METHODS AND RESULTS OF HYDROGEOLOGICAL RESEARCH RELATED TO BAUXITE MINING

by

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Stages of systematic hydrogeological research related to bauxite mining are discussed together with some current hydrogeological problems and the possible means and methods of protection against mine water.

The organization of hydrogeological research as an integral part of prospecting for bauxite is also reviewed and the most widely used methods of observation and evaluation of hydrogeological data are briefly accounted for.

Hydrogeological research has a twofold target in bauxite geology. Closely related to exploration occasional hydrogeological observations, measurements and investigations are carried out in exploratory holes on the one hand; and either simultaneously with or independent from the exploration, special holes of hydrogeological purpose are established on the other. These special holes are built out to permanent monitor-wells where fluctuations of the water-table can be regularly recorded and evaluated.

A new method of the interpretation of geophysical well-logs is introduced by which important hydrogeological information can be obtained and thus utilized for practical hydrogeological purposes.

A special fieled of hydrogeological activity is the one related to shaft-sinking by big-hole drilling. Optimum siting of large-diameter holes drilled for dewatering purposes is possible only when preceeded by detailed and careful hydrogeological study of the area in question.

Since, although operating succesfully, the hydrogeological service has its own problems, the author gives an outline of the most urgent fields of development, too.

About two third of all workable reserves of the country being situated below the karst water-table, bauxite mining in Hungary is threatened first of all by karst waters of of the Upper Triassic aquifers /i.e. cracked and fissured limestones and dolomites/ of the Transdanubian Central Mountains.

Since there are no impermeable layers between ore and wall-rocks, karst-water inrushes may practically be unobstructed in the mines.

Thorough knowledge of all recharge, discharge-and flow phenomena of the karst-water regime is therefore essential from the point of view of the mining activities. Actual in-situ prices of the ore and thus the economy of mining are namely the direct consequence of water-hazard and the possible means and ways of protection against water-inrushes.

DEWATERING SYSTEM OF THE BAUXITE MINES OF HUNGARY

From 195o on various methods of protection had to be put into action against karst-water inrushes. Since the methods of protection have to be carefully fitted always to the hydrogeological s etting of the area in question, the methods worked out for the three main bauxite-producing areas - - namely Nyirád-Nagytárkány, Halimba and Kincsesbánya - are of course different. These three main areas - each representing a more-or-less independent hydrogeological unitcan be taken also for the examples of the three standard types of dewatering used in Hungary. The characteristics of these standard types are given in the followings.

Nyirád-Nagytárkány

It is the area most seriously threatened by the water-hazard. Production of bauxite began in 1935 here, and up to 195o mining was going on safely, without any water-problem to be matched. Having had a discharge of 3 cubic meters pro min the first water-inrush was minor enough not to cause insoluble problems: mining operations went on with the widely used passive dewatering system in action. The case, however, called the attention to hydrogeology and its practical implications. From 1963 on, when mining operations were extended to deeper-seated parts of the deposit, to switch over the active - preventive - dewatering became inevitable. At first active dewatering was realized by means of water-galleries driven into the dolomitic aquifer but in 1966 the most economic method of dewatering by submersible pumps installed into large-diameter holes took over. From 1966 on in all 33 big-holes had been drilled, 25 of which are in operation even now. With an end-diameter of 14oo to 2ooo millimeters each hole has an output of 3 to 21 cubic meter water pro min. They are located always along the periphery of the mining concentration to be protected. As a result of active dewatering going on in the Nyirád-Nagytárkány area, since 1966 the difference between the original and the drawdown water-table has reached the 1oo meter and mining operations are going on in a safe dry environment.

Halimba

For geological reasons, water-hazard is less serious here than it is in the other bauxite producing areas. It has a peculiarity, however, namely that it is not only the Triassic but also the Tertiary /Eocene/ aquifers which cause trouble in the mine. Accordingly protection has to go on along two parallel lines. Karst-water inrushes from the roof-side are averted by means of the active protection system while occasional inrushes from the Triassic bedrock are handled by the conventional passive dewatering method. The reasons for the Triassic aquifers' being not so serious a hazard here is that all the fissures and cracks of the bedrock are sealed by a layer of impermeable argillaceous bauxite underlying the industrial-grade ore.

