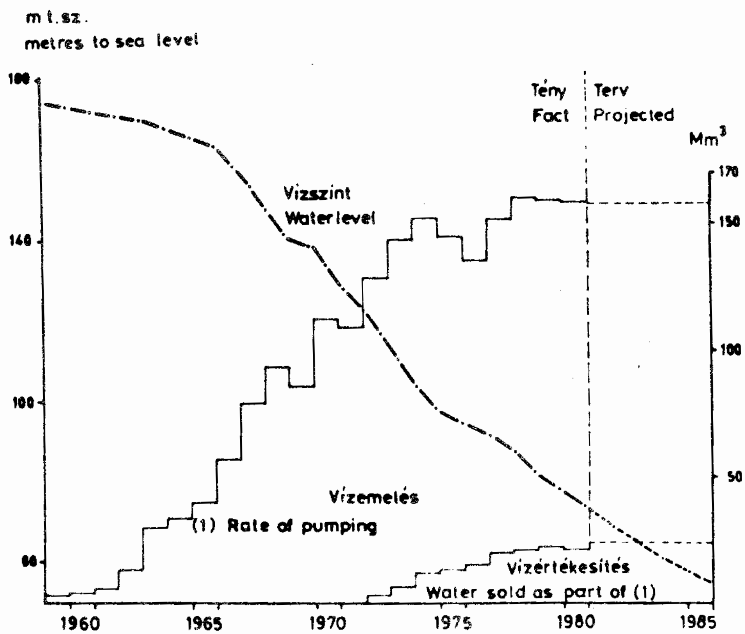
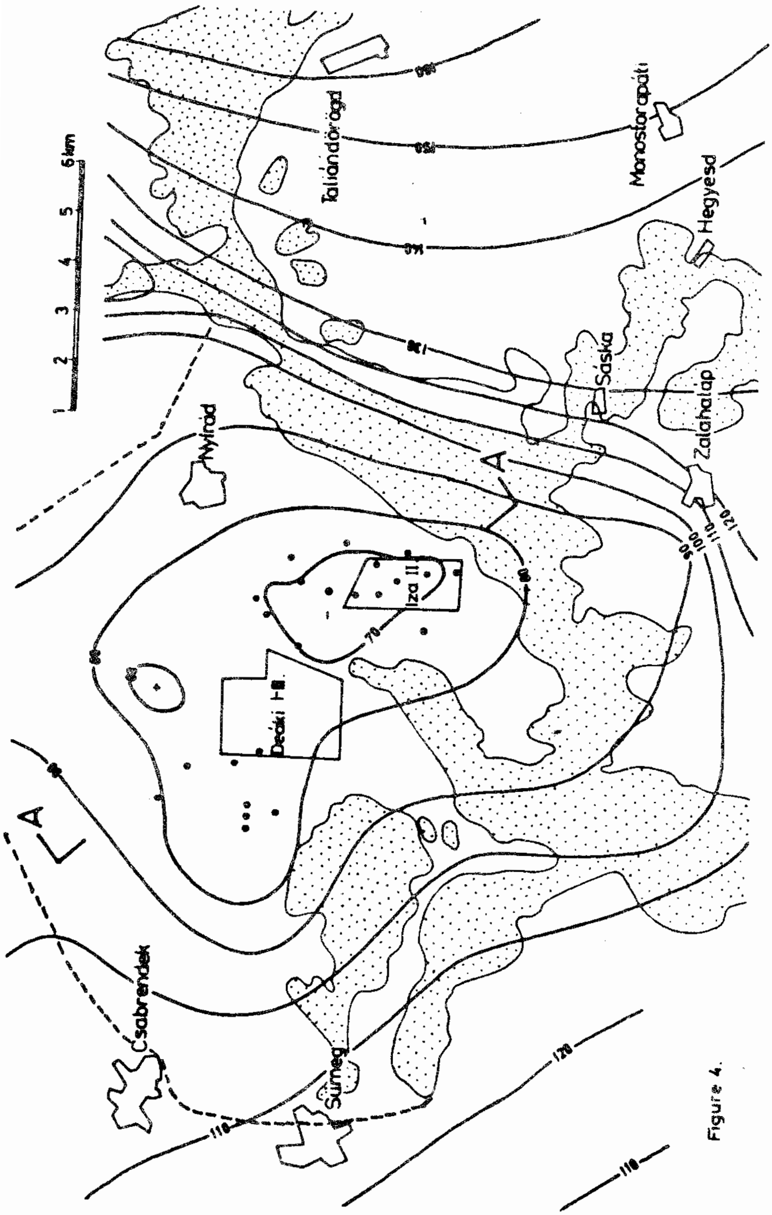



Figure 5.


