The Hydrogeological Problems of Groundwater Protection in Mining Regions

By V. A. MIRONENKO[1]

(Leningrad Mining Institute, USSR)

Abstract

The investigations of the Leningrad Mining Institute on this problem are carrying out in the following main directions: 1) The analysis and study of contaminants migration at particular sites of mining development; 2) The working out of theoretical and methodical basic principles of aquifers migration tests; 3) The working out of methods of the forcasting of groundwater pollution processes; 4) The theoretical and methodical substantiation of hydrogeological observations of groundwater pollution processes; 5) The working out of the measures at the groundwater control and their rational use at the particular sites of mining development.

The research that have been carried out by the present moment have covered the wide range of mining and geological conditions - as from the point of view of specific genetic types of water-bearing rocks (porous, fissured and fissured-porous), as well as from the point of view of pollution sources (surface waste water basins and underground basins of non-standard water) and the character of the latter's migration (tracers, physically neutral effluents, heavy or light ones). The combination of specialized migration tests and observations carryed out at many sites, as well as the following analysis of the data of field study allowed to get useful theoretical, methodical and practical results on the all directions above mentioned. As the summing up of these results the author proposed the concept of controlled groundwater pollution. This conception is based "on three whales" - groundwater self-purification, engineering prevention measures and ground-water monitoring correlated with each other by succesively refined (according to the observation data) hydrogeological forecasts.

Lerge-scale mining operations are often resulted in ground-water resources depletion and deterioration of its quality over the extensive areas adjacent to quarry and mine fields.

In most cases mining areas have a strained water balance since the ground-water discharge by the drainage systems dominated over the aquifer recharge.

The hydrochemical situation in the area usually changes abruptly for the worse so that additional, sometimes very expensive, water-protection measures are needed to bring the conditions of water supply back to normal.

In view of their exceptional practical significance and enormous scale, coupled with a high degree of complexity, this processes are closely examined in many countries.

The state of the art and analysis of numerous publications show that the problem can be solved only on the basis of close integration and interaction between the hydrodynamic and hydrochemical research methods, which up to now are substantially separated from each other in hydrogeology. The most effective way to deal with this problem in practice is through effective management of ground-water resources and quality in a particular mining area. Its primary goal is to find out the optimal ratios between the ground-water volumes taken up by the drainage systems and those returned into the aquifers (naturally or artifically) in the area.The conception of optimality suggests the protection of ground-water quality throughout the region. And although in some cases it is possible to exclude the ground-water pollution under the selected mining and dressing technology at all, in most cases,however, this problem is also one of optimization and the concern for ground-water protection must be the necessary element while designing the schemes of mining. This approach made us to propose the conception of controlled groundwater pollution in mining regions. This conception is based "on three whales" - groundwater self-purification, engineering prevention measures and groundwater monitoring (specialized regime observations) correlated with each other by successively refined (according to the observation data) hydrogeological forecasts.

The formulated management problem makes clear the prime objectives of hydrogeological investigations: 1) evaluation and prediction of hydrodynamic regime of groundwater; 2) the same for hydrochemical regime, and 3) substuntiation of measures to assure groundwater protection.

Within these three branches of investigations we shall describe first of all the methods of evaluation of input data for subsequent forecasts, because the effective protection of groundwater is, above all, the problem of a chronic lack of information.

For the first branch of investigation connected with hydrodynamic regime emphasis has to be placed on the study of the following aspects:

1. Boundary conditions at rivers and natural basins, using widely for this purpose the results of observations of groundwater dynamics; methods for solving the appropriate inverse problems are developed in detail;

2. Leakage conditions, which may be evaluated on the basis of aquifer tests and regime observations on groundwater dynamics, among them thermometric ones; we mean the well-known method of Papadopolus which, however, does not happen to be very reliable

in the cases of non-homogeneous (stratified) aquitards.

3. Technogenic permeability changes induced by rocks deformations at the sites disturbed by underground mining.

4. Hydrodynamic regime near technical basine, lined by low-permeable deposits. Here it is important to say that reliance on the standard infiltration tests has proved to be ineffective in evaluating the permeability of clay linings. In particular, they fail to account for the lateral water flow in stratified soils and the permeability changes subsequent to future compaction under the weight of the technogenic sediments (meanwhile these changes may attain one or two orders of magnitude). Therefore, in practice, we should use large-scale infiltration tests with neutron soil - moisture measurements, thermometry and tracers to mark the moisture front movement. These experiments bring adequate data to assess the boundary conditions of the third type at the outline of the basin and to perform then the modelling of the hydrodynamic regime in its locality.