As to the rate of pumping, it should be noted that in the case of the Eocene aquifers it is only the recharge that has to be pumped out, while from the bedrock discharges not exceeding a few hundreds of litres pro min are to be counted with as maxima, and water-inrushes as minor as that can fairly be considered as negligible from the point of view of mining. It is to be admitted, however, that when extended over the western part of the Halimba basin, mining operations will most probably be faced by more serious water-hazard. The aquifer underlying the ore is namely of the dolomitic type there, and - having a higher discharge capacity - dolomites, even if partially sealed, are more apt to cause water-problems than limestones are.

Kincsesbánya

The first water-inrush took place in 1948 with a discharge of 1,o m^3/min. When proceeding towards deeper-seated parts of the deposit mining was faced by the problem of increased frequency and discharge of the water-inrushes. The idea of some artificial tapping of the water-reservoir and thus the establishment of an active dewatering system emerged in 1953. According to the Kincsesbánya-method water-galleries are driven into the dolomitic bedrock and dewatering is executed by drilling several tapping holes from the galleries. The water thus collected is being pumped by submersible pumps via water-shafts onto the surface. The pumped-out water is pure and essentially of drink-water quality. As a result of continuous pumping the drawdown karstic water-table is now about 15o meters less than it had been previously. Discharge from the aquifers of the Eocene cover-sequence is not worth mentioning here. At the eastern part of the deposit, however, mining operations are seriously hindered by considerable amounts of water stored in the quick-sand type Pliocene cover-beds.

The above outlined dewatering systems, although effectively protecting the mines against all water-hazards, have their shortcomings from the environmental side so that nowadays the working out of some alternative methods is one of the most important problems awaiting solution.

THE ORGANIZATION OF HYDROGEOLOGICAL RESEARCH IN SERVICE OF THE BAUXITE MINES OF HUNGARY

As a consequence of the above outlined hydrogeological problems it turned out as early as the beginnings of underground working, that without regular hydrogeological observations, both the planning and the execution of any underground mining operations may be illusory. An integrated hydrogeological service was established therefore during the early fifties, in order to solve all hydrogeological problems emerging in connection with both prospecting and mining. The complex process of hydrogeological research includes the analysis of all available stratigraphical, structural geological, geophysical and hydrogeological information and by synthesizing them its ultimate goal is the setting up of the hydrogeological model of the area in question.

The stages of this complex activity can be outlined as follows.

The first stage - called also the reconnaissance stage - is carried out by several scientific research institutions and various companies specialized in general hydrogeological research. It consists of basic research on the one hand and applied hydrogeology on the other, the latter being carried out on contract with one or the other of the several mines, water-supply associations and prospecting companies working on the area in question. According to our particular field of interest, during this early stage of research we are going to reveal the most important general hydrogeological characteristics of the potentially bauxitiferous areas of the country.

Preliminary hydrogeological research is focussed already on to bauxitiferous areas where reconnaissance survey indicated a karstic water-table elevated high enough to necessitate some dewatering system to be worked out when planning the mine.

The preliminary stage of hydrogeological research is closely related to the preliminary and proving drilling stages of exploration.

The objects of preliminary hydrogeological research are

- establishment of the depth of the deposit as related to the water-table,
- establishment of the expectable permeability of the rocks building up the area concerned,
- establishment of the location, geometry and transmissivity of the most important faults,
- estimation of the expectable water-damages and study of the possibilities of utilization of the pumped-out water

- hydrogeological mapping in order to reveal all springs, sinks, caves and other karst phenomena in the area concerned
- collection and review of all data produced by the meteorological stations of the area
- beginning the building out of a hydrogeological observation network

Detailed hydrogeological research has to provide all basic hydrogeological information necessary for planning of the mining operations. It has to reveal

- the lithology of every stratum both horizontally and vertically
- the permeability or impermeability of the rocks building up the area in question
- all water-tables and their natural fluctuations
- permeability and transmissivity of the rocks
- the figures of precipitation and the rate of infiltration
- when the deposit in question is the immediate continuation of another deposit already under development, detailed hydrogeological research has to review all geological and hydrogeological information produced by the active mine, but relevant to the new area, too.