Taliándörögd
Monostorapáti
Hegyesd
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Iza II
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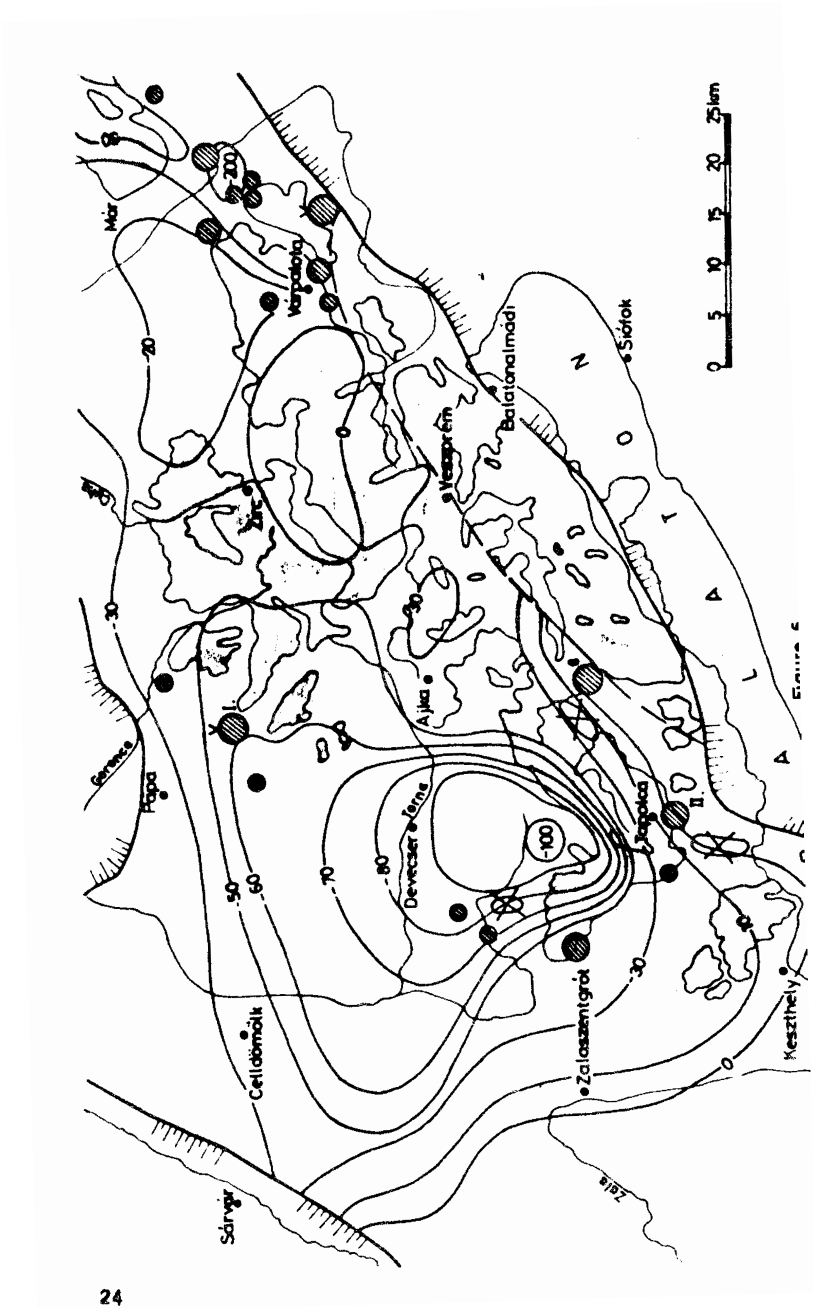
A
A
5km

Figure 4.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Balatonalmádi
Siófok
Pápa
Gerence
Ajka
Devecser
Torna
Tapolca
Zalaszentgrót
Keszthely
Celldömölk
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20
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0
-50
-60
-70
-80
-100
-30
-10
I.
II.

