Hydrogeology of Ore Deposits

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and

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PREFACE

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Today a distinct need has arisen to review the general direction of technological schemes and the contents of complex hydrogeological and engineering geological investigations. Normally, in any complex investigation, a study of ore deposits involves sharply defining new problems at all stages, which should have been resolved priorly, during the stage of prospecting, in order to determine the economic viability of the deposits and also their area of concentration.

This book presents the following material:

1. A series of complex investigation directed towards understanding the various stages of prospecting, planning and development of a project
2. Estimation of economic viability and concentration of an ore body.
3. Indispensable examination of the complexity of hydrogeological and engineering geological investigations based on work carried out through a unique programme that is applicable at all stages of study of an ore body.

Besides N.T. Plotnikov (Ch. 1-12) and I.I. Roginets (Ch. 13 and partly Ch. 3 and Ch. 10), others who contributed this book include: G.G. Startsev (Ch. 14), E.P. Pisanets (Ch. 7), I.A. Barkalov (Ch. 10), E.M. Semenova and V.V. Segreev (Ch. 9), B.V. Borevski, S.K. Semenov and A.A. Subbotina (Ch. 10), G.H. Kashkovski and F.A. Losev (Ch. 11) and V.S. Plotnikov (Ch. 13).

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PART I

GENERAL HYDROGEOLOGICAL CONDITIONS

CHAPTER 1

Basic Problems in the Study of Hydrogeological Conditions of Ore Deposits

The mining industry is highly developed in the Soviet Union. During commercial exploitation of new ore deposits situations involving highly complex hydrogeological and engineering-geological conditions are commonly encountered. In the working of such deposits one invariably has to resort to a preliminary and then a continuous drainage operation in the mines for the removal of considerable volumes of groundwater. This results in drastic changes in the geological environs, particularly when mining activity is underway in closely situated ore deposits [23]. In such cases the commercial working of ore deposits becomes complex and requires special hydrogeological and engineering geological studies solely for the timely solution of two major problems—guarantee of safety while mining and creation of conditions for high productivity of labour.

A new problem of no mean magnitude has recently arisen in hydrogeology and engineering geology, as a result of the intensive development of the ore mining industry. This problem concerns the protection and preservation of the mine and surrounding environment from the negative or adverse influence of the technological aspects of mining ore deposits [28].

This problem has created the need for modern studies on the technological processes that exert a direct influence over the drainage aspects of mining and exploitation of ore deposits and also influence the design of mining plants and machinery.

In the complex study of ore deposits due attention must also be paid to engineering technological problems concerned with safety measures during mining and problems pertaining to preservation and protection of the surrounding environment, which in turn heavily influence mining practises.

At present, mining activity can be tentatively classified into two types depending on structural characteristics and degree of their influence on aspects of the environment around mines.* The second type of structure is by far the most common and includes the following units:

a. Mining unit handling shafts through ore-bearing rocks.
b. Beneficiation unit and its invariable ancillary, the tailings dump (reservoir of mine waste and water discharge).
c. Department concerned with agricultural, drinking and industrial water supply, processing independent water resources.
d. Township of miners, situated in close proximity to the mines in most cases, where technogenic** processes are likewise in operation.

Experience has shown that exploitation of ore deposits and the resultant flooding of mine areas adversely affect technological processes as well as aspects of the surrounding environment. In all undertakings processes of interaction between water supplies and drainage systems are not uncommon. The major source of pollution of surface and sub-surface waters are tailings dumps, which require proper exploitation and management. The site of storage of the gangue dump presents a striking change in natural landscape and pollution of groundwaters is likely, while in hilly terrains technogenic processes of submergence of surface installations take place.

Therefore, resolution of the new problems challenging hydrogeology and engineering geology to protect the mine environment lies in the complex evaluation of all aspects of mining activity. Only by means of a scientific methodological approach is it possible to successfully solve the problems of protection and preservation of the environment which arise during mining activity.

In this connection one has necessarily to take a rational approach towards all aspects of mining practise, in order to minimise their influence on environmental changes. Besides, there is also a distinct necessity to determine the complex and rational utilisation of all the useful components of the ore deposits. Briefly, then, the methods to be adopted would comprise proper use of mine waters for water supply and irrigation or extraction of the useful components then contain. Hence mining practise has to be designed on the basis of rational schemes of drainage so that safety measures are provided for in mine management and exploitation of ore deposits on the one hand, while resolving the problem of a rational use of mine waters for practical purposes on the other.

The new problem of determining which activities of hydrogeological and engineering geological studies need to be carried out at different stages of investigations during the commercial working of ore deposits, has been solved. These

*First type of structure not defined in Russian original—General Editor of English translation.

***Technogenic (and its noun technogenesis):* This is the literal and phonetic translation of the Russian word which the author has used and which was first used in Russian literature in 1937 by A.E. Fersmanom. The word technogenesis is used to denote geological, geomorphological, geochemical and geophysical changes which result from the technological developments on the earth's crust through the interference of man with nature.

The editors of the English translation have decided to retain this literal translation as it best describes the concept even though the term has yet to find its way into English dictionaries.

activities are: (1) exploration and thorough prospecting of ore deposits; (2) design and construction of mining operation; (3) commercial working of deposit (long-term exploitation); and (4) conservation of the mine and its environment.

Exploration and prospecting of ore deposits mainly seeks to solve the following traditional problems:

a. Study of the natural-historical, hydrogeological and engineering geological conditions of the ore deposit.

b. Prognostic evaluation of the possible sources of flooding in the mines and their collective characteristics.

c. Estimation of the sources of water supply for the projected mining activity.

d. Prognostic evaluation of mining technological aspects of the commercial exploitation of the ore body.

But it is essential that the following new problems be included in the stage of exploration and prospecting of ore deposits:

1. Prognosis of the influence of future long-term exploitation; on all major aspects of mining practise; on possible changes in the complexion of the geological environment; and on the ecological quality of the surrounding environment as a whole and recommendations for a rational location of the mining operation.
2. Formulation of adequate measures to preserve and protect the mine environment on the basis of the hydrogeological situation (i.e., prepare a rational scheme of drainage in the mine workings).
3. Submission of suitable recommendations for obtaining maximum practical use of the mine waters [23].

The crux of the new problems is that in the stage of exploration and prospecting of the deposit one must prepare a sufficiently valid account of the possible development of technogenic processes and the technogenesis of future commercial scale working of the ore body, in order to estimate their possible degrading effect on the environment and also to make recommendations for the protection of the same.

The second highly important requirement arising from the new problems in the field of conservation of the environment is the need for simultaneous hydrogeological and engineering geological investigations at the stage of prospecting of ore deposits through a single programme and a single methodology and above all under a single team of executives. This is well explained by the fact that the negative influence of technogenic development on the mine environment is the result of interaction between technogenic, hydro- and engineering geological processes. Planning of the exact technogenesis can therefore be undertaken only on the basis of an integrated analysis of the results of hydrogeological and engineering geological investigations of ore deposits. In the sub-stage of detailed prospecting, when the contours of the ore deposit are fairly accurately determined, the scale and structure of future mining activity and the whole rational complex of hydrogeological and engineering geological studies have necessarily to be carried out in close co-ordination with the preliminary plan of work on commercial exploitation. The co-ordination of the plan ought to be examined by the organisations interested in the project.

Complex studies conducted at the stage of exploration and prospecting of deposits ought likewise to provide information on safe hydrogeological and engineering geological infrastructures—not merely plan the major aspects of prospective mining activity, but also plan the facilities requisite for the preservation and protection of the mine area and its environs, which includes areas of human settlement as well as of mining activity (aspects of hydrogeological problems). It is thus very important that recommendations relating to the preservation of the environment be worked out at the stage of prospecting of the deposit or even conceived at the pre-planning stage.

For a successful solution to the new problems in the field of hydrogeology and engineering geology of ore deposits, arising at the stage of prospecting, great significance is attributed to the Manual (specifications) of the Government Commission on Mineral Resources under the Council of Ministers of the USSR (GCMR USSR). The instructions given in the Manual are somewhat obsolete in the present-day context since the new requirements of the national economy cannot be benefitted by them. The Manual therefore needs revision to precisely determine the rational conditions for commercial exploitation of ore deposits without degradation of the surrounding environment.

In the stage of planning and development of a mining undertaking, major problems are these: (a) the most rational system of commercial working of the ore deposit and scheme of drainage in the mines, keeping in mind an estimate higher than that actually required; (b) rational allocation of space for the areas of major activity likely to go into the structure of mining practise; and (c) measures to preserve and protect the environment in and around the mines.

The above problems vary in complexity but each reveals the importance of hydrogeological and engineering geological considerations.

The most significant and complex problem at the stage of planning and development is the selection and basis of a rational scheme of drainage in mining practise. At what stage is the latest technology in drainage operations applied during the exploitation of ore deposits? Above all, with our present knowledge that groundwaters of ore deposits during mining operations can be a 'poisonous foe', miners must remove and dispose of them far from the mine vicinity. But such a drainage plan for mine workings does not envisage present-day requirements of complex utilisation of all the useful components in ore deposits and adoption of suitable measures to protect the whole environment from the adverse influence of technogenic processes.

Considering the modern trend in rising water consumption and the need to protect the environment, it is peremptory that sub-surface waters of ore deposits be considered valuable minerals that ought to be fully utilised in fulfilling the needs of the national economy.

The foregoing details prompt one to conclude that there is a dire necessity for a thorough improvement in the technological scheme of drainage in mining operations during the exploitation of ore deposits. This in turn requires revision of the major instructions and contents of the hydrogeological and engineering geological studies to be conducted on ore deposits. Drainage of mine workings in ore deposits has to be pursued not as just a simple engineering technological problem, i.e., as a means of disposal of groundwater and isolation of mine products from their waters by transporting the latter long distances beyond the limits of the mine area, but as a complex problem demanding firm assurance of safety measures in working the deposit and also a rational utilisation of the mine waters.

Experience has shown that it is also important to make a rational provision for space for the major segments of mining activity, namely: (a) construction of rock terraces (water reservoirs); (b) beneficiation plant and associated tailings dump; (c) water supply stations; and (d) township.

The above listed activities have to be carried out keeping in mind the autonomous functioning, conservation and protection of the environment and also exclusion of the influence of natural drainage on the planned drainage outlay.

It is evident from the above discussion that there is a need at the stage of planning and development of mining, to conduct additional and more detailed hydrogeological and engineering geological studies mainly to determine the concrete requirements proposed in the plan of action. At the sub-stage of setting up a mine it is very important to continuously conduct hydrogeological monitoring for a successful implementation of the plan of mining activity with respect to the drainage system, civil engineering works for water supply, facilities to protect the mining operation from sub-surface and surface waters, preservation of the environment, preparation of the ground to dump the gangue, provision of suitable storage of tailings and construction of the mine's township.

The most prolonged stage is that of exploitation of ore deposits. Overseers of the hydrogeological situation must guarantee the following: (a) safety measures during the commercial working of the deposit; (b) high productivity of labour; and (c) conservation of the environment of the attached township and protection of the people from any negative influence of technogenesis.

Major directions of hydrogeological and engineering geological studies at this stage are:

1. Complex hydrogeological documentation for all kinds of preparatory and full-scale mining.
2. Complex *in situ* study of the regime of sub-surface and surface waters and the technogenic processes with respect to the mining works in areas of active drainage, water supply installations, tailings dump storage of gangue material and the territory of the mining township. These complex investigations have to be undertaken for permanent supervision or monitoring of the exploitation of ore deposits, maintenance of safe working conditions, prevention of

various accidents, development of additional measures of protection of the environment and to check the reliability of hydrogeological and engineering geological prognoses on the basis of the results of studies carried out at the stage of prospecting the deposit.

Complex *in situ* study of the disturbed hydrogeological and engineering geological conditions during the process of exploitation of the ore deposits, as mentioned earlier, has to be conducted under a single programme and methodology. During this, in each concrete case it is important to determine the most effective modes of organisation in order to monitor the hydrogeological conditions in mining practise.

It is necessary to stress in particular the indispensability of extension of complex *in situ* experiments on ore deposits even to the stage of their conservation. Experience has taught us that in each stage, when elementary regimes of hydrogeological and engineering geological observations are absent, such neglect might perhaps cause damage to the surrounding environment. It is also known that the technogenic processes of displacement of rocks in zones of collapse continue to develop into the zone of working of the deposit even after the completion of mining activity. Closely connected with this are the long-term deformation of the surface, sub- surface communications and common surface installations. It is further known that long-term pollution of sub-surface waters in parts of the conservation tanks for waste products or in parts of stored gangue materials, where processes of wind erosion are active, give rise to a polluted environment. At present, in many ore deposits no observations are conducted (in primitively protected openings, adits, shafts and open cut mines). This, in principle, is contrary to the modern requirements of preservation of the mining environment. Again, it is essential to continue at least minimal complex studies on ore deposits at the stage of their conservation (to preserve the principle of continuity) for the purpose of preserving the environment and developing recultivation of the technogenic landscape.

At the different stages of study and working of the ore deposits it is obligatory to maintain: (a) safe conditions in the mining of deposits; (b) high productivity of labour; (c) rational utilisation of mine waters; and (d) environment in the zone of influence of mining activity.

CHAPTER 2

Basic Problems of Hydrogeology of Ore Deposits

CLASSIFICATION OF MAJOR TYPES OF UNDERGROUND WATERS

While examining the problem under study, it is worthwhile to recapitulate the basic questions concerning the hydrogeology of ore deposits and above all the conditions which characterise the general pattern of groundwater flow in country rocks, i.e., in this case, ore-bearing country rocks and classification of the major types of groundwaters occurring in the areas of mining activity. These studies are undertaken mainly to estimate the major sources of water discharge during mining operations.

Studies on the water-bearing capacity of different lithological units of the crust are carried out during the process of exploitation of ore deposits. The various crustal rocks studied include carbonates, intrusives (granites, granodiorites, syenites etc.), terrigenous sedimentary and metamorphic rocks (argillites, sandstones, tuffaceous sandstones, schists etc.).

Ore districts in the USSR are hydrogeologically characterised by a wide development of fracture filling and sub-soil waters and fracture- and vein-filling waters confined to the crustal rocks of varied lithological composition. Rarely, stratified aquifers under artesian conditions (mainly belonging to the platform areas) are encountered.

Investigations carried out to establish the factors which determine the formation of underground waters in crustal rocks indicate the importance of fine fracturing on a regional scale, faulting and degree of dislocation of rocks and, for carbonate rocks, their chemical activity and karstification in addition to the fractures present in them.

It is well known that fracturing is present in any rock mass—sedimentary, igneous or metamorphic. In grouping carbonate rocks, however, besides fracturing, karstification is also taken into account.

Large fractures or joints are prevalent in deposits occurring in the folded geosynclinal belts where crustal rocks have repeatedly undergone intense deformation. Fairly distinct fracturing can also be traced however in rocks constituting platform regions.

Fine fracturing of rocks, as is normally understood, refers to the collective occurrence of a large number of small-sized fractures that cannot be represented even on the most detailed geological map. But still the presence of fine fractures or joints forms a very important factor as a structural element in bringing out the history and conditions of formation of rocks.

Besides, larger joints of the local type (particularly in folded belts) commonly appear in rocks along zones of crushing, brecciation and heavy fracturing related to both large and small tectonic dislocation extending to various depths. These structures usually assume a very complex setup. Finally, as pointed out already, carbonate rocks are characterised by a varying degree of chemical activity which is intimately linked with the karstification imposed on the abundant earlier formed small fractures. In carbonate rocks the distribution of small fractures is the most common (regional type); the fractures appear to be scattered throughout the thickness of the rock layers and large karst cavities or sinks are localised by the prevailing structural conditions in the narrow parts of tectonic fault zones or along the zones of interformational movements.

The foregoing structural elements of the crustal rocks create conditions which facilitate percolation (infiltration) of atmospheric precipitation, movement, accumulation and natural pollution of underground waters and also predetermine the conditions of their interaction with surface waters. Therefore, the primary conditions of formation of the structural elements of crustal rocks determine the pattern of formation and accumulation in them of various types of underground waters. It has been established that the formation of structural elements takes place in different ways for rocks of varied lithological composition, depending upon their physico-mechanical as well as chemical properties, their relation to tectonic processes and other factors. These explain the distinguishing features in the conditions of water-bearing capacity or flow of groundwater of some lithologically different crustal rocks [23].

Tectonic dislocations assume special significance while considering the aquifer characteristics of crustal rocks because they are often related to the increased abundance of water and deeper circulation of underground waters. In mining operation, increased abundance of water along zones of tectonic dislocations is already defined in their being sources of output of mine waters. Tectonic faulting of crustal rocks is often exemplified by the presence of thick zones of brecciation, crushing and strong fracturing (for example, in a group of intrusive rocks the joints extend up to a depth of 300-500 m, indicating such a physical environment which is highly favourable for migration and accumulation of fracture-vein fillings of underground waters. In thick carbonate rocks large open karst cavities occur along the zones of crushing of tectonic dislocations. These form the most favourable environment for the circulation of fissure-karst waters.

It is said that groups of sedimentary and metamorphic terrigenous rocks, which in folded geosynclinal belts possess a complexly dislocated structural setting, in their own natural conditions in zones of tectonic faulting often form zones of crushed rocks of shallow thickness (the first few centimetres) or gouge due to friction and sliding. This environment is less promising for the accumulation of fracture or fissure-vein fillings of underground waters.

In ore deposits of the platform areas, particularly those of the lower stages (as for example the iron ore and bauxite deposits of KMA), the strata overlying the ore deposit contain several horizons of aquifers of the artesian type.

For future investigations it is necessary to thoroughly revise the classification of underground waters, primarily in the light of hydrogeological conditions of ore deposits of folded geosynclinal belts as well as platform areas. This would have application in solving practical problems related to the assessment of sources of formation of possible water discharge during mining and would lead to the adoption of suitable measures for drainage and protection of the mining process from underground waters.

A revised classification would mainly consider the following factors:

a. Formation of structural elements—Fractures or joints and karsts and their role as promoters of favourable conditions for water storage and circulation.
b. Depth of occurrence and form of underground waters.
c. Practical significance of classified types of underground waters for estimating the degree of flooding of the deposit and assessing such waters as sources for water requirements.

Underground waters in the environs of ore deposits can be broadly divided into five major types (for arid and humid regions only). The characteristics of these five types are briefly listed in Table 1.

Groundwaters of deluvial formations are characterised by wide distribution in regions of ore deposits. This type is weakly developed according to the thickness of the water-bearing horizons that are confined to loams, sands or sandy loams. It is further characterised by high heterogeneity. The degree of flooding is commonly not significant (the specific yield in wells varies from 0.01 to 0.05 1/s). Therefore, water inflow in mine workings is not appreciable. During the stripping of these horizons in the benches of an open cast mine, processes of sliding and creeping set in. Hence, the normal practice of terraced drainage is applied, mainly to ensure stability of the benches of an open cast mine.

Groundwaters of alluvial formations of river valleys are a sufficiently well-studied type. They are also fairly widely distributed in ore deposits. These are fresh waters and potable. They form in sandy-pebbly formations of underground flow. Groundwaters in river valleys invariably possess an intimate hydraulic link with surface waters. In sufficiently thick formations (upto 80-120 m) significant natural resources and reserves of groundwater form. As shown by experience, in the industrial working of deposits, flooding during operations in certain ore formations is most common and constitutes the main water discharge. Different measures are jointly undertaken to protect mine working both from groundwaters and the surface

Table 1: Classification of Underground Waters of Ore Deposits (For Arid and Humid Zones, USSR)

Type of Underground Waters	Water-bearing Country Rocks	Thickness of Water-bearing Horizon (in metres)	Conditions of Interaction with Surface Waters	Remedial Measures for Protection from Waters
1. Quaternary Deposits				
(a) Groundwaters of deluvial origin	Loam, sand, sandy loam	1 to 15	No connection	Draining water bearing horizon
(b) Groundwaters of alluvial deposits	Sandy pebbles	10 to 150	Intimate hydraulic connection	Draining water-bearing horizon. Damming or isolating surface waters during mining operations
2 Fracture—'ground' type	Jointed crustal rocks (intrusives, terrigenous effusives) of varied lithological composition	20 to 100	No connection	Pumping out waters accumulating within open pit or inside shaft
3. Fracture—vein type	Zones of crushing in country rocks or strong fracturing around tectonic faults	0.2-0.5 to 200-300	Connection between surface and ground waters present in some cases	Pumping out water from shafts
4. Fracture—karst type	Fracturing and karstification of carbonate rocks (limstones, marbles, dolomites, marls)	100-300 to 1,500-2,000	Close hydraulic link	Preliminary and exploitation stage lowering of water table through external and internal pumping system of drainage
5. Interbedded piezometric type (bedded-porous and bedded-fractured)	Varied lithological composition; fractured and porous rocks	10-20 to 100-150	In some cases connection established through interaction with groundwaters	Preliminary and exploitation stage lowring of water table through combined internal and external drainage system; protection of rational system of outer and inner open cast mines through proper drainage strategy

waters from rivers. They include damming and isolation of surface waters, draining of water-bearing horizons and others. In many ore mines operating on this basis, groundwater resources are utilised in an organised supply of water for drinking, agricultural and industrial purposes.

From the foregoing, it is obvious that groundwaters of alluvial formations, should be carefully considered at all stages of study and working of ore deposits, not only with due regard to their role in flooding during mining but also as potential and reliable sources of water supply for drinking, agricultural and industrial purposes.

The fracture-filling and ground type includes underground waters occurring at the upper part of the geological cross-section of varied lithological composition of ore-bearing crustal country rocks, such as terrigenous and intrusive rocks. These waters are confined to the zone of weathering or heavy fracturing of the regional type and form gently expressed basins. The lower limits of fracture-filling groundwaters underlying the zone of weathering form part of the crust where open joints become scarce and hence the rocks are practically impermeable.

The areas of recharge and occurrence of fracture-filling groundwaters invariably coincide in space. Local reports by hydrographic network stations on fracture-filling groundwaters are used for monitoring and hence the general direction of movement of such waters under natural conditions is truly indicated for the region covered under the hydrographic network. Fracture-filling groundwaters thus form the uppermost part of the zone of active sub-surface water current.

The natural resources and supplies of fracture-filling groundwaters are limited and scattered according to the nature of the basin areas. These waters contribute to flooding in mining operations particularly during large-scale exploitation of ore deposits. Their influence is perceptible up to a depth of 80-120 m and is confined to the upper horizons of the ore bodies. Below the zone of weathering, regional fracturing is sharply reduced and the rocks naturally are not water-bearing. Chemically, these waters are fresh and primarily contain calcium hydrocarbonate.

Fracture-vein waters are confined to zones of large and small tectonic dislocations and different depths of penetration and structural complexity. Fracture-vein waters occur as linearly flowing currents in rock bodies. The different zones containing these waters cannot be isolated from the enclosing geological environs and they are hydraulically linked with the regional water-bearing system of the fractural type in ore-bearing country rocks, as well as that of fracture-filling groundwaters and groundwaters of the alluvial deposits of river valleys.

Studies point out that fracture-vein waters of ore-deposits possess an hydraulic head and lie in areas of recharge situated far from the site of mining activity. Their temperature regime is not subject to sharp variations and does not exceed the average temperature of the atmosphere.

The degree of abundance of water in rocks in zones of tectonic dislocations depends on their structure and complexity—thickness of zones of crushing or brecciation, permeability of the rocks and other factors. Observations at mining sites have indicated that the highest degree of water potential in tectonic zones occurs in carbonates and intrusive rocks and the discharge from a concentrated chamber amounts to 150-300 m^3/hr. In terrigenous rocks the water content capacity along such tectonic zones is commonly rather weak and does not exceed 10-30 m^3/hr in isolated sites.

The local surface drainage system over areas of ore deposits commonly forms a natural drain for fracture-vein waters during which their discharge directly into the alluvial sandy-pebbly deposit is observed.

Observations and documentations of mine working reveal that in most cases, fracture-vein waters of tectonic fault zones form one of the major sources of flooding of ore deposits. During the execution of mining without recourse to advanced exploratory boring for hydrogeological wells, fracture-vein waters may emanate as sudden outbursts, thus creating an occasional heavy water discharge in shafts and horizontal mine tunnels.

Fracture-karst waters are encountered in ore deposits associated only with mineralised carbonate rocks which form the major country rocks (limestones, marbles, dolomites, marls). Studies have shown that a basin of fracture-karst waters forms in the areas of fractured and karstified rocks. It has also been found that there is a distinct general hydraulic connection between widely separate zones of strong fracturing and karstification to which the concentration of sub-surface water currents is related.

The formation of fractures, joints and karst features in carbonate rocks depends upon a series of factors, the most important of which are these:

1. Conditions of stratification of carbonate rocks (structural elements vary in coarse and fine-layered carbonate rocks).
2. Degree of dislocation and tectonic faulting (a high degree of fracturing and karstification characterises complexly dislocated carbonate rocks).
3. Degree of chemical activity in carbonate rocks of high chemical activity (with $CaCO_3$ content upto 70-80% karstification is usually high).

The major factors listed above predetermine the differences in conditions of formation of structural elements of carbonate rocks in folded belts or platform areas.

The depth of circulation of fracture-karst waters depends on the thickness of carbonate rocks and the conditions of formation of their structural elements. In some ore deposits, fracture-karst waters have been found at depths up to 1,300-1,800 m. Studies on ore deposits further indicate that fracture-karst waters possess their own specific properties with regard to conditions of formation, distribution and connection with the surface waters of a river system.

It is pertinent to emphasise the fact that the wide distribution of fracturing and karstification of carbonate rocks provides them with all the needed characteristics of large reservoirs. Hence relatively large and natural water resources and natural reserves are always formed in basins of fracture-karst waters, which to a significant extent introduces complications in the process of commercial exploitation of ore deposits associated with carbonate rocks.

While studying the conditions influencing the aquifer characteristics of carbonate rocks, it is imperative to pay attention to their degree of heterogeneity with respect to filtration or leakage. Under such circumstances the established laws may call for more qualified and reliable prognosis of the safety measures to be undertaken during mining. Because of lack of understanding of the heterogeneity of filtration, sudden discharges of fracture-karst waters very often take place in sub-surface mining and commonly result in total flooding of the shafts causing great damage to the mining industry. They also lower the tempo of mining activity. To provide safety during mining it is advisable to do advance drilling of prospective drainage boreholes directly from the system of sub-surface mines for the sole purpose of preliminary lowering of hydraulic heads of fracture-karst waters.

Interbedded waters are usually confined to stratified rock formations and occur in between horizons of impermeable strata. Circulation of sub-surface waters in country rocks takes place in porous (interbedded pore waters) or regionally fractured or jointed media (interbedded fracture waters). These waters are rarely encountered in the deposits of folded geosynclinal belts. Their hydraulic head is low and the resources and reservoirs of such waters are few. Hence the complexity of their interlinkage is seldom revealed during mining operations. The most extensive occurrence of interbedded waters is found in ore deposits, where they form the sole water-bearing complex of artesian waters occurring in a huge column of sedimentary rock series over the ore horizon.

In conclusion, a brief account of the characteristics of the different types of sub-surface waters suggests some situations that constrain their chemical composition. In an overwhelming majority of cases, in the upper horizons and, at times, throughout the depth of working of ore deposits, under natural conditions only fresh waters form (in all the differentiated types). These waters contain hydrocarbonate of calcium and rarely hydrocarbonate-sulphate of calcium. They belong to the zone of active groundwater flows.

In certain cases a sharp increase in mineral content, say up to 12-30 g/l, is noticed with depth and the groundwater composition rich in sulphate of calcium and sodium. In certain deposits associated with carbonate country rocks brines with a mineral content in the range of 120-170 g/1 are formed with calcium chloride and sodium chloride as the major constituent salts.

Under conditions of long-term exploitation, in almost every case, under the influence of technogenic (geotechnical) processes, oxidation normally results in an increase in mineral content up to 1-5 g/l. Groundwaters acquire sulphate composition. However, such changes in the chemical composition of groundwaters sometimes do not occur during the process of continuous exploitation.

PATTERNS IN CONDITIONS OF GROUNDWATER FLOW IN CRUSTAL ROCKS

The characteristics of formation of structural elements of different lithological formations of rocks predetermine the conditions of formation and accumulation in them of sub-surface waters and their connection with surface waters. Let us first examine the conditions of groundwater flow in groups of intrusive and metamorphic rocks and later in carbonate rocks.

It is well known that intrusive formations comprise a large group of rocks with a high diversity of petrographic composition. As for the hydrogeological relations in ore deposits, relatively widely occurring and very well-studied rock types of such an environment are granites, granodiorites and syenites. The principal scheme exemplifying conditions of groundwater occurrence in these groups of rocks is shown in Figure 1.

As indicated in the Figure the conditions of groundwater occurrence in intrusive rocks exhibit distinct vertical hydrogeological zoning.

The first hydrogeological zone is characterised by a wide distribution of fracture-groundwaters related to rocks of the upper part of the section—zone of abundant small fractures and joints (processes of weathering).

Regional fine shallow fractures of relatively similar size are seen, showing the horizontal attitude of these intrusive rocks. This feature helps to create conditions favourable for the formation of basins of fracture-groundwaters. Natural resources and reserves of fracture-groundwaters are generally few and scattered over this region. The regional hydrographic grid separating surfaces of intrusive rocks plays, from a hydrogeological point of view, the role of a natural drainage. Hence springs often appear along the slopes of river valleys. As a rule, the rate of flow of groundwater is not high and in most cases the yield fluctuates highly. The close hydraulic link between surface waters and fracture-groundwaters explains another feature, i.e., the hydrographic (drainage) system on the surface of intrusive rocks develops along the directions of the regional joints. This control is excellently exhibited in all ore deposits of intrusive rocks (Almalik, Kadzharan, Sor and other ore deposits).

The thickness of the zones of jointing or fracturing in intrusive rocks, as known from studies on ore deposits, varies within wide limits. It depends upon the age of the relief, degree of ruggedness etc. For example, in an ore deposit in Siberia the thickness of the zone of fracturing connected with the formation of a basin of fracture-groundwaters, reached 30 to 40 m, whereas in the ore districts of Uzbekistan and Armenia it is 60-90 m.

At levels below the first zone (see Figure 1) the degree of opening in the fractures or joints (joint space) gradually diminishes with depth and accordingly the degree of flooding in intrusive rocks attenuates. Underground mining extended below the first hydrogeological zone encounters an almost dry belt wherein water currents are confined only to the zones of tectonic dislocations. The lower boundary of the upper zone reaches almost up to levels decided by the erosion of the regional hydrographic system.

Considering the fact that the natural resources and reserves of fracture-groundwaters of intrusive rocks are scarce, the water currents encountered during mining of the first hydrogeological zone from the surface are usually not significant. For example, the total flow of fracture-groundwaters in one of the open cast mines in Uzbekistan contributed 40-60 m^3/hr. Drainage of the open pit in this connection was carried out by conventional practice under protected intra-open pit pumping. It is pertinent to note that the hydrogeological influence on changes in the surrounding environs proved very weak. (The impact during draining operations was felt only in an area of 0.5 to 1 km^2.)

In one of the ore deposits of Siberia, fracture-groundwaters amounted to 50-80 m^3/hr of the water flows in an open pit mine during stripping . Under such conditions almost no specific measures were required for the protection of the surrounding environs. Very little flooding during mining is seen in the upper hydrogeological zone in almost all cases of ore deposits of this category.

The second hydrogeological zone (see Figure 1) is characterised by sporadic occurrence of fracture-vein waters truly belonging to the zone of tectonic dislocations. Mining in this zone encounters highly irregular flooding. Large discharges

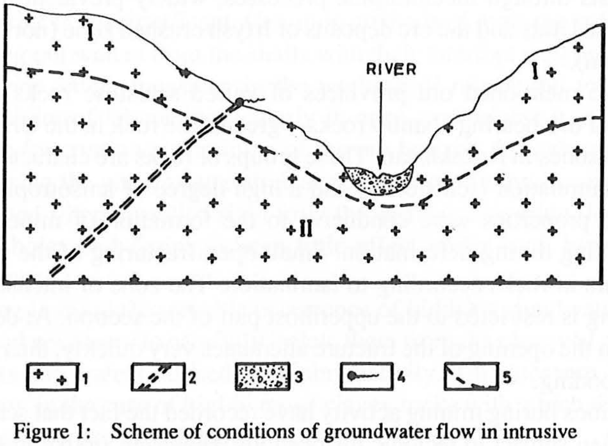

Figure 1: Scheme of conditions of groundwater flow in intrusive rocks

1—intrusive rocks; 2—tectonic dislocation; 3—alluvial sandy-gravelly formation; 4—spring; 5—boundary between the hydrogeological zones. Zones of groundwater distrubution: I—dominated by soil interstices and cracks in rocks: II—Characterised by cracks and veins in rocks.

of fracture-vein waters (from 20-30 to 60 m^3/hr) gush out when the tectonic fault zones are directly intersected. However, in areas between the fault zones water discharges are rarely noticed. Tectonic dislocations are commonly indicated by the development of zones of brecciation, crushing and increased development of fractures, 0.2-0.3 to 1-5 m wide and rarely more than 5-10 m. Observations conducted in the regime of mining activity have established gradual diminution with time of groundwater flows of the fracture-vein type, particularly after excavation during underground mining. A gradual exhaustion of the natural resources and reserves of fracture-vein waters is thus common.

In some ore deposits of the Caucasus and Siberia fracture-vein waters emanating from tectonic fault zones are saturated with carbondioxide gas. These waters possess highly batneological properties.

The manifestation of a pattern in conditions of groundwater flow in intrusive rocks is very significant in estimating the general degree of flooding during mining and the degree of complexity in continuous exploitation of ore deposits. In this connection experience has shown that continuous mining in any system of mining activity can be carried out by conventional methods and that no special methods are required to protect the mining work from groundwaters. Complete drainage of these waters can be effected through protected pumping of the inner parts of shafts or waters stagnating in open pits.

Characteristic conditions of groundwater flow are observed in the group of schistose metamorphic rocks. This group comprises typical schistose rocks, argillites and also the group of effusive rocks transformed into sericite and chlorite-sericite schists through metamorphic processes, widely prevalent in the copper deposits of the Urals and the ore deposits of Irtysh crushed zone (northeastern part of Kazakhstan).

The above mentioned ore provinces of varied schistose rocks contain vast thicknesses of ore-bearing country rocks—greenstone rock in the Urals and schistose crushed zones in Kazakhstan. These groups of rocks are characterised by fine layering or lamination (schistosity) and a high degree of anisotropism and plasticity. These properties were conducive to the formation of minor and highly complex folding during deformation. Small open fracturing of the regional type mainly occurs in rocks according to lamination. The zone of intense weathering and fracturing is restricted to the uppermost part of the section. At depths greater than 10-20 m the opening of the fracture attenuates very quickly, thus reducing the degree of flooding.

Observations during mining activity have recorded the fact that schistose rocks are fairly often subject to tectonic dislocations. However, unlike intrusive rocks, tectonic dislocations in schistose rocks do not involve any large thickness (first few centimetres, rarely 10 to 20 cm) and further, are filled with clayey attrition or 'product gouge'—the normal product of increased shearing in country rocks.

Such conditions of formation of structural elements in schistose rocks determine their hydrogeological properties. Hydrogeological zoning found in intrusive rocks is also noticed in a vertical section of these rocks. In the upper zone (zone of intense fracturing) where the thickness is 10-20 m or rarely 30-40 m (mainly in copper deposits of the Urals), fracture-groundwaters form. In the second zone, fracture-vein waters occur in the zone of tectonic dislocations.

Natural resources and reserves of groundwater of the fracture-ground and fracture-vein type are very limited. The rates of water flow in the system of mining in certain ore deposits of the Urals reach 20-30 and rarely 50-80 m^3/hr. Surface river waters raise the rate of flow to 200-350 m^3/hr in Leninogorsk, Tishin and other deposits. Close to some ore districts of the western part of Uzbekistan ancient kearizes (man-made collection galleries near horizontal underground water) are found in the upper hydrogeological zone of schistose rocks at depths of 10-15 m. Some kearizes extend 10-15 km with groundwaters flowing at 100 m^3/hr.

Schistose rocks possess hidden groundwater currents. Under natural humidity these rocks assume comparative stability in underground mining. However, under increased moisture conditions, possibly arising due to utilisation of water in mining technology (drilling of boreholes), schists very quickly lose their tenacity, swell and later become viscous. During constant technogenic flooding of schists at the dead ends of an underground mine a slurry of viscous mass is produced and an excess accumulation of such material can result in a sudden outbrust.

The general pattern of conditions of groundwater flow thus established for schistose rocks, their hidden characteristics and also cumulative experience on exploitation of certain ore deposits, impel us to draw the following conclusions.

1. The degree of flooding during mining operations in ore bearing schistose rock series is not significant. Common methods of drainage suffice, such as pumping out waters from the shafts with their interiors well protected. Still, to provide safety measures in the working of mines and to ensure high productivity of labour (particularly in open cast mines) it is necessary to provide for continuous draining of the ore horizon through special techniques, using the underground drainage system of mining in conjuction with perforated filters installed right from the surface. Lowering the water table in boreholes and drainage have little effect under such hydrogeological conditions.
2. Keeping in mind the possible occurrence of hidden groundwater currents it is indeed necessary to carefully isolate them from the observed groundwater currents and waters utilised in mining activity. This measure is excluded, however, in the case of highly moist clayey rocks with which the properties of water flow are associated.
3. In view of the insignificant degree of flooding in groups of schistose rocks, drainage operations during mining of deposits have no perceptible effects on the surrounding medium (over an area of approximately 1-1.5 km^2).

Water-bearing characteristics of carbonate rocks are unique. There is a group of ore deposits geologically characterised by a relatively wide distribution of carbonate rocks—limestones, marbles and dolomites. This group comprises the bauxite occurrences of the Urals, certain ore deposits in Kazakhstan, Siberia and others. The peculiarities of conditions of water flow in these rocks determine the hydrogeological characteristics of the ore deposits, methods of mining, drainage operations and protection of mining activity from groundwaters and also preservation of the surrounding environs from negative technogenic or geotechnical processes.

In folded geosynclinal belts carbonate rocks in the regions of ore deposits are usually complexly dislocated and significantly thick, comprising a complete system of folds of the second and third orders. The thickness reaches more than 1,500-2,000 m.

Within the limits of platform areas in regions of ore deposits, carbonate rocks exhibit gentle attitude and are not dislocated. Their thickness ranges from 60-80 to 150 m. Differences in the structural conditions of bedding of carbonate rocks in ore deposits of folded belts and platform areas influence the varied aspects of their hydrogeology [23, 26].

As mentioned above, the property distinguishing the structural elements of carbonate rocks from other lithological units is the fact that not only regional and local fractures and joints, but also the system of karstification contributes to the accumulation of underground waters. The primary element is fracture or joint while the secondary element is karst. These two structural elements enable carbonate rocks to become a potential groundwater reservoir. Studies undertaken in underground mines indicate that the degree of fracturing and karstification depends, as explained earlier, on a series of factors: chemical activity, degree of dislocation, textures, structures etc. The aggregate of all structural elements of carbonate rocks helps to subdivide them into two groups according to their hydrogeological significance viz., (a) regional and (b) local, based mainly on fracturing and karstification. The first group exhibits fine fractures and small karst features (caverns etc.). These elements are very often uniformly distributed throughout the entire thickness of the rock series (on the surface of the layers and across in sections). The second group of structural elements is often localised within the limits of the delineated tectonic fault zone, along zones of interformational tectonic thrust or at intersections of different systems of joints. The different medium and large-scale forms of karst chambers essentially belong to this group.

Conditions of groundwater flow of carbonate rocks and associated ore deposits, situated in folded geosynclinal belts, are characterised by the following distinctive patterns.

1. Basins of fracture-karst waters have usually formed in such areas. During dewatering in the process of mining ore deposits, a single cone of depression develops over a wide area.

2. In plan and in section a high degree of heterogeneity of filtration is noticed in carbonate rocks. This means that in underground mine workings highly irregular flooding is common. Large groundwater flows develop in mine areas located at the intersection of fracturing and karstification of the local type. In between zones of local fracturing, areas of mine development are dry, which can be accurately pinpointed during mining of a series of deposits (bauxite deposits of the Urals and others).
3. In the section of carbonate rocks a vertical hydrogeological zoning is discernible as shown in Figure 2. Natural resources and natural reserves of fracture-karst waters are usually significant and mainly formed in the second zone—a zone of high groundwater flow. Consequently, in this zone mining operations are very complex and demand implementation of special measures of protection.

4. Fracture-karst waters of carbonate rocks invariably possess a close hydraulic link with the surface waters of river valleys. In the upper part of the basin the levels of fracture-karst waters often lie at great depths (up to 20-30 m) and therefore filtration losses of surface waters are typically observed in car-

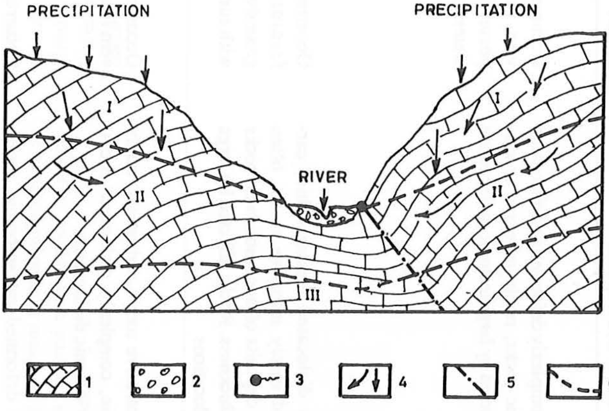

Figure 2: Scheme of vertical hydrogeological zoning in carbonate rocks.
1—Limestones; 2—pebbles; 3—spring; 4—direction of flow of underground water; 5—tectonic dislocation; 6—boundaries between hydrodynamic zones.
Zones : I—infiltration and transit of waters in cracks and krasts; II—active flow of underground water, accumulation of major natural groundwater resources and natural water reserves in cracks and karsts; III—slow-moving groundwater flow and accumulation of mineralised waters in cracks and karsts.

Table 2 : Major Hydrogeological Problems Encountered During Commercial Exploitation of Ore Deposits of Different Mining Regions in the USSR

Mining Region	Characteristics of Geological Structure of Country Rocks of Ore Deposits	Characteristics of Hydrogeological Conditions	Major Hydrogeological Problems
The Urals	Primarily complexly deformed and dislocated metamorphic rocks, rarely intrusive or carbonate, affected by large tectonic dislocations	Occurrence of fracture-ground, fracture-vein, rarely fracture-karst fresh waters, possessing hydraulic link with surface waters of rivers and lakes	Sound scheme of drainage operation during mining and preservation of surrounding environs in the northern Urals. In Central and Southern Urals besides the problem cited above, water supply for the mining complex forms an additional problem
Kazakhstan	Complexly dislocated metamorphic, carbonate, and rarely intrusive rocks. often covered by deposits of unconsolidated rocks of varying thickness. Rocks affected by large tectonic dislocations	Occurrence of ground, fracture-ground, fracture-vein; fracture-karst fresh groundwaters, possessing hydraulic link with surface waters of rivers	Water supply mainly for central part of Kazakhstan. Reasonable scheme for drainage of mine waters and preservation of surrounding environs, particularly in north-eastern and southern Kazakhstan
Central Asia	Primarily intrusive rocks, carbonates, rarely metamorphic, complexly dislocated rocks. Affected by tectonic dialocations	Occurrence of fracture-ground, fracture-vein fresh groundwaters	Major problems—water supply and preservation of environs; to a lesser degree, satisfactory scheme for drainage during mining
The Caucasus	Complexly deformed metamorphic rocks, rarely intrusive and effusive rocks. Intersected by tectonic dislocations	Occurrence of fracture--ground, fracture-vein fresh waters possessing hydraulic link with surface waters	Major problems—water supply and preservation of environs; to a lesser degree, satisfactory scheme for drainage during mining
Eastern Siberia	Primarily intrusive rocks, rarely metamorphic rocks. Subjected to tectonic dislocation and occurrence of zone of frozen ground of varying thickness	Occurrence of fracture-ground, fracture-vein waters of diverse mineralisation and also slightly frozen waters	Mainly problems of water supply and conservation of environs to a lesser degree suitable scheme of drainage during mining operations

Russian Platform	Two structural units sharply defined: lower ore-bearing metamorphic rocks, highly complexly dislocated and the upper overlying supra-rock series comprising horizontally disposed sandy, clayey and carbonate rocks	Ore-bearing country rocks with highly mineralised waters under pressure; water-bearing horizons with fresh waters under hydraulic head characterise overlying strata of sedimentary rocks	Suitable scheme of drainage during mining, preservation of environs and water supply facility
Shield Areas (Kola and Ukrainian Crystalline Massifs)	Ore-bearing sedimens to metamorphic and igneous rocks covered with deposit of unconsolidated rocks	Ground-layered and fracture-vein waters (fresh and mineralised) hydraulically linked with surface waters of rivers and lakes	Kola Peninsula—simple problems of suitable scheme of drainage and preservation of environs. Region of Ukrainian shield—complex problems of dewatering during mining and water supply facility

bonate rocks. In the lower part of the basin partial natural discharges of fracture-karst waters are commonly seen in the form of large springs.

The basic patterns of groundwater flow in carbonate rocks listed above in fact determine the mining technical aspects of commercial exploitation of ore deposits. Mining development encounters two major sources of flooding, viz., fracture-karst and surface waters of a river system.

Thus, development of mining activity in carbonate rocks usually encounters a very high degree of flooding. The total water discharge in different cases attains a rate of 16,000-22,000 m^3/hr and the value in different horizons ranges from 3,000-4,000 and rarely 5,000-6,000 m^3/hr. This introduces considerable complexity in the commerical development of ore deposits and requires:

a. Adoption of special methods for digging shafts—method of preliminary drilling followed later by water drawdown effected through exploitation, advanced methods of drainage, cementation or bitumenisation of mine working etc.
b. Adoption of special methods to safeguard the horizontal underground workings—drilling of advanced exploratory and drainage wells, special drainage tunnels in underground mines, construction of impermeable coffer dams etc.
c. Special methods of advanced and exploitational drainage using different systems of internal drain wells including provision of constantly acting drainage units on the flanks of the cone of depression.
d. Isolation of the surface waters of the regional river system and also isolation of the mine waters from getting discharged to the surface.
e. Implementation of special measures to protect and preserve the surrounding environs from the negative influence of technogenic processes. The influence of drainage during mining can affect several hundred square kilometres of the surrounding environment.

It is likewise apparent from the account given above that the occurrence of general hydrogeological patterns under varying conditions of groundwater flows in different lithological units calls for the involvement of a specialist-hydrogeologist at the stage of mining construction or, preferably, even from the commencement of the stage of exploitation of ore deposits. The services of a specialist are needed to estimate mining conditions and to assist in the choice of methods of protection of the mines from groundwater hazards and also surface waters. The patterns identified help to plan in advance the implementation of suitable measures for effective drainage, protection and preservation of the surrounding environs.

Studies on ore deposits have shown that in some deposits situated in platform areas the conditions of groundwater flow become very complex when the geological section exposes a fairly complex group of rocks exhibiting aquifer horizons under hydraulic head. To understand the hydrogeological situation in such cases it is convenient to divide the geological section into the following layers:

a. Middle layer of characteristic ore-impregnated bedrock. The conditions of groundwater flow in this layer have been examined above.
b. Upper layer of rock series overlying the ore-bearing horizon. The conditions of groundwater flow are directly related to the ore-bearing country rocks below the surface waters and the atmosphere above.
c. Lower layer of rock series underlying the ore-bearing country rocks. The conditions of groundwater flow in this layer are intimately linked with the ore-bearing middle layer.

Thus, hydrogeologically, there are three water-bearing complexes, i.e., the upper complex, middle ore-mineralised complex, and lower infra-ore complex. The characteristics of each water-bearing complex have to be examined individually in order to evaluate the influence of each water-bearing horizon on the commercial mining of the ore deposit.

Experience has shown that such highly complex hydrogeological conditions predetermine the adoption of specific measures of carrying out mining and protection of mine workings from groundwaters and also preservation of the mine environs [20].

So, the water-bearing horizons of the upper series overlying the mineralised layer have to be studied with a view to hydrogeological flooding during the introduction of shafts or stripping in the case of open cast mines. Such studies also help in the choice of drainage methods during and prior to exploitation of ore deposits. Hydrogeological data on the water-bearing horizons of ore-mineralised country rocks are essential for estimating conditions of carrying out preparatory and actual mining operations. Data on the infra-ore rock series and their water-bearing characteristics are extremely valuable in estimating the degree of their influence on the safety measures undertaken during commercial working of the ore deposits.

In conclusion, a series of major hydrogeological problems, which arise during the commercial working of ore deposits distributed over different mining regions of the USSR, are presented in a conveniently tabular form (Table 2). The deposits vary in ocurrence and cover folded geosynclinal belts, platforms and shield areas. The list of problems determines the major directions of the hydrogeological investigations to be undertaken on ore deposits at all stages of their studies.

CHAPTER 3

Natural Gases in Ore Deposits

NATURAL GASES UNDER THE INFLUENCE OF DEGASIFICATION OF COAL DEPOSITS

In the process of exploration and exploitation of mineral deposits of the Soviet Union, the presence of natural gas is also observed in addition to large water discharges. This situation complicates commercial working of mineral deposits to some extent and has led to the adoption of more competent additional measures to guarantee safe conditions of mining.

An intensive gas regime was first noticed in one of the large mineral deposits of the northern Soviet Union where analysis revealed the presence of methane, hydrogen, carbon monoxide, carbon dioxide, heavy hydrocarbons and nitrogen. This deposit is situated in the region of permafrost, which ranges in thickness from 0 to 350 m. Open thawed grounds characterise the river valley regions where the thickness of frozen mass varies from 150-250 m. Today, all mining activities are conducted in this zone of permafrost. The deepest horizons in such regions approach almost to their lower border.

In geological composition, the region comprises parts of sedimentary, tuffaceous and igneous rocks (Figure 3). The oldest formations belong to the Devonian and are composed of limestones, shales and marls with intercalated gypsum and anhydrite. On the eroded surface of the faulted Devonian lies the coal-bearing series composed of shales, sandstones, argillites and beds of coal. The thickness of the coal-bearing series does not exceed 300 m.

Stratigraphically, in the section described above, the coal-bearing formation is overlain by a cover of effusive rock series (thickness varying from 80 to 350 m). Sedimentary and effusive formations have been intruded by intrusive rocks, to which ore mineralisation is related.

Such a geological structural setting, with coal beds characterising the lower part of the section and ore bodies confined to the upper part, determines the occurrence of natural gases in such ore deposits.

Large joints and fissures striking northeast play a vital role in the migration of natural gases. Complex normal and very deep strike-slip faults intersect almost the entire folded complex.

In such a region of ore deposits the following four types of underground waters occur: (1) ground and fracture-groundwaters above the permafrost horizon form within the limits of the zone of seasonal thawing; (2) groundwaters of open thawed ground form under river valleys; (3) inter permafrost waters along zones of large tectonic dislocations; and (4) fracture waters under the permafrost horizon distributed in the bed-rock zone possessing hydrostatic pressure and high mineralisation.

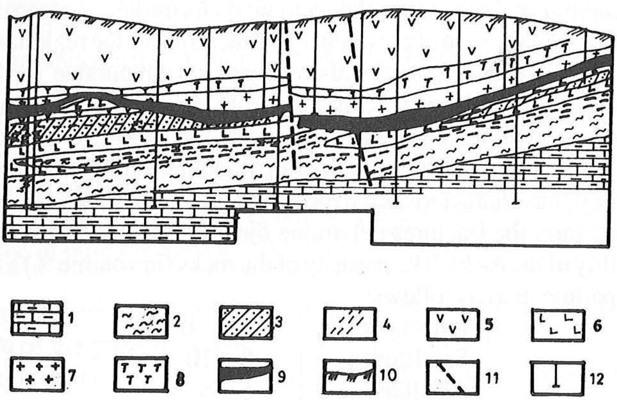

Figure 3: Schematic geological section of an ore deposit
1—Shales and marls of Devonian; 2—Lower Permian formation; 3—Upper coal—bearing Permian formation; 4—coal seams; 5—effusive series; 6—porphyrites; 7—gabbro-diorites, gabbro; 8—gabbro-diabases; 9—commercial segregations of ore; 10—soil and vegetative cover; 11—fault; 12—borehole.

Fumaroles exuding from the mine workings contain 70% methane and at times 90 and even 100% (a jet of pure methane).

Carbon dioxide is the common component of the natural gases and is encountered in the upper horizons of the section, though in small quantities. Large quantities of carbon dioxide are encountered, however, in coal beds close to their outcrops. Nitrogen, like carbon dioxide, is widely distributed in the deposits but is characteristic of gases of igneous rocks and found in gases of coal deposits close to their exposures.

The following patterns of natural gas occurrence and related facts have been established through studies carried out in ore deposits.

1. The coal-bearing suite produces high quantities of methane at its contact with igneous rocks. At places where conditions favour an exchange of gases with

the surface, coal-bearing beds are saturated with carbon dioxide and nitrogen, besides methane.

The origin of methane in the deposits is related to the processes of coal formation from vegetative remains. The possibility of origin of free methane in coal-bearing rocks due to thermal metamorphism resulting during the emplacement of intrusives is not excluded however. Similarly, it can be assumed that methane in coal beds underlying the ore bodies exists in a free as well as absorbed state. The genesis of those gases prevalent in the deposits, such as carbon monoxide, heavy hydrocarbons and hydrogen, is also thought to be associated with post-intrusive processes.

2. The main paths of vertical migration of gases from the coal deposits towards the zone of ore deposits are the tectonic dislocations, accompanied usually by a concomitant zone of crushing. Fine fracturing of the regional type widely distributed over all the rocks also serves as a favourable medium for the migration of gases. However, this fracturing greatly influences the redistribution of gases within a layer or in two layers lying close to each other. Under natural conditions, a single system of fractures acting as channels for the passage of gas characterises the rocks of both the coal and ore-bearing suites. Furthermore, the fractures determine the absolute positive role of gas-permeability of the rocks. The porosity of the rocks (in volume %) as determined by experiments is as follows:

Igneous rocks	:	2.5—6
Sandstones	:	8—10
Argillites	:	6—8
Carbonaceous Argillites	:	8—10

Natural gases accumulated in the deposits until the formation of permafrost, when the processes of natural degassing of coal beds became very active. In the latest permafrost the processes of degassing of the geological structure slowed down to a significant degree and, at present, the region exhibits a tendency to become gasproof.

In the zones of rocks with temperatures below 0°C the exudation of methane is limited, as is the case when permafrost conditions are inducted into the methane zone. Fractures here possess little exposure. They are 'healed' by ice. This leads to a shifting to parts where large tectonic dislocations are present, with which fumarolic exudations of methane are associated. The discharge of fumaroles rarely exceeds 4.6 1/min; still, fumaroles with a yield of 15 1/min are also encountered. Most of the fumaroles in this zone are active but the activity attenuates over a period of 6 to 12 months. Finally, the fumaroles are periodically active, with periods of activity ranging from 10 to 40 days and at times more.

3. Underground waters prevalent in the deposits play a positive role in the natural degassing of coal beds. Interestingly, the general direction of move-

ment of sub-frozen waters under pressure and that of gases in the deposits coincides. The role of groundwaters related to the penetrated thawed ground is particularly high in bringing about degassing of coal beds. Were it not for the water-bearing thawed ground being recharged directly from the coal beds outcrops near the surface, the coal-bearing series might be almost completely degassified to a considerable depth. At great depths (600-700 metres) the action of groundwaters of the thawed ground zone in degassing coal beds might be sharply reduced.

During studies a close connection between the chemical composition of underground waters and the distribution in them of gases was established.

a. Underground waters containing hydrocarbonates of calcium are commonly distributed in the upper part of the zone of nitrogen-carbondioxide gases.
b. Underground waters containing sulphates of calcium and sodium belong to the lower part of the zone of methane-carbon monoxide-nitrogen gases.
c. Waters rich in hydrocarbonates of sodium are commonly seen in the zone of nitrogen-methane with the upper part of the zone predominantly methane.
d. Sub-surface waters containing hydrocarbonate salts and chlorides of sodium normally occur in the zone of complete absence of 'gaseous weathering,' i.e., the zone of pure methane gases.

The chemical compositions of underground waters of deposits likewise serve as indicators of the probable composition of gases and their zoning distribution. Very often this is important for forecasting the gaseous abundance in ore horizons where mining activity has been planned.

The occurrence of natural gases in ore deposits has necessitated the adoption of the following special measures for maintenance of safe conditions against mining hazards:

1. Reduction of working in mines with a gaseous regime along with the strict observance of all rules in force.
2. Guarantee of optimal conditions of ventilation in mines with an independent ventilation facility for each block and provision of two series of pumping sets (working and reserve) within the limits of the mine, one for the upper horizon and the other for the lower horizon.
3. Timely advance preparation of new horizons to enable their preliminary artificial degassing.
4. Organisation of a constantly working gas service to carry out systematic supervision and control of maintenance of the gaseous regime.
5. Exploratory boreholes for timely location of methane-bearing fractures or zones, drawing up prognostic horizontal plans and degassing of the lower horizons during draining of underground waters.

NATURAL GAS CONTENTS OF ORE BODIES IN REGION OF VOLCANIC ACTIVITY

Ore deposits in which emanation of natural gases has been observed are situated in Trans-Baikal within the absolute elevations of 1,400-1,500 m. The ore district lies in the intermontane river valley. The hill ranges surrounding the valley run northeasterly. The average annual atmospheric temperature is –2.6°C. Permafrost in the region of ore deposits occurs as 'islands' and is widely developed in the low-lying areas, river valleys and along the slopes. It is absent along the water divide and in the south-facing slopes. The thickness of the zone of permafrost rocks on the average is about 20-30 and rarely 50-60 m. In the recent alluvial formations below the valley channels permafrost is absent. Here reverine thawed rocks are seen.

Geologically, the region comprises rocks of different age and varied composition. The largest area is represented by intrusive rocks: granites and grandiorites of the Upper Paleozoic era and granitoids of the Mesozoic era. To lesser areas are confined Mesozoic effusive formations: porphyrites their tuffs, tuffobreccias and also conglomerates and sandstones. Conglomerates and sandstones of the Lower Cretaceous period commonly fill tectonic depressions. The ore deposit described here belongs to such a depression (Figures 4 and 5). The rocks in association with the ore deposit include granites which fill most of the depression and Jurassic porphyrites and sandstones—conglomerate series of the lower cretaceous—fill the rest.

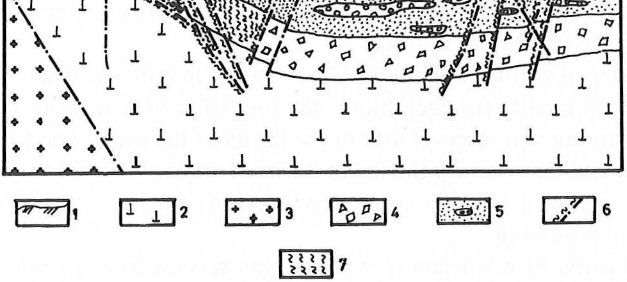

Figure 4: Schematic geological section of ore deposit, Trans-Baikal

1—loamy cover; 2—granites; 3—granites-aplites; 4—conglomerates; 5—sandstones with lenses of conglomerates; 6—zones of dislocation containing ore-bearing quartz veins; 7—quartz.

Underground waters of two types have been differentiated in the ore deposit of Trans-Baikal: (a) Groundwaters of the alluvial formation covering the channel of the thawed ground of river valleys and (b) sub-freezing fracture waters of crustal rocks under hydraulic pressure.

The most widely developed waters in the deposits are the sub-freezing fracture waters of the igneous and sedimentary crustal rocks which constitute the ore-bearing country rocks and form a single aquifer horizon.

The intersections of tectonic fractures and ore-bearing quartz veins constitute major water-bearing structures. Fractures with plenty of water are those which have undergone crushing after ore mineralisation.

The sub-freezing horizon of piezometric fracture waters opens into the deposit through a large number of boreholes and also while mining. The discharge of the highest yielding wells at times reaches 3-5 l/sec with the pressure in the wells situated 10 m above the elevation of the present river bed. Sub-freezing waters possess high mineralisation within the limits of the ore field and normally exceed 5-7 g/l. They contain a large quantity of carbon dioxide (up to 3 g/l). Chemically, these waters contain hydrocarbonates of sodium.

The presence of gas in sub-freezing waters is noticed in all boreholes and mine workings. Interestingly, wherever ore mineralisation is absent or fairly weak, mineralisation of fracture waters of the sub-freezing horizon also exhibits a sharp decline but, however, retains the chemical composition of hydrocarbonate of sodium, while in underground waters hydrogen sulphide is encountered. The main

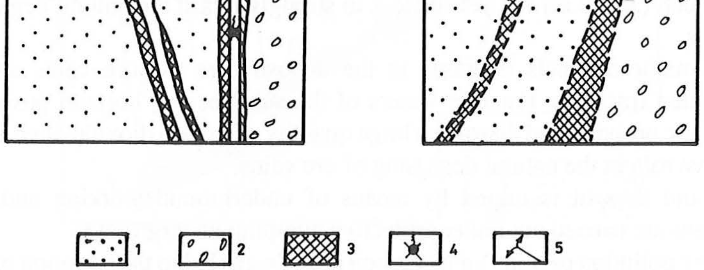

Figure 5: Schematic plan and cross-section along line I-I of deposit 1—sandstones; 2—conglomerates; 3—ore veins; 4—'Grifon' (outlet of underground waters with CO_2); 5—self-discharging underground drainage well with carbon dioxide.

area of occurrence of hydrogen sulphide waters is situated northeast of the ore district beyond the limits of the eastern dislocation.

When fracture waters of the sub-freezing horizon open into the deposit during mining operations, they form the main source of flooding. The escape of these waters is in the form of an intense narrow jet or a concentrated flow along the open fractures of the ore-bearing quartz veins. A study has shown that in a span of one year the general rate of flow of these waters does not vary significantly and is estimated at 90-110 m^3/hr.

One of the serious obstacles in the normal exploitation of an ore deposit is its natural gas content. The presence of large quantities of carbon dioxide gas in mine waters and also the usual fumarolic exudation directly in mines through the ore veins makes the execution of preparatory and actual mining operations very difficult. Above all, the mine air is intensely saturated with carbon dioxide which varies from 18 to 88%.

Investigations have established that: (a) with depth of mining the content of carbon dioxide in mine waters increases as does the intensity of fumarolic release of gases; and (b) the gas content in mine waters over the course of a year is subject to changes but the maximum (higher than 3 g/l) occurs from July to September.

Analyses of gases of mine waters have shown that this content of hydrogen sulphide is definitely less significant than that of carbon dioxide. Hydrogen sulphide is obviously associated with the organic remains in Jurassic conglomerates. Determination of other gases in groundwaters has not been done.

Interestingly the fracture-waters opening directly into the ore-bearing country rocks (sandstones and conglomerates) during mining, including those of some tectonic dislocations, usually do not contain carbon dioxide. These waters are fresh. Hence the gas content in the deposit is linked with certain intersecting fractures of structurally deeper aspect.

The genesis of carbon dioxide in the fracture waters of ore veins is obviously related to the end stage processes of minor volcanic action, which is fairly conspicuous in the region close to the deposit (the Quaternary basalts). Permafrost plays a major role in the retention of carbon dioxide in the ore veins. Its thickness is not much (30-50 m) but yet suffices to strongly retard the natural degassing of ore veins.

The major channels of gases in the deposits are the ore veins and some deep-seated fractures. Fracture waters of the sub-freezing horizon possess high hydrostatic pressure and dissolve a large quantity of carbon dioxide; then thus play a positive role in the natural degassing of ore veins.

The ore deposit is mined by means of underground working and mining operations are carried out under protective pumping underground.

Heavy pollution of mine air by carbon dioxide gas led to the adoption of special measures for the protection of the miners from its deleterious effects. The major measure was the introduction of competent artificial ventilation in mines. For the purpose of preliminary gaseous drainage in the working horizons, artificial ventilation in the mines has to be combined with drilling of special underground hydrogeological drainage wells (boreholes) so as to pass through preparatory horizons or special exploration drainage systems along the ore veins, established at two or three horizons with depth.

It is possible to effect methods of exploitation of gaseous drainage in underground workings by means of advance drilling of drainage wells which, to a considerable extent, facilitate execution of preparatory and actual mining activity.

Mine waters containing carbon dioxide may be utilised in the medical treatment of workers outside health resorts by supplying mineral waters directly to city hospitals. Apparently such waters throughout the Soviet Union possess a high therapeutic value.

OCCURRENCE OF NATURAL GAS IN DEPOSITS UNDER THE INFLUENCE OF COMPLEX PROCESSES

An interesting occurrence of abundant natural gas associated with ore deposits has been reported from northern Caucasus. This deposit is worked at the present time through shafts. In order to study its perspective, detailed geological studies were conducted in adjacent regions. During the course of exploration and exploitation, inflammable and toxic gases such as hydrogen sulphide, carbon dioxide, nitrogen and gases of the methane group were detected.

The study region presents typical geomorphic features, i.e., Cis-Caucasian median ranges, changing over southwards to high hill ranges. Local rivers deeply dissect the surface of the hilly terrain. The river directly cutting across the ore field

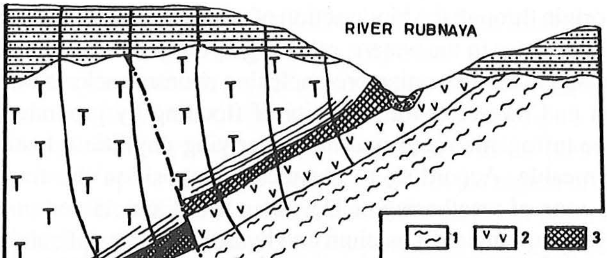

Figure 6: Schematic cross-section of ore deposit, North Caucasus
1—phyllitic rock; 2—quartz-albitophyre; 3—ore body; 4—siliceous shales; 5—tuffs, shales; 6—sandstones and shales of Jurassic period; 7—alluvial deposit; 8—tectonic dislocation; 9—borehole.

in the study region exhibits significant erosion of the ore-bearing country rocks and thereby exposes the ore bodies.

A geological section of the studied deposit revealed rocks of the Devonian, Permian, Jurassic and Quaternary periods (Figure 6). The Devonian formation is composed of a volcanogenic-sedimentary complex of rocks—shales, tuffs and ore-bearing porphyritoids. They outcrop in the valleys of local streams flowing over an asymmetrical anticlinal fold.

In the southern and southwestern parts of the deposit the ore-enclosing country rocks of the Devonian are covered by red conglomerates and sandstones of the Upper Permian and also the Jurassic period. Towards the south, beyond the limits of the ore deposit, rocks of the Carboniferous period are seen. These formations contain deposits of coal.

Alluvial pebbles (thickness up to 10 m) are spread over the Quaternary formations, thus forming the components of tidal and supra-tidal terraces of the rivers.

In the exposed part of the Devonian is situated the anticlinal fold; through its axis can be traced a wide transverse deep fracture zone.

Hydrogeological conditions of the deposit were studied to ascertain the degree of flooding and exploration of the possible sources of water supply for the mining project. Three types of underground waters occur in the region of the deposit: ground-alluvial formation, fracture-ground belonging to the zone of heavy fracturing of crustal rocks and fracture-vein zones related to tectonic dislocations.

Fracture-groundwaters are present in the Jurassic sandstones and Devonian ore-bearing tuffogenic sedimentary rock series. Chemically, these waters are related to the type containing hydrocarbonates of calcium with generally a low mineral content (0.3-0.6 g/l). In many springs and some boreholes fracture-groundwaters of Jurassic formations contain hydrogen sulphide. In the regions of northern Caucasus hydrocarbonates of calcium and hydrogen sulphide are widely detected in waters of the Jurassic layers. The content of hydrogen sulphide suggests biochemical origin through the biotic action of micro-organisms which decompose the dissolved sulphates in the waters, releasing hydrogen sulphide.

Water seepage in the Devonian ore-enclosing country rocks is traced to depths of 150-200 m and thereafter the intensity of flooding by groundwaters sharply declines in the tuffogenic rocks and the underlying phyllitic schistose rocks are almost impermeable. According to chemical composition the fracture-groundwaters of the zone of weathering of Devonian rocks are classed under the types containing hydrocarbonates of calcium and hydrocarbonates of calcium and magnesium.

Fracture-vein waters confined to the zones of tectonic dislocations are under pressure. They are encountered in deposits during the process of exploration of some wells (boreholes) located primarily along the zone of the NW striking fault and also along the zones of 'blind' tectonic dislocations.

These prizometric waters differ distinctly in chemical composition from the remaining types of groundwaters occurring in the deposit. These waters are of the sodium chloride type with dense residues up to 3-5 g/l. It has also been established that these waters contain easily distinguishable gases: hydrogen sulphide, carbon dioxide, nitrogen and methane.

At the first stage of study only toxic gases were detected—hydrogen sulphide, carbon dioxide and at deeper wells, inflammable gases from the methane group. In certain wells the escape of the methane group of gases was so intense that jets of gas were seen burning continuously at the mouths of the wells for a long time. Similarly, the data collected indicated the possibility of vertical hydrochemical and gaseous zoning, which has been observed in other areas of ore deposits. Unfortunately, data on quantitative characteristics and complete chemical composition of the gases found in the deposits are very scarce.

The natural gas in the Devonian series of ore-enclosing rocks might perhaps have originated due to the migration of gases from depths, where bituminous shales occur amidst the underlying phyllite-like shales. Methane may perhaps be present in the bituminous shales in a free state as revealed by the occurrence of methane under high pressure in the exploratory boreholes. The gases might have migrated along the deep-seated tectonic dislocations which have served as passage ways.

Furthermore, methane and other gases may also originate in ore deposits by migrating from the region of coal deposits situated hypsometrically lower to the south from the occurrence of the ore body at approximately 8 to 10 kms. Obviously the coal deposits are confined to the Carboniferous formation. The anticlinal fold of the Devonian ore-enclosing country rocks might act as the reservoir for migrating gases.

It was found that during the introduction of shafts while mining the presence of gas in the ore deposit demanded adoption of special preventive measures from harmful, toxic and dangerous inflammable gases. Proper ventilation of the mines had to be provided instantly.

Similarly, the appearance of gas in some of the ore mines of Siberia pose specific complexity in commercial working of the deposits. Such deposits call for familiarisation with the methods of mine stripping. Halogenoterrigenous and sulphate-carbonate rocks of the Cambrian period are observed in parts of the geological section, particularly in the upper structural unit of the platform.

The entire section of rocks of the ore-bearing series in the region of the deposits is exposed in parametric drilling. The basement of the platform occurs at a depth of 2,126 m and the deposit has in fact been prospected up to a depth of 1,200 m.

The deposit is situated at the centre of a cupola-like structure composed of carbonate rocks of the Lower Palaeozoic. The ore body is overwhelmingly distributed in the zones of regional fractures or joints of sub-meridional disposition, which are related to deep-seated tectonic dislocations (Western, Parallel, Central and Eastern) striking northwest. Data through magnetic surveys place the thickness of the tectonic dislocations at 400 m.

The deposit is strictly confined to the zone of Central fracture. The country rocks and ore body are complicated by a system of smaller tectonic dislocations, which virtually contribute to the flooding of the deposit.

Cryopedologically, the deposit lies in the field of massive permafrost rocks and is characterised by a series of properties. First, there is a significantly deep penetration of negative temperatures. According to thermal data the zero degree isotherm lies at depths of 740-770 m. In the cryopedological section permafrost rocks are exposed at intervals of 0 to 300 m and frozen rocks between 300 and 700 m. The average annual temperature of permafrost rocks at depths of 12-15 m is around –4°C. The mean temperature gradient of the permafrost section is 0.4-0.5°C per 100 m.

The wide development of permafrost rocks of vast thickness determines the deep position of the roofs of sub-freezing water-bearing complexes, which enable mining of the upper part of the ore body in very comfortable conditions without interference from underground waters. The presence of permafrost rocks in the berths of open cast mines increases their stability, which allows an increase in general angles of the open pit.

Parts of the sub-freezing water-bearing complex participate in the flooding of the deposit and are composed of the carbonate suite of rocks of the Cambrian period. Water-saturated rocks are the fractured and cavernous dolomites and limestones with lenses of argillites and anhydrite in the upper part. Underground waters open into the wells at depths of 231-336 m. The general thickness of an aquifer complex varies from 150 to 190 m. Groundwaters attain high pressure at 175-216 m. The piezometric level stabilises at a depth of about 100-120 m. The temperature of the brine waters is negative. The inferred water conductivity through the section is placed at 196 m^2/day. The coefficient of piezo-conductivity varies from 2.6×10^6 to 1.2×10^7 m^2/day. The coefficient of elastic volume of the layer possesses a magnitude of 1.03×10^{-5} to 1.4×10^{-4}. The mineral content of the underground waters of the deposit varies with depth of layer. It was nearly 41-58 g/l in the open pit mines. It rises to 85-90 g/l and further to 270-370 g/l.

Hydrogeological studies have established that all underground waters of the water-bearing complex situated at a depth of 300-450 m, contain dissolved gases in fairly large proportions—from 0.01 to 0.03 m^3/m^3 in fractured rocks to 0.1 to 0.3 m^3/m^3 in highly fractured rocks. This gas factor reaches a significant 0.4 in zones of tectonic dislocations. Natural gas can be divided qualitatively into two types—one in which nitrogen is predominant and the other with methane predominant. The nitrogen content in gases of the nitrogen type varies from 83-97%, hydrogen 2.5-15%, argon 0.45-0.9% and carbon 0.5%. Methane type gases contain 86-88% methane, ethane 6-7%, nitrogen 2-5% and hydrogen 2%. Water of the water-bearing complex in particular contain 120-130 m/l of hydrogen sulphide. Its accumulation contributes to the presence of bitumen and other organic substances in the rocks formed under biochemical reduction of sulphates in an anaerobic environment.

The roofs of the water-bearing horizon provide conditions favourable for the accumulation of gases in certain cases, thus forming gas 'caps'. When boreholes encounter these sites, the gases quickly dissipate and their volume is relatively reduced.

Mining of the deposit is carried out by open cast methods. The estimated depth is 420 m. The forecast of underground water currents in an open pit during its maximum depth of working is nearly 2,000 m^3/hr.

Drainage of an open cast mine is provided by an inner ring of boreholes which lower the water table. The pump sets are of the high pressure, anti-corrosive type as are the inferior open pit drainage pumps.

Considering the high level of mineral contents of sub-freezing waters, which contain toxic gases, and the need for preserving the environment, a modern drainage technique for open cast mines has been adopted according to the scheme known as 'drainage burial'. In this method water is not discharged to the surface but removed through a closed system of water pipes that terminate in carbonate rocks lying in the zones of increased filtration capacity.

The various examples examined above do not, of course, exhaust all the different natural conditions of occurrence of gas in ore deposits discovered to date. Still other deposits where harmful and highly explosive gases exist to some extent have yet to be studied. The chances of discovering natural gases in ore deposits are greatest in those where mining has been undertaken at great depths (more than 800-1,000 m).