Continuous record of hydrogeological data is a task to be performed in active mines /or in areas prepared for development/ which are seriously threatened by the water-hazard. Observations are carries out both in the underground workings and at the surface.Rate and effects of dewatering as well as the progress of the depression cones can be monitored by recording the data of severalobservation stations located in drifts, cross-cuts and other underground rooms. Investigation and possibly also prediction of water-damages belong also to the tasks of detailed hydrogeological research. Since new geological or hydrogeological observations may of course modify the hydrogeological model of a given area, as mining operations progress, all geological and hydrogeological information produced by them are to be carefully recorded by the hydrogeologist.

The most imsportant data to be recorded are
- location, direction and filling of faults, major fissures or other elements of structure,
- degree of fragmentation, permeability, transmissivity and discharge-capacity of the wall-rocks,
- water-temperature and rate of spontaneous and provoked inflows and their variations,
- water-quality

All hydrogeological data recorded during the mining operations are utilized later on when preparing final reports on a given deposit, or when planning the development of adjoining areas.

The hydrogeological observation network

In order to reveal the details of hydrogeology of the bauxitiferous areas a hydrogeological observation network was established. At first this network covered the areas under development only, but later on it has gradually been extended over the potential areas, too. From 1953 on in all 318 observation wells had been established. 145 of them are being in operation even now. In the majority /about 9o percent / of the observation wells the variations of the water-table of the main karstic reservoir /the Mezozoic carbonate complex/ are being measured, but in the Nyirád-Csabpuszta area also water-tables confined to the Eocene aquifers are being monitored, and some of the wells at Kincsesbánya record the fluctuations of the water-table of the Pliocene strata. Together with local networks of other mining companies, our network is an integral part of the Transdanubian Regional Observation Network established and operated by the State Institute for Water-Supply Management and Hydrogeological Research. Thus, whenever the establishment of a new well is propopsed its exact site is selected by mutual agreement of the partners concerned.

The first observation wells were established at the center of the mining concentrations the water-table variations of which were to be monitored. Later on as the depression cone grew larger, additional wells were established along the periphery of the depression, yet within the expectable area of influence of the drawdown. The pattern of the wells is fitted to the estimated flow-pattern of the karst-water so that part of the wells are aligned parallel, part of them perpendicular to the flow lines.

Thanks to regular repair and maintenance of the partly or completely damaged wells, the record of hydrogeological data in several wells can be taken for near-continuous for the last few decades. /See Fig. No. 2 /

Water-table measurements and processing and evaluation of the data

Depth-to-watertable in most wells is recorded by the traditional "point-measurement" method, using normal hand-operated devices. When settling out the schedule of the measurements, individual characteristics of the wells /such as fluctuations of the water-table or the intensity of the regional variations in the surrounding area/ were all taken into consideration. At places close to the pumping site water-table measurements are carried out weekly, while along the periphery water-table is recorded once in every fortnight.

22 of the observation wells are installed with automatic REPLINPNEU water-table recorders. Of the continuous records microcopies are made which are processed progressively in the office. The results of the point-measurements are evaluated

monthly. The cause of anomalous figures - if any - are traced down instantly. Data collected at Kincsesbánya and Nyirád /which are most seriously threatend by the water-hazard/ are summarized in detailed hydrogeological charts /=contour-maps/ quarterly. Unmatched in the country, it is our Company, which compiles a 1: loo thousand scale general hydrogeological chart annually. This chart comprises always the latest figures of the karstwater table of the Transdanubian Central Mountains. The 1 January 1981 issue of the chart is shown by Fig.No. 3 Changes of the water-table contour lines are being evaluated continuously.

Hydrological and hydrogeological investigations

Hydrogeological information obtained from exploratory boreholes is always indirect, thus - independent from the actual stage of exploration - it has to be taken for preliminary. This kind of preliminary hydrogeological information includes the stratigraphy of the rocks enetrated, the rate of penetration, the geophysical well-logs, and the lithology of the cores recovered. Losses of the circulating fluid /with both the exact depth of the highly permeable strata and the rate of fluid losses recorded/, together with the mud-levels measured after penetrating the permeable sections, although providing approximate figures only, are all to be considered as important hydrogeological information, too.