24

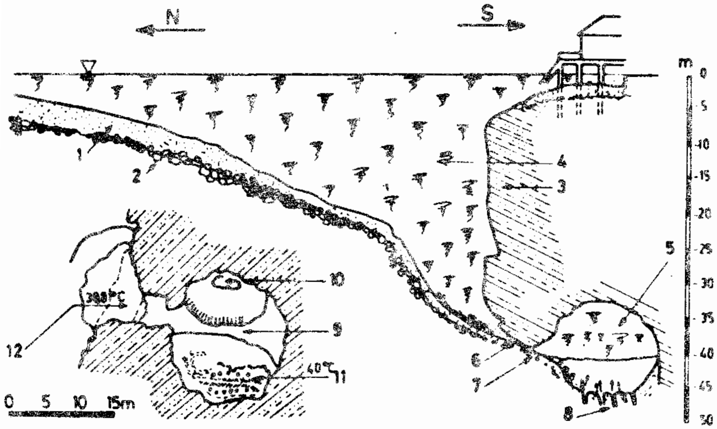


Figure 7.

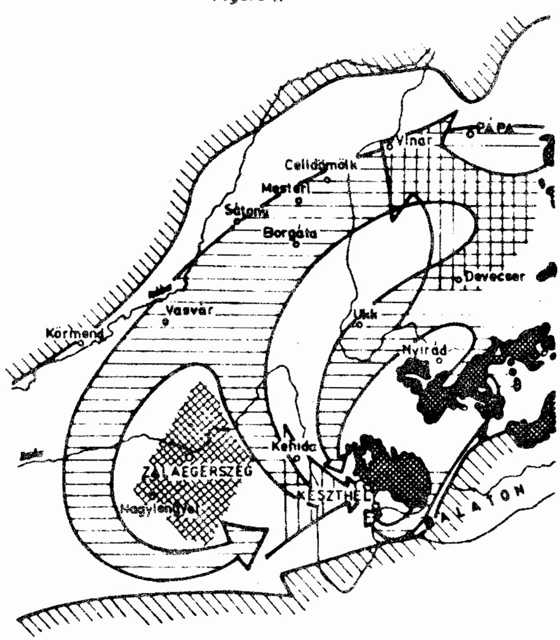


Figure 8.

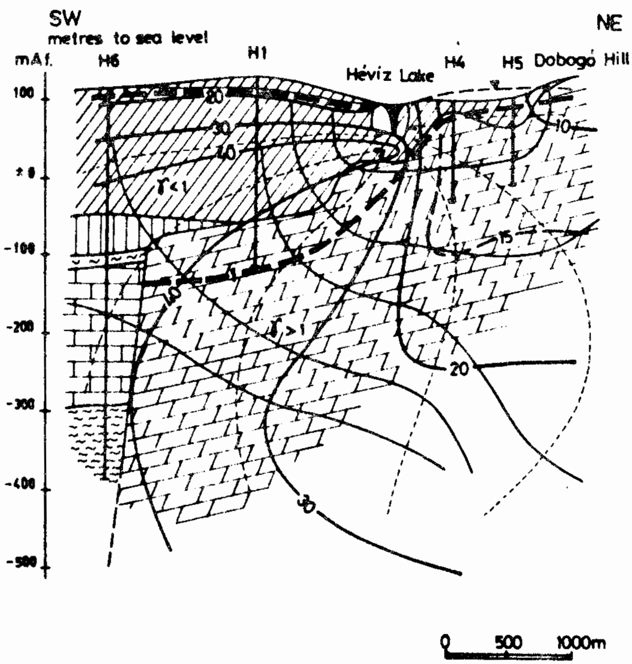
SW
metres to sea level
mAf.
H6
H1
Héviz Lake
H4
H5
Dobogó Hill
NE
100
± 0
-100
-200
-300
-400
-500
20
30
40
10
15
20
0 500 1000m

Figure 9.