All these aspects considered together emphasise the need for conducting hydrogeological studies along with other special studies during the stage of prospecting ore deposits in order to understand their gas potential.

CHAPTER 4

Review of Modes of Drainage in Mining

GENERAL FACTORS INFLUENCING THE CHOICE OF MODES OF DRAINAGE

Drainage during mining operations under varied hydrogeological and engineering geological settings forms a potential technical means of providing safety during the commercial working of mineral deposits. But the simultaneous operation of a number of mineral deposits occurring close together along with the associated drainage often results in crustal rock alteration under natural conditions, depletion of groundwater resources and formation of some degree of technogenesis. These two contrasting tendencies decide the choice of a rational scheme of drainage, measures of preservation of the surrounding environs and also the need for maximum utilisation of mine waters for overall water supply and irrigation.

Planning of drainage layout and development of drainage techniques during the process of mining are problems of a specialised nature for institutes or agencies entrusted with major projects relating to commercial mining of mineral deposits. Project organisations which undertake the task of planning mining and related activities should, however, be provided with sufficient reliable hydrogeological and engineering geological information about the areas under study. The results of complex research carried out at the stage of exploration of ore deposits, are utilised for formulating schemes of drainage and adopting suitable measures of protection of the mines from flooding.

As emphasised earlier, investigations at the site must be completed at the stage of development of the mines. It is also necessary to continue required complex hydrogeological and engineering geological studies at the stage of commercial working of the mineral deposit. The most important of all the complex studies carried out at this stage include *in situ* observations on the regime of underground waters, tests on exploitation of the drainage facility and also conditions of formation of technogenic processes [7, 23].

It is pertinent to present a brief summary of the measures developed for the protection of mines from underground and surface waters. The choice of system of drainage in the mines and preservation of the surrounding environs are determined by a series of factors:

1. Geological factors which characterise the lithological composition of ore-bearing country rocks and rocks of the overlying series—the thickness, nature of disposition, tectonic dislocations, fracturing and karstification of rocks, depth of occurrence of ore bodies and their textures and structures.
2. Hydrogeological factors which determine the conditions of water flow in crustal rocks (ore-bearing) and unconsolidated formations—characteristics of aquifer horizons, conditions of their distribution and recharge; hydraulic connection between surface and sub-surface waters, characteristics of major calculated hydrogeological parameters, their degree of filtration and heterogeneity in plan and vertical section; chemical composition of all types of underground waters occurring in association with the ore deposits, their corrosive action on concrete and metal; character of flooding of ore deposits, expected rate of flow of water in mines and their balancing structures (sources of flooding in mines).
3. Engineering geological factors—mechanical compositions of unconsolidated formations and physico-mechanical properties of crustal rocks and mineral deposits; fracturing and degree of stability of rocks in mines (underground mines and berths of open cut mines); and modes of changes occurring in rocks at stage of exploitation.
4. Geomorphological and climatic factors which decide—character and degree of ruggedness of relief of the future underground or open cut mine area; hydrographic system of area of mining activity and regime of surface runoff (annual and multi-annual logs); influence of surface waters on possible flooding of deposit; thermal regime of air and surface waters and character of streams appearing over area of deposits because of atmospheric precipitation.
5. Factors characterising the gas potential in mineral deposits—natural gases and conditions of their formation; corrosive and chemical action of the gases; degree of saturation of gases and consequent protective measures in mines.
6. Factors of technogenic origin characterising—prognostic evaluation of possible development in stage of exploitation of different types of hydrogeological and engineering geological technogenic processes and technogenesis, as a whole; measures of protection of features of geological environs and ecological situation of neighbourhood of mine areas from negative influence of technogenesis; and the most important processes of interaction of drainage arrangements with operating water supplies.
7. Factors characterising techniques in mining engineering for opening and exploitation of ore deposits and their controlling technology; depth of laying of shafts or open cut mines; rate of progress of mining face; requirements for indicating degree of moisture of ore bodies etc.
8. Economic factors, which decide comparative estimate of schemes of drainage based on required data collected from mine site; merit and choice of drainage schemes either for open cast or underground mines; economic

viability of measures of preservation of the environs from negative influence of technogenesis.

9. Factors of complex utilisation of all the components of the study area including underground waters for practical use (water supply and irrigation).

This brief outline of the major factors which influence the choice of scheme of drainage in mines of ore deposits duly emphasises the importance of the characteristics of the geological environment.

SCHEMES OF DRAINAGE IN MINING

Further to the account of basics in mining practise described above, it may be mentioned that the mining industries in the USSR adopt various types of special and original schemes of drainage in mines. Some are examined here.

Scheme of open drainage: This is the simplest method, often practised in the drainage of underground and open cast mines by means of intra-mine pumping. According to this scheme, all water currents in the system of underground or open cast mining are taken up directly to intermediate or central pumping stations where the mine waters are then pumped to the surface through pipes.

During open cast mining of ore deposits such simple schemes of drainage are applicable in simple hydrogeological conditions of the mine site, when the exposed banks in the mine are stable and the rock benches fractured and sheared. At these places surface and sub-surface waters exert almost no influence in changing the properties of the rocks. Water-bearing rocks at the edges and benches possess no tendency towards filtrational deformation.

Discharges of groundwaters reaching the tilted edges of an open pit start forming drainage and built-up canals and are later diverted through pipes into a reservoir-basin established along the bottom of the working face. Thus, under the conditions of open drainage the organisation of intra-open cut mine currents of groundwaters deserves special attention.

For example, such a scheme of pumping has been employed in the drainage of underground mines of ore deposits. A central pumping station with water intake sufficient to hold the volume of general mine waters is established at the lower working horizons. In all high level working horizons mine waters are led into drainage channels and later slowly transferred through pipes lying between the horizons into a reservoir or tank, from which the central station pumps them to the surface.

Such systems of open drainage are prevalent in many well-known ore deposits exploited by open cast or underground mining, for example in Siberia, the Urals, Kazakhstan, the Caucasus and other regions. Experience gathered from the exploitation of ore deposits reveals that the system of open drainage in such simple natural conditions is thoroughly justified and the effectiveness of the drainage fully guarantees protection from mining hazards.

System of special purpose drainage: This is employed in ore deposits of complex natural conditions. The general rates of flow of groundwaters in this system of mining (both open cast and underground) average between 150-300 m^3/hr and rarely reach 500 m^3/hr. Still, country rocks in the rims of open pits as well as in shafts do not possess the stability of slopes and are characterised by occasional shearing, particularly when there is additional moisture in the rocks. This situation often demands advance drainage of ore deposits. A few types of special schemes of drainage are required in open cast mines of ore deposits. In the case of no surface streams in the area of the deposit, the sources of flooding are mainly underground waters and atmospheric precipitation. Here during the stripping of the deposit, drainage in an open pit and in ore deposits is done by means of a system of sub-surface drainage layout closely following the contour of the open cut mine, pumping shafts in combination with drainage wells and also through filters (Figure 7). Temporary water currents resulting from atmospheric precipitation are slowly transferred to the horizons of drainage tunnels. The major problem of an underground system of drainage in open cut mines is one of assuring advance drainage in the mines and ore bodies.

According to the depth of the open cut mine, two or three underground drainage horizons are commonly set up as shown in Figure 7. In certain cases the underground system of drainage in the open pit is combined with additional measures of

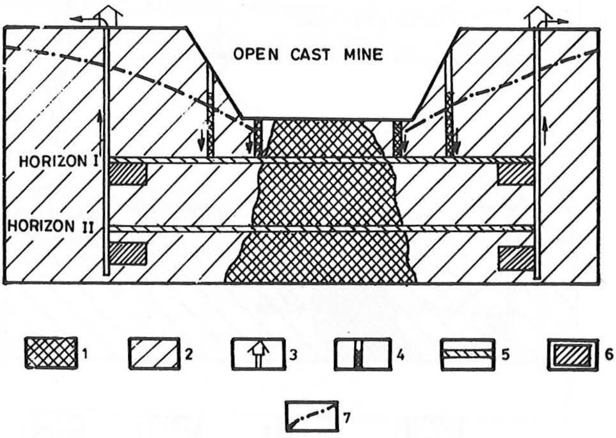

Figure 7: Scheme of sub-surface drainage in open cast mine
1—ore body; 2—ore-bearing country rocks; 3—pump shaft; 4—porous filter; 5—underground horizontal drainage tunnel; 6—reservoir and pumping station; 7—depression of groundwater table. Arrows indicate direction of flow of mine waters.

protection of the benches and banks of the open cast mine from filtrational deformation through drainage of the benches by drainage channels and boreholes [7].

In such cases where protection of mines from possible flooding by surface waters is required, the sub-surface system of drainage becomes complicated with additional drainage facilities. When there are minor streams of rivers (third or fourth order), far removed or isolated from surface waters beyond the limits of mine working, then drainage of an open pit is quite possible.

Currents of groundwater possessing a hydraulic connection with surface waters often form in the alluvial deposits in valley regions of large rivers. When an open cut mine lies immediately adjacent to a river valley, then protection of the mine from flooding and the faces or sides of the pit from deformation is achieved by a system of wells that lower the water table as shown in Figure 8. Mining practises in some ore deposits in Kazakhstan have demonstrated that such a drainage scheme of local character is highly effective and provides complete safety not only to the flanks of the open cast mine of complex sandy-pebbly formation, but also protects

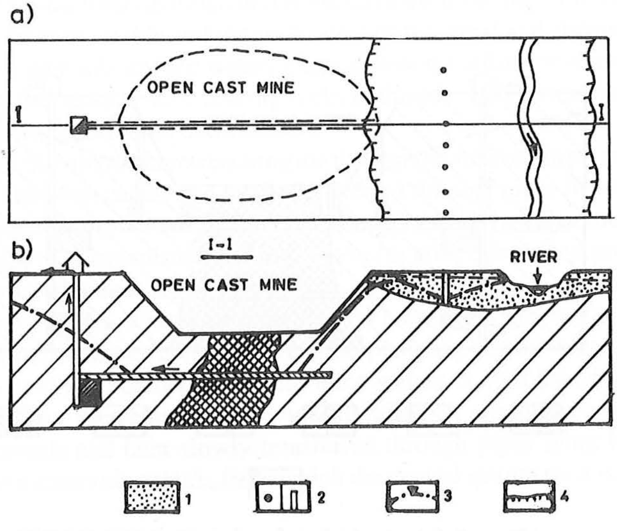

Figure 8: Combined scheme of drainage in open cast mine
1—alluvial deposit; 2—linear row of wells for lowering water table; 3—static level of underground waters; 4—contours of river valley.
See Figure 7 for rest of legend.

the mine from additional sources of flooding. In any case, complexity during the exploitation of open cut mines under such a combined scheme of drainage has never been encountered in practise. This emphasises the effectiveness of this approach. The application of local draining and lowering of the water table by means of pumping wells is technically simple, although it becomes complicated during exploitation. Use of submersible pumps in the wells requires constant monitoring for their useful exploitation.

The system of local drainage of an open pit or the shaft ground may adopt a different mode to some extent. For example, in one of the ore deposits in north-eastern Kazakhstan local drainage of a flooded rock series (sandy-pebbly alluvia, 120 m thick) resting directly over ore-bearing rocks was adopted, utilising a combination of schemes. As a result, it was established that underground waters of a river valley regime constituted the source of flooding in the pit. To protect the mines from groundwaters of alluvial deposits, the withdrawal of river waters was carried out first and then a shaft pump introduced directly into the crustal rocks (at a depth of 150 m) to reach the pumping station and also the underground horizontal adits. In a cross-section of the river valley along the course of the drainage system, a linear row of boreholes (with porous filters) were drilled. Thus there were 22 holes 50 to 60 m apart. The principal scheme of drainage is shown in Figure 9. Such a unified scheme of drainage enabled the quick and complete drainage of the sandy-pebbly deposit and likewise effectively isolated the mining activity from the major source of flooding of the ore deposits.

In real situations of commercial working of ore deposits materials are encountered which require somewhat advanced open cast methods of mining initially

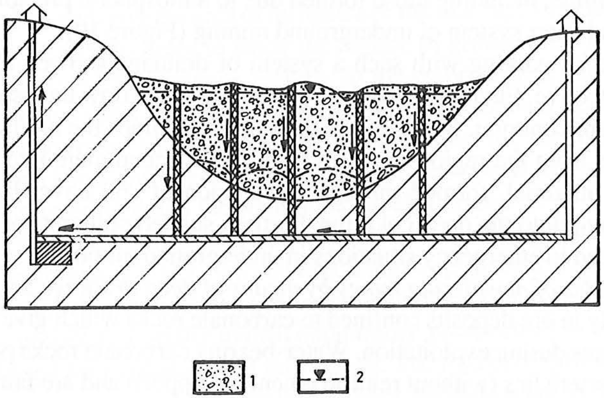

Figure 9: Principal scheme of local drainage in aquifer of sandy-pebbly deposit
1—alluvial cover of sandy-pebbly deposit; 2—level of underground water before pumping.
See Figure 7 for rest of legend.

(commonly at a depth of 250-300 m) and later the deeper ore horizons are mined through sub-surface shafts. Similar composite methods of working are adopted in areas where the geological environment presents conditions associated with the

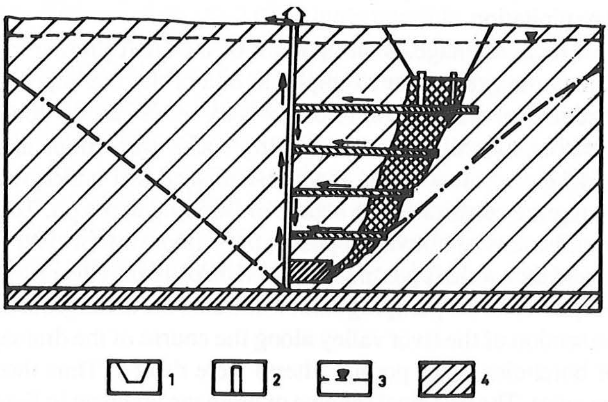

Figure 10: Scheme of drainage in open cast mine with intrashaft water pump
1—open cast mine; 2—injection well; 3—level of ground water table before exploitation; 4—impervious rocks.
See Figure 7 for rest of legend.

second model. Under such mining conditions all water flows formed in the area of the open cast mine, including those formed due to atmospheric precipitation, will join the groundwater system of underground mining (Figure 10).

Experience in working with such a system of drainage showed that it is not admittedly effective. First, in the regime of general water flow undesirable heavy spring bouts are common. Secondly, in underground mines the entire volume of water currents from the region of an open pit might accumulate into a pulp-like mass of rock material, formed through the erosion of soil cover by rainwater currents draining into the open cut mine. Further, sudden outbursts of such 'fluid rock' might lead to emergency situations in underground mining.

Special modes of dewatering mines by means of deep drainage are adopted in practise mostly in ore deposits confined to carbonate rocks which give rise to vast water discharges during exploitation. Water-bearing carbonate rocks possess high strength characteristics (without reinforcement or support) and are fairly stable in underground mining; so too are their benches on the banks of an open cast mine. These rocks do not change their physical properties during water drainage. Tectonic zones of faulting in limestones where the rocks are highly crushed are exceptions, however. During the drainage of such flooded zones by means of pump wells debris

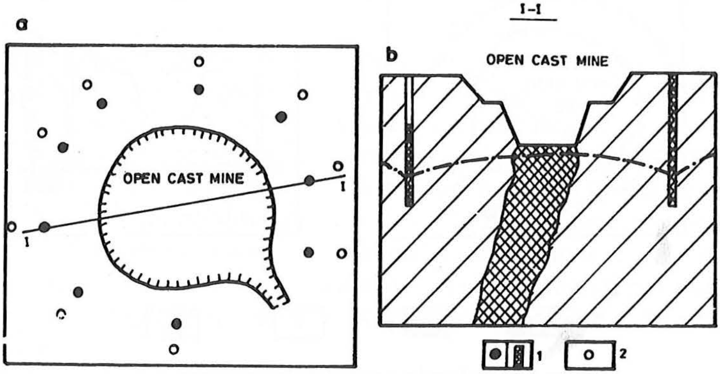

Figure 11: Scheme of drainage in open cast mine by means of water-lowering wells
Wells: I—water lowering; II—observational.
See Figure 7 for rest of legend.

of filtration-collapse (with finer fractions) appear around the well and form cave-in funnels which might result in the deformation of surface installations at the mine.

The drainage process in open cast mining of ore deposits in limestone country rocks is carried out in two stages. At the first stage of commercial working of the deposit (approximately at a depth of 100-150 m) the open pit mine is drained by means of a circular arrangement of wells drilled along the periphery of the mine (Figure 11). Wells intended to lower the water table are provided with submersible vertical pumps and over the area of influence of the drainage system of observation wells is established in order to study the regime of groundwaters and to estimate the effectiveness of the drainage facility. At the second stage, during the working of deeper ore horizons, drainage is carried out by a combined operation, using an advance underground annular drainage gallery around the perimeter of the open cut on the one hand, and a remodelled system of wells provided with porous filters on the other, to bring down the water table level (Figure 12).

Water-bearing carbonate rocks are very often characterised by a high degree of filtration heterogeneity. Hence while executing the projected plan of action during mining through drainage of the open cast mine utilising a circular system of pump wells, it is necessary initially to drill exploratory-prospecting wells at every point or site selected for exploitation of the deposit. The results of drilling and sampling of the exploratory-prospecting wells are very helpful in correcting and exactly determining the location of the groundwater-level reducing boreholes. Such a methodical approach towards the construction of a drainage system definitely increases its effectiveness.

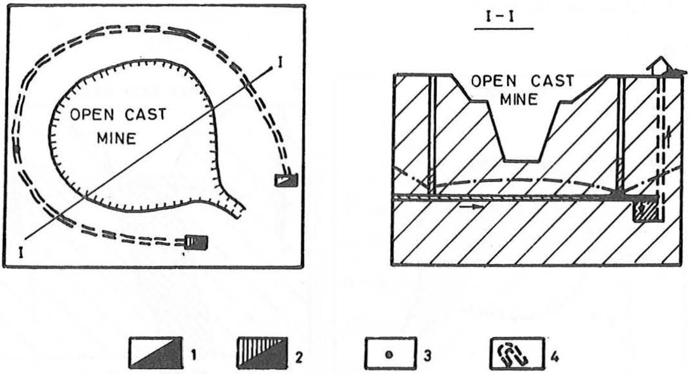

Figure 12: Combined scheme of drainage in open cast mine
1—water suction shaft with pumping station; 2—ventilation shaft; 3—porous filter; 4—underground drainage gallery.
See Figure 7 for rest of legend.

Corrosive brines of high mineral content (up to 120-170 g/l) are encountered in the mine waters of ore deposits occurring in the carbonate rocks. This situation in fact complicates the implementation of the drainage process and disrupts mining activity. Hence remodelling of the boreholes with special anticorrosive submersible pumps becomes necessary.

Drainage operations in mining shafts of ore deposits associated with carbonate rocks are conducted in two stages, as carried out presently in the commercial exploitation of a series of ore deposits. At moderate depths of mining (up to 200-300 m) the general water flows may be directly fed into the system of underground mine workings at their lower horizons where, by means of a central pumping station the mine waters are pumped to the surface. Notwithstanding the comparatively high rate of water flow (up to 10,000-12,000 m^3/hr) the intra-mine pumping for dewatering in underground mines has proved economical. At this stage of drainage in the process of preparatory and cleaning operations of mines, adoption of additional special measures of protecting mining activity from groundwater hazards is necessary. Firstly, drilling of the mine faces is taken up without fail for advance drainage wells for the purpose of taking preliminary conservative measures in the non-uniform flooding of limestones with residual hydrostatic pressures. Secondly, it is necessary to install an automatic waterproof retention mechanism during the introduction of the shaft well into every horizon for retaining and regulating discharge of mine waters. These mine waters constitute a single massive discharge during their sudden outburst from the zones of flooding and cause submergence of mine workings. It is thus pertinent here to underscore the necessity for protecting mines from sudden outbursts of mine waters through a system of waterproof retention structures.

Nevertheless, for depths greater than 300-400 m the mining of ore bodies requires implementation of the second stage of drainage, which combines the scheme of intra-shaft pumping and also an installation of exterior drainage assembly of wells (equipped with submersible pumps) directly connecting the surface with the sides of the cone of depression (of the depressed water table) close to the major source of flooding of the deposit. Surface waters are those of a river system established on the surface over the area of ore mineralisation (Figure 13). By means of such a drainage assembly it was possible to reduce the rate of flow of mine waters to 30-35% in one of the ore districts of the Urals. The advantage and effectiveness of the exterior drainage assembly are unlimited. Drainage units have to be looked upon as a large-scale water supply machinery. Captured underground waters may serve not only industrial requirements but also meet domestic and drinking water requirements.

Similarly, a combined scheme of drainage (shaft pump in combination with exterior drainage assembly) has to be thoughtfully and thoroughly examined as a very effective and progressive scheme, which has been labelled the 'Drainage-

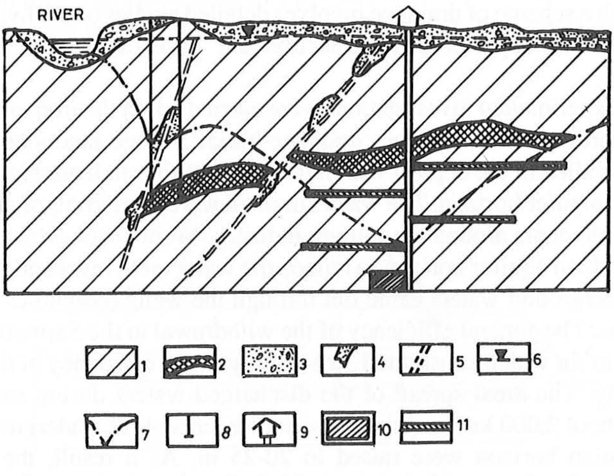

Figure 13: Schematic geological-hydrogeological cross-section of ore deposit in carbonate rocks
1—ore containing, water-bearing carbonate country rocks; 2—ore-body; 3—unconsolidated Quaternary formation; 4—ancient karst belts filled with unconsolidated materials; 5—tectonic dislocation; 6—static level of groundwater; 7—cone of depression; 8—intra drainage wells; 9—shaft; 10—water reservoir and pumping station; 11—underground horizontal drainage tunnel.

Water Supply'. Such a scheme has been implemented in the drainage operations of some ore deposits in the Urals and KMA.

Given the complex hydrogeological conditions in water-bearing carbonate rocks, the introduction of shaft holes involves special methods: (a) protective advance cementation of the walls of the shaft; and (b) protection of the circular system of multiple boreholes fitted with submersible pumps.

It has been pointed out that during the working of deep ore horizons in carbonate rocks (depth more than 500-800 m) natural gases appear: methane, carbon dioxide and hydrogen sulphide. This setting requires additional measures for degassing of the deposits.

It is well documented by experience that drainage while mining ore deposits occurring in carbonate rocks significantly changes the ecology of the surrounding countryside. Drainage operations over a large territory lead to a depletion of moisture from the enclosing environment (springs, groundwaters in wells used for water supply etc.).

Protection of the environment of a mine site from pollution is a complex problem. Pollution might result from the fault zone carrying mineralised mine waters to the ground surface. Here it becomes essential to investigate the channels of passage of brine waters which lie buried in deep structural horizons. In such natural conditions the scheme 'drainage-burial' has proved highly effective. That is, mineralised waters in the ore deposit, after draining from open cut or shaft mines, are removed some distance from the site and buried in deeper water-bearing horizons. Such a scheme of drainage involves detailed studies of the hydrogeology of the region of ore deposits for the selection and basis of burial of mineralised mine waters.

Intensive experimental investigations were carried out in the iron ore deposit of Belozerh according to the scheme 'drainage-burial'. Three junctions of suction wells were installed in the deposit within the limits of the shaft area so as to reach the Sarmatian aquifer horizon. The waters drained were used in supplying water to towns and settlements around the mining industry. From seven wells introduced into the Buchakian aquifer horizon to reduce the water table level and dewater the mine, the underground waters came out through the wells (boreholes fitted with suction pumps. The general efficiency of the withdrawal in the Sarmatian horizon was 350-400 m^3/hr which constituted 30% of the general efficiency of the drainage system facility. The areal spread of the discharged waters during experimental studies was about 2,000 km^2 and the artesian pressures of the underground waters in the Sarmatian horizon were raised to 20-25 m. As a result, the populated settlements close by could utilise the high yield of underground waters for agricultural purposes. It is obvious from this data that experimental industrial research in 'drainage-burial' has provided undoubtedly positive results. Areas under arid climate, however, may require the construction of special evaporator-reservoirs for mineralised mine waters.

Individual system of drainage in mines of ore deposits: This system presents its own rational and special methods of drainage in mining practise, tailored mainly to the characteristics of highly complex hydrogeological and engineering geological conditions.

Experience has shown that the individual system of drainage in mining of deposits is complex. During open cast mining, drainage is carried out by means of (a) intra-open cut mine pumping, (b) system of surface or exterior drainage facility, and (c) additional measures of machine-operated drainage. In the case of underground mining, drainage in mines is effected by (a) external advance deep-seated drainage (preliminary or precautionary and later exploitation drainage) and (b) special techiques of mining. In both cases it is necessary to protect the surrounding environment from the negative action of technogenesis.

Special techniques of individual drainage are particularly useful in ore deposits of complex natural conditions, mainly reflected in hydrogeological and engineering geological settings. Complexity includes multilevel distribution of groundwater horizons in rock series overlying the ore-bearing zone, direct flooding in ore-containing country rocks, unstable rock masses in underground mines and those characterising the slopes of open cast mines.

During open cast mining of ore deposits in the selection of the scheme of drainage, it is imperative that certain properties be considered. Since the rock series overlying the ore-bearing zone are composed wholly of water-bearing complexes the open pit mine can perhaps be stripped to expose a few water-bearing horizons. This might result in the formation of distinct horizons of seepage of underground

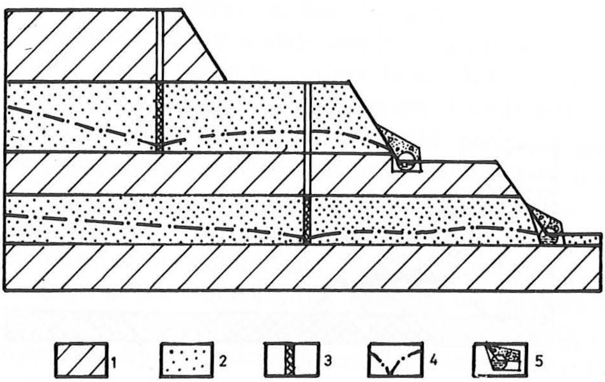

Figure 14: Scheme of stepped intra-open-cast disposition of drainage wells combined with horizontal drainage at toe of each aquifer layer 1—impervious rock; 2—aquifer; 3—drainage well provided with porous filter; 4—cone of depression; 5—horizontal drainage tunnel at toe of each aquifer layer.

waters and also the possible formation of processes of filtration deformation along the benches of the open pit. To prevent such hazardous conditions resulting from the above mentioned features, it is mandatory to provide the area of open pit with some stepped placement of drainage wells as illustrated in Figure 14.

Depending upon the specific hydrogeological setting of the study deposit, stepped placement systems might combindly operate if the upper aquifer horizons possess high permeability and storage capacity compared to the lower horizons, or if in a cross-section of an aquifer complex high permeability and storage capacity are observed in the lower horizons, when the effect of absorption appears quite prominent. In the first case drainage of ledges and benches of the open cut mine is represented by its own system of pump wells along with drains of horizontal trenches (with ground fill) at the base of benches of the permeable rocks. In the second case, utilising the effect of absorption, drainage of the benches may be carried out through a system of suction pumps at the level of the horizon of absorption.

While determining the hydrogeological conditions affecting the stability of the flooded non-working bank of the open pit, it is desirable to take preventive measures by drilling horizontal drainage tunnels, as was done in the Lebedin open cast mine of KMA [22] and also in some open cut mines of Armenia, where the horizontal wells dewatered sands of the Cretaceous period (Figure 15). In one of the ore deposits of Armenia the drainage tunnels were introduced from the western slopes of the open mine to intercept the tectonic dislocation and drain waters from the zone of flooding (Figure 16) [23].

During the exploitation of some iron ore deposits which intercept the filtration water currents oozing through the slopes, a filtration plant of the type LIU-5 was installed.

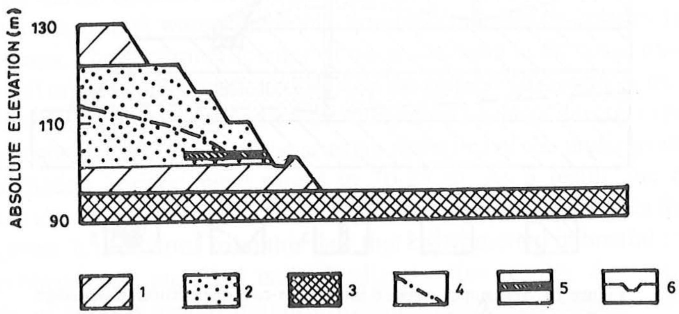

Figure 15: Scheme of drainage of non-working benches by means of horizontal drainage wells
1—slightly permeable rocks; 2—water bearing sands; 3—ore layer; 4—curve of depression of water table; 5—horizontal drainage well; 6—water discharge canal.

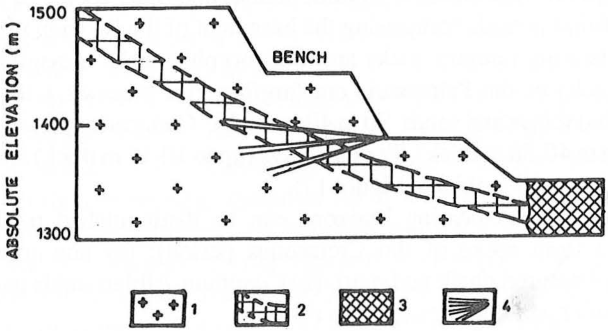

Figure 16: Scheme of drainage in western bank of ore deposit in Armenia
1—ore-bearing (intrusive) country rocks; 2—tectonic dislocation zone of groundwater flooding; 3—ore body; 4—radiating cluster of drainage wells.

The ore bodies in some deposits lie at great depths (up to 200-300 m) and during the construction of an open cast mine there appears a dire necessity to strip all water-bearing horizons distributed in the rock series overlying the ore-bearing layer. Experience has shown that under such conditions it is convenient to adopt a combined operation of sub-surface drainage and surface drainage through hydrogeological wells and intra-open cut mine drainage conduits.

A combined scheme of drainage is very complex in application and in mining practise is commonly carried out in two stages. In the first stage a preliminary drainage is implemented by means of a circular system of wells, aligned along the outer contour of the open pit and fitted with submersible pumps, over the vertical shaft. Such a scheme requires the build up of an open cast mine through the gradual connection (in case of necessity) of an additional intra-open pit drainage system. In the second stage construction of a contoured system of sub-surface drainage in the form of water pump shafts and horizontal mining is undertaken, so that the shafts follow the trace of the boreholes (for reducing the groundwater level). Subsequently, all the pump wells are fitted with porous filters. Such a combined scheme has been successfully implemented in some large ore deposits of the USSR. Much experience has been gained in combined techniques suitable to the individual hydrogeological characteristics of a given mining district during the commercial working of the iron ore deposits of KMA.

DRAINAGE OF THE LEBEDIN DEPOSIT

The Lebedin deposit, KMA (Kursk Magnetic Anomaly), is situated mid-course of the Oskolets River. It belongs to a folded anticlinal complex of metamorphic rocks (ferruginous quartzites, crystalline schists and other rocks) of the Archaean and Precambrian periods comprising the basement of the Russian platform.

The ore-bearing country rocks are metamorphic rocks transgressively overlapped by rocks of the Palaeozoic era (argillaceous breccias 1 to 16 m thick), Jurassic period (clays and sands 30 to 40 m thick), Cretaceous period (clays, sands and marls up to 40-50 m thick), Tertiary clays (up to 10-15 m thick) and Quaternary formations (up to 30 m thick) (Figure 17).

Three major water-bearing horizons can be distinguished in the Lebedian deposit (two from rocks of the Cretaceous period): (a) non-artesian horizon occurring in fractured chalk and marl, (b) Cenoman-Albian sands and (c) zone of weathering of crystalline Precambrian rocks.

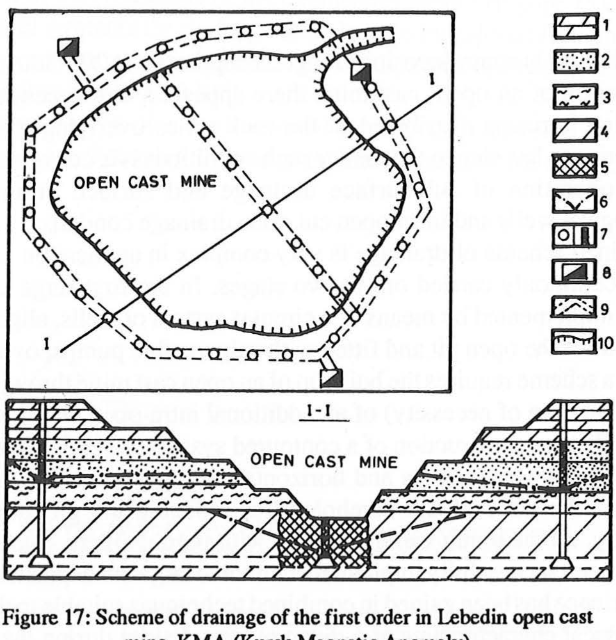

Figure 17: Scheme of drainage of the first order in Lebedin open cast mine, KMA (Kursk Magnetic Anomaly)
1—marl; 2—sand; 3—clay; 4—ore bearing country rocks; 5—ore body; 6—cone of depression; 7—porous filter; 8—water pump shaft; 9—underground drainage works; 10—contour of open cast mine.

Chalky-marl and Cenoman-Albian aquifers are hydraulically generally connected to form almost a single aquifer horizon exerting an influence on the flooding of the deposit. The coefficient of filtration of the chalk-marl unit ranges from 3 to 50 m/day, whereas the Cenoman-Albian sands show 11 to 20 m/day.

At present, because of protracted lowering of the water table during the construction and exploitation of the Lebedin open cast mine and the townships water supply works, the levels in the water-bearing horizon of the mines have dropped to 45-50 m. As a result, the chalk-marl unit has become completely dry while the discharges of underground water from the base of the sands are led into the system of drainage trenches along the contours of the open cut mine.

Aquifers of the ore-bearing crystalline rocks are confined to the upper 50 m zone of the oxidised quartzites and enriched iron ores. The piezometric level (phreatic surface) at this horizon coincides with the level of the aquifer horizon in the Cenoman-Albian rocks. The impervious lower horizons of the crystalline country rocks are composed of compact quartzites and the upper ones of Jurassic beds. The coefficient of filtration of the water-bearing horizon of the ore containing crystalline rocks is around 1 m/day. Ore-enriched layers and fractured quartzites possess considerable storage capacity.

While exploiting the deposits in the crystalline rocks at a depth below 65-70 m at the Lebedin mine where groundwater occurs under artesian conditions, complex hydrogeological conditions and significant groundwater currents necessitated the adoption of special engineering solutions for drainage (see Figure 17). The system of drainage presently in force in this open cut mine consists of two drainage contours:

1. An external one consisting of pump wells (to lower the water table) which guarantee preliminary drainage in the period of construction of a mine and are provided with porous filters after the introduction of sub-surface draining in mining operations.
2. An internal construction in the lower part of the sandy bed in the form of horizontal drainage along the permanent slopes of the open cut and drainage trenches with an overload of sloping gravel filters (or with horizontal drainage wells). The horizontal drainage taps up to 30% of the general mine waters.

The system of drainage in the Lebedin deposit was introduced during its exploitation in the year 1960 and over the years has been perfected to coincide with developments in open cast mining. In 1984, 150 filters and rejuvenated wells were bored towards the sub-surface working which were specially designed for additional drainage of the Cenoman-Albian sands. The total productive capacity of the wells of the external drainage contour is 1,600 m^3/hr (about 30% of that of the groundwaters). The average productive capacity of the porous filters is 12 m^3/hr. The capacity of the filters diminishes with constant drainage of the layer (lowering of groundwater level) and siltation of filters. Different methods of desiltation of the filters have not yet produced the desired effect.

The underground drainage contour in the mine includes: (a) drainage adits along the horizon at +20 m, extending for 30 km, (b) central underground pumping station at drainage shaft No.1 with ten pumps, each with a productive capacity of 1,000 m^3/hr, yielding a total volume from four drainage basins of 14,600 m^3 and (c) additional pumping station built at the drainage shaft No. 4 with five pumps of the same type.

Water from the filters and rejuvenated drainage wells of the external drainage contour and from drainage along the base of the slope and trenches of the inner drainage contour and also atmospheric precipitation reach the underground mines at the +20 m horizon through drainage wells.

Withdrawal of water is carried out by the central underground pumping station at shaft No. 1, the pumping station at shaft No. 4 and the deep pumping station of the quartzite open cast mine at 100 m horizon.

Furthermore, there are two automatic pumping stations in the underground drainage complex to supply mine waters for domestic-potable water purposes. Of the waters withdrawn from the Lebedin open cut mine, 60% is used for industrial supply to the beneficiation plant and 8-10% for potable water needs, with the latter constantly increasing.

To monitor the effective lowering of the water table and to assess the efficacy of the drainage facility, a special network of hydrogeological observation wells has been established. Hydrogeological conditions at the site monitored through observations of such boreholes revealed two kinds of major aquifer horizons—one in rocks of the Cretaceous period and the other in rocks of ore-bearing crystalline complex. Observation wells are placed step-wise in a radial pattern diverging from the open cast taking into account development of the cone of depression and also the technogenic source of intense recharge in the region of tailings dump and reservoir.

A special scheme of individual drainage that takes into account concrete hydrogeological conditions is highly complex. It consists of a rational combination of the complete system of known methods of engineering construction to protect the mines from flooding by underground waters and to guarantee safe conditions of working the ore deposit. As a concrete example of a general kind of complex drainage system that has been individualised, drainage according to the concept of 'drainage-water supply' can be successfully implemented. This process also includes construction in the drainage system of automatic pumps for domestic-potable water supply.

Little consideration has been given in the complex drainage scheme of the Lebedin mine to the preservation of the surrounding environment, nor to such important components as underground waters. Hence the corrosive influence of these waters is evident in the drainage constructions and also the water supply installations of the public distribution system. Furthermore, corrosion results in the pollution of fresh waters because of the inevitable infiltration loss from the area of tailings and reservoirs.

Underground mines exploiting deep-seated ore bodies (up to 500-800 m) possessing particularly complex hydrogeological and engineering geological conditions similarly require adoption of individualised techniques of drainage because of situations arising from the characteristics of each deposit. In such cases it is pertinent to consider the following aspects:

1. The depth of occurrence of an ore body often requires adoption of abyssal drainage. Hence, mining would significantly influence the drainage regime of fresh groundwaters in aquifer horizons situated above the ore-bearing rock series, which are intensively utilised for a complete domestic-potable water supply in the urban sector and for agriculture in rural settlements. Moreover, as shown by experimental undertakings, the influence of drainage on the pumping installations might cover large areas in the mining territory. Hence a choice of rational scheme of drainage in the mines has to consider not only solutions for engineering geological problems related to the safe working of mines, but also solutions for the second very important problem—preservation of the surrounding environment around—and above all protect the fresh underground waters from total depletion.
2. It is very important to envisage the possible use of anti-filtration screens in the scheme of drainage in mines in order to significantly reduce the negative influence of drainage on the surrounding environment.

   Anti-filtration screens have been most widely used in our country in hydraulic engineering construction from the point of view of the filtration losses in diversion channels and under dams. Very little data have been collected relating to the efficacy of application of anti-filtration screens in the construction activities of a township near the mine, except for data on results of special methods of sinking shafts in mines. Nevertheless, adoption of such measures during shaft mining of ore deposits is advisable, even though fairly complex problems arise while fixing up screens. Drainage in mines under the protection of anti-filtration screens can be an effective means of preventing fresh underground waters from becoming depleted. The possibility of application of this method of drainage, the selection of its most rational parameters (depths of occurrence, degrees of isolation, etc.), and also assessment of the effectiveness of this method in each case have to be completed taking into account the hydrogeological conditions of a specific area and utilising the valuable aid of mathematical modelling on EVM (electronic computer). For approximate results one can use analytical calculations, the principles of which have been discussed in earlier publications [21, 22].
3. A less important factor in the right choice of scheme of drainage is the implementation of appropriate mining technology. Of course, given the

Table 3: Principal schemes of drainage in mines and preservation of their environment (measures of conservation of nature)

Scheme of Drainage	Objection	Major Constructions	Nature of Deposits for which scheme Recommended
Drainage-water supply	Drainage in mine working and utilisation of mine waters for domestic drinking water supply	Intra-shaft (intra-open cut) pumping and independent pipe line for groundwaters in underground mines; external drainage facility, pipe line	In ore deposits with relatively not much groundwater flows
Drainage-water Supply-Irrigation	Same as above and also for industrial purposes and irrigation	Same as above	In ore deposits with considerable ground water currents
Drainage-Burial	Drainage in mine working and preservation of environment in areas of mining activity	Intra-shaft (or intra-open cut) pumping; Exterior drainage facility and system of suction (pressure) pumps	Ore deposits in which mineralised mine waters occur
Drainage under Protection of Antifiltration Screens	Same as above	Intra-shaft (or intra-open cast) pumping; external ring of antifiltration screens	In ore deposits with considerable ground water currents

complex conditions of a deposit, the selection of sites for mining ore bodies should be based on careful mapping of the area.

These technological schemes find convenient applications in the mining of such ore deposits (Yakovlev, Gostishen, Vislov, KMA) where there are 12 aquifer horizons in the rocks overlying the ore beds. The upper horizons contain fresh underground waters which are utilised for supplying potable water to large towns.

To conclude, drainage in mines is both a powerful and an indispensable technological operation which assures safety in the commercial working of ore deposits under different hydrogeological conditions. The problems of effective utilisation of all the useful components of the deposits and preservation of the environment mainly involve adopting such schemes of drainage in mines that their implementation will reduce the negative influence of technology-induced processes, which alter the character of the environment, and to also guarantee maximum utilisation of the mine waters.

Considering all these aspects a general table (Table 3) has been prepared which highlights briefly and succinctly the characteristics of the most rational schemes of drainage, which is one of the major means of conservation of nature during the commercial working of ore deposits.

CHAPTER 5

Technogenesis and Technogenic Processes During Exploitation of Ore Deposits

GENERAL CONSIDERATIONS

As mentioned earlier, problems of conservation of the environment around regions of exploitation of ore deposits and utilisation of mine waters for potable water supply or irrigation have inevitably appeared in the practise of the mining industry. The first problem appeared under the influence of the rapid rate of the productivity of our country, particularly in the mining industry–the major supplier of natural resources of mineral raw material indispensable for the development of the national economy. Details relating to the growth of the mining industry have been exhaustively discussed in earlier publications [23, 33, 34 and others]. The problems originated for the following reasons:

1. Mining of deposits of economic minerals on a commercial scale is carried out in our country at great depths. For example, coal mines reach 1,200-1,500 m in depth are likely to go below 2,000 m.
2. High tempo of growth of productivity led to opening and working of new ore deposits situated in very complex hydrogeological and engineering geological conditions. The working of such deposits on a commercial scale requires a preliminary and later a constant drainage operation. Therefore, exploitation of these deposits is often done simultaneously with continuous tapping of groundwaters from aquifer horizons.
3. Our mining industry commonly works on a series of closely situated deposits simultaneously. This results in drainage operations over a significant areal (up to some thousands of cubic kilometres), which in turn is the root cause for transformation of the existing conditions of the natural landscape.

Mining of economic mineral deposits has been done to great depths for example in the commercial working of Krivorozhsk iron-ore basin, some parts of KMA and other regions. Working deep-seated ore or coal horizons always introduces changes in the surrounding environment.

The most conspicuous influence on changes in the geological environment and the ecological situation in and around regions of the mining industry is produced by drainage of the mines during exploitation of the deposit. A few examples are illustrative. During the drainage operation in the iron-ore open cast mines of KMA region, underground waters are withdrawn to the extent of 50,000-60,000 m^3/hr and in some polymetallic deposits during flooding seasons the rate of withdrawal varies from 18,000-20,000 to 35,000 m^3/hr. Underground waters being pumped out from the large group of copper deposits occurring within the boundary of the southern Urals are estimated at 60,000-70,000 m^3/hr.

During the drainage of mine water in the coal basin of a Moscow suburb, discharge of fresh underground waters is placed at 60,000-70,000 m^3/hr— an output far greater than the requirement for fresh groundwaters for water supply to large cities and industrial complexes. It is indeed very sad that fresh mine waters of the Moscow suburban coal basin are not being utilised for water supply. As a result of intensive pumping of mine waters in some regions, the fields adjacent to the shaft have started to subside, resulting in swampy territory.

Such highly intense withdrawal of underground waters during the drainage operation in mines leads to total disruption of the hydrogeological and hydrological conditions throughout the region, which undoubtedly brings about changes in the ecological situation of the surrounding environment. Thus, in regions under the influence of the mine pumping in the Moscow suburban coal basin, a distinct lowering of the rate of flow of surface streams (small rivers) has been recorded due to the reduced recharge caused by the discharge of underground waters.

In some ore deposits, under the influence of powerful mine pumps large wells drained waters so completely (with discharges up to 300-500-700 l/sec) that in the areas adjacent to this facility an 'oasis irrigation' was organised. Similar changes of higher magnitude are observed in the landscapes around the coal mines of Donbas and western Donbas, the ore deposits in central Kazakhstan, many parts of Rudny Altai, the southern urals and other mining belts in our country.

Yet another important phenomenon has been observed due to intensive pumping of underground waters in mines of ore deposits where drainage of aquifers lying at depths of 300-500-800 m is implemented. In such deposits, during exploitation, a very thick technogenic zone of aeration is formed, where technogenic processes of oxidation of the ore bodies start developing intensely.

Commercial mining of ore deposits by either open cast or sub-surface mining methods results not only in changes in hydrogeological conditions but also significantly transforms the general landscape conditions of the region, particularly when there is simultaneous activity in a series of associated mines. The group of deposits in Uzbekhistan illustrates this point. Commercial working of this large group of closely situated deposits is carried out primarily by the open cast method, and also by an adit system with blind shafts. As a result, exploitation of the open cast mines in the mining district over an area of some hundreds of square kilometres gave rise to management of an immense quantity of mine waste and oxidised ores, in addition to radically disturbing the general geographical landscape and hydrogeological conditions and adversely affecting the development of the vegetation cover. An analogous transformation of landscape conditions is evident in the exploitation of the large group of iron ore deposits in the Krivorozhsk basin.

Where ore bodies occur in carbonate rocks, during the drainage operation in mines, under the influence of subsidence-karst processes a typical technogenic karst landscape is established, exhibiting numerous karst features such as collapse-sinks etc. Thus, during the exploitation of some ore deposits associated with carbonate rocks, in the sphere of influence of mine construction from the front up to a distance of 70 km, more than 1,500 karst sinks have appeared on the surface due to draining of the carbonate rocks. This has significantly increased the complexity of construction of the surface installations at the mine site.

Drainage of underground waters directly from mines is very often highly contaminated by the processes of oxidation of ore minerals and also discharges from the surrounding settlements and establishments. In some copper mines the mine waters possess high contents of copper, iron and other elements, which require preliminary removal before letting the waters out as effluents into the surrounding environment.

During the underground mining of economic mineral deposits without adequate working space (with a collapsing hanging wall), sagging movement of the rocks very often takes place and as a consequence surface deformation or subsidence occurs. These cause a radical change in the landscape.

Deformation due to indiscriminate dumping of mine waste without due consideration of the engineering-geological aspects (for example, landslide processes in mining operation) and also of the processes of oxidation of the disseminated ore minerals (giving rise to acidic waters) can cause changes in landscape conditions, deformation of surface installations and pollution of the surrounding environment.

Changes in the characteristics of the environment in and around mines originate during the exploitation of large reservoirs of underground water supplies intended for providing an economic potable water supply and for use in mining operations. Intensive growth of the mining industry has determined utilisation of underground waters completely for water supply in many regions of our country. In many undertakings, in keeping with the rise in requirement, large independent water-supply reservoirs have been constructed to withdraw underground waters at rates varying from 500-800 to 5,000-7,000 l/sec. With this in mind groups of pipelines and ground pipes have also been installed.

In mining practise there is also a clear tendency towards giving due attention to the withdrawal of water from the earth's interior, with a two-fold aim. While drainage is necessary for mining operations and retaining safe conditions of working the deposit, on the other hand it is equally important to solve the no less serious problems of a domestic drinking water supply and a water supply for the mining industry.

From the point of view of a rational or optimal utilisation of natural resources and preservation of the surrounding environment, it is extremely essential to combine the solution of the above-mentioned two problems which, in fact, form an integral part of the modern schemes of drainage and fundamental problems in hydrogeological investigations. Unfortunately, however, in practise a rational scheme of drainage-water supply is very rarely worked out in mines, where underground waters of drainage installations are fully utilised for supplying water to an entire township and other departments of the undertaking.

During the exploitation of large water-supply units two highly important problems arise. Firstly, the drainage of moisture spreads over a large area and gradually introduces changes in the surrounding environment. Secondly, in practise very often processes of interaction take place between the water supply units and the drainage constructions related to mining operation. As a result, pumping equipments go out of action and for constant water supply it even becomes necessary to shift the drainage pipeline of underground waters. For example, in one of the mines in Kazakhstan the pipelines carrying underground waters for provision of a drinking water supply to the mine township had to be shifted three times. A similar situation has arisen at a number of such mine sites [27, 28].

It has been emphasised above that changes in the characteristics of the surrounding environment during exploitation of ore deposits are influenced not only during drainage in the mining operation but also during the operation of water-supply machinery. Contamination of surface and underground waters takes place in the areas of storage of liquid and solid wastes due to unavoidable losses from the tailings dump and also pollution of the atmosphere through the escape of gaseous wastes from metallurgical plants. In many mining enterprises beneficiation plants and metallurgical factories are in operation (mining undertakings of the second and third group according to the degree of influence on the surrounding environment). In many mining establishments in the Urals, Central Asia and Kazakhstan, urban lands or settlements are situated directly on the outskirts of mine workings, which determine the technogenic changes in the surrounding environment under the influence of mining activity. Furthermore, township lands resting directly over the area of mining practise, particularly those situated in the arid zone of our country, find many uses for water—irrigation of crops, watering gardens, building streets etc. The organisation of a centralised water supply scheme for towns and a canal system, lead to inevitable loss of water from water conduits and the canals. Under the influence of infiltration of irrigation waters and waters from the water supply pipelines laid on the ground, a horizon of soil waters is formed. These waters often submerge basements in dwellings and lead to a rise in groundwater level in township constructions and associated flooding and discharge of effluents.

During the exploitation of different segments of mining activity other radical changes take place: (a) in the hydrological regime of the local river system as a result of intensive and deep drainage of surface waters from mining operations; (b) in the hydrodynamic regime under the influence of drainage in mines (reflected in the prominent changes of the level of the regime, pressure gradients of the filtration current of underground waters, exhaustion of the groundwater resources); (c) in the hydrogeochemical regime of underground surface waters, in the areas of disposal of impure mine waters, tailings dump and reservoir, and also stocking of excavated gangue materials; and (d) in the geodynamic regime in the sphere of influence of mining activity.

It is evident from the foregoing that the rapid growth of the mining industry has given rise to a new phase of more intensive interaction in the man-nature system and a deeper negative influence on changes in the environment. This very important status quo explains the major trends of complex hydrogeological and engineering geological studies being undertaken to foresee problems to be solved not only in the traditional mining industry, but also in the field of maximum utilisation of groundwaters to meet practical needs and during mining for a rational allocation of this facility to all major units requiring water, taking into consideration the protection and preservation of the environment.

These in essence form the modern requirements for in-depth studies on ore deposits at all stages of mining, including exploitation and conservation.

FUNDAMENTAL CONCEPTS AND THEIR ANALYSIS

It is pertinent to examine some fundamental scientific concepts and also the hydrogeological aspects of the general problems of preservation and protection of the environment, primarily in relation to the influence of the growning mining industry on the environment.

The scientific concepts involved here pertain to the following: the surrounding environment, geological environment, technogenic processes and technogenesis (technology-induced processes and phenomena), and hydrogeological aspects of general problems [23].

It is essential to understand that what surrounds us is connected directly or indirectly to the active life and productive activity of man, while trying to simplify *the surrounding environment* in mine areas for a preliminary discussion of the problem. To evaluate the surrounding environment at the level of the biosphere as a whole four components should be considered, i.e., the atmosphere, the hydrosphere, the lithosphère and the soil. The optimal regime of the system provides highly favourable conditions for the growth of the biosphere as a whole. Within the limits of these four components the unique water envelope of our planet is formed; the surface part or hydrosphere and the part underground, the hydrogeosphere, lie between the lithosphere and the soil cover. All types of underground waters, irrespective of location, lie within the limits of the hydrogeosphere [28].

At the level of human habitation and productive activity the surrounding environment has to be considered as a six-component system: the atmosphere, the hydrosphere, the lithosphere, the soil, the animal world and the vegetation. These major components of the environment co-exist, interact and form a regular mechanism of direct and inverse relations. The breaking of this pattern of direct and inverse links leads to drastic changes in the regime of interaction amongst the principal natural components of the surrounding environment. Such an interference results, for example, from the multiple engineering activities of man.

Natural (here the underground) waters form an integral part of the mine environment and play a decisive role in the life and productive occupation of man. In fact, water forms an essential constituent of the surrounding environment providing conditions necessary for the existence and growth of all life on earth (the biosphere). Considerable significance is attached to the formation of a favourable regime of the environment surrounding man today due to the historically complex global cycle of moisture on our planet.

The surrounding environment as an independent material system has its own characteristics as does the optimal regime for the growth of the biosphere. The most striking characteristic of the environment, however, is its capability for adjustment. Any violation of the regime of the environment which arises out of the negative influence of technical processes will result in the degradation of the ecological status quo.

The surrounding environment and its interaction with man as a highly complex material system is studied under a large group of sciences, among which is the science of ecology, which is multi-facetted and systematic. This special branch of the sciences, in addition to dealing with different aspects of general problems discusses the 'conservation of the environment'. Similarly, the geological aspects of general problems are dealt with by a group of sciences about the earth (earth sciences). In the context of problems of water in the mines of ore deposits and the surrounding environment, the earth sciences that are most significant are hydrogeology, engineering geology and geocryology. In this connection, it is important to define a scientific base such as the geological environment. Besides the status of its general problems, the geological environment has to be considered as an integral component of the environment of habitation and productive activity of mankind. In its normal ambit of study geology explores the upper part of the lithosphere, which structurally comprises four principal components: the rocks, the underground waters, the natural gases and the micro-organisms.

These components under natural and disturbed (fractured and faulted) conditions remain constantly interacting, forming a dynamic equilibrium below the earth's surface. In fact, the geological environment has to be considered as a function of the internal development of our planet in its historic perspective. Hence, its study assumes historic significance. During studies on the geological environment, maximum interest is evinced in that part associated with the active form of life and the productive activities of man. In the mining industry the depth of working of the deposits reaches upto 2,000 m and in the case of oil and natural gases, this depth may be as much as 6 to 7 km.

It is in this sphere of activity, i.e., mining of ore deposits, that technogenic processes, constantly appear profoundly changing the characteristics of the geological environment, as well as the intrinsic features of the surrounding natural environment. In the upper layers of the geological environment the biosphere develops with all its diversity under the different climatic zones of our country. In this respect three zones of natural geological environment have been delimited on a regional scale: the arid, the humid and the cryogenic (cold). This aspect has to be borne in mind while evaluating the negative influence of the technogenic processes on the geological environment during drainage in the mining of ore deposits situated in different climatic zones.

The geological environment in its natural and disturbed conditions possesses specific physical, hydrogeological, engineering geological and biological properties. The properties of the different components of the geological environment have been sufficiently well studied. Still, the changes that these properties undergo under the conditions of mutual interaction amongst the constituent components, particularly in a disrupted or disturbed regime, are highly complex and at present have not been well understood. Hence, amongst the fundamental properties of the geological environment it is possible to observe: (a) variation in space and time; (b) heterogeneity exhibited in hydrogeological aspects because of filtration properties of different rocks; and (c) discreteness displayed in such properties of rocks as fracturing, karstification etc.

Considerable significance is attached to the hydrogeological and engineering geological properties of the geological environment, viz., permeability of rocks, their stability in the mining operation, conditions of interaction of solid and liquid phases of the geological environment with natural and technogenic gases and with micro-organisms, which introduce changes in the properties of the rocks as well as in the underground waters. This understanding is necessary to evaluate the mining engineering conditions of ore deposits and the formation of technogenic processes arising out of the exploitation of ore deposits.

For example, the results of studies on true quicksands have shown that their properties have been significantly decided by the biochemical processes appearing as a result of the activity of gas-exuding micro-organisms. It was established that accumulation of gas-forming products, formed due to the activity of living micro-organisms, takes place in the water saturated, dispersed rock medium. Under the influence of these processes in sands, saturated with underground waters, an excessive inner pore pressure develops. Finally, this contributes to the energy factor that provides the specific properties of quicksands.

Thionine bacteria may play a vital role in the technogenic changes of properties of the geological environment, since they are capable of thoroughly oxidising hydrogen sulphide to sulphuric acid. Here an example from past experience is noteworthy. During the construction of an underground (tube) railway at Kiev, as the underground work commenced it was found that, under the influence of the activity of thionine bacteria, the waters became highly corrosive and began to corrode steel-concrete structures of the railway and complicated its construction in some parts.

Processes of formation of natural and technogenic gases in the geological environment and their interaction with rocks and underground waters have not been studied in detail. Meanwhile, commercial mining practise of ore deposits shows that gradually, in proportion to the increasing depth of mining, natural gases appear which complicate the working of ore deposits. According to the degree of their interaction on certain components of the geological environment and the formation of technogenic processes, all natural gases can be conveniently divided into two groups: chemically active and inert. The most conspicuous changes in the characteristics of the different components of the geological environment are effected under the influence of chemically active gases, such as carbon dioxide and hydrogen sulphide. This interaction, as has been shown by the experience of working some ore deposits, has brought about a distinct break or change between hard rocks and their alteration to an unstable rock mass, thus complicating mining engineering conditions. Natural gases in the geological environment may exist in a free absorbed state or be present in underground waters.

The geological environment possesses specific physical, hydrogeological, engineering geological, geochemical and biological properties. To the fundamental general properties of the geological environment, the following are intrinsically related: (1) their variation in space and in time; (2) their heterogeneity as revealed through heterogeneity of filtration properties of various types of rocks (permeable, slightly permeable etc.); (3) mutual adjustment of characteristics, i.e., nature of environmental changes under natural and disturbed conditions; and (4) discreteness in characteristics as displayed in rocks through fracturing, karstification, tectonic dislocation and so forth.

Under the influence of technogenic processes during the exploitation of the major targets of mining activity, the above list of characteristics of the geological environment may change either toward a positive or negative direction with respect to their relationship with the biosphere [20, 22, 23].

In fact, all the activity of the ore-mining establishment originates in the sphere of the geological environment, particularly in the mines. It is therefore necessary to discuss some typical models of the geological environment as they apply to mine construction or mine development.

It is possible to distinguish four common and widespread types of geological environments according to the conditions of mine excavation, the degree of flooding, commercial working and formation of technogenic processes and their influence on the innate characteristics of the geological environment for varied conditions of ore deposits.

Type I: This geological environment presents hard crustal rocks of varied lithological composition (Figure 18): intrusive, effusive and metamorphic terrigenous rocks characterised by very firm linkage amongst mineral constituents. In fact, this type combines all hard rocks, the inner structural elements of which comprise fine open regional fracturing of multiple origin. This environment is favourable for infiltration and accumulation of underground waters (in the zone of weathering). With depth, however, as pointed out earlier, the degree of fracturing in rocks distinctly diminishes, and in crustal rocks water seepage is observed only along tectonic zones.

Increased fracturing of rocks and, consequently, their permeability are often observed in zones of tectonic dislocations. Hydrologically, rocks of the first type of geological environment are characterised by non-homogeneous filtration both in plan and section. Two types of groundwaters form in these rocks: fracture-ground and fracture-vein. When the hard rocks are covered by a Quaternary formation of not much thickness, unconfined groundwaters are also encountered. All the types of underground waters are fresh and contain hydrocarbonates of calcium.

In some ore deposits, carbon dioxide of deep-seated origin and gases of the methane group are encountered in rocks of the first type of geological environment (ore deposits of Siberia and the Caucacus), and this to some extent complicates the mining process. Micro-organisms and their role in the constitution of the first type of geological environment have been very poorly studied. In the overwhelming majority of cases, rocks forming part of the second type of geological environment, comprise those which are unstable during underground mining as well as along the flanks and benches of open cast mines, except those of the tectonic fault zone, wherein the rocks are never stable and require partial stabilisation.

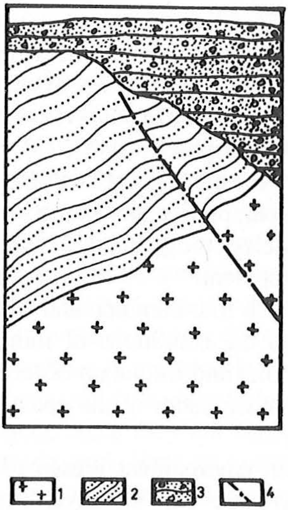

Figure 18: Lithological cross-section of first model of geological environment
1—intrusive rocks; 2—quartzites; 3—unconsolidated Quaternary formation; 4—tectonic dislocation.

Experience has shown that during drainage operations in mines, appreciable changes in characteristics of the geological environment do not take place. However, in weak zones of tectonic dislocations filtration might develop, to which under mining technogenic processes is related the erosive action of underground waters and the deformation of mine workings, i.e., washing out of finer fractions from the rocks of the zone of tectonic faulting.

Type II: This geological environment includes semi-hard rocks (Figure 19): different sericite and chlorite schists, metamorphic effusives etc., weakly stable under sub-surface mining conditions as well as along the banks and benches of open cast mines. In some copper deposits of the Urals and polymetallic deposits of the Irtysh crushed zone (northeastern Kazakhstan), metamorphic chlorite-sericite-ore-bearing schists, because of continuous moistering, lose their binding strength and behave as plastic and viscous bodies. Drilling of mines in this group of rocks requires continuous props and effective drainage along the benches of an open cut mine.

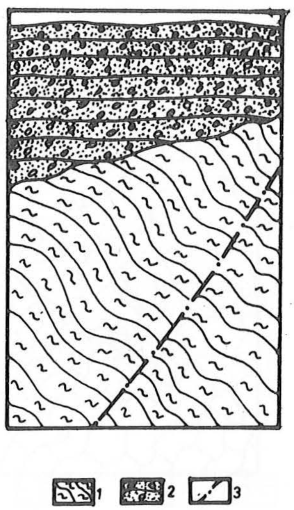

Figure 19: Lithological cross-section of second model of geological environment
1—schists; 2—sandy-pebbly formation; 3—tectonic dislocation.

The environment typical of the formation of fractured groundwaters in rocks is the fine regional fracturing which, below the zone of weathering, quickly attenuates with depth. High water content is confined only to the zones of tectonic dislocations. Fracture-groundwaters very often are fresh and contain hydrocarbonate of calcium. However, their chemical composition might change and acquire an acidic character during the exploitation of copper deposits under the influence of processes of oxidation. Exploitation of copper deposits may result in technogenic gas formation in the mine area (due to underground fires and calcining of massive ores).

Distribution from the surface of fairly thick (80-120 m) unconsolidated sandy-pebbly alluvial and delu-proluvial formations is prominent in the structure of the second model. It is obvious that these rocks are characterised by high permeability, forming a geological environment sustaining pools and accumulations of groundwaters. These waters very often possess a close hydraulic link with surface waters. Commercial working of ore deposits under such conditions, particularly in open cast mines, requires drainage of the unconsolidated rocks and also disposal or isolation of surface waters.

Drainage of unconsolidated rocks always leads to some extent to the formation of technogenic processes—their secondary consolidation and deformation of the surface.

Type III: This geological environment comprises the group of carbonate rocks (Figure 20), commonly highly reactive (limestones, marbles, marls, dolomites).

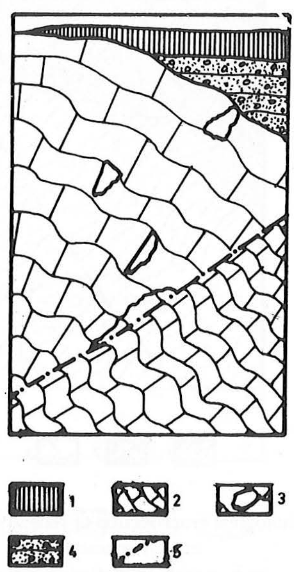

Figure 20: Lithological cross-section of third model of geological environment
1—cover formation; 2—carbonate rocks; 3—karst chamber; 4—unconsolidated formations; 5—tectonic dislocation.

Their structural features differ sharply from those of all other lithological varieties of rocks; their highly prominent open fracturing or jointing and karstification do not attenuate with depth or areal distribution.

In hydrological aspects the third type of geological environment is characterised by well-defined filtration heterogeneity, which is typical of a disrupted pattern of water distribution in a continuous system. Carbonate rocks are normally stable during open cast or underground mining and hence require no reinforcement. Underground waters of carbonate rocks exhibit high variation in mineral content from fresh waters to brines. Because of this high mineral content (150-270 g/l) underground waters exhibit corrosion, which to a considerable extent complicates the execution of drainage operations in mines (requiring machinery provided with special anti-corrosive pipes and other related accessories and also the adoption of measures to protect the surrounding environment from pollution). Experience in drainage operations of mine workings of certain study areas fully justifies this conclusion.

Gases of deep-seated origin, i.e., hydrocarbons, helium, carbon dioxide, occur in deep ore horizons (at depths of more than 500-800 m). Gases of biogenic origin include hydrogen sulphide and others.

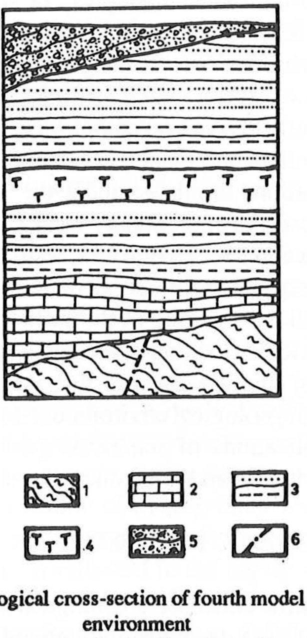

Figure 21: Lithological cross-section of fourth model of geological environment
1—ore-bearing country rocks; 2—limestones; 3—sandy-pebbly rocks; 4—marl; 5—unconsolidated formation; 6—tectonic dislocation.

Micro-organisms of the geological environment of the third type have not been studied to date. During drainage of the water-bearing horizons of carbonate rocks of ore deposits, secondary 'collapse-karst' technogenic processes often develop and, as a consequence, deformation of the surface (collapse funnels) and of surface installations takes place.

Type IV: This geological environment is presented as a section of a multi-layered system (Figure 21) comprising parts of interstratified aquifer horizons of varied lithological composition (sands, sandstones, marls, limestones) and slightly permeable and rarely impermeable rocks (easily distinguishable layers—clays, clayey shales etc.) The thickness of the rock series overlying the ore-bearing zones ranges from 90-150 to 600-800 m. Ore-containing country rocks are represented by ancient metamorphic formations.

Hydrogeologically, this environment is characterised by the formation of a water-pressure system of multi-tiered arrangement of aquifer horizons. Hydrogeological zoning is exhibited in the vertical section in which the upper aquifer horizons contain fresh underground waters with hydrocarbonate of calcium while the lower horizons may exhibit a gradual increase in mineral content and changes in chemical composition.

The rock types constituting the fourth type of geological environment form the so called infra-ore series. These rocks are unstable in underground mines and in the flanks of open cast mines. Hence adoption of special modes of drainage is required to prevent mine hazards.

Natural gases and micro-organisms of the geological environment of the fourth type have been little studied. It can only be surmised that at great depths (greater than 600-800 m), particularly in zones of tectonic dislocations, gases of deep-seated origin (carbon dioxide, helium and others) are likely to be encountered.

During drainage operations in mines, under the influence of low hydrostatic pressure, technogenic processes of secondary weak consolidation of sandy-clayey rocks commonly take place in a series of rocks, resulting in differential settlement of the surface and consequent deformation of the related shaft structures and underground communications. Sagging of the surface likewise effects changes in the general landscape, periodic flooding of the territory etc. (as, for example, in the regions of coal deposits of southern Donbas, a coal basin in the Moscow region).

The four type models of geological environment detailed above are intended for utilisation in future applications of industrial geological classification of ore deposits occurring in the humid and arid zones of our country.

CONCEPT OF TECHNOGENIC PROCESSES

In examining the scientific concepts of geological aspects of conservation of the surrounding environment, it is desirable and valuable to propose one more concept—the technogenic processes.

As pointed out earlier, during drainage operations in mines of ore deposits, the exploitation of large reservoirs and tailings dumps always produces changes in the characteristics of the geological environment under the influence of technogenic processes. To study the mechanism of formation of technogenic processes, to illuminate their nature, to estimate the degree and direction of changes in geological environmental characteristics, and to plan sound measures of protection accordingly—all these form part of the exercise in creating necessary safe conditions in the commercial working of ore deposits and also in the process to guarantee conservation of the environment around human habitation. In other words, this exercise attempts to solve the major problems of ore complexes.

These very important scientific-industrial problems guide in fact the major direction of research in the large complex of hydrogeological, engineering geological and geocryological studies that are carried out on ore deposits at all stages of exploitation.

Generally speaking, the technogenic processes comprise a group of closely and mutually interconnected and interacting hydrogeological, engineering geological, geocryological and biogenic processes which take place in the geological environment under the influence of the engineering activity of man in general and in the area of mining activity in particular.

During the commercial working of ore deposits, specific technogenic processes of a purely hydrogeological or engineering geological nature may appear, which also exert an influence and change the characteristics of the geological environment. For example, underground mine outbursts might be related to specific technogenic engineering geological processes which appear during the exploitation of ore deposits. Similarly, the pollution of mine waters with chemical elements and others is also related to technogenic processes.

According to the nature of interaction in the geological and usually over the surrounding environment, technogenic processes may be divided broadly into two categories—positive and negative. The essential criterion of formation of technogenic processes is the heat-mass transfer between the geological environment and the surface of the earth as a whole. This aspect has been brought to our attention by academician V.I. Vernadskii. Applying this criterion it is possible to distinguish three major types of technogenic processes [28].

Type I: These technogenic processes, according to the direction of heat-mass transfer, are characterised by the withdrawal of matter and heat from the geological environment to the surface (for example, during drainage operations in mining ore deposits and also during exploitation of underground waters in a series of large water reservoirs). The negative influence of the first type of technogenic processes on the geological environment is reflected in the highly varied forms of sagging and 'cave-ins' or collapse features of the surface, deformation of surface installations, attenuation of underground water resources, delinking of intercommunications between surface and underground waters, and other features.

Technogenic processes of the first type are most active in the mining industry. They exert an influence not only in changing the characteristics of the geological environment, but in altering the ecological balance of the surrounding environment as a whole.

An excellent example of the processes of the first type is one that embraces large areas of distribution and extends to considerable depths.

Type II: These processes develop during the exploitation of flooded areas, when changes in geological environmental features originate under the influence of heat-mass transfer taking place from the surface towards the interior of the lithosphere.

Similar processes are in action in regions of mining activity during the management of tailings dumps and reservoirs at sites of accumulation of liquid and solid industrial wastes from beneficiation plants. The negative influence of the second type of technogenic processes on the characteristics of the geological environment is seen in the form of areal pollution of shallow underground waters and surface waters, as a result of the inevitable loss of liquid industrial wastes from the sides of the tailings dump.

An excellent example of the second type of technogenic processes, showing their influence on the geological environment, is often evident in a small area adjoining the lower reaches of the tailings dump.

Type III: Formed due to the interaction between the technogenic processes of the first and second type, the third type is quite complex. It is well displayed in places, distinctly recognisable, where simultaneous drainage and flooding operations are undertaken in mine areas. Such processes might usually form, for example, in the township attached to mining activity, situated along the borders of the project area. In such cases technogenic processes are evidenced during the drainage operation as well as during the flooding of the township area through degraded irrigated lands and the inevitable loss of waters from the centralised storage and distribution network.

Such conditions of formation of technogenic processes of the third type might form, for example, during the exploitation of mineral deposits in carbonate rocks, where the negative influence of collapse-karst processes (formation of foundering sinkholes), rise of the groundwater table and submergence of township housing complexes may occur simultaneously. The conditions of interaction of technogenic processes of the third type and their negative reaction in the geological environment have been little understood.

Let us examine briefly the characteristics of the conditions of formation of some technogenic processes and their influence on the geological environment. A concise account of the most widespread technogenic processes taking place during drainage operations in mines and their interaction with the geological environment is presented below.

Drainage of water-bearing country rocks in the series overlying the ore-bearing (supra-ore) rocks, as well as those within them.	Crustal fault interlinking underground and surface waters; depletion of groundwater resources in supra-ore aquifer horizons; drainage of moisture in zone of cone of depression—springs, wells and reservoir wells.
Processes of secondary consolidation of drained unconsolidated rocks and secondary compaction of sandy-clayey rocks during lowering of water pressure in artesian aquifer horizons causing surfacial compaction.	Sagging (deformation) of surface and resultant possible deformation of surface installations; underground communications; shafts and drainage constructions; disruption of general landscape and periodic flooding of low-lying areas.
Subsidence-karst structures during drainage of aquifer carbonate rocks.	Formation on surface of karst sinkholes, deformation of surface, surface installations and underground communications; dislocation of geographical landscape over regions of development of cone of depression and formation of typical karst topography.
Processes of movement of rocks and zones of rupture in area of development of mining.	Formation in rocks of technogenic fracturing and sink funnels in zone of collapse; formation of zones of additional technogenic recharge of underground waters and their influence on flooding in mines.
Hydrogeological processes in parts of tailings dump and dumps of gangue rocks (reservoirs).	Pollution of surface and underground waters.
Processes of filtration deformation of rocks along benches of open cast mine (during insufficient dewatering).	Deformation of benches and flanks of open cut mines commonly resulting in breach of safety conditions for mine working.
Filtration-erosion processes during drainage of flooded zones of tectonic dislocations.	Deformation of benches and flanks of open cast mine or underground mines.
Processes of swelling and destabilisation of clayey rocks.	Deformation of underground mines.

Processes of oxidation of ore minerals.	Chemical pollution of mine waters [increased content of some components, compared to GOST (All Union State Standard) and general mineral content].
Processes of flooding of township area of mine complex.	Weakening of stability of civil and industrial constructions.
Interaction of drainage installation facility with action of reservoirs of underground waters utilised for complete water supply of towns.	Lowering of general discharge of reservoir and commonly complete drainage of underground waters of productive aquifer horizon, a situation that requires shifting of the reservoir.