The next stage of hydrogeological research is the drilling of special holes directly for the sake of hydrogeological observations. In order to provide exact figures of local hydrogeological parameters the siting of such holes has to be based on sound geological and hydrogeological considerations. When having a sufficient number of point-measurements, mathematical-statistical methods can be used to calculate average figures, which stand rather precisely /= within an order of magnitude/ for the actual hydrogeological parameters of the area in question.

The two basic methods of hydrogeological research, in connection with the prospecting for bauxite, are recharge-tests on the one hand and the plotting of drawdown curves on the other. Both methods are simple and rapid, with a highly economic time- and cost consumption and almost nil instrumentation. Recharge-tests should always be preceeded by 24 to 72 hour periods of simple cleaning or pumping. When cleaning of the hole was undertaken by pumping the rate of spontaneous discharge can also be studied before the recharge manouvre is set on. One of the most common problems of recharge-tests is the effective record of the rate of decline of head, especially when the depth-to-water table is great and/or the recharge-capacity is high. When using the conventional methods of observation, sometimes only those sections of the drawdown-curve can be taken up which are close to the steady-state water level. Step-type recharge-tests offer a solution to this problem. When recharge is effectuated stepwise and the dynamic levels belonging to various constant yields are measured, the yield-vs-drawdown-curve of the well can be constructed by using the results of these measurements. When permitted by local consitions, all of the above described methods may be put into action so that the results be really representative of the hydrogeology of the area of influence of the well in question.

The results are interpreted by using common equations of hydraulics. / 1 /
Point-measurements are processed by means of mathematical statistics. /See Fig № 4 /

Hydrogeological information contained by conventional geophysical well-logs may be extremely helpful when trying to outline the hydrogeology and the details of the flow-pattern of a given area. By means of special hydrogeology-oriented processing of well-logs of both the "ordinary" prospecting holes and the hydrogeological observation wells, coefficients like the areal fracture-porosity may be calculated and mapped. Together with the figures of specific fracture-porosity and specific transmissivity /both related to unit lengths of coring in the bedrock/ these coefficients may remarkably contribute to the recognition of tectonic lineaments and all zones most probably threatened by the water-hazard. An example of such a complex evaluation of geophysical and hydrogeological data is the one carried out in the Nagyegyháza area /see Fig.No 5/. Collection and critical review of all relevant data was succeeded here by a comparison of the characteristics of the area of protection with the characteristics of areas where effective dewatering is already going on.

Probability and density functions of the transmissivity-coefficients of the Nagyegyháza and Nyirád areas respectively, are shown in Fig.No 6. Note that the Nagyegyháza figures were calculated on the basis of hydrogeological data observed in individual holes, while the transmissivity figures of the Nyirád basin are known by experience, from the results of the active dewatering having been in operation since more than lo years already.

The figures of specific fracture-porosity and specific transmissivity of both of the above areas were also compared /see Fig.No 7/. It can be seen at the first glance that as to transmissivity, there is a rather remarkable difference between the two areas.

Water-flow is practically unimpeded within the argillite-free fracture system of the aquifers of the Nyirád basin, while at Nagyegyháza, although due to intense tectonism the bedrock is fractured and loose, transmissivity is remarkably lower than in Nyirád. It can thus be stated that it is not merely fracturing which is responsible for transmissivity. /Despite the fact that about 5o percent of the Nagyegyháza wall-rocks are practically loose, accessible waterways are restricted to about 1o to 12 percent of the total volume of the wall-rock.

It is to be admitted that the reliability of the results attained by the above outlined methods of hydrogeological research has its limitations /=the accuracy of hydrogeological parameters may be rather low, and there may be several details which have had to be neglected during the investigations/, but all the same, the accuracy of these results being within an order of magnitude, they may serve as a firm basis during the first stage of planning of the dewatering-system of a given area.

Construction of detailed plans and planning of the execution needs of course more exact averages and more reliable local figures of the above mentioned hydrogeological parameters. The calculation of these additional data is the task of special hydrogeological research. The siting of large-diameter abstraction wells and the planning of the maximum rate of abstraction is a typical example that calls for such special hydrogeological research. In the Nyirád area, for instance, the drilling of each large-diameter hole was preceeded by a series of hydrogeological measurements carried out in"pilot-holes" sunk in the axis of the projected big-hole.