For the same purpose, we use the thermal sounding of lining, as well as the method of tracing a seasonal temperature wave by the boreholes near the basin.

The last of above mentioned factors is 5. The vertical peremability of water bearing rocks at the possible sites of brines upconing under mining workings and drainage wells. Its values are found in tracer experiments by the "vertical doublet" scheme.

For the second branch of investigations connected with geochemical regime the primary concern should be directed to studying the migration parameters of the aquifers, as they control the intensity of mass transfer in ground-water. Their values are obtained by field migration tests with tracers and by laboratory experiments. The latter are efficient for porous rocks when the results of tests on separate samples can usually be extrapolated to rocks in situ. Beyond that, such experiments may be helpful in mass-transfer studies on fissure-porous rocks. Clear-cut distinctions are to be made between the experimental procedure in high- and low-permeable rocks, particularly in the specification of boundary conditions.

An important though still debatable question concerns the methods for laboratory estimation of sorption parameters, Most authors are strongly in favour of dynamic tests but the errors caused by high experimental velocities are oftentimes too large so that the results of static experiments are far more preferrable.

In the field experiments most common is the tracer injection into the centrical well with the subsequent observing of its distribution within the stratum via observation wells. Trials according to the "doublet" scheme are less frequent but very effective. In any case, we prefer this kind of experiment at depths more than 30 to 50 metres. As the mass experiment for approximate evaluation of rocks capacity,injections of tracers into observation bore holes during pumping tests may be used.

The inevitable impact of scale effects, owing to the limited spreading and short duration of mass transfer in experiments, makes it necessary to discuss expedient limits of their applications in different rock complexes. Here the distinction is mast clear for porous rock complexes versus fractured rocks. If applied to porous sandy-clay rock complexes, field tracer tests are either ineffective or fail to offer any advantages over laboratory experiments.

By contrast, no other alternative exists for field indicator tests in fractured rocks. And as ground-water contamination is generally most intensive in essentially fractured rock complexes, field tracer tests have to be the necessary part of the standard set of hydrogeologic exploration techniques in all cases when it is necessary to preserve ground water in fractured aquifers from pollution. Interpretation of tests in fractured rocks may be carried out in accordance with the simplest diffusion model (a microdispersion model), and in fracture-and-porous rocks, in accordance with the Loverie calculating scheme, of unlimited capacity (a macrodispersion model). I place special emphasis on this fact, since in the western publications, it seems to me, the influence of real heterogeneity of fracture-and-porous rocks on the results of field migration tests is underestimated.

By the way, in order to have a better picture of this influence, we suggest to carry out tests with the tracers both penetrating and non-penetrating into porous blocks.

So far the experience with tracer tests has been very limited - the fact demanding their thorough planning. Most useful for that are the hydrogeophysical studies in test wells involving flow-rate measurements and especially resiativity (or thermometry) logging. This is all the more valid when the movement of tracer is governed by the vertical non-uniformity in rocks composition and flitration properties. Special attention should be given to the preliminary evaluation of hydrochemical time lag in observation wells, that is a possibility of sharp difference between tracer concentration in a stratum and in a bore hole where it is subjected to additional dilution.

A separate field for investigations is connected with the behaviour of various chemical components after their entry into the aquifer, with principal attention to probable self-purification of ground-water. Herein consideration is to be given to the changes of the physicochemical situation caused by diffusion into semipervious layers or blocks, to the mixing of water of different chemical composition, to the pattern of oxidation-reduction processes, to disruption of the gaseous status of aquifers and other relevant factors. At fig. 1 one can see an example showing the importance of these processes. During the development of one of the salt deposits in the Urals, the brines with mineralization 300 g/l were thrown into the tailing pond. Diffusion of salt water through the clay lining resulted in increased permeability of the lining several dozens of times. So the brines started to infiltrate intensively into the aquifer composed of carbonate fracture-and-porous rocks. The spreading of salts, however, is a very slow process due to their diffusion from fractures into porous blocks. Within ten years, the front of salinization advanced through one or two kilometres. Noteworthy is to mention that at this distance the chloride-sodium composition of water changes completely to chloride-calcium one. It is also interesting to note, that the desalinisation process after eliminating tail pond will take more than 50 year.

Many of such processes may be effectively studied only by regime observations which are the third branch of investigations.

While serving the control functions directed at the timely detection of unfavourable trends in the groundwater, regime observations also help to improve the accuracy of the input data adopted at the designing stage and to provide the basis for the adjustment of design provisions and additional engineering measures.