The most prominent changes in the characteristics of the geological environment and also of the surrounding environment as a whole, develop in the areas of formation of cones of depression during the dewatering of mines. Under the influence of deep and highly prolonged drainage in mines of mineral deposits radical changes in the hydrogeological, engineering geological and landscape (geomorphic) conditions occur. In the process of protecting the drainage and reinforcement of mine working favourable and safe mining-engineering conditions are ensured in the commercial exploitation of ore deposits, but at the cost of negative influences on the surrounding environment.

Analogous technogenic processes form during the exploitation of large reservoir units since the direction of heat-mass transfer in these cases is one and the same.

Similarly, the following technogenic processes commonly occur in reservoir constructions: (a) physical siltation of fluvial alluvial deposits in river valleys in regions of reservoirs where infiltration is active along the margin, leading to their reduced general yield; and (b) physico-chemical silting of filters and the critical parts of the reservoir wells requiring constant attention and repair.

As pointed out earlier, during exploitation of the tailings dump and reservoirs, technogenic processes of chemical contamination of underground and surface waters occur because of reduced infiltration losses of liquid industrial wastes. Normally, filtration front of pollution currents forms along the natural paths of movement of underground waters under the influence of technogenic processes.

It is well known that on-going global processes of interaction occur between the hydrogeosphere, hydrosphere and the atmosphere of our planet—the hydrologic cycle. Under the influence of these processes, the gaseous products of pollution thrown into the atmosphere from metallurgical plants migrate along with moisture into the soil (after atmospheric precipitation) and later into underground waters—but first into shallow groundwater horizons.

Experience reveals that some forms of chemical contamination in underground waters do not produce oxidation or corrosion but are weakly absorbed in rocks and hence might migrate for long distances from the centre of contamination (for example, the phenols). Therefore the protection of underground waters from chemical pollution is often a complex problem. In this connection regimal observations of all centres of contamination assume special significance and have to be organised at the early stages of formation of technogenic processes.

CONCEPT OF TECHNOGENESIS

As discussed above, in many ore-mining provinces of the Soviet Union the influence of technogenic processes on the changing characteristics of the geological environment and not uncommonly on changes in the ecology of the surrounding environment, might be either local or regional in character and extend to great depths. Under the influence of these changes in the upper part of the geological section and on the surface the *technogenesis of the mining profile is formed* [26].

The scientific concept of 'technogenesis' was suggested as early as 1937 by academician A.E. Fersman during his studies on mineral deposits. In accordance with his definition, *technogenesis is the result of the geochemical activity of man during the exploitation of mineral deposits.* Technogenesis in the mining industry strongly favours the formation of geochemical landscapes of technogenic origin. In the same way, according to A.E. Fersman, technogenesis plays a major role in the geochemistry of the upper part of the earth's crust, disturbing the natural trend of the geochemical processes.

According to another and narrower definition, technogenesis denotes that 'group of geomorphological processes induced by the industrial activity of man'. The influence of man on the natural development of geomorphological processes may be direct or indirect.

At the present stage of rapid development of the ming industry and the intense influence of man's activity on the changes brought about in the surrounding environment, a wider and more general concept of technogenesis must be understood. In other words, we must comprehend the complex negative influence of various technogenic processes. This would lead to a more precise understanding of the formation of hydrogeological, geochemical, engineering geological and other anomalies in the geological environment.

With such ideas it is desirable to consider technogenesis as a generalised concept which simply refers to a total integrated operation of geochemical, hydrogeological, engineering geological, bio-geochemical and other technogenic processes which occur during the engineering activity of man. The formation of technogenesis in the upper part of the earth's crust and on the surface results in a radical dislocation of natural, hydrogeological and engineering geological conditions. A technogenic landscape thus forms over the region of man's engineering activity.

Having learned that technogenesis of different kinds may form during the exploitation of different types of economic mineral deposits in the geological environment, it is desirable to distinguish these differences during mining: (a) mineral deposits of mining profile; (b) mining-chemical series of mining-chemical profile; and (c) gas-oil deposits of the oil and natural gas profile. Each exposed profile of technogenesis possesses specific characteristics according to the predominance or intensity of appearance or functioning of one or the other of the technogenic processes.

Thus the peculiarity of the technogenic mining profile lies in its complex influence on changes in the ecologic status quo of the surrounding environment, during which technogenic processes of the first type primarily predominate and progress. Typical examples of such technogenesis are observed in the workings of the iron ore deposits of KMA of the Krivorozhsk basin and others.

It may likewise be concluded that in regions of intense development of the mining industry, particularly during mass-scale mining activity, striking changes in the geological environment and the ecological status quo of the surrounding environment as a whole take place under the influence of technogenesis. A distinct technosphere thus develops at the upper part of the cross-section of the lithosphere.

In the context of the formation of technogenesis in the surrounding environment of a different profile and the variety of forms resulting under natural conditions, considerable significance is attached to the prognostic estimation of the possible development, during exploitation of ore bodies, of one or the other technogenic processes, particularly at the stage of conducting preliminary hydrogeological and engineering geological investigations (the pre-project stage of prospecting mineral deposits). The early stage of prognosis might enable the simultaneous assessment and adoption of measures of conservation of the environment from the degrading action of technogenesis and provide the most favourable conditions for rational utilisation of natural resources.

The theoretical bases of formation of technogenesis as a whole and the technogenic processes in operation today have yet to be fully understood. Special scientific studies should therefore be undertaken along these lines. Scientific and methodical principles of prognostic evaluation of the possible development of technogenic processes and the precise hydrogeological factors to be considered with regard to the protection of the environment from the negative influence of technogenesis have not been adequately defined. At present, for prognostic estimation of the development and negative influence of technogenic processes of the first and the second type, known hydrodynamic and hydro-geomechanical methods have to be utilised. Typical analytical estimates can be adopted for comparatively simple hydrogeological conditions. However, for more complex hydrogeological situations of different case histories methods of mathematical modelling with AVM (analog computer) are followed.

The first order significance for an effective prognosis of consequences of technogenesis lies in the system of comprehensive natural observations and reliable safe measures necessary for prognosis of information. Some methodical applications of prognostic evaluation of technogenic processes have been dealt with in the following chapters.

Highly important geological and environmental changes may take place at the stage of conservation of mined mineral deposits. It is well known that all the pumping machinery is flooded with water at this stage because of the continuous flow of mine waters. Thus there is not only a simple flooding of mines but also a rise in level of underground water in the series of earlier drained rocks. At this stage of moisture conservation of the mine pit, heat-mass transfer over the earlier formed cone of depression (over a long period of drainage) has already started, proceeding not from top to bottom as during the drainage but from bottom to top towards the earth's surface. With the resumption of exploitation of natural resources, the level of groundwater rises again, leading to the formation of technogenic processes—flooding and submergence of earlier built surface installations and underground communications in township areas situated on the outskirts of mining projects. At other places the quality of the underground waters deteriorates due to interaction with waters from the reservoir system established at the stage of exploitation and the consequent influence of the drainage system. An increase in general mineral content results with a rise in content of sulphates. Such a negative influence of repeated technogenic processes on the surrounding environment was evident, for example, in the moisture conservation of Klyuchev mines in the Urals. This very much emphasises the need for extending complex investigations in undertakings at the stage of their moisture conservation, with the sole purpose of prevention and control of the negative after-effects of technogenesis.

CHAPTER 6

Industrial-Geological Classification of Ore Deposits

PRINCIPLES OF INDUSTRIAL-GEOLOGICAL CLASSIFICATION OF ORE DEPOSITS

At various stages of study and working of ore deposits, it is very essential to determine the problems and principal directions of hydrogeological and engineering geological studies in order to solve the problems in terms of the requirements for prospecting, development and exploitation of the deposits, as well as conservation and protection of the surrounding environment. The primary aims and problems of the studies at different stages of investigation and exploitation of ore deposits are given in Table 4.

It can be seen from Table 4 that the study of hydrogeological and engineering geological conditions of ore deposits at different stages of their working constitutes a continuous chain of investigations. The primary objective of this chain includes adoption of a principle of continuity (of operation), first and foremost continuation of *in situ* study of the groundwater and surface water regime, and also of technogenic processes. Such continuous studies on ore deposits provide only the quantitative and reliable first-hand information necessary for evaluation of possible commercial exploitation of the given targets.

The complex study of hydrogeological and engineering geological conditions of an ore deposit on the basis of a unique programme, with the simultaneous operation of all type of investigations at every stage of exploitation of the ore deposit, forms the most methodical practise today. Only under such circumstances is it fairly possible to rely on prognostic data on the possible influence of drainage on mining activity in the development of technogenic processes at the site. This data can also be utilised to ensure safe conditions for commercial exploitation of deposits and preservation of the surrounding environment.

A perusal of the data presented in Table 4 shows that it is very important to precisely define the direction, method, aims and problems of complex studies, and also to ascertain the complexity of the target and the scheme of its commercial exploitation.

Table 4: Principles and Principal Problems of Complex (Hydrogeological and Engineering Geological) Investigations Required at Various Stages of Study and Working of Ore Deposits

Stage of Investigation (1)	Specific Purpose of Investigation (2)	Basic problems Involved (3)
Prospecting of ore deposits (reconnaisance details)	Work out bases for the following: a) Techno-economical report (TER) on commercial working of deposit, waterworks of prospective undertaking and protection of surrounding environment (for deposits with complex modes of occurrence) b) Project programme for deposits under simple natural conditions	General pattern of changes of hydrogeological and engineering geological conditions of ore district and parts of mining construction; present original complex information for compilation of the Techno-economical report (TER) or project plan; forecast or predict rate of water currents in mining operation and recommend suitable scheme of drainage and water supply and also measures to protect environment around the mine
Planning (design) and construction of mining industrial undertaking	Improvement of certain aspects of project plan and basis of construction of mining complex, taking into account characteristics of the study area (ore deposit) and also planning of desired facility to protect and conserve surrounding environment in light of prognostic estimate of possible negative influence of technogenesis	Detailed hydrogeological and engineering geological studies of the project area under specific conditions visualised in planning major aspects of prospective undertaking; personal supervision (by author of report) during mining construction and operation of facility installed for protection of geological and surrounding environment
Commercial exploitation of ore deposit	Work out basis for safe hydrogeological and engineering geological conditions of commercial development of ore deposits; utilisation of mine waters for various purposes and protection of surrounding environment from negative influence of technogenesis	Detailed *in situ* hydrogeological and engineering geological investigations of regime of underground waters and technogenic processes under conditions of continuous exploitation of major segments of undertaking (mining department, management of dumps reservoirs, tailings, township and machinery towards preservation of environment)
Conservation of the mining establishment (open cast mine, subsurface mine)	Preservation and protection of surrounding environment	*In situ* studies on regime of underground waters and technogenic processes; additional measures for protection of environment, in case for necessity, in accordance with requirements of the State Mining Authority, USSR

Hence it is desirable to have a practical handbook on investigations relating to large complexes in order to systematise the diverse the natural conditions of ore deposits and to classify them as geological-industrial or industrial-geological. Such classifications were proposed earlier by G.N. Kamenskii, S.V. Troiskii, D.I. Shegolev, S.P. Prokhorov, N.I. Plotnikov and others. All of them have now become obsolete.

In the light of modern requirements of the mining industry and the new problems arising in the field of protection and preservation of the surrounding environment, a new broad-based industrial-geological/geo-industrial classification of ore deposits in the USSR outside the zone of formation of permafrost has been presented in Table 5. The new geological industrial classification mainly takes into account the following major factors which determine the complexity of the mining of ore deposits.

1. Degree of complexity of the geological environment, characterising complexity of the hydrogeological and engineering geological conditions of ore bodies. Four types of geological environment have been listed above: their components and characteristics have been briefly examined and a short account of the characteristics of the different components also presented (rock types, underground waters, natural gases and micro-organisms). The structure and constitution of the geological environment play a prominent role in the general estimate of the degree of complexity of mining construction in ore deposits and also in the selection of a rational scheme of location and accommodating other units of the industry.

   Infact, geological environmental characteristics determine: (a) conditions of drilling in the mine (general and special) physico-mechanical and hydraulic properties of rocks and the degree of their stability in mines (to assess if reinforcement of the mines is required or any additional preliminary drainage of benches in open cast mines etc.); (b) degree of flooding of deposit and above all the general potential water currents in the system of mining, the sources of their formation, specific utilisation of mine waters and degree of their corrosion; and (c) possible occurrence of gases in mines (natural or technogenic gases, their approximate composition and need for protective measures).
2. Degree of complexity of development of technogenesis at the stage of exploitation of ore deposits. In accordance with the prevailing intensity of this factor it is necessary: (a) to evaluate technogenic processes and their negative influence on changes in the geological environmental characteristics and the ecological status quo of the surrounding environment during drainage operations in the mines, exploitation of water supply reservoirs and tailings dump in the region of the mine's township; and (b) to evaluate the complexity of the necessary protection of the surrounding environment of

human habitation and industrial activity from the retarding influence of technogenesis.

3. Degree of complexity of commercial exploitation of ore deposits. This factor determines: (a) the need for adoption of general, special or individual methods of dewatering mines; (b) the choice of the most rational scheme of drainage, taking into account utilisation of mine waters for domestic water supply or for irrigation and also protection of the surrounding environment; and (c) selection of rational hydrogeological and engineering geological conditions in the different departments of mining activity (management of dumping of gangue and also tailings dam and reservoir from the beneficiation plant, water supply system, township areas, recreation zone, amusement parks etc.).

Taking into consideration the factors enumerated above, four distinct groups of ore deposits can be distinguished in the humid and arid zone belts of the Soviet Union, where hydrogeological and engineering geological settings vary greatly (see Table 5). Such an industrial-geological classification has vast practical application: (1) tentative choice of major lines of complex hydrogeological and engineering geological studies of the major activities of work of a multi-disciplinary character at different stages of the study and working of ore deposits; (2) prognostic evaluation of the possible development of technogenic processes during exploitation of the deposits and also technogenesis in general; and (3) defining protective measures for the surrounding environment.

Nevertheless, it is important to precisely assess the natural conditions of the ore area under study and to assign it a place in the industrial-geological classification. While examining the natural conditions of ore deposits of different ore provinces in the USSR, it is readily seen that each group in the proposed classification can be further divided into sub-groups on the basis of certain criteria. For example, in the third group of environments of ore deposits, mainly comprising carbonate country rocks, it is possible to recognise a sub-group of deposits in which surface waters are almost nil. The Zhairem and Khaidar ore deposits, for example, might be placed in this sub-group. However, such refinements in classification introduce no principal changes; some reduction in the complexity of mining practises and a change in choice of scheme for protection of the mines from flooding may be indicated.

As for ore formations situated in the area of occurrence of permafrost rocks, the natural conditions of these sites possess characteristics and distinguishing features which classify them as a unique industrial-geological group. The frozen conditions of ore deposits as projected in practise exert a profound influence on their commercial exploitation. As for studies on frozen hydrogeological conditions of ore deposits, these are more conveniently carried out through a special programme.

Table 5: Industrial-geological classification of ore deposits

Group	Degree of Complexity of Geological Environment	Sources of Flooding: Average Prognostic Rate of Flow of General Water Currents (in m^3/hr)	Conditions of Commercial Exploitation	Degree of Complexity of Technogenesis	Practical Examples
I	Simple structure (first model of geological environment)	Primarily underground waters (fracture-ground and fracture-vein) rarely surface waters of the regional hydrographic network (50-100; rarely up to 300)	Simple (requires adoption of common methods of mining; drainage can be carried out with the help of intra-underground intra-open cast mine pumping; rarely requires diversion of river waters)	Weak appearance of technogenesis over not very large area (up to 1.5-2.0 km^2)	Some ore deposits of the Urals, Central Kazakhstan Central Asia etc.
II	Complex structure (second model of geological environment)	Underground (ground, fracture-ground, fracture-vein) and surface waters of the regional hydrographic network (200-300, rarely up to 800-1,200)	Complex (requires adoption of diversion of river waters besides common scheme of drainage; also construction of exterior or advance underground schemes of drainage in mines)	Technogenesis over limited area (up to 2-3, rarely 5 km^2); requires purification of mine waters during their utilisation for complete water supply or irrigation	Ore deposits of the Urals and Kazakhstan

III	Very complex structure (third model of geological environment)	Fracture-karst underground waters and surface waters of regional network; 8,000-12,000, rarely up to 25,000-32,000	Very complex (requires, besides normal methods, adoption of special techniques of drilling and special schemes of drainage, in this case the scheme 'drainage-water supply'; withdrawal-injection pumping, advance drainage in mines with external and intra-shaft methods and also diversion or isolation of river waters	Technogenesis over considerable area (from some hundreds to thousands of square kilometers); requires protection of environment from negative action of technogenic processes, purification of mineral waters and their utilisation for complete water supply and irrigation	Ore deposits of the Urals, Kazakhstan etc.
IV	Extremely complex structure (fourth model of geological environment)	Primarily underground waters of complex aquifer characteristics	Highly complex (requires advance preliminary and exploitation-stage drainage methods with help of rational combination of normal, special and individual schemes, in this case scheme of 'drainage-water supply' and specific preparatory drilling in mining practise	Technogenesis over limited area (up to several hundred square kilometres), requires adoption of special methods of protection of surrounding environment from negative influence of technogenic processes and also utilisation of mining waters for only water supply or irrigation	Iron ore deposits of KMA and others

CHARACTERISTICS OF CLASSIFIED GROUPS OF DEPOSITS AND COMPONENTS OF THEIR INTENSIVE STUDIES

Let us examine the characteristics of the classified groups of ore formations, their major lines of study and the contents of investigations at different stages of their study and commercial working.

The *first group*, as highlighted by data given in Table 5, is, in fact, characterised by comparatively simple hydrogeological and engineering geological conditions of commercial mining of the deposit and simple measures of protection of the surrounding environment.

The geological environment of the target areas presents primarily stable (though fractured) rock types (intrusive rocks, metamorphic quartzites, sandstones, conglomerates etc.), fresh underground waters (fracture-ground and fracture-vein), slightly permeable nature of the rocks in the mining area, chemically inactive gases of mostly atmospheric origin (nitrogen etc.), and rare occurrence of gases of deep-seated origin (carbon dioxide). Micro-organisms are sparsely developed and hence have little influence on the characteristics of the rest of the geological environment. The physico-mechanical properties of the country rocks enclosing the deposits exhibit almost no change during flooding.

Insignificant water currents in the mines assure safe conditions during commercial working with the adoption of general protective methods of intra-open cast mine or intra-shaft pumping. In the benches of open cast mines and in underground mines the stable rocks need no reinforcement or additional supporting facility. In fact, no special method of drilling either for mining or scheme of preliminary drainage during exploitation is usually required for the deposits included under the first group.

Technogenic processes are minimal during the period of exploitation of ore deposits of this group and the cone of depression forms only over an area of 1.5-2.0 km^2 (within the limits of operation of technogenesis). The drainage influence of pumping is only marginally felt in the surrounding environment. Technogenic processes might lead to draining of moisture in the sphere of mining activity and possible pollution of mine waters. The negative influence of technogenic processes of drainage on transformation of the ecological status quo of the surrounding environment is commonly not significant and hence needs no adoption of special protective measures. Herein lies the principal difference between this first group of deposits and the rest.

Conditions of commercial mining of deposits become somewhat complicated if there is need of adoption of measures of protection of mine workings from surface and groundwaters of alluvial formation—the regional hydrographic system with usually no significant discharges. In practise this is achieved by isolating the surface waters (through construction of iron-concrete pans and drainage of groundwater horizon) or by diversion of surface streams beyond the limits of influence of mining activity.

Simple conditions of industrial working of ore deposits of the first group define the major directions and principal kinds of complex hydrogeological and engineering geological studies at the stage of prospecting, exploitation and conservation of ore targets.

A short account of the whole purpose and contents of the principal kinds of complex investigations for the study of the ore deposits of the first group is presented in the following pages.

At the stage of preliminary and detailed prospecting of deposits, it is essential to conduct large scale complex hydrogeological and engineering geological mapping directly over the area of the main ore field and the areas that are likely to be exploited in the future. For this purpose one has to use maximum information on hydrogeological and engineering geological aspects collected through different kinds of strictly geological prospecting methods. The complex survey has to be conducted on a well-prepared geological base. During this survey (in the case of necessity, i.e., mainly during poor exposure of crustal rocks), it is most necessary to do a fair amount of drilling of special hydrogeological wells and also geophysical surface and core data collection. It is also desirable to conduct experimental anti-filtration studies by means of probing pumps fitted to the individual bores of geological prospecting and hydrogeological wells. Such studies provide data on the filtration characteristics of water-saturated country rocks. It is also equally necessary to conduct qualitative probes of underground and surface waters.

Proper engineering geological studies—study of the physico-mechanical properties of rocks and their fracturing—constitute an essential division of investigations. Special hydrogeological studies have to be taken up for exploration and prospecting of possible sources of water supply of the future enterprise and planning and construction of reservoir facilities according to the category of the deposit (as per the specifications given in the Manual of Instructions, GKZ-USSR).

After field studies have been completed a special supporting observation system of *in situ* studies should be organised for continuous information on the regime of underground and surface waters in parts of the mining construction and also the site of future water supply facilities. Upon the completion of complex field studies it is possible to obtain exhaustive hydrogeological and engineering geological information for prognostic evaluation of the commercial working of the deposit, possible development of technogenic processes, development of recommendations for preservation of the environment and for evaluation of possible sources of water supply from the mining establishment.

The complex studies enumerated above emphasise the necessity for conducting investigations under a unified programme and for carrying out geo-exploration activities in close collaboration with organisations that specialise in geological prospecting.

At the stage of planning and development of the mine the need to carry out certain additional complex studies might arise, primarily to demarcate precisely the area of distribution of the given ore deposit. Such studies might involve drilling of prospecting boreholes for hydrogeological and engineering geological purposes (to be followed by more detailed probes) in parts of the proposed shaft (mine) areas, disposal of gangue materials and tailings dump, and also planning of the township, these investigations are commonly undertaken according to the facilities and capability of the project organisations.

In the construction of the mine it is extremely essential to provide for hydrogeological and engineering geological documentation during the preparatory and mining stages, ensure personal supervision of construction by a specialist and also conduct exhaustive observations on the regime of underground and surface waters and technogenic processes right from the stage of prospecting of the deposit.

At the stage of exploitation of the targets of the first group, studies are primarily concerned with continuous *in situ* investigations of the regime of underground and surface waters in all segments of the mine's undertaking (mining department, tailings dump, water supply unit, township sector). Similar *in situ* studies are also undertaken on technogenic processes with the basic aim (in case of necessity) of implementing additional measures to protect the surrounding environment from their negative influence.

The following intensive studies are taken up at this stage:

a. Constant hydrogeological documentation of all mine cuttings (conducted side by side with geological documentation).
b. Systematic sampling and determination of quality of mine waters (determination of chemical and sanitary-bacteriological composition of waters).
c. *In situ* study of the regime of underground waters in observation wells, water flows in mining operation (comprising all aquifer horizons); study of conditions of possible contamination of underground waters in parts of the tailings dump and the regime of underground waters in the reservoir sites; there should be a supporting and relief system of observation points to translate complex studies on the regime of surface and underground waters into action.
d. Controlled evaluation of conditions of discharge of mine waters from the point of view of preservation of the environment.
e. Recognition of (periodic) inspection of the mine's township and the whole environment with a view to preserving and protecting the landscape as a whole.

All these complex studies are accomplished by periodical (better every year) laboratory tests on materials and compilation of annual records in which the results of the studies are systematically presented. Finally, recommendations are made for safer working conditions in the mines in the future; additional measures of protection of the environment and prognostic estimates of the possible water currents to deeper horizons in the mines are also attempted.

Besides operational (annual) experimental data on hydrogeological and engineering geological materials, it is desirable to systematise and generalise the materials according to the experience gained over many years of exploitation, with particular reference to a comparative evaluation of the prognostic and physical data.

The results of such studies are very helpful in perfecting the methodology of investigations in future enterprises.

At the stage of conservation of the target of mining it is expedient to continue studies on the preservation and protection of the environment so that the possible incidence of accidents, which rises with an increase in activity of technogenic processes over time, can be avoided.

The second group of deposits, as seen from Table 5, is characterised by complex natural hydrogeological and engineering geological conditions of the deposit, complex conditions of their exploitation and protection of the surrounding environment . These conditions reflect the second type of geological environment. The unique feature which distinguishes this group from the first is the fact that during exploitation of the targets it is necessary to adopt, in addition to common methods, special techniques of drilling, modern methods of exploitation and drainage and various other special measures to ensure safe working of the deposit.

The geological environment of the second group of ore deposits is characterised by complex conditions. A cross section of the ore district comprises parts of weakly stable semi-hard crustal rocks (often complexly deformed) exhibiting a profuse development of fractures and tectonic dislocations. Unconsolidated formations of considerable thickness occur as a cover and are invariably water bearing. Some varieties of metamorphic rocks possess the property of latent viscosity, which introduces difficulties in mining. All these factors make it necessary to adopt continuous reinforcement during the entire process of underground mining and specially designed modern drainage methods in open cast mines, mainly to protect unstable slopes.

Underground waters of various types are widely encountered in the following zones of occurrence of ore deposits:

(a) groundwater in the unconsolidated cover formation;

(b) fracture-groundwaters in the zone of weathering of crustal rocks; and

(c) fracture-vein groundwaters in the zones of tectonic dislocations.

River valleys of recent origin of the second and third order are very often noticed over the surface of areas of ore mineralisation. They are commonly perennial streams.

Radical changes in the interaction of underground and surface waters take place during drainage operations in mines, when artificial drainage plays a useful role. Hence the need to isolate or divert the surface waters of rivers beyond the limits of the zone of drainage influence of rocks arises, because they form the principal source of flooding of the deposit.

Oxidation of mine waters in the copper deposits might change their chemical composition during the exploitation of deposits under the influence of technogenic processes. The most intense reaction takes place in the chemical composition of underground waters of sulphide mineralisation. In this, the pH of water often reaches a value as low as 2-3; mine waters acquire a corrosive property with respect to rocks, ferro-concrete and metallic constructions. The general mineral content of mine waters increases two to three times. Inert and chemically active gases of the atmosphere and also those formed at depths (carbon dioxide) may be distributed in the mines.

The influence of micro-organisms on changes in the characteristics of the geological environment during future exploitation of ore deposits has hardly been studied.

The complexity of the geological environment in the second group of deposits makes imperative the adoption of a rational combination of conventional and special techniques of advanced exploitation and drainage in order to ensure safe hydrogeological and engineering geological conditions of mining and also to implement suitable measures for protection of the surrounding environment.

A multi-tier system of advance drainage of open cast mines by means of underground drainage operations below them in combination with porous-filter wells introduced from the surface is commonly adopted during stripping of the deposit. Such a drainage system completely vouchsafes high effectiveness of advance drainage of an open-mine operation and protection of the mine from underground waters. Water currents in the shafts commonly exceed the permissible norms for conventional methods of installation, at more than 25-35 m^3/hr. Therefore, special techniques of shaft sinking are undertaken.

In mining practise advance and operational drainages are implemented for some ore targets by means of a combined scheme—linear rows of surface drainage wells are sunk to drain water from water-bearing unconsolidated rocks (of fairly large thickness) and also intra-shaft pumping.

In mine areas where flooding is contributed by surface waters, additional protection of mine working from river waters has to be ensured either by diversion or isolation of the stream. Such measures have been employed in many mines.

During the drainage of ore deposits of the second group several technogenic processes arise and exert a negative influence on changes in the geological and surrounding environmental characteristics: (a) breaks in the general landscape condition in areas of mining constructions and adjoining territories; (b) filtration-deformation of benches of open cast mines during insufficient drainage; (c) filtration-subsidence processes in flooded zones of tectonic dislocations; (d) appearance of properties of latent viscosity and waterlogging of clayey ore-bearing country rocks; (e) drainage of fresh underground waters of Quaternary deposits, commonly utilised for a centralised water supply system catering to the needs of settlements in and around the mine site; and (f) hydrogeological processes of oxidation, pollution of mine waters etc.

A large complex of technogenic processes decides the measures of protection of the surrounding environment from their negative influence, viz., necessary reclamation of the soil; organisation of the centralised water supply for the adjoining township touching upon the draining influence of drainage installations; utilisation of mine waters for industrial water supply etc.

At the various stages of study, working and conservation of the second group of deposits, it is expedient to conduct the necessary quantum of complex hydrogeological and engineering geological investigations.

At the stage of prospecting deposits of the second group the following activities are envisaged.

1. All complex investigations enumerated under the first group of deposit.
2. Drilling of special hydrogeological and engineering geological wells which, in co-ordination with geological prospecting activity, constitutes the basis for the compilation of specialised maps of the ore deposit under study.
3. Experimental studies on filtration—exploratory and experimental (pilot) pump tests on wells to study the hydrogeological parameters of aquifer horizons including tests on cluster of well pumps.
4. Complex geophysical and hydrogeochemical investigations (surface and logging techniques).
5. Studies for prognostic estimate of technogenic processes, determination of their negative influence and development of recommendations for preservation and protection of surrounding environment.
6. Experimental study on exploitation in a pilot area close to the existing mine for a comparative assessment of the hydrogeological conditions and utilisation of the results in providing protection of the environment around the present mine site.

It is absolutely necessary, during hydrogeological studies conducted at the stage of prospecting, to establish the main sources of flooding in mines and spell out recommendations for a scheme of drainage for all future mining operations and measures of protection of the environment. These recommendations have to be incorporated in the planning of the industrial working of the deposit.

As evident from the short account of the major kinds of activity, complex studies at the stage of prospecting of the second group of deposits possess an independent character and might involve the services of specialists—hydrogeologists and engineering geologists—in the geological prospecting expedition. A well-organised plan of action can solve the problems likely to arise in this situation [18].

At the stage of planning and construction **of the mine per se, intense studies have to be continued with more emphasis giving to the requirements of the specifically identified sectors of the undertaking—shaft or open cast mine construction and parts of different units located at the mine site. At the stage of construction the primary concern is vigilant supervision by the architect of the project over all project activities such as drainage constructions and completion of detailed hydrogeological documentation of all kinds of mine developmental works.**

Complex studies assume greater importance *at the stage of exploitation* of the second group of ore deposits in the field of prevention of mining hazards and protection of the surrounding environment. The major lines of intense study are very similar to those outlined for the first group of deposits except for those given below:

1. Systematic and planned supervision of the constituent activities of all types of drainage constructions and evaluation of hydrogeological and engineering geological effectiveness of drainage installations and also adoption of additional measures of protection of mines from their major sources of flooding.
2. Studies on the conditions of formation of technogenic processes and their negative action on changes in the surrounding environment, and developing additional arrangements for the protection of the environment.
3. A comparative analysis of prognostic estimates of the commercial working of the deposit on the basis of data obtained from prospecting and during exploitation.

The following major kinds of hydrogeological works have to be carried out at the stage of exploitation of the deposit of the second group:

1. *In situ* intensive studies on the regime of underground waters (level, rate of flow, chemical composition and temperature) directly at the mines (including open cast) and also on the surface through boreholes specially equipped for this purpose. Such investigations are conducted for the following purposes:
   a. Study of the area of distribution of the cone of depression and subsequent estimate of the degree of influence of drainage of the mine on ecological changes in the surrounding environment and formation of technogenic processes;
   b. Evaluation of residual (retained) hydrostatic pressure of underground waters through all the principal horizons of mine workings, adoption of additional measures for draining underground waters, drainage of the horizon and provision of safe conditions for future expansion of the mining activity for the entire deposit;
   c. Develop additional operational measures to protect the surrounding environment;
   d. Prognostic estimate of the rate of flow of groundwater for deeper horizons demarcated for mining, which might be possible by hydraulic method, hydrodynamic calculations or the method of modelling over EVM. It is also important to study the hydrochemical and sanitary conditions of contaminated mine waters, conditions of their disposal to the surface and recommendations relating to their utilisation.
2. *In situ* studies of technogenic processes appearing in the process of commercial exploitation of the deposit.

3. Hydrogeological and engineering geological documentation of all mining activities and preparation of plans of flooding in different horizons and systems of the complete mining practise.
4. Detailed *in situ* studies on the regime of underground waters and their influence on water-supply equipment.
5. Periodic reconnaissance—inspection of the mining establishment with a view to assessing the effectiveness of the facility for the preservation of the surrounding environment.

The complex investigations *at the stage of conservation of the deposits of the second group* are no less significant. Experience has demonstrated that the absence of the most elementary hydrogeological and engineering geological supervision in the period of conservation of the deposit leads to very serious after-effects, namely extensive damage and loss to the national economy. The main objective of these studies is strict supervision and observation of the mining work for conservation of the deposit and protection of the environment.

For planned, systematic and operational working of the mining establishment of a deposit belonging to the second group of complexity, it becomes necessary to organise at the target area special hydrogeological services which have to form part of the geological mining survey of the undertaking. Cumulative experience in this respect reveals that such organised forms of hydrogeological operations set right the operational facilities and solve all the hydrogeological problems of the mining enterprise.

The third group (See Table 5) includes all deposits in which the geological constitution incorporates intensely flooded carbonate rocks. Their conditions are akin, in general, to those enumerated for the third model of the geological environment.

The complexity of commercial management of the deposits of this group essentially consists in excessive degree of flooding of ore-bearing country rocks with considerable flow of groundwater currents in the mines, reaching 18,000-22,000 m^3/hr. Such hydrogeological conditions during mining of the deposits require recourse to special and original measures of protecting the mines from flooding. However, this entails considerable complexity in the preservation of the surrounding environment because of the larger areal of influence of the drainage system of the mines.

Rock types in this group are limestones, marbles and dolomites, well known for their stability. Hence during underground mining no support by way of reinforcement is required. As already mentioned, carbonate rocks possess special structural elements. A combination of fracturing and karstification can be easily traced in these rocks and this feature accounts for their increased water content compared to other lithological units of ore-bearing country rocks. Hence these rocks form excellent reservoirs of underground waters. In addition to this feature, a very high degree of non-homogeneous filtration both in plan and in section can also be traced in carbonate rocks. This situation creates difficulties and, in certain cases, excludes the application of hydrodynamic methods of calculating the prognostic rates of flow in mine working and hence requires adoption of schemes of the method of modelling over EVM. Ore deposits associated with carbonate rocks are relegated to this group.

The following two types of underground waters characterise deposits of the third group: (a) groundwaters of the covers of unconsolidated formations and (b) fracture-karst waters of ore-bearing calcareous country rocks.

When a network of hydrographic stations is established over some ore-mineralised areas, a close hydraulic link develops between fracture-karst waters and surface waters. Under such conditions surface waters contribute to flooding of the mines. During their drainage a drastic change originates in the regime of interaction between underground and surface waters. Mining activity in the process of exploitation of the ore body plays the role of artificial drainage. Chemical composition of the underground waters in the deposit of the group under review shows them to be fresh, with mineral contents reaching 15-30 g/l (in some deposits strong brines with a concentration of 170-190 g/1 are also encountered).

Gases in the deposits of the third group are of atmospheric, biogenic and deep-seated endogenic origin (carbon dioxide, hydrogen sulphide, methane and others) and exhibit a corrosive action on metal and ferro-concrete. Hence, anti-corrosive machinery is used in drainage operations. The role of micro-organisms in this geological environment has never been studied.

During drainage of the deposit subsidence-karst technogenic processes develop and profoundly influence landscape conditions and features of the surrounding environment. Similarly filtration, subsidence processes appear in the mine area when the zone of flooding is encountered while intercepting tectonic fault zones and operating drainage wells to lower the water table. These processes lead to deformation of reinforced structures in the mines and also sagging of the earth's surface around the well of the cone of depression.

The group of deposits discussed above, as already pointed out, is characterised by a high degree of water saturation. In deposits where there are almost no surfacial water bodies, the total flow of water currents in the mines might reach 3,000-5,000 m^3/hr and under conditions where there is a river system with constant or varying flow, this value might reach 18,000-22,000 m^3/hr. Such a high degree of groundwater storage makes it compulsory to protect the mine works from underground and surface waters throughout the entire organisational set-up of the mining complex by: (a) construction of impervious 'coffer dams' in the underground mines close to the shaft walls before starting preparatory mining activity, which involves penetrating the flooded zones of carbonate rocks; (b) construction on the surface along the flanks of the cone of depression of thick outer drainage connections to tap part of the filtered currents and take them to the mine works; (c) special methods of drilling of shafts (under the protection of lowering the water level or cementation); (d) isolation in concrete canals of surface waters and discharge of mine waters within the limits of the zone of influence of the mine working; (e) construction of reduced drainage wells in underground mines for removing the residual (reserved) hydrostatic pressures of fracture-karst waters; (f) drilling multi-holed, water-level lowering wells; and (g) implementation of the original schemes: drainage-water supply, drainage-irrigation and withdrawal pumping.

It is necessary to adopt suitable measures to protect the surrounding environment from the negative influence of technogenic processes, subsidence-karst phenomena etc.

Hydrogeological and engineering geological studies on the deposits of the third group, in view of their high degree of complexity, have a unique status in the general complex of geological prospecting works at all stages of study and exploitation. Experience in activities at the stage of exploration and exploitation of deposits of the third group has shown that the problems have to be successfully solved before commencement of intense studies at the stage of organisation of independent hydrogeological studies with well equipped techniques and machinery.

At the stage of prospecting all complex studies have to be carried out as in the case of the first and second group. Of course, due attention must be paid to studies on fracturing, karstification, and filtration heterogeneity of carbonate rocks; the nature of distribution of open karst cavities in such rocks, covered by unconsolidated formations to which during the dewatering of mines are related the formation of collapse-karst technogenic processes; and analysis of processes of radical break of interlink between fracture-karst and surface waters, subsidence-filtration processes during draining of flooded zones of tectonic dislocations and so forth.

During the prospecting of deposits of the third group considerable significance is attached to hydrological studies related to the prognosis of water currents in the mines and maximal utilisation of the resources of fracture-karst waters, which are extracted from the sub-surface during exploitation of drainage waters of the future mining activity.

Experience has taught that during the operation of rational schemes of drainage of mines, mine waters can be fruitfully utilised for domestic, potable and industrial water supply, and also for purposes of protecting the surrounding environment through irrigation of the soil. In this it is very necessary to assess the characteristic requirements of the scheme of 'drainage-water supply' detailed in Chapter 11. At the stage of prospecting of the deposit, it is likewise essential to work out very sound recommendations regarding the choice of a rational scheme of drainage for every specific instance (target) of future mining and maximum utilisation of mine waters.

When in ore-bearing country rocks of the deposit under study underground waters of high mineral content have formed, a distinct necessity arises to conduct special studies for a preliminary solution of problems relating to the preservation of the surrounding environment, intimately linked with the withdrawal of mine waters and their discharge during the future exploitation of the deposit. For conditions of the arid zone, the discharge of mineralised mine waters has to be carried out through a system of reservoir-evaporators. Here, the peculiarity of investigation consists in the choice and hydrological foundation of the sites of construction of the reservoir-evaporators.

In other zones, at the stage of prospecting, it is preferable to study the geological-hydrogeological conditions on the basis of possible adoption of the drainage scheme 'withdrawal injection' (pumping out/in) in the proposed mine area. It is indeed necessary in this direction to carry out full-scale studies: drilling of special hydrogeological wells, carrying out geophysical-surface and logging surveys and also experimental filtration, the result of which would later help to construct a prospecting model over EVM computer, using the scheme of drainage withdrawal-injection in the regime very close to the conditions likely to prevail in the future exploitation stage.

At the stage of planning and mining operation in deposits of the third group still more detailed, specialised and intense studies have to be undertaken primarily to meet the requirements for specific planning of all the major units of the future undertaking. At this stage in parts of the mining construction it is peremptory to drill prospecting wells along the walls of the planned shafts, to choose special methods for their sinking, and along the contour of the proposed scheme of the outer drainage facilities (for future open cast mines) to improve the specific hydrogeological conditions of drainage, including evaluation the non-homogeneous filtration of the carbonate rocks, both in plan and cross-section, and their influence on the implementation of the most rational solutions.

In the case of deposits where mineralised underground waters containing brines prevail, there is an imperative need to continue hydrological studies by adopting the scheme of drainage burial in bulk filtration-experimental tests. These studies, as mentioned earlier, precisely define the requirements for the preservation of the surrounding environment.

Considering the complexity and time-consuming nature of such studies, it is recommended that a special programme of action be spelled out regarding methods and technological scheme of industrial-experimental tests based on the hydrogeological characteristics of the target area under study.

The need for conducting special engineering geological studies arises on the basis of plans worked out to either isolate or divert the major source of flooding of the deposit— the surface waters — beyond the limits of their influence on mining, and also to decide on the choice of site to dispose of mine waters and isolate them for the purpose of elimination of secondary absorption in karstified carbonate rocks.

Special precaution has to be exercised during the choice of site for stacking industrial wastes from beneficiation plants (tailings dump) so that the infiltrated liquid phase of these wastes cannot gain access to the water-bearing, ore-containing carbonate country rocks. This avoids possible chemical contamination of mine waters intended for domestic water supply and irrigation. It is also necessary to conduct special engineering geological studies to solve this problem.

As pointed out earlier, all laboratory investigations of materials must be duly completed, since these materials play a vital role in the complex investigations of the hydrogeological problems analysed through methods of mathematical modelling over EVM (prognostic evaluation of the general currents, preliminary recommendation of the scheme of dewatering of mines etc.).

The stage of exploitation of the deposit of the third group forms the most critical phase for hydrogeological studies. The principal problems of intensive studies at the stage of exploitation of the ore deposits, as in the previous cases, are guarantee of safe conditions in hydrogeological and engineering geological characteristics during mining of the deposit throughout the entire period of its exploitation. With this objective in mind, comprehensive studies on the regime of underground and surface waters in the underground mining operation and also on all outer drainage installations, are conducted to assure safe and continuous working and estimate the efficiency of working. Details of the studies to be undertaken have been well examined in the enumeration of the hydrological conditions of the deposits of the second group. The important component of intensive studies on the regime of underground waters for this group of deposits is the field study of the residual hydrostatic pressures of fracture-karst waters in the mines. Conservation of the pressures on mining activity is made possible under the influence of filtration heterogeneity of the carbonate rocks and often leads to sudden outbursts of fracture-karst waters into the horizons prepared for starting mining activity, which might disrupt the whole scheme of action. Therefore, it is essential to systematically study the regime of levels of fracture-karst waters through observation wells and if high hydrostatic pressures are encountered in certain parts, to take proper measures to reduce them by means of drilling special drainage wells sunk directly into the underground mine working . The results of integrated studies of the groundwater regime might allow, should the need arise, additional measures of protection of the mines from flooding and an increment in the mine's drainage facility.

In situ studies on the regime of underground waters have likewise to be continued at the sites of reservoirs and tailings dump to enable hydrogeological monitoring for their effective exploitation and also over the township area to ascertain beforehand the possible development of processes which might lead to a rise of the water table.

From the overall significance of the large complex studies on the regime of underground and surface waters, it can be seen that a system of special exploratory and relief observation points has to be organised over the entire area of the undertaking, covering the major sectors of its functioning. The principles of the configuration of the observation network are discussed in Chapter 7.

The *in situ* study of the area of operation of technogenic processes, particularly of subsidence-karst processes and contamination of underground waters, is very closely connected with the study of the regime of underground and surface waters. The main purpose of these studies is determined by the requirements of preservation and protection of the surrounding environment from the negative action of technogenic processes, including the protection of the surface installations of the undertaking from possible deformation under the influence of formation of a cone of depression in regions of subsidence-karst formation.

Important questions arise when the mine enterprise wants to safely utilise almost all the mine waters for domestic water supply as well as for irrigation of the soil. Investigations on this aspect are directed towards *in situ* determination of the quality of the mine waters.

In accordance with these problems, major lines of study and details of complex investigations are designed. In addition to the studies enumerated for deposits of the first and the second group, some additional aspects should be highlighted, particularly those pertaining to the geological environmental characteristics.

At the stage of conservation of the target deposit, as in earlier cases, it is expedient to continue *in situ* study of the regime of underground waters and technogenic processes for the sole purpose of preservation and protection of the surrounding environment.

In the fourth group are included deposits possessing complex hydrogeological and engineering geological conditions during their commercial working, complex structure of geological cross-section and conditions of protection of the surrounding environment. To this group can be related the iron-ore deposits of the KMA and others [22].

A geological cross-section of one of these deposits shows parts of weakly stable ore-bearing metamorphic and igneous rocks overlying a thick series (up to 150-300 m, rarely up to 500-600 m) interstratified sandy-clay and carbonate formations. In the series of ore-bearing country rocks and also the cover formations normally confined aquifer horizons occur in which the underground waters possess highly variable mineral contents (from fresh to minerlised); the upper aquifer horizons usually contain fresh waters and are connected with the surface waters of the regional hydrographic system. In the study areas three types of underground waters are common: artesian interbedded-interstitial and layered-fracture waters and in the Quaternary formations, groundwaters of alluvial and diluvial deposits. At great depths of emplacement of the ore bodies (in the mines) chemically active gases of deep-seated origin (carbon dioxide and others) may form. The formation of micro-organisms in natural and disrupted conditions has been studied very little.

The total flow of water currents in the system of mine working of these deposits varies on the average from 1,500 to 2,000 to 3,500 and rarely reaches 5,000-6,000 m^3/hr.

Considering the highly complex natural conditions of ore deposits of the fourth group, the detailed studies carried out during prospecting assume very great significance and more authority. In fact, all the principal problems pertaining to hydrogeological and engineering geological bases for safe conditions of commercial exploitation of the deposit and preservation of the surrounding environment have to be solved at the stage of prospecting.

In this connection all the complex investigations envisaged for deposits of the first, second and third group, have also to be taken up for this group of deposits.

In the deposits, based on their complexity, the following principal kinds of hydrogeological and engineering geological investigations have necessarily to be undertaken at the required level.

1. Drilling of special wells for highly varied application: cartographic (in the preparation of complex mapping of the area of ore-mineralisation), exploratory-prospecting (to study conditions of occurrence and distribution of all aquifer horizons, their interaction with natural conditions, qualitative probing of underground waters and study of the physico-mechanical properties of rocks), experimental-prospecting (for organising experimental-filtration studies) and observational (to understand the regime of underground waters).
2. Experimental-filtration tests: exploratory, experimental and multiple withdrawal to study the hyrogeological parameters of the aquifer and also other non-aquifer horizons of rocks. Successful lowering of the water table through experiments forms an integral part of the basic aim of the filtration tests.

   Experimental lowering of the water table is very often conducted from the lowermost water-bearing aquifer horizon by withdrawal through a group of prospecting wells (2-5 wells); in this study the experimental part has to be equipped with a safe system of stepped observation wells for all the aquifer horizons distributed in the rocks of the ore bearing suite as well those of the overlying series.

   The major comprehensive application of the experimentally conducted water-level lowering is a study of the effectiveness of the working scheme of drainage in mines and later utilisation of the data obtained for precise determination of hydrogeological parameters of the aquifer layers.
3. In connection with the modern technology of drilling of wells (fast drilling with periodic core recovery) great significance is attached to the geophysical mapping necessary for all hydrogeological wells, in order to precisely decipher the lithological sequence and also to make a preliminary assessment of the filtration properties of underground rocks.

4. *In situ* study of the regime of underground and surface waters is one of the principal studies, the results of which might be successfully utilised in selecting the scheme of drainage to be undertaken in the mining of the deposit.

   With this aim in view, it is necessary to organise an exploratory and supporting observation system in the area to be prospected, which characteristically consists of a multi-tier placement of observation wells. This enables study of the regime of all types of underground waters in the hydrogeological cross section of the aquifer complex, distributed in the ore-bearing as well as in the overlying rock series.
5. Considering the requirements for utilisation of all the useful components of the ore deposits, including fresh underground waters and the high water content of deposits of the fourth group (during the drainage of which a considerable quantity of underground waters is pumped out), great importance is given at the stage of prospecting of the ore deposits to the hydrogeological basis for the scheme of drainage selected in the deposit and protective measures in mining against surface and groundwaters.

   To ensure safe conditions of commercial mining of the deposit, experience in exploitation underscores the adoption of a rational combination of conventional, special and individual (unique) methods of drainage, including examination of the possibility and effectiveness of the schemes drainage-water supply, drainage-irrigation and also drainage under the protection of anti-filtration screens.

   The basis of each of the schemes of drainage of a deposit enumerated above requires determination of the lines of hydrogeological investigations since they are mutually positively related. This aspect has been discussed in Chapter 11. It is preferable to conduct such investigations at the stage of detailed prospecting of the ore deposit, when the hydrogeological characteristics of the target area are fairly well defined. It is extremely necessary to have the plan of hydrogeological activity approved by the sanitary project organisation. This helps in the preliminary assessment of the efficacy of the chosen scheme of drainage, which has to be completed according to the results of the studies thoroughly documented during commercial stripping of the deposit for a critical analysis of the situation. Here it is pertinent to observe that the prognostic estimate of the rate of flow of water currents in the mines, the basis of the rational schemes of drainage of the deposit and measures for the protection of the mines from underground and surface waters are relatively complex . They have to be reviewed for alternative solutions for choice of optimal conditions and should arrive at a final decision using the method of mathematical modelling over EVM. Hence the contents of all kinds of hydrogeological studies should be geared to meet the requirements of mathematical modelling.

6. No less indispensable during the prospecting of ore deposits are the complex studies related to the prognostic evaluation of the possible formation of technogenesis and its negative influence on the geological environmental characteristics, and also the degradation of the ecology of the surrounding environment at the stage of exploitation of the prospective mining enterprise. For this, it is ideal to prepare a preliminary assessment of the possible area of influence of the cone of depression during the dewatering of mines of the deposit under study, complete a prognostic estimate of the possible formation of various technogenic processes, analyse their negative influence and accordingly work out measures of protection of the surrounding environment. The scheme of drainage implemented in the mining enterprise forms an integral part of the facility to be adopted to protect the surrounding environment.

   To solve the problems expected to arise in the field of hydrogeological influence on the preservation of the surrounding environment, it is mandatory to give due credence to the development of the following technogenic processes: (a) draining of centralised and decentralised water reservoirs occurring in the region of the deposit and used for general water supply to towns in the neighbourhood and other settlements; (b) degree of drainage of surface waters of the regional river system during dewatering in mines and the necessity of their isolation or diversion; and (c) degree of secondary reduced compaction of the sandy-clayey formation during the drainage of rocks of the series overlying the ore horizon and its influence on the deformation of the surface, the underground communications, surface installations etc. As in the earlier cases, intense studies during prospecting of ore deposits have to be completed through laboratory experimental data collection on the materials and also the preparation of the report (together with compilation of data on explored reserves of ore deposits) in which eventually the hydrogeological and engineering geological bases of commercial working of the deposit under study are also incorporated.

At the stage of planning and development of mining practise (as in the case of ore deposits of the third group) additional and more detailed and complex studies have to be undertaken as a preliminary requirement for working out the plan of the prospective project and the allocation of the principal sectors of the industry over the area of exploitation.

The following kinds of activities have therefore to be planned accordingly : (a) drilling of wells and filtration experiments in the region of the proposed mine shafts (in underground mining), (b) continuance of intense studies of a more extensive character over the area under investigation by conducting experiments on an industrial scale of select schemes of drainage for the chosen area of study (drilling of additional wells and filtration experiments) and also extension of studies on method of modelling over EVM to assess the effectiveness of the scheme of drainage, and (c) intensive studies on certain aspects of mining practise—dumping of gangue materials, collecting of industrial wastes (tailings) and planning of the nearby township. Such studies are undertaken by project organisations or through the cooperation of specialised hydrogeological organisations. At the stage of development of the different sectors of the mining establishment, hydrogeological documentation for mine preparation such as drainage construction etc., becomes very essential. Effective supervision by experts at all stages of development of the mine is equally important. Continuation of *in situ* observations on surface and sub-surface water regimes at this stage is highly useful so that continuity of supply of the most important information on hydrogeology is guaranteed.

At the stage of exploitation of ore deposit intensive investigations have to be completed in order to solve the following principal problems: (a) assurance of safe conditions and uninterrupted working in all the sectors of the mining operation and also hydrogeological monitoring for maintenance of all the planned activities before actually starting mining per se, exploitation of drainage facility, water supply system, tailings and maintenance of the mine's township area; (b) estimation of effectiveness of the scheme of drainage to the adopted in the mining undertaking; (c) establishment of a hydrogeological basis for additional facilities of effective drainage of the deposit—a necessity when highly complex conditions arise during exploitation of the deposit; and (d) preservation and protection of the environment from the negative influence of technogenesis in all major activities of the mine enterprise.

Studies on the following kinds of hydrogeological, hydrological and engineering geological investigations are envisaged for solving major problems:

1. Complex *in situ* observations on the regime of level of underground waters, rate of flow of water currents in the mines (open cast), water yield from drainage operations and water supply facility, surface waters, chemical and sanitary-bacteriological composition of underground and surface waters and analysis of technogenic processes.

   Intense studies have to be carried out through a well-organised and well-equipped enterprise, provided with monitoring and an allied supporting network—observation points (observation boreholes sunk in areas of mine tailings at water in-take points and township area, in underground mines or inside open cast mines, hydrometric stations of the hydrographic network, geodedic datum marks equipped to study the influence of drainage operations etc.).

   To proceed along these lines it is necessary, of course, to obtain systematic and exhaustive information to solve the current practical problems as well as those which might appear afresh during the exploitation of major targets in mining practise.

For this particular group of ore deposits it is very important to conduct *in situ* observations on the formation and development of technogenic processes right in the mines, over the surface, and on parts of tailings dump and water supply installations. Simultaneous assessment of their degree of negative influence on the disruption of safe conditions of commercial working of the deposit, characteristics of the geological environment and the ecological situation of the surrounding environment, demands a series of protective measures.

During the detailed exploitation of the deposits of the fourth group it is absolutely essential to pay due attention to the study of the most widely occurring technogenic processes outlined below:

a. Radical change in the conditions of interaction between the aquifer horizons (particularly with the horizons containing fresh underground waters utilised for water supply), between underground and surface waters and also interaction between active natural drainage and water-supply systems of the mining project.
b. Processes of secondary compaction of drained unconsolidated rocks and decreased compaction of sandy-clayey rocks overlying the ore horizon during the lowering of pressure of the artesian aquifer horizons, leading to deformation of the surface and not uncommonly to deformation of underground communications and surface constructions.
c. Processes of filtration deformation of benches of an open cast mine, formed during highly excessive pressures of underground waters and insufficient degree of drainage of the aquifer zones.
d. Processes of filtration-subsidence deformation of mine working during drilling in flooded zones of tectonic dislocations and so forth.
e. Technogenic processes of pollution of underground and surface waters at sites of tailings dump and also discharge of unpurified mine waters.
f. Processes of submergence of township areas under the influence of excessive ground moisture.
g. Processes of depletion of exploited reserves of underground waters through water supply etc.

To carry out detailed studies in accordance with the various processes outlined above, it is desirable to devise a plan of action, to define and execute the required specific quantum of drilling of additional hydrogeological and engineering geological wells, and to construct exploratory observation hydrometric stations and geodedic datum marks.

The principles of allocation of exploratory observation wells and the methodical implementation of *in situ* observations are discussed in Chapter 7.

2. Detailed repetitive (technogenic) hydrogeological and engineering geological mappings of the entire mining complex are conducted mainly to prepare maps and assess the evolutionary changes taking place under the influence

of technogenic processes in the geological environment as well as in the ecological status quo of the environment. The information obtained from the technogenic map might enable more basic and meaningful planning of additional arrangements for the protection of the environment.

The scale of the complex technogenic map is decided independently in each case, according to the area of development of technogenesis, degree of complexity of the problem and other factors.

Nevertheless it is essential to re-examine at this stage of exploitation of deposits of the fourth group, the possibility of adoption of other measures suggested earlier in this text for the first, second and third groups of deposits.

Thus it follows from the detailed account presented above that during the study of ore deposits of the fourth group an entire series of difficult problems arises at the stage of their exploitation, which require a large volume of fairly complex and highly important investigations. Long experience has shown that for the successful solution of the problems enumerated above relating to a mining project, it is imperative to form an independent, specialised hydrogeological service organisation empowered to frame laws of control, backed by modern technical expertise.

PART II

STUDY OF HYDROGEOLOGICAL CONDITIONS AT STAGE OF EXPLOITATION OF ORE DEPOSITS

CHAPTER 7

Composite Studies in Area of Mining

GENERAL OBSERVATIONS, PROBLEMS AND CONTENTS OF STUDIES

It was earlier pointed out that significant changes in the hydrogeological, engineering geological and geocryological conditions originate under the influence of technogenic processes during the management of the principal sectors of mining practise—mining, dumping gangue and tailings, reservoir construction and development of the township areas. At the very stage of exploitation it is necessary for the mining enterprise to conduct an entire series of specialised activities, the direction and contents of which are intimately related to the study of technogenic (destructive) conditions. Such studies are conveniently termed 'technogenic hydrogeological and engineering geological studies'.

The most prominent changes in the characteristics of the geological and surrounding environment as a whole, take place during the dewatering of mines. The entire engineering operation during direct exploitation of mine targets, including the different systems of drainage of underground waters, envisages assured safe conditions of commercial working of the deposit. However, a tendency towards degradation of the ecological situation of the surrounding environment appears during the mining operation under the influence of technogenesis. Technogenic studies on all aspects of the mining complex ought to include, therefore, hydrogeodynamic, hydrogeochemical, geodynamic, hydrological and geocryological (in rocks under permafrost conditions) investigations.

Hydrogeodynamic investigations have to be directed towards *in situ* studies at the mine site, such as the regime of levels and temperatures of underground waters, discharge from water supply wells, dewatering and drainage installations, and also studies on the regime of groundwater flow in underground mines and areas of open cast mines, the regime of interconnection between underground and surface waters and also drainage lines from the reservoirs [30, 31].

The hydrogeological information so collected has to be used to evaluate: the water-bearing capacity of the ore-bearing country rocks and the overlying supra-ore series of rocks; the effectiveness in the mine area of the influence of water supply, drainage and protective installations; residual hydrostatic pressures of mine waters formed over the mine workings; conditions of formations of cone of depression; possible development of the technogenic processes of submergence of the mine's township; improvement of hydrogeological parameters; and the basis for additional measures of protecting the mines from flooding and the reservoirs from total depletion of underground water reserves.

Hydrogeochemical investigations include: Chemical composition of underground waters and its change with time under the influence of technogenic factors in all the principal sectors of the mining enterprise; conditions of contamination of underground surface waters in the mines, reservoirs, stocks of gangue materials, tailings dump from the beneficiation plants and discharge of mine waters. Geochemical studies provide information that assists in estimations of the following: degree of pollution of underground waters, conditions of migration with time of polluted underground waters and measures to protect the surrounding environment from possible ecological degradation.

Geodynamic engineering-geological investigations comprise: The study of the conditions of formation of technogenic processes of deformation of rocks in parts of the mines (in underground mines and benches of open cast mines), technogenic processes initiated by tailings dumps and reservoir sites and potential landslide processes [23].

All these investigations have to be undertaken mainly to evaluate: the stability of rocks in underground mines and along the benches and flanks of open cast mines; stability of the dams of tailings and the slopes of gangue dumps; conditions of formation of zones of movement and collapse of rocks during mining; possible deformation of surface overparts of large reservoir structures; and possible development of natural geodynamic processes (landslides along the slopes, mud flows etc.) in the region situated in the areas of the mining enterprise.

Hydrological investigations comprise an *in situ* study of the regime of surface waters of the regional river system, situated directly over the territory of the mining establishment and also of the annual profile of the rate of flow in rivers, the water table level and quality of the underground waters. The principal direction of these investigations includes assessment of the influence of river flow on flooding of the deposit and the development of additional measures to protect the mine works from surface waters.

Experimental data emphasise the necessity for conducting periodic complex observations in those parts of the mines preserved when mining activity has been stopped (shafts, open cast mines, adits, ancient dumps of gangue, tailings dump etc.). The main direction of periodic investigations is to preserve and protect the environment from the negative influence of technogenic processes which might develop at the stage of conservation.

A series of technogenic investigations at the stage of commercial exploitation of ore deposits, as seen from the details presented, are of paramount importance and hence ought to be conducted over the various targets of study with care and precision. Learning from this very important experience, all complex technogenic investigations have to be carried out through a unified programme and unified method by the hydrogeological unit of the undertaking.

The problems enumerated above determine the course of investigations to be chosen at the stage of commercial working of the ore deposits from those listed below:

a. Detailed complex (hydrogeological and engineering geological) technogenic map of the territory, embracing all the principal sections of the mine undertaking—mines, parts of dumping grounds of gangue and poor quality ores, beneficiation plant and tailings waste from the plant, independent reservoir construction and the mine's township.
b. Detailed mapping of underground mines and areas of open cast mines.
c. *In situ* study of the regime of underground and surface waters over the entire spectrum of the mining territory.
d. Drilling works for organising exploratory and supporting network regime on the surface and in underground mines for advanced study of hydrogeological conditions, passage of groundwaters and purposes of their drainage.
e. Laboratory studies on the chemical and sanitary bacteriological composition of underground and surface waters and also physico-mechanical properties of the rocks.
f. Topographic-geodedic and survey work for plan height correlation of observation points of regime-wise observations and also *in situ* study of technogenic geodynamic processes.
g. Laboratory testing of materials.

Let us consider the contents and some methodological procedures for conducting the major kinds of complex investigations.

DETAILED TECHNOGENIC (REPETITIVE) SURVEY

The detailed complex hydrogeological and engineering geological survey is called 'technogenic' because the process involves documentation and surveying of the disrupted (technogenic) conditions formed under the influence of exploitation of the principal targets of mining practise.

Under the influence of technogenesis in the region of mining activity, there develops, at the upper part of the earth's crust a microtechnogeosphere, a detailed study of which should be directed towards technogenic survey. In this study traditional methodological techniques are applied. Usually for detailed surveys (mapping) the common scales are 1:10,000, 1:25,000 or 1:50,000, depending upon the target of the study area. As long as complex technogenic survey is required for studying and mapping the disturbed hydrogeological and engineering geological and hydrological conditions, it is essential to conduct periodic surveys not earlier than five to eight years from commencement of exploitation of the ore deposit (depending on the degree of complexity in mining the ore deposit). An integrated technogenic survey should be carried out at the mine site on the basis of a well-prepared geological map, also using available earlier literature on this aspect (at the stage of exploration of the target) dealing with natural hydrogeological and engineering geological conditions. Knowing that extensive data accumulates during investigations of various types conducted for the mining enterprises, the technogenic survey or mapping should take maximum advantage of such available information. In the same manner. technogenic surveying attempts to integrate, correlate and analyse the vast hydrogeological and engineering geological information obtained at the stages of exploration and exploitation of the ore deposit and also as a result of selected field traverses, if necessary.

From the results of the technogenic survey it is possible to compile the following maps: (a) hydroisohypse (hydroisopiez) maps reflecting the regime, and structure of the disrupted filtration current; (b) maps of distribution of various technogenic processes formed under the negative influence of technogenesis; (c) maps showing thickness and structure of the technogenic zone of aeration of the drained rocks in the mining fields; and (d) hydrogeochemical maps indicating the chemical composition and contamination of the underground waters under technogenic conditions.

Other technogenic maps can be prepared for certain mining projects, depending upon their natural characteristics. Comparing the natural and disturbed conditions in the sphere of action of the mining enterprise, it is possible to assess the degree and conditions of formation of technogenesis and also suggest, if necessary, additional measures of protection of the surrounding environment from the negative influence of technogenesis.

Considering the fact that ore deposits possess different degrees of complexity of the geological environment and commercial exploitation, technogenic mapping has to be carried out primarily during exploitation of targets of the third and fourth group according to the classification presented (see Table 10). It is during the exploitation of ore deposits occurring in intensely flooded carbonate rocks and also in targets where the thick supra-ore rock series present a multi-layered aquifer system that conspicuous changes develop in the natural conditions, and technogenesis spreads over a large area and extends to a great depth.

DETAILED SURVEY OF UNDERGROUND AND OPEN CAST MINES

This survey is indispensable during the exploitation of all ore deposits. The essential component of the survey is systematic documentation of hydrogeological and engineering geological conditions forming an integral part of all underground and open cast mines. The first hydrogeological and engineering geological documentation of the mines, as a first step of investigation, is commonly conducted at different intercepting horizons or along different benches of open cut mines. The main task of such studies includes compilation of horizon-wise hydrogeological and engineering geological plans. It is necessary to carry out mapping along these lines on a well-prepared geological base map in order to reflect in the horizon plan the character of yield of the mine waters (in the form of drips, thin jets or concentrated flows), their discharge during the opening, the elements of disposition of water-bearing fractures, stability of the rocks in the mines, appearance of geodynamic processes etc. (Figure 22).

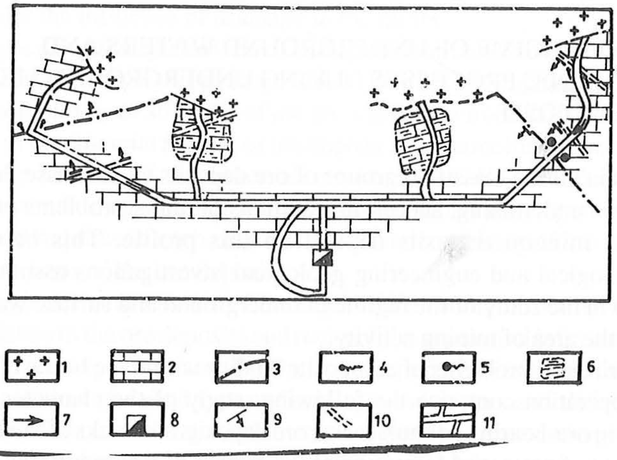

Figure 22: Geological-hydrogeological plan of working horizon of mine

Rocks: 1—igneous; 2—carbonate; 3—tectonic dislocation with zone of brecciated rocks (requires reinforcement of mines).

Discharges of underground waters: 4—highly concentrated; 5—in form of small jets; 6—in form of itensive drips; 7—direction of movement of mine waters; 8—shaft (central); 9—elements of dip of tectonic dislocations and small open fractures; 10—water-bearing

The complex mapping of the different horizons of underground mines and benches of open cast mines requires continual evaluation of the conditions and degree of flooding, to identify the basic observation points for *in situ* studies of the regime of mine waters and also to carry out operational measures to protect the mines from a high degree of flooding. Combined hydrogeological and engineering geological plans ought to be prepared for each of the drilled horizons, embracing such investigations throughout the complete system of the mine undertaking [23].

In the process of mapping of underground mining, it is very essential to conduct primary documentation of hydrogeological wells, which are driven for conducting advance studies on the conditions of management of the mines or of drainage activity in the different parts of the undertaking.

During engineering geological mapping, while engaged in primary documentation it is necessary to establish the forms of various geodynamic processes appearing in the mines: parts of intensive fracturing of the rocks; large tectonic dislocations; degree of instability in rocks, requiring continuous or partial reinforcement; appearance of rock bursts; viscosity of clayey rocks and others.

On the basis of the analysis of documentation of underground mines, the most typical parts of horizons have to be chosen for the construction of a basic and supplementary observation network to carry out *in situ* studies on the regime of mine waters and technogenic processes.

STUDY OF REGIME OF UNDERGROUND WATERS AND TECHNOGENIC PROCESSES DURING UNDERGROUND METHOD OF MINING DEPOSIT

Mines in all the classified groups of ore deposits characterise the basic profile of the mine undertaking; successful solutions of major problems of production of economic mineral deposits depend on this profile. This being so, *in situ* hydrogeological and engineering geological investigations assume primary significance in the study of the regime of underground and surface waters within the limits of the area of mining activity.

The principal problems of composite studies within the limits of the area under mining operation comprise the following: study of the character and degree of flooding in ore-bearing country rocks, ore deposits and rocks of the supra-ore zone; appearance of pattern of formation of the regime of water currents along different flanks, horizons and deposits as a whole; detection of technogenic processes (landslides, collapse or caving-in of surface, rock outbursts, sudden discharges of underground waters etc.), in underground and open cut mines; estimate of regime of activity in underground (intra-shaft) and at toes of benches (in open pits) and also effectiveness and technical components of external drainage installations [19].

Another important aspect is the study of the chemical composition and degree of pollution of true mineral waters, their possible corrosive action on concrete and metallic constructions in the mines, the nature of gas formation in mines and its hazards in commercial mining of the deposit and also evaluation of mine waters for their utilisation in domestic water supply and irrigation.

The basis of all these investigations is the well-organised network of *in situ* observation points over the mining territory.

At the present time, the scientific methodological basis of organisation and location of the observation network including preliminary studies at the stage of commercial working of the deposit prior to organisation of the network is inadequately known. Hence it is expedient to enumerate general recommendations according to the basic principle of organisation and distribution of the observation network, which might be utilised during planning of the regime [18, 30, 23].

Principle of continuity of observation network: In the process of exploration of deposits it is well known that *in situ* studies are always carried out on the natural regime of underground and surface waters. For this purpose, within the limits of the exploratory ore field, one or the other system of observation boreholes and water-meter stations is organised. A remodelling of the principal points in the observation network is highly important in the future stage of exploitation of the deposit. It should include, besides the basic observation system, continual monitoring of the regime under disrupted and disturbed conditions. The principle of continuity during such conditions involves, at the exploitation stage, studies on the character and changes in the natural hydrogeological status in the target (ore) area as a whole under the influence of drainage in the mines.

Principle of estimation of characteristics of natural conditions of study area: Natural conditions include hydrogeological, engineering geological, hydrological, the degree of complexity of structure of the geological environment and the degree of complexity of commercial mining of the deposit. This principle forms one of the basics in the oganisation of the observation network. This principle inherently contradicts the standard approach towards organising observation points over any study region and requires in each case a creative understanding of the features of the natural conditions of the ore deposit.

Hydrogeological characteristics of the object under study characterise: degree of water abundance in the ore deposits and rocks of the supra- and infra-ore-bearing series, conditions of disposition and distribution of aquifer horizons and complexes, chemical composition of varied types of underground waters and their corrosive action; and conditions of recharge and interconnection between underground and surface waters. Together, these characteristics determine the sources of flooding in mines (underground and open cast), the choice of corresponding schemes of drainage of the deposits and measures of protection of the mines from floods and the surrounding environment from technogenesis. In the final analysis these facts serve as the basis for the effective disposition of a special observation network for conducting *in situ* hydrodynamic and hydrogeochemical investigations.

Engineering geological characteristics of the target area under study characterise mainly the degree of stability of rocks in mines, their potential for development of technogenic and hydrodynamic processes at the stage of commercial exploitation of ore deposits and also possible changes in the properties of rocks under disrupted conditions.

This group of engineering geological characteristics determines the choice of measures in mines to protect them from deformation, the need for adopting additional measures of local drainage in order, for example, to improve the stability of benches of the banks of open pit mines etc. As in the previous case, these factors might also form the basis for planning observation points and conducting *in situ* geodynamic studies.

The complexity of structure of the geological environment in some ore districts can also be determined by the character and degree of emission of natural gases, mainly those that are harmfully toxic and chemically active. The presence of gases in the study areas requires additional means of protection of mines from toxicity and corrosion and also defines additional *in situ* studies. The character of interlink between underground and surface waters and likewise the aquifer horizons, constitutes the most prominent factor characterising the hydrogeological peculiarities of a deposit and decide the conditions of distribution of observation points. Timely study of these factors at the stage of exploitation of ore deposits allows evaluation of the effectiveness of the adopted system of drainage and measures of protection of the mines from flooding. A tentative scheme of multi-layered arrangement of observation wells is presented in Figure 23. This scheme facilitates study of the hydrogeological characteristics of the deposit. Each aquifer horizon ought to be provided with an observation well.

With regards to planning geodynamic points over the area of the deposit for *in situ* observation, taking into account the characteristics of the engineering geological conditions, it is possible to envisage a scheme of their location entirely from the mine-surveying practise of the enterprise, which necessarily conducts systematic observation of the deformation of rocks in the shaft mine as well as on the surface. Instrumental observations on the deformation of the surface during underground and open pit mining of the deposits are carried out by means of a system fixed along the profiles of the geodetic benchmarks.

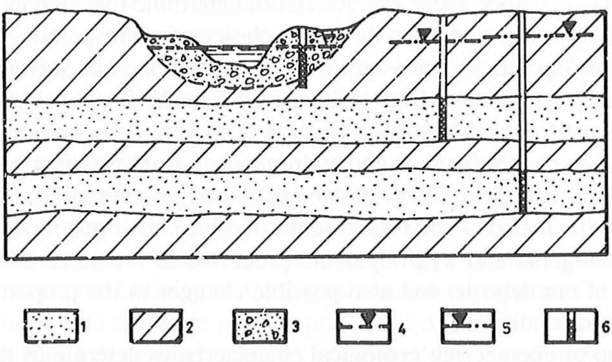

Figure 23: Model diagram of multi-layered disposition of observation wells

Rocks: 1—aquifer; 2—weakly permeable; 3—unconfined alluvial aquifer.

Level of waters: 4—ground; 5—artesian; 6—observation wells fitted with filters.

Mining engineering principle: This principle applies essentially to both underground and open cast methods of mining ore deposits. These methods and their associated problems of complex 'on the site' investigations predetermine the mode of organisation of the observation network. For example, during the working of ore deposits by the open cast method, the principal problems of *in situ* complex studies are assuring timely supervision of the stability of the banks of the open cast, prevention of their deformation, estimation of the effectiveness of drainage etc. For a successful solution to these problems, the observation system should be situated directly over areas of open cut mining (for estimation of intra-open cast pumping of water), the most flooded parts of the benches, and also outside the open cast mine to study the regime of work on the external drainage constructions.

The underground method of mining has its own peculiar observation system and means for solving certain hydrodynamic problems. During intense flooding of ore deposits of the third and fourth groups, according to the degree of complexity of mining (vide Table 5), it may be necessary (in addition to studies of the regime of water currents and conditions of development of cone of depression) to control the regime of residual (conserved) hydrostatic pressures that form during mining of the principal working horizons under the influence of the filtration heterogeneity of water-saturated rocks. Large residual pressures commonly cause sudden outbursts of mine waters in underground mines. These processes lead to flooding of the mines and subsequently to disruption of the smooth functioning of the enterprise, necessitating laborious works to reduce the hazard. All these reflect the need for organising a special observation system both on the surface as well as in underground mines.

Hydrodynamic principle: This relates to structures and boundary conditions of filtration currents that form around mine areas during drainage operations. The structure of the filtration current obviously reflects the character of deformation in space. In a number of cases, during the drainage of open cast and underground fields under dislocated conditions in the aquifer horizon, a plane-radial (rarely plane-parallel) structure of current forms. Within the limits of development of a cone of depression, the filtration current has to be considered a singular hydraulic link system. The distinct influence on the structure of the currents within the limits of the cone of depression brings about planar inhomogeneity of the geofiltration medium closely connected with meteorological and structural geological features of the rocks of the aquifer series. The planar heterogeneity in permeability might retain a continuous character or be piecemeal in distribution. In the latter case the entire field of currents must be considered as though composed of different zones and each zone has to be treated as homogeneous. Changes in parameters along the borders of the zones are spasmodic. The planar heterogeneity of the layer is very well reflected in the conductivity map. For a layered cross section enclosing the ore deposit, heterogeneity through a permeable medium in a vertical direction is quite characteristic, particularly when an inter-stratification of water-bearing (aquifer) and slightly permeable (separator) rocks is encountered. According to this premise, due to the conspicuous difference in the permeability of the water bearing and adjacent separating layers, movement of the liquid flow in non-permeable layers has to be considered only in a vertical direction, while in horizontal beds the horizontal character of filtration must be reckoned with.