Before siting the pilot-holes a complex structural geological study of the immediate surroundings has to be undertaken. All the results of the examination of the core samples recovered from exploratory holes of the area in question has to be taken into consideration, too. The aim of this complex study is to select those points where the aquifer is situated at optimum depths and where the expectable transmissivity of the strata is highest. The deeper the aquifer is seated, the longer the life of the abstraction-well will be. The rate of abstraction is in turn the function of the transmissivity of the strata penetrated: higher transmissivities facilitate a higher rate of abstraction.
As to drilling technology it is important that hardly penetrable aquifers of the cover /e.g. conglomerates/ be as thin as possible.

The effectiveness of the structural-geological study preceeding the actual drilling work is clearly demonstrated by the fact that in 1981 the percentage of pilot-holes resulting in cancellation of the proposed site of the abstraction well was as low as 2o.

The main target of drilling pilot-holes is to obtain detailed hydrogeological information concerning the deep-seated parts /= at present below 2oo ms/ of the main aquifer. As a result of hydrogeological measurements carried out in the pilot-holes also horizons of maximum discharge can be marked out, and thus the installation-plan of the filters can be completed with greater accuracy.

The possibility of water-absorption along those sections of the main aquifer which are situated above the afore-mentioned limit-depth of 2oo m has of course to be excluded.

The aim of investigation of the aquifers of the cover sequence is to provide hydrogeological data necessary for the execution of the so called "preliminary" shafts /sunk by the traditional way/. Based on these investigations the rate and permanency of inflows provoked by the shaft-sinking procedure can be estimated and likewise the appropriate methods of prevention can be selected.

Experiences of big-hole drilling having been accumulated during the past decade are also to be taken into consideration when interpreting the data of any particular pilot-hole. That is why all the operating abstraction-wells of the Nyirád area are under continuous observation. In addition to this also hydrogeological information obtained from the pilot-holes is always cross-checked on those obtained later on from the abstraction-wells themselves. Based on analogy, "factors of correction" can thus be calculated for every particular area, and the differences between hydrogeological parameters calculated from normal pilot-hole data, and those expectable in the large-diameter abstraction-wells or the preliminary shafts can be estimated with a remarkable reliability for the area in question.

The effectiveness of the above-described complex hydrogeological activity preceeding and accompanying the drilling of large-diameter hole is proved by the fact that only 7 of the 33 shafts drilled for the sake of dewatering had to be abandoned before reaching its goal, and their failure was due to drilling-technological problems rather than to hydrogeological ones.

To sum up all,it has to be pointed out that hydrogeology,as an integral part of prospecting for bauxite,can be taken for fairly succesful, at least at the present level of our knowledge about karst regimes. It is to be admitted, however, that despite the effective dewatering-systems built out during the past decade, there are a series of new and unexpected problems emerging nowadays.

As an example let us recall the unexpected environmental impact of the Nyirád dewatering operations: The thermal springs of Hévíz /= a world-famous hydropathic establishment of tradition/ may be seriously affected by the extension of the depression cone of the Nyirád dewatering system. Another example in Kincsesbánya, where an active dewatering system based on abstraction of provoked inflows was built out with an exemplary water-utilization establishment. Despite careful preparations and proper execution, however, the water-table could not be satisfactorily lowered, not even in the closest surroundings of the tapping units. Recently the development of the new Bitó-II deposit is being threatened by an unusually hot /3o°C/ water-inflow. The

presence of thermal water may lead to failures of the pumping installations and also the utilization of the pumped out water in the rural water-supply /as it was intended/ may involve difficulties when the temperature is as high as that.
It is clear from the above that active dewatering - although essentially succesful - has its problems, too, and that mining companies will have to seek for some other solution soon, to facilitate the exploitation of deep-seated deposits without severe environmental impact.

TRENDS OF DEVELOPMENT

For the sake of an efficient development, nationwide standardization of both the techniques of measuring and the methods of data-processing is imperative. Hydrogeological parameters measured and calculated by various institutions will be comparable only when brought under regulation by an overall compulsory state order. The adaptation of conventional instruments to our own special problems is another important field of development. As for an example let us recall that because of the deep steady-state level of the karst-water, the low stability of the hole-walls and the small diameter of the hole, the purchase of suitable pumps and compressors is generally problematic. Geophysical solution of certain special hydrogeological problems calls for development also in the field of the well-logging instrumentation.