In particular, they define the lateral dispersion parameters and the parameters of physical-and-chemical interaction of effluents with rocks, as well as the possible changes in the permeability of rocks as a result of such an interaction.

The most important aspect is the possibility of more precise evaluation of velocity field using the observation data, temperature and resistivity measurements in particular. In the case of highly mineralized effluents, a great help in locating the boundaries of the contamination plume may be rendered by surface geophysical methods (in particular, vertical electrical sounding).

Sharp differencies exist in planning the observations in two principal cases of pollution in the mining regions. The first one is associated with contamination from the surface technogenical basins and the second one, with upconing of the deep brines of natural genesis to mining drain. The last situation is observed at the Korshunovsk iron-ore deposit in Siberia (fig.2). The pit develops an eruptive pipe. With intensive drainage of pit the deep brines started to upcone towards the drains what had never been expected at the design stage (it was considered that the brines were separated from the pit with reliable aquitards). Besides, the main influx of brines takes place in a narrow zone assigned to the contact of sedimentary rocks and the eruptive pipe. The only way to evaluate these processes still at the prospecting stage is to use the observation results after the first years of exploatation.

The hydrogeologic parameters finded by experiments and observations provide basic inputs for forecasting the ground-water contamination and depletion. The most effective way for that is mathematical modelling and particularly numerical one. In dealing with the problem of ground-water protection numerical modelling is useful for: 1) justification of physical transport models; 2) justification of computation model; 3) forecast of contaminants distribution in ground-water and substantiation of the sanitary protection zones in the vicinity of water intakes; 4) planning and interpretation of field migration tests and regime observations.

Results of all these investigations provide a starting ground for management of water resources and quality and designing of engineering measures - both active and preventive ones. For example effective control of contamination can be achieved through the screening of technical waterbasins by artificial materials, or perposeful hydraulic filling of low-permiable "tails". Then artificial resources replenishment may be developed through the transfer of the surface runoff into a subsurface one or through the secondary discharge of pumped mine water via special infiltration pools and boreholes. In particular, injection wells can be used to put up a "hydraulic barrage" as a means to limit the spreading of the piezometric cone around the mine.

At one of the deposits in Yakutia, a possibility being discussed of protection against deep brines by injecting of fresh water which should create a impervious frozen zone along the contact with low-temperature brines.

The foregoing measures, seeking for hydrodynamic objectives, produce naturally a large regulating effect on ground-water quality as well. Aside from them, control of the contamination processes implies also a comprehensive appraisal of the water's capacity to sulf-purification in rocks, owing to sorption effects, ion exchange, destruction of unstable components and other factors. These processes are controlled by vertical differentiation of the flow velocities and so very effective may be artificial redistribution of the flow rate among the elements of the water-bearing system (for instance setting up of drainage wells with appropriate screened intervals or provision of water-level drawdowns excluding a direct water inflow into wells from the rocks having poor "cleaning" characteristics).

In all cases such preventive and controlling measures are much cheaper and more simple than the rehabilitation of polluted aquifer.

For the effective management of ground-water resources and quality is necessary the attentive examination of possibility of the drainage water use for water supply. Moreover, experience has demonstrated the use of drainage waters to have a large potential for provision of drinking water in some areas.

There are examples when the supply of drainage water for domestic purposes made it possible to satisfy the need for water of large communities, reducing the prime cost of mineral product by as much as 10 to 20 percent.

The most stringent constrains on this possibility are imposed, besides the chemical composition of the pumped water, by the demand for sanitary protection of the water-intake drainages.

Let us consider an example of one of the deposits in the Kursk Magnetic Anomaly where the contamination from the tailing pond (fig. 3) extends through two strata of sands and chalks. Though the chalks are fractured rocks, the advance of contamination front therein is sharply retarded by diffusion into the porous blocks. However, the dispersion effects here are very strong and minor concentrations of pollutants spread through chalks much faster than the main front. In this situation, it is a good idea to pump water only from the sands, but a group of observation bore holes should be installed also in chalks. Such bore holes will permit an early warning about the advancing contamination front.