With regard to boundary conditions of the filtration currents in the plan, these reflect the conditions of mutual relations of water-bearing horizons with the surrounding environment and at the first instance with such factors as hydraulic link with surface waters (river, lake, pond). A study of the form and regime connecting water-saturated rocks with surface waters forms one of the important divisions of the complex *in situ* technogenic studies. Such a study envisages special observation points on the boundaries of the layer.

Thus the hydrodynamic principle fairly sharply defines the planning and location of the observation network to carry out *in situ* complex studies on ore deposits at their stage of exploitation: in plan—a radial diverging (centrifugal) system and section, a multi-layered system of observation points.

In each specific study area the distribution of the observation network has to be based on the basic principles presented above.

In conclusion, we suggest some methodological recommendations for planning the regime of the observation system, which should usefully take into account the following salient points: (a) in underground mines—*in situ* and removable overflow weirs and observation borewells; and (b) on the surface—borewells, water-gauge stations along the rivers and geodetic bench marks. Systems of observation points can be divided into two groups on the basis of their objectives: basic and auxiliary or supplementary.

Basic regime network: This forms an indispensable, minimum and long-standing network of observation points for *in situ* complex studies of the regime; the information collected through these studies allows timely solution of hydrogeological and engineering geological problems appearing in each specific study area at the stage of its exploitation.

Considering the purpose as a whole, the basic observation network, in engineering relations, should involve cost-oriented machinery that will ensure trouble-free and continuous use for a long time.

Under these conditions it is possible to obtain the primary qualitative hydrogeological and engineering geological information necessary.

In all sectors of the mining enterprise it is *necessary to organise a unified basic network of observation points.* Such a network comprises:

1. A system of observation borewells proceeding from the surface into the mines in order to study the regime of the level of groundwaters, their chemical composition and also discharge of various drainage establishments; observation wells distributed in parts of the reservoir constructions between the water supply and drainage installations (to study the regime of water withdrawal and conditions of interaction between them) and also wells situated in the regime of industrial repository from the beneficiation plant (tailings dump) in order to study the regime of advancing front of possible chemical contamination of underground waters.

2. A system of observation points (stationary overflow weirs, hydrometric stations etc.) situated directly in the underground mines and on the surface to enable studies on the regime of mine waters, flow rate of springs and underground waters.
3. A system of engineering geological points of observation (geodetic benchmarks etc.) providing information on the regime of geo-dynamic processes in the area of mining activity (both surface and subsurface), water supply installations and tailings dump.

Thus the basic regime network is inherently complex in character and *in situ* investigations have to be conducted jointly by geological, hydrogeological and mine survey teams.

Supplementary network: This should comprise timely and functional observation centres (borewells, weirs, geodetic benchmarks etc.), well equipped for periodic study of the various targets of the project, as required by the appearance of certain details, characterising the peculiarity or complexity of hydrogeological and engineering geological conditions of exploitation. For example, with the help of indications of some complex structures of filtration currents which form in the field of drainage in mines, it may appear necessary to bore on-the-surface observation wells in addition to the basic network, data from which would help in precise mapping of the hydroisohypse. This map is essential for solving a series of practical problems (determination of the direction of major currents of underground waters towards mine areas, study of conditions of interaction with the surrounding environment etc.).

The supplementary or auxiliary network, as the term implies, is only additional to the working basic network and is organised in cases of emergency or necessity. After completion of the necessary investigations from observation points, the auxiliary system of wells can be dismantled without detriment to the quality of the studies to follow.

A study of the regime of underground waters and geodynamic processes during underground mining of ore deposits ought to be integrated from two related directions of investigations, which are carried out both in the mines and on the surface.

The following observations have to be carried out during on-the-spot studies of the regime of underground waters and technogenic processes: (a) on the regime of water currents in the mines, on the temperature regime and chemical composition of mine waters along different flanks of the shaft area, different horizons and also within the limits of shaft mining as a whole; (b) on the regime of residual (conserved) hydrostatic pressures of underground waters over the purification plants and mining at preparatory and exploitation stages of the horizons; (c) observations during boring of advance hydrogeological exploratory wells (observation for discharge, chemical composition and temperature) introduced directly into underground mines in order to lower residual pressure and for drainage of underground waters; (d) on the chemical composition, corrosive action and sanitary conditions of mine waters discharged to the surface; (e) on the regime of the independent water supply pipeline installed directly in underground mines for the purpose of organising domestic drinking water supply utilising mine waters (observation of discharge, chemical composition and temperature of mine waters); (f) on the regime of underground waters directly over the surface in the sphere of influence of shaft water pumping, external drainage installations and also areas skirting the mines; and (g) study of technogenic processes formed on the surface including the organisation (if necessary) of *in situ* geodynamic observations on the deformation of the surface and of surface installations.

This short account depicts the characteristics of the principal kinds of intensive studies recommended mainly during the exploitation of ore deposits of the second, third and fourth group, which are characterised by complex and extra-complex structures of the geological type and complex conditions of mining. Commercial working of these deposits is accompanied by special methods of drainage, individual application of protection of mines from flooding and negative influence of technogenic processes in the surrounding environment. Under such conditions, the need arises for such composite investigations. As for ore targets of the first and partly the second group, characterised by simple conditions, flooding is less intense and its area of influence limited over the surrounding environment. Hence the

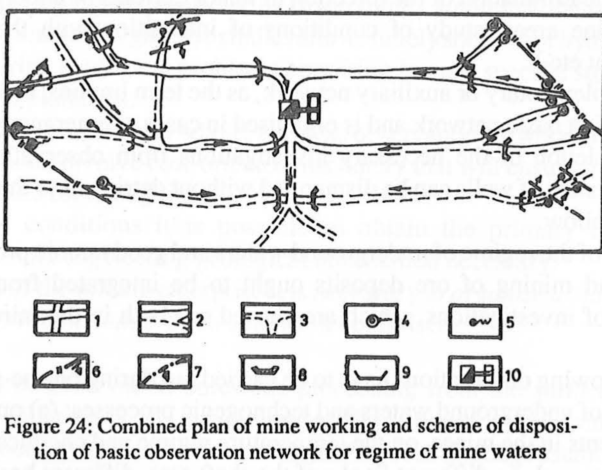

Figure 24: Combined plan of mine working and scheme of disposition of basic observation network for regime of mine waters

Mining in flooded horizons: 1—third; 2—fourth; 3—fifth; 4—concentrated discharge of underground waters, with discharge over 1,000 m^3/hr; 5—jet flow of underground waters with discharge of more than 5-10 m^3/hr; 6—tectonic dislocation with dip direction; 7—open small water-bearing fractures and their tilts; 8—main points of observation network (overflow weirs); 9—supplementary point of observation, 10—shaft with reservoir and pumping station. Arrows indicate direction of flow of mine waters.

composition and content of the complex studies of the regime of underground waters may be greatly simplified: (a) drainage of the deposits of the first two groups is usually carried out by simple methods under the protection of intra-shaft and intra-open cast water pumping and (b) the sphere of influence of shaft pump in changing the characteristics of the surrounding environment is very much limited, to say an area of not more than 3 to 4 km^2. Experience in commercial working has shown that complex hydrogeological and engineering geological studies at the stage of exploitation of deposits related to the first group are conveniently and directly incorporated in the components of the geological survey of the mining enterprise.

Let us examine the methodological procedure of conducting *in situ* studies within the limits of mine workings. The exploratory observation network directly in underground mines ought to be provided with a stationary spillway construction, whereas the supplementary observation network should have dams that can be dismantled. Figure 24 presents a tentative scheme for disposition of the regimes of basic and supplementary networks of one working mining establishment. This deposit belongs to the series of intense flooding of limestones and according to the degree of hydrogeological complexity, its working relates the deposit to the third group under the classification discussed above. Such a network distribution and

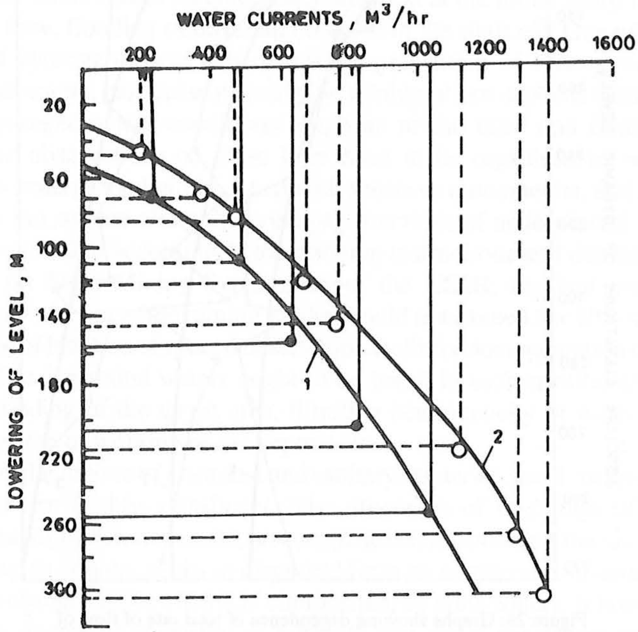

Figure 25: Graphs showing changes in rate of water flow with lowering of level during open cast working in western (1) and far-western(2) deposits.

data from investigations of the regime were helpful in assessing different degrees of flooding of mines and establishing the significance of specific water currents according to crosscuts and adits (water current for a 100 metre long drilling), which are divided along the eastern and western flanks of the deposit and possess different degrees of propensity for flooding, accordingly, different measures to protect the mines from flooding were adopted.

To recommend a uniform rate of measurement of discharges of mine water currents along the main network is very different, since it is essential to study

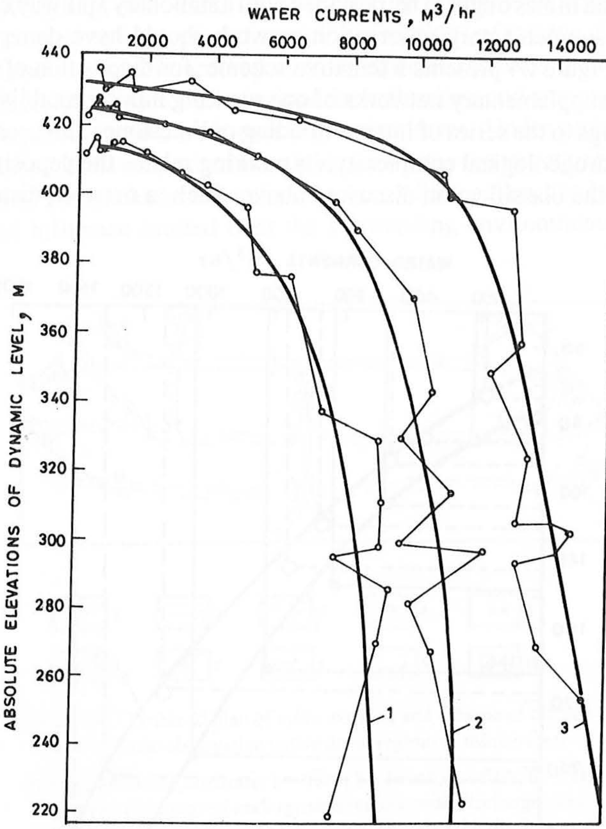

Figure 26: Graphs showing dependence of total rate of flow of water on lowering levels of underground waters during underground mining of deposit

Mean rates of flow of waters: 1—minimum; 2— intermediate; 3—maximum.

simultaneously the hydrogeological characteristics of each of the sources of flooding in the mines, their regime etc. For an analysis of such a regime along the main network, the rate of observation might be once in 10 to 15 days. Chemical analysis and estimation of bacteriological sanitary composition should be carried out once or twice in a three month period.

Analysis of hydrogeological data collected through many years of study of the regime of mine waters strongly suggests a pattern of general rate of flow of water in different horizons, which in turn depends upon the depth of working of the deposit, to which is related the gradual lowering of the level of underground waters. Such a dependence, for example, has been amply demonstrated by conditions in both the open cut mine and the underground mine (Figures 25 and 26). This data can be utilised for prognostic estimates of water flow at greater depths by projecting it to horizons to be worked in the future through graphic-analytical extrapolation (prognostic estimate of rate of flow of water by hydraulic method).

In situ observations on the regime of residual (conserved) pressures of underground waters over the reference points of the working and preparatory horizons, very significant for estimating safe conditions of working ore deposits.

Residual pressures often form during the drainage of ore-bearing carbonate country rocks and are attributed to the heterogeneity of their filtration. Sudden outbursts of underground waters in mines originate under the influence of excessive pressures and often lead to an emergency situation at the mine: sharp increase in the rates of flow, flooding of different horizons in the shaft etc. One of the major problems of hydrogeological expertise is the prevention of sudden outbursts of underground waters, particularly during the mining of ore deposits situated under complex hydrogeological conditions (deposits of the third and fourth group). Regime-wise observations on these lines have to be organised on wells sunk directly into underground mines, fitted with sensitive monometers, and also wells drilled from the surface along the principal directions of underground workings. Let us remember that according to the standing instructions and directions of the Committee on State Mining Supervision of the USSR, residual pressures of underground waters over the mining works should not exceed $3 \times 10^5 - 4 \times 10^5$ Pa. The principle of location of special observation wells for documentation of residual pressures of underground waters ought to be based in each specific case on the degree of flooding of the target area, filtration heterogeneity of water-saturated rocks, the system of working of the deposit etc.

Studies on the regime of chemical and sanitary-bacteriological compositions of mine waters are highly significant. The processes of oxidation of sulphide mineralisation of pyrite, marcasite, arsenopyrite etc. constituting the ore body and also occurring in country rocks in dispersed form or as discrete clusters, result in very intense changes in the chemical composition of mine waters. It is essential to establish the degree of corrosion of concrete and metal constructions by mine waters. Commercial working of some ore deposits in the USSR are well known examples of the highly corrosive action of mine waters on the pumping installations of pumping wells, which led to partial discharge from the system and to disruption of continuous drainage activity.

An *in situ* study of the regime of water flows in mines has to be accompanied necessarily by systematic observations on all the working pumping stations of the mine undertaking: factual data on their yield, correspondence of general yield of pumping stations to increased yield predicted for different horizons, as well as yield from the mine field as a whole, etc. It is beneficial, obviously, to conduct such investigations jointly with the chief engineer of the undertaking. Joint studies along these lines ought to form the basis for bettering and later reconstruction of the general scheme of the mine's pumping machinery and also ensuring trouble-free performance of all the drainage installations in the mine.

Engineering geological observations should also be organised side by side with an *in situ* study of the hydrogeological conditions of all horizons of the mine. The following geodynamic processes appear most often in mining constructions: (a) swelling, viscosity and heaving of clayey and clay-like rocks; (b) collapse of roofs in mines during mining in flooded zones of crushed tectonic dislocations or zones of intense fracturing; (c) sudden outbursts as viewed from the working space of accumulated pulp-like mass in the mining horizon during exploitation of the ore deposit associated with metamorphic, effusive and clayey rocks; and (d) rock bursts and other processes.

During studies on the general conditions of deformation of rocks of the ore deposit, it is essential to bear in mind that under the influence of underground mining of the deposit a zone of slides and commonly rock collapses is formed in the massif. These zones of technogenic deformation spread gradually, first in the rocks immediately overlying the region of extraction of the ore-bearing rocks and later very often develop upwards and are traceable even up to the surface in the form of bench-collapses, sinks, widening of joints etc. In order to study these forms thoroughly, it is useful to organise *in situ* observations of the regime of development of technogenic processes after a mine survey and on the basis of detailed mapping. Experience has shown that these processes develop very slowly over a long period of time (even after the conservation stage of the mine and its environment) and normally result in the degradation of the landscape and the environment. A system of observation geodetic benchmarks is fixed along the main profiles, comprising zones of sliding and brecciation of rocks, and also the adjoining virgin areas, by means of *in situ* studies on engineering geological processes at the mine area.

As observed earlier, in the process of exploitation of certain ore deposits, natural gases appear. This situation somewhat complicates the commercial working of the deposits. In these cases additional safety measures need to be adopted. The cases cited above by no means exhaust all the ore deposits in which natural gases are encountered. While conducting commercial exploration of deep-lying ore horizons in working mines, systematic probing in the basic network of wells for possible contents of natural gases in the underground waters is absolutely essential.

Study of the regime of underground waters directly through wells drilled from the surface forms an integral part of a large complex of *in situ* regimes of observations. Such studies have to be completed simultaneously through a single method in all the observation points of the system of the basic network, observation borewells and water-meter points established in the underground mines, across

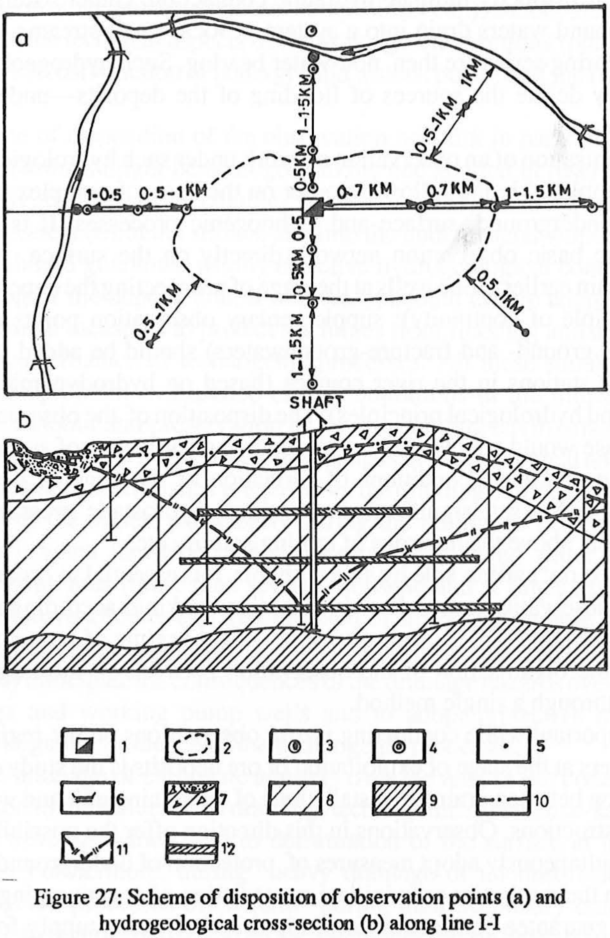

Figure 27: Scheme of disposition of observation points (a) and hydrogeological cross-section (b) along line I-I

1—shaft; 2—outline of area of mining; 3 and 4—observation wells of main network: 3—on underground waters in ore-bearing rocks; 4—on underground waters in quaternary deposits; 5—observation wells of auxiliary network; 6—hydrometric stations on rivers; 7—quaternary formations; 8—ore-bearing country rocks; 9—rocks beneath ore-bearing series (non-water-bearing); 10—level of underground waters; 11—cone of depression; 12—underground mine levels or drives.

river channels or springs. Figure 27 shows a tentative scheme of allocation on the surface of the principal and subsidiary networks over an ore deposit which, according to its natural conditions belongs to the second group (see Table 5). Three types of underground waters are distributed in such an environment: groundwaters of alluvial, sandy-pebbly deposits and sandy-clayey deluvial-proluvial formations, and also fracture-groundwaters of ore-bearing country rocks of the Palaeozoic era. The levels of all types of underground waters remain at one single elevation, which suggests their distinctly intimate hydraulic connection. Under natural conditions the underground waters drain into a system of local small streams. Rocks of the infra-ore-bearing series are then non-water bearing. Such hydrogeological conditions sharply define the sources of flooding of the deposits—underground and surface waters.

The organisation of an observation network under such hydrological conditions is better completed in the following order on the basis of complex studies of the regime of underground, surface and technogenic processes. It is necessary to establish the basic observation network directly on the surface, which should include certain earlier probe wells at the stage of prospecting the deposit (according to the principle of continuity); supplementary observation points (borewells—divided into ground- and fracture-groundwaters) should be added later and also hydrometric stations in the river courses (based on hydrodynamic, mining engineering and hydrological principles). The disposition of the observation network in such a case would enable study of the degree of influence of surface waters on the flooding of mines, conditions of formation of the cone of depression and technogenic processes, significance of residual hydrostatic pressures of underground waters above the horizons of mining activity etc.

As pointed out earlier, side by side with this, it is essential to organise the basic network of observation points directly into mine workings according to the scheme illustrated in Figure 24. The complex study of the regime of underground waters as well as the organisation of the observation network on the target should be conducted through a single method.

Most important while conducting *in situ* observations on the regime of underground waters at the stage of exploitation of ore deposits is the study of conditions of interaction between drainage installations of the mining unit and working water supply constructions. Observations in this direction offer the possibility, if necessary, to simultaneously adopt measures of protection of underground waters from depletion in the reservoirs or to initiate construction of new pumping installations in order to guarantee continuous domestic drinking water supply for the mining establishment.

In situ observations on the exploitation of external drainage constructions form an integral part of the large complex of investigations on the regime of underground waters. They are almost always carried out during the underground mining of ore deposits. It was observed earlier that external drainage constructions might be built in the form of drainage junctions, consisting of groups of interacting borewells and porous filters, introduced from the surface into the ground along the route of special underground drainage workings or along a linear series of drawdown wells. The problem *in situ* hydrogeological investigations of external drainage constructions face is controlling their effectiveness and ensuring continuous work on drainage intersections. In this connection, the regime of observations, besides providing the major documentation of the principal hydrogeological parameters (discharge wells, levels of underground waters, chemical composition etc.), should also provide for supervision of the technical aspects of the drainage intersections (pumping operation, possible corrosive action of underground waters, position of the filters in wells etc.).

The scheme of disposition of the observation network in parts of the external drainage installations might be analogous to the one applied in reservoir installations. Similarly, the data from complex studies of the regime of the mine and the underground waters (from the surface and into the underground workings) in each distinct case should guarantee wholly effective hydrogeological control for commercial mining of the deposit and, if necessary, should ensure adoption of additional operational measures to protect the mines from flooding and an evaluation of the negative influence of technogenic processes. All these should ultimately solve the basic problem—assurance of safe conditions in the mines, increased productivity of labour and preservation of the surrounding environment.

The most conspicuous influence on the changes of the geological and surrounding environmental characteristics is exerted by the draining activity of the drainage constructions of the mines, particularly during the mining of deep ore horizons (800-1,000 m), when the depressed surface of the lowered water table might encompass a large area (more than several thousand and at times several tens of thousands of square kilometres). The problem of investigation here is mainly to forecast the possible development of the region under the cone of depression, simultaneously anticipate the consequences of the drainage hazards over the regime of the springs and working pump wells and to adopt protective measures to minimise the negative influence of the technogenic processes.

During the drainage of carbonate aquifers over the area of the cone of depression, in addition to the influence of draining, technogenic subsidence-karst processes may also develop, which lead to deformation of the surface in the form of collapse-sinks. Furthermore, during heavy drainage of unconsolidated aquifer rocks, technogenic processes often form during their secondary consolidation. These give rise to compaction of the rocks, sagging of the surface and deformation of underground communications. For example, under the influence of processes of secondary consolidation, in one ore deposit porous filters extending through a sandy-pebbly aquifer deposit to a thickness of 120 m were totally deformed.

During exploitation of deposits technogenic processes appear most active along the zones of movement and crushing of rocks within the mining area, as shown by the formation of collapse-sinks on the surface, open fractures, fissures, subsidence of the surface along cracks in a compact surface etc. There are even instances of these processes being evident despite filling the stopes with muck. In all probability, to carry out cent per cent effective filling of the stopes is practically impossible. The relatively simple and objective method of forecasting geodynamic technogenic processes in the zone of crumbling and adjacent areas is the method of natural-experimental investigations, based on setting up both on the surface and in the mines, *in situ* mine survey-cum-geodetic technogenic observations. With this in view, it is necessary to organise a basic network of different kinds of geodetic benchmarks of observation stations. Instrumental investigations have to be conducted jointly by the hydrogeological and mine survey departments. Experience has also revealed that it is desirable to determine the disposition of basic geodetic stations of observation through a system of main profiles, which lie in the zone of displacement of rocks, with adjacent areas little affected by deformation. Procedures for instrumental observations along the basic network of geodetic profiles have been discussed in depth in handbooks and manuals of mining methodology.

As regards other technogenic geodynamic processes taking place directly in the underground mines, their study envisages large-scale mapping (documentation) of zones of deformation and instability of the rocks. Such mapping can conveniently be undertaken using the prepared geological map as the base. Taking into account the general geological-structural and mining engineering conditions, the study area, the detailed documentation would throw light on the reasons of formation of the processes and implement suitable measures to protect the mines from deformation.

Experience with exploitation of ore deposits in the USSR has clearly shown that in some deposits technogenic processes such as rock pressures develop during mining. For study and local prognosis of rock pressures during mining of ore deposits, special equipment and methodology have to be employed to document basic parameters and probable indicators of rock pressure hazards in the mining operation (equipment BP-18 and MGD). The main indicator of a rock pressure hazard is the coefficient of brittleness of rocks, which is obtained during the natural course of investigation. While analysing the significance of data on the coefficient of brittleness of rocks in more than five areas pinpointed for inspection, it was found that all were prone to such pressure hazards. Microseismic zoning of different horizons might provide useful results for prognosis of rock pressures on the basis of detailed mapping of the dynamic impulses in mines and also the anomalies indicative of significant pressure-hazard zones of blocks.

It is prudent to emphasise the importance of organising studies of complex hydrogeological conditions of ore deposits of the fourth group (vide Table 5). The complexity of commercial working of this group of deposits is evident when we peruse the cross-section of rocks overlying ore-bearing series and those containing ore bodies in which the distribution of aquifer horizons in a somewhat layered arrangement is typically conspicuous. It is, therefore, often necessary during the exploitation of the deposit to first employ a preliminary and then constant dewatering of mine waters for consumption. In the KMA region, simultaneous with dewatering, fresh underground waters have been used intensively for complete centralised water supply to the cities and also for agricultural purposes. These characteristics add to the earlier described principles of planning the disposition of a basic observation network for complex studies on the regime of underground and surface waters. A multi-layered disposition of observation wells across the aquifer complex is inevitable. Such an arrangement of wells permits the study of conditions of interaction between aquifer horizons, the influence of drainage in mines on their regime, probing of the sources of flooding of the deposit etc.

STUDY OF REGIME OF UNDERGROUND WATERS AND TECHNOGENIC PROCESSES DURING OPEN CAST MINING OF ORE DEPOSITS

The complex study of the regime of underground waters and technogenic processes, at the stage of mining of ore deposits through the open cast method, is generally more varied in character. In this context it is pertinent to examine the contents of *in situ* investigations for each of the earlier distinguished groups of ore deposits according to the degree of complexity of hydrogeological and engineering geological conditions (vide Table 5). The nature and contents of the complex investigations involved in the exploitation of ore deposits of the first group are very well defined by the simple structure of the geological environment and equally simple conditions of commercial mining. The geological-hydrogeological setting of the ore deposits of the group under discussion is highly favourable for the drainage of open cut mines by a system of open-interior open-pit drainage, providing safe conditions of mining (the rocks of the deposit are usually quite drainable and the benches of the mine highly stable, not changing their properties during the drainage operation). Case histories on the mining of large segments of ore deposits in the USSR belonging to the first group, fully support the high efficacy of an open drainage system. Under these conditions complex studies at the stage of open cast mining have, however, to be undertaken along these major directions: (1) systematic (planned) study of conditions of flooding in ore-bearing rocks and ore deposits and also technogenic processes, including hydrogeological and engineering geological documentation along the benches and flanks of open cast mines; (2) *in situ* study on the regime of general water currents in the open pit; and (3) *in situ* study of the composition of mine waters and the influence of their discharge on the surrounding environment [2, 23, 24].

The studies outlined first are essential to prepare the geological base through systematic hydrogeological and engineering geological documentation, and preparation of plans for all the benches of the mine. Such studies are jointly carried out by the geological survey department of the mine undertaking. For documentation of the general rate of water flow in the receiving sump of the open mine, a measuring instrument (recording water meter etc.) that can provide uninterrupted information should be fixed at the site.

To study the conditions of formation of the cone of depression in the plan and to estimate its draining influence during dewatering of open cast mines on the surrounding environment, it is compulsory to maximise the earlier drilled (at the stage of prospecting the deposit) prospecting wells for basic observations. Drilling special observation wells over the field of development of the cone of depression in the first group of deposit is not at all desirable. Many instances have shown that the cone of depression during the drainage of open cast mines of deposits of the first group does not develop over an area larger than 1.5-2.0 km^2. However, a feeble formation of technogenic processes is evident. The study of the chemical composition of mine waters is usually conducted by the method of sampling for completion of laboratory analysis. For simple hydrogeological conditions sampling waters for analysis once or twice in a three-month period suffices.

Conducting intense studies introduces certain complexity during open cast mining of ore deposits situated below the base level of erosion, when a distinct hydraulic link is observed between surface and underground waters. In such case it is necessary to fully equip the hydrometric observation posts in the river valley in order to estimate the degree of influence of surface waters on the flooding of deposits and, if need be, measures can be adopted to drain waters to protect the open cut mine from surface waters. Figure 28 presents a tentative scheme of disposition of basic observation posts in one ore deposit. This deposit belongs to the intrusive rocks category and is characterised by little water abundance. For *in situ* observations on the regime of underground waters of an open cast mine, wells were utilised for probing at the stage of exploration of the deposit. The dispositions of the hydrometric stations adopted directly in the adjacent valley (station Nos. 1 and 2) permit assessment of the degree of infiltration loss of surface waters resulting from the draining influence of the mine's pumping operation. At the stage of mining of the deposit, say up to a depth of approximately 120 m, where the influence of surface waters was never present, the general rate of flow in the open cast mine reached an average of 50-60 m^3/hr. While deepening the open cast mine below the base level of erosion, the interlink between surface and underground waters was re-established increasing the rate of flow to 150-200 m/hr. If with further deepening of the mine the general rate of water flow should also increase, there will be an immediate need to isolate the surface waters of the river from the zone of their influence on the open cast mine. The frequency of observations on the regime of the surface and underground waters in such a case should be increased to once in 10 days.

The complex studies at the stage of exploitation of deposits of the second group are determined by the characteristics of their natural setting. The geological environment of the deposit is characterised by complex conditions, in particular engineering geological characteristics (high degree of fracturing of rocks, deformation of slopes in open cast mines in the form of landslides and fissures). Studies on open cast mines reveal the prominent influence on the stability of semi-sheared rocks along the slopes of benches of open cast mines caused by rain and meltwaters.

This requires protection of the mines from these sources of flooding. The complex geological environment envisages the essential application of engineering measures through preliminary- and exploitation-stage drainage of mines as a whole, including drainage of ore deposits. Above all, drainage by means of underground drainage of mines introduced into the open cast set-up is adopted. All

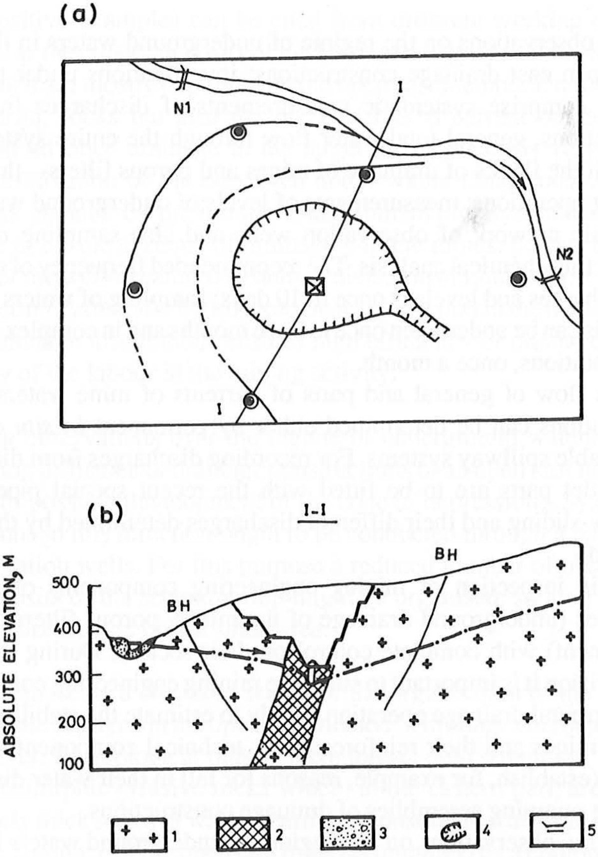

Figure 28: Disposition of basic observation network during open cast mining of an ore deposit

1—intrusive country rocks of ore-deposit; 2—ore-bearing vein formation; 3—sandy-pebbly alluvial deposit; 4—outline of open cast mine area; 5—hydrometric observation stations; 6—intra-open cast mine pumping station; 7—observation well; 8-hydro-isohypse; 9—cone of depression; 10—sump and intra-open cast observation station.

these together determine the composition and contents of the complex studies of the regime of underground and surface waters, and also the study of the technogenic processes during the prolonged period of exploitation by the stripping method, of the second group of ore deposits. Finally, the programme of intense studies should also incorporate, in full, details of the work listed earlier for the study of the first group of ore deposits.

The following divisions of investigations should also be included in the programme of studies.

1. *In situ* observations on the regime of underground waters in the system of intra-open cast drainage constructions: investigations under this category should comprise systematic measurements of discharges from drainage installations, general total water flow through the entire system, and also through the flanks of drainage of mines and porous filters—through all the drilling operations; measurements of levels of underground waters through the basic network of observation wells and also sampling of waters for conducting chemical analysis. The recommended frequency of measurement of discharges and levels is once in 10 days; sampling of waters for chemical analysis can be undertaken once in three months and in complex hydrochemical conditions, once a month.

   The flow of general and parts of currents of mine waters in drainage installations can be determined either by permanent *in situ* or temporary removable spillway systems. For recording discharges from different filters the outlet parts are to be fitted with the recent special pipe bends with cudlow-sliding and their different discharges determined by the volumetric method.
2. Periodic inspection of mining engineering components of the drainage facilities (underground drainage of the mines, porous filters and pumping equipment) with complete control on their sectors. During the process of supervision it is important to study the mining engineering component of the underground drainage operation (firstly to estimate the stability of the rocks in the mines and their reinforcement), technical component of the porous filters (establish, for example, reasons for fall in their water discharge etc.), and the pumping assemblies of drainage constructions.

   In situ observations on the regime of underground waters in the system of drainage constructions and in the sphere of their influence on the surface should be subject to the solution of the principal problem—*estimate the effectiveness of drainage of the open cast mine area as a whole or its most complex parts,* based on implementing additional drainage measures or intensifying existing ones. This is very important for assuring advance drainage of open cast mines of ore deposits and safe conditions for the commercial working of the deposits. While ensuring efficiency of the drainage of open cast or underground mine areas, it is imperative to understand those technogenic hydrogeological conditions during which the given regime of drainage in the mines and ore deposits (essentially lowering of the groundwater table) thoroughly supports safe conditions, either during excavation of the mine or during exploitation of the ore body, thus accounting for high productivity. If these conditions during exploitation of the drainage constructions are not fulfilled, then for some reason or the other the system will not function effectively.

Some positive examples can be cited from different working deposits of the USSR, such as the copper deposits of the Urals and deposits of the KMA and other regions, which are mostly exploited by the open cast method. Drainage of not only the ore-bearing rocks but also the ore horizons is carried out by a system of underground advance drainage in the target areas, which is very important for successful excavation of the ores even under winter conditions. A regime-wise network was planned by the mining establishments for systematic and complex supervision of all the systems of drainage—in the mines, porous filters and also inspection of the well-organised system of diversion of rain waters etc. At the same time conducting systematic hydrogeological supervision in the deposit on the work related to drainage installations ensures high efficiency of drainage and also high productivity of the labour in the mining activity.

3. *In situ* observations over the regime of underground waters in the area of draining influence of drainage constructions of an open cast mine (within the field of possible development of the cone of depression). Systematic investigations in this direction ought to be conducted through a basic network of observation wells. For this purpose a reduced number of observation wells of deposits of the second group might be organised, so long as the cone of depression covers only a small area.

Figure 29 presents a chematic sketch of the organisation of the main regimal network at a site engaged in the open cast method of mining. This deposit is situated close to a river. Its geological make-up comprises ore-containing, weakly water-bearing metamorphic effusive rocks which, in the eastern part, are covered by a comparatively thick series of water-bearing unconsolidated alluvial formations (up to 30-40 m). Drainage of the open cast mine is completed by a combined technique: by means of an internal linear series of level-lowering (pump) wells aligned along the left bank of the river and also by intra open cast water pumps.

The main observation network was organised on the basis of utilisation of earlier drilled geo-exploration wells, which emphasises the preservation of the principle of continuity during the study of a disrupted regime of underground waters in unconsolidated alluvial formations. For studies of the influence of drainage on the surrounding environment, special wells were bored; on the left tributory of the river two hydrometric obsrvation posts were established to study the regime of surface waters and to assess the influence of river waters on the flooding of the open cast mine. Such a setting of the basic observation network and also systematic observations of the working of the drainage lines of the water-level lowering wells and intra-mine pumping emphasise the need for estimating the sources of flooding at all places, the effectiveness of protection against flooding and guarantee safe conditions in the mining of the ore deposit. The frequency of measurement of levels

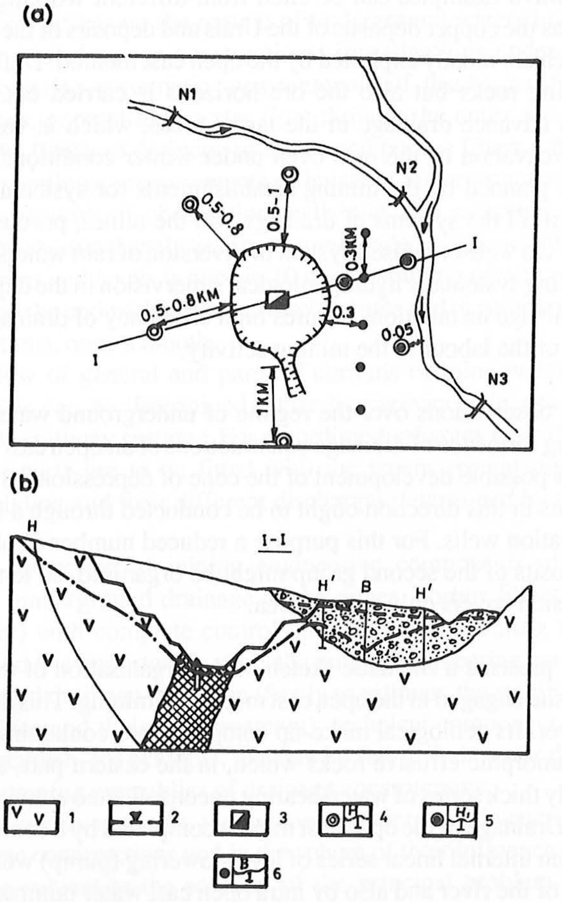

Figure 29: Scheme of disposition of main observation posts during open cast mining of deposit

1—ore-containing effusive country rocks; 2—level of groundwater; 3—advanced pumping station; 4 and 5—observation wells of basic network penetrating: 4—country rocks, 5—alluvial deposits; 6—water-level lowering wells.
For rest of legend see Figure 33.

of underground waters, discharges of pump wells, total rate of flow in the open cast mine and rates of flow of surface waters through the basic network of mining enterprises was as follows: once in ten days but at flood time, approximately once in five days.

In situ observations directly within an open cast mine must form part of the general complex of studies on hydrogeological and engineering geological conditions at the stage of commercial working of a deposit by the open cut method. Investigations should necessarily follow these lines: (1) documentation and regimal observations on residual pressures of underground waters along the benches and slopes of an open cast mine and also the rate of flow of water currents; (2) systematic observations of the components of drainage and diversion network of rain and meltwaters, which is usually established on the surface around the open pit; and (3) regimal observations of the components of drainage constructions situated directly along the benches and slopes of the mine, constructed to impart stability from crushing and sliding. In sections where landslide processes are likely to occur, it is desirable to organise instrumental observations through geodetic reference points along the flanges of the mine. For this purpose it is most important to organise a geodynamic station. Such instrumental investigations are commonly conducted together with the mine-survey personnel of mining enterprise. To predict the deformative technogenic processes on the benches of the mine, in practise the geological party of mining enterprises in the Urals and KMA adopt rational complex geophysical methods: geo-electrical, ultrasonic and microseismic investigations.

Increase in the electrical resistivity of the rock massif exposed during repeated electro-profiling of the filed of inspection constitutes the geo-electrical indicator for estimating the possible development of landslide processes along the benches of an open cast mine. Continuation of every cycle of geophysical investigations along select profiles takes about 3 to 5 hr. The results of electro-profiles obtained in the form of electrical resistivity curves with time directly reflect the degree of stability of the rocks along the banks of an open cast mine. If no changes in electrical resistivity are noted, that indicates excellent stability of the rock mass constituting the benches of the mine. A significant increase in the electrical conductivity of the rocks over a period of a few days is suggestive of formation of fractures and microfractures in the rock massif at depth. Disappearance of the intense moisture zone during the process of electro-profiling clearly indicates the possible formation of slide surfaces in the rocks series.

A series of prognostic experiments on the stability of the benches of open mines were carried out by means of ultrasonic investigations in the wells. It was found that ultrasonic impulses appear in the rocks adjacent to the flanks of the mines, under the influence of state of strain and also certain structural features (availability of defects in the structure of the flanks). Special instruments were employed for these studies. It was established that if during observations of the rocks massif an increase in ultrasonic impulse registered above the sound level of significance, this was another distinct indication of the beginning of processes of deformation. Application of the ultrasonic method requires the organisation of a basic network of observational wells over the inspection parts of the flanks of an open cast mine.

Study of the regime of underground waters in ore deposits of the third group at the stage of their open cast mining reveals certain characteristics. The latter are very well defined by geological-hydrogeological conditions. As observed earlier, ore-containing country rocks are chracterised by high stability during mining of carbonate rocks, covered surfacially by a water-bearing sandy-loamy formation with an average thickness of 10-30 m and at times more. In carbonate rocks a basin of fracture-karst waters usually forms in which the underground waters invariably have a close hydraulic link with the surface waters. The rate of filtration in water-bearing carbonate rocks is highly heterogeneous but along certain zones conductivity is high. Today some ore deposits of the Urals, Kazakhstan and Siberia are exploited by open cast mining. Considering the high water potential in carbonate rocks, these deposits are usually mined under the protection of an internal drainage construction in the form of a circular system of water-level reducing (draw-down) wells, with assured advance drainage of the mine and consequently safe conditions of mining.

The multifacetted study of the regime of underground waters and technogenic processes in deposits of the third group includes the following principal problems: (a) study of conditions of drainage of an open cast mine (effectiveness of drainage) formed over the field of influence of the cone of depression, including a study of the regime of operation of external drainage constructions, considering them as reservoir/water supply constructions according to the scheme 'drainage-water supply' and also technogenic processes (mainly collapse-karst processes); (b) study and evaluation of conditions of interaction between fracture-karst and surface waters; (c) guarantee of stability of the flanges of the mine in unconsolidated cover formations; and (d) study of the chemical composition of fracture-karst waters and their corrosive action and study of the conditions of their isolation from their link with the protected surrounding environment, particularly when the mineral contents of the waters are high.

To solve the problems enumerated above, as in the earlier cases, it is essential to organise a basic network of observation points—hydrogeological borewells and, if needed, hydrometric stations over the local river system etc. Figure 30 depicts the scheme of disposition of the basic observation network in one of the mines of Kazakhstan. This deposit belongs to a thick series of water-bearing carbonate rocks of the Palaeozoic era, characterised by tectonic dislocations in a folded-faulted complex with the surface of crustal rocks covered by an 8-12 m thick layer of sandy-loamy Neogene rocks. There is no local hydrographic network. Hydrogeologically, the deposit presents its own limited basin area of fracture-karst waters of highly varied mineral content (from 2-3 to 25-30 g/l). In the plan a sharp contact between water-bearing limestones and weakly permeable effusive rocks is conspicuous. In the cover formations a horizon of fresh waters is encountered,

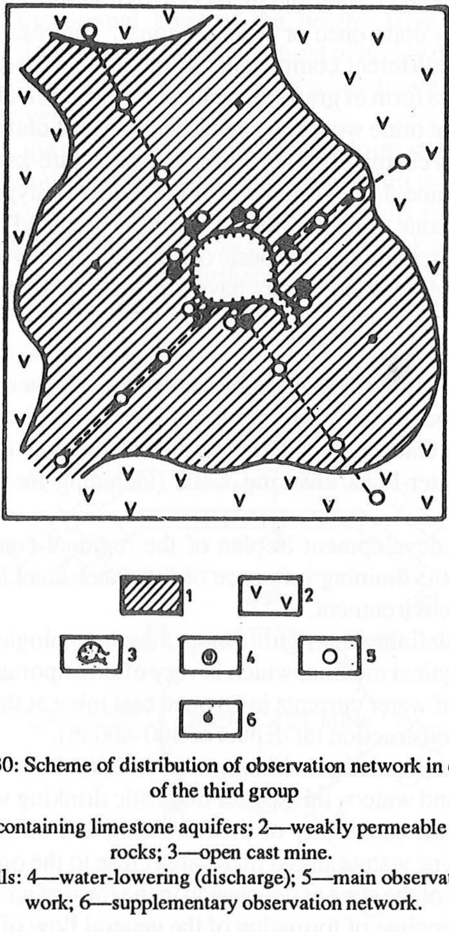

Figure 30: Scheme of distribution of observation network in deposits of the third group

1—ore-containing limestone aquifers; 2—weakly permeable effusive rocks; 3—open cast mine.
Borewells: 4—water-lowering (discharge); 5—main observation network; 6—supplementary observation network.

which differs from the horizon of fracture-karst waters of the consolidated clays (3-5 m thick).

In such geological-hydrogeological conditions, the natural resources and natural reserves of fracture-karst waters of carbonate rocks constitute the major sources of flooding in the mines. Of course, the deposit is exploited by open cast mining. The main observational network was aligned according to the radial (centrifugal) scheme on the basis of maximum utilisation of geo-exploration wells, introduced into the deposit at the stage of prospecting. Drillings for additional observational wells of the relief network were undertaken for stripping fissure-karst waters close to the dewatering works and divided into two—one for stripping or opening groundwaters and the other for fissure-karst waters. *In situ* observations over the main network are conducted once in ten days. Observations are carried out on levels of underground water discharge by the pumping wells and chemical composition of fracture-karst waters and their corrosive action. Sampling of waters for chemical analysis is done once or twice a month. The results of *in situ* regimal observations of the different components of the mine undertaking are processed simultaneously in the form of graph: dependence of general rate of flow in the open cast mine on depth of mine working; changes in levels of underground waters with time; and changes in chemical composition of the fracture-karst waters with depth of working of the mine. Likewise, maps of the hydro-isohypse at different times, information on the cone of depression etc. are also prepared.

The scheme of disposition of the basic observational network and *in situ* studies of the regime of underground waters have allowed the solution of the following problems:

a. Periodic evaluation of the effectiveness of the advance drainage of the open cast mine through analysis of graphs of levels of regime versus discharge of wells and regulation of withdrawal of fissure-karst waters of the circular system of water-level lowering wells (including the boring of additional shafts).
b. Study of the development in plan of the regional cone of depression and estimates of the draining influence of the water-level lowering wells in the surrounding environment.
c. Precision in defining the significance of hydrogeological parameters by the graphic-analytical method, which is very often important for forecasting the rate of flow of water currents in an open cast mine at the stage of the second order of its construction (at depths of 300-400 m).
d. Study of the influence of withdrawal of fracture-karst waters on the regime of underground waters, utilised for domestic drinking water supply and also estimates of the possibility of their draining and infiltration of the aquifer horizon of mine waters stored in the area close to the open cast mine directly over the field of the cone of depression in the form of an 'evaporator-storage'.
e. Study of the regime of formation of the general flow of water currents in the circular system of water-level lowering (pump) wells for providing data on hydrogeological conditions etc.

Thus a proper choice of the basic observation network over the deposit under study and also the adoption of *in situ* investigations of the regime of underground waters, have very much helped to solve the important applied problems of guaranteeing trouble-free operation of the working of the deposit. In more complex natural situations of exploitation, through open cast mining, when surface waters introduce flooding in the mine, additional problems arise in the study of the regime of underground waters. One of these is the study of the conditions of interlink between underground and surface waters. Let us now consider these conditions with a concrete example.

The ore deposit is worked on an experimental commercial scale by open cast mining, maintaining the normal level of the nearby large river (Figure 31). Ore-containing country rocks of the deposits consist of highly dislocated carbonate rocks of the Palaeozoic; their fracture-karst waters are hydraulically connected with surface waters of the river.

In such conditions, the surface waters of the river form the principal source of flooding in the open cut mine. Protection of the mine from sources of flooding is effected by means of water diversion and drainage dams forcing back surface waters of the river at a distance of 120-150 m from the bank and also the circular battery of water-level reducing wells. Furthermore, an intra-open cast water pump has been set up directly in the open cut mine. The main problems of the study of

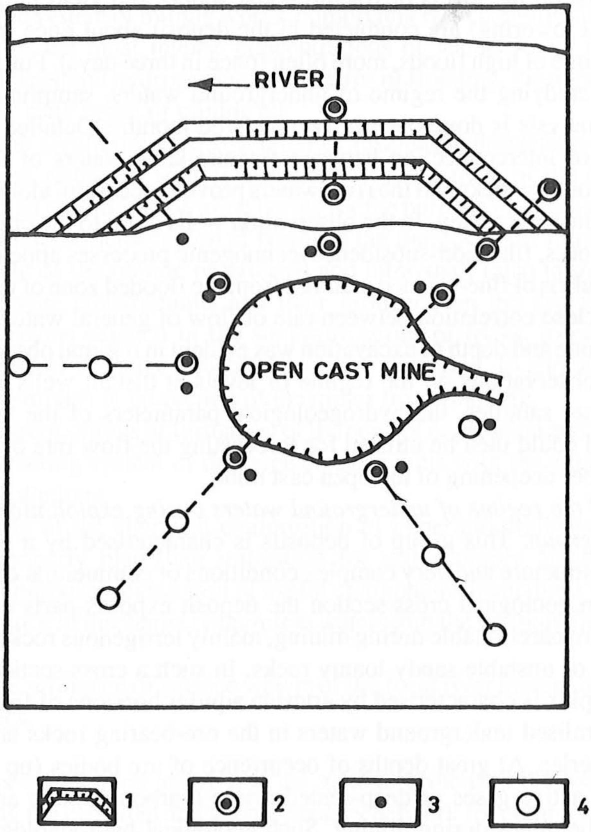

Figure 31: Scheme of disposition of observation posts

1—advance dam wells; 2—water-lowering; 3—observation, new borehole; 4—observation, boring at stage of prospecting.

the regime of underground waters in the given hydrogeological situation included conditions of interlink between fracture-karst waters and surface waters of the river, estimation of the effectiveness of external drainage constructions, appearance of distinct pattern of changes in the general water currents in the mine with depth of working at the mine and also an analysis of the technogenic processess that formed during the drainage of the open cast mine.

To solve the foregoing problems, a radial (centrifugal) system was introduced for the basic network of observational wells (see Figures 30 and 31). In providing the basic observation network, the earlier drilled geo-exploration wells (sunk at the stage of prospecting the site) were utilised and drilling of special and strictly hydrogeological observation wells close to the water-level lowering wells was also completed (to monitor and exert control over the levels). In addition, several wells were drilled directly in the river valley with drilling carried out during winter. Observations on the levels of fracture-karst waters and yield in discharge wells (water-level lowering) are conducted in the deposit about once in five days but during the time of high floods, more often (once in three days). Furthermore, in the process of studying the regime of underground waters, sampling of waters for chemical analysis is done once in two to three months. Detailed studies on the conditions of interconnection between fracture-karst waters of the ore-bearing carbonate country rocks and the river waters proved successful along the near-bank regions of the river valley. In the observation wells close to the circular battery of pumping works, filtration-subsidence technogenic processes appeared, producing extensive debris of fine-grained material from the flooded zone of tectonic dislocations. The close correlation between rate of flow of general water currents in the open cast mine and depth of excavation was evident in regimal observations. Using data from observations on the regime of levels at distant wells and analysis of general water samples, the hydrogeological parameters of the layer were well defined and could then be utilised for forecasting the flow rate of water currents during further deepening of the open cast mine.

Study of the regime of underground waters during exploitation of deposits of the fourth group. This group of deposits is characterised by a highly complex geological structure and very complex conditions of commercial exploitation (see Table 5). In geological cross-section the deposit exposes parts of metamorphic rocks that are barely stable during mining, mainly terrigenous rocks overlain again by a series of unstable sandy-loamy rocks. In such a cross-section of rocks, the whole complex is characterised by artesian aquifer horizons of fresh and increasingly mineralised underground waters in the ore-bearing rocks and rocks of the supra-ore series. At great depths of occurrence of ore bodies (up to 600-800 m) chemically active gases of deep-seated origin (carbon dioxide and others) may appear in the mines during mining. Such geological-hydrogeological conditions determine the highly complex situation of the commercial working of deposits of the fourth group. Natural resources and reserves of underground waters of artesian horizons contribute to the flooding of mines. In the case of a hydraulic link of underground waters with surface waters, drawing up of the resources may result.

As demonstrated by a number of case histories, exploitation of such deposits requires firstly, a rational collection of conventional and commonly accepted methods of protection of mines from flooding and secondly, adoption of special and individual methods of preliminary- and later, exploitation-stage drainage of the mines by means of a fairly complex system of external drainage constructions and also a system of drainage facilities directly inside the field of an open cast mine.

The extremely complex conditions of ore deposits of the fourth group highlight the following problems, requiring intensive studies on the regime of underground waters:

a. Study of the conditions of formation and regime of general currents of mine waters in the system of mining works, comprising two categories (the flanges and areas of the most intense concentrations of water flows) in order to estimate the general hydrogeological patterns of flooding, the dependence of rate of flow with depth of mining etc.
b. Study of the conditions of distribution of residual hydrostatic pressures of underground waters of aquifer horizons along the trace of the main mine workings and also along the mine berths for the purpose of averting possible sudden outbursts, deformation of berths in the flanges of the mines etc.
c. *In situ* study of the regime of external and intra-shaft (also intra-open cast mine) drainage constructions and their influence on the drainage of the aquifer horizons situated in the supra-ore series of rocks, to evaluate the effectiveness of drainage constructions and, if needed, to adopt additional operational modes of protection of the mines from flooding.
d. Study of the conditions of formation of the cone of depression and evaluation of the interacting system of drainage constructions with the existing water supply installations.
e. *In situ* study of the chemical composition of mine and drainage waters in order to properly plan their utilisation for water supply, irrigation, balneological purposes; extraction of useful components from these waters and also allowance of discharge of harmless waters into the surrounding environment.
f. Study of the influence of surface waters of the local river system on flooding of the mines.

The problems enumerated above and the general principles discussed earlier help in organising the principal and supplementary network for complex studies of the regime of underground and surface waters.

In choosing the scheme of disposition of the observation network, it is necessary to ascertain the rational combination of the methodological procedures described earlier during the discussion of the first, second and the third group of complexity of ore deposits. It is also necessary to study the hydrogeological characteristics of a given deposit in each concrete case. For example, during a study of the technogenic regime of the industrial working of the iron-ore deposits of the KMA by the open cast method, there appeared a need for a multi-layer arrangement of observation wells along the major centrifugal lines intersecting primarily all the aquifer horizons. In the supra-ore series of rocks of the iron-ore deposits of the KMA, the distribution of some artesian aquifer horizons is well known. The waters from these horizons are partly used for centralised domestic water supply to large towns and worker colonies. Preliminary- and exploitation-stage drainage of the aquifer horizons in the unstable rocks of the supra-ore series in the Lebedin, south Lebedin and Mikhailov open cast mines resulted in the significant formation of a regional cone of depression throughout the area. Under such hydrogeological conditions it is most important not only to protect the effectiveness of drainage of the area and to provide secure conditions for mining the deposit, but to also simultaneously evaluate the influence of drainage on the surrounding environment, from the point of view of conservation of resources of underground waters and also conditions of interaction between external drainage constructions and large reservoir installations of the region, constructed to provide water supply to large townships [20].

CHAPTER 8

Complex Studies During Water Reservoir Constructions

GENERAL CONSIDERATIONS AND PRINCIPAL PROBLEMS OF INVESTIGATIONS

It is known that domestic drinking and industrial water supplied for mining enterprises are based in the majority of cases on independent water reservoir constructions for underground or surface waters. These reservoirs thus constitute an integral part of the structural aspect of the enterprise and hence a study of the regime of underground waters at the stage operation through pipeline construction must invariably include hydrogeological and engineering geological investigations. Thus thrust of the complex studies on water reservoir constructions should be toward operational prospecting of deposits of underground waters. The general problems constituting the work and the methodological procedures to be adopted in hydrogeological activities at the stage of operational prospecting of underground waters have been sufficiently detailed in earlier works (27). Hence, only those complex investigations particularly related to water reservoir constructions in mining enterprises are examined here.

In practise, water supply constructions in mining enterprises are of the following types: (1) water reservoirs situated within the limits of the mining activities of the enterprise taking, which utilise already discovered reserves of various types of underground water (rarely pipelines are constructed in order to utilise surface waters): (2) water reservoir-drainage constructions installed directly on the flanges of the cone of depression that forms during drainage in mining works and utilisation of underground waters flooding ore deposits (drainage of mines according to the scheme) 'drainage-water supply'; and (3) water reservoirs constructed directly in the system of underground mining in the form of independent pipelines, mainly intended for supply of mine water.

Different types of water reservoir constructions determine some of the characteristics of the methodological procedures of the complex of *in situ* investigations at the stage of their operation and also decide one of the modes of disposition of the basic observational network.

Among the first type of water-reservoirs on ore deposits, the most widely occurring are infiltration water reservoirs constructed over deposits of underground waters of river valley regions. It is well known that exploitable water reserves of infiltration water reservoirs are formed mainly at the expense of surface waters which have penetrated underground. Based on reservoirs situated over deposits of underground waters in river valley complexes, water supply has been arranged in the large mining enterprises of Central Asia, Kazakhstan, Siberia, the Far East etc. During exploitation of infiltration water reservoirs, a restricted field of cone of depression normally formed, with an average area of 3-5 km^2. Hence the influence of underground waters on the surrounding environment is negligible.

Relatively large area of cone of depression and consequent increased degree of influence on changes in the surrounding environment result during the operation of water reservoir constructions situated in artesian basins and also in areas of deposits of fracture-karst waters. These characteristics of exploitation of underground waters in different hydrogeological conditions have to be well understood during the planning of the main observational network over the water reservoir regime.

The second type of pipeline construction, as the term implies, is commonly combined with the general system of drainage (dewatering) of mines. This system of interacting borewells is generally situated on the flanks of the cone of depression that forms along the periphery of the entire area of mining. During the combined operation of this system two problems are solved—assured domestic, drinking and industrial water supply for the enterprise and lowering of intensity of flooding in mines. This dual problem has been most successfully solved in some deposits of the Urals. The water-reservoir drainage units are situated in areas lying between the principal sources of flooding of deposits, namely, surface waters of large rivers and the northern flank of the cone of depression formed during drainage of the underground mines. Through application of the same drainage unit fracture-karst waters are withdrawn in quantities up to 60,000-70,000 m^3/day, satisfying the complete water requirement for the mining operation and concomitantly reducing the lowering of the general rate of flow of water currents in the mines by 30 to 35%. Analogous water-reservoir drainage systems for domestic, drinking and industrial water supply have been organised through utilisation of underground waters of ore deposits in the Stoilen mine and south Lebedin open cast mine of the iron-ore formation KMA. Underground waters, amounting to 18,000 m^3/day are withdrawn at the Stoilen mine from the system of porous filters introduced from the surface into the horizon of the drainage gallery. Waters are withdrawn from the aquifer horizons of the cretaceous period and also from ore-bearing crystalline rocks [20].

Extensive introduction in mining practise of the system 'drainage-water supply' has enabled the solution of the important problem of complex utilisation of all the useful components of deposits, including underground waters. The introduction of the second type of pipeline construction is more essential because very often in the later period of commercial working ore deposits of highly complex hydrogeological features appear, requiring advance drainage of mine working and extraction of a significant quantity of underground waters from considerable depths.

The third type of water reservoir presents its own independent pipeline of concentrated discharge of mine waters, constructed directly in underground mines, with water delivered to the surface through independent water conduits. This type of water reservoir is preferable in severely flooded ore deposits in a system of underground mines (drainage of the deposit is carried out without external drainage installations). In practise, the third type of reservoir has been successfully used in one of the ore deposits of Kazakhstan. In this case there is a concentrated discharge of fracture-karst waters from ore-bearing carbonate rocks directly from an independent pipeline. Mine waters are utilised for domestic water supply of the township, various constructional and industrial purposes (beneficiation plants and other needs) and also for irrigation.

Under conditions of an independent centralised water supply in mining enterprises, the principal problems of complex investigations are providing rational conditions of exploitation of underground waters and, if necessary, improving productivity of the water reservoir through artificial recharge of the reserves. These problems ought to be solved by studies along these lines: (1) *in situ* study of the basic parameters of the regime of underground waters and, if needed, of the surface waters too; (2) preservation of the underground waters from contamination and depletion and the surrounding environment from the negative influence of technogenic processes; and (3) technical supervision of the working of the reservoir construction.

In the first line of approach hydrodynamic and hydrogeochemical studies are involved in order to understand the regime of levels of underground waters, discharge of each reservoir well and also the total productivity of all reservoirs; the regime, temperatures and quality of underground waters (chemical composition, sanitary conditions and contents of harmful components). If the reservoir is situated over a river valley and belongs to the infiltration type, it is most important to study the regime of surface water flow (changes with time of rate of flow, quality of waters and influence of changes of surface water current on quantity of exploitable water reserves).

The second line of study envisages periodic analysis of data on the exploitation of the water reservoir. Through data from *in situ* regimal observations evaluation of the possible development of technogenic processes in the reservoir area should be completed. Technogenic processes include depletion and pollution of underground waters, deformation of underground communications and sagging of the surface.

The quality of fresh underground waters has to be evaluated in terms of three basic parameters, viz., chemical, sanitary-bacteriological composition and organoleptic properties. These indicators are strictly determined according to the Government's standard specifications (GOST 2874-82). Determination of the quality of underground waters means assessing their possible chemical contamination through industrial effluents from the mining enterprise, petroleum products, introduction of agricultural wastes, mine waters etc.

In many mining enterprises, during the operation o external water reservoir constructions (of the first type) technogenic processes of interaction of the pipeline with the operating drainage installations may appear. In order to study these processes and attempt their control, it is most essential at the outset to be convinced of the possible formation of processes of interaction by analysing the hydrogeological conditions. If so, then parts of the special network should be provided with observation wells.

It is clear from this discussion that hydrodynamic and hydrogeochemical studies thus assume supreme importance in the assessment of conditions for the exploitation of underground waters of the water reservoir regime.

Investigations according to the third direction of approach are commonly carried out by the technical servicing department, in order to simultaneously supervise the technical aspects of all the machinery involved in the enterprise and to adopt suitable measures for non-stop working of the mine's installations, including equipment for automation of *in situ* regimal observations, which ought to be established over the reservoir and observation wells.

ORGANISATION OF OBSERVATION NETWORK AND CONTENTS OF INVESTIGATIONS

For a qualitative treatment of complex investigations within the limits of the water reservoir sector, it is imperative to organise a special network of observation posts—borewells and, if necessary, hydrometric stations. Also, while providing a primary and supplementary network, the general principles ought, of course, be known (see Chapter 7), but certain characteristics of conditions of exploitation of the reservoir should also be heeded, including the requirements for organisation of zones of sanitary conservation in the reservoir. When planning the operation of zones of sanitary conservation of sources of water supply and water supply lines (pipes) for domestic and drinking purposes, it is necessary to organise zones of sanitary preservation in all the water reservoirs in order to control, prevent and protect the sources of water supply from contamination. Zones of sanitary preservation are divided into three belts: I—rigorously treated regime and II and III—controlled precautionary regimes.

Hydrogeological and sanitary conditions of organisation of zones of sanitary preservation have been sufficiently detailed in an earlier work [33].

The recommendations presented above for organising a basic observation network emphasise the need for adopting the following schemes of disposition of this network over the reservoir areas. Within the limits of the first belt of the zone of sanitary preservation, it is essential to organise a basic network that allows collection of authentic information on the regime of discharges of the reservoir wells, dynamic level, temperatures and quality of the underground waters and also the regime of surface waters (rate of flow of river current and quality of surface waters). Figure 32 presents a scheme of distribution of a basic network within the precincts of an actual reservoir sector, i.e., the first belt of zone of sanitary preservation. Every water reservoir well ought to be fitted with a small tubular-piezometer for *in situ* study of the regime of dynamic level and a flow recording instrument for studying discharges from the well (Figure 33). It is also important to protect observation wells in the reservoir sector at the stage of prospecting the deposit, in order to guarantee the principle of continuity, i.e., collection of data on the regime under natural and disturbed conditions.

Furthermore, additional observation wells should be drilled according to the scheme illustrated in Figure 32. Additional observation wells are aligned taking into account the filtration heterogeneity of the productive aquifer layer, sanitary conditions of the water reservoir sector and other factors. However, to study the surface water regime hydrometric stations provided with standard instrumentation suffice.

Hydrologically, the first belt of the zone of sanitary preservation is characterised by a high dynamic level and relatively quick change under the influence of a series of factors (temporary cessation of pumping in the wells, flash floods in the river etc.). This belt forms the zone of prompt study of all the components of the regime. All observation and water reservoir wells have to be equipped with automatic

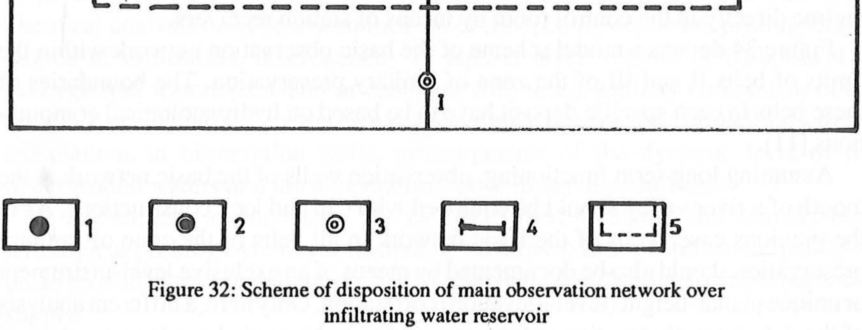

Figure 32: Scheme of disposition of main observation network over infiltrating water reservoir

1 to 3—borewells: 1—water reservoir with piezometric observation tubes, 2—observational, preserved after prospecting of deposit, 3—observational, dug during exploitation of water reservoirs; 4—hydrometric stations over river 5—approximate boundary of Belt I of zone of sanitary preservation; I-I—line of cross-section.

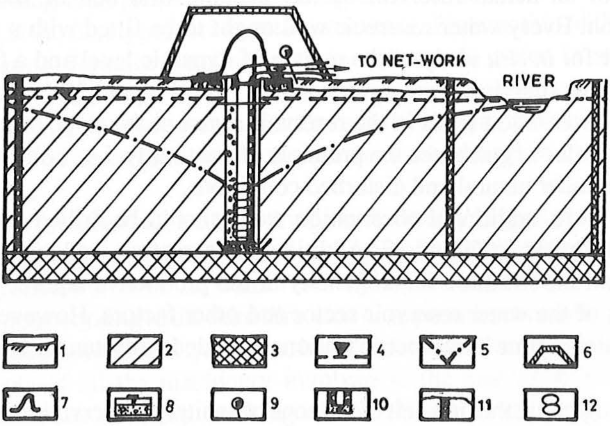

Figure 33: Scheme of disposition of observation wells along line I-I of Figure 32 over part of infiltration reservoir

1—soil-vegetation cover; 2—water-bearing rocks; 3—water-impervious rocks; 4—natural water table of underground waters; 5—cone of depression; 6—(pumping) station building; 7—electromotor pump; 8—concrete reinforcement of pump; 9—flow meter; 10 and 11—filter wells: 10—water reservoir, 11—observation; 12—pump. Line of cross-section I-I same as in Figure 32.

measuring instruments for reliable continuous registration of the water level and discharge from wells. Equipment of the type 'Valdai' or digital-printout gauge of the type 'RUTS' (of the system VSEGINGEO) is recommended. In large reservoirs it is desirable to automatically centralise registration of operational data on the regime directly in the control room by means of station receivers.

Figure 34 depicts a model scheme of the basic observation network within the limits of belts II and III of the zone of sanitary preservation. The boundaries of these belts in each specific deposit have to be based on hydrogeological computations [11].

Assuming long-term functioning, observation wells of the basic network at the mouth of a river valley should be equipped with cap and lock constructions. As in the previous case, wells of the basic network in all belts of the zone of sanitary preservation should also be documented by means of an exclusive level-instrument or unique planar-height (level-elevation) correlation. Only here, a different analysis of the data from observations of the regime has to be carried out (construction of groundwater contour map, different graphs etc.).

One of the major considerations in the study of the regime of underground waters relates to the timing and frequency of measurements of their levels, discharge of wells, chemical composition and temperature.

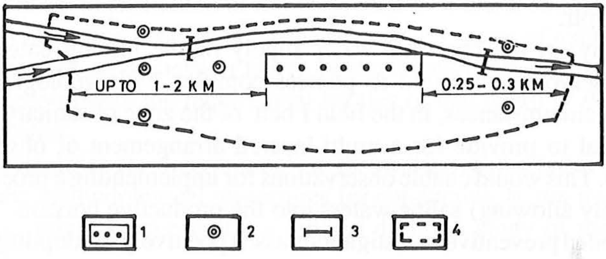

Figure 34: Model scheme of disposition of basic observation network in belt II and III of zone of sanitary preservation

1—water reservoir part and belt I of zone of sanitary preservation; 2—observation wells; 3—hydrometric stations over river ; 4—boundary between belts II and III of zone of sanitary preservation.

To study the regime of level and discharge (yield) of wells in belt I of the zone of sanitary preservation over the water reservoir sector, as mentioned earlier, it is desirable to continue documentation over time without a break. In the absence of automatic apparatus for frequent documentation of discharge and dynamic level of the underground waters, it is known from experience that data has to be collected once or twice a day. Measurements of temperatures and sampling of waters for controlling the quality of underground waters have to be conducted in accordance with the instructions and requirements. In actual practise, sampling is undertaken about once or twice in ten days.

With regard to *in situ* observations within the limits of belts II and III of the zone of preservation, the frequency of measurements and the sampling of waters for chemical analysis must be determined for every specific deposit depending on the degree of infiltration, heterogeneity of aquifer layer, regime of withdrawal of underground waters (constant or changing with time), sanitary component of the area and other factors. Experience has again shown that for practise and subsequent calculations in observation wells, measurements of the dynamic level of the underground waters and the temperatures once in ten days suffice.

It is pertinent to emphasise the fact that hydro-dynamic and sanitary-bacteriological probing assumes considerable signifance in the estimate of quality of underground waters as an important parameter in their utilisation for drinking water supply.

For belts II and III of the zones of sanitary preservation, an indispensable requirement is measurement in wells according to the strictly framed schedule, wherein constant changes in the alignment of observation points should be avoided to enable primary documentation of the regime of underground waters. *In situ* observations over the regime of surface waters (rate of flow and quality) are carried out at hydrometric stations (hydrometric bridges: staff measure water level in the river; etc.) in accordance with the methods, instructions and requirements of the Hydrometeorological Survey of the USSR, and also working conditions of the water reservoir.

Practically, in the domestic water supply of the mining enterprise, known working reservoirs are found to possess complex hydrogeological conditions. Under such circumstances, in the field I belt of the zone of sanitary conservation, it is essential to provide for a multi-layered arrangement of observation wells (Figure 35). This would enable observations for implementing a process of restricting (or freely allowing) saline waters into the productive horizon. The results of such controlled preventive investigations assist positively in adopting simultaneous measures for protecting fresh underground waters from intrusion of saline waters.

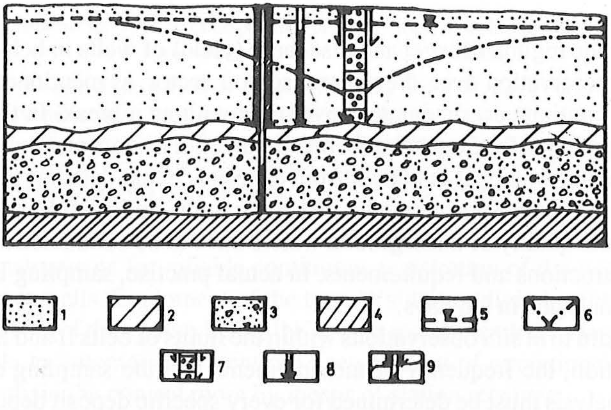

Figure 35: Scheme of multi-layered disposition of observation wells

1—Water-bearing rocks with fresh water; 2—low permeable separator layer; 3—water-bearing rocks with saline water; 4—impervious rocks; 5—water table under natural conditions; 6—cone of depression; 7—water reservoir well equipped with tubular piezometer and flow meter; 8—observation well into fresh waters; 9—observation well into saline waters (well isolated in zone of fresh water by cementation).

In water reservoirs of the infiltration type some time must be spared for the study of the regime of hydraulic connection between underground and surface waters. It is also practically established that during prolonged exploitation of infiltration reservoirs in river valleys, there is often a gradual increase in the hydraulic resistance of unconsolidated formations because of sedimentation and siltation. These technogenic processes lead to degradation of the river bank infiltration of surface waters and recharge of reservoir wells. Systematic observations through wells specially equipped for this purpose also require simultaneous adoption of operational methods of desiltation of rivers flowing over unconsolidated deposits.

With regard to the organisation in the water reservoir sector of a supplementary (temporary) network, this question has to be examined independently for every specific case according to the requirement for this or that detail of the regime of underground waters.