It seems to be favourable, all the same, that despite the present successes of active dewatering, research has already been directed to new fields and that the search for some new, most probably complex method of effective dewatering has begun. Settling of the new methods into daily run of hydrogeology is, however, the task of the future.

Fig. 1. Transdanubian part of bauxite zone /Szantner Ferenc/

Fig. 2. Alteration of water table in bauxitic areas, in comparison with that of the control station Nemesvámos No. 1, where the water table is not influenced by tapping.

1. Control station Nemesvámos No. 1.
2. Fenyőfő /Hgf-1/
3. Border area of Nyirád /HgN-37/
4. Border area of Kincsesbánya /Ma-56/
5. Central area of Nyirád /HgN-48/
6. Central area of Kincsesbánya /Rp-47/

Fig. 3. Triassic karstic water-system of the Transdanubian Central Mountains

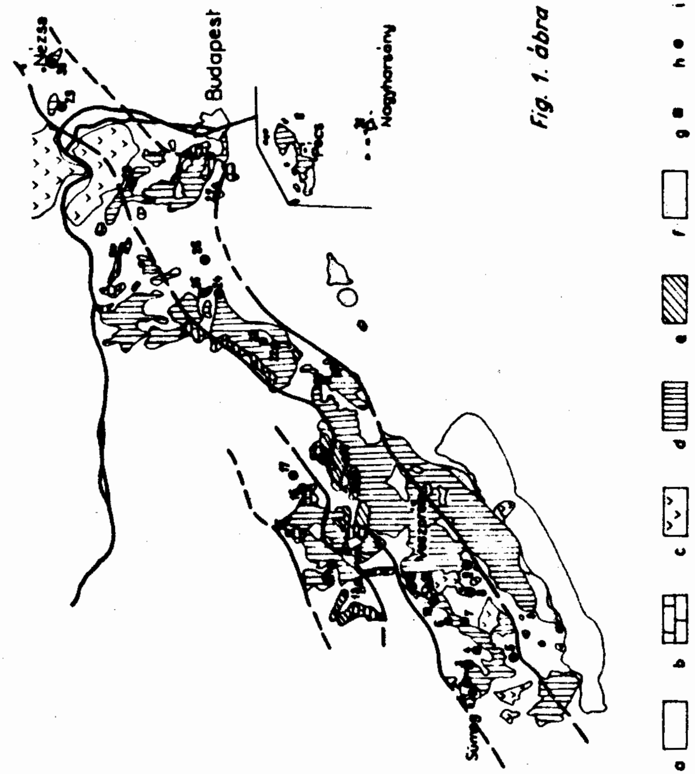
1. Contours of Triassic carstic water-system /above sea level/ in Jan. 1981
2. Monitoring station of water table in the Transdanubian Central Mountains

Fig. 4. Density diagram of water drip index /l^x/ in the Nyirád basin, constructed from water-sinking test data

Fig. 5. Isometrical line map constructed from the specific water drip index /l^x/ in the Nagyegyháza basin

Fig. 6. Diagram of the transmissivity-coefficients /Nagyegyháza, Nyirád/

Fig. 7. Relativ frequency of specific break up /t^x/ and specific water drip /l^x/ indexes



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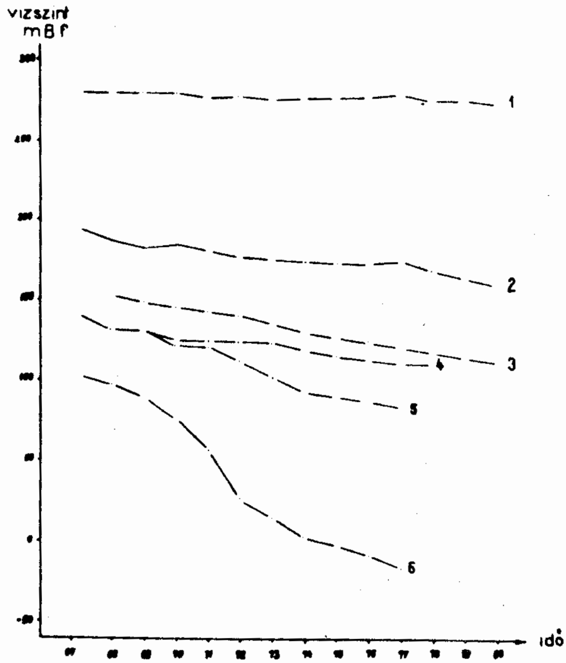