Conclusions

The key conditions for successful progress of future research on the problem are: 1. the complex character of exploration and designing attained for the parallel solution of the problems of mine workings drainage and ground-water protection, that suggests the integration of research branches which are significantly divorced in hydrogeology by a longtermed tradition; 2. broad use of the adaptive approach based on gradual refinement of the calculation models through the data acquisition with the progress of the exploration, construction and operation of mines; 3. analysis and scientific generalization of the data concerning representative regions where reliable parameters of migration and filtration have been found during mining operation through the solution of the corresponding inverse problems. The latter two aspects are considered specially important because the study of the problem in question has to rely broadly on the ideas and methods largely untested in practice and which extend far beyond the limits of the standard investigations. Nevertheless, the experience now available from investigations in several major mining areas brings good evidence of the economic efficiency and large future potential of the integrated approach outlined here.

Fig.1. The scheme of groundwater contamination.

I - the tailing pond; II - the river valley; 1 - observation wells (number of well/salinity, g/dm^3); 2 - spings; 3 - isolines of salinity, g/dm^3; 4 - stratigraphical contacts, 5 - siltstone and clay sand; 6 - limestone and marl, 7 - clay and marl; 8 - clay lining; 9 - salt stratum with underground workings; 10 - mould of subsidence.

Fig.2. The scheme of saltwater upconing.

1 - isolines of salinity, g/dm^3; 2 - drainage wells; 3 - boundaries of the ore body.

Fig.3. The scheme of groundwater contamination for short (a) and long (b) time periods.

I - the tailing pond; II - the open pit. 1 - isolines of concentration $\overline{C}$=0,5; 2 - dispersion zone's boundaries; 3 - chalk and marl; 4 - sand; 5 - drainage wells.