The basic principles for determining the disposition of the basic observation network and the methodological procedures for conducting *in situ* investigations outlined above, might be successfully utilised during a study of the regime of

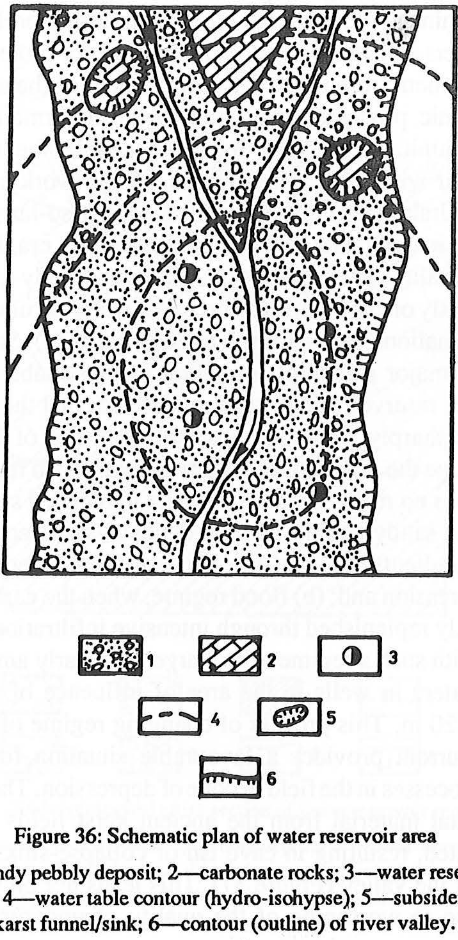

Figure 36: Schematic plan of water reservoir area

1—sandy pebbly deposit; 2—carbonate rocks; 3—water reservoir well; 4—water table contour (hydro-isohypse); 5—subsidence-karst funnel/sink; 6—contour (outline) of river valley.

underground waters in water reservoirs constructed over areas of artesian basins and the basin of fracture-karst waters. As in the previous case, organisation of the zone of preservation should be based on the filtration heterogeneity of the aquifer rocks, the multi-layered structure of the aquifer complex and complexity of hydrogeochemical conditions in the reservoir sector.

In the process of complex studies of the regime of underground waters it is imperative to provide for periodic inspection of the sanitary aspect of all the belts of the zone of sanitary preservation, in order to reflect the results of such supervisions on the hydrogeological map of the area of influence of reservoir construction. Depending upon the degree of complexity of the general sanitary conditions of the region of location of the reservoir, it is desirable to carry out such supervision once or twice a year.

Technogenic investigations of the areas of reservoir construction have to be conducted to assess the technogenic processes (subsidence-karst, secondary consolidation during drainage of rocks, etc.) that form during prolonged exploitation of underground waters and also to work out measures for protecting aspects of the surrounding environment from the negative influences of the technogenic processes [27]. Technogenic processes may lead to the deformation of surface and underground communications. Very intensive development of collapse-karst processes have been witnessed, for example, in the working Yangil reservoir construction in the Urals. This deposit belongs to a not-so-large basin of fracture-karst waters formed in carbonate rocks of the Palaeozoic era. It is situated over a broad single river valley system in which alluvial sandy-gravelly and loamy formations rest directly on the karstified surface of water-saturated limestones. The thickness of the formations varies from 1 to 20 (Figure 36). Surface waters of the river constitute the major source of formation of exploitable reserves of underground waters of the reservoir. Their regime indicates that the annual rate of flow in the river differs sharply from that observed at times of floods. Under such conditions of recharge the reservoir functions in fact in two regimes: (a) low level regime, when there is no recharge, which results in reduced storage of reserves of groundwaters in the sandy-pebbly alluvial deposits and fracture-karst waters of limestones, while gradients of the infiltration currents register a sharp rise over the field of cone of depression and; (b) flood regime, when the earlier reduced volume of reserves is quickly replenished through intensive infiltration of surface waters.

In connection with such a regime of recharge, the yearly amplitude of variation of underground waters in wells in the area of influence of the water reservoir reaches more than 20 m. This process of changing regime of dynamic level and gradients of the current provides a favourable situation for the formation of subsidence karst processes in the field of cone of depression. The subsidence-debris of cretaceous detrital material from the ancient karst fields lying close to the surface is rejuvenated, resulting in cave isn or collapse-sinks or swallow-holes, within the limits of the valley (Figure 37). This leads not only to deformation of the surface but also to worsening of the quality of underground waters in the reservoir. Under such hydrogeological conditions it is therefore desirable to choose the most rational condition of exploitation of the reservoir, in order to avoid the formation of collapse-karst processes.

Experience with the exploitation of waters in mining practise points out that processes of deformation of engineering constructions over the reservoir area during mining might also originate under the influence of natural engineering geological processes—mud flows, potential landslides, collapse of surfaces etc. All these emphasise the necessity for carrying out *in situ* experimental engineering geological studies on the exploitation of underground waters along these lines: (a) studies directly over the area of zone of sanitary preservation of the working reservoir construction in order to understand the conditions of formation of technogenic processes; and (b) studies on the mine regions adjacent to the reservoir

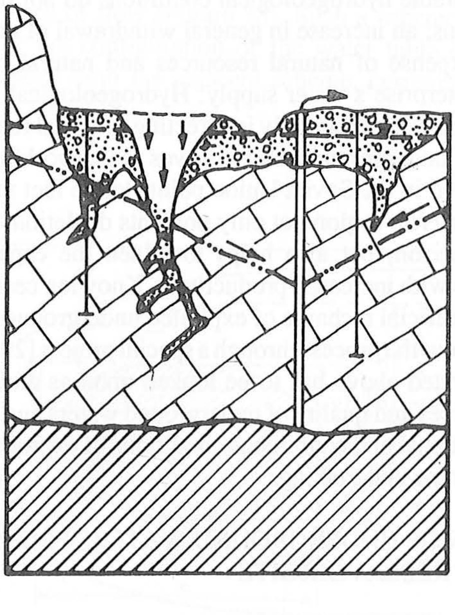

Figure 37: Hydrogeological cross-section of water reservoir sector.

1—Carbonate rocks; 2—sandy-pebbly deposit; 3—water-impervious rocks; 4—level of water table before exploitation; 5—cone of depression; 6—subsidence-karst sink/funnel. Wells: 7—reservoir; 8—observation.

sector in order to ascertain the conditions of formation of natural geodynamic processes and to estimate their possible influence on the deformation of reservoir constructions. In the former line of study a periodic inspection is emphasised and in the case of complex conditions, mapping of the engineering geological situation of the reservoir sector has to be undertaken. The results of periodic inspection should be recorded and reflected in the duty charts.

With regards to an *in situ* study of the regime of underground waters in reservoirs of the second type (reservoir-drainage system) and also the third type, it is essential to adhere to the following. *In situ* investigations in such reservoirs of the valley sites are carried out according to the programme prepared at the close of the total general estimate of the effectiveness of the drainage installations and the programme of study of these installations as reservoir constructions.

Finally, it is emphasised that the significance of hydrogeological work lies in their forming the basic links towards artificially compensating (recharg) exploited reserves of underground waters in the functioning reservoir constructions. The point is that favourable hydrogeological conditions do not prevail in all working reservoir formations; an increase in general withdrawal of underground waters is possible at the expense of natural resources and natural reserves to meet the demands of an enterprise's water supply. Hydrogeological information thus assumes prime importance particularly in directing artificial recharge to compensate for exploitation of underground water reserves in the working reservoir complex. Experience gathered in the Soviet Union points to the fact that artificial recharge of the working reservoir region not only prevents depletion of water resources of the productive horizon, but also helps to widen the capacity of the pipeline extensions to cope with increased productivity. Knowing certain characteristics of the technique of artificial recharge of exploited underground water resources, it is expedient to carry out the process through a special project [29]. The entire complex of studies enumerated above has to be looked upon as an important link in the direction of resources and quality of underground waters and the medium, guaranteeing the most rational and continuous conditions of exploitation of the functioning reservoirs of mine undertakings.

PRESERVATION OF UNDERGROUND WATERS FROM POLLUTION AT RESERVOIR SITE

In situ study of the quality of underground waters at the water reservoir site is one of the important problems of complex investigations. Chemical and bacterial pollution of underground waters might very well originate under the influence of technogenic factors: penetration into the productive water-bearing horizon of toxic effluents from industrial (tailings dump, reservoirs etc.) and agricultural activities, discharges from settlement areas, and also mine waters. The most difficult to remove or eliminate are the chemical contaminations or pollutants which seem to increase the concentration of minerals and organic toxic components in fresh underground waters. Bacterial contamination is evidenced by the presence of micro-organisms in the waters.

Methods of forecasting conditions of contamination of fresh underground waters in general and in reservoir sites in particular are discussed in many publications [4, 9, 11, 25]. We discuss below only the principal hydrogeological bases of preservation of underground waters from contamination, adopting the methods suggested in the references cited.

Migration of pollutants from their sources towards the reservoir depends upon a series of factors: filtration heterogeneity of the rocks of the productive horizon, natural draining of water-saturated structures etc. The hydrodynamic factor, characterising the presence or absence in the study region of the natural movement of underground waters, is an indisputably important one.

In this connection there is an important concept known as the 'field of recharge of the reservoir construction'. Such a field, the extension or area of which in plan is limited by lines of flow of the water reservoir sector, is sharply delimited by what are known as neutral lines of flow (Figure 38). Such a scheme of flow lines is probably the result of the configuration of the water table contours (hydro-isohypse) in plan. As seen from the adjacent scheme, currents of underground

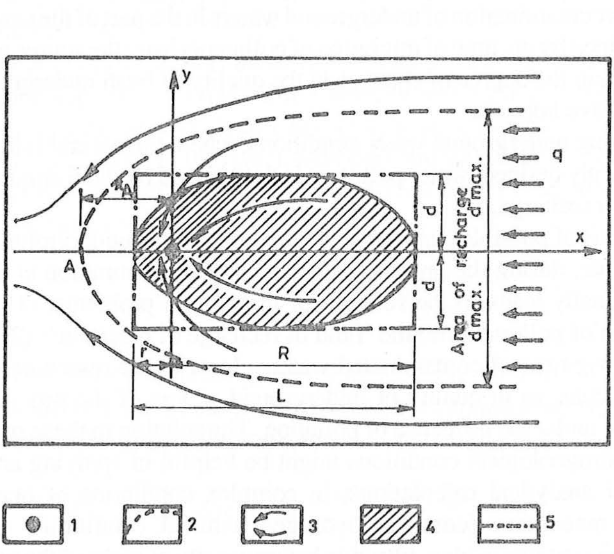

Figure 38: Model scheme of movement of underground waters towards reservoir through natural flow

1—water-divide point A; 2—water reservoir; 3—flow lines; 4—field of reservoir recharge; 5—boundary of zone of sanitary preservation.

waters flow directly within the limits of this field of lines towards the reservoir well. Beyond the limits of this field of well recharge, the lines bend round the reservoir, and pass the exploitation wells. Below the current of underground waters, the field of recharge of the reservoir is limited by the water-divide point A and upwards the current is theoretically not restricted. The 'field of general recharge' characterises the 'field of distribution' of the productive horizon as a whole, within the limits of which the movement of groundwaters is directed towards the water reservoir, which is again a field of recharge, forming part of the aquifer horizon, within the limits of which lowering of level of underground waters originates in accordance with their withdrawal. Within the limits of the basin of underground waters, where their natural velocity is practically absent, the two areas closely coincide. Under conditions of veritable movement of underground waters, the field of recharge of the reservoir part of the field of recharge of the aquifer horizon. These recharges can be termed 'reservoir recharge' and 'aquifer recharge' respectively.

It follows from these theoretical premises therefore that if contamination of waters in groundwater flows occurs directly inside the field of reservoir recharge, then sooner or later contamination reaches the reservoir well. In basins where the 'aquifer recharge' and 'reservoir recharge' coincide, the direction of contamination or pollution of waters in the area of catchment might theoretically originate from any random point in the productive aquifer horizon. In such hydrogeological conditions contamination of underground waters in the part of the catchment would be determined by the time of migration of pollutants from the source to the reservoir site and again the degree of changes in the quality of fresh underground waters of the productive horizon.

In flowing underground water conditions, where the natural rate of movement can be sharply defined, water pollution is determined by the formation of the field of reservoir recharge.

Prognosis of possible changes in the quality of fresh underground waters in the reservoir site, during the presence of sources of contamination at the productive horizon, finally leads to the solution of three main problems: (1) possibility of penetration of pollution into the 'field of recharge of reservoir'; (2) estimation of time of movement of contaminated waters closer to the reservoir arena; and (3) degree of changes in quality of underground waters of the productive horizon, originating under the influence of pollution. The solution to these problems under simple hydrogeological conditions might be helpful in applying an approximate method of analytical calculations; in complex conditions of operation of the reservoir machinery (complex hydrogeochemical conditions, complexity of boundary conditions in plan, filtration heterogeneity of rocks of the productive rock series etc.), mathematical modelling is preferable.

Solution of the first problem originates on the basis of the situation in plan of the neutral line of flow of the relatively conspicuous contour of contamination of underground waters. Let us examine the two methods encountered in practise under conditions of unconfined or partially confined layers.

When the aquifer horizon is of unlimited extent, for a single reservoir or a concentrated group of exploitation wells working in the flow of underground waters with the quantity of yield (Q_y), the distance from the reservoir construction up to water-divide point A down the current or flow direction (see Figure 38) can be determined by this formula:

$$X_A = \frac{Q_y}{2\pi\, kmi_e}$$

Half the width of the field of reservoir recharge (d) along the line of the reservoir construction can be determined according to

$$d = \frac{Q_y}{4\pi kmi_e}$$

where km = water conductivity of the layer; i_e = gradient of natural flow.

For the linear row of wells the position of water-divide point is determined according to

$$X_A = \frac{b}{\pi} \text{ arth } \frac{Q_0}{2mbki_e}$$

where b—the distance between wells in the row; Q_0—yield of independent (interacting in the row) well axis; y—coincides with line of row; and x-axis is directed along flow line.

In semi-confined layer with contour of constant pressure (for example, in the river-infiltration type of reservoir): For a solitary well or a group of wells concentrated over an area situated along x-axis at a distance (R) from the river (y-axis coincides with the contour of the river), with the natural flow direction towards the river, the situation of the water-divide point A along x-axis is determined according to the following function:

$$X_A = \sqrt{R^2 - \frac{QR}{\pi kmi_e}}$$

For the linear row of wells, of greater length, when the wells are located at a distance (R) from the river, in those hydrogeological conditions the position of the water-divide point along x-axis is equal to

$$X_A = \frac{b}{2\pi} \text{ Arch} \left(\text{ch } \frac{2\pi R}{b} - \frac{Q_0}{kmbi_e} \text{ sh } \frac{2\pi R}{b} \right).$$

For conditions under consideration when natural flow of underground waters is directed towards the river, the water-divide point would lie between the reservoir and the contour of the aquifer recharge. With an increase in discharge of the reservoir and a decrease in aquifer recharge at the expense of natural resources of underground waters, the water-divide point would come closer to the contour of constant pressure.

Solution of the second problem can also be attempted approximately through the scheme 'piston displacement'. According to this scheme, the advancing contour of contamination commences uniformly (for conditions of homogeneous filtration characteristics of the layer) without taking into account the filtration heterogeneity of the water-saturated rocks of the productive horizon, and also without considering interaction of contamination with the rocks.

For conditions of the basin of underground waters in an unconfined homogeneous layer, when the natural rate of flow is not significant, it is practically possible to discard the solitary well of the group of wells ('large well') situated at a distance of X_1 from the straight-line boundary of the contaminated waters. The time of advancing contaminated waters from a random point on the boundary of division between fresh and contaminated waters can be determined according to this formula (a single well or a group of wells over the field, transformed to the scheme of 'large well')

$$t = \frac{\pi mn}{Q}\left(r_1^2 - r_2^2\right)$$

where m—thickness of aquifer horizon; n—porosity of the rocks of aquifer horizon; Q—yield from the reservoir construction; r_1 and r_2 refer to initial and final positions of the points, which can be determined by the formulae

$$r_1 = \sqrt{X_1^2 + Y_1^2} \quad ; \quad r_2 = \sqrt{X_2^2 + Y_2^2}$$

where X_1 and X_2 = distances along x-axis; Y_1 and Y_2 = distances along y-axis.

When the reservoir construction works under conditions of groundwater flow (single well or cluster of wells in the field), the time of advance of the contaminants, along any flow line inside the field of reservoir recharge from the initial position at the boundary of the contaminated waters (from the source of contamination) up to the site of the reservoir, can be determined according to the function:

$$t = \pm \frac{n}{l_e}\left[X_1 - X_A \ln\left(\cos\frac{Y_1}{X_A} + \frac{X_1}{Y_1}\sin\frac{Y_1}{X_A}\right)\right].$$

where X_1 and Y_1 are the abscissa and ordinate of the initial position of the point; the signs plus and minus indicate movement with or against that of the flow.

For an unconfined linear row of wells, under conditions in which the length of row is five to six times greater than the distance before and parallel to the boundaries of contaminated waters (in fact, this corresponds to conditions of a continuous layer), for conditions of the basin the time of migration of pollutants from initial position X_1 up to control point X_2 can be determined according to the formula:

$$t = \frac{2\pi kmb^2}{\pi Q_0} \ln \frac{\text{ch} \frac{nX_1}{b}}{\text{ch} \frac{nX_2}{b}}$$

For conditions of filtration current, when the boundary of contaminated water is situated higher with respect to the current, the time of migration of polluted waters towards the row of wells of the reservoir can be approximately determined by the formula

$$t = (n \, \Delta \, X_1) \Big/ \left(\frac{q_0}{2m} + v_e\right) \; ; \; q_0 = Q_0/b$$

where q_0 = solitary discharge of waters; v_e = velocity of filtration of natural flow of underground waters.

For hydrogeological conditions conforming to the calculated scheme of semi-confined homogeneous layer with contour of constant pressure (river), the time of movement of polluted waters towards the reservoir can be approximately estimated in the following manner:

1. For a single or group of wells ('large well'), under basin conditions according to the formula

$$t = \frac{\pi nmd^2}{3Q} \left[2 + \left(\frac{X_1}{d}\right)^3 - 3 \frac{X_1}{d} \right],$$

where Q—instant yield of well (or group of wells) situated along x-axis at a distance (d) from the contour of the constant pressure (river), X_l—initial (originating) position of contaminated waters.

2. For conditions of natural flow directed from the contour of aquifer recharge along x-axis towards the well, according to the formula

$$t = \frac{n}{v_e}\left[(d - X_1) - \frac{X_A^2 - d^2}{2X_A} \ln \frac{(X_A + d) \; (X_A - X_{1)}}{(X_A - d) \; (X + X_{1)}} \right]$$

If the boundary of contaminated waters coincides with the contour of constant pressure ($X_l = O$), then,

$$t = \frac{n}{v_e}\left(d - \frac{X_A^2 - d^2}{2X_A} \ln \frac{X_A + d}{X_A = d} \right)$$

For the linear series (unconfined length) of wells, situated parallel to the contour of constant pressure (river) at a distance (d) from it, the time of advancement of polluted waters during conditions wherein this movement is directed away from the river, is determined according to the following function:

$$t = \frac{nbm}{Q_0}\left(d\, cth\, \frac{2\pi d}{b} - \frac{b}{2\pi}\right)$$

The third problem consists in evaluating changes in the quality of samples of waters of the reservoir, which might be subject to the influence of contamination. In such cases prognostic estimate of the changes in the quality of fresh waters might be conducted according to any of the indications of potable quality as detailed in the Government's standard specification GOST 2874-82. Let us examine how changes in the degree of mineral content can be forecast. Let it be noted that the analytical solutions detailed below are approximate and answer a simple scheme of hydrogeological conditions of reservoir areas. For complex schemes, when the planar filtration heterogeneity of the rocks of the productive aquifer horizon is distinctly traced and so also the layered cross-section of the aquifer complex, the complex boundary conditions in plan etc., it is necessary to solve the problems utilising the method of mathematical modelling over the computer EVM.

For a single well or group of wells of areal distribution transformed according to the scheme 'large well' *situated in an unconfined layer under basin conditions*, the change in general mineral content of waters (C) at the well as a result of mixing of fresh and sub-standard (polluted) waters can be estimated according to the following function:

$$C = C_0 + \frac{C_1 - C_0}{\pi} \arccos \sqrt{\frac{T}{t}}\,,$$

where C_0 = mineral content of fresh underground waters in the reservoir; C_1 = mineral content of sub-standard (polluted) underground waters; T = time of arrival at well of first portion of sub-standard waters; t = flowing time.

Expression (1) is applicable when $t > T$.

The maximum mineral content of underground waters in the reservoir (during $t \rightarrow \infty$ is equal to the average of values C_0 and C_1; that is,

$$C_{max} = \frac{C_0 + C_1}{2}\,.$$

Under conditions of filtration flow, if the straight line boundary of sub-standard waters lies within the field of aquifer recharge at a distance of X_1 from the well (or group of wells over the area of wells) upstream in the flow (the direction of movement of natural flow and of sub-standard waters coincides), then the forecasting of changes in general mineralisation of fresh underground waters in the reservoir can be done using the following formula:

$$C = C_0 + \left(C_1 - C_0\right)\left(\frac{l}{\pi}\, arct_g\, \frac{Y}{X_1} + \frac{2v_e\, Ym}{Q}\right)$$

where X,Y = distances from the wells to straight-line boundary of sub-standard waters corresponding to x- and y-coordinates.

Analysing the different conditions of changes in quality of underground waters in the reservoir site, V.M. Goldberg observes that, by and large, during this process three major variants are likely: (a) complete deterioration of underground waters in the reservoir up to the extent that the waters are labelled sub-standard; (b) partial degradation in the quality of sampled waters; and (c) temporary or occasional degradation in the quality of fresh underground waters.

Complete deterioration of the quality of underground waters might occur, for example, during the draw-up of sub-standard waters from rivers under basin conditions or natural flow, when the boundary of the sub-standard waters intersects the whole field of recharge of the reservoir and lies at the upper reaches of the flow.

In concluding this chapter, let us discuss the methodological approach estimation of the balance/budget of reserves of underground waters.

An assessment of the balance of underground water reserves in the active water reservoir after some exploitation has been done, utilises the method of dissection of the hydrograph of exploitation of reserves of underground waters, as proposed by I.A. Barkalov. This method is essentially a comparative evaluation of the hydrogeological data compiled while prospecting the deposit of groundwaters with data accumulated over the years on exploitation of the reservoir, in order to determine more reliable major sources of formation of exploitable resources of underground waters and to precisely define the rational regime of work of the pumping machinery. At the stage of exploration of the deposit of underground waters one cannot always successfully estimate the influence of all the boundary conditions of the water flow in plan and section. This is perhaps due to the fact that experimental-filtration works at this stage are conducted for a shorter interval of time than during the prolonged stage of exploitation. At the stage of exploitation of the reservoir, hydrogeological factors determining the sources of formation of exploitable reserves of underground waters are fully functional, fairly reliable and sharply defined by data on regimal observations of the work of pumping. Division of the hydrograph of exploitable reserves is done by means of a general analysis of averages of factual total water withdrawal, the regime of level of underground waters and data on exploration of the deposit.

Let us look at the break-up of the hydrograph of exploited resources of underground waters from a specific example. The deposit of fracture-karst waters belongs to carbonate rocks of the Palaeozoic era. The reservoir is exploited under unconfined conditions of the layer, the short-term influence of a temporary water current and then the constant influence of a water storage that is not large.

In construction of the hydrograph the theoretical curve I (Figure 39) is plotted on the basis of parameters obtained at the stage of exploration and curve II, on the actual or true lowering of the level of underground waters in the process of exploitation of the reservoir according to regimal observation over a period of not less than four to five years (during this period the influence of all principal boundary conditions of the aquifer layer may already be conspicuous in the sector covering the pump set construction). In the example examined the period of regimal observation corresponds to the calculated period of exploitation of the deposit. The following additional hydrogeological conditions of operation of the reservoir were adopted:

a. The discharge of water reservoir varies gradually with the range in variation from 50,000 to 65,000 m^3/day.
b. Spring flows appearing in the zone of development of the cone of depression contribute to the formation of exploited resources. Other sources of water comprise temporary adjacent water bodies or reservoirs, at certain times surface waters of the permanent reservoir (river) compensating for the underground water resources of the region and finally, operation of the voluminous reserves of fracture-karst waters.
c. While conducting experimental studies at the stage of exploration to determine the parameters of the layer, the influence of the additional discharge of springs in the relief zone was not, however, studied.

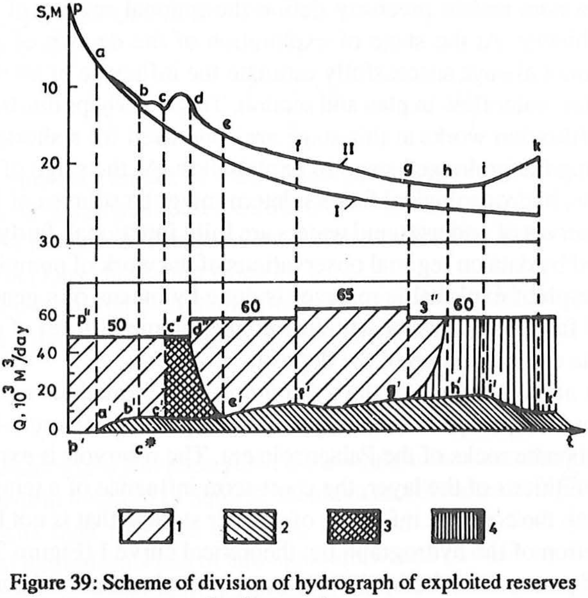

Figure 39: Scheme of division of hydrograph of exploited reserves of underground waters

1—storage volume of reserves of underground waters; 2—decrease of spring currents with regard to seasonal variations; 3—resources drawn from temporary water reservoir; 4—resources drawn from permanent water reservoir (river); I—theoretical curve; II—real curve.

In Figure 39 *a* is the starting point of the diversion of the real curve II from the theoretically projected I and indicates commencement of inclusion of spring currents in exploitation. The distinct bend observed between points *b* and *c* of curve II determines the volume of spring waters contributing to the exploited waters. The general conductivity of the reservoir in this period amounted to 50,000 m^3/day. The estimate of additional recharge through the springs contributes to curve I, corresponding to this discharge. The volume of additional recharge is determined by the area in the Figure (a′ b′ c′ c) according to the difference between actual discharge of the reservoir and discharge determined by theoretical computations. The area of the Figure (p′ a′ b′ c′ c" p") corresponds to the capacity volume forming part of the exploited reserves. Points *c* and *d* on curve II produce a peak ascent of the level of waters at the expense of the resources drawn from the temporary reservoir body over the dry river channel. The general volume of the contributed resources is expressed by the area (c′ c" d" e′). Later, general water withdrawal was initially increased to 60,000 and then to 65,000 m^3/day. As in the previous cases we determine four points e, f, g and h by projecting them on to (e′ f′ g′ and h′) in the graph using $Q = f(t)$. Segment ($e' - h'$) again expresses the discharge of the reservoir, including spring flows and voluminous reserves of fracture-karst waters. Point *g* to point *h* covers the period of gradual stabilisation of the level, which indicates the inclusion of a new additional source of recharge at the expense of filtration during this period close to the water diversions from water reservoirs. The interval of the curve between points *h* and *i* corresponds to the water withdrawal during the complete stabilisation of the level of underground waters. In segment ($i - k$) filtration of waters from surface water storage far exceeded the discharge of water from the underground reservoir. This has naturally resulted in the reduced flow of water through the springs.

Thus, the graph $S = f(t)$ reflects the character of lowering of level of underground waters according to the computed curve (during the given initial withdrawal of 50,000 m^3/day) and also according to the actual curve of lowering of level, constructed through data on regimal observations at the centre of the water reservoir. The graph $Q = f(t)$ reflects the real significance of withdrawal of waters with time and the genetic conditions of the exploited deposits involved in the period of observations on the functioning of the reservoir. The beginning of involvement of the reservoir in one or the other aspects of the water resources balance is determined by the kink in curve II, and the volume of withdrawn waters for these constituent reserves with respect to the general reservoir is determined by the characteristics obtained through projection of these points on the curve $Q = f(t)$.

Results of the estimated balance structure of exploited reserves of groundwaters, determined through computation of the hydrograph (a complex graph), can be used for specifications of the scheme of location of primary regimal network and also technological scheme for conducting *in situ* observations. It is also possible to utilise this method for estimating the balance structure of sources of flooding of ore deposits exploited by the open cast method.

CHAPTER 9

Complex Studies in Part of the Industrial Tailings Dump Under Exploitation

PROBLEMS OF INVESTIGATIONS AND PRINCIPLES OF ORGANISATION OF OBSERVATION NETWORK

As observed earlier, the beneficiation unit often forms an integral part of a mining enterprise. The unit consists of the beneficiation plant and the indirectly connected basin of storage of industrial wastes (tailings dump). The tailings dump is characterised by a comparatively complex hydrotechnical operation over an area where dumping and storing of solid phases of toxic industrial wastes are undertaken. The liquid residual phase is reworked (rendered harmless) to be utilised again for providing a continuous water supply to the beneficiation plant.

Studies during exploitation reveal that parts of the tailings dump, because of unavoidable infiltration loss of liquid wastes or accidental effluents, form potential sources of chemical contamination of underground and surface waters.

In the arid zone of the Soviet Union, where the level of underground waters lies close to the surface, chemical contamination might spread to the soil cover under the influence of intense evaporation. In such a case the need arises for conducting *in situ* experiments over the area of the industrial waste repositories in order to study conditions of migration of contaminants in underground waters, forecast possible changes in the quality of fresh underground waters and also possible flooding in the mines, to protect underground waters from chemical contamination. Such *in situ* observations have to be conducted along two distinct lines: hydrodynamic and hydrogeological investigations (complex investigations are carried out on the basis of primary and supplementary networks over the regime of wells).

The formulation of regimal observation ought to start from the computation of theoretical bases of conditions of migration of contaminants in underground waters and their interaction with the rocks. The problems of prognosis of conditions of chemical contamination of underground waters are usually solved on the hydrodynamic base of theory of mass and heat transfer, known processes of convection and also processes of interaction of underground waters with the rocks (physico-chemical processes). The major theoretical aspects of migration of contaminants or pollutants have been covered in detail in different works [4, 7, 11, 20, 36]. A very brief summary of the general theory of migration is presented below.

The important factor of migration of contaminants in underground waters is known as the convective transfer. This form of migration results due to hydraulic transfer of particles of water by filtration current. The true velocity of filtration (V_e) and the effective porosity of the water-bearing country rocks (n_0), principally control the transfer of underground waters. Physico-chemical processes, made complex by the migration of contaminated underground waters, include sorption and desorption as well as solution. To resolve practical problems of prognosis of possible changes in the quality of underground waters the most simple formulation of migration—according to the scheme known as 'piston drive' (driving out one liquid by another with no mixing of the two), is adopted. According to this scheme, conditionally all the particles of waters in the homogeneous aquifer layers migrate into the zone of complete saturation with uniform velocity. The physico-chemical processes taking place during this scheme have not, however, been studied.

In real conditions of exploitation of basins—storage reservoirs of tailings—migration of contaminants takes place in the upper shallow aquifer horizons during the relatively large natural velocity of flow of underground waters, that is, under conditions of primarily convective transfer of substances together with the water phase. Observations from experience gained in exploitation, reveal that formation of the field of contamination originates at a certain phase. In the early phase, under the influence of unavoidable infiltration loss, a mound of contamination forms at the bottom of the basin and spreads over the surface of the groundwaters. In this phase migration of the zone of aeration originates in the rocks. The starting phase of contamination of underground waters is similarly characterised by a regime of free filtration; the phase of free filtration may be prolonged from one to two years.

Furthermore, in the processes of filtration the second phase—confluence of flows from industrial tailings reservoir with groundwaters—approaches and a regime of supporting filtration current is formed in the zone of infiltration. At this phase waste waters are dislodged by the groundwaters. Finally, the third phase approaches. It truly represents the migration of contaminants along the aquifer horizon, forming a contamination front in plan of the flow. The formation of a field of pollution of underground waters below the tailings reservoir depends upon a number of factors, of which the most important are: significance of natural velocity of flow, filtration heterogeneity of water-bearing country rocks and also difference in density of waste and underground waters. Under an insignificant difference in density and a high velocity of flow, the field of contamination would be primarily distributed in the upper part of the aquifer horizon.

In situ hydrochemical investigations should determine: discharge of waste waters filtering from the reservoir of industrial wastes; estimate of distribution of pressures in the aquifer horizon and natural velocity of flow of underground waters and precise migration parameters of the layer. Hydrogeochemical investigations must be directed towards conditions of migration of contaminating substances in underground waters (distribution of concentrations of contaminants in space and time).

Special primary and supplementary networks of observation wells should be organised over areas of exploitation of reservoirs of toxic industrial effluents. A complex *in situ* study of the regime of underground waters in the area of exploitation of the tailings dump is imperative to ensure control-prevention functions. Control functions consist of early detection of contamination of underground waters and collection of information for operational forecasting. Preventive functions consist of timely development and introduction of operational measures for protecting underground waters from contamination and the surrounding environment as a whole from the negative influence of technogenic processes.

During the organisation of the primary or basic network it is essential to take into account the following guiding principles of placement of the observation wells.

Principle of recording of lithological-structural and natural-hydrogeological conditions of the study area: Conditions of formation of filtration current in plan, thickness and lithological composition of water-containing country rocks, filtration properties of rocks and their heterogeneity in plan and section, presence of zones with increased natural velocities of filtration through which it is possible to expect more intensive penetration of contaminants etc. These conditions can be qualitatively determined during the scheme-formulation of the field of filtration. This principle can be used for the choice of distances between exploratory wells. Hydrogeological relations of the sector of the basic network should be fairly well studied.

Principle of totality of investigations to guarantee solution of the problem of preservation of quality of underground waters. This principle is broad and encompasses methodological procedures that incorporate: (a) centrifugal disposition of observation wells diverging from tailings dump in the direction of movement of natural flow; (b) study of conditions of migration of contamination not only in plan (areal extent) but also in cross-section of the aquifer (keeping in view filtration heterogeneity in the profile section), for which, when thick enough, a multi-level disposition of wells is indispensable; (c) layered arrangement of observation wells of the primary network from the inception of investigations and later, collection of new hydrogeochemical information in the process of *in situ* investigations of the regime; and (d) drilling observation wells in direct proximity to the pioneer dams of the reservoir basins, so that the initial stage of migration can be fixed and finalised through investigations.

The principle involves a fairly distinct definition of the pattern in the regime of dispersion of contaminating components in the aquifer horizon (formation of contour of contamination in plan and section, conditions of advancement of contour with time according to plan, distribution of concentrations of contaminants in underground waters etc.). It follows from this principle that the early alignment of observation wells ought to be laid out close to the reservoir basin (approximately 30-100 m) and the gauging section placed en route to the protected object (in the

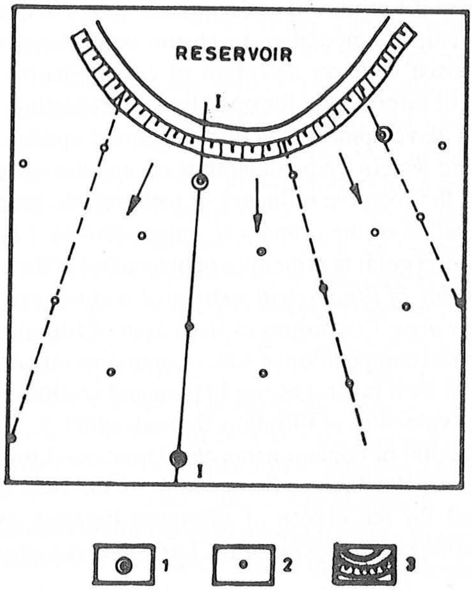

Figure 40: Approximate scheme of disposition of primary observation network in part of tailings dam (reservoir)

1 and 2—observation wells: 1—multi-level; 2—solitary; 3—pioneer tailings dam
I-I—line of cross-section. Arrows indicate direction of movement of natural flow.

present case, the working reservoir). The distances between wells in radial alignments have to be determined for every study sector, taking into account the principle discussed. Figures 40 and 41 present schematic diagrams of disposition of the basic network of observation wells in the area, adjacent to the reservoir in the realm of the region to be protected, under the first stage of investigation. If the aquifer horizon is very thick, it is very important to decipher the profile of filtration heterogeneity of the rocks. Hence, it is essential that a multi-level disposition of observation wells be implemented.

Principle of determining boundary conditions of flow in plan: This embraces all the preventive functions of complex investigations and predetermines the conditions of distribution of observation wells. Above all, the targets to be protected from possible pollution are rivers, water tanks with fresh waters, active reservoir area etc. Observation wells between the objects of protection and the tailings reservoir have to be placed according to the hydrogeological profile in such a way

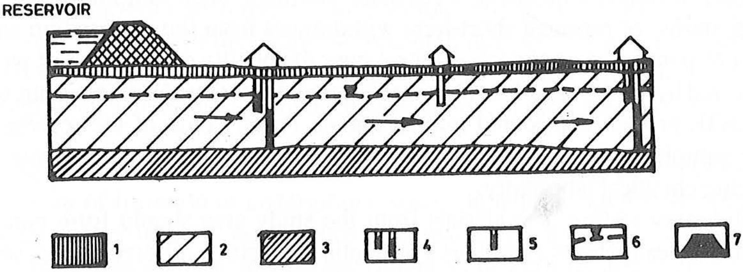

Figure 41: Hydrogeological profile along line I-I (see Figure 45) of primary network of observation wells

1—weakly permeable loams; 2—aquifer rocks; 3—impermeable rocks observation wells equipped with filters; 4—multi-level; 5—solitary; 6—level of underground waters; 7—pioneer reservoir dam Arrows indicate direction of movement of underground waters.

that it is possible to determine at the right time, the period of movement of the front of contamination and later, in case of necessity, to be able to take appropriate preventive measures.

An important aspect of the complex investigations in the tailings reservoir is the method of conducting *in situ* observations. Studies should comprise the following: regime of level and temperature of underground waters; changes in quality of underground waters with time, originating under the influence of migration of pollutants; formation (in plan) of contour on the field of contamination and its movement with time; concentrations of contaminants or pollutants in underground waters; and also well-defined significance of natural velocity and migration parameters. The frequency of observations on levels of underground waters and sampling of well waters for laboratory determinations is difficult to stipulate; it should be determined independently for each concrete case, depending upon the degree of complexity of the study area, the velocity of advancement of contaminants along the layer (velocity of natural flow of underground waters) and other factors. The choice of frequency of observations must perforce to be established experimentally at the first stage of conducting natural investigations.

Sampling of waters close to the pioneer tailings dam reservoir must be done more frequently than in regions remote from it. For example, according to the information provided by V.A. Mironenko, the average velocity of movement of the front of contamination in the areas of KMA close to Lebedin's tailings reservoir reaches 200-250 m/year and in the Stoilen area, 300 m/year. According to the data of V.M. Gol'dberg, in one of the areas, the velocity of distribution of contamination in the sands of the Cretaceous period changed from 40 to 130-150 m/year. In practise, the frequency of hydrodynamic and hydrogeochemical observations is once or twice a month.

Sampling of waters for subsequent laboratory analyses and estimation of contaminants is done by means of well-water samplers. Such samplings ought to be representative of repeated short-term withdrawals from the observation wells by means of pump sets or augers. Control over the quality of pumping of wells can be effected by means of resistivity meter logging. Water samples from sources other than wells are not considered representative. Preservation of the representative water samples has to be undertaken coincidentally with requirements of the servicing chemical laboratory.

Laboratory testing of materials from the study area should form part of the complex investigations as well as systematic analysis of different maps, sections, profiles and graphs. One of the most important aspects of the study is the compilation of operational hydrogeochemical maps of the observation network covering the tailings reservoir, the area to be protected from contamination, and the field lying between these two. Results of hydrogeochemical sampling, reflecting temporal (annual) follow-up of the formation and advancement of the pollution front are permanently recorded on such maps. Similarly, maps of groundwater contours and flow lines, hydrogeological and hydrogeochemical sections showing samples obtained etc., should be constructed. Figure 38 is a schematic diagram showing conditions of contamination of underground waters of the upper Cretaceous aquifer horizon in a sector of exploitation of an industrial slurry dump (as reported by V.M. Gol'dberg and V.M. Moshkin).

PROGNOSIS OF CONDITIONS OF CONTAMINATION OF UNDERGROUND WATERS

Prognostic evaluation of the conditions of contamination of underground waters in that sector of the tailings reservoir under exploitation consists of a solution to the following problems: (a) quantitative estimation of filtration loss through the tailings dump; (b) evaluation of time of arrival of infiltration of waste waters from the bottom of the basin to the level of the underground waters; and (c) timely assessment of the conditions and degree of distribution of contaminants directly in the aquifer horizon. The results of prognostic estimation or investigations in nature ought to be so geared as to enable adoption of measures for the protection of the target area from contamination.

An approximate solution to the practical problems enumerated above, under simple hydrogeological conditions, can be attempted on the basis of analytical relations according to the scheme 'piston' drive. For complex conditions and larger areas the method of modelling is preferred.

The concept of 'piston' drive embraces mathematical relations which involve time and distance of advancing contour of contaminated waters. It is assumed that conditionally contaminated waters are neutral in their relations with the rocks and the underground waters of the study horizon, and do not come into contact with them and interact. That is, processes of molecular diffusion and sorption are not taken into account. Such a procedure in many cases helps to solve the practical problems satisfactorily. Hydrogeological prognosis of migration of contamination in layered media without reference to sorption processes requires, in fact, an estimation of the upper limits of spread of contamination, that is, guarantees of a certain strength factor which is very essential for controlling changes in the quality of underground waters and simultaneous adoption, if necessary, of protective measures.

The important factor in the prognostic evaluation of migration of contamination is the velocity of filtration of underground waters in natural conditions. Analysis of the map of underground water contours prepared for the study sector in each specific case, demands more precise determination of the direction of flow of the underground waters. In the case of the known value of coefficient of filtration of the aquifer rocks, the natural velocity of flow has the mathematical relationship V_e—ki/n_0, where k—coefficient of filtration, I—gradient of current, and n_0—effective porosity.

For simplification of the prognostic condition of migration of contamination in underground waters of the basin of industrial tailings, depending on their configuration, the scheme plan can be presented in the form of a circle (closed contour of basin, with length-wise and cross-wise measurements comparable).

The problem of determination of time of arrival of effluent liquids from tailings to the level of underground waters can be solved approximately by the formula:

$$t = \frac{n_0 H_0}{k}\left[\frac{m}{H_0} - \ln\left(1 + \frac{m}{H_0}\right)\right] ,$$

where n_0—porosity of rocks at the zone of aeration; H_0—height of layer of waste waters in tailings reservoir; m—thickness of rocks in zone of aeration.

Natural observations and calculations as per the formula above reveal that the time for liquid wastes to reach the level of underground waters is essentially determined by filtration properties of the rocks of the zone of aeration. This time on the whole, however, is not usually large. For example, for values of coefficient of filtration of rocks less than 0.5 m/day, this time runs to a few tens of days, and for a value less than 0.01 m/day up to a hundred days. The confluence of level of groundwaters with the bottom of the reservoir in the process of migration of industrial effluents (formation of conditions of propped-up filtration) in general, takes place quickly—in a period not exceeding about one to two years. Hence, an estimate of the propped-up (supportive) filtration from the reservoir of waste waters might originate under a conditionally propped-up regime.

If in the basin the column of liquid wastes changes with time, that is, $H_0 = f(t)$ and the specific yield $q > k$, then the time taken by the wastes to reach the level of groundwaters can be determined according to the following function:

$$t = \frac{m}{\frac{(l-n)k}{2n} + \sqrt{\frac{(l-m)k^2}{4n^2} + \frac{qk}{n}}} ;$$

where q—effective discharge or yield of industrial waste Q/F (Q—general yield of wastes; F—general area of filtration).

For homogeneous rocks of the zone of aeration, the general discharge Q_{cp} of filtration of industrial wastes from the reservoir of circular configuration can be determined by the following relationship:

$$Q_{cp} = \frac{km\ H_0}{0.366\ lg\ (R/R_K)} ,$$

where R—distance from centre of tailings reservoir up to contour of recharge of the aquifer horizon; R_K—radius of circular basin.

For the linear form of the reservoir basin the discharge of wastes from the tailings (q_{cp}) per unit length can be determined by the formula

$$q_{cp} = km\,H_0\ (\Delta\ L) ,$$

where $\Delta\ L$—hydraulic resistance, determined for a homogeneous layer according to the relation:

$$\Delta\ L = B - \frac{2m}{\pi}\ \ln\ \text{sh}\ \frac{\pi B}{2m} ,$$

where B—semi-width of basin.

The filtration losses from a technical reservoir can also be determined by direct methods: (a) balançed; and (b) spot sampling (using infiltrometers of VNII VODGEO's submersible type or VNIMI's floating type of system) with the subsequent total results over the whole field of the reservoir basin [4, 20].

When filtrations of contamination reach the level of groundwaters, their migration along the layer starts together with underground waters. The velocity (V) of movement of contaminated waters during filtration from basins of extended character, can be approximately computed at the bottom along the current according to the relation:

$$V = \frac{q_{cp}}{2mn_0} + \frac{v_e}{n_0} , \qquad ...(1)$$

where q_{cp} — filtration losses of industrial effluents along a unit length of the reservoir; m—average thickness of aquifer horizon; n_0 —porosity of aquifer horizon; v_e— velocity of filtration of natural current of underground waters.

The arbitrary choice of distance (x) over which contaminated waters intermix in the layer with time (t), for a linear form of basin is equal to $v_e\, t$.

For basins of circular configuration, calculations can be done as for a circular gallery with the discharge equal to that of filtration from the tailings reservoir of waste waters. During these conditions the arbitrary choice of distance (x_1) through which contaminated waters migrate along the layer over time (t) under the influence of filtration loss from the basin Q_f can be determined using the formula:

$$x_1 = \sqrt{R^2 + \frac{Q\phi\, t}{\pi\, n_0\, m} + \frac{v_e\, t}{n_0}} - R\,. \qquad ...(2)$$

With the help of approximate computations utilising equations (2) and (3), it is possible to estimate the time over which migration of contaminated waters might reach the area to be protected from pollution. These approximate calculations are helpful in planning the disposition of the primary observation network. It is pertinent to notice that the velocity of natural current forms an essential factor under the conditions of flow of underground waters, for the migration of polluted waters. The more the velocity of the natural current, the less the area of flow of contaminated waters in the aquifer layer; during this, waste waters would spread not throughout the thickness of the aquifer horizon, but primarily within the limits of the upper part. Towards the bottom, according to the current, the thickness of the zone of flow would register an increase. When the thickness of liquid wastes is very high, contamination may spread throughout the thickness of the aquifer horizon.

As observations indicate, the velocity of distribution of contamination in underground waters confined to granular rocks, commonly spreads from a few tens to a hundred metres per annum. This velocity may reach a few kilometers per annum in fractured and karstified carbonate rocks.

Considering the fact that the source of contamination of underground waters is contained for a long time after conservation of the tailings dump, it is extremely necessary to continue complex *in situ* investigations over the study area even during the period after cessation of exploitation of the tailings of industrial waste.

Measures to protect underground waters from contamination over areas where tailings are reworked, may following this scheme: (a) essential reduction of filtration loss from industrial tailings through careful box-screening of technical reservoirs, i.e., impervious insulations; (b) utilisation of purified waste waters for the system of repeated recycling to provide water supply for the beneficiation plant; and (c) tapping infiltrated industrial waste waters through construction of a closely spaced system of drainage borewells for renewed utilisation in the water supply. This method of protection is discussed below.

ANALYSIS OF INFLUENCE OF STORAGE OF INDUSTRIAL WASTES ON CONTAMINATION OF UNDERGROUND WATERS

The technical reservoir basin of accumulation of industrial waste is situated within the limits of the flood terraces of a large river, the surface current of which acts periodically over the course of a year. The basin receives inputs from the beneficiation plant, reworking copper ores. Washings from the industry started in 1961. The plan period of exploitation of the basin was established in 19 to 20 years. The area of tailings dump occupies 800 ha and the rated volume, 225 million m^3.

Geologically, part of the technical reservoir area is composed of a sandy-pebbly alluvial formation of the Upper Quaternary period. Within the limits of the study region, zones of different permeability are exposed in the section of sandy-pebbly rocks.

The upper 30-40 metre thick zone comprises pebbles with sand filling the interstices. A second zone, 30 to 35 metres thick, lies underneath which, in the southern part of the tailings basin, is composed of pebbles with a sand matrix of finer grain size and in the northern part is replaced by loamy formations with distinct pebble inclusions. The coefficient of filtration in the most permeable upper part of the aquifer horizon varies from 120 to 500 m/day. The average coefficient of filtration is 200 m/day. The permeability of the lower pebbly zone (40-70 m) is of the order of 10 m/day. Below 70 m, the permeability of the deposit reaches 0.5-1 m/day. The thickness of the zone of aeration in natural conditions changes from 6 to 10 metres. Filtration properties of the rocks of the zone of aeration were not studied.

In the sandy-pebbly deposit a relatively thick current of fresh groundwaters is formed with the general mineral content varying from 0.2-0.4 g/l of hydrocarbonates of calcium.

A first order storage was constructed in 1961 right on the ground without insulating the bottom. Washings from the industry accumulated on the surface, introducing complexity in the sandy-pebbly deposits with good filtration properties. Under these conditions, an intensive infiltration of wastes very quickly resulted in contamination of groundwaters. At this period, all the volume of liquid discharge into the tailings was filtrated through the bottom and was partly evaporated. A second-order storage was built in 1971 with an insulation layer constructed over the clayey-rock formation. However, even under such conditions the volume of infiltration currents remained nearly at 40,000-50,000 m^3/day. Later, the volume dropped to 30,000 first and then to 10,000-15,000 m^3/day. After screening the bottom of the tailings dump filtration of industrial wastes or contaminants was observed primarily close to the dam. Exploitation of the tailings at the end of the first year itself resulted in the formation below the pioneer dam of an aureole of contaminated waters, which began mixing with the underground waters at the rate of 10 m/day. Contamination of the underground waters was studied based on changes in degree of mineral content. The general mineral content of liquid wastes directly discharged over the site was estimated at 1.5 to 2.5 g/l. However, because of evaporation over the area of tailings discharge, the general mineral content of the currents increased to 10 g/1.

A study of the process of contamination of underground waters was conducted through *in situ* observations via the basic and supplementary network of borewells. At the first stage the observation network was set up directly next to the pioneer dam. Hydrodynamic and hydrogeochemical observations were conducted in the wells, with an average of one observation in 10-15 days. At the second stage, according to the rate of advancement of the aureole of contamination, the supplementary network of observation wells was established following the radial system shown in Figure 42.

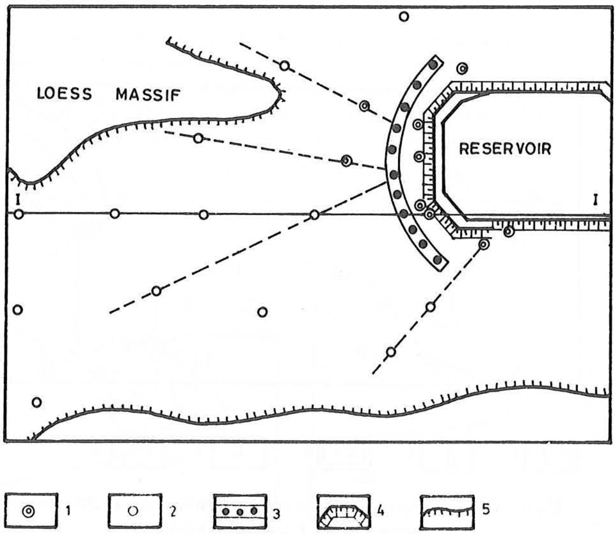

Figure 42: Scheme of disposition of observation and exploitation wells

Observation wells; 1—first stage of study; 2—second stage of study; 3—exploitation drainage wells; 4—dam; 5—contour of river valley
I-I—line of section.

The depth of the observation wells was determined by the thickness of distribution of the highly permeable sandy-pebbly aquifer rocks, which was nearly 20-30 m. Each well was lined with a screen throughout its depth. Independent observation wells were drilled to a depth of 60 to 70 m to study conditions of migration of contaminants in the vertical section.

All complex *in situ* observations (for determining the level and changes in mineral contents of underground waters) were carried out once or twice a month initially and later extended from once to two or three times a month. The results of regimal observations permitted an estimate of changes in the plan structure of the aureole of contamination in different periods of exploitation of the tailings dump. According to the periodic data obtained (approximately once a year) the following were compiled: groundwater contour (isophreatic surfaces) and flow lines of underground waters; and hydrogeochemical maps and sections of distribution of general mineral contents of underground waters, formed under the influence of filtration currents from the tailings reservoir (Figure 43). The rate of distribution of the aureole of contaminated underground waters along with their mineral contents reached an average of 120-150 m/year.

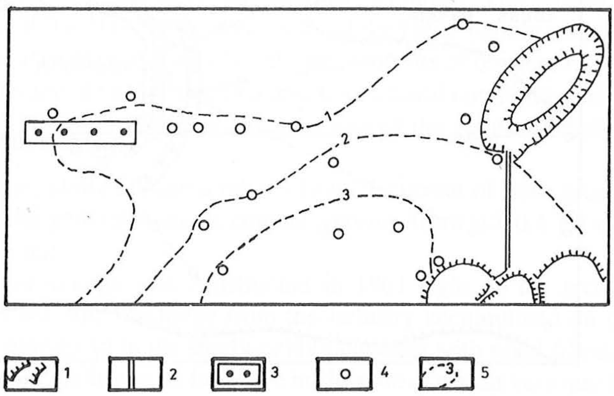

Figure 43: Schematic conditions of contamination of underground waters of the Cretaceous horizon

1—contours of slag storage and settling tanks; 2—overflow canal; 3—reservoir (wells); 4—observation well; 5—mineralisation contours (values in g/l).

To protect fresh underground waters from contamination, in accordance with the recommendations of VNII VODGEO (All Union Scientific Investigators' Institute of Hydrogeology), planning and construction of the drainage system close to the pioneer dam were carried out (Figure 44). The system consisted of 45 interacting borewells (29 working and 16 in reserve); the distance between the wells was kept at 250 m. Drainage wells were bored to a depth of 60-70 m and were fitted with porous filters throughout their depth. Pumping out contaminated underground

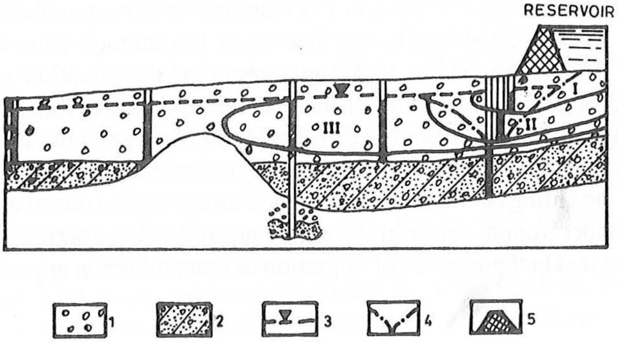

Figure 44: Geological-chemical profile along line of cross-section I-I (see Figure 47)

Sandy-pebbly deposits: 1—highly permeable; 2—weakly permeable; 3—groundwater table; 4—cone of depression along line of drainage; 5—pioneer dam
I, II, III—zones of contamination of underground waters of different mineral contents: I—more than 3 g/1; II—more than 1 g/1; III—0.7-1.0 g/1.

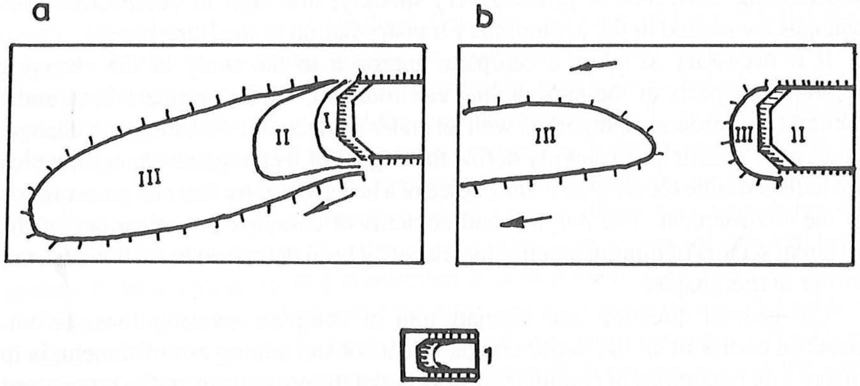

Figure 45: Schematic distribution of mineral contents of underground waters

1—Tailings dam and reservoir
I, II, III—zones of distribution of underground water with varying mineral contents: I—more than 3 g/1; II—more than 1 g/1; III—0.7-1.0 g/1
Arrows indicate direction of movement of underground waters.

water in quantities of 25,000-30,000 m^3/day provided directly the requirements, at the stage of repeated water supply, of the beneficiation plant. The protective measures adopted permitted, to a considerable extent, the necessary insulation of the source of contamination. Thus, in 1975 the aureole of contamination was found distributed over a considerable distance from the tailings dam through flow movement (Figure 45, a). In 1976, as a result of the adoption of preventive measures, a break in distribution of the underground water front occurred, with mineral contents ranging from 0.7 to 1.0 g/l (vide Figure 45, b). This situation is positively reflected in the general hydrogeological setting of the study area.

In 1983 the tailings dump was conserved, although *in situ* observations over the regime of underground waters in the region are still being continued to ascertain whether any residual processes of migration of contamination appear in the study area.

ORGANISING A MONITORING SYSTEM IN MINING ENTERPRISES

A change in the ecological situation of the environment around the region of mining activity can originate under the influence of both natural as well as technogenic processes. Any change under the influence of natural processes takes place slowly and the period of change is measured in historical epochs. An exception to these historically applicable rules is the revolutionary behaviour of nature, as exhibited by the phenomena of earthquakes and volcanic eruptions. Contrarily, technogenic changes in properties of different components of the surrounding environment proceed very quickly, although in perspective such changes are related to the evolutionary transformation of the lithosphere.

It is necessary to adopt a complete approach to the study of the changing ecological aspects of the surrounding environment, which originate both under natural (background changes) as well as under technogenic (technogenic change) processes. This helps to sharply define the degree of technogenic changes, which are indispensable for prognosis and choice of a basis for protection and preservation of the environment. The purpose and contents of complex investigations of the different sectors of mining practise have already been described in sufficient detail earlier in this chapter.

The general direction and ultimate aim of complex investigations, as emphasised earlier in all the major compartments of the mining establishment, is to ensure safe conditions of commercial working of the ore deposit and to protect and preserve the ecology of the environment, and the living standard and productive capacity of the workers. Considering the need for co-ordinating the large complex of investigations conducted at the stage of exploitation of ore deposits, the positive availability of general scientific and methodical guidance for investigations, the centralisation of collection, processing and analysis of hydrogeological and engineering geological information and also adoption of operational measures for successfully solving the major problems, it is most important to evolve a complex system of monitoring large mining enterprises.

Monitoring, as a significant scientific term, has to be understood as a system of registration which involves collection of some kind of information with the aim of generalisation, control and dissemination of results to the general user. Primarily, in conducting complex investigations on ore deposits at the stage of their exploitation, this scheme of monitoring is nothing but a well-organised, target-oriented system of documentation of natural investigations of the regime of underground waters and technogenic processes, providing for collection of information, its processing, analysis and recommendations for solving practical problems in the protection of the surrounding environment from the negative influence of technogenesis.

Yu A. Izrael' [13] points out in his works that the scientific term 'monitoring' was proposed in 1972 at the Stockholm conference of the United Nations Organisation. In concept and content the term is meant to convey the meaning 'form of control'.

Judging from the use of this term in publications in our country and abroad, the term 'monitoring' is applied not only as a system of observation (registration) and obtaining of primary information, but also as an element of active control providing proper direction for the study of the object or the problem. *On the whole, the scientific understanding has obviously to be considered a purposeful system of controlled precautionary studies, involved in obtaining information for prognosis and defining lines of study of the process under investigation.* Yu A. Izrael' [13] considers that the system of observations required to distinguish changes in the constitution of the biosphere resulting from the influence of human activity, is correctly called 'monitoring'. Such an explanation of the term is shared by academician I.P. Gerasimov [6]. In later publications Yu A. Izrael' somewhat modified the scientific meaning of the term 'monitoring' to mean a system which synthesises information for exposing and estimating technogenic effects in the surrounding environment. As a consequence of these definitions, the prognosis and management of technogenic processes which lower or dampen the importance and practical direction of one or the other type of investigation, are not included in the system of monitoring. In this connection it is important to be more precise in defining the scientific denotation of the term 'monitoring', primarily in a study of the technogenic changes in hydrogeological and engineering geological conditions at the stage of commercial exploitation of ore deposits. It is necessary to understand the complex system of monitoring the hydrogeology of ore deposits as a unique system of controlled natural investigations (recording observations and collection of information), for the purpose of *in situ* study of technogenic processes, whose negative influence may lead to changes in the geological environment as well as in the ecological background of the living and working conditions of miners.

Taking into account the practical direction of monitoring, at the closing stage of the complex investigation, one should consider processing (generalising) and analysis of the data collected, prognostic estimation of technogenesis, and also the hydrogeological basis of the measures taken to protect the environment. Therefore, the complex system of monitoring the hydrogeology of ore deposits must possess preventive-control functions. Because the natural investigations on ore deposits are complex, in any given case it is essential to look upon monitoring as a multi-purpose information system. Hence, a study of the technogenic processes and the regime of underground waters in all sectors of the mining complex where technogenesis develops, forms an integral part of in-depth investigations.

Similarly, by its own definition, one should not consider the complex system of monitoring as a new system of natural studies, requiring the organisation of a special network of observations. The complex of *in situ* observations and control over the status of the technogenic changes in hydrogeological and engineering geological conditions during the exploitation of ore deposits and the observation network (vide Chapters 5 and 6), have to be fully incorporated in the information system of monitoring. Monitoring must be based precisely on the basis of the primary and supplementary networks of observation wells and observation points. The question, therefore, is the creation of a new observation network and the regulation of a single universal preventive-control network at the mining enterprise, intended for complex *in situ* study of the technogenic processes over the entire complex at the stage of exploitation.

To arrange for more reliable isolation of monitoring of the degree of changes resulting from the negative influence of technogenesis in different sections of the mining enterprise, and later the adoption of more effective measures of protection of the surrounding environment, it is equally necessary to obtain information on the natural changes in the characteristics of the different components of the natural situation (the background constitution). Therefore, during organisation of the complex system of monitoring at the mine site, the *in situ* observation network ought to include areas adjacent to the study area proper for the purpose of understanding the natural regime of underground waters and geodynamic processes. This inherently necessitates additional requirements in the organisation of the system of monitoring at the mining complex.

As demonstrated by experience, the complex system of monitoring is applicable to areas of complex hydrogeological and engineering geological conditions prevalent in ore deposits of the third and fourth group of geo-industrial classification (vide Table 5).

Technical instrumentation of the observation network and automation of primary documentation of the observation regimes (automatic recording and retrieval of information in independent or centralised receiving panels) constitute a very important division of the complex system of monitoring. In the Soviet Union progress has been made in this direction mainly through automation and recording of the functioning of the shaft pump. It noteworthy that an automatic system has been introduced in all drainage installations at the Bacon mines of the Nirod bauxite deposit in the People's Republic of Hungary. This deposit belongs to a relatively thick series of carbonate rocks of the Paleozoic, forming part of the synclinal structure. The ore-bearing rocks possess a very high water potential. The deposit is excavated by underground mining under the protection of exterior drainage constructions. The system of drainage construction possesses an areal character. Drainage centres are situated mainly in the zones of maximum water abundance (at the intersections of tectonic fractures) and comprise borehole shafts 2 m in diameter penetrating to a depth of 300 m; special boring equipment is used for drainage operations. Each shaft well is provided with three to four electro-submersible pumps, each producing 450 m^3 water per hour.

All such drainage centres (numbering 40) are provided with such pumps. The total yield of fracture-karst waters amounts to 18,000 m^3/hr. After 21 years of industrial exploitation of the bauxite deposit the level of fracture-karst waters was lowered by 110 m in the mines. Observations have established the fact that for draining one metre of the rock mass within the limits of the mining area, 20 million m^3 of mine waters have to be pumped out.

All observations on the system of drainage constructions (observations such as levels, discharge temperature etc.), including observations on the working of the pump set (automatic regulation of exploitation), complete automation and programming are handled through an EVM computer. It is known that the system of monitoring includes constant supervision of the levels and discharges of mineral waters distributed in the health resort zone of Lake Balaton. Similarly, problems of general investigations must comprise preventive-control functions over the regime of a large group of mineral springs. In this connection, levels of absolute elevation controls have been established, below which the general lowering of fracture-karst waters is not allowed at the deposit. The entire quantity of pumped-out fracture-karst waters is used for domestic, drinking water and technical water supply at the mine site.

As has been amply proved by experience, such a system of hydrogeological monitoring must provide extensive information of high reliability, assure the assigned regime of drainage an economical power supply, ensure safe mining conditions against underground waters and preserve the environment from negative technogenic influences.

Processing materials from *in situ* observations assume considerable significance in the general system of monitoring, particularly during the solution of problems relating to prognosis of the negative influence of technogenic processes on the surrounding environment. While studying the formation of technogenesis, certain problems on prognosis can be solved through analytical calculations specially worked out for typical schemes (vide Chapter 11). It is of course convenient to solve complex prognostic problems through mathematical modelling over an EVM computer.

In conclusion, let us note certain forms of organisation of monitoring in regions of ore deposits. The major role in the organisation and execution of complex investigations to provide a unified information system is played by the hydrogeological unit of the mining enterprise, without which it would be almost impossible to handle the mining activity of ore deposits of such complexity as those of the third and fourth group.

Still, for the successful solution of problems hydrogeological monitoring has to be guided by necessary laws and supported by technical excellence.

Monitoring has to be carried out under the general guidance of the chief geologist or the chief engineer of the mining enterprise.

The principal structure of the complex investigations—the major directions of approach and the principal problems involved—of the system of monitoring of the hydrogeology of ore deposits at different stages of their commercial working is presented briefly below:

The major directions of studies are: (1) Controlled supervision for ensuring safe hydrogeological and engineering geological conditions in the commercial working of the deposits; (2) *in situ* study of technogenic changes in the hydrogeological and engineering geological conditions during exploitation of all the targets in the undertaking; and (3) preservation and protection of the geological environment and the ecological character of the surrounding environmental living and working conditions of the people.

The principal problems of the complex studies comprise: (1) collection, processing and analysis of primary hydrogeological and engineering geological information; (2) warning of possible changes (or advent of hazards) in safe conditions of mining and the negative influence of technogenesis; and (3) prognosis of possible development (tendency towards development) of technogenesis, the basis for introducing preventive measures of environmental conservation.

CHAPTER 10

Processing of Information Obtained Through Complex Studies

GENERAL PROBLEMS AND METHODICAL PROCEDURES FOR THEIR SOLUTION

The laboratory processing of hydrogeological and engineering geological data, technogenic processes and primary documentation of mine survey data comprises and completes the complex investigations at the stage of exploitation of ore deposits. The general direction of laboratory studies is well defined by the major problems; a brief account of the problems and the methodological procedures for their solution is outlined below:

In field studies of hydrogeological conditions during mining, it is essential to process the materials in the laboratory as given below:

1. From the data collected during exploitation of ore deposits, the complexity of hydro- and engineering geological conditions at that stage can be re-estimated. This problem can be solved through more precise earlier (at the stage of exploration) compiled large-scale maps and cross-sections, reflecting the technogenic changes in conditions obtaining in the main aquifer horizons, recharge and discharge of underground waters, linking of underground and surface waters, formation of cone of depression, hydrological role of tectonic dislocations in flooding of mines and also other boundary conditions of filtration currents.

   Such maps help to periodically evaluate the degree of technogenic changes in hydrogeological and engineering geological conditions, formed under the influence of drainage of mines, and also the degree of influence of drainage of deposit on the geological and surrounding environment. The results of such an analysis might be used for defining measures to be taken to protect the environment from negative technogenic influences. During the compilation of maps of technogenic changes, traditional operational methodological procedures may be used.
2. The nature and content of the groundwater of ore-bearing country rocks and supra-ore series (in plan and section) at the stage of exploitation and condi-

tions of flooding of mines have to be characterised through analysis of hydrogeological horizon-plans or plans of flanges of open cast mines. The general patterns might be utilised for estimating hydrogeological conditions with increase in depth of drilling. This analysis involves the construction of different useful graphs, reflecting the conditions of formation (maximal, minimal, half-yearly) of the temporary tracks of water currents, distinct along the flanks of the deposit, separate horizons at different depths in the analogous, geological-hydrogeological conditions, etc. On the whole, processing and analysis of such materials would be very helpful in characterising the conditions and degree of flooding in mines and adjoining areas of development, locating most of the flooded zones and determining changes in the rate of flow with depth. These data might also be useful for precise positioning of the observation points in underground mines and also developing additional measures for their protection from flooding.

3. Another essential scientific exercise is estimation of the engineering-geological (mining-engineering) conditions during drilling and exploitation of ores by shaft or open cast mining through the use of plans of different levels or horizons (fracturing of rocks, tectonic dislocations, working of unstable rock mass, appearance of technogenic processes etc.). Such plans can be combined with hydrogeological plans of flooding and later used in devising measures to protect the mines from geodynamic processes.
4. To precisely locate the major sources of flooding in mines and to estimate their balance structure through analysis of hydrogeological conditions of the deposit and balance studies. In this connection, it is desirable to construct complex graphs reflecting changes in the rate of flow with time (whether in underground or open cut mines), levels of underground waters in various parts over the cone of depression, atmospheric precipitation and regime of surface currents of the local river system (Figure 46). When the necessary information is available, the problem can be solved through analysis of the hydrograph of water flows. Analysis of such materials might be used in planning additional measures of protection of the mines from flooding and also precising the location of observation points of the regimal network.
5. Periodic evaluation of the effective functioning of the intra-shaft (intra-open cast) and also external drainage constructions, ensuring continuation of dewatering of the mines and safe conditions of mining. Such problems are solved through analyses of graphs characterising the regime of general productivity of drainage wells and levels of underground waters in the area of mining. Graphs are plotted with the following coordinates—$\Sigma Q_{dr} = f(t)$ and $S = f(r, t)$. Comparisons of these data with prognostic (projected) values and also with the factual situation of drainage conditions are taken into account in solving problems. Such comparative analysis together with data on the technical aspects of the drainage constructions allow determination of the degree of drainage in mines, safe conditions of their working, exposition

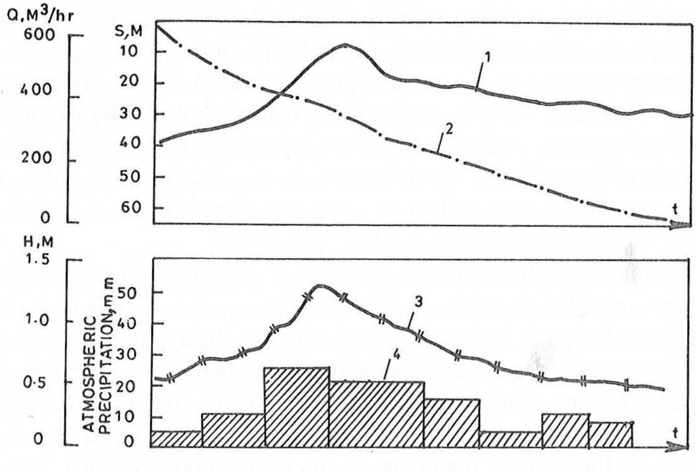

Figure 46: Complex graphs

1—general water flows (Q); 2—level of underground waters (S) at centre of mine working; 3—level of waters (H) in river; 4—atmospheric precipitation.

of reasons for unsatisfactory working of the drainage system and, at times, adoption of additional measures for more effective drainage.

6. Periodic assessment of quality of mine waters and changes in it with time under the influence of technogenesis is a very important problem. It can be solved through analysis of regimal observations on the chemical and sanitary-bacteriological composition of the mine waters by constructing graphs, with changes in the general mineral content (M) of the mine waters with time with the coordinates $M = f(t)$ and also the harmful components in water. Such an analysis helps to solve certain practical problems regarding utilisation of mine waters for industrial water supply and irrigation. It also permits evaluation of the conditions of discharge of the mine waters to the surface and their possible influence on the environment.
7. To determine the condition of formation of the cone of depression lowering the water table, structure of filtration current and significance (conservation) of hydrostatic pressures over the principal working and preparatory horizons. This problem can be solved through periodic (preferably quarterly) preparation of groundwater contour maps under confined and unconfined conditions (isophreatic surfaces) and also large-scale hydrogeological profiles constructed throughout the area of cone of depression, along the principal underground workings or banks of the open cast mines. Analysis of groundwater contour maps, plotting of directions of flow and hydrogeologi-

cal profiles assist in evaluating the structure of the technogenic filtration current, determining the significance of residual hydrostatic pressures of underground waters in mines, estimating the degree of influence of drainage during mining on characteristics of the geological environment and ecology of the surrounding neighbourhood, and determining the effect of drainage on drainage constructions and conditions of work being carried out at the reservoir site for domestic and drinking water supply for the mining complex.

Furthermore, analysis of generalised materials in certain cases recommends additional measures to reduce the negative influence of technogenic processes in the surrounding environment (for example, to reduce inadmissible residual pressures of underground waters).

Maps of distribution of aquifer rocks of varying thickness within the limits of the cone of depression are indeed significant for analysis of the formation of the technogenic hydrogeological situation during mining of ore deposits. Such special maps in fact characterise the structure of the technogenic zone of aeration and change in conditions of recharge of the aquifer horizon.

8. Precisely determine the hydrogeological parameters of water-bearing country rocks on the basis of data from *in situ* regimal observations. This problem has to be solved through processing hydrogeological data obtained from observation wells, characterising the regime of productivity of drainage constructions (within and outside the shaft) and the regime of level of underground waters over the same time intervals of observations. As a result of processing this material, the hydrogeological parameters of the layer can be determined by simple analytical calculations or the graphic analytical method and, in complex cases, through mathematical modelling [3, 27, 29].

From the hydrodynamic point of view, accurate determination of hydrogeological parameters in the area on the basis of regimal observation data is extremely important. It is known that a broad recharging underground water flow, observed over an extended period of time, yields much more reliable hydrogeological information than a random experimental pumping carried out at the stage of exploration of the ore deposit. Many years of work relating to drainage installations have shown significant influence on the pattern of regime of water levels, during which all the natural factors of the real situation appear, which control the rate of flow of water in the mines (boundary conditions of flow in plan and section, filtration heterogeneity of water-saturated country rocks, conditions of interaction between horizons, etc.). All these taken together not only make possible a fuller analysis of hydrogeological conditions, but also the right choice of method of re-evaluation of hydrogeological parameters.

The results of determination of hydrogeological parameters, may be utilised subsequently for accurate forecasting of possible flows in the projected plan sites below the ore horizons, estimation of conditions of interaction between drainage and water supply installations, prognosis of future development and its influence on the surrounding environment of the cone of depression etc. Analytical and graphic-analytical procedures to obtain true hydrogeological parameters of the layer according to the data from regimal observations are presented below.

9. It is required to periodically make a correct estimate of the rate of flow of water in mines in deeper ore horizons, in accordance with the development of mining activity.