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Fig. 3 ábra
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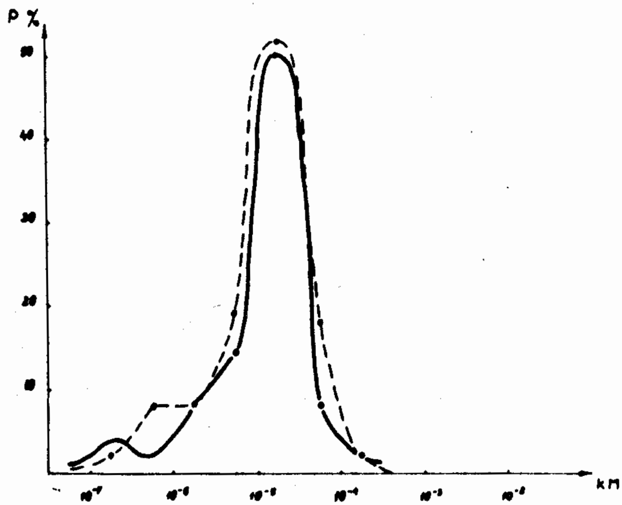

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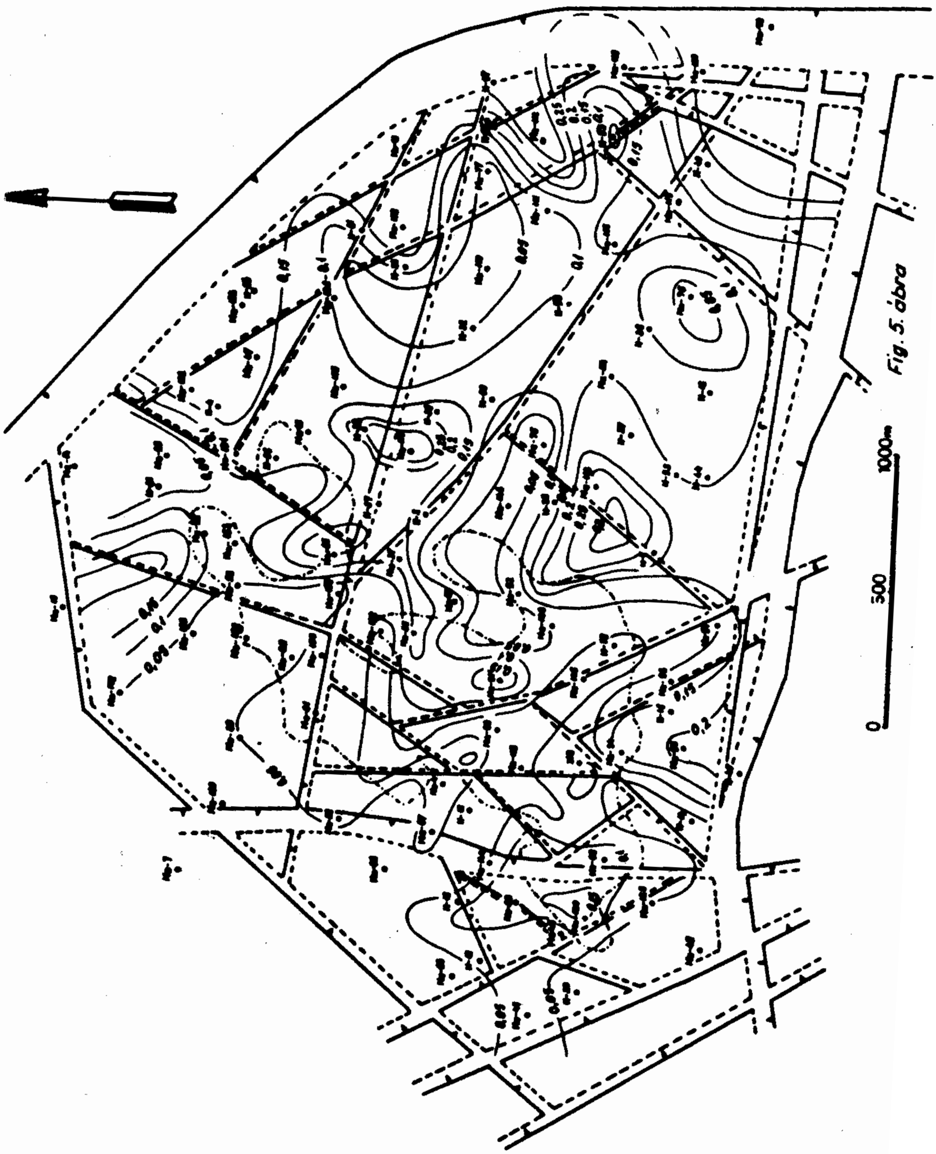