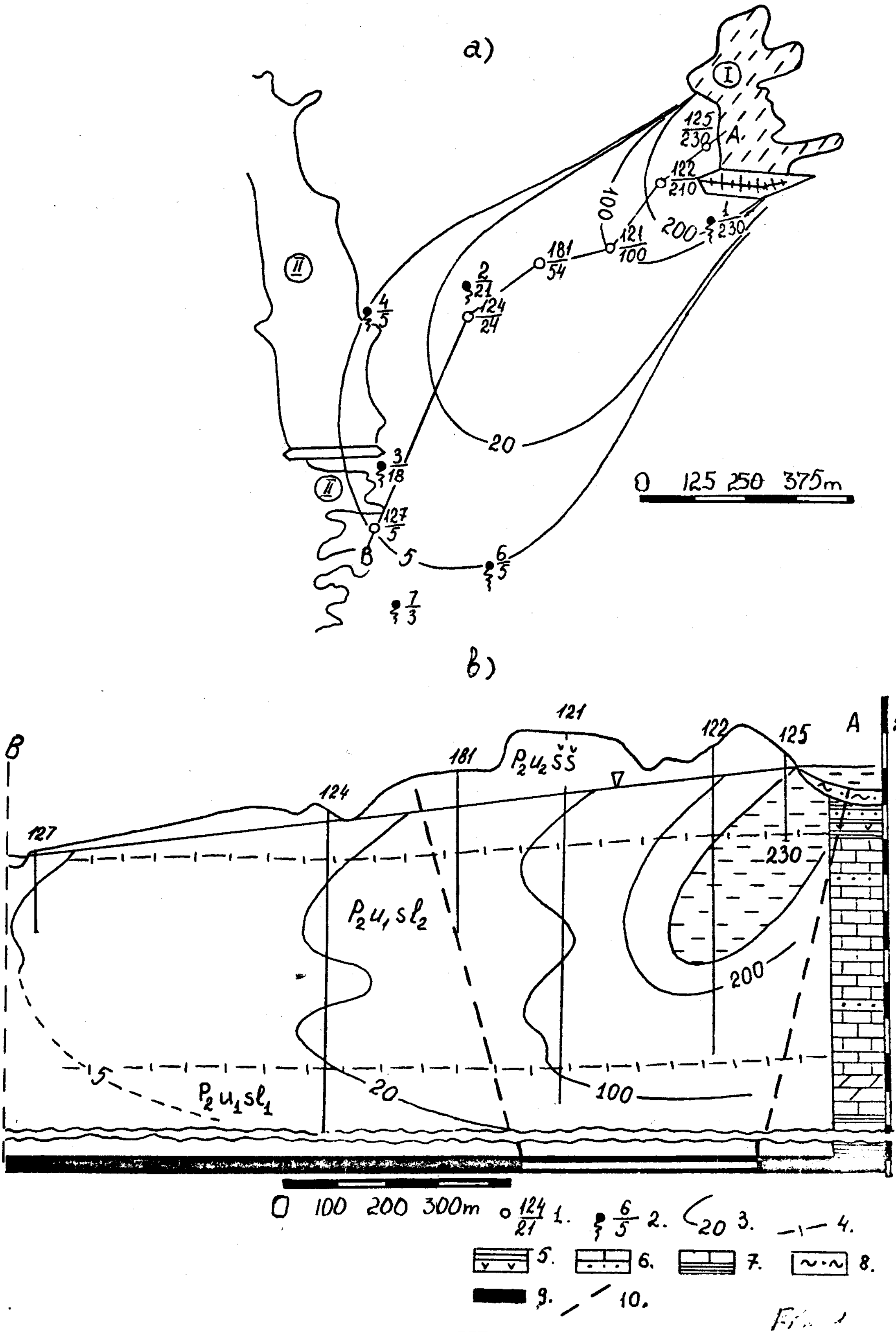
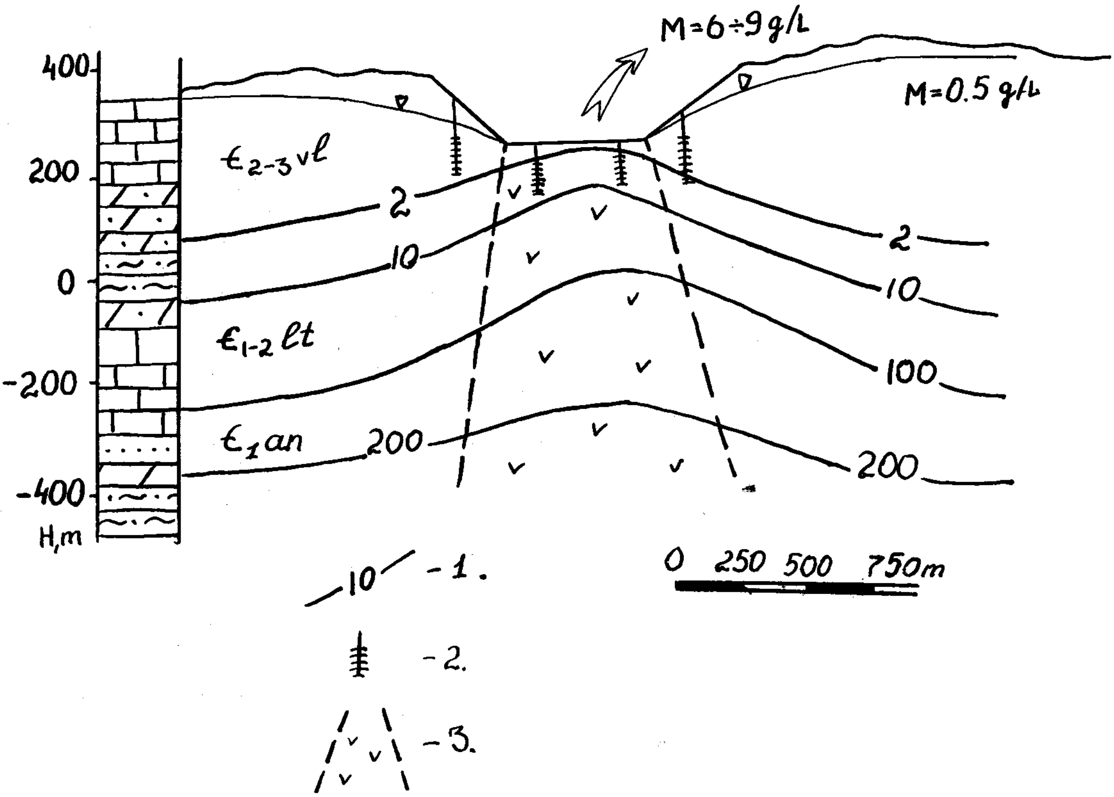
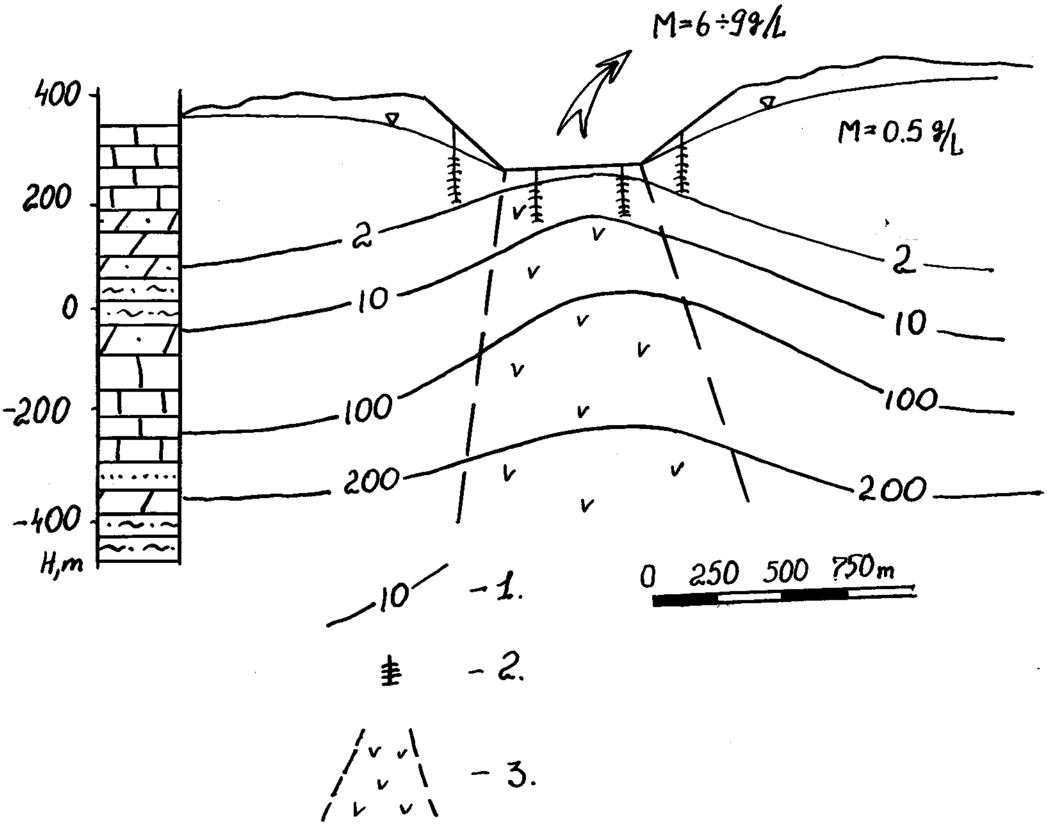