   Prognostic estimation of the rate of flow in mines (during surface and underground mining) is commonly carried out at the stage of planning the mining enterprises, when the principal scheme of drainage of the area is determined. Nevertheless, at the stage of mining of ore deposits it is advisable on the basis of regimal observational data to periodically carry out correction of earlier estimated prognostic values, which permit necessary changes in the system of drainage in mines. With a sufficient amount of hydrogeological information, precise prognosis of the rate of flow of water at deep horizons becomes possible through the hydraulic method, wherein the relationship of flows on the lowering of levels is reflected in a graph constructed with the coordinates $\sum Q = f(S)$. This graph characterises an empirical rule established experimentally during drainage in mines over the time of exploitation of the upper horizons. In certain sites the hydrodynamic method may have to be used. Along with this, in practise, industrial working of ore deposits is possible under complex hydrogeological conditions (for example, working deposits of the third and fourth group cited in Table 5). In such cases correction of the prognostic values of the general water flows in mines at lower horizons is effected through mathematical modelling (see Chapter 12).

10. Processing of data on the temperature regime of underground waters and rocks is essential to continue evaluation of certain hydrogeological processes at the mines. It is recommended that composite graphs reflecting the temperatures (T) of mine waters with time and depth be constructed and related to the temperature of the rocks, processes of oxidation of mineral waters etc. [In the graph, $T = f(t)$; $T = f(S)$]. It is equally important to remember that the temperature regime of mineral waters is studied under conditions of the natural thermal field in faulted areas. Therefore, a comparative estimate of data on the temperatures of underground waters in natural and faulted conditions has to be determined in a number of cases, such as, for example, sources of formation of water flows in the mines.

11. Comparison of the earlier obtained estimate at the stage of exploration on the prognosis of hydrogeological calculations with factual data obtained during the stage of commercial mining. The degree of reliability of earlier evaluated hydrogeological prognoses for assessment of the rate of flow and degree of influence on the surrounding environment is ascertained, and any discrepancy between prognostic and factual data explained. The problem can be solved by comparing a series of data, such as hydrogeological parameters

of aquifer horizons, rate of water flows in mines, effectiveness of drainage constructions and depth of lowering of water table, hydrogeochemial data and others. Such a comparative examination is very valuable for the collection of necessary materials and subsequent completion of a truly systematic operation of hydrogeological works at the stage of exploration of ore deposits.

12. Compilation of the results of complex investigations forms an integral part of the laboratory works. Experience gathered from the hydrogeological services at the Mintsvetmet complex indicates that the operational results of the investigation have to be recorded in quarterly and annual reports. In the operational reports it is essential to highlight the complex hydrogeological situation of the mining enterprise (regime of flow of water along horizons, flanks and mine as a whole, situation over mines of residual hydrostatic pressures, changes in chemical and sanitary-bacteriological composition, aggressive (corrosive) action of mine waters, effective functioning of drainage constructions, degree of appearance of technogenic processes and their influence on deteriorating conditions in mining etc.). A special division in the operational records ought to provide additional recommendations for the development of the hydrogeological (geological) survey unit of the enterprise for future development of the regimal network, better safety measures in mining, better drainage facilities and protection of the surrounding environment from the negative influence of technogenesis.

In the field of study of the regime of underground waters in the water reservoir areas, laboratory processing of the materials has to be carried out along these lines:

1. Processing of earlier documentation of hydrodynamic and hydrogeochemical *in situ* observations over the regime of underground waters by means of constructions of graphs reflecting changes with time; discharges of exploitation wells and all reservoirs; dynamic level of underground waters divided according to observations in wells, at the centre of the reservoir and along the field of influence of cone of depression; temperature of underground waters, their general mineral contents and chemical and bacteriological compositions. For infiltration of water reservoirs it is necessary to construct graphs characterising the regime of surface flow in the river. Such graphs characterise the regime of activity in the water reservoir and are essential not only for the future operational record, but also for analysis of post-experimental exploitation of underground waters.
2. Specification of hydrogeological parameters of the aquifer layer according to data from regimal observations (conductivity of the layer, coefficient of filtration, coefficients of level and piezo conductivity). If the water reservoir works under conditions of a non-stationary regime of filtration, then the value of infiltration parameter ΔL characterises additional hydraulic resistance of

the river channel, and specifications of the hydrogeological parameters can fulfil both the former case of analytical and graphic-analytical calculations as well as the complex hydrogeological conditions of large interacting reservoirs through the method of mathematical modelling. A distinct example of a working reservoir, wherein certain methodological procedures of determining hydrogeological parameters have been used according to data from regimal observations, has been examined below.

3. Study of conditions of formation of the faulted regime and structure of filtration current over the field of influence of the reservoir through periodic construction of the hydrodynamic network. This network consists of maps of groundwater contours under unconfined and confined conditions, with isophreatic surfaces reflecting lines of equal 'heads' and also flow lines (lines running perpendicular to the isopiezometric lines) characterising the structure of flows in the field of cone of depression. Such maps, constructed at different periods of exploitation of the reservoir wells, fairly sharply reflect the conditions of deformation of the flow in plan, heterogeneity of the filtration properties of the productive layer and direction, velocity and degree of influence of pumping installations on the surrounding environment.
4. Analysis of the regime of exploitation of reservoir construction through correlation with hydrogeological materials characterising the regime of water reservoir working on pumping, with data on exploration of the deposit and prognostic value of the exploitable resources of underground waters approved by GKZ, USSR. A comparative estimate has to be made according to the following major parameters: well discharges (for each well independently and total discharge of all wells in the reservoir), lowering of level, general mineral contents and other major components characterising the quality of underground waters, temperature regime and hydrogeological parameters of the productive aquifer horizon. Such an analysis enables an estimation of the degree of reliability of the explored reserves of underground waters.

Correlation of hydrogeological data is initially preferable in the form of tables and then in the form of combined graphs. During analysis it is very important to compare hydrogeological-technical plan data with factual, namely, depths of occurrence of wells (under exploitation), their construction, conditions of providing filters, distances between wells, and constitution of technical installation. Later a comparative assessment may be attempted in a systematic way wherein one can establish correspondence or discrepancy between experimental exploitation of the water reservoir and the projected prognosis based on results of exploration of groundwater reserves. In the case of discrepancy in the regime of exploitation of the degrading region, it is imperative to establish hydrogeological or technical reasons, such as, for example, a tendency towards lowering of underground waters in dewatering wells below the permissible value for the given reservoir. This tendency might lead to negative consequences and the need for adopting means of protecting underground waters from their sources of exploitable reserves. Timely analysis of the regime of exploitation might likewise enable constant regulation of reservoir activity and provide the most rational conditions for withdrawal of underground waters, which is most important for assured uninterrupted water supply to the areas concerned. It has been reiterated above that in the practise of commercial working on true ore deposits, technogenic processes of interaction between drainage and water-supply installations might appear. While analysing the regime of exploitation of water reservoirs it is necessary to investigate these technogenic processes. This allows for timely action while regulating conditions for domestic and drinking water supply to the enterprise [27].

5. To evaluate conditions of possible increase in the general productivity of the working reservoir in relation to additional demand for water in the undertaking. In practise, this need arises fairly often in mines. The problem can be solved through re-estimation of the exploitable reserves of underground waters according to data from regimal observations and the results of analysis of the regime of exploitation of the water reservoir. Investigations in this direction might apply either the method of analytical calculations (for simple hydrogeological situations) or the method of mathematical modelling (for complex situations) to arrive at the proper solution. Results of such studies have to be used for formulating additional hydrogeological investigations over the reservoir region and subsequent reconstruction of the pumping machinery. As for estimating (if necessary) the artificial recharge of exploitation reserves of underground waters, the solution to this problem has to be found through special field experiments [28].

In studying conditions of contamination of underground waters in areas of exploitation of tailings reservoirs, the direction of laboratory processing of materials is well defined by preventive-control and prognostic evaluation of *in situ* studies.

1. Preliminary processing of the data collected in the form of tables and various graphs, reflecting systematic primary documentation of hydrodynamic and hydrogeochemical investigations (changes with time of levels and temperatures of underground waters, their general mineral levels and contents of toxic components, results of plane-height correlation of observation network etc.).
2. Compilation of maps based on results of systematisation of isophreatic groundwater surface maps and directions of filtration currents for the purpose of estimating conditions of formation of structures, direction of movement of flows and precise determination of the important parameter—natural velocity of underground waters. Such maps characterise the hydrodynamic

network of filtration of contaminated waters; their compilation has to be undertaken at different periods of time and definitely not less than twice a year, considering the complexity of controlling functions.

3. Compilation of specialised hydrogeochemical maps of the study area. These maps incorporate changes over the period of observation of temperature of underground waters, contents of toxic components and general mineral levels. Such maps can be used for operational prognosis of the advancing front of contamination.
4. Outline of the hydrogeological conditions of the study region in the standard or originally planned scheme. The essence of the hydrogeological outline is that it reflects the real natural situation of the area being transformed into a geofiltration scheme and the principal boundary conditions of flow in plan and section. The major boundary conditions in plan comprise rivers, reservoirs, basins (tailings reservoirs), large tectonic dislocations playing a role in hydrogeological conditions, concentrated spring flows, filtration heterogeneity of aquifers etc. The cross-section should reflect the structure of the aquifer unit, its thickness, filtration properties and also the character of the underlying and overlying formations.

Investigations along these lines permit use of the scheme worked out and the standard planned approach for a long-term prognosis of the movement of the front of contamination in underground waters and, if need be, adoption of timely measures to protect the study area from contamination. In complex hydrogeological conditions of the region under investigation, mathematical modelling is recommended for long-term prognoses.

ANALYSIS OF REGIME OF WATER FLOWS IN MINES

Analysis of the regime of general water currents in mines forms an important division of generalisation and systematisation of hydrogeological information. The possible general water currents (Q_g)in the system of mining (open cast or underground) can be characterised by the following balance equation:

$$Q_g = Q_{nr} + \frac{Q_{ni}}{t} + \frac{Q_{pi}}{t} + \Delta Q_{pr} \quad ,$$

where Q_{nr} — natural resources of underground waters of aquifer horizons, underlying drainage at stage of exploitation of ore deposit; Q_{ni} and Q_{pi} — natural and proportional increase of reserves of underground waters in the same horizons; ΔQ_{pr} = 'pulled-up' resources due to drainage of surface waters or from overflow of underground waters from aquifer horizons in rocks overlying the ore deposit; t — time.

A heavy downpour of rain might cause periodic flooding of open cast mines of ore deposits. A study and estimate of the balance structure of water currents in mines constitute a very important aspect of laboratory processing of information from complex investigations. Assessment of the sources of formation of water currents in open cast or underground mines requires refinement of the system of protection of mines from underground and surface waters, and also rectification of the directions of study and scheme of selecting observation points.

Analysis of the regime of water flows in the system of mine workings is advisable using complex graphs $\Sigma Q = f(t)$ reflecting changes in flow with time, graphs showing levels of underground waters of observation wells situated over different parts of the cone of depression (at the centre and along the periphery), $S_w = f(r, t)$ and also the principal regime-forming factors (atmospheric precipitation and data on flow of surface waters).

The hydrogeological information collected on ore deposits enables us to observe the following major patterns of formation of general water currents in open cast or underground mines of ore deposits, taking into account industrial-geological grouping of the ore bodies (see Table 5).

Ore deposits of the first group include deposits with simple hydrogeological conditions whereby the ore-bearing intrusive rocks and metamorphic rocks contain fracture-ground waters of the zone of weathering and fracture-vein waters of the zones of tectonic faulting, the natural resources and natural reserves of which are highly limited. Figure 47 presents a graph of the regime of water flows and level of underground waters of the Sibai open cast mine. Characteristic of this type of regime is the gradual but insignificant increase of general water flows following

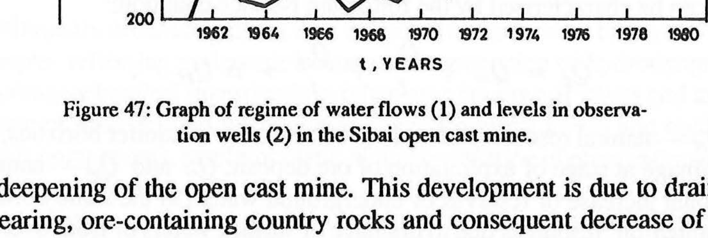

Figure 47: Graph of regime of water flows (1) and levels in observation wells (2) in the Sibai open cast mine.

annual deepening of the open cast mine. This development is due to drainage of water-bearing, ore-containing country rocks and consequent decrease of natural reserves of fracture-ground waters. From 1975, surface waters were involved in the water flows of the open cut mine, which are reflected in the graph by the spasmodic increase in water currents. Observation well 54W (vide Figure 47) is situated close to the open cast mine and fairly sharply reflects the spasmodic regime of levels in the zone of active derangement of the filtration current. According to observation well 3TS, situated some distance from the open-pit regime, regimal levels are characterised by a smooth graph.

In another ore deposit situated in the Far East (Figure 48), a similar regime of water flow was observed until 1977. Later, the flooded zone of metamorphic ore-bearing country rocks was fully drained and with an increase in depth of mining the general water currents began to diminish slowly at the expense of changes in conditions of recharge of the aquifer formations. No influence of surface waters on flooding in the mines was observed. But such an influence is fairly sharply reflected in the graph of water currents in one of Ural's ore deposits (Figure 49). Until 1978

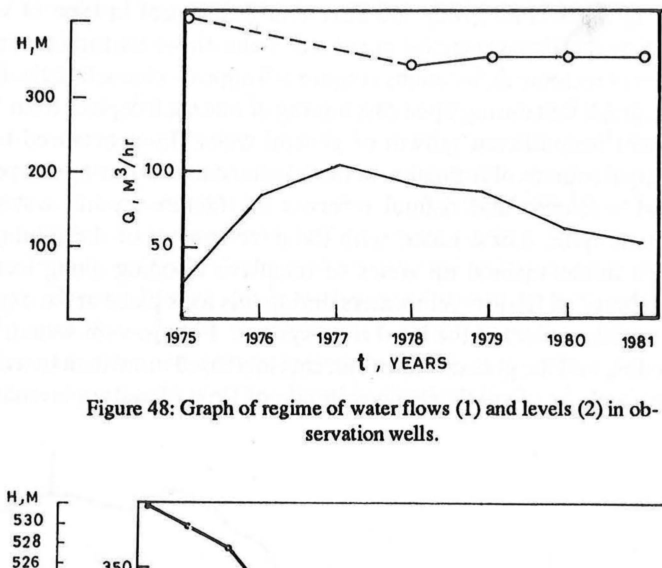

Figure 48: Graph of regime of water flows (1) and levels (2) in observation wells.

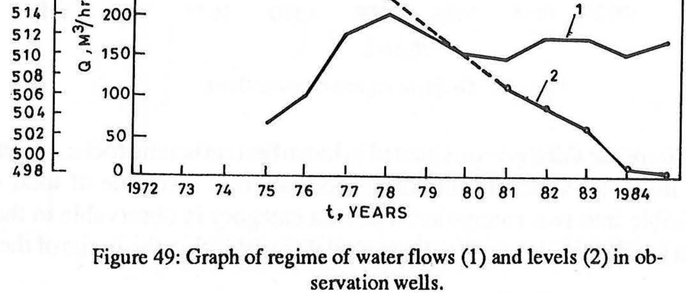

Figure 49: Graph of regime of water flows (1) and levels (2) in observation wells.

during the working of the open cast mine in the zone of distribution of fracture-ground waters, a fairly marked increase in general water flows was observed. Below this zone in the ore-bearing country rocks a weak zone of flooding was seen. Resources of fracture-vein waters were highly reduced. Hence during the subsequent period of mining no growth in general flows was observed. The level of underground waters was constantly lowered and later stabilised.

Almost an identical type of formation of regime of total water flows is evident in other ore deposits of the first group situated in the Urals, the Caucasus, Central Asia, central Kazakhstan, Siberia etc., where ore-bearing rocks consist of intrusive and metamorphic rocks.

The described type of formation of regime of water currents in mines can be termed primarily hydrogeological, although in certain cases this type of regime somewhat changes its character under the influence of infiltration of surface waters.

Ore deposits of the second group are also hydrogeological in type of water regime, although a significant increase in general water flows during opening of the flooded zones of tectonic dislocations (Figure 50) appears characteristic. It can be seen from the graph that during open cast mining of one such deposit from 1960 to 1969, an almost insignificant growth of general water flows occurred in the mines. The principal sources of formation of these water currents during this period were the natural resources and natural reserves of fracture-ground waters of ore-bearing metamorphic rocks. Later, with the development of the mining industry, open cast mines opened up zones of intensive flooding along tectonic dislocations. Recharge of fissure-vein waters during this took place at the expense of drainage of surface waters of the local river system. Fissure-vein waters were involved in flooding and the general water currents increased more than two times. Later, over time, a phase of subtle changes in rate of flow of water currents was evident.

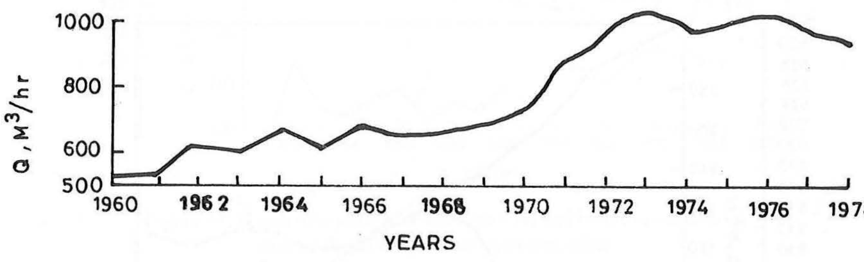

Figure 50: Graph of regime of water flows.

Ore deposits of the third group, situated in karstified carbonate rocks, are subject to intensive flooding, which results in the formation of a regime of total water currents divisible into two categories. The first category is observable in that ore field where a local river system has developed directly within the limits of the cone of depression. A close hydraulic link between fracture-karst and surface waters is highly typical of these conditions. The local surface riverine network is fed both by snow and rains. A short-term action of surface waters (2-2.5 months a year) appears in the form of stormy springtime flash floods, exhibiting a distinct influence in the formation of maximal water currents in mines. The regime of underground waters is considerably influenced by the regime of atmospheric precipitation (rainfall) and surface waters. During such natural conditions of water flows in the system of underground mining, the pictures obtained with annual or multi-annual data not only depict the hydrogeological characteristics of ore deposits of this group, but also the hydrometeorological and hydrological factors. A fairly close dependence is established between size/magnitude of water currents and regime-forming factors. The complex graph presented in Figure 51 reflects the close correlation between ground and surface water flows. In Figure 52 this link is emphasised by data on the regime of surface currents of the local hydrographic network for a period of 16 years from the introduction of mining for different mining enterprises.

In the deposits under discussion, intensification of recharge of the aquifer horizon was accurately determined. The total water currents formed through three sources: natural resources and natural reserves of fracture-karst waters, drawn resources and infiltration of floodwater discharges of local rivers. In the multi-year regime of total water currents the following pattern was observed: From 1948 to 1964 (Figure 53), with mining development extending down to different horizons, a fairly distinct growth of general water currents was recorded, during which infiltration of floodwater discharges of the rivers exhibited no prominent influence on the regime of water currents. Therefore, there is no peak in the graph suggestive of absence of maximal water flow. In this period a regional cone of depression

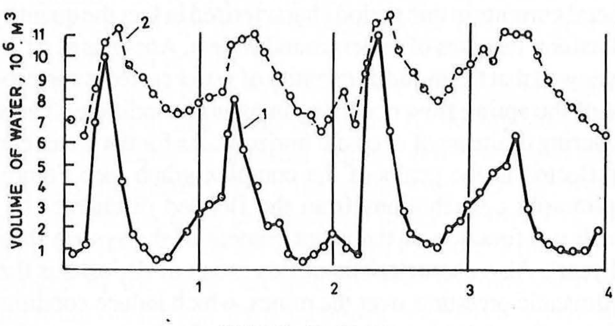

Figure 51: Graphs of loss of surface flows (1) and general groundwater flows (2) in system of underground mines.

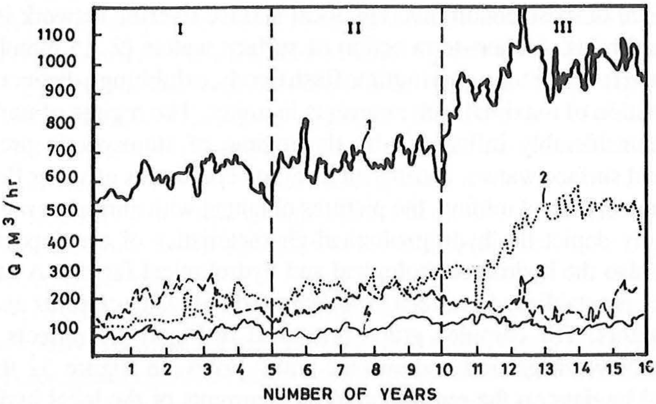

Figure 52: Graphs of fluctuation of water currents along a southeastern ore body (1), Maslyan ore zone (2), a western ore deposit (3) and surface flows (4) over deposit

I, II, III—stages of development of mining.

developed which, in 1968, reached some major boundaries of the aquifer horizon from the south and the north. During the same period the mining engineering factor played a prominent role in the formation of the water currents.

In the period 1968 to 1984, another characteristic pattern was observed. In spite of further development in mining (mainly depth-wise), water currents were minimal on the whole in the underground mine and had almost stabilised. During this, along the flanks of the cone of depression the levels of fracture-karst waters continued to drop with time (due to continuation of the process of drainage of the layer). The period of formation of mineral water currents continued from about June to December and was characterised as a period of independent regime, when fracture-karst waters of the carbonate rock formations received no recharge at all. Hence the general currents in this period characterised in fact the quantity of natural resources and natural reserves of underground waters. Analysis of data on regimal observations showed that the minimal quantity of water currents corresponded with the total value of the spring flow occurring in natural conditions. The spring flow averaged out during drainage of deep ore horizons. As for the water currents, their maxima are reflected in the peaks of the complex graph (see Figure 53). They characterise primarily contributions from the flooded discharges of rivers, the regime of which is a function of the water content of the system throughout the 'hydrological year'. Also characteristic of this group of deposits is the formation of residual hydrostatic pressures over the mines, which induce conditions responsible for sudden outbursts of fracture-karst waters. Such a regime of water flows may be related to the hydrogeological-hydrological type when their formation

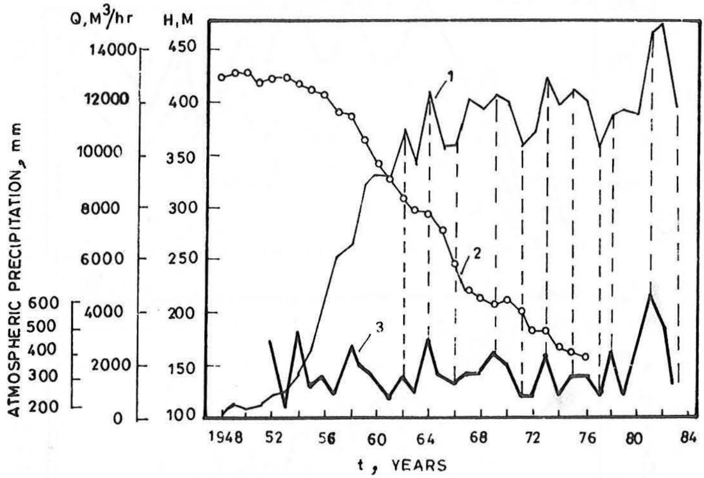

Figure 53: Serialised graph

1—general water currents; 2—changes of levels of underground waters; 3—atmospheric precipitation.

exhibits the prominent influence of hydrological-meteorological factors and, to a lesser extent, voluminous reserves of fracture-karst waters.

The second category of water regime found in ore deposits of the third group is characterised by the fact that in the field of ore-bearing aquifer carbonate rocks a local hydrographic system and surface waters are typically absent; thus these do not contribute to flooding in mines. Furthermore, the basin of fracture-karst waters is bound by impermeable borders. In such hydrogeological conditions the water currents in an open cast mine originate through two sources—natural limited resources and natural reserves—and marked changes in recharge of underground waters in faulted zones do not occur. A distinct type of hydrogeological regime thus forms over the region (Figure 54).

Ore deposits of the fourth group: The regime of water currents that forms during drainage of ore deposits of this group is unique. As mentioned earlier, the entire aquifer complex, primarily of artesian aquifer horizons, generally comprises sandstone-clay and carbonate rocks of the supra-ore series. The iron-ore basin of KMA, where a number of areas are presently under exploitation, belongs to the fourth group of ore deposits. The ore deposits of Lebedin, Mikhailov, Stoilen and others are worked by the open cast method. The hydrological regime in these deposits forms primarily through the depletion of material (water) from the 'elastic' reserves of underground waters of the artesian horizons, occurring in the rock formations overlying the ore, and also through the infiltration of surface waters.

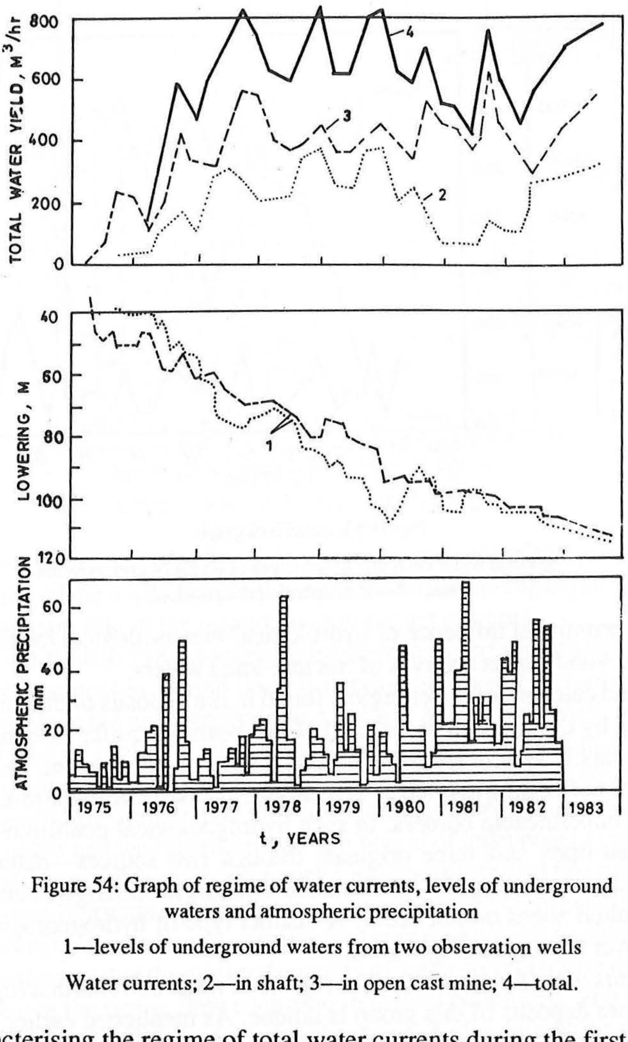

Figure 54: Graph of regime of water currents, levels of underground waters and atmospheric precipitation

1—levels of underground waters from two observation wells

Water currents; 2—in shaft; 3—in open cast mine; 4—total.

Data characterising the regime of total water currents during the first ten years in the Lebedin and Mikhailov open cut mines is graphically depicted in Figure 55.

It is clear from the graphs in Figure 55 that the water currents increased with deepening of the open cast mines. Initially, there was a fairly distinct lowering of water levels, but with working of the mines over a period of time, the rate of water level drop slowed down. In fact, the level in some wells situated close to the open cast mine stabilised (borehole 1010 in the Lebedin open cast mine area). But in the Mikhailov deposit the underground waters of the Callov-Bathian and Mosolovian

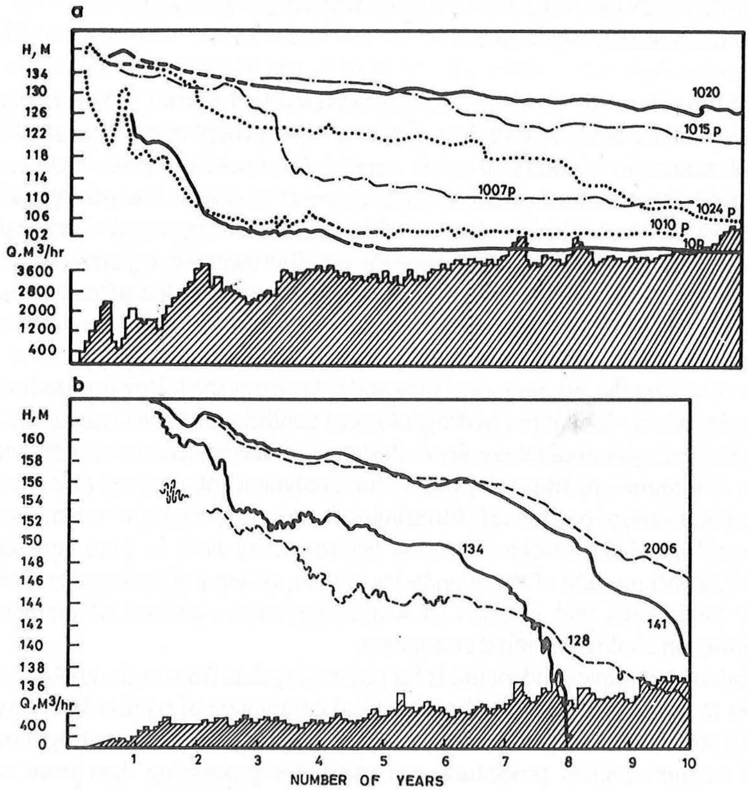

Figure 55: Graph showing fluctuations in water levels

a—Cenoman-Albian aquifer horizon dependent on pumping water in area of Lebedin mine; b—Callov-Bathian aquifer horizon dependent on pumping water in area of Mikhailov mine (compiled by V.S. Plotnikov and R.I. Savishcheva)

Numbers near curves are well numbers.

aquifer horizons have been sharply characterised by a continuous, uninterrupted drop in level throughout the period of drainage of the open cast mine. Such a feature is characteristic of a pressure regime. The general water currents of the drainage waters have increased almost ten times in accordance with depth of open cut mining. During this, no uneven increase in water current has ever been observed in the mines and no large residual hydrostatic pressures along the benches of the mines ever recorded. Such characteristics of formation of the regime of water currents and levels are typical of mines situated in areas of artesian basins of the platform type and gradually form a hydrostatic-head type regime.

REFINEMENT (SPECIFICATION) OF HYDROGEOLCGICAL PARAMETERS OF AQUIFER LAYER USING DATA FROM REGIMAL OBSERVATIONS

The refinement or specification of calculated hydrogeological parameters of aquifer horizons according to data obtained from a study of the regime of underground waters in working areas is needed for resolving these problems: (a) prognostic estimation of possible water currents in deeper horizons planned for future exploitation; (b) re-evaluation of exploitable underground water resources of reservoir structures, keeping in view the possible increase in general demand for water or the most rational withdrawal; and (c) determination of measures to be adopted to protect the degraded environment from the negative influence of technogenic processes.

In estimating the parameters of the aquifer horizons the following methods may be employed: (a) for simple hydrogeological conditions of the study area and not very complex system of reservoirs or drainage constructions—analytical methods (for *in situ* regime of filtration) or graphic-analytical calculations (for conditions of non-stationary regime of filtration of currents); and (b) under complex hydrogeological conditions (filtration heterogeneity both in plan and section), complex configuration of the boundaries in plan, systems of drainage construction of the study area and systems of water reservoirs—method of mathematical modelling on analog or digital computers.

Modern techniques and methods for processing data from regimal observations, mainly to refine calculated hydrogeological parameters of aquifer horizons, have been detailed in earlier published work [3, 27, 29, 36]. Here we highlight only the major methodological procedures necessary for processing data from regimal observations.

1. In practise, dewatering of mines and exploitation of reservoir constructions may give rise to a non-stationary, quasi-stationary or stationary regime of filtration, which predetermines selection of the method for estimating hydrogeological parameters of the stratum.
2. As follows from the principal equation of Theiss, in the isolated artesian layer lowering of underground waters within a specific period of time after pumping has started, is related to the logarithmic time of straight-line relation. This important theoretical consideration forms the crux of the principal graphic-analytical method for estimating the hydrogeological parameters of the layer for a non-stationary regime of filtration through the construction and analysis of special graphs: tentative plotting—$S + \ln t$; areal plotting—$S + \ln r$; combined—$S + \ln t/r$, where r = distance between central and observation wells. The straight-line part in the special graph reflects the pattern of changes in levels during a quasi-stationary regime. A typical

characteristic of the field of a quasi-stationary regime is the same tempo of lowering of water levels in all points of this area.

3. The relatively constant general discharge of drainage constructions or reservoirs constitutes one of the indispensable conditions of application of the graphic-analytical method for estimating hydrogeological parameters of the layer. To assess the character of water withdrawal, it is necessary first to construct a combined graph—$Q = f(t)$ and $S = f(t)$—for observation wells. If a change in discharge from drainage constructions is evidenced in the graph, then the factual change of its discharge might be reorganised into a stepped graph (Figure 56). In this case of processing data from regimal observations it is preferable to adopt the method of summation of filtration currents. During this, it is proposed that every degree of change of general discharge of drainage machinery correspond to the inclusion of new wells in the exploitation of the reservoir, working with productivity of equal difference between the stages of general discharge or yield. In this case, it is necessary to determine the effective time of working of the water reservoir (t_{pr}). Then, during the construction of the semi-log graph, temporary observations are plotted along the axis of the abscissa ($\ln t_{pr}$) in place of ($\log t$).

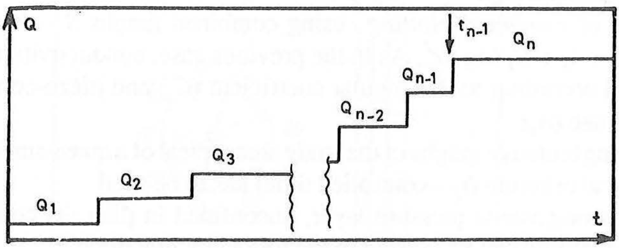

Figure 56: Stepped graph of water reservoir.

During the linear change of discharge, for the semi-logarithmic graph, it is expedient to use the effective lowering of level

$$\frac{S}{Q(t)} - \log t_{pr}$$

This method has been examined below, using a specific example.

4. During analysis of data from regimal observations, it is necessary in each case to construct a calculated geofiltration scheme of the area under study, assuming typical conditions for which the typical analytical relations are: (a) unlimited in plan, aquifer horizons with either single or multi-layered structure; (b) confined in plan, aquifer horizons (semi-confined layers) connected with surface water flows and aquifer horizons or confined impermeable contours; and (c) layered-belt in plan, closed layered circle, etc. [3].

During transformation of the hydrogeological conditions of the study area which exemplify the typical calculated geofiltration scheme of non-confined or partly confined layers, for determination of parameters of the layer, a straight-line relation of the graph S – log t is utilised; for the scheme of belt-forming layers—$S - \sqrt{t}$; in closed layers—$S - t$.

5. Determination of the hydrogeological parameters of the layer through data from regimal observations utilising the graphic analytical technique can be carried out by three distinct methods:

Method of tentative plotting using the graph—$S = A_t + C_t + \log t$: This can be constructed by tracing through time lowering or stabilisation of the levels. The value of water conductivity and the coefficient of piezo-conductivity are found through plotting the angular coefficient (C_t) and the initial ordinate (A_t) on the graph.

Method of areal plotting through construction of graphs with the coordinates S – log r and the function—$S = A_r - C_r \log r$. This method consists of plotting changes in levels as a function of distance (r) from the observation well to the disturbed (reservoir) mine working. Permeability of layer and coefficient of piezo-conductivity are plotted directly on the graph according to angular coefficient (C_r), and the initial ordinate (A_t).

Method of combined plotting using combined graphs S – log t/r^2 and the function $S = A_k + C_k \log t/r^2$. As in the previous case, conductivity of the layer is determined according to the angular coefficient (C_k) and piezo-conductivity, the initial ordinate (A_k).

In plotting tentative graphs of the study area typical of a quasi-stationary regime, the analytical criterion (t_k—controlled time) has to be used.

For a homogeneous pressure layer, unconfined in plan, its conductivity and piezo-conductivity can be utilised in the following functions.

For tentative plotting:

$$S = \log t \; ; \; km = \frac{0.183\,Q}{C_t} \; ; \; \log a = 2 \log r - 0.35 + \frac{A_t}{C_t};$$

$$C_t = \frac{S_2 - S_1}{\log t_2 - \log t_1},$$

where C_t = angular coefficient.

For areal plotting:

$$S = \log r \; ; \; km = \frac{0.366Q}{C_r}; \; \log a = \frac{2A_r}{C_r} - 0.35 \log t;$$

$$C_r = \frac{S_1 - S_2}{\log r_2 - \log r_1}.$$

For combined plotting:

$$S = \log \frac{t}{r^2} \;;\; km = \frac{0.183\,Q}{C_k} \;;\; \log a = \frac{A_k}{C_k} - 0.35 \;;$$

$$C_k = \frac{S_2 - S_1}{\log \frac{t_2}{r_2^2} - \log \frac{t_1}{r_1^2}}.$$

The initial ordinate (A) intercepts the graph on the axis of the ordinate; accordingly,

$$\log t = 0,\ \log r = 0.1 \text{ and } \log \frac{t}{r^2} = 0.$$

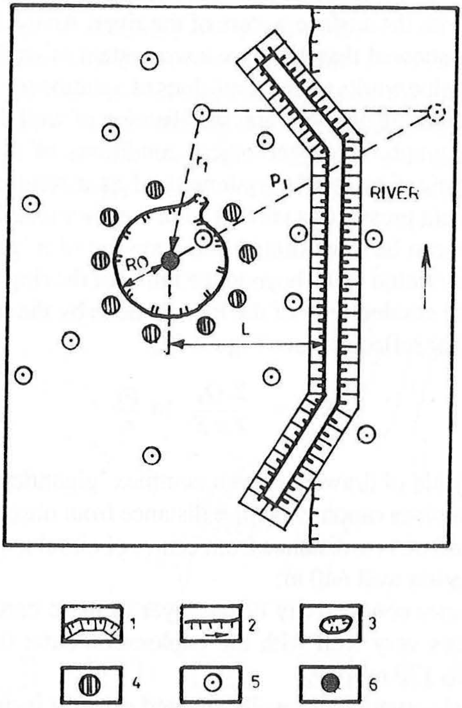

Figure 57: Calculated scheme of determination of hydrogeological parameters

1—protecting dam; 2—river channel and direction of stream current; 3—open cast mine. Wells : 4—drawdown; 5—observational; 6—centre of lowering of level.

Processing of hydrogeological data from regimal observations conducted over ore deposits under conditions of layered aquifer horizons and also under confined conditions in the plan of layers, possesses certain characteristics. In interpreting such data one must use the methodological procedures outlined in published works [3, 27, 29, 36].

Rarely, in practise, a stationary regime of filtration is observed during drainage of mines of ore deposits, particularly those situated close to a river. For such cases, we shall now present refinements of the hydrogeological parameters of the layer according to data from regimal observations through the method of analytical computations. For example, an ore deposit is temporarily exploited through an experimental open cast mine situated on the left bank of a large river. Mining is carried out under a protective experimental drainage dam and a circular system of water-lowering (drawdown) wells (Figure 57).

The ore body here comprises highly metamorphic carbonate rocks with intensive fracturing and less intense karstification. Underground waters of the ore-bearing suite showed lowering of levels during trial tests and possess highly complicated links with the surface waters of the river. Analysis of the graphs—$Q = f(t)$ and $S = f(t)$—showed that the drawdown system of wells at specific depths of the trial open pit mine works under conditions of a stationary regime of filtration; areas with varied lowering of levels and stabilisation of well discharges are easily singled out on the graph. Hydrogeological conditions of the area contains the deposit under investigation can be systematised as a semi-confined layer with boundaries of constant pressure as viewed from the river side. The circular system of drawdown wells can be transformed into a system of a 'gigantic well'. While positioning the observation wells beyond the limits of the ring of drawdown wells, determination of the conductivity of the layer is done by the method of analytical calculations of mirror reflection (see Figure 57):

$$km = \frac{\Sigma Q_1}{2\pi S} \ln \frac{p_1}{r_1}$$

where ΣQ = total yield of drawdown well complex 'gigantic well' 306 m^3/hr; S = lowering of level in observation well; p_1 = distance from observation well up to its mirror reflection 980 m; r_1 = distance from centre of circular system of drawdown wells up to observation well 640 m.

The value of water conductivity of the layer in these conditions reaches 158 m^2/day which agrees very well with the exploration data; this value ranged on average from 125 to 170 m^2/day.

Using regimal observations in wells situated directly inside the experimental open cut mine, water conductivity of the layer can be determined according to the formula

$$km = \frac{\Sigma Q}{2\pi S} \ln \frac{2L}{R_0},$$

where L = distance from centre of open cast mine to boundary of layer; R_o = radius of open pit. In this case, the values of conductivity of the layer changed within their limits.

For cases where the change in total productivity of the drainage constructions is observed in the form of a stepped graph, it is advisable to distinguish the different steps of the constant discharge in the graph or to transform the graph as a function of time [27].

Using the same method it is likewise possible to process data from regimal observations on the remaining observation wells, allowing characterisation of conductivity of the aquifer rocks in the entire field that influences drainage of open cast mine. Along with this, the results of refinement of the hydrogeological parameters of the layer might be used for prognostic evaluation of the general water currents (Q_{pr}) in the projected levels at greater depths of the open cast mine. For the studied example, $Q_{pr} = \dfrac{2\pi\, km\, S}{\ln (2L/R_0)}$

Let us consider the determination of the hydrogeological parameters of the layer for conditions of a non-stationary regime of filtration, for the area of a drainage construction in an upper Devonian artesian aquifer complex. The water-saturated rocks are fractured limestones and dolomites, generally 50 to 100 m thick. In the artesian territory under study the aquifer complex possesses almost universal distribution except in the southwest part where it tapers beneath Jurassic clays (impermeable boundary layer). Such hydrogeological conditions might modify the

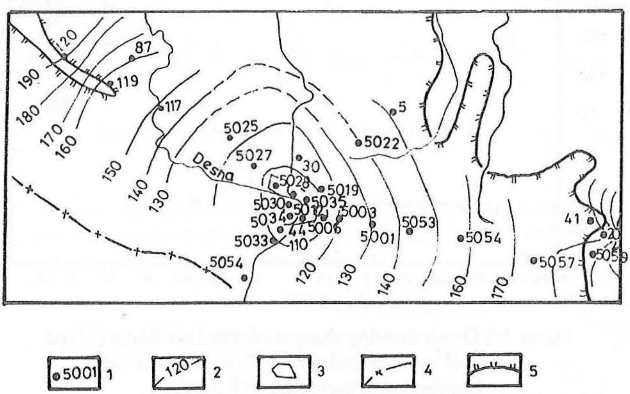

Figure 58: Schematic hydro-isohypse map of upper Devonian aquifer complex

1—observation well and its number; 2—hydro-isohypse on 30 Dec. 1978; 3—grouped reservoir; 4—boundary of water-bearing complex; 5—boundary of complex distribution of Jurassic clays.

calculated scheme of semi-confined layer into one of impermeable boundary. A schematic map of the water table contours and a scheme of the observation wells is illustrated in Figure 58.

The most uniform exploitation of underground waters in the reservoir site was initiated in 1927. The size of the reservoir gradually increased (with maximum observed in the post-war years) and stabilised (155,000-160,000 m^3/day) between 1973 and 1979. In addition to this major reservoir in the region, there are many smaller ones that exert little influence on the regime of underground waters.

Throughout the period of exploitation the non-stationary regime of filtration of rocks became fixed and in the process the level lowered to 65-70 m. As a result of intensive exploitation, an extensive cone of depression has formed, extending somewhat northwest to southeast with a radius of 85-95 km (see Figure 58). Systematic observations beyond the regime of underground waters of the productive aquifer horizon over the field of water reservoir and adjoining areas were organised in 1966-1968. In 1980 110 exploitation wells were established almost uniformly throughout the major reservoir site. Hence the field reservoir was transformed into the scheme of 'gigantic well' for purposes of computation. By processing regimal observations it was possible to establish changes in the reservoir over time from the very beginning of its exploitation (Figure 59).

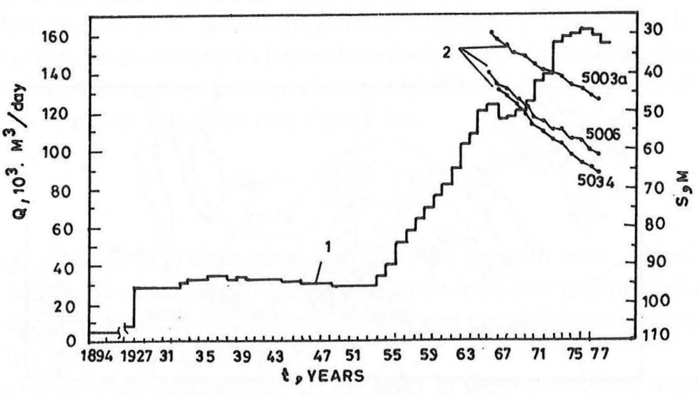

Figure 59: Graph showing changes of water discharge (1) and levels of underground waters (2) in reservoir site
Numbers near curves are well numbers.

From 1928 to 1955 the factual discharge of the reservoir (Q_1) remained constant (in the discharge of this period an insignificant output between 1894 and 1928 was taken into account). In 1956 productivity of the reservoir increased to Q_2 but later reduced in a linear equation with the tempo of discharge (γ) up to the moment t_2

(year 1972). Starting from 1973 the reservoir worked with relatively constant discharge (Q_3). Such a character of change in discharge is fairly often encountered during the exploitation of reservoirs. In determining hydrogeological parameters the values of lowering of levels in the observation well were also adopted for the following period (1973-1978); the time interval (t) was taken into account from the very beginning of systematic exploitation, i.e., from 1928, for incorporation in the graphic construction.

The equation for determining the range of lowering of level with regard to 'inheritance' of the previous period of work of the reservoir and also considering the computed scheme of semi-confined layer with one impervious border, as arising from the hydrogeological setting of the reservoir, is presented below:

$$S = \frac{0.366}{km}\left[Q_3 \log \frac{2.25\,a}{r\,p} + Q_1 \log \frac{t}{t - t_1} + Q_2 \log (t - t_1)\right] +$$
$$\gamma\left[(t - t_1) \log (t - t_1) - (t - t_2) \log (t - t_2) - (t_2 - t_1)\right], \quad ...(4)$$

where a = coefficient of conductivity level; r and p = respective distance from observation wells (according to which the parameters are determined) to the centre of the 'gigantic well' or from the centre to the mirror reflection of the observation wells; and tempo of discharge $\gamma = (Q_3 - Q_2) / (t_2 - t_1)$.

In the determination of parameters by the graphic-analytical method we incorporated the values of time passed and effected lowering of level. Lowering of level was determined by means of division of both parts of equation (4) by Q_3—the value of discharge at the latter stage of working the reservoir:

$$\frac{S}{Q_3} = \frac{0.366}{km}\left[\log \frac{2.25a}{rp} + \frac{Q_1}{Q_3} \log \frac{t}{t - t_1} + \frac{Q_2}{Q_3} \log (t - t_1)\right] +$$
$$\frac{\gamma}{Q_3}\left[(t - t_1) \log (t - t_1) - (t - t_2) \log (t - t_2) - (t_2 - t_1)\right] \quad ...(5)$$

Table 6 : Synoptic table of original data and results of calculation of hydrogeological parameters of layer, based on some observation wells

Number of Observation Wells	Distance from Centre of 'gigantic well' m		Coefficients		Hydrogeological Parameters m^2 / day	
	to Observation Well	to Mirror reflection	$C \times 10^4$	$A \times 10^4$	km	a
5,012	9	25	3.45	− 7.95	1,060	1.5×10^6
44	9	64	3.95	− 10.45	920	5.9×10^6
5,031	26	45	2.50	− 5.90	1,460	2.3×10^6

Time passed (t_{pr}) was determined according to the following function:

$$\frac{Q_1}{Q_3} \log \frac{t}{t - t_1} + \frac{Q_2}{Q_3} \log (t - t_1) + \frac{\gamma}{Q_3} [(t - t_1) \log (t - t_1) - (t - t_2) \log (t - t_2) - (t_2 - t_1)] = \log t_{pr} \quad ...(6)$$

Further we adopted:

$$C = 0.366/(km) \quad ; \quad ...(7)$$

$$A = C \log \frac{2.25\, a}{rp} \quad ...(8)$$

and obtained the equation in the form of a linear function of changes in effected lowering of level from the logarithmic value of time passed ($S/Q_3 = A + C \log t_{pr}$).

Through the most highly representative observation well (over a long period of *in situ* observations) the graph in the co-ordinates $S/Q_3 - \log t_{pr}$ (Figure 60) of lowering of level of underground waters was constructed for the variant in which only the mean total water discharge from the major reservoir for the period 1973-1978 was reckoned. The values of coefficients A and C were determined directly from this graph and the value of water conductivity and piezo-conductivity for each observation well from formulas (7) and (8) (Table 6).

The average values of the parameters, determined as arithmetic means from the selection of partial values, were: water conductivity—1,100 m^2/day and coefficient

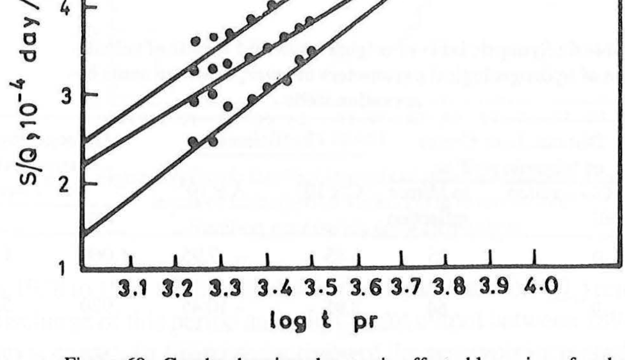

Figure 60: Graphs showing changes in effected lowering of underground waters during water discharge.

of piezo-conductivity—3.6×10^6 m^2/day. These parameters calculated by the same method for the variant in which the water discharge from the entire region was considered (including small reservoirs—200,000 m^3/day) were 1,300 and 3×10^6 m^2/day respectively.

It is advisable to use the revised graphic-analytical method of determining the hydrogeological parameters of the layer during a complex scheme of water withdrawal and also during exploitation of external drainage constructions, while dewatering the mines.

During a stepped variation of discharge from the reservoir or drainage constructions, the factual change in withdrawal of underground waters might be transformed into a stepped graph as shown in Figure 56. In this case processing of data from regimal observations ought to be carried out by the method of complexity of filtration currents (method of superposition). It is suggested that in this each step of change in discharge corresponds, as it were, with the introduction of new wells in the exploitation of the reservoir, situated at the same place, working with the productivity and uniform difference between their present and earlier discharges. Lowering of level of underground waters in the observation well during this is looked upon as the total effect of the work of these two reservoirs; hence a similar operation ought to be repeated as many number of times as there are number of changes in discharge of the reservoir. Under such conditions, lowering of level might be expressed by the following formula (for conditions of infinite pressure horizon in plan)

$$S = \frac{Q_n}{4 \pi km} \left[\ln \frac{2.25a}{r^2} + \sum_{i=1}^{n} \alpha_i \ln (t - t_{i-1}) \right] ,$$

where Q_n = finite total discharge from the reservoir leading to the latter stage; km = conductivity of layer; a = coefficient of piezo-conductivity; α_1 = frequency of withdrawal $\frac{Q_i - Q_{i-1}}{Q_n}$; Q_i = discharge of reservoir in separate steps; t = time interval; t_i = time of initiation of first, second and following stages of discharges, considered from the beginning of exploitation of the reservoir.

Proceeding further,

$$C = \frac{Q_n}{4 \pi km} ; \qquad \text{...(9)}$$

$$A = B \log \frac{2.25a}{r^2} , \qquad \text{...(10)}$$

time passed might be calculated using the formula

$$\sum_{i=1}^{n} \alpha_i \ln (t - t_{i-1}) = \ln t_{pr} \qquad \text{...(11)}$$

Using equation (9) and (11) we obtain the following equation straight away:

$$S = C + A \ln t_{pr}$$

Determination of hydrogeological parameters of the aquifer horizon based on data from regimal observations, as in the previous instances, is carried out by the graphic-analytical method, where during plotting of the tentative graph it is necessary to consider the logarithm of time passed. In this aspect the parameters have to be determined according to change in level of underground waters in the observation wells, corresponding to data on the later stage of constant discharge of the reservoir (Q_n) and the previous step of discharge producing yields of Q_1, Q_2 .... Q_{i-1}, which appear in the form of 'inheritance' in the lowering of level from all the preceding periods of activity of the reservoir or drainage machinery.

DETERMINATION OF HYDROGEOLOGICAL PARAMETERS OF AQUIFER ROCKS BY MEANS OF MATHEMATICAL MODELLING

For quite some time now, hydrogeological investigations of ore deposits have been employing methods of mathematical modelling [5, 15, 16]. This is because drainage in mines in many ore-mineralised areas originates in very complex hydrological conditions. Thus to choose the most rational scheme of drainage in mines and to select the best means for protecting them and other aspects of the environment through common methods of analytical calculations, is almost impossible. This situation is particularly apparent in the industrial working of deposits of the third group (vide Table 5) in which the ore-bearing carbonate rocks are characterised by the same high degree of filtration heterogeneity seen in the fourth group. Often a complete system of interconnected artesian aquifer horizons has formed in the rocks overlying the ore deposit. Such horizons possess very complex conditions of limitation in plan and cross-section.

Invariably, while solving straight prognostic problems, using an AVM or EVM, through determination of general water flows in the system of mines and a rational scheme of drainage, problems are mostly solved through determination of the hydrogeological parameters of the aquifer rocks.

The theory and methods of solution of hydrogeological problems by means of determination of effective parameters of the layer using mathematical models have been detailed in many publications [5, 15, 16, 37]. Hence here only a few major case studies of mathematical modelling are described. These methods are recommended only for complex investigations of ore deposits.

An analysis of experiments on drainage of ore deposits for the purpose of determining the hydrogeological parameters of the layer using an AVM or EVM computer, presents its own complex 'hydrogeological problem', because it is essential that the conditions of formation of water currents in the mines be carefully examined over many years of drainage, based on hydrodynamic parameters of the multi-layered geological section, influence of natural and technogenic limiting conditions and also possible change in conditions of recharge of underground waters within the limits of the main field of development of the cone of depression.

According to the general theory of modelling of the hydrogeological processes of an entire complex, the problems may be broadly divided into two types:

1. Prognostic problems that seek to solve prognosis of the regime and balance of underground waters in areas of engineering activities. This means prognosis of the general water flows in the mines and selection of a rational scheme of drainage of the deposit or prognostic estimate of the general productivity of the reservoir.
2. 'Inverse' problems directed towards the determination of the mathematical hydrogeological parameters of the aquifer horizons.

Here, too, investigations carried out to determine the hydrogeological parameters of a layer using an AVM or EVM computer form part of the general complex of problems; they are likewise resolved through the method of mathematical modelling. The general complex of problems as well as the general methodological procedure involved in the preparation of hydrogeological information for complete modelling are briefly examined in Chapter 12.

In the first stage of the process of modelling the important aspects are: transformation of the natural hydrogeological conditions in the calculated geofiltration scheme of the area under study, reflecting the external and internal limiting conditions of the current in plan and section, structure of the current in faulted conditions, type of regime of water current (stationary, non-stationary, quasi-stationary), filtration heterogeneity of aquifer rocks, etc. The calculated geofiltration scheme, as seen from its contents, forms in fact the hydrogeological model of the study area, reflecting the principal hydrodynamic properties of the filtration current formed in faulted zones.

In the second stage of modelling the geofiltration scheme of the study area ought to be used for constructing, on the basis of the principles of the similitude theory and mathematical analogy, a grid or digital prognosis model, depending on whether the solution to the hydrogeological problems is arrived at using an AVM or EVM computer. After due verification that the mathematical model is realistic and assessment of the quality of the original information, the hydrogeological problems posed are solved.

Solution of inverse problems in the model is commonly achieved through conditions of stationary and non-stationary filtration. Determination of parameters of conductivity of the layer, field recharge of the aquifer horizon, and origin of overflow in layered cross-section—these are solved via the solution of inverse problems under conditions of a stationary regime of filtration. The coefficient of gravitational (μ) and elastic volume (μ^*) of the layer are determined through the solution of inverse problems under conditions of a planar non-stationary geofiltration.

During modelling of the inverse problems model fragments and a general model of the study area within the limits of the principal territory of the faulted regime of underground waters are used. Modelling on fragments is implemented for estimating mathematical parameters within the limits of the typical areas on planar or sectional (profiled) calculated schemes for detailed representation of the conditions of formation of the filtration current (usually on large scales of 1:5,000-1:25,000).

Modelling of general calculated schemes usually assume solution (of problems) of certain stages on maps scaled to 1:25,000-1:200,000. In the first stage the inverse stationary problem is solved in order to estimate the conditions of recharge of underground waters, their discharge into the river or deeper horizons and distribution of the water currents according to the calculated horizon in the years of varied assured water content. Such a problem is solved for conditions of the natural regime up to the exploitation of deposits. That requires the use in models of results of hydrometric studies over the river, which exercise control on the model of general underground water current in the river and, in a number of cases, the model of underground recharge. A solution to this problem has become more imperative in recent years since now during the dewatering of mines, there is a need to use mineral waters in domestic and drinking water supplies, which demands a 95% guarantee of water throughout the year (if the supply/demand ratio is to be met).

Normal water currents in the mines are estimated for the annual water resource varying within 5 and 10% . In that case, the given model requires examination of hydrodynamic currents taking into account the demands of agricultural problems and also the solution to problems relating to ecological changes in the territory during drainage of the deposits (the problem of preservation of the surrounding environment during the drainage in mines). Subsequent stages of modelling of general calculated schemes presume re-examination of the complex models based on the results of water-level lowering in the deposits (see Chapter 11). For increased reliability of results of modelling it is, of course, desirable to separate sections of time for a stationary faulted regime; the expression of these in the models presumes estimates of volume parameters of aquifer horizons and layered divisions.

Modelling of non-stationary problems relates the volume characteristics of the aquifer horizons and layered divisions, which are controlled according to the tempo of lowering of levels with time in a given regimal well. Reliability of solution of inverse problems according to the estimate of hydrogeological parameters might be increased by: (a) acquisition of additional information through special field studies on volume characteristics of the aquifer horizons and layered divisions in type areas; and (b) integration of hydrodynamic, hydrochemical, hydrogeothermal and hydrological conditions in a single computed scheme.

The conducted sequence of solution of inverse problems constitutes only the beginning and should be repeated for cross correlation according to calculated parameters. Modelling of inverse problems according to experimental drainage of mine workings to estimate mathematical parameters and studies of the general water exchange of underground waters of a given territory compel us to approach the problem of sensitivity of the computed scheme through the parameters and refinement of further methods of the entire complex of regimal observations.

To solve the inverse problems listed above and the following straight prognostic problems, processing of data from the entire territory is a preliminary requisite for characterising the hydrogeological situation of the study area under natural and disrupted conditions, thereby providing the necessary basis for further information. A list and contents of the necessary hydrogeological information are presented in Chapter 12.

PROBABILITY-STATISTICAL METHODS OF PROCESSING INFORMATION FROM COMPLEX STUDIES ON REGIME OF UNDERGROUND WATERS

The fairly large amount of primary hydrogeological information from complex studies of the regime of underground waters during use of the drainage system, reservoir machinery, tailings dump and reservoirs and other aspects of mining requires systematisation, which can be done through the probability-statistical method.

The essence of this method of processing is the application of the theory of probability and mathematical statistics for resolving innumerable hydrogeological problems, including studies on conditions of formation of the regime of underground waters in technogenic situations.

The theoretical premises of the probability-mathematical method for processing hydrogeological information have been worked out sufficiently well. Therefore, we shall discuss only the basic methodological procedures for probability-statistical studies and technological processing of data on the regime of underground waters.

Above all, by means of the aforementioned method it is possible to: (a) determine the general indicators characterising the basic patterns of the disrupted (faulted) regime of underground waters formed at the stage of exploitation of ore deposits; (b) establish correlation between the main regime-forming factors in technogenic conditions and also the correlative function between water currents in the mines, hydrometeorological and hydrological factors; (c) construct different analytical graphs and establish changes in major indicators of the regime of underground waters in space and time (level of underground waters, water currents in mines, temperature of underground waters etc.) and also solve a series of other analytical problems; and (d) establish criteria of hydrological probability through mathematical processing of the data collected and estimate the reliability of the primary hydrogeological information on the study area.

In practise, hydrogeological investigations are amenable to experimental application of probability-statistical methods for prognostic estimate of the general water currents in the system of mining through experimental drainage of ore deposits.

Technological processing and analysis of the primary hydrogeological information are conveniently carried out in a distinct sequence.

1. Estimation of the general characteristics of all the components of the regime of underground waters and their changes with time is determined by means of construction of type curves of seasonal and multi-yearly regime of level, discharge, temperature and chemical composition.

   If the data from observations over the regime of water currents encountered in the system of mining or underground waters in the reservoir area are subjected to processing, then it is desirable to construct a combined chronological graph of the regime of levels, discharges and regime-forming natural factors—atmospheric precipitation, surface water currents and technogenic factors.

   Type curves give details about the stability in time and space of regime of underground waters during the period of one year as the climatic cycle, so for a multi-year period one must establish qualitatively the dependence of the main parameters of underground waters on regime-forming factors.
2. Processing of materials through determinations of statistical characteristics of the temporal series of the given regimal observations, estimation of the interior pattern of alternation of much-water/lean-water years and also the law of their distribution and possible extrapolation to the following years of the parameters of the regime of underground waters in the fields of both high and low percentage of guarantee.

   The general procedure for establishment of the law of distribution of the temporal series of regimal observations and compilation on this basis of the hydrogeological prognosis, consists of certain successive stages in processing the data. First, determination of the statistical parameters of a series of observations and the volume of sampling of information has to be completed. Then, histograms and empirical curves of distribution of values of the parameters of the regime have to be done. On the basis of these graphs it is possible to establish the law of distribution and experimental values of levels of underground waters, water currents, discharges from reservoirs etc., leading to variations in water availability throughout the year.

   As a result of data processing, the mean multi-annual and mean annual values of the basic parameters of the regime, the amplitude of variation and other hydrogeological parameters characterising the regime of underground waters, can be highlighted.
3. Processing of data to reveal the genetic pattern of multi-annual variation in basic parameters of the regime of underground waters. Initially one must construct special chronological graphs of fluctuations in levels, discharges, parameters of the regime, etc., and then plot the differential integral curve and curve of special regression, carry out expansion of provisional observations for the regime of underground waters in the Fourier series, expose the

cyclic character and further establish trend changes in the original series (trend analysis). It is essential to complete the complex processing of the series of observations using an EVM computer.

CHAPTER 11

Prognostic Evaluation of General Water Currents in Mines and Options of Schemes of Drainage

GENERAL CONSIDERATIONS AND EVALUATION OF WATER CURRENTS BY THE HYDRAULIC METHOD

Prognostic estimate of the general water currents in a system or in independent open cast or underground mines is invariably attempted at the stage of planning of commercial working of the ore deposits. The results of hydrogeological and engineering geological studies constitute the basic information collected at the stage of prospecting ore deposits. Estimates of prognostic water currents serve as the basis for mining engineering conditions which influence the progress of mining activity, measures of protection of mines from flooding and also the option and choice of the most effective schemes of drainage in mining operations as a whole. The following factors have to be given due consideration in this regard: (a) the principal pattern of hydrogeological and engineering geological conditions of the ore body; (b) filtration properties of the ore-bearing country rocks and those overlying the ore; (c) balance structure of the possible sources of formation of water currents in mines, and the role in this structure of surface waters; (d) technology of stripping and conditions of mining ore deposits; (e) influence of drainage in mines on possible changes in characteristics of the geological environment and ecological situation of the surrounding environment; and (f) utilisation of mine waters for the entire water supply or irrigation etc.

In the process of prolonged exploitation of ore deposits, continued generally for over 50 years, the hydrogeological and engineering geological factors determining conditions of formation of water currents and mining engineering conditions, undergo prominent changes, the prognosis of which at the stage of exploration is indeed very complex. The limits (boundaries) of the filtration current are altered in plan so that, based on conditions of recharge of underground waters, changes in regime of underground current originate. During this, a system of mines plays the role of a deep-seated basis of drainage and changes in the geological environment develop. Further, at the stage of exploitation of ore deposits, as observed earlier, fairly intensive formation of the whole complex of technogenic processes takes place. Due to the negative influence of such processes, commercial working of the ore bodies requires necessary corrections. The most conspicuous changes in natural hydrogeological and engineering geological conditions originate at the stage of exploitation of ore deposits of the third and fourth groups according to the degree of complexity of their mining (see Table 5). In the process of exploitation of ore deposits it very often becomes necessary to sink new shafts, to reconstruct open cast workings and to additionally deepen underground mines.

At the stage of commercial working of ore deposits, it is essential to periodically conduct re-evaluation of general water currents in the mines for the purpose of increasing the efficiency of the working drainage facility as well as any additional drainage construction, improving the hydrogeological conditions of conducting mining activity at deeper ore horizons, arranging additional measures of protection of surrounding environment from the negative influence of technogenesis etc.

Similarly, during prognostic evaluation of water currents in mines and drainage constructions at the stage of exploitation of ore deposits, not only the faulted hydrogeological and mining engineering conditions (conditions and tempos of further development of the mines), but also technogenic changes which originate at the stage of commercial exploitation of the deposit must be considered. The information requisite for solving these problems is obtained through the results of complex hydrogeological and engineering geological investigations carried out at the stage of exploitation of ore deposits.

The theoretical bases and methods of prognostic estimation of water currents in mines are comprehensively described in published works [9, 10, 18, 19, 20, 21, 22].

The choice of methods of prognostic estimation of water currents and scheme of drainage is made differentially, based on the degree of complexity of the geological environment and industrial exploitation of ore deposits, as presented in the industrial-geological grouping (see Table 5).

For ore deposits of the first and second groups the following methods are employed for prognostic estimation of water currents in a system of mines or in independent mines: (a) hydraulic; (b) hydrodynamic (method of analytical computations); and (c) balancing. For ore deposits of the third and fourth groups, with complex and highly complex hydrogeological conditions, forecasts on water currents can be made using: (a) the method of mathematical modelling; and (b) the hydraulic method (mainly for ore deposits of the third group).

Processes of formation of water currents in a system of mines are very complex, compared with the current of underground waters moving towards borewells in water reservoir constructions. This explains why, for example, during the development of underground mines in plan and with depth, the water intake part of the general system of the reservoir site constantly changes in space. Thus in all known analytical functions for standard hydrogeological conditions, factors of continuity of the water intake part of pumping are taken into account. Related to this, while determining the general prognostic water currents, it is important to carry out hydrogeological schematisation of the natural conditions of the study area in co-ordination with the technological characteristics of the mine's advancement. In open cast mining of ore-bearing areas, where in principle the contour of the water intake part does not change significantly, minor errors nevertheless creep in. Furthermore, for the third group of ore deposits (see Table 5) occurring in carbonate rocks characterised by heterogeneity of permeability, water currents in a system of mines often form at the expense of large concentrated yield-sources of mine waters, which makes the application of common analytical computations very difficult. The geotechnical complexities mentioned above determine certain assumptions and conventions in forecasting the general water currents in the system of mining.

Hydraulic method of prognostic estimation of general water currents. This is based on analysis of data related to experimental drainage in mines of the working mining enterprise. For ore bodies of the first and second groups, this method, as indicated by studies, gives fairly tolerable results of prognostic value of water currents and is sufficiently proved in practise. The method is based on the application of functional characteristics of total water currents from the lowering of level (in the given case, on principle, from the depth of mine working which, for conditions of distribution of fracture waters, is thoroughly admissible). Essentially, the methodological procedure is as follows. On the basis of data from regimal observations for factual general water currents and regimal level of underground waters from the observation well situated close to the centre of disturbance of the filtration current, certain graphs are constructed on coordinates $\Sigma Q = f(t)$,

$$S_{cp} = f(t) \text{ and } \Sigma Q = f(S).$$

It is desirable to plot tentative graphs of total water currents—$\Sigma Q = f(t)$ of mean value level $S_{cp} = f(t)$—separately for maximal, minimal, and mean annual values of water currents. Such auxiliary graphs should precisely define the character and tendency of changes in the course of total water currents, depending on the lowering of levels of underground waters (see Figure 46). The principal graph—$\Sigma Q = f(S)$—in the presence of reliable hydrogeological information, very specifically characterises in a general pattern the changes in total water currents, depending upon the amount of lowering of the level. On the basis of the pattern established through factual data, it is possible to forecast the value of possible rates of flow of the water currents during future deepening and development of mines of ore deposits. For an approximate prognosis, however, it is possible to make use of the simple graphic method, by means of extrapolation of the data of the main graph, assuming extrapolation within the limits of nearly 50% from the general value of lowering level from the start of extrapolation. For more precise solutions the graphic-analytical method may be employed, reflecting the empirical functions of discharge from the lowering of level—simple empirical functions entering the formulae of Dupois, Streker, Al'tovskii and others [14, 27]. In choosing one or the other empirical function it is essential to fulfil the following procedures of data processing. If the graph of the function $\Sigma Q = f(S)$ presents a straight line passing through the beginning of the co-ordinate, then, for forecast-estimate of the water currents, Dupois' formula can be used. When a different kind of function is obtained in the graph (primarily attenuation of a parabolic curve), it is necessary to construct supplementary graphs of change of specific water currents from the lowering of level—$q = f(S)$ $\log Q = f(\log S)$ or $Q = f(\log S)$—which calls for choosing the necessary empirical relation for prognostic evaluation of the water currents [12]. In practical experience of hydrogeological studies, the hydraulic method of prognostic estimate of the general water currents has been completely justified in many areas.

The balance method, based on calculation of the balance structure of water currents, and the input and output characteristics of the filtration current, envisages approximate determination of the prognostic evaluation of the general water currents for areas exhibiting local development of aquifer horizons. This method can be applied during the presence of quantitative characteristics of the balance structure of all possible sources of formation of water currents. This method, in fact, determines the possible limits of the general currents of the mine as a whole.

The hydrodynamic method of estimation of prognostic water currents in a system of mines is based on rigorous mathematical solutions. Depending on the degree of complexity of hydrogeological conditions of ore deposits, the hydrodynamic method of estimation of prognostic water currents can be accomplished: (a) for simple conditions by means of analytical computations, utilising during the function for standard schemes of calculations; and (b) for complex conditions, through the method of mathematical modelling by AVM or EVM computer.

Adoption of the hydrodynamic method requires adherence to methodological procedures in the following order. First, it is necessary to conduct a thorough analysis of the hydrogeological information available on the ore deposit, such as: (a) hydrogeological maps of distribution of aquifer horizons and groundwater contour maps constructed at different time intervals; (b) maps of conductivity of the principal aquifer horizons based on precise values of hydrogeological parameters of the layer according to the given regimal observations, technogenic changes, and their past occurrences during the stage of exploitation of the deposit; (c) complex graphs characterising the regime of water currents in the mines, changes in levels of underground waters in observation wells situated at varying distances from the centre of disturbance of the current, the regime of surface current and also the regime of occurrence of atmospheric precipitations; and (d) technological schemes of mine development (tempo and conditions of development).

The filtration rating of the scheme of the study region has to be arrived at on the basis of results of analysis of technogenic hydrogeological conditions. The study area is characterised by the boundaries (limits) of the filtration current in plan as well as in section in disturbed or faulted conditions. If the geofiltration scheme has to be related to the standard categories, then, further calculations of prognostic water currents have to be done by means of known analytical computations for the standard planned scheme. In the complex computational scheme, solution of the given problems has to be done through the method of mathematical modelling.

The major standard planned scheme in mining practise very often encompasses: (a) occurrence of unconfined stratum in plan of large areal extent; (b) semi-confined, in plan, of layer, with one border constituting area of recharge (constant pressure, for example, near the river); (c) layered belt with different conditions of recharge and current at its limits; and (d) enclosed layer possessing confined field of distribution, primarily with impermeable contours.

Later, computations are carried out for every aquifer horizon delineated in the section in the following succession. The general water currents in a system of mines at the assigned depth of later development of the ore deposit is determined. The values obtained on the prognostic water currents have to be appraised from the point of view of their influence on safe conditions for mining (in this case, stability of slopes of an open cast mine). Then analysis of the effectiveness of the drainage system in operation in the mining enterprise has to be completed in co-ordination with results obtained from the prognostic estimate of the water currents. Based on this analysis, necessary corrections have to be incorporated in the working drainage system (the mechanism of working of the drainage construction is improved, new discharge wells or additional pump fittings are introduced in the mines during intra-shaft pumping etc.).

The most effective procedure for simplifying analytical computations for prognostic estimate of the general water currents, is the principle of 'gigantic well', which involves general configuration of the mines in plan, resulting in a circular contour of drainage with the radius r_K. For transformation of an open cast field, this procedure may be reliably incorporated in computations. But for underground mining of ore deposits, when the disposition of the mines according to the horizons commonly exhibits too much variation and the ore bodies are mixed in space (for example, during the working of gently dipping ore bodies), the principle of 'gigantic well' might lead to diminished reliability in analytical computations. Under such complex conditions of configuration of the reservoir part of the 'gigantic well', estimation of the water currents has to be done by the method of mathematical modelling using an AVM or EVM computer.

The estimated radius of the 'gigantic well' can be determined: (a) according to the perimeter (P) of the mines, where $r_\Lambda = P/(2\pi)$; or (b) according to the field (F) of the rocks, where $r_K = \sqrt{F/\pi}$.

For open cast mines the estimated radius of the 'gigantic well' is calculated according to the formula of N.K. Girinski:

$$r_K = \eta \frac{L+1}{4}$$

where L — length of quarry; b — width of quarry; η — coefficient, dependent upon value of b/L:

b/L	0.05	0.1	0.2	0.3	0.4	0.5	0.6
η	1.05	1.08	1.12	1.14	1.16	1.17	1.18

Expressions for the radius of influence (*R*) of the 'gigantic well' as applied to standard schemes of limits of the current (for stationary regime of filtration) during different conditions of recharge of the aquifer horizons (Figure 61) are as follows:

1. Open cast mine field near the linear boundary with constant pressure (near the river or reservoir): $R = 2L$.
2. Open cast mine field in the band-forming layer between the limits with constant pressure (of the river or the reservoir):

$$R = \frac{2}{\pi} L_0 \sin \frac{\pi L}{L_0} .$$

3. Open cast mine field in the band-forming layer with constant pressure and impermeable contour:

$$R = \frac{4}{\pi} L_0 \operatorname{tg} \frac{\pi L}{2L_0} .$$

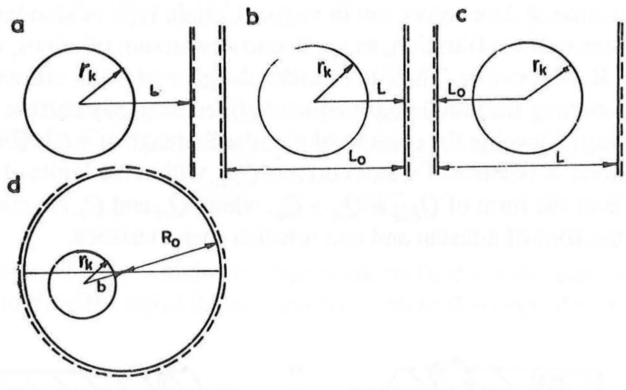

Figure 61: Computational schemes to determine radius of influence of 'gigantic well'

Open cast mine field: a—near linear boundary with constant pressure; b—in band-forming layer between limits with constant pressure; c—in band-forming layer with constant pressure and impermeable contour; d—in circular region with constant pressure on outer limit.