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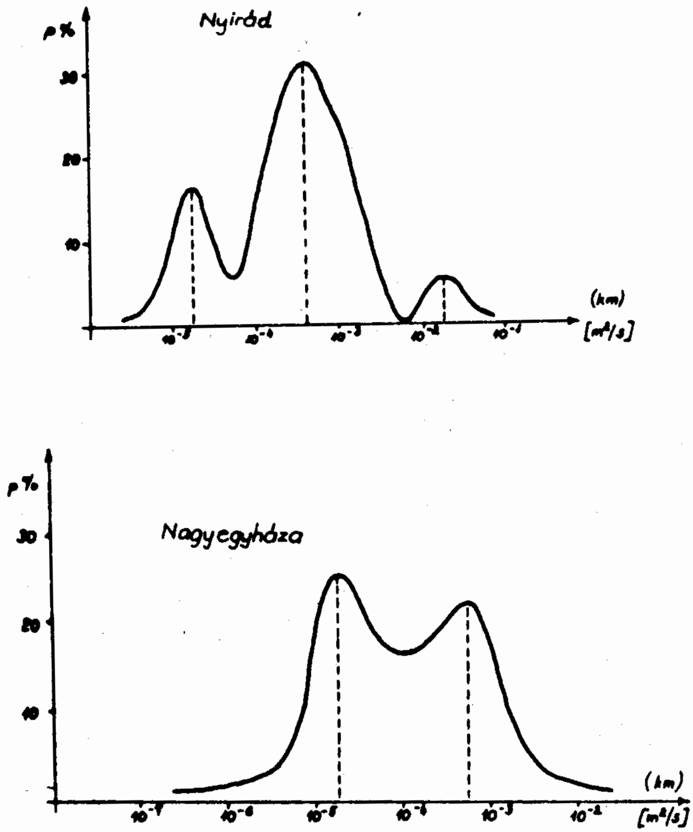

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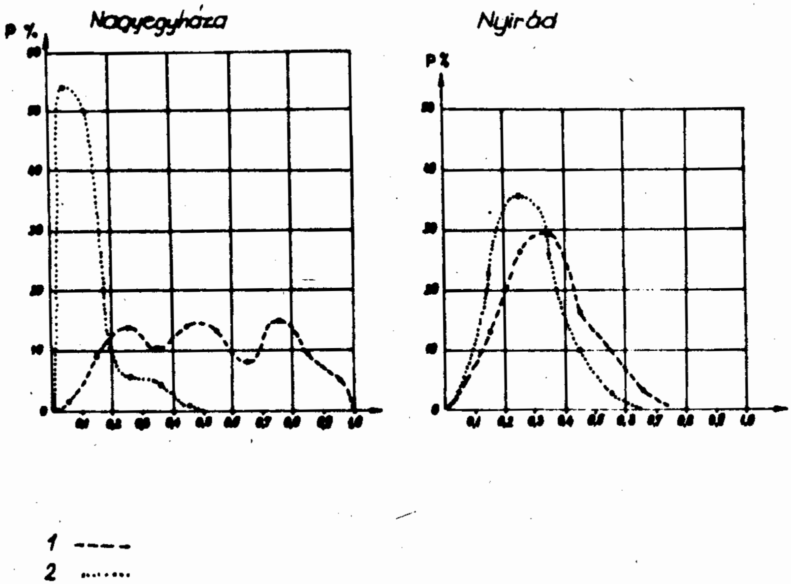

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