Fig. 4

Reproduced from best available copy


M=6÷9 g/L
M=0.5 g/L
400
200
0
-200
-400
H,m
$Є_{2-3}vl$
$Є_{1-2}lt$
$Є_1an$
2
10
100
200
0 250 500 750m
10 - 1.
- 2.
- 3.


M=6÷9 g/L
M=0.5 g/L
400
200
0
-200
-400
H,m
2
10
100
200
0 250 500 750m
10 - 1.
- 2.
- 3.

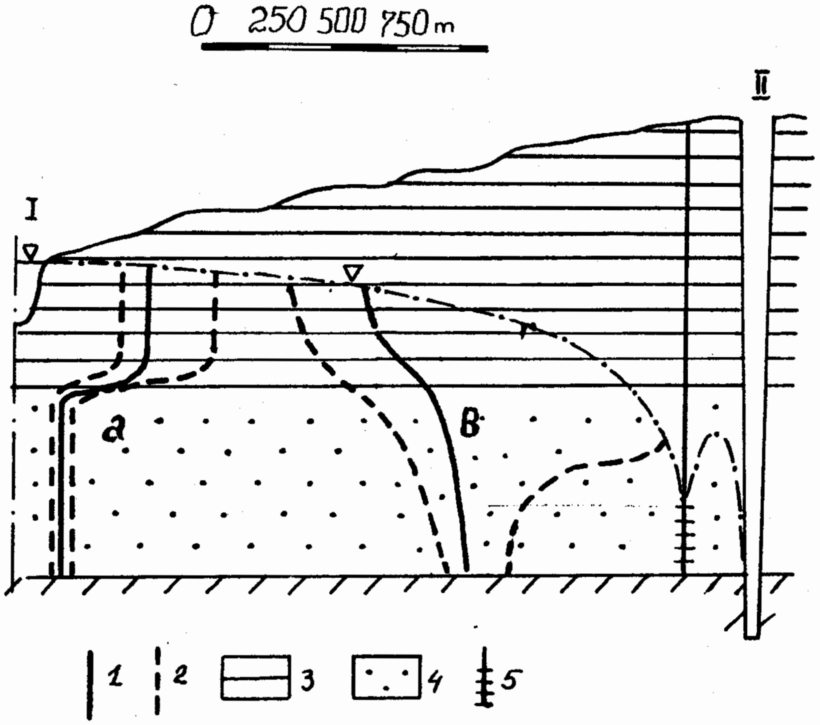


Fig. 3.