4. Open cast mine field in circular region with constant pressure on outer limit:

$$R = R_0 - \frac{b^2}{R_0} .$$

For conditions of unsteady regime of filtration, the computed radius of influence according to the scheme of 'gigantic well' can be approximately determined using this formula (during the given lowering of level) $R_t = r_K + \sqrt{\pi at}$ where t = calculated time. The analytical functions for a standard planned scheme that might be used for prognostic estimate of currents in a system of mines during open cast or underground methods of commercial mining of ore deposits have already been well described [19].

During the working of certain ore deposits under conditions of distribution of artesian aquifer horizons, drainage must be done in two stages: in the first stage a complete release of piezometric pressure is arranged and in the second stage, direct withdrawal from the aquifer layer. In such hydrogeological conditions, during drainage in mines, an artesian-non-artesian regime of filtration current is produced. The nature of a confined-unconfined filtration process is such that the balance structure of the water currents towards the mine's workings is determined on the one hand by the elasticity and on the other by the gravitational character of natural resources of underground waters of the drainage horizon. To estimate the general prognostic water currents under a confined-unconfined regime, the solution proposed by N.N. Verigin, the method of integral correlation and its partial case-method of integral balance, based on calculation of data balance within the limits of the cone of depression, are in vogue. Certain type or standard problems of confined-unconfined filtration, as applied to dewatering of mines, were solved earlier by V.K. Mamontov. Thus, to estimate the general water currents in a field of open cast mining for radial confined-unconfined unsteady current he used the given lowering of level in the contour of circular drainage of wells (Figure 62).

The equation of balance of water currents Q_{Gen} within the limits of the cone of depression is in the form of $Q_{Gen} = Q_H + Q_b$, where Q_H and Q_b are corresponding currents in the zone of artesian and non-artesian characteristics.

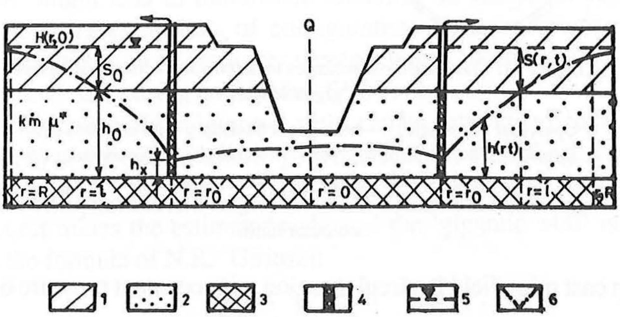

Figure 62: Scheme of radial artesian-non-artesian unsteady current

1—loams; 2—sands; 3—impermeable rocks; 4—borewell; 5—water table level in natural position; 6—cone of depression.

We may consider that the level of underground waters along the contour of the circular battery of wells declines instantaneously, that is, in a period of time significantly less than the duration of drainage up to a certain given level (h_K). With these conditions, as viewed from the region of the artesian zone, the prognostic water currents (Q_H) can be determined according to the following equation:

$$Q_H = \frac{2\pi km\, S_0 \;\; (l - \overline{R})}{\overline{R} - \ln \overline{R} - l}$$

where $\overline{R} = l/R$; l = distance from the well up to artesian-non-artesian current; $\overline{R}$ = radius of depression.

The quantity of the non-artesian component of the balance of current

$$Q_b = \frac{2\pi\, \mu}{h_{cp}\, t} \left[\beta\left(\frac{l^2 + 3r_0^2}{l^2} - \frac{r_0^2}{2} \ln \frac{l}{r_0} - \frac{r^3}{3l} \right) + h_0 \left(\frac{l^2 - 3r_0^2}{6} + \frac{r_0^2}{3L} \right) \right],$$

where

$$\alpha = \frac{S_0}{\overline{R} - (\ln \overline{R} - 1)} \; ; \quad \beta = \frac{U_0 - h_0\, \alpha \left(1 - \frac{r_0}{l}\right)}{\ln - l + \frac{r_0}{l}} \; ;$$

$$U_0 = 0.5 \left(h_0^2 - h_K^2 \right).$$

The size of the field of filtration (L) involved in the process of withdrawal of water can be determined according to the following function:

$$L = \sqrt{6a^* t - t_0} + \sqrt{6a^* t_0} \quad .$$

The time (t) during which the depressed surface on the contour of water withdrawal reaches the top of the artesian layer can be determined according to the formula

$$t_0 = \frac{\pi\, S_0\, Km\, \mu^*}{q^2}$$

where km = conductivity of layer; a^* = coefficient of piezo-conductivity; μ^* = specific yield of layer; q = linear flow of current forming in the artesian and non-artesian zone of layer.

In accordance with the conditions of integral balance, the linear flow of the current would be

$$q = \frac{4\, S_0\; k\, m}{L - l} + \frac{2\; \mu\; l^2}{h_{cp}\;\; t - t_0} \left(\frac{q}{12k} + \frac{2\, S_0\;\, h_0}{L - l} \right) \quad . \qquad ...(12)$$

Function(12) demands that for the known value (L) it is important to determine the zone of non-artesian filtration. As in the previous cases, the estimate of the general water currents serves later as the basis for selection of a circular system of drainage in order to dewater an open cast mine (choice of number of wells, distance between them, their discharges and depths).

In conclusion, let it be noted that in practice, for drainage operations in mines of simple conditions, analytical computations may be adopted for the appraisal of contoured systems of drainage wells situated in the form of a linear row or circular battery, around an open cast mine or along the flanks of the cone of depression. Under complex conditions, problems relating to drainage in mines can be solved by means of mathematical modelling. We present here certain procedures of application of analytical solutions for comparatively simple hydrogeological conditions.

During the working of ore deposits certain conditions are encountered in practise when drainage wells are situated between an open cast mine (along the slopes of an ideal open cast mine) and a river (close to the slope of an ideal open cast mine). Such a linear row of drainage wells is prescribed in order to protect the mines from flooding and also for guaranteeing stability of the banks (slopes) of the open cast mine (Figure 63). Such hydrogeological conditions are seen, for example, in the Ayat ore deposit. The peculiarity of exploitation of drainage systems in such conditions is that at the foot of the aquifer horizon, in horizontal disposition, the confining bed provides a place for the 'passage' of underground waters based on

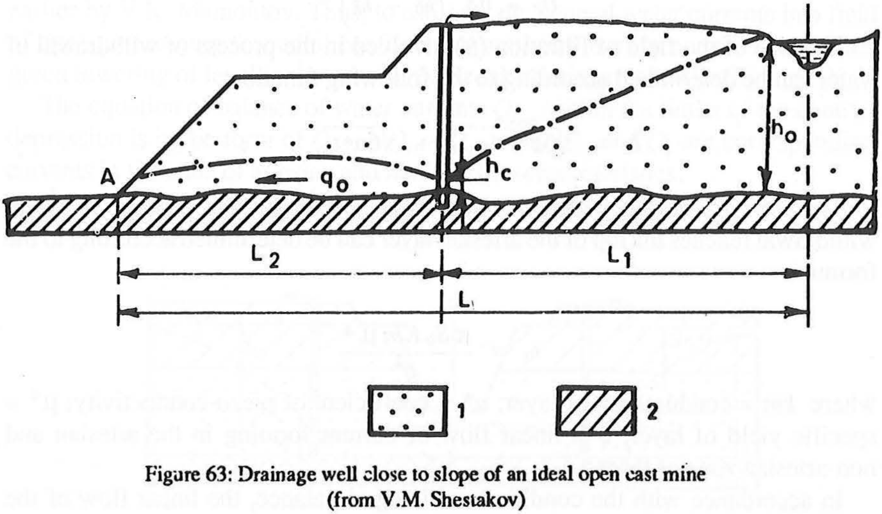

Figure 63: Drainage well close to slope of an ideal open cast mine (from V.M. Shestakov)

Rocks: 1—aquifer; 2—aquiclude.

the slope of the bank of the open cast mine (see point *A* in Figure 63).

For unconfined conditions in the regime, the discharge of the drainage well can be determined according to the following equation [36] :

$$Q_w = 0.5\ k\ \frac{h_0^2\ \dfrac{L_2}{L} - h_c^2}{\dfrac{L_1\ L_2}{b\ L} + f_{kc}} \tag{13}$$

In practical calculations the planned productivity (Q_w) of the well often has to be defined. During these conditions, the expression (13) might be presented in the following manner :

$$b = 2\ \frac{Q_w}{k}\ \frac{L_1}{h_0^2 - \dfrac{L}{L_2}\ h_e^2 - 2\ \dfrac{Q}{k} \times \dfrac{L}{L_2} \times f_{kc}}$$

where b = is defined by choice for given value of Q_w during conditions of drainage of open cast mine; h_o = depth of current along 'passage' in open cast mine; h_e = thickness of filtration current up to start of drainage operations.

To determine the specific yield (q_o) of the current flowing along the slope, the following equation holds good:

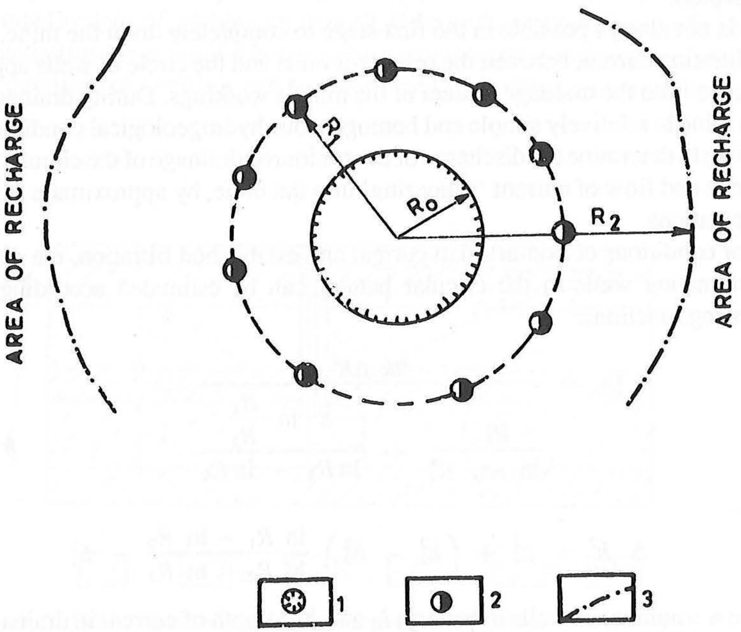

Figure 64: Scheme of disposition of circular battery of drainage wells

1—open cast mine; 2—drainage wells; 3—boundary of area of recharge.

$$q_0 = k\frac{h_c^2}{2L_l} + \frac{Q}{L} \times f_{kc} .$$

The value of f_{kc} is calculated from the expression $f_{kc} = 0.336 \log \frac{l}{2\pi r_c}$, where r_c = radius of well.

V. M. Shestakov points out that it is essential to adopt the value of the specific yield of the current (q_o) during calculations originating from conditions of filtration stability of the slopes. Stability of the slopes depends upon the structure and lithological composition of the rocks. In practise, different filtration overloads are applied on the basis of the slope, in order to increase the stability of the slope of an open cast mine.

When ore deposits are exploited by the stripping method, very often a system of drainage is implemented by construction of an external ring of drainage wells aligned along the contour of the open cast mine as shown in Figure 64. In such a system the drainage of mines is carried out in two stages: in the first stage, all the wells are fitted with submersible pumps and work as drainage installations; and in the second stage, all the drainage wells are converted and provided with porous filters through which the sub-surface drainage of both the working and pumping shafts pass.

It is not always possible in the first stage to completely drain the mine. Part of the filtration current between the open cast mine and the circle of wells appears to 'squeeze' into the drainage system of the mine's workings. During drainage of an open mine in relatively simple and homogeneous hydrogeological conditions, it is possible to determine the discharge of the contoured drainage of the circular battery of wells and flow of current 'squeezing' into the mine, by approximate analytical computations.

For conditions of non-artesian current and established filtration, the discharge of interacting wells in the circular battery can be estimated according to the following functions:

$$Q_0 = \frac{\pi k \, \Delta h^2}{\dfrac{R_1^{n+1}}{\ln n r_0 \, R_0^n} - \dfrac{n \ln \dfrac{R_1}{R_2}}{\ln R_2 - \ln R_0}} ; \qquad \text{...(14)}$$

$$\Delta h^2 = h_0^2 + \left(h_2^2 - h_0^2\right)\frac{\ln R_1 - \ln R_0}{\ln R_2 - \ln R_0} - h_1^2 \qquad \text{...(15)}$$

where n = number of wells in battery; h_1 and h_2 = depth of current in drainage well and area of recharge respectively.

Between the contours of the obstructed drainage and the open cast mine it is possible to determine the depth of filtration current 'squeezing in,' as viewed from the drainage wells, as follows:

$$h_2^2 = h_e^2 - \frac{\left(h_1^2 - h_0^2\right) \ln \frac{R_1}{r}}{\ln R_1 - \ln R_0}$$

It is possible to determine the discharge of underground waters reaching the open cut mine through intra-mine pumping according to the formula

$$Q_k = \pi k \frac{h_1^2 - h_0^2}{\ln \frac{R_1}{R_0}} .$$

Using the expressions provided, it is also possible to assess the effectiveness of functioning of obstructed well drainage and according to formulas (14) and (15) the analytical computations for porous filters during changeover to the second stage of drainage of an open cast mine. In utilising the above expressions for conditions of occurrence in ore deposits of artesian waters, it is essential to substitute h_0^2 by 2 m H_o, h^2 by $2m\,H_1$ and h_0^2 *by* $2m\,H_2$, where m = thickness of aquifer horizon; H_o, H_1 and H_2 = values of pressures at corresponding contours.

Commercial working of some ore deposits might encounter such hydrogeological conditions wherein the rock series overlying the ores might contain two distinct artesian aquifer horizons, separated by weakly permeable rocks (Figure 65). In an underground system of working the deposit, if the underground mines in the region are situated in the lower aquifer horizon, the general currents in the system of mines during conditions of overflow can be determined according to the formulas:

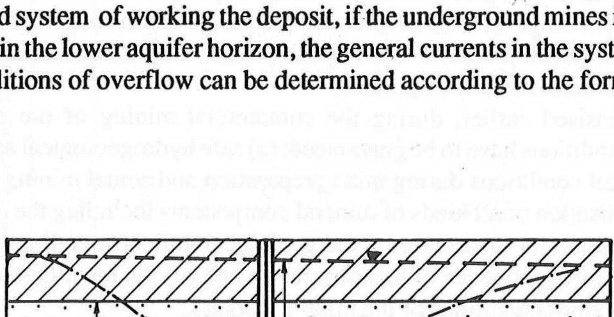

Figure 65: Scheme of determination of general water currents in system of underground mines in which two artesian aquifer horizons are present

1—upper aquifer horizon; 2—lower aquifer horizon; 3—weakly permeable rocks (aquiclude); 4—static level (water table); 5—cone of depression; 6—mine working.

$$Q = \frac{8\pi \ (k_2 m_2)\ S_0}{-E_i\left(\dfrac{r_k^2}{4a^* t}\right) + W\left(\alpha, \dfrac{r_k}{B}\right)};$$

$$a^* = \frac{km_2}{\mu_2^* + \mu_{0/2}}\ ;\ \alpha = \frac{r_k^2}{4a_1^* t}\ ;\ a_1^* = \frac{km}{\mu^* + \dfrac{\mu_0}{6}};$$

$$B = \sqrt{\frac{k_2 m_2 m_0}{k_0}};$$

where $k_2 m_2$ = conductivity of water in lower aquifer horizon wherein the mine is situated; a^* = coefficient of piezo-conductivity; W = functions, the values of which are presented in Table 7; B = parameter of overflow; μ^* = water yield of lower aquifer horizon; μ_0 = water yield of weakly permeable layer (aquiclude).

CHOICE OF RATIONAL SCHEMES OF DRAINAGE IN MINES

We have observed more than once that the prognosis of general currents in shaft pipes, open cast mines, and shaft zones is conducted in order to select one or the other scheme of drainage, ascertain measures to protect mines from flooding etc. At the modern stage of intensive development of the mining industry, for the planning and development of each specific mine the most rational scheme of drainage in mines is highly important.

As emphasised earlier, during the commercial mining of ore deposits the following conditions have to be guaranteed: (a) safe hydrogeological and engineering geological conditions during mine preparation and actual mining activity; (b) complex utilisation of all kinds of mineral components including the mine waters; (c) preservation and protection of the geological and surrounding environment from the negative influence of technogenesis; and (d) the most favourable socio-economic (living) conditions of the mine's workers.

The basic requirements have to be met mainly by adopting the most rational scheme of drainage in mines and also the optimal disposition of the major sectors of the mining enterprise over the deposit. The following constitute the most rational schemes of drainage:

1. 'Drainage-water supply' scheme: Two large problems are involved in this scheme—drainage of mines and necessary use of underground waters for a complete water supply. In this scheme of mining practice there are two variants: (1) drainage and domestic potable water supply; (2) drainage and industrial water supply.

The first variant of this scheme constitutes the most rational one. In introducing this variant, it is necessary to construct surface as well as sub-surface external drainage installations (see Chapter 6) which meet all the specifications stipulated

TABLE 7: Values of function W (α; r_k / B)

	Values of function W when r_k/B is equal to								
α	0.01	0.05	0.1	0.2	0.4	0.6	0.8	1	2
0.0005	6.975	6.853	4.853	3.504	2.228	1.553	1.130	0.841	0.227
0.001	6.307	5.796	4.829	3.504	2.228	1.553	1.130	0.841	0.227
0.005	4.721	4.608	4.296	3.457	2.280	1.553	1.130	0.841	0.227
0.01	4.036	3.98	3.815	3.288	2.225	1.552	1.130	0.841	0.227
0.05	2.468	2.458	2.427	2.311	1.928	1.493	1.121	0.841	0.227
0.1	1.823	1.818	1.805	1.753	1.564	1.312	1.050	0.819	0.227
0.5	0.560	0.559	0.558	0.553	0.534	0.504	0.465	0.421	0.194
1	0.219	0.219	0.219	0.218	0.214	0.206	0.197	0.186	0.114
2	0.049	0.049	0.049	0.049	0.048	0.047	0.046	0.044	0.034
5	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

in GOST 2874-82 for quality control of domestic potable water supply and organisation of zone of sanitary preservation. Here a more stringent approach to the prognosis of general water currents in the system of planned drainage constructions becomes imperative. The crux of the situation is that prognosis of the general currents must be done in accordance with the requirements detailed in the instructions manual of GKZ, USSR for exploitation of reserves of underground waters as the source for a potable water supply, including the basis of exploitation of groundwater reserves in accordance with a high industrial category (A and B).

Results of limited study in this direction demonstrate that it is entirely possible to carry out prognosis of the general water currents in the system of mines (as sources of an economic potable water supply) both at the stage of exploration and commercial exploitation of the ore deposits. Positive solutions to such problems in the deposits of Kazakhstan, the Urals and KMA reliably support this conclusion.

In this connection it is essential to reconsider the technology and contents of the hydrogeological investigations to be completed at the stage of exploration of ore deposits. Simultaneously, rigorous calculations in planning investigations to accord with the Instructions of GKZ, USSR [14] perforce constitute a major aspect, from which arise more comprehensive activities such as drilling and experimental filtration studies and also a detailed examination of the quality of the underground waters. At the exploration stage it is necessary not only to undertake a prognostic estimate of possible water currents in the system of future mining works, but also to assess the exploitable reserves of underground waters as sources of a potable water supply for the prospective undertaking and, accordingly, complete a complex evaluation of the use of underground waters. The solution to these two problems presumes the use of different hydrogeological procedures in estimating water currents.

Under the scheme 'drainage-potable water supply,' one must conform at the stage of exploration of ore deposits to the standards specified in GKZ, USSR in confirming proved exploitable reserves of underground waters.

Given the data on new industrial-geological grouping (see Table 5), it is peremptory to primarily conduct hydrogeological investigations for the sole purpose of complex prognosis of water currents and exploitable reserves of underground waters, at the stage of exploration of ore deposits of the third or fourth group. These two categories of deposits possess very complex natural conditions which invariably favour the formation of water currents in mines. Occasionally, complex estimates might be warranted during the exploration of ore deposits of the second group. With regard to deposits of the first group, usually simple hydrogeological conditions prevail during mining and hence complex prognosis is not required.

At the stage of commercial exploitation of ore deposits the problem of complex use of mine waters is readily solved. The problem looms large only when there is constant increase in water currents during mining activity. Experience has shown, however, that in almost all working mines, the need arises at the stage of exploitation to look for an additional source of water supply.

In a working mine provided with drainage installations the main line of study for a complex estimate of hydrological conditions lies in organising a comprehensive programme of *in situ* observations over the regime of underground waters. In this connection the study of the external drainage constructions of the mining enterprise should relate to the demands of the stage of exploring exploitable underground waters and concomitantly proceed according to the instructions of the GKZ, USSR.

In certain areas mine waters are successfully used for a domestic potable water supply by organising an automatic and well-isolated special pumping machinery directly in underground mines. In mines of ore deposits where underground waters appear as large concentrated currents (up to 2,000-3,000 m^3/hr) such a variant of an underground automatic pumping mechanism is highly effective. The inadequacy of this scheme of pumping lies in the fact that with deepening of mining, it becomes necessary at the lower horizons to shift the automatic drainage facility in order to avoid possible drainage of mine waters into part of the pipeline under the influence of continuing mining activity at still deeper horizons.

In introducing the second variant of the scheme 'drainage-water supply,' a simplified hydrogeological basis is assumed and the requirements of estimating the quality of mine waters are fewer. This is because in the second variant of the scheme the problem is merely providing an industrial water supply to the beneficiation plant, thermal electric stations and other industrial sectors of the enterprise. In this situation mine waters from any scheme of drainage in mines can be used, and supplied through external drainage constructions and pumping within the mine and quarry.

As for the quantitative estimate of underground waters, in this case the requirements (i.e., confirmation of the proved reserves of underground waters) ought to be fulfilled as done in the first variant. In a series of large mining undertakings of the USSR the second scheme of drainage was successfully introduced and fully satisfied the modern requirements of multiple use of the economic components of ore deposits. In the vast majority of cases the problem of use of mine waters for the entire industrial water supply was positively solved at the stage of exploitation of ore deposits on the basis of results of a study of the regime of underground waters.

2. 'Drainage-irrigation' scheme. Essentially this scheme utilises mine waters for a complete artificial irrigation of the ground adjoining the territory of the mining enterprise and also the ground comprising the territory of the mine's township. This scheme is particularly important to mines situated in the arid zone of the USSR. The scheme 'drainage-irrigation' is directed towards providing the mine site a cultivable landscape, an auxiliary economy and eventual betterment of socio-economic conditions of living for the labour population in mine towns. Considering that during this scheme, mine waters

intended solely for irrigation might be used periodically, only during the vegetative period, for the remaining period of the year it is desirable to use the waters pumped out of an open cast or underground mine for construction of small ponds or reservoirs in relaxation and rest resorts. Taking into account the purpose of the scheme 'drainage-irrigation', it is very necessary to constantly monitor the quality of the mine waters, using personnel from the hydrogeology division of the mining enterprise.

The scheme 'drainage-irrigation' is exemplified in a mining enterprise in Kazakhstan where mine waters have been successfully used for irrigation and rest resorts have been so developed that mine workers in a township situated in a semi-arid zone feel a complete change in landscape, which forms a colourful oasis with excellent parks, gardens with fruit-bearing trees and vineyards. Other excellent examples of use of mine waters for irrigation are seen only in Uzbekistan and Kirgiz.

While guaranteeing the practical introduction of the scheme 'drainage-irrigation', it is essential in each specific area to consider in the construction projects of the enterprise, the socio-cultural background which constitutes an integral part of the complex of mining ore deposits.

As pointed out earlier, during the draining of mines of certain ore deposits we encounter highly mineralised waters which reach the stage of brines (with mineralisation from 10-20 to 170-220 g/l). During such hydrogeological conditions in commercial working of ore deposits, the very complex problem of effluents of mineralised mine waters becomes evident. In conformity with recent requirements for preservation of the surrounding environment, discharge of mineralised waters directly on the surface, into the reservoir or in the river channel is strictly forbidden. Therefore, for such ore deposits individual and not standard schemes of drainage of mines must be planned. Depending on the specific structural-geological and hydrogeological conditions of the study areas of ore deposits with highly mineralised waters, three modes of drainage can be adopted: (a) 'drainage-burial'; (b) 'drainage-injection'; and (c) 'drainage and extraction'. Let us examine the essential principles of these modes.

The mode 'drainage-burial' as the name implies, envisages underground burial of mineralised or brine mine waters at deeper horizons in the earths' crust [8]. For this purpose favourable geological-hydrogeological structures should exist close to the mining enterprise for the burial of brines (presence of favourable receptacles or reservoirs). Sufficient experience has been gained in the Soviet Union on underground burial of toxic industrial effluents and also how to use saline petroliferous waters along and within the boundary of flooding of oil deposits. For mine waters possessing high mineralisation it is possible to apply the method of injecting brines into reservoir wells. The mode 'drainage-burial' with the help of injection wells might completely eliminate discharge of mineralised mine waters onto the surface and guarantee protection of the surrounding environment from contamination.

The mode 'drainage-burial' does not find much favour because the volume of buried containers is minimal (reduced intake capacity of deeper reservoirs). It is known from experience that the intake capacity of reservoirs at deep structural horizons in the system of absorption wells is reduced by the discharge of brines or industrial currents within the limits of 200-300 m^3/hr. During this, the optimum intervals of depth for underground burial, as seen from experience with industrial effluents, may vary from 500 to 1,700 metres. Rocks at deeper horizons are characterised by fairly low filtration properties and hence complexities arise in the discharge of mine waters at depths less than optimal.

It is quite obvious that this mode of drainage in mines requires special prospecting and experimental hydrogeological investigations. Such studies are required mainly at the stage of prospecting of ore deposits so that it is possible in advance to positively solve the problem of burial of brackish mine waters. Results of studies in this direction emphasise that this problem should be examined when planning exploitation of ore deposits.

Together with this, it is expedient to conduct certain special hydrogeological studies at the stage of construction of the enterprise and exploitation of ore deposits. Details of modes and methods of burial of industrial currents have already been published [8] and can be used in solving problems relating to the mode 'drainage-burial'.

The mode 'drainage-injection' may be an original approach. The essence of the concept is as follows. During drainage of the mines the mineralised mine waters pumped out are not discharged on to the surface, but led through conduits and disposed of at some distance from the mine area and by means of injection wells pumped back into the same aquifer horizon of ore-bearing rocks. In this mode, in the area of pumping, the volume of brines might spread radially in all directions and part might be directed towards the region of the mines. In the aquifer horizon, on the front of activity 'mining-injection' there will form a semi-closed balance scheme. It appears that through regularisation of withdrawal of mine waters and mode of injection it may be possible to obtain the effect of drainage of the ore bed and guarantee preservation of the environment around.

At present, in one of the ore deposits where the mine waters possess high mineralisation special investigations are underway to assess the basis and introduction of the 'drainage-injection' mode in mining practise.

For practical purposes no less important is the mode 'drainage-extraction'. This mode includes organisation of not-so-complex technological practices at the mining enterprise, envisaging extraction of all the major useful components from mine waters (the brines). Only after this, without damage to the environment, mine waters are discharged into the closest surface streams. Extraction of the useful components from brines has to be considered an effective means of purification of mine waters.

At the institute VSEGINGEO fairly simple technological processes of extraction of principal useful components from brines have been worked out and these might be used in mining enterprises.

For some time now literature in our country and abroad has highlighted an interesting mode of possible drainage in mines of ore deposits under the protection of anti-filtration screens introduced along mine contours. This mode is carried out to protect natural resources and reserves of underground waters from depletion, which is very important for regions with an acute deficit of water resources. Both here and abroad experiments are conducted to protect anti-filtration filters in the practise of hydrotechnical and industrial construction. The greatest depth of working of anti-filtration filters is about 100-150 m. Normally, in drainage of mines of ore deposits such an experiment is not undertaken due to the complexity of technical devices for this purpose. Still, in content and direction the mode 'drainage under protective screen' is highly progressive and its study in general ought to add to increased efficiency in the industrial working of ore deposits.

ESTIMATE OF RESERVES OF UNDERGROUND MINE WATERS UNDER EXPLOITATION

The need for utilising (underground) mine waters for complete water supply and irrigation has been repeatedly emphasised. It is absolutely natural that this problem be solved at the modern engineering level in accordance with the existing requirements of planning. Here assessment and confirmation of reserves of mine waters must conform to the instructions presented in GKZ, USSR or the territorial commission on deposits of economic minerals organised by the Republican Industrial-Geological Unions (TKZ).

According to the working Instructions Manual of the GKZ, USSR the reserves of underground waters under exploitation are estimated and taken into account on the basis of results of basic hydrological studies conducted in deposits and also data on the exploitation of underground waters. Therefore, *in situ* observations on the regime of underground waters, which are conducted over the drainage constructions of the mining establishments, ought to be considered as purposeful (result-oriented) hydrogeological studies, which are commonly carried out at the stage of exploration for strictly exploitable deposits of underground waters.

Data on proved deposits of underground waters are used in future plans of the water supply of the mining enterprise. During mining the working drainage constructions have to be justly looked upon as different kinds of reservoirs, built under specific hydrogeological conditions. For example, the outer pump wells or porous filters in the system of underground drainage in mines introduced along the outer contour of an open cast mine for leading its drainage, can be fully linked with the reservoir construction of a circular or linear system. Systems of outer drainage intersections set up on the surface between the contour of the mines and the contour of constant pressure (for example, river or reservoir) assigned for the purpose of intercepting the filtration current, can be considered reservoir constructions of the infiltration type working under conditions of interaction with intra-mine pumping. It is highly complex to determine the type of reservoir construction when the drainage system is of the intra-mine type of pumping waters directly into underground mines. Transformation of such a type of reservoir into a system of 'gigantic well' up to a certain degree is provisionally connected with the water intake part of the reservoir (system of mines) which, as mentioned earlier, periodically changes in space (since there is constant development of mining over the area of the enterprise).

For a potable water supply from the mining establishment, mine waters can be put to use provided they meet the requirements of quality (chemical composition and sanitary conditions) as prescribed by GOST 2874-82. Arising from these requirements, for a complete domestic potable water supply, it is recommended that mainly mine waters discharged by means of outer drainage constructions or automatic pumping installed in underground mines be used. In all remaining cases, according to sanitary conditions, mine waters can be utilised for industrial water supply or irrigation.

The estimate of exploitable reserves of mine waters ought to be considered along with the requirements detailed in the working classification of exploitable reserves of underground waters (GKZ, USSR) and the instructions meticulously followed. Under the term exploitable resources is included the quantity of underground waters which might be obtained from deposits by means of rational techno-economic operation of reservoir machinery during the given regime of exploitation, the quality of water and satisfactory requirements over the period of calculated water consumption. Unfortunately, no specific example of calculation of exploitable reserves of mine waters is cited in the Government Standards Manual (GKZ, USSR). Scientists of the Institute VSEGINGEO are presently working on the problem and their results may be published in the official document, GKZ, USSR.

Unlike the actual deposits of underground waters, the estimate of exploitable reserves of mine waters is not constant. This is due to the fact that, as pointed out earlier, according to the development of underground and stripped mining, the field of water intake in plan or cross section changes periodically. Therefore, particularly during evaluation of exploitable reserves of mine waters, it is necessary to consider not only the hydrogeological conditions of the area of drainage constructions but periodically changing mining engineering conditions of the area of occurrence of the deposit. During significantly changing mining engineering conditions originating in the process of prolonged commercial exploitation of the ore deposit (ore bodies are mined for more than 50-80 years), a periodic re-assessment of exploitable reserves of mine waters is mandatory. According to observations on activities at the Mintsvetmet mine, usually the most prominent mining engineering conditions are evidenced every 12 to 15 years.

In all cases of evaluation of exploitable reserves of mine waters, in final calculation the net result is the stable productivity of the functioning drainage constructions; the resultant discharge explains the concrete conditions of lowering of level at a given depth of mining the ore deposit. During this, in conformity with the specifications of GKZ, USSR it is expedient to present the mean minimal productivity values of drainage constructions for a multi-year period.

Presently, in the hydrogeological department of the USSR, estimates of exploitable resources of underground waters are carried out by means of the following methods: hydrodynamic, hydraulic, combined (when the two methods are implemented simultaneously), balance and analog computer. The hydrodynamic method is based on the adoption of relatively rigorous mathematical functions, given by differential equations of the filtration current. There are two varieties of this method: analytical computations, primarily for the typical or standard planned scheme and the method of mathematical modelling using an AVM or EVM computer.

For simple hydrogeological conditions (for example, a linear row of pump wells placed between the river and the contour of the mine), in estimating reserves most often analytical methods are adopted; for complex conditions (for example, conditions of interaction of drainage constructions and intra-mine pumping), the method of mathematical modelling is followed.

The hydraulic method of estimation of reserves of underground waters is based on the use of hydrogeological information obtained directly from experimental data or data from exploitation (for example, data from exploitation through drainage constructions). A practical estimate of resources is based on pattern of change of discharge, for example, of drainage constructions, from values of lowering of the water table level, adjustable graphs according to data from regimal observations, with allowance made for admissible extrapolation along the discharge curve. Essentially the balance method for estimating exploitable resources involves compilation of the balance of underground waters of the region of work on reservoir (drainage) constructions.

Considering that in mining establishments invariably *in situ* observations are carried out over the regime of underground water in regions of drainage constructions, it is quite desirable to implement hydrodynamic and hydraulic methods in estimating exploitable resources of mine waters. According to the data on the regime of prolonged experimentation work on drainage constructions, the exploitable reserves of mine waters might be related to the high categories A and B and used as a basis for planning the water supply.

It is essential to carry out *in situ* observations over the regime of activity of drainage operations primarily for evaluation of exploitable reserves of mine waters in ore deposits of the third and fourth groups according to the degree of complexity of hydrogeological conditions, since these groups are usually highly prone to flooding. The general water currents in them might reach 50,000-1,50,000, rarely more than 2,50,000-3,00,000 m^3/day. To a lesser extent these recommendations are applicable to ore deposits of the second group, where the total water currents might reach 12,000-24,000 m^3/day. For confirmation of exploitable reserves of mine waters in this case it is pertinent to refer to the instructions given in either GKZ, USSR (for deposits of the third and fourth groups) or in TKZ (for deposits of the second group). For ore deposits of the first group, in which the degree of flooding is low—with general water currents from 2,000 to 5,000 m^3/day, for confirmation and execution of exploitable resources neither GKZ, USSR or TKZ need to be consulted. These waters can be used for a variety of purposes without confirmation of exploitable resources.

In the process of conducting *in situ* observations over the regime of mine waters in the area where drainage constructions are working, primarily to evaluate their exploitable resources, it is essential to study: (a) the discharge of each pumping well (water table level-lowering) and total productivity of the complete machinery; (b) dynamic level of mine waters in pumps and observation wells· and (c) chemical composition and sanitary-bacteriological properties of mine waters and their temperature.

Today, in the practise of the hydrogeological department, USSR some official estimates from experimental work on the exploitable reserves of mine waters are collected for complete water supply and irrigation, although the urgent need for such estimates was realised long ago.

Purposeful work in this direction has been conducted by the Ural'sk hydrogeological expedition. In certain ore deposits being commercially exploited, as a result of many years of regional observations over the productivity of external or outer drainage constructions and dynamic level, exploitable reserves of mine waters were estimated by the hydraulic method. Thus, in the Novo-Troitsk deposit of fire clays the exploitable reserves of mine waters of the higher category were confirmed in accordance with GKZ, USSR and the quantity fixed at 12,000 m^3/day for household water supply for the town of Bagdanovich. In another enterprise the quantity of reserves of mine waters was 14,000 m^3/day for water supply to the town Rezh.

The local hydrogeological unit of the Department of Mining, Ministry of USSR successfully solved the problem of domestic potable water supply for the townships of northern Ural'sk and Kentau by utilising mine waters. Similarly, in areas of exploitation of the iron ore deposits of KMA, both a potable water supply and an industrial water supply are provided to the mine's township by mine waters.

In the Mikhailov iron ore deposit of KMA, for example, the exploitable reserves of mine waters were confirmed by GKZ, USSR. This deposit is exploited by open cast mining. Along the perimeter of the mine an advance (according to depth) system of underground drainage has been established, constituting a circular system of horizontal underground drainage adit with two pumping shafts, porous well filters and water discharge wells introduced into the bottom of the open cast mine.

Table 8: Standardisation of Drainage Constructions and Hydrogeological Conditions of Ore Deposits Primarily to Estimate Exploitable Reserves of Fresh Mine Waters at the Stage of Mining

System of Drainage Constructions	Hydrogeological Conditions	Balance Structure of Water Currents	Utilisation of Mine Waters	Practical Examples
(1)	(2)	(3)	(4)	(5)
		During underground mining of commercial ore deposits		
1. System of interacting external (outer) drainage constructions (areal or linear) and intra-mine pumping	In ore-bearing country rocks and rocks of supra-ore series are distributed waters of fracture, fracture-vein type and rarely groundwaters of unconsolidated formations, hydraulically connected with surface (constantly active) waters (river, lake, water reservoir)	Complex natural resources, natural reserves of mine waters and also 'pulled' resources due to infiltration of surface waters	Discharge of external drainage constructions for household and drinking water supply; discharge of intrashaft pumping for industrial water supply and irrigation	Mineral deposits of the Urals (including N. Urals), Tishin and Kazakhstan
2. Underground drainage construction (in combination with porous filters) in rocks of supra-ore series, without intra-mine pumping	Distribution of underground waters of artesian horizons of aquifer complex of supra-ore series (layer fracture and fracture-karst waters) and also groundwaters of unconsolidated formations	Complex natural resources and natural reserves (water currents formed under conditions of interaction between aquifer horizons)	For household and drinking water supply	Presently Yakovlev. Gostishchen and Vilov ore deposits of KMA and others may be included in future

3. Intra-mine pumping: (a) with automatic underground pipeline (in underground mines) b) without automatic pump; single mine pump collects all water flows	Primarily fracture-vein and fracture-karst waters. Also groundwaters of unconsolidated formations: a) hydraulically connected with temporarily flowing surface currents: b) in absence of surface waters over field of mining activity	Complex natural reserves and resources and also periodically increased resources. Comparatively simple natural reserves and natural resources of mine waters	Discharge of waters through automatic pipeline for waste and drinking water supply. Discharge of mine pumps for industrial water supply and irrigation	Mirgalimsai ore deposit and others. Zyryanov, Leninogorsk, Nikolaev ore deposits of the Urals
During commercial exploitation of ore deposits by open cast mining				
4. External advanced drainage (ring system of pump wells, porous filters and underground drainage works) without pumping from quarry	Distribution of mainly fracture-vein and fracture-karst waters	Simple natural reserves and natural resources of mine waters	Discharge through drainage constructions, exclusively for domestic and drinking water supply	Zhairem, Tishin, Lebedin and others
5. External drainage constructions working in combination with pumping in quarry	Distribution of fracture-vein and fracture-karst waters of ore-bearing rock series; groundwaters of unconsolidated formations linked with surface waters	Complex natural reserves; natural resources of underground waters of 'pulled up' resources	Discharge through external drainage constructions for exclusive drinking water supply; discharge of intra-open cast pumping for industrial water supply and irrigation	Gorev, Leningorsk, some ore deposits of KMA and others
6. Intra-quarry pumping	Distribution of primarily fracture-vein and fracture waters	Simple natural resources and natural reserves of underground waters	Discharge of mine waters for industrial water supply or irrigation	Kadzharan, Almalyksk, Sorsk and others

Ore bodies are confined to the crystalline rocks in the basement of the platform; there are three principal aquifer horizons in the supra-ore series of sandy-clayey and carbonate rocks of the Meso-Cenozoic and Middle Devonian era. From the beginning of exploitation of the deposit the level of underground waters has come down in the region of the open cast mine to 55-65 m and the cone of depression has spread over 40 to 50 km.

An estimate of exploitable resources of mine waters was made by means of the hydrodynamic method on the basis of hydrogeological observations made *in situ* over the regime of underground waters, characteristic experimental behaviour of drainage of the open pit field and also activity of reservoirs in the zone of influence of the open cut mine. Further, collection, processing and anlysis of a large volume of factual data spread over many years of observations and also hydrogeological information during exploration of the deposit were carried out. With regard to the complex border conditions of filtration currents in plan and section, studies to estimate exploitable reserves of mine waters were completed by the method of analog modelling, primarily applicable to the existing system with due provision for future deepening of the mine and simultaneous drainage of all the aquifer horizons.

To ensure reliability of construction of a mathematical model of the study area, it was necessary initially to solve the inverse equation for the purpose of refinement of the principal hydrogeological parameters of the aquifer horizons—properties such as conductivity and capacity of the differentiated layers and also border conditions of the filtration current. Calculations incorporated the scheme of multi-layered series, consisting of three aquifer horizons and two weakly permeable layers. As a result of the first stage of modelling the geo-filtration scheme was refined, reflecting the natural hydrogeological conditions of the deposit. Later, the correct prognosis of the problem was resolved through estimation of exploitable resources of mine waters. The problem was solved on a regional model in an unsteady situation, considering the development with time of the field of cone of depression, disposition of the functioning reservoirs, tailings dumps etc. The water currents in the drainage system of the model were matched with the contour of drainage workings of border conditions of the second generation, during the given values of lowering and time of drainage operation.

In the second and following stages of modelling, water currents are estimated for an extended period of exploitation of a mining enterprise, most often over a period of 20 to 30 years.

During investigations on models of inverse and prognostic problems, the regime of sources of recharge over the water content of the year is considered (according to the occurrence of atmospheric precipitation, surface current in low rainfall years and also the mean for a multi-year section). This calls for estimation of exploitable resources of mine waters depending upon the water content of the year, during which the most reliable appear to be, according to the data compiled, resources for low rainfall years. Estimates of such reserves are found to be qualitatively reliable.

As a result of the direct solution of the prognostic problem, in conformity with GKZ, USSR the quantity of exploitable reserves of mine waters demands guarantee of 'technical water' for any large commercial mining territory. In any given concrete hydrogeological conditions, protection of the surrounding environment is a very important problem during continued drainage of an open cast mine, besides questions relating to the possible sources of reserves of underground waters in active reservoirs. Studies on models have shown that conspicuous technogenic changes of hydrogeological conditions of the region are never foreseen.

Experimental data collected in the same manner in ore regions of the Urals, KMA and Kazakhstan highlight the efficacy of such investigations, assuring rational utilisation of mine waters during the dewatering of mines of ore deposits.

Table 8 presents in a general manner the standardisation of drainage constructions and hydrogeological conditions of ore deposits, primarily to evaluate exploitable reserves of mine waters. According to the degree of complexity of mining engineering conditions, standardisation is attempted separately for underground and open cast mining of ore deposits respectively. The standardisation can be used in selecting the mode of estimation of reserves and also in determining the specific purpose of mine waters. For example, for complex conditions characteristic of the first, second and fifth type, an estimate of exploitable reserves of mine waters can be arrived at only through the method of mathematical modelling using an AVM or EVM computer. These mine waters are recommended for a potable water supply. For conditions characterising all the remaining differentiated types, to estimate exploitable reserves of mine waters analytical computations or the hydraulic method can be used successfully. These mine waters are recommended for use in an industrial water supply or irrigation depending upon their sanitary condition.

CHAPTER 12

Adoption of Methods of Mathematical Modelling for Prognosis of Hydrogeological Conditions in Areas of Mining Ore Deposits

GENERAL CONDITIONS

The solution of the prognosis of hydrogeological problems by means of methods of mathematical modelling of ore deposits with complex (third group of deposits) and more complex (fourth group of deposits) conditions, possesses a number of priorities before attempting analytical calculations and justly demands consideration of the following: (a) to strictly take into account the configuration of the complex boundary conditions of the filtration current in plan and section, the conditions of recharge of underground waters and also filtration heterogeneity of water-bearing country rocks; (b) to refine to a considerable degree the estimated hydrogeological parameters of aquifers and the dividing layers of rocks; and (c) to carry out multi-variant solutions of applied prognostic problems through computer processing and to choose the most optimal of these to ensure the most effective drainage in mines and adoption of rational measures to protect the environment.

Physico mathematical modelling of natural and technogenic hydrogeological processes using a modern AVM or ETsVM has to be considered one of the important scientific methods involving complex hydrogeological conditions [16]. Such approaches fully encompass the effective solution of hydrogeological problems in the field of drainage in mines of ore deposits and also problems relating to the protection and preservation of the surrounding environment during many years of mining.

At a given stage of development of mathematical modelling, three basic directions can be distinguished: (a) an analog model, based on electrodynamic analogy, recognised in this case by a continuum, or discrete conducting elements (continuous and grid-analog model); (b) programmable or digital modelling based on utilisation of the method of finite elements of finite differentials using advanced

EVM; and (c) modelling using hybrid systems with their own automated grid models, operating on ETsVM. Due to its ease of operation and accessibility to a large circle of specialists (hydrogeologists), a wide range of hydrogeological problems can be solved by analog modelling.

One meets with undoubted success through the perspective of programmable modelling using an EVM for solving straight (prognostic) problems. Preparation for digital modelling includes working out mathematical and programming efficiency for an EVM, i.e., presentation of original hydrogeological information in codes and symbols suitable for an EVM. In the concluding phase, construction of a model over an EVM presents a complex programme and collection of punched cards containing decoded original information on the modelled object of study. At present, standard programmes are commonly used for modelling the process of drainage in mines.

The solution of hydrogeological problems in the field of determination of water currents and the choice of scheme of drainage in mines might be fulfilled in two ways : (a) for solitary but complex ore deposits the problems might be solved by means of existing grid models on AVM, requiring comparatively quick collection of the necessary resistances, volumes and changeover from one problem to another; and (b) for groups of closely situated deposits in which commercial working is carried out simultaneously, involving a large quantity of interacting drainage constructions and reservoir machinery, it is essential to solve the problem by working on specially created constantly acting models (in AVM or EVM).

Constantly acting models permit systematic establishment and exercise of control in time over rational conditions of drainage of ore deposits, development of measures of protection of the surrounding environment without involving a large volume of additional hydrogeological works, and a long-term prognosis of development of cones of depression. Such constantly acting models, for example, might be produced for the region of ore deposits of KMA as a whole where, at the present time, a series of large drainage constructions are working during open cast mining close to the occurrence of ore bodies of the Krivorozhsk iron ore basin.

During modelling of the system of drainage in mines the assigned value of lowering of level of underground waters (depth of mining of the ore deposit) during which safe conditions of working are assured, forms the major criterion. Such an approach involves construction of a model in the mining industry under conditions of available capacity of natural reserves of underground waters during complete drainage of part of all of the thickness of an aquifer horizon. Modelling to assess the general water currents and the process of drainage of mines suggests also determination of necessary time of lowering of water level and linking of this time with graphs of advancing mining activity in the establishment. During this, it is important to consider certain variants of schemes of drainage, technological bases of mining operations and also to make allowance for all technogenic changes conducted at the stage of exploitation of ore deposits.

The theoretical, methodological and practical aspects of mathematical, mainly analog modelling, to solve principally hydrogeological problems have been worked out by V.M. Shestakov, L.K. Gokhberg, I.S. Pashkov, I.K. Gavich, D.I. Peresun'ko, I.I. Krashin, V.S. Plotnikov, I.E. Zhernov, V.I. Lyal'ko, G.A. Shneiderman, V.A. Mironenko and many others. Theoretical principles and methods of modelling have been sufficiently detailed in works published by the above-mentioned authors [5, 15, 16, 31, 34, 36]. Hence, in this chapter we present general methodological procedures for adoption of analog modelling in solving filtration problems and also the requirements and contents of original (basic) hydrogeological information.

STAGES OF INVESTIGATIONS

Formulation of the problem for modelling involves how to plan and expand mining of ore deposits in the future, determination of the necessary depth of drainage in mines, duration of their drilling, and degree of reliability and contents of the necessary hydrogeological information.

Investigations of hydrogeological processes by methods of mathematical modelling for a thorough estimate of the possible water currents and schemes of drainage are commonly carried out in certain distinct stages as follows.

First stage: Multi-directional generalisation and analysis of information available on the original meteorological, geological, hydrological and hydrogeological situation relating to the region of ore deposits, for the preparation of data in a systematised manner to enable compilation of the plan scheme and creation of a basic mathematical model. A large volume of special laboratory experimental data must be collected at this stage.

Second stage: Regionalisation of the territory under investigation, primarily for conditions of modelling and also transformation (schematisation) of natural hydrogeological conditions of the deposit in the estimated scheme. Investigations of this type are important as a base for the original mathematical model. The changeover from the hydrogeological scheme of the field study to the filtration scheme is critical and important. Considering a special micro-regionalisation of the entire study area as a base for subsequent schematisation, the factors to be placed must include those determining the characteristics of formation of natural resources and reserves of underground waters and possible water currents in the mine. Such factors might include: hydrological parameters characterising water conductivity and capacity of aquifer rocks; geological-hydrogeological constitution of aquifer horizons (thickness, homogeneity); geological-structural attitude of rocks (aquifer rocks and intervening semi-permeable layers); connection of underground waters with sources of their recharge (including surface waters); hydraulic constitution of filtration current of underground waters; regime of underground waters in natural and disrupted conditions; chemical composition of underground waters; and mining engineering conditions of the study area (conditions of mining of the deposit—method, depth of working etc.).

Primary schematisation of the hydrogeological situation of the ore deposit is carried out by common practises in the form of maps, section profiles and graphs with some simplification of natural conditions. Here it is necessary to implement the following principles of schematisation of natural conditions: (a) simplification of structure of filtration current, based on knowledge of spatial filtration, to simpler planar or linear form; (b) averaging of values of hydrogeological parameters of the layer and determination of pattern of their changes over the field; (c) simplification of structure of aquifer series in a vertical manner, through knowledge of the multi-layered structure as gained from hydrogeological indicators, into one- and two-layered system; (d) schematisation of curvilinear functions by stepped graphs; and (e) attenuation of measurements of field of filtration through calculation of boundary values of influence of disturbing factors (radius of field of action of drainage constructions).

Third stage: Construction of equivalent model on AVM on the basis of generalised hydrogeological data and compiled computed scheme.

Fourth stage: Preliminary investigations on model through solution of so-called inverse problems, in order to specify hydrogeological parameters of the layer, boundary conditions of the study area, and verification and refinement of the adopted estimated scheme. These investigations, as noted earlier, are conducted in two sub-stages. First sub-stage: Solution of stationary problem on the model in order to obtain precise values of water conductivity and also boundary conditions of the filtration current, operating in a natural situation. Second sub-stage: Solution on the model of non-stationary inverse problem in order to refine the capacity characteristics of the aquifer rocks and the general structure of the model.

It must be emphasised here that the solution of truly prognostic problems without the preliminary stage of correction of the calculated scheme through solution of inverse problems, as revealed through experience, could lead to gross errors and unacceptable results.

Fifth stage: Investigations of alternate (variant) problems on the model in order to prognostically estimate hydrogeological conditions of commercial working of the ore deposit, select a rational scheme of drainage, and assess necessary measures of protection of the surrounding environment.

Thus, the stage-wise operations detailed above or the technological investigations for mathematical modelling can solve the following prognostic problems: (a) determination of the total prognosis of water currents in a system of mines suggesting sources of flooding in them; (b) selection of a rational scheme of drainage of deposit and protection of mines from underground waters and assessment of their effectiveness; (c) determination of degree of interaction of drainage constructions with working water reservoirs in the mining enterprise and, on the basis of these results, development of measures to avert possible source of reserves of fresh underground waters in the reservoir area; (d) estimation of possible area of development over the field of cone of depression of lowered levels of underground waters formed under the influence of drainage constructions in mine areas and determination, if needed, of measures of protection of the environment from the negative influence of technogenesis; and (e) selection of a more rational disposition of primary and supplementary network of observation wells for *in situ* studies of the regime of underground waters.

It is likewise possible to solve a series of very important prognostic problems demanding a sound base for safe hydrogeological conditions in the commercial working of ore deposits. The solution to the above-enumerated hydrogeological problems can be carried out through different stages of study of the ore deposit—at the stage of its exploration and at the stage of prolonged exploitation.

For the stage of detailed exploration of ore deposits the results of modelling can be used in planning commercial exploitation, which is very often associated with protection of the environment. At the stage of exploitation of the deposit very often complex hydrogeological problems arise, related to the basis of commercial working of deeper ore horizons in the deposit and preservation of the disturbed surrounding environment.

Practical hydrogeological studies involve experimental estimation of the complex and little studied areas through mathematical modelling of ore deposits in the following order of approach: First, what is termed exploration modelling is attempted wherein the following are evaluated: (a) prognostic problems of a preliminary nature and also the amount of geological and hydrogeological information provided on the study area as basic inputs for modelling; and (b) the need for conducting additional natural investigations over the study area and a decision regarding the volume of such studies.

As a result of exploration modelling, a comprehensive and fairly sensible plan of what additional geological and hydrogeological investigations are needed can be worked out for areas with complex natural conditions. Additional information on the deposit, obtained through special natural studies, might serve as a sound basis for the subsequent conclusive stage of modelling wherein certain prognostic problems are more reliably solved.

In conclusion, it is pertinent to underscore one more highly important aspect. The adoption of modern methods of mathematical modelling for the solution of hydrogeological problems requires the involvement of two specialists—one in hydrogeology and the other, in mathematics (mathematical studies, computer programming). It is extremely necessary that the hydrogeologist be conversant with the general theoretical basis, methodological principles and information requirements for mathematical modelling. His collection of original hydrogeological information over the region ought to be acceptable and purposeful.

On the other hand, there are also the requirements of the specialist of mathematics involved in the study of hydrogeological processes. He should be familiar with the principles of geology and hydrogeology. Such an interaction between scientists of different disciplines working for a common goal would positively facilitate solving genuine hydrogeological problems through progressive methods.

Close co-operation or interaction is necessary between geologists and mathematicians to simultaneously engage in their respective studies and jointly work out a single programme of hydrogeological investigations for the adoption of mathematical methods of prognosis of mining ore deposits.

INVENTORY AND CONTENTS OF HYDROGEOLOGICAL INFORMATION NECESSARY FOR MODELLING

Adoption of the method of mathematical modelling for the solution of applied problems in the field of hydrogeology of ore deposits requires relevant and reliable information prepared well and systematically. Without the requisite information it is almost impossible to solve the applied problems of modelling. Therefore, the method of mathematical modelling presents specific requirements and concomitantly, highly influences the technological scheme of conducting hydrogeological works at the stage of prospecting and exploitation of ore deposits (known as feedback). It is necessary to understand these requirements in relation to all kinds of hydrogeological investigations over the area of ore deposits. The main requirements for the original hydrogeological information in fact are determined by the method of mathematical modelling using an AVM or ETsVM. Let us now consider the necessary inventory and contents of the original hydrogeological information, with these aims in view.

Compilation of maps of complex study and factual information of area under investigation: These form the necessary condition of preparation of the original information for modelling the hydrogeological process. The themes include geological, geological-structural, hydrological, geomorphological, engineering geological and hydrogeological aspects. The main purpose of the complex map is that in conjunction with other data it constitutes the futuristic physical model of the area of investigation through transformation of the natural conditions in the standard hydrogeological scheme.

Such a map has to be compiled by laboratory analysis as a result of systematisation and generalisation of available information characterising the results of exploration and experimental drainage of deposits. Practical experience in this direction shows that firstly functionally useful maps, separately indicating factual information, degree of study of the region along the aforesaid lines and also conditions of formation of filtration current, have to be compiled, thus:

1. *Map of hydrographical network of region of study* (river, lake, tailings reservoir, irrigation or transport canal etc.). The conditions of interlink between surface and underground waters possess special significance for modelling. Therefore, it is essential to indicate on the map conditions of drainage of underground waters of the river system, areas of their absorption, field of natural discharge of underground waters and also regime of surface

current (permanent and temporary water currents including current through irrigation canals). It is also essential to illustrate this map with collective tabular information characteristic of annual and multi-annual hydrogeological regime of surface current.

2. *Map of factual information on region under investigation* (borewells for different purposes and their disposition over area, springs, shaft wells, working reservoir and drainage constructions, and mines). Factual hydrogeological data are utilised not only in future construction of the model, but also for control of investigations during direct modelling.
3. *Geological-structural map of the area of study* and geological sections through it. The map should characterise the principal structures and conditions of occurrence of rocks of different lithological compositions, their facies change in plan, tectonic dislocation of regional and local nature and their role in the control of hydrogeological conditions etc. It is equally important to distinguish lithological complexes according to their water permeability. It is peremptory to characterise in details the conditions of tectonic faults: their trend, thickness of the fault zone and conditions of water-bearing capacity. In the same way, the geological map of the study area can be used in future for estimating the boundary conditions of the infiltration current and construction of a standard scheme.
4. *Hydrogeological maps of the region under study* constitute one of the principal methods of documentation, necessary for the augmentation of the physical model of the area, electrical model and also controls for the process of modelling. It is expedient to construct the following hydrogeological maps: (a) map reflecting the major hydrogeological conditions of the study area (area of distribution of principal aquifer horizons); (b) map of isophreatic surface under unconfined and confined conditions (hydro-isohypse and hydro-isopiezo respectively) in natural situation and at the stage of exploitation of ore deposits in dislocated zones at different conditions and periods of working of the deposit; (c) map of hydrogeological parameters of water-bearing country rocks (conductivity of layer, piezo-conductivity etc.); and (d) hydrogeological map showing conditions of recharge of underground waters.

All hydrogeological maps have to be prepared on the same scale for geological and hydrogeological sections. In the hydrogeological section information on the regime of underground waters is very important. Information that controls the veracity of the computed schemes and the data obtained during solution of filtration problems such as heads (pressures), levels of underground waters, thickness of ground currents, discharges decreasing in space and time, are indicative of the regime of underground waters. The greater the volume of information about the regime of underground waters, the more dependable solutions to filtration problems will be. For ore deposits at the stage of exploitation, it is important to collect data on the regime's general and differential (according to horizons) water currents in mines, levels of groundwaters and changes of these parameters in space with time in the form of complex graphs (see Figure 46).

It is extremely important to take note of the constraints in the method of mathematical modelling in hydrogeology. Examining the model as a triad, 'the environment—boundary conditions—reactions of system' it becomes possible to define the problem of non-available information through any component of the computed scheme, when any two are known. For example, knowing the available parameters of the environment and the boundary conditions in the model it is possible to obtain the reactions of systems in the form of isolines (contours) of pressures of levels, and through them other hydrodynamic characteristics—rate of flow, gradient of current and flow discharge. Similarly, from the data available on boundary conditions and distribution of levels of underground waters in space and time, it is equally possible to establish the hither-to-unknown parameters of the environment.

Let us look at the contents of hydrogeological maps. General hydrogeological conditions should be defined first: boundaries of distribution over the area, of all aquifer horizons, including limits of underground waters possessing different amounts of mineral matter; areas of natural discharge of underground waters and area of their recharge; sources of contamination of underground waters, springs, borewells etc. In a multi-layered structure of the study region, it is desirable to construct hydrogeological maps separately for all the major aquifer horizons.

Hydro-isohypsometric (hydro-isopiezometric) maps provide very important information for modelling. An analysis of such maps constructed for natural and disrupted zones envisages estimation of the hydrodynamic conditions of the region, structure of filtration current, linking of underground and surface waters, assessment of factors influencing the distribution of pressures of underground waters in aquifer horizons, formation of regime of underground waters and also conditions of their recharge and discharge. As observed above, in the process of modelling the groundwater contour (hydro-isohypse) maps directly suggest controlling the approach to the solution of reverse problems on the electrical model. In the multi-layered constitution of the hydrogeological cross-section, it is essential to construct hydrohypse maps for every principal aquifer horizon for the most qualitative modelling.

Similarly, information on the regime of underground waters is of exceptionally great significance for the solution of prognostic problems. While paying attention to the importance of hydrogeological information contained in the groundwater contour maps prepared during the stage of exploration of the ore deposit and more so during the process of exploitation, it is very important to simultaneously organise studies of the regime of underground waters and during the construction of the regimal network strictly consider the most rational location of observation and mapable wells, primarily to compile hydro-isohypse (hydro-isopiezo) maps, as mentioned in Chapters 7, 8 and 9.

No less important for modelling are maps of hydrogeological parameters of aquifer horizons characterising filtration characteristics of water-bearing country rocks. In this aspect it is desirable to compile maps delimiting micro-regions of the study area for every aquifer horizon, according to values of the co-efficient of conductivity or the co-efficient of filtration of rocks and also the co-efficient of level conductivity (piezo-conductivity) of the layer. During preparation of maps of hydrogeological parameters of the layer it is obvious that there is no need to regulate the limits of gradation of values of independently calculated parameters. It is, however, important to reflect the degree of filtration heterogeneity or degree of heterogeneity of the layer and boundaries of the separate contours in plan.

Finally, for modelling the hydrogeological process it is important to compile a hydrogeological map reflecting the conditions of recharge of underground waters. On such a map it is necessary to indicate for the different areas: (a) different values of infiltration recharge of underground waters at the expense of atmospheric precipitation; (b) different conditions of hydraulic links between underground and surface waters; and (c) different conditions of interaction between aquifer horizons (parts of overflow or absorption of underground waters).

Hydrogeological information relating to the structure of the roof and floor of the aquifer horizon of the differentiated layer forms an essential requirement in the process of modelling. It is very difficult to draw all the maps listed to the same scale. The choice of scale in most cases depends upon the area under study and its complexity.

In modelling, systematisation of the original hydrogeological information in the form of different general graphs and cumulative tables is highly significant. Here, the most important are graphs characterising the regime of underground waters in natural and disturbed conditions, graphs of discharges of wells and also wells which reflect the regime of water currents. Under fixed hydrogeological conditions graphs of temperature regime of underground waters can be used.

It is well known that the regime of levels sufficiently correctly characterises the conditions of recharge and flow of underground waters and the conditions of interaction between the aquifer horizons and their connection with the surface waters. Utilisation of this information in modelling requires determination of a series of important hydrogeological parameters. Similarly, for example, data on the regime characterising the correspondence of levels of underground waters of different pressure horizons in the cross-section of the study area might involve determination of filtration properties of differentiated (foliated or thinly laminated) weakly permeable rocks. This parameter, defining the permeability of differentiated rocks, is important for determining the interaction of aquifer horizons and quantitative estimation of the processes of overflow.

It is pertinent to observe at this point that foliated or thinly laminated rocks, normally possess very weak filtration properties. To determine the parameters pointed out above by pump tests is very complex. Hence data on *in situ* observations over the regime of levels of underground waters in the different pressure horizons demands determination of water permeability of the rocks constituting the differentiated layers. Such a situation belongs to the study of regime of levels of underground waters and levels of surface waters in river valleys, the results of which require determination of filtration resistance of rocks constituting recent riverine sediments. The parameter characterising the filtration resistance of the river channel is considered one of the main computed indicators during evaluation of the total water currents in mines situated close to the river valley and also of the exploitable reserves of underground waters of the infiltration reservoirs.

For a general analysis of data on the regime of underground waters it is expedient to compile what is known as modern or complex graphs, characterising changes with time in all the major regime-forming factors (regime of levels, atmospheric precipitation, surface current etc.).

In conclusion, let us note that the inventory of principal hydrogeological information presented above, necessary for the solution of complex problems by the method of mathematical modelling and detailed technological investigations, in fact, predetermine the characteristics and contents of the hydrogeological works, which involve carrying out indispensable laboratory studies and special field tests. It is essential to consider these inverse connections during the preparation of data. In recent years the EVM computer has been used in solving many practical problems in all fields of the national economy. This has required the training of a wide circle of specialists and supervisors in highly varied fields. Organisation and initiation of hydrogeological services of mining enterprises into mathematical methods and the training of specialists in this direction positively assure success in solving the wide range of problems encountered in the field of drainage, water supply and prognostic estimate of technogenesis.

PART-III

ANALYSIS OF INFLUENCE OF EXPLOITATION OF ORE DEPOSITS ON CHANGES IN THE GEOLOGICAL ENVIRONMENT

CHAPTER 13

Ore Deposits of the Third Group

Let us consider a typical example to understand the influence of commercial working of an ore deposit assigned to the third group because of its degree of complexity (see Table 5), on changes in the geological environment. Such a deposit is highly susceptible to flooding and its hydrogeological and mining engineering behaviour during exploitation and also the influence of mining on the surrounding environment are, indeed, extremely interesting.

BRIEF CHARACTERISTICS OF NATURAL FACTORS

This exemplary deposit is situated within the limits of the southwest slope of the Karatau ridge, with its maximum absolute elevation reaching 1,500-2,176.9 m above msl. The southwest slope of the ridge is intensely dissected in the region of the deposit by valleys of small rivers—Zapadnaya, Central'naya, Vostochnaya, Dal'nevostochnaya and others (Figure 66). In the lowland steppe area of the region, far south of the deposit, these rivers merge to form a single surface runoff.

The distribution of annual surface runoff in these rivers is presented in Table 9. This runoff is formed at the expense of rain as well as snowfall. The rivers Zapadnaya and Vostochnaya run directly along the western and eastern flanks of the ore deposit.

As exemplified by the data, the distribution of annual surface runoff of the riverine network is highly irregular. From February to June, runoff is observed in all the rivers while flooding (high runoff) characterises March, April and May. There is no surface flow for nearly seven months. Flow is noticed year-round only in the upper reaches of the Zapadnaya River where, in the valley, natural discharge of fracture-karst waters is seen in the form of springs. During high-water years winter floods periodically contribute to runoff in almost all the rivers. Such a regime of surface flow exerts considerable influence on the regime of water currents in the system of underground workings of the mine. A modern graph of the regime of surface current of rivers and water currents in the system of mines has been presented in Figure 56. The highest infiltration losses from the rivers are observed in spring floods (March-May). During this period maximal water currents form in the mines.

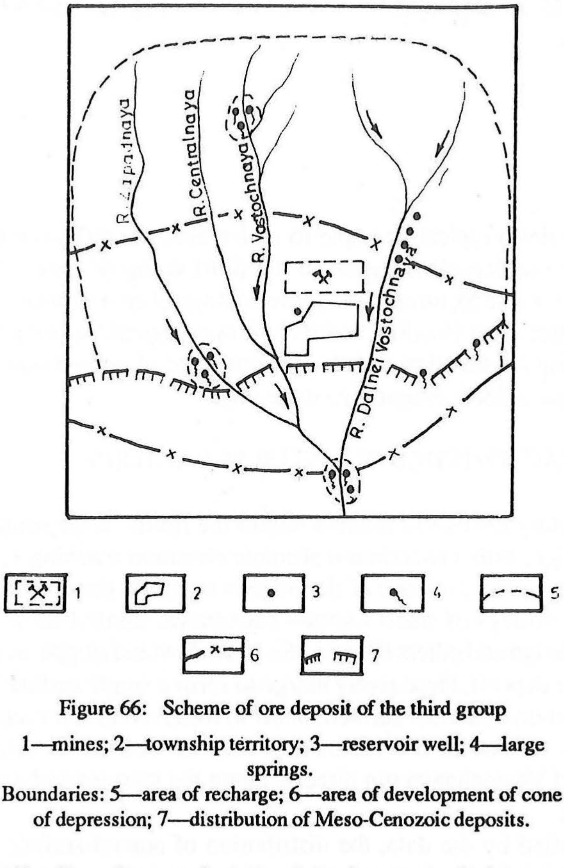

Figure 66: Scheme of ore deposit of the third group

1—mines; 2—township territory; 3—reservoir well; 4—large springs.
Boundaries: 5—area of recharge; 6—area of development of cone of depression; 7—distribution of Meso-Cenozoic deposits.

The rivers distributed over the ore deposit act as drainages under natural conditions for all types of underground waters. Atmospheric precipitation forms the main source of recharge of surface and underground waters. Hypsometric elevations of the ridge exert a significant influence on the regime of resultant atmospheric precipitation over the region as a whole. Observations have established that for the region of the deposit within the limits of absolute elevations of 300 (the area of mining) up to 1,000 m (the upper reaches of the river), the annual total atmospheric precipitation varies from 340 to 660 mm. In between, for a rise of every 100 m in surface elevation, an increase in atmospheric precipitation to the extent of 50-60 mm per annum takes place.

Table 9 : Local and seasonal distribution of surface runoff of local river system in region of ore deposits (m^3/day)

River	Area of water discharge km^2	Months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Dalinevostochnaya	342	0.0	0.6	38.2	39.9	20.9	0.4	0	0	0	0	0	0
Vostochnaya	178	0.0	4.9	74.5	14.3	6.3	0	0	0	0	0	0	0
Zapadnaya	230	0.0	1.8	26.1	48.5	22.4	1.2	0	0	0	0	0	0

Note: Value of runoff are averages of observations over a four year period.

The distribution of mean annual atmospheric precipitation is presented in Table 10.

Table 10: Distribution of annual atmospheric precipitation (average of many years), in mm

Observation Point		Spring	Summer	Autumn	Winter	Yearly Total
Station	395 m	143	33	60	147	383
Station	700 m	166	29	68	207	470
Station	821 m	232	39	91	259	621

Atmospheric temperature is characterised by wide variation throughout the year. The mean atmospheric temperature in the region of the deposit is 10-12°C. In winter the mean temperature varies from –5° to –7°C and in summer (May-September), from 24° to 27°C.

Discordance, with time, of periods of maximum atmospheric precipitation and maximum evaporation of moisture constitutes a very important factor in estimating the infiltration recharge of underground waters through atmospheric precipitation in natural conditions. Hence, in the winter-spring period, when the atmospheric temperature is comparatively low, highly intensive recharge of underground waters of deposits takes place due to infiltration of atmospheric precipitation falling on the surface.

In the zone of draining influence in the mining of ore deposits, the regime of interconnection between surface and underground water exhibits radical changes. These conditions are briefly discussed below.

GEOLOGICAL SETTING

Geologically, the region of the ore deposit is situated in a highly varied complex of rocks, both according to their lithological composition and age. The mining area of the region is composed of rocks of the Palaeozoic era, dipping (southward from the deposit) under a series of rocks of the Mesozoic era and Tertiary period in the plains. Formations of the Quaternary period—alluvial deposits of the river valleys and deluvial deposits of hill slopes—are distributed in the montane and valley parts of the region.

From the viewpoint of assessment of hydrogeological conditions of the region, it is desirable to divide the rocks constituting it into four complexes according to lithology, age and conditions of formation of the environment favouring accumulation of underground waters (Table 11).

An anticlinal zone changing over to a synclinal ore towards the north forms the principal folded structure in the region. Moving southwards from this zone, carbonate rocks dip gradually under the series of rocks of the Cretaceous and Tertiary periods. The folded structures of the region are complicated by tectonic dislocations comprising thrusts and gravity faults. The Main, the Southern and Anasai thrusts form the largest and the most complex structures (with displacements ranging from 300 to 1,000 m) and are oriented northwest and meridionally, as though limiting the anticlinal zone.

Table 11: Characteristics of complexes of rocks constituting southwesterly slope of ridge (from bottom)

Rock complex	Lithological composition and Age of Rocks	General thickness, m	Area of distribution
First (oldest)	Effusives, sandstones, conglomerates, tuffs, argillites, siltstones, with bands of limestones of Lower and Middle Paleozoic; complexly deformed into folds of second and third order	3000-5000	Comprise the water-divide part of ridge, entire area in upper reaches of local river system and directly underlie carbonate series of rocks in area of ore deposit
Second	Complexly deformed ore bearing carbonate rocks—limestones, dolomites, marbles of Middle and Upper Paleozoic, affected by large tectonic faults, carbonate rocks lie unconformably over argillite series of plastic rocks	1500–3000	Comprise entire area of ore mineralisation and principal zone of recharge of underground waters
Third	Wackes, marly rocks of Mesozoic and Tertiary eras	20-250	Constitute the entire plain country and lie transgressively over Paleozoic carbonate rocks, close to ore deposit
Fourth	Sandy pebbly alluvial deposits and loamy bouldery deluvial formations of Quaternary period	1-12	Comprise terraced surface and recent channels of river valleys and slopes of mountain ridge

The Southern thrust is the largest extension and presents its own complex tectonic structure in a NW direction. This structure coincides with the zone of intense fracturing and karstification and brecciation of carbonate rocks up to a thickness of 200 to 300 m. The Southern thrust extends southward, later through the valley of the Zapadnaya River, further continues into the area of the ore deposit and thus encroaches on the valley of the Vostochnaya River.

Directly over the area of the deposit this thrust is coupled with a complex network of other tectonic dislocations—the Main thrust and associated faults of the meridional trend forming the complex conjugate geological structural field that plays a dominant role in the hydrogeology of the region.

Structural elements in truly carbonate rocks (fracturing and karstification) are highly significant in estimating the hydrogeological conditions of the deposit. Investigations have revealed that in the series of carbonate rocks two distinct types of fracturing and karstification predominate: (1) local and (2) regional. The first group combines varied forms of large open fractures (fissures) and karst belts belonging usually to zones structurally complicated by tectonic dislocations, interlayer movements or contact with underlying argillites. More often open karst belts, characterised by cavities, sinks and so forth, have formed in the carbonate rocks at places of intersection of two or three fracture sets of different orientation: northwest and meridional trends intersected by bedding-parallel fractures. Local fracturing and karstification are most intensely distributed in sections of carbonate rocks of the Carboniferous period. Carboniferous limestones are chemically most reactive as revealed by studies on their properties. Rarely structural elements of the local type are encountered in limestones of the Devonian period.

The second group of structural elements—regional fracturing and micro-karstification—is distributed over almost all sections of the carbonate rocks. This group embraces very small, often polished or healed fractures and micro-karst bands of calcite. Their distribution is not uniform in either plan or section.

The character of layering or lamination in the carbonate rocks influences formation of the structural elements. In thinly layered limestones a dense network of regional fractures is evident whereas in thickly layered limestones large intersecting joints and, to a lesser degree bedding-parallel joints prevail.

The complex of rocks comprising effusives, sandstones, argillites etc., is characterised by different patterns of formation of structural elements—the media for accumulation and infiltration of underground waters. Fine fracturing of the regional type occurs in them, mainly according to the nature of layering of the sedimentary-metamorphic rocks. At the same time the slightly open small fractures are, in fact, confined only to the uppermost part of the cross-section, a zone of intensive recent weathering to a depth of say 30-50 m (rarely exceeding 50 m). Lower down in the zone of weathering, the open fractures very quickly attenuate and the rocks become practically impervious. Under certain circumstances, in the zone of tectonic dislocations, represented by breccia, fracturing of the local type is encountered.

The third and fourth type of rock complexes (see Table 11) are characterised by a porous medium most favourable for infiltration and accumulation of layered and ground/underground waters.

HYDROGEOLOGICAL CONDITIONS OF DEPOSIT

Four types of underground waters can be distinguished based on the conditions of their formation and confinement: (a) fracture-groundwaters of the crust of weathering of bedrocks of varied lithological composition of the Lower Paleozoic (the first) complex; (b) fracture-karst waters of ore-bearing carbonate country rocks of the Devonian and Carboniferous period (second complex); (c) artesian waters in wacke-type interlayers of the Cretaceous period; and (d) groundwaters of the unconsolidated alluvial sandy-pebbly deposits of Recent river valleys.

The first type of underground waters is distributed mainly in the upper parts of the basins of the local river system, directly over the surface of the ancient first complex of rocks (Lower Paleozoic), lithological units of which are presented in Table 11. A general outline of the conditions influencing the rate of flow of waters entering this ancient complex follows.

Water currents appear over a regional scale in these rocks only in the upper part of the cross-section—in the zone of weathering, where small proto-tectonic fracturing has somewhat opened up under the influence of Recent processes of weathering, penetrating to a depth of nearly 30-50 m. Fracture-groundwaters distributed in this zone possess limited natural resources and are intensely drained by the local hydrographic system. Discharges through springs are minimal (0.1 to 0.05 l/d) and the major portion is totally depleted by autumn. In the second zone the open small fracturing (jointing) very quickly attenuates and hence the rocks become almost impermeable. In this zone water seepage occurs only through tectonic dislocations. In the general water balance of the region, fracture-groundwaters play a distinct role in regulating the flow of atmospheric precipitation over the upper part of the basin of the local river system.

Other conditions of flooding are observed in the thick series of carbonate rocks. Characteristics of the structural elements of the carbonate rocks (fracturing and karstification) determine the conditions of formation and accumulation of significant quantities of natural resources and reserves of fracture-karst waters. The following characteristics in the conditions of water seepage of carbonate rocks are known from experience with drainage conditions in the mines.

1. Over the area of development of carbonate rocks a single basin of fracture-karst waters has formed, the region of recharge of which coincides with the boundaries of distribution of the carbonates, and the region of accumulation mainly coincides with synclinal structure, particularly with the inclined part of the structure south of the ore deposit. The hydraulic link between the currents of fracture-karst waters is prominently reflected by the structure of region of cone of depression formed under the influence of dewatering in mines of the deposit. The general underground current from the side of the basin is certainly formed under the influence of pumping in the mine.
2. In the vertical section of the basin of fracture-karst waters, three hydrodynamic zones, as shown earlier under the principal scheme (see Figure 2) can be identified.

   In the upper part of the section (about the local base line of erosion), directly in contact with the atmosphere, is the zone of influence of underground waters that move primarily in a vertical direction. In this zone (thickness ranging from 80-100 up to 150 m) fracture-karst waters accumulate only within the limits of the annual amplitude of variation of level. The second zone, situated in the vertical section between the local and the regional base line of erosion (with intervals of depth ranging from 80-120 to 500-800 m), is characterised by intense accumulation of fracture-karst waters and intense underground currents. The major natural resources and natural reserves of fracture-karst waters form particularly in the second hydrodynamic zone.

Discharges of fracture-karst waters of the second zone, under natural conditions resemble a large group of fairly dense springs, the action of which can be fixed before the start of mine draining. Springs in the upper reaches of the Vostochnaya River discharge 650 l/day. There are springs in the valley of the Zapadnaya and other rivers also.

The discharge of fracture-karst waters is noticed along large tectonic dislocations, primarily at the zone of contact of carbonate rocks with the transgressive overlap of wacke-type rocks of the Cretaceous and Tertiary period. Below depths of 500-800 m in the basin of fracture-karst waters lies the third hydrodynamic zone of slow underground current, moving towards deeper horizons southwards from the ore deposit in the direction of inclination of the general structure of carbonate rocks, where Paleozoic rocks are transgressively overlain by wacke-type formations of the Mesozoic era and Tertiary period. Geologically in this part of the region, in the deeper horizons of carbonate rocks and variety of sandy rocks of the Cretaceous period, the underground waters acquire an artesian regime and form a fairly large artesian basin.

3. A high degree of hydrogeological heterogeneity is observed in the section of all the flooded series of carbonate rocks. This is excellently traced, for example, during the continual operation of underground mining of the ore deposit. Flooding in underground mines is mainly confined to zones of development of local fracturing and karstification, with which is associated the major concentration of currents of fracture-karst waters. Very often flooding is negligible and the mines are almost dry between these zones of limestone.

The basin of artesian waters is situated in the southern part of the ore field. Deeper horizons of this basin are composed of carbonate rocks of the Paleozoic and the upper horizons of wacke-type rocks of the Cretaceous period. Accordingly, in the section of the basin of artesian waters two aquifer horizons can be distinguished—the first in limestones of the Paleozoic and the second in sands of the Cretaceous. Results of exploration by borewells have revealed a hydraulic connection between the two aquifer horizons.

The groundwaters distributed in the region belong to the sandy-pebbly alluvial formation of the river valleys and, according to conditions of distribution, possess an azonal character across the entire area of the above-cited hydrogeological divisions of the region. The groundwaters have an active hydraulic connection with the surface waters. The local hydrographic system, together with the series of sandy-pebbly alluvial formations, acted as a natural drainage for all types of underground waters up to the commencement of draining the mines. In part of the above natural zone of discharge losses of surface waters from the carbonate rocks were observed.

As shown by investigations, all the types of underground waters distributed in the region of ore deposits are fresh, containing hydrocarbonates of calcium. If we consider the hydrogeological conditions of the deposit on a regional basis along the southwestern slope of the ridge, then we can isolate certain characteristics of the three individual divisions and also the connections between the hydrogeological regions or basins (Figure 67). In the upper reaches of the river system lies the basin of fracture-groundwaters, belonging to the complex effusive metamorphic rocks.

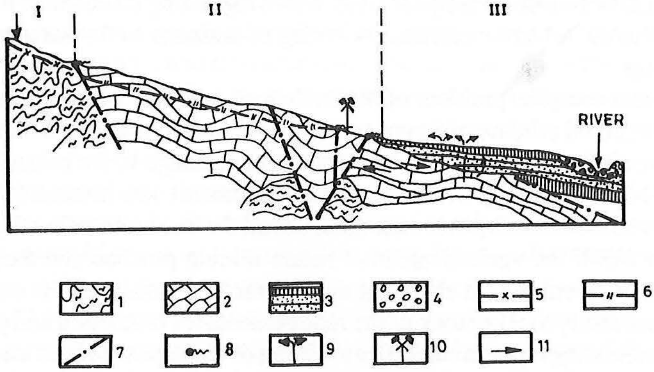

Figure 67: Geological-hydrogeological profile

1—effusive-metamorphic complexly deformed rocks of Paleozoic era; 2—carbonate aquifer rocks of Paleozoic era; 3—wacke-type rocks of Mesozoic era; 4—alluvial deposits of rivers; 5—level of fracture-groundwaters of metamorphic rocks; 6—level of facture-karst waters; 7—tectonic dislocations; 8—springs; 9—flowing artesian well; 10—the mine; 11—direction of flow of underground water.

I to III—basins: I—fracture-groundwaters; II—fracture-karst waters; III—artesian.

Farther south, distributed over a large area is the basin of fracture-karst waters of carbonate rocks of Paleozoic age. Still farther south lies the basin of artesian waters, in which two aquifer horizons are distinguishable—one in limestones of the Paleozoic and the other in Cretaceous sands.

As seen from the cross-section (see Figure 67), the mines of the ore deposits are situated in the southern boundary area of the fracture-karst waters abutting the basin of artesian waters. All these were taken into consideration and the complex hydrogeological conditions in the mine area determined.

MINING ENGINEERING CONDITIONS OF COMMERCIAL EXPLOITATION AND SCHEME OF DRAINAGE OF ORE DEPOSITS

Ore mineralisation in the deposits lies mostly at great depths and hence it was decided to undertake underground mining on a commercial scale. The general depth of working is nearly 600-850 metres and further planned to 1,000-1,100 m; the general area of the mines spreads over 10 to 12 km^2.

Based on extra-complex hydrogeological conditions, underground mines were driven by a special technique—under the protection of grouting conducted from the mine faces. Special methods of mining in a horizontal direction were also adopted. The most flooded parts were temporarily isolated from sudden outbursts by the construction of a waterproof dam with a regulating mechanism for discharge of mine waters. Advance exploratory boring of drainage wells was also systematically set up.

The most complex problem of the study area was the choice of, and basis for, the most rational scheme of drainage. As the deposit is situated in an arid zone, it was convenient to preliminarily adopt advance drainage in the mines because the problem of water supply in the mining establishment was invariably paramount. Hence it was essential to put to maximum use all the local resources of underground waters to fulfill the various needs of future mining practise and the township's economy. Furthermore, in choosing the scheme of drainage of the deposit it was equally necessary to take stock of the requirements for protection and preservation of the surrounding environment. Deep mining of the deposit would inevitably lead to radical changes in the hydrogeological conditions of the region. Large springs situated in the sphere of influence of mining might be fully drained in the future and change their regime as would the flow of surface waters of the local river system. All these losses had necessarily to be compensated.

Thus it was necessary to devise such a scheme of drainage and dewatering of the deposit that would solve all the major problems, namely: (a) guarantee safe commercial exploitation of the ore deposit situated in highly complex hydrogeological conditions; (b) decide all the kinds of water supply for future mining, including local springs, i.e., beneficiation plants, thermal power stations and potable water supply for the planned township; (c) improve the ecological situation of the surrounding environment and, first and foremost, provide favourable conditions of living and ensure productivity of labourers through the supply of mine waters for irrigation and a much-needed green landscape; and (d) particularly assure protection of the surrounding environment from the negative influence of technogenic processes.

In this connection an original scheme of drainage in the mines was planned and introduced in the study area, considering beforehand the following aspects: (a) setting up an extra large pump in the underground mines to tap all the general water currents of the mine waters for their subsequent utilisation on the surface for all purposes; (b) introduction of special advance drainage modes in the underground mines directly within the limits of the area of the deposit, in every working horizon of the mine situated 3-5 m below the horizon of the principal works, in order to preliminarily drain the horizon and guarantee safe conditions during continual mining of the deposit and excavation of the ore bodies; (c) systematic boring of advance exploratory hydrogeological wells directly from the working faces of all principal mines, in order to precisely gauge hydrogeological conditions, assure additional drainage of mine waters and also provide safe working conditions; (d) construction of waterproof coffer dams in the particularly hydrogeologically dangerous areas in the underground mines, in order to isolate the sources of flooding (including sudden outbursts) and subsequently regularise the discharge of mine waters; (e) construction in the lowermost flooded horizons of the underground mines of automatic pumping (under sanitary conditions) of uncontaminated mine waters, to enable their utilisation in a potable water supply directly to the township through a special pipeline; and (f) maximum utilisation of mine waters for multifarious needs of the mining establishment and agriculture, including organisation in the territory of the future township of irrigation of part of the land, in order to provide the workers sanitary living conditions and a better ecological environment.

As shown by experience during exploitation of the deposit, the devised scheme of drainage was thoroughly checked and permitted to proceed and its solution of the above-listed problems quite successful. In accordance with the approved plan the mine shaft in the ore deposit was located in the area between the valleys of the Zapadnaya and Vostochnaya Rivers, where they cross the mountains to enter the plains. The mine's township is located in the flat land farther south of the mine.

For more than forty years of industrial mining of this ore deposit, investigations were systematically conducted over the mine's undertaking and vast experimental data on the mining works under extremely complex hydrogeological conditions was collected. The following balance structure of the sources of flooding in the mines was established through investigations resulting in the formation of general water currents:

$$Q_{gen} = Q_{e.p} + Q_{e.z}/T + \Delta Q_{pr}$$

where $Q_{e.p}$ = natural resources of fracture-karst waters in the ore-bearing carbonate country rocks; $Q_{e.z}$ = natural reserves of fracture-karst waters; ΔQ_{pr} = 'pulled up' resources drawn from drainage in the mines, mainly at the expense of infiltration of surface waters of the local hydrographic network; T = time.

It is suggested that in the later period of industrial working of the ore deposit additional reserves be formed, particularly at the expense of the overflow of artesian waters from the aquifer horizons of the Cretaceous sandstones. Natural resources of fracture-karst waters and additional inputs constitute the most significant contributors to flooding in the mines, part of which results in 70 to 80% of all the water currents in the system of mines.

Based on results of regimal *in situ* observations of the hydrogeological department of the mine's establishment, complex graphs were compiled. These graphs indicate the total annual average and maximum daily rate of flow of underground waters in the system of mines, average annual atmospheric precipitation, area of development of cone of depression and also regime of levels of underground waters in observation wells (Figure 68). In a multi-annual section these graphs help to distinctly delineate the general pattern of formation of water currents in the mines and the regime of levels of underground waters in close proximity to and also remote from the mines. It is possible to distinguish certain characteristic stages in the formation of water currents. In the first stage (1942-1948) the average annual water currents gradually increased to 190 m^3/hr. In the second stage (1949-1953)

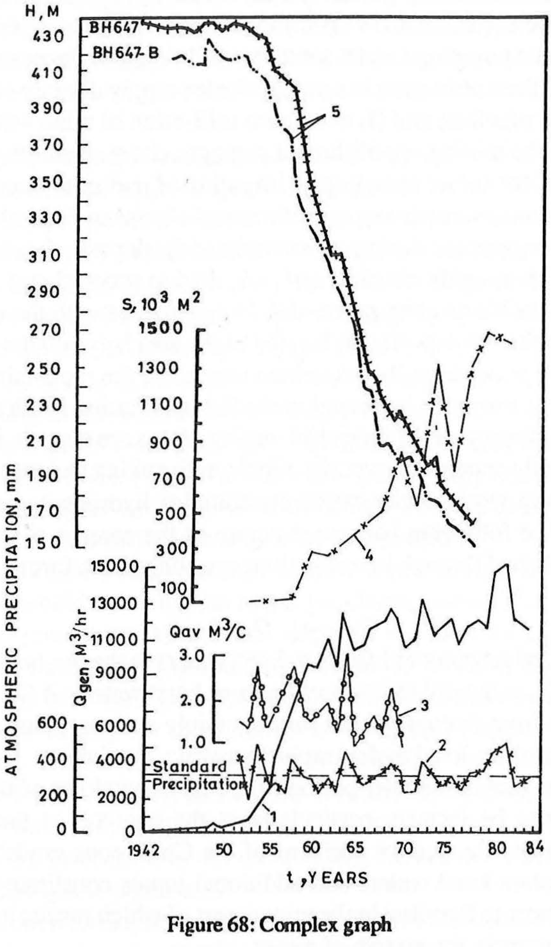

Figure 68: Complex graph

1—regime of general water currents (Q_{gen}) ; 2—atmospheric precipitation; 3—average discharge of Central'naya River (Q_{av}); 4—area (S) of cone of depression; 5—change of level of underground waters (H).

the growth in mean annual water currents registered at 560-800 m^3/hr. During this period the depth of the mines never exceeded 40-50 m. The water currents were formed exclusively at the expense of natural resources of fracture-karst waters. The area of cone of depression (2-5 km^2) never extended beyond the limits of the deposit.

In the third stage (1954-1962) the mining front was intensely widened and the depth of working of deposit reached 270 m. The average annual currents of mine waters increased every year from 1,400 to 9,700 m^3/hr, the maximum diurnal rate of flow reached 6,000-13,000 m^3/hr and the annual volume of discharge through pumping 75-85 million m^3. In this period a significant part of the natural resources of fracture-karst waters was tapped in the system of mines. Under the influence of drainage the cone of depression gradually widened and its area reached 250-280 km^2, which was quickly felt in the regime of numerous springs flowing gravitationally towards the southern and western flanks of the deposit. Thus, in the low-water period of 1955 large springs situated at 1.5 km from the mine were completely drained and in 1956 springs located 15 km from the mine. Thus, significant change in the structure of the underground currents took place, during which the major natural resources of fracture-karst waters were involved in the system of mine pumping. The total discharge of all the springs (around 2 m^3/s) in 1958 was completely tapped by mining works. In the fourth stage (1962-1984) the average general annual water currents increased to 12,000-15,000 m^3/hr and the maximal diurnal mean—up to 24,000 m^3/hr.

The graphs shown (Figure 69) present as an example the regime of levels of underground waters from observation well Nos. 647, 1000, 306-B and 385-B, situated almost dead centre in the mines. As seen from graphs for 1954-1968 the minimum and maximum levels of underground waters registered a sharp decrease. The rate of decrease of levels was 5-25 m per annum. Towards the end of 1962, the maximum depth of lowering of level of underground waters was 170 m and in 1984—390 m. In the fourth stage a gradual stabilisation of the mean minimal water currents in the mines characterised the working of the deposit. The water currents in the mines exhibited, in fact, all the characteristics of the general natural resources of fracture-karst waters.

Figure 70 presents a schematic geological-hydrogeological section of the ore deposit. The dynamics of lowering of levels of fracture-karst waters is shown for the minimum level over the years. It is evident that a systematic lowering of underground waters occurred. Figure 71 presents a map of the hydro-isohypse of the principal aquifer complex of the deposit and also the lines of flow of main filtration currents. The cone of depression possesses an asymmetric structure in plan. It is elongate along a NW-SE axis—the trend of the major large tectonic dislocations.

The lines of flow indicate that the major currents of fracture-karst waters formed in the montane area flow down directly into the zone of influence of the cone of depression, i.e., along the zones of drainage flowing southeasterly.

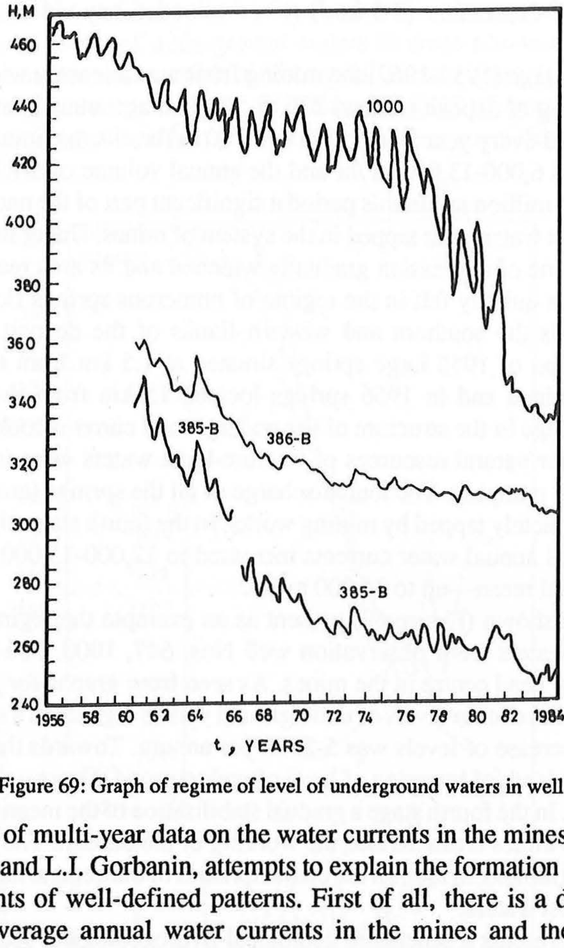

Figure 69: Graph of regime of level of underground waters in wells.

An analysis of multi-year data on the water currents in the mines compiled by V.P. Gorbanin and L.I. Gorbanin, attempts to explain the formation of the regime of water currents of well-defined patterns. First of all, there is a direct relation between the average annual water currents in the mines and the quantity of atmospheric precipitation over the catchment area. The maximum water currents in the system of mines are formed primarily at the expense of infiltration loss of surface current from the rivers. Observations have established that the major rivers of the region of the deposit embrace the cone of depression and guarantee the formation of up to 65-92% of the total water currents in the mines.

An intensive compensation for the earlier decrease in storage of natural reserves of fracture-karst waters at the expense of loss of surface waters of the channels during the period of flooding, leads to the formation of exceptionally high maximal water currents in the mines in the form of peaks. Normally the maximum water currents in the mines are observed in April, somewhat less in May and very little

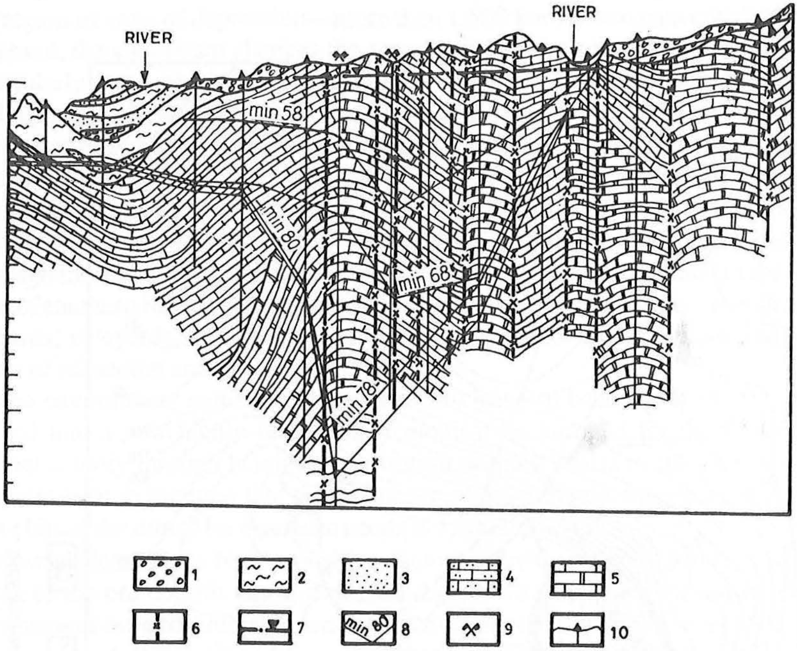

Figure 70: Geological-hydrogeological profile

1—unconsolidated Quaternary formations; 2, 3, 4—wacke-type rocks of Cretaceous period; 5—carbonate rocks of Paleozoic era; 6—tectonic dislocations; 7—level of underground waters (water table) under natural conditions; 8—cone of depression at various points of time of drainage of rocks (min 68 in 1978) ; 9—mine shaft; 10—well.

in March. The maximum daily water currents in this period were recorded in the years 1973 (22,000 m^3/hr), 1981 (23,100 m^3/hr) and 1982 (31,000 m^3/hr including an outburst).

Collection of vast hydrogeological data on the water currents in the mines is of undoubted interest in making of comparative analysis of factual water flows with earlier computed prognostic estimates. Such a comparison points out that in ore deposits of very complex hydrogeological conditions it is essential to conduct the prognostic estimate through the method of mathematical modelling.

TECHNOGENIC PROCESSES AND THEIR INFLUENCE ON CHANGE IN THE SURROUNDING ENVIRONMENT

During the period of commercial exploitation of this exemplary ore deposit over many years, the general level of fracture-karst waters of carbonate rocks at the centre of the mine field reached 500-550 m, and the general area of formation of

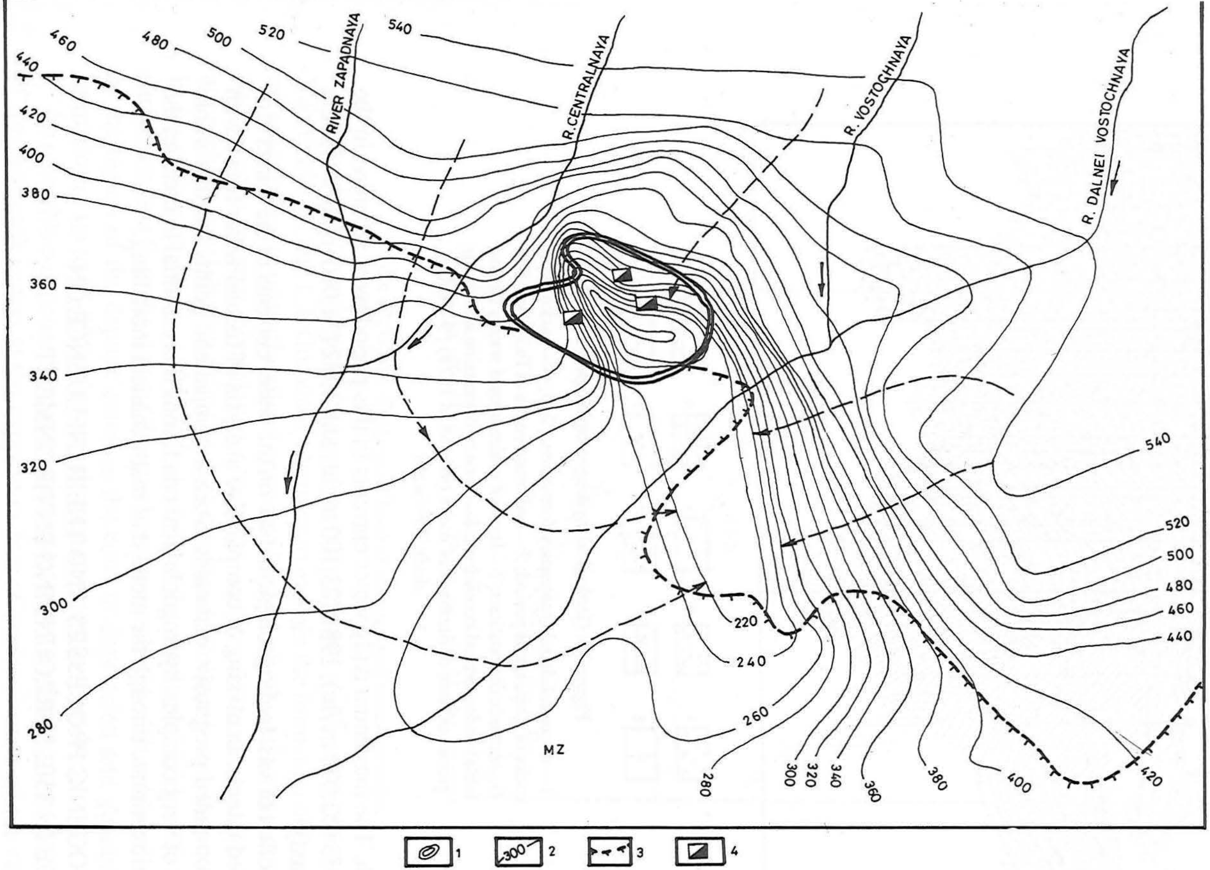

Figure 71: Map of hydro-isohypse

1—boundary of mining area; 2—hydro-isohypse; 3—boundary between Meso-Cenozoic deposits; 4—mines. Arrows indicate direction of groundwater flow.

the region of cone of depression—more than 1,500 km^2. These data convincingly point out, the significant changes the surrounding environment was subjected to, particularly the geological environment at the area of the deposit, as a result of prolonged mining and drainage in the mines.

Implementation in practise of the planned scheme of drainage envisaged a successful solution to all the problems of water supply in the mine area (for both domestic and industrial use) through utilisation of mine waters and also irrigation of the land in the township area including kitchen gardens for the local population. Through the adoption of the given scheme the town of Kentau, situated in the arid zone of southern Kazakhstan, has been transformed into a colourful oasis with fruit orchards, vineyards, avenues of flowers, excellent parks with fountains and also zones of relaxation and rest.

The environment surrounding the township has also been significantly transformed into a new highly favourable ecological background for living and industrial activity through maximum utilisation of mine waters of the deposit. It is pertinent here to mention that the actual per capita requirements of water in the township of the mines for domestic needs is 1,200-1,300 l/day.

Nevertheless, these highly positive factors notwithstanding, drainage in the mines of the ore deposit has also produced negative changes in the surrounding environment over considerable areas. Of the set of complex negative technogenic processes, the following may be mentioned: (a) processes of drainage and processes of exhaustion of sources of natural reserves of underground waters related to the former; draining of moisture from the surrounding area of influence of drainage constructions (draining of spring flows etc.); (b) processes of radical change in the regime of interconnection of underground and surface waters; (c) subsidence-karst processes, with deformation of the surface and surface installations; (d) processes of contamination of mine and also underground waters in zones of exploitation of the tailings reservoir; (e) processes of submergence of parts of the city due to runoff during irrigation, water in the streets, city squares etc.; and (f) deformation of the surface due to rockslides in the mining area.

Processes of drainage of water-bearing country rocks and drainage of moisture from the surrounding territory were responsible for effecting the most conspicuous changes in the surrounding environment. Under the influence of drainage in the mines, as mentioned earlier, radical change in the regime of interlinkage of underground and surface waters took place. Mines located in horizons situated at depths far lower than the base level of erosion, began to play the role of artificial drains. Over the field of the cone of depression and closely linked with it, distinct infiltration losses of surface waters from all the rivers of the local hydrographic system became apparent, which constituted the main sources of flooding in the mines during the period of high floods. The drainage area of the water-bearing country rocks of Paleozoic limestones at the central part of the cone of depression assumed the role of accumulator of infiltration losses of river waters and regulator of underground currents.

In recent years collapse-karst technogenic processes and processes of submergence of the township area have begun to appear, which are degrading the ecological situation of the surrounding environment.

Figure 72 presents a hydrogeological cross-section of the area in which collapse-karst processes are active in the water-bearing country rocks of Paleozoic limestone. It was earlier observed that all large karst belts in the area of the deposit belong to zones of tectonic dislocations and, first and foremost, to the complex system of conjugate Main and Southern overthrusts. Karst belts of the local type have developed mainly along such large faults and almost all the recorded subsidence-karst sinks can be traced here. The largest deformation of surface installations over the ore deposit in the field of collapse-sinks took place directly within the boundaries of the suburban constructions.

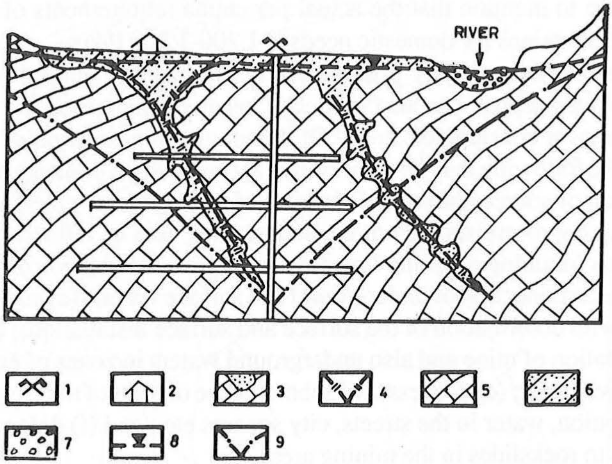

Figure 72: Cross-section of part of territory showing occurrence of subsidence-karst processes

1—shaft; 2—building affected by deformation; 3—ancient karst belt; 4—collapse-sinks; 5—limestones; 6—unconsolidated material of ancient karst belt; 7—pebbles; 8—level of underground waters; 9—cone of depression.

Considering the location of the township of the mines in a territory adjacent to them and within the bounds of the regional cone of depression, special complex hydrogeological and engineering geological investigations were carried out to ascertain the conditions of formation and prognosis of possible distribution of subsidence-karst processes and also to plan the mining enterprise for protection of the surrounding environment. In the territory under study an additional network of observation stations was established for a more detailed study of the regime of underground waters and the probable process of deformation of the surface. The results of these complex studies and regimal observations emphasised the need to forecast possible development of collapse-karst processes and to avoid in advance their negative influence on the surrounding environment.

It was pointed out earlier that the entire township's territory is irrigated. Infiltration losses of irrigating waters determined the formation of zones of aeration of the aquifer horizon of soil waters in intercalated sandy rocks. The township area presents a flat relief and the slope of the plains to the south offers poor natural drainage. Thus favourable conditions exist for flooding of certain residential buildings situated in the low-lying areas of the town. Partial flooding of the basement degrades the engineering geological characteristics of the geological environment and could affect the stability of civil engineering constructions. Results of detailed investigations conducted in part of the area to assess the conditions of formation of technogenic processes of submergence of residential buildings, revealed the need for measures to protect the geological environment through arranging micro-drainages in different parts of the township.

The short account presented above, projecting the characteristics of influence of commercial exploitation of an ore deposit on the character and degree of changes in the surrounding environment, impels the following conclusion. It is very important at the pre-plan stage of mining to conduct a prognosis of possible appearance of negative technogenic processes which, during future exploitation, would undoubtedly degrade the ecology of the environment in and around the mine. Special complex investigations along such lines are hence very essential. No less important is to look far ahead and provide for the protection of the environment from the negative influence of technogenic processes in the initial plan itself for working ore deposits, in order to preclude the inevitable appearance of such processes.

Finally, a rational distribution of the different sectors of mining during exploitation of the ore deposit and particularly the location of housing sectors away from the boundaries of mining activity and associated commercial enterprises, assume considerable importance.

CHAPTER 14

Extra-complex Conditions of an Ore Deposit

NATURAL CONDITIONS

The exemplary ore deposit is situated in the eastern USSR within the limits of the left bank of the lower course of a large river. The width of the river in a recent channel next to the area under study is more than 2.5 km. The discharge of the river in the low-level season is some hundreds of cubic metres per second. Part of the ore bodies of the deposit lie directly under the recent river channel, giving rise to additional complex natural conditions of commercial working of the deposit. With the construction of the hydroelectric station planned in the near future, exploitation of the deposit became even more complicated under the influence of technogenic factors.

Geologically, the area comprises a series of rocks of the Proterozoic era, 750-950 m thick, with layers of limestone and interbedded quartz-carbonate schists. Carbonate rocks and the underlying schists are ore-bearing. The entire series of rocks of the deposit is very complexly deformed by tight folds and fractured or faulted structures. Except for the precipitous banks of the river, more ancient rocks everywhere are covered with sediments of the Quaternary period, and are of alluvial, eluvial and eluvio-deluvial origin. The river terraces consist of alluvial deposits of gravel-pebbles, sandy-pebbles and sandy-loams. Their thickness within the limits of the river channels is less that 5.0 m but along the bank where they form the upper terraces reaches 28 m. Eluvial deposits in the region of the ore field fill 'pockets' of the crust of weathering of bedrocks to a depth of 40-250 m and are the products of weathered limestones.

The deposit belongs to the eastern limb of the synclinal fold of the second order (Figure 73). In the limb of the synclinal fold, at the foot of the deposit, a zone of fine schistosity in the ore-bearing country rocks striking NW and dipping SW has been traced. Its thickness is 100-150 m. Rocks of the hanging wall of the deposit are broken by innumerable shear fractures in which surfacial inter-layered zones of fracturing and (crushing) brecciation are visible. The thickness of these rocks, intensely crushed, slickensided and broken by a dense network of joints in the exposed part of the deposit on the bank is estimated to be 10-12 m, and under the river bed, 50 to 100 m (as revealed by borehole data). Altogether in the entire hanging wall of the deposit 13 significant zones of intense fracturing have been encountered. The problem of conditions of formation and distribution of the large karst belts characterising the ore-bearing carbonate country rocks is very important. Directly over the outcrops to the right and left of the bank, open and comparatively large karst belts up to 0.5-1.0 m are traceable. Small caverns and zones of increased fracturing of rocks encountered during the process of boring wells at various depths, particularly between 350 and 1,210 m. Large karst belts were not encountered while drilling boreholes for exploration of the limestones. Nevertheless, it can be expected that with depth a karst belt might occur under very complex conditions.

Changes in the ore-bearing country rocks, under the influence of metamorphism and tectonic deformation, produce a different picture. For example, in the northwestern ore body (below the river channel) intense processes of leaching have occurred along the zones of rock crushing, producing a peculiar type of cavernous rock at places of intense crushing at depths of up to 132 m. In other tectonic zones occurring in the area of the ore deposit, rocks close to or bordering the dislocations have been finely crushed into tectonic sands (cataclasites) or still finer pulverised clay (gouge or melanite). Deep crushing of the rocks has resulted in the formation of breccias in many places. The transition zone between the brecciated and sheared rocks is characterised by fracturing of varying intensity, which has given rise to kakirites. This brief account of the characteristics of the deposit highlights the very

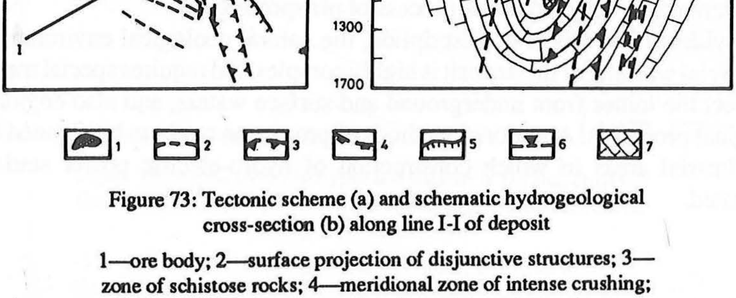

Figure 73: Tectonic scheme (a) and schematic hydrogeological cross-section (b) along line I-I of deposit

1—ore body; 2—surface projection of disjunctive structures; 3—zone of schistose rocks; 4—meridional zone of intense crushing; 5—river bank; 6—water table before mining of deposit commenced; 7—limestone

complex hydrogeological and engineering geological conditions of the commercial enterprise.

According to data on experimental infiltration studies conducted by various organisations, the filtration properties of the ore-bearing country rocks and the unconsolidated alluvial deposits exhibit a wide range of changes. The coefficient of filtration of the alluvial deposits ranges from 0.001 (loams and wacke-type formations) up to 151 m/day (gravelly-pebbly deposits). Proterozoic ore-bearing rocks in different conditions of attitude and change, register a large scatter in values of the coefficient of filtration. The average values for the coefficient of filtration (m/day) for different rock types is as follows:

Bare, weakly fractured rocks	0.25-0.46
Rocks of zone of fine attrition	0.54
Cataclasites	4.24
Breccias	0.40
Rocks of zone of deep crushing	20.36
Intensely fractured rocks	1.0-46.80

Three types of underground waters are recognised in the area of the ore deposit, viz., groundwaters of the Quaternary deposit, fracture-groundwaters of the crust of weathered bedrock and fracture-vein waters of the zone of tectonic dislocations. All these types are hydraulically inter-connected and thus appear to constitute a single aquifer complex, distributed not only in the area of the deposit but also beyond its limits. The depth of occurrence of level of underground waters varies from 1.5 to 20 m; recharge originates at the expense of infiltration of atmospheric precipitation and the underground current moving from the sides of the hypsometrically overlying high terraces of the river valleys (beyond the limits of the deposit). All three types of underground waters are discharged under natural conditions into the region of rivers (in the form of springs and underground water).

The underground waters, according to chemical composition, mainly contain hydrocarbonates of calcium and magnesium and are fresh, with mineral contents varying in different parts of the deposit from 0.273 to 1.64 g/l. The general hardness is 2.7-24.1 millimole; pH = 5.0-7.8. River waters contain hydrocarbonates, with mineral contents normally 0.1 g/l, general hardness 2 millimole and pH 7.3. Natural gases were never detected in the process of prospecting.

As evident from this brief description, the natural geological environment for commercial working of the deposit is highly complex and requires special measures to protect the mines from underground and surface waters, and also engineering geological processes. Additional methods of protection ought to be planned for all the industrial areas in which construction of hydro-electric power stations is anticipated.

COMMERCIAL WORKING OF DEPOSIT AND SYSTEM OF PROTECTION OF MINES FROM FLOODING BY SURFACE AND UNDERGROUND WATERS AND ENGINEERING GEOLOGICAL PROCESSES

In the deposit under study the ore bodies are situated right below the water-bearing areas. The conditions of commercial working of the deposit have been further complicated by an increase in water level in the river of 40 m subsequent to the erection of the power plant, GES.

Plans for working the deposit included pushing the river aside considerably towards the right bank, alternate use of two retaining dams and adoption of a special system of drainage. A combined mode of mining the deposit was devised. The upper part of the ore horizons, up to a depth of 400 m, would be worked by open cast mining further for depths of 1,000 m or so, underground mining would be

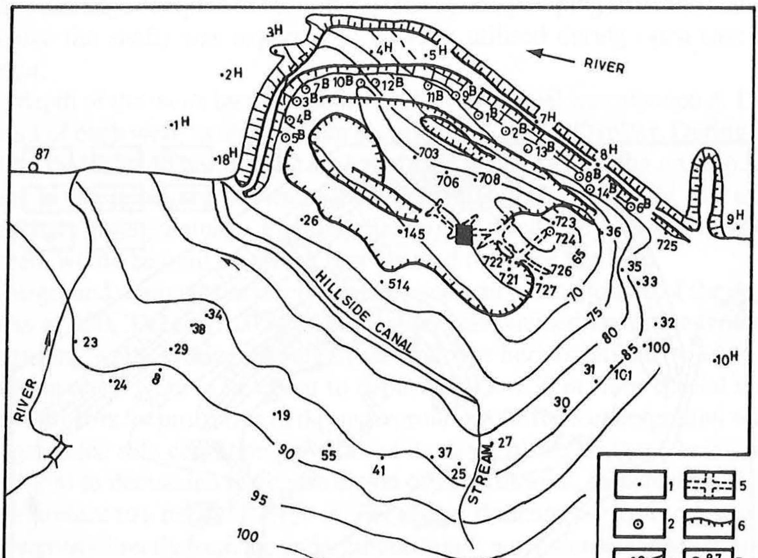

Figure 74: Map of hydro-isohypse and stations of regimal observation over part of the open cast mine during experimental industrial working in December, 1984

1—wells of network of regimal observations; 2—pump wells for lowering water table level; 3—hydro-isohypse; 4—RESh (exploration-exploitation shaft); 5—drainage in mines; 6—slopes of open cast mine; 7—relative multi-annual/mean elevation of level of waters in river; 8—hydrostation.

adopted. Under the additional complex conditions of the deposit and the absence of any past experience in exploitation of a similar set-up, work on the deposit was planned in three stages.

The first stage envisaged construction of an experimental open cast mine of the first order and working the deposits up to a depth of 60 m, below the river channel area during the non-regulated position of water levels in the river, under the protection of temporary small overflow dams (height 6-8 m) against surface waters of the river and a system of surface drainage against underground waters (Figure 74).

At the second stage, based on data collected through experimental studies, an open cast mine of the second order was constructed and the deposit worked up to a depth of 400 m, under the protection of capital overflow dams up to a height of 12 m, and a complex of surface and underground drainage (Figure 75).

The third stage envisaged construction of an underground mine and working the deposit to the proposed depth under the protection of a system of drainage, which would have been perfected in the process of open cast mining.

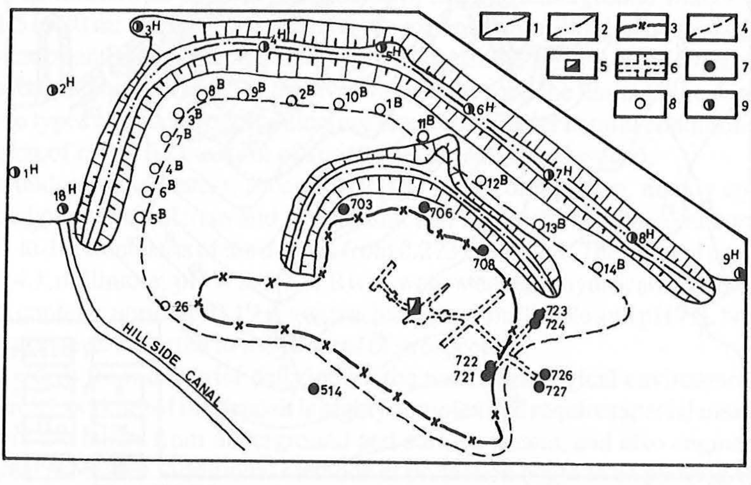

Figure 75: Scheme of protection of open cast mines for implementation of experimental industrial scheme (EIS) and experimental commercial scheme (ECS) from surface and underground waters

1—axis of dam EIS; 2—axis of dam ECS; 3—outer boundary of mine EIS; 4—outer boundary of open cast mine ECS; 5—exploration-exploitation shaft (RESh); 6—drainage in underground mine RESh; 7 and 8—water-level-lowering pump wells along boundaries of EIS and ECS respectively; 9—observation wells.

Protection of the open cast and underground mines from surface waters of the river was carried out by construction of a temporary dam that later became a capital buffer dam. Surface waters infiltrating through the dam from the river side were to be jettisoned by special drainage in the vicinity of the dam. At places of dam intersection of zones of intense fracturing and crushing, the section of intense fracturing and shearing of rocks under the capital dam would be fitted with anti-filtration cement screens.

To protect the mines from underground waters during the second stage of commercial working of the deposit, one of the planning institutes suggested a combined scheme of drainage, which would include the system of four horizons of underground drainage of the mines and the pump wells. The principles of construction and functionality of the scheme are as follows. Under the protection of the contoured system of alignment of pump wells bored from the bottom surface, along the contour or boundary of the open cast mine the drainage works of the horizon will be penetrated at a depth of 100 m from the bottom surface. Investigations have established that the rocks lying below this horizon possess the highest filtration properties. This horizon had hence to be considered the major one; later the entire drainage complex of the horizon (stockyard, pumping shaft and construction above the shaft) was expected to be fully utilised during open cast mine operation.

The depth of the wells intended to lower the water level was planned at 130 m. The yield of each well, as shown from calculations, was 100 m^3/hr. During mine operation there would be 15 to 20 such drainage wells. Depending on tapping by drainage in the mines, of the water-lowering wells, the latter might function as porous filters during drainage. Pumping stations for discharge of mine waters from the system would be built on all the four planned drainage horizons.

Underground drainage horizons would be constructed in the area of the deposit at depths of 220, 330 and 420 m. Construction was planned under the protection of dewatering wells. During drilling of the drainage horizon at 420 m, additional observation wells were to be bored to depths of 200-250 m from special underground chambers for protection of the underground mine from underground waters.

To guarantee safe conditions of work at the level of the drainage horizon at a depth of 100 m demanded the construction of anti-filtration cementation screens from the surface to a depth of 2,150 m. For deeper drainage horizons construction of such screens directly from the underground mines was recommended. Similarly, a belt system of anti-filtration screens was to be constructed over areas of tectonic dislocations to safeguard against the development of subsidence-erosional processes and washout of crushed and sliding rocks.

The effectiveness of the planned anti-filtration screens was estimated by the method of mathematical modelling on planar profile models using the equipment EGDA. Successive stages of the action of all four drainage horizons were modelled for both inclusion and exclusion of anti-filtration filters. Modelling revealed that such screens would be highly effective. Reduction of the general current of underground waters in the system of drainage with the construction of impervious screens reached 33%.

During modelling and analytical calculations of the anti-filtration screens, certain specific effective parameters (Table 12) were adopted.

Table 12: Effective parameters for anti-filtration screens

Zone	Water conductivity of rock m^2/day	Thickness of screen, m	Radius of distribution of tamper solution, m	Distance between pressure wells, m	Distance between rows of wells, m
Crushing	2,100	25	13	22	11
Fractured limestones	1,580	16.7	9	15	7.5
Leaching and schistosity	35	10.0	6	9	4.5
Metamorphic limestones	230	—	—	—	—

The first experimental construction of cementation screens was introduced in the area in 1974. Results of experimental-industrial investigations revealed that for the specific engineering, geological and hydrogeological conditions in the area under study, the erection of anti-filtration screens was a highly complex process and required more detailed investigations of an experimental-industrial nature. Hence, it was resolved to continue investigations along this line so that subsequently necessary corrections could be implemented in the planned drainage.

PROGNOSIS OF WATER CURRENTS IN THE MINES

It is well known that in planning the drainage system to be used in mines it is essential to carry out a prognostic estimation of the general water currents. An estimate of the water currents in the ore deposit was done for conditions of the first order of open cast mining.

Hydrological calculations were carried out based on data from the previous study of the geological-hydrogeological conditions of the deposit by planned implementation of the methods of drainage according to the time table of the operation. The geofiltration scheme adopted for the given conditions was based on the non-artesian semi-confined layer from borders of constant pressures (river) and envisaged incomplete drainage arranged along the river. Under such hydrogeological conditions the movement of underground waters assumes a stationary character during a short interval. According to the filtration properties of the rocks the entire area of this ore deposit can be divided into two parts—the sector of the river channel with a higher coefficient of filtration of rocks (k_1 = 4.2 m/day) and the sector of the bank over which the open cast mine is located (k_2=1 m/day). For all the studied upper series (300 m) of aquifer rocks, a weighted average (k = 2.6 m/day) was adopted for the radius of influence in the calculations the average distance was taken from the centre of the open cast mine or the contour of drainage constructions up to the zone of constant pressure—the river, with respect to the special overflow dam of the mine. Lowering of the level to the depth of the open cast mine (100 m; first order) was reckoned from the statistical level of underground waters, and for the lower horizons (at depths greater than 100 m), from the lower level. These levels were calculated taking into account the influence of filtration screens (which ought to be constructed under the base of the water overflow dam) by the method of averaging the coefficients of filtration.

Prognostic general water currents of the underground waters in the open cast mine of the first order were estimated by analytical calculations for the scheme 'gigantic well' of the incomplete type under unconfined conditions according to the following function:

$$Q = \pi kS \left[\frac{S}{\ln\left(\frac{R+r_0}{r_0}\right)} + \frac{2r_0}{\frac{\pi}{2}\, 2\, arcsh \frac{r_0}{T+\sqrt{T^2+r_0^2} + 0.515\frac{r_0}{T}\ln\frac{r_0}{T}}} \right],$$

where k = weighted average values of coefficient of filtration; S = lowering of level of underground waters; R = radius of influence; r_0 = given radius of 'gigantic well'; T = height of centre of working part of well under confined stratum.

Prognostic currents of underground water towards the circular system of pump wells constructed around the open cast mine for advance drainage was determined according to the following equation (for conditions of an already adopted computed geofiltration scheme):

$$Q = \pi ks \left[\frac{2}{\ln\left(\frac{R^n}{nr_0^{n-1}r_c}\right)} + \frac{2T\beta}{1+\beta N} \right] ;$$

where = mean coefficient of filtration of rocks, including influence of anti-filtration screens and zones of schistosity; n = number of wells, r_c = radius of well.

The values T, β and N can be obtained according to the formulas:

$$T = H-h \;;\; h = S + \; l/2 \;;\; \beta = n/\xi \;;$$

$$\xi = \frac{T}{l}\left[2\ln\frac{4T}{r_c} - f\left(\frac{l}{2T}\right) - 1.38\right] \;;\; N = \ln\frac{R_n}{nr_0^{n-1}T} ,$$

where H = height of unreduced level of underground waters at place of location of well (considered from base of layer)—thickness of aquifer horizon of groundwaters; h = height of statistical level under centre of working part of well (filter); l = height of column of water at incomplete well (length of working part of well).

Determination of discharge of the system of interacting water-level reducing wells was carried out according to the equation of A.V. Romanov for the linear series of ideal vertical drains with the introduction of the coefficient of irregularity α into the equation, as suggested by S.K. Abramov:

$$Q_0' = \frac{\pi k_2 \ (2H - S) \ S \alpha}{\ln \dfrac{\sigma}{\pi r_c} + \dfrac{\pi R_1 R_2}{\sigma \pi}} \ ;$$

$$\alpha = \frac{l}{H} \left[1 - 7 \left(\ln \frac{l}{H} \sqrt{\frac{r_c}{H}} \right) \right] ,$$

where k_2 = coefficient of filtration of rocks in river bank part of deposit; σ = half distance between wells in row; R_1 and R_2 = distance from drainage system corresponding to dam and area of recharge (in the given case in this border the condition adopted is $Q = 0$); l = depth of discharge of centre of working part of filter under statistical standard.

In all analytical calculations the following values of parameters were used.

Coefficient of filtration of ore-bearing country rocks:	
a) in river bank part of deposit	1 m/day
b) in channel part	4.2 m/day
Lowering of level of underground waters in first order open cast mine	100 m
Number of pump wells lowering water level (and depth)	120 (130 m)
Distance between wells	80 m

Analytical calculations of the prognostic estimate of water currents in the open cast mine of the first order were also done using the method of mathematical modelling on equipment EGDA. Two types of models were attempted: two-dimensional in section and two-dimensional in plan.

The results of prognosis of water currents by the methods of analytical calculations and mathematical modelling are shown in Table 13.

Prognostic water currents in the open cast mine of the second order and mining by the underground method were approximately estimated by analytical methods and the method of mathematical modelling. Such approximate prognostic estimates are desirable as is rectification of the system of drainage based on the results of experimental-industrial working of deposits by an open pit mine of the first order. While making a prognostic estimation of the hydrogeological conditions in the mining of this particular ore deposit, special attention must be paid specifically to the scheme of submergence of sectors of mining constructions after the completion of the planned hydrothermal power plant, GES.

Table 13: Results of prognostic estimation of water currents (m^3/hr) in the open cast mine of the first order

Sector of Water Currents	Results of modelling: Along Linear Sections	Results of modelling: Along Planar Model	Results of Analytical Calcuala-tions	Average Values
Open cast mine, I order (depth 100 m)	5232/4390	3900/5250	5890/4370	5000/4700
Horizontal drain	10150/8680	10100/8030	10078/7621	10100/8100
Contoured arrangement of water-level reducing pump wells	15680/10150	16400/11450	15208/12038	15800/11200
Linear arrangement of pump wells along river bank	—	3400	—	—
Horizontal drain along bank	—	3350	—	—

Note: Numerator—data without considering filtration screens and zone of schistosity of rocks; denominator—data taken into account.

HYDROGEOLOGICAL INVESTIGATIONS DURING EXPERIMENTAL-INDUSTRIAL WORKING OF DEPOSIT

Considering the complex structure of the geological environment and the extra-complex conditions of commercial working of the ore deposit under review, special hydrogeological and engineering geological works were taken up even at the stage of detailed exploration of the deposit. Utmost attention was paid to the study of filtration and physico-mechanical properties of the ore-bearing and associated country rocks as well as alluvial deposits including rocks constituting the tectonic dislocations and the role of these faults under conditions of flooding of the deposit.

Besides the experimental hydrogeological wells drilled at the stage of exploration at 40 m from the river channel in the central part of the main ore body, an experimental exploration shaft (RESh) was later drilled to a depth of 43 m (below the elevation of the river channel) with horizontal mining (adit) extending generally over a distance of 303 metres (see Figure 75). The shaft was introduced under the protection of water-level-reducing wells with a yield of 400 m^3/hr. Again, an additional pump was used in the underground mine with an initial yield of 20 m^3/hr, which later increased to 100 m^3/hr. The general currents in the underground mines and the pump wells in 1963 constituted 440 m^3/hr.

To study the conditions of interrelation between underground waters of the ore-bearing country rocks and surface waters of the river at the deposit, prolonged group-wise pumping was continued simultaneously from 12 exploratory hydrogeological wells over a period of 21 months during 1961-1963, with the total yield changing from 300 to 900-1,470 m^3/hr. Observations in levels of water were made in 90 wells within the area of the deposit and in 50 wells beyond its limits. It was established by experimental works that the lowering of levels of underground waters reached 21.9 m at the centre of the drainage massif. During this a cone of depression formed along a front of 1,500 m, along the bank of the river. Across the river bank it was 1,200 m and under the river channel (see Figure 75) observation wells fixed the interruption of level of underground waters from the channel deposit of the river at 150 m. This shows how highly complex the hydraulic link of these waters is.

Based on results of experimental filtration work, additional analytical calculations were carried out in order to refine the data on filtration properties of the rocks throughout the region of detailed exploration of the deposit. The results of hydrogeological investigations were compiled mainly in 1967 as part of the planned programme at the construction in the mine area of the first order mining-beneficiation undertaking; the programme also envisaged construction of experimental open cast mine and temporary overflow dams. In accordance with the requirements of the plan, additional complex work was taken up in the area to obtain detailed studies of engineering mining and hydrogeological conditions of industrial working of the deposit. In the river bank on the western part of the ore field two drainage shafts were driven to depths of 110 and 104 m (at 97 and 91 m below the level of the river). Experimental drainage shafts form part of the general drainage system of protection of the open cast mine of the first order. From the shaft walls horizontal working in the neighbourhood extended 1,145 m and workings of the drainage horizon were also introduced. Water-level-reducing wells were bored along the contour of the shaft field and also a network of observation wells to a depth of 100-150 m (see Figure 75).

Drainage shafts were introduced up to a depth of 100 m under the protection of water-level-lowering wells. During this, the maximum current of underground waters reached 50 m^3/hr in the shaft. Mine waters appeared at the surface in the form of concentrated flows through different fractures. The number of water-level-lowering (pump) wells functioning along the contour in the neighbourhood of the shaft (during the drilling of the two shafts) was raised from 10 to 20 with a general discharge of 450-650 m^3/hr. Observations revealed that during the experimental mining construction work the experimental pump wells did not function effectively (some of the wells showed small discharges; some contained desiltation filters).

Concomitant with the foregoing, detailed investigations were conducted along the trace of the buffer dam 1,400 m long, planned as a means of protecting the experimental open cast mine of the first order from surface waters of the river. In connection with the extra-complex conditions of working, the adopted system of drainage was intended to provide safe functioning of the experimental mine.

In 1975 the experimental-industrial scheme (EIS) was implemented in the deposit through excavation of ores by the stripping method. The main aspects of this scheme were: experimental mine, water-protecting dam, drainage and water-level-lowering systems. As a result of the functioning of the drainage complex and the experimental-industrial scheme the following could be completed: hydrogeological and mining engineering conditions of the upper part of the deposit, within the limits of which was envisaged working of the open cast mine of the first order; study of the stability and filtration properties of the rock bodies of the waterproof dam, filtration properties of the rocks mainly in the dam and also the rocks and ores lying in the river channel; interlink of underground waters with surface waters of the river; and ascertaining the effectiveness of the adopted scheme of protection of the open cast mine in the experimental sector from underground and surface waters. Lowering of the water level in the mine of the experimental unit (see Figure 75) was conducted mainly by means of three wells (Nos. 721, 722, 724). During lowering of the level of the underground waters up to the roof of the workings of the prospecting drainage shafts, the total discharge from the wells was 560 m^3/hr. Consequently, the cone of depression became elliptical in plan, with the longer axis trending parallel to the strike of the water-saturated rocks.

Implementation and experience with exploitation of the open cast mine in the experimental sector revealed that the system of water-protecting structure erected (the drainage installation) guarantees reliable protection of the mines from flooding of surface and underground waters. The waterproof dam was constructed from local materials (limestones, marls) and totally impedes infiltration of surface waters from the river side. Controlled probes into the body of the dam up to its base revealed that it was dry throughout.

Accumulated experience in mining engineering construction under complex natural conditions prompted the mine authorities to take a decision in 1976 regarding construction for the ECS. This scheme envisaged an open cast mine 60 m deep provided with a system of protection from surface and underground waters (see Figure 74), a beneficiation plant, reservoir construction and other accessory units. The principal dimensions (in metres) of the mine and associated structures of the experimental commercial working of the deposit are as follows:

Length of open cast mine along surface	490
Width of mine	220
Depth of mine	60
Depth of lowering of level of underground waters in system of drainage	100
Length of waterproof dam	750
Maximum distance of axis of dam away from river bank	230

Calculations showed that the prognostic rate of flow of water in the open cast mine at the planned depth might reach the value of 1,100 m^3/hr.

Experimental working of the ore deposits was carried out in the open cast mine at a depth of 22-25 m from mean multi-yearly level of the river. Drainage in the mine was executed by means of pump well Nos. 26, 1B, 2B, 3B, 4B, 5B and 724

(Figure 76). As a result of experimental drainage and observations over the regime of underground waters, it was established that the pump wells of the northern part of the contoured system (well Nos. 7B, 11B, 12B) exerted no influence on drainage in the mine. These wells, unlike the mine per se, were located in a comparatively thick zone of schistose rocks (see Figure 75). Natural impermeable screens play a distinct role in the filtration relations of the zone of schistose rocks. Of lower hypsometric position, well (heads) Nos. 9B and 11B with well-established hydraulic links with the river constituted flow well of underground waters. Waters gushing along the hillside canal were drawn from well No. 1B and pumped by submersible pumps into the river. Because of the overflowing dam close to well No. 1B a spring formed at the expense of filtration waters from the river. The total discharge from the flowing well Nos. 9B and 11B and the spring was about 100

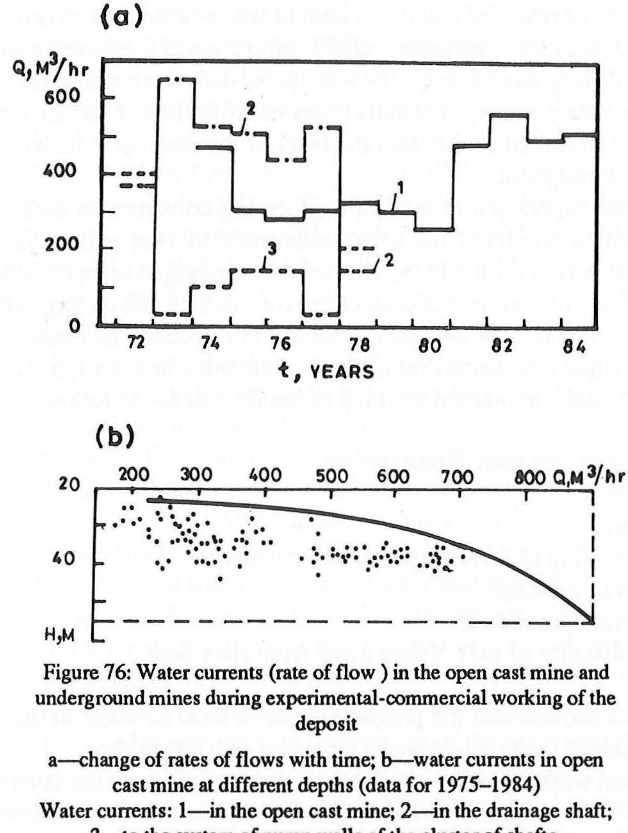

Figure 76: Water currents (rate of flow) in the open cast mine and underground mines during experimental-commercial working of the deposit

a—change of rates of flows with time; b—water currents in open cast mine at different depths (data for 1975–1984)
Water currents: 1—in the open cast mine; 2—in the drainage shaft; 3—to the system of pump wells of the cluster of shafts.

m^3/hr. Over the zone of schistose rocks springs appeared at places in the open cast mine with a discharge of 3-5 m^3/hr. The hydraulic link of all the established springs and flowing wells with the river was reflected in the chemical composition of the waters. In the process of experimental working of the deposit, the presence of finely schistose rocks played a significant role as anti-filtration screens and hence emphasised the need for correction while planning the drainage of the open cast mine, disposition of the capital waterproof dam and also conditions of construction of technogenic and anti-filtration cementation screens.

Experimental open cast mining revealed the need for considerable refinement of computed hydrogeological parameters of the aquifer rocks of the mine and verification of the reliability of the method of prognosis of water currents in the mine, discussed in the earlier section.

In the process *in situ* regimal observations, it was established that during the performance of certain water-level-reducing wells debris of fine-grained washed material was brought to the surface by the waters and intensive silting-subsidence-filtration technogenic processes resulted. In well No. 10B subsidence-filtration technogenic processes were accompanied by sedimentation at the bottom of the surface and formation of collapse cavities. These factual observations underline the importance of subsequent systematic studies of subsidence processes and their possible negative influence on mining engineering conditions in working ore deposits.

On the whole, hydrogeological investigations undertaken during the experimental-commercial working of the deposit presented well-defined, step-wise, purposeful information on the influence of technogenic factors on the surrounding environment, thereby enabling the adoption of solutions on the basis of inverse relations.

PRESERVATION OF THE SURROUNDING ENVIRONMENT DURING COMMERCIAL WORKING OF ORE DEPOSITS

Experience accumulated during working of ore deposits and detailed studies of hydrogeological and engineering geological conditions, enable prognostication of the possible development of technogenic processes in a deposit and their negative influence in the surrounding environment.

Redistribution of structures of underground currents undoubtedly originates directly under the influence of drainage in mines. Mines form the major drainages for all types of underground and surface waters. Changes in the hydrochemical situation can well result from the influence of processes of oxidation of ore mineralisation, exploitation of the tailings dump etc.

As established by observations, under the influence of water lowering in a deposit, subsidence-filtration and possibly subsidence-karst processes may develop, which pose an imminent danger in the stream channel area. Because of the negative influence of these processes, the need may arise for a radical betterment of the entire system planned for lowering water level and protection of mines from surface waters. The results of experimental studies conducted for prognosis of possible development of subsidence processes in fractured rocks in zones of tectonic dislocations in relation to gradients of filtration currents are of great interest (Table 14).

Table 14 : Gradients of filtration current

Width of fracture, in mm	Gradient of filtration current at contact of	
	Sandy Loam with Limestones	Loam with limestones
1	0.2	1
2	0.04	0.4
3	0.02	0.3

Prognoses of the formation of a cone of depression have shown that the gradients of currents during further exploitation of a deposit may far exceed tolerable values of gradients, leading inevitably to erosive processes. In such a case it is essential to continue natural and experimental investigations and to take their results into account while planning future drainage of the deposit and protection of the geological environment from the negative influence of technogenic processes.

The boring and blasting operations constantly underway in an open cast mine may effect changes in the filtration properties of rocks and lead to the development of degrading processes. Thus *in situ* observations are mandatory over the regime of activity of pump wells and springs before and after drilling (boring-blasting) works in an open cut mine. Based on such observations the size of cartridge to be used, method of blasting and distance from point of observation to epicentre of blasting can be determined. The specific objective of these particular *in situ* observations should be to precisely define the technology of boring-blasting operations in order to guarantee safe conditions in the future.

Preservation of the surrounding environment in a mining enterprise requires even at the stage of experimental working of a deposit, an assessment of its relation to any river bank in order to preserve the quality of surface waters. Possible sources of contamination are: mining unit, beneficiation plant, and housing colony. In this connection the actual problems of complex study of the regime of underground and surface waters in all sources of possible formation of technogenesis become prominent.

It is essential to emphasise that the regimal hydrogeological observations conducted in the study area should be systematic and commence from the stage of detailed exploration. The observation network should likewise be systematised so that all sectors of the mining enterprise spread over the entire area of the ore deposit are covered, including reservoir construction of future tailings, workers' dwelling units etc.

In conclusion let it be mentioned that in deposits with extra-complex conditions, it is possible to undertake experimental-commercial working with simultaneous extraction of ore. This, however, makes it obligatory to constantly correct the priorly worked-out plan.

Footnote Reference*

1. Abramov, S.K. 1973. Podzemnye drenazhi v promyshlennom i gorodskom strontel'stve (Underground Drainages in Industrial and Urban Construction). Stroizdat, Moscow.
2. Abramov, S.K., M.S. Gazizov and V.I. Kostenko. 1976. Zashita kar'era ot vody (Protection of Open Cast Mines from Water). Nedra, Moscow.
3. Borevskii, B.V., B.G. Samsonov and L.S.Yazvin. 1979. Metodika opredelennya parametrov vodonosnykh gorizontov po dannym otkachsk (Method of Determination of Parameters of Aquifer Horizons from Pump-test Data). Nedra, Moscow.
4. Bochever, F.M., N.N. Lapshin and A.E. Orodovskaya. 1979. Zashita podzemnykh vod ot zagryaznenni (Protection of Underground Waters from Contamination). Nedra, Moscow.
5. Gavich, I.K. 1980. Teoriya i praktika primenennya modelirovannya v gidrogeologii (Theory and Practise of Adoption of Modelling in Hydrogeology). Nedra, Moscow.
6. Gavin, I.K., S.M. Semenova and V.M. Shvets. 1981. Metody obrabotki gidrogeologicheskoi informatsii s variantamii zadach (Methods of Processing Hydrogeological Information with Variants of the Problems). Vysshaya Shkola, Moscow.
7. Gidrogeologicheskie issledovaniya v gornom dele (Hydrogeological Investigation in Mining Practise). Ed.: V.A. Mironenko. Nedra, Moscow, 1976.
8 Gidrogeologicheskie issledovannya dlya zakhoronennya promyshlennykh stokov v glubokie vodonosnye gorizonty (metodicheskie ukazannya). [Hydrogeological Investigation for Burial of Industrial Effluents in Deep Aquifer Horizons (Methodological Instructions)]. Eds.: K. I. Antonenko and E.G. Chapovskii. Nedra, Moscow, 1976.
9. Gidrogeologicheskie osnovy okhrany podzemnykh vod (v dvykh tomakh) [Hydrogeological Bases of Protection of Underground Waters (2 volumes)]. Centr Mezhdunarodnykh Proektov GKNG YUNESKO, Moscow, 1984.
10 Gidrotekhnika v gornom dele i stroitel' stve (Hydrotechnology in Mining Work and Construction). Ed.: N.A. Plotnikov. Nedra, Moscow, 1978.

* Some references were incomplete in the Russian original—General Editor.

11 Gol'dberg, V.M. and S. Gazda. 1984. Gidrogeologicheskie osnovy okhrany podzemnykh vod ot zagryazneniya (Hydrogeological Bases of Protection of Underground Waters from Contamination). Nedra, Moscow.

12 Drobnokhod, N.I., L.S. Yazvin and B. V. Borevskii. 1982. Otsenka zapasov podzemnykh vod (Estimation of Reserves of Underground Waters). Vysshaya Shkola, Kiev.

13 Izrael', Yu. A. 1984. Ekologiya i kontrol' sostoyannya pripodnoi sredy (Ecology and Control of Composition of the Natural Environment). Gidrolitizdat, Moscow.

14 Instruktsiya po primeneniyu klassifikatsii ekspluatatsronnykh zapasov podzemnykh vod k mestorozhdeniyam pit'evykh i tekhnicheskikh vod (Instructions for Adoption of Classification of Exploitable Reserves of Underground Waters to Deposits of Potable and Industrial Waters). Izd. Upravleniya Sovmina SSSR, Moscow, 1984.

15 Krashin, M.I. and D.I. Peresun'ko. 1976. Otsenka ekspluatatsionnykh zapasov podzemnykh vod metodom modelirsvaniya (Estimate of Exploitable Reserves of Underground Waters by the Method of Modelling). Nedra, Moscow.

16. Lukner, L. and V.M. Shestakov. 1976. Modelirovanie geofilyratsii (Modelling of Geofiltration). Nedra, Moscow.

17. Mel'nikov, N.V. 1974. Vudushchie gornye razrabotki (Future mine planning), pp.18-27. In the book: Ratsional'noe Ispol'zovanie Zemnoi Kory. Moscow.

18. Metodicheskie rekomendatsii po provedeniyu gidrogeologicheskikh issledovanni na stadii detal'noi razvedkn mestorozhdenii tverdykh poleznykh iskopaemykh (Methodological Recommendations Based on Hydrogeological Investigations Conducted at the Stage of Detailed Exploration of Solid Economic Mineral Deposits). VIMS, Moscow, 1981.

19. Mironenko, V.A. and Yu. A. Norvatov. 1979. Gidrogeologicheskie raschety v gornom dele (hydrogeological computations in mining practise), pp. 335-364. In the work: Spravochnoe Rukovodstvo Gidrogeologa, vol I. Nedra, Leningrad.

20. Mironenko, V.A.,V.G. Rumynin and V.K. Uchaev. 1980. Okhrana podzemnykh vod v gornodobyvayushchikh raionakh (Protection of Underground Waters in Mining Regions). Nedra, Moscow.

21. Osushenie vyrabotok v neodnorodnykh vodonosnykh sistemakh (Drainage Planning in Heterogeneous Aquifer Systems). Nedra, Moscow, 1977.

22. Osushenie pri stroitel'stve zhelezorudnykh mestorozhdenii (Drainage during Construction of Iron-Ore Deposits). Nedra, Moscow, 1977.

23 Plotnikov, N.I., I.I. Roginets, V.A. Avetisyan et al. 1985. Okhrana okruzhayushchei sredy pri osushenni rudnykh mestorozhdenii (Protection of the Surrounding Environment during Drainage of Ore Deposits). Nauka, Moscow.

24 Konoplyantsev, A.A., L.S. Yazvin, I.V. Garmonov et al. 1978. Otsenka izmenenii gidrogeologicheskikh uslovii pod vliyaniem proizvodstvennoi deyatel'nosti (Evaluation of Changes of Hydrogeological Conditions under the Influence of Industrial Activity). Nedra, Moscow.

25. Plotnikov, N.I. 1984. Gidrogeologicheskie issledovaniya na mestorozhdeniyakh tverdykh poleznykh iskopaemykh (Hydrogeological investigations in solid economic mineral deposits), pp. 185-187. In the book: *Osnovy Gidrogeologii. Metody Gidrogeologicheskikh Issledovanii.* Nauka, Novosibirsk.

26. Plotnikov, N.I. 1985. Ponski i razvedka presnykh podzemnykh vod (Exploration and Prospecting of Fresh Underground Waters). Nedra, Moscow.

27. Plotnikov, N.I. 1979. Ekspluatatsionnaya razvedka podzemnykh vod (Prospecting of Exploitable Underground Waters). Nedra, Moscow.

28. Plotnikov, N.I. and S. Kraevskii. 1983. Gidrogeologicheskie aspekty okhrany okruzhayushchei sredy (Hydrogeological Aspects of Protection of the Surrounding Environment). Nedra, Moscow.

29. Plotnikov, N.I., N.A Plotnikov and K.I. Sychev. 1978. Gidrogeologicheskie osnovy iskusstvennogo vospolneniya zapasov podzemnykh vod (Hydrogeological Bases of Artificial Supply of Reserves of Underground Waters). Nedra, Moscow.

30. Pravila tekhnicheskoi ekspluatatsii vodoprovodov i kanalizatsii (Laws Relating to Technical Exploitation of Water Supply and Sewerage). Stroizdat, Moscow, 1965.

31. Printsipy razmeshcheniya seti gidrogeologicheskikh nablyudatel'nykh punktov v estestvennykh i narushennykh usloviyakh (metodicheskie rekomendatsii) [Principles of Disposition of Network of Hydrogeological Observation Stations in Natural and Disrupted Conditions (Methodological Recommendations)]. Nedra, Moscow, 1974.

32. Lebedyanskaya, Z.P., L.Z. Levi, G.N. Kashkovskii et al. 1972. Prognoz vodopritokov v gornye vyrabotki i vodozabory podzemnykh vod v treshchinovatykh i zakarstovannykh porodakh/Z (prognosis of water currents in the mines and water reservoirs of underground waters in fractured and karstified rocks). Nedra, Moscow.

33. Rekomendatsii po gidrogeologicheskim raschetam dlya opredeleniya granits 2 : 3 poyasov Zon Sanitarnoi okrani istochnikov kozyaist-venno—lit'evogo vodosnabzheniya. (Recommendations on hydrogeological calculations for the determination of the boudaries of belts 2 and 3 of the zones of sanitary protection of the sources of drinking water supply.) VNIIVODGEO, M., 1983.

34. Sergeev, E.M., 1979. Inzhenernaya geoligiya i okrana okruzhau- zei sredi (Engineering geology and protection of the surrounding environment) Vestnik MGU Ser. Geologiya, No. 6, pp. 75-85.

35. Sergeev, E.M., 1985. Nauchno—tekhnicheskii progress i okrana o kruzhauzei sredi (Scientific-technological progress and preservation of the surrounding environment.) Zemlya and Vselennaya, No. 2, pp. 35-41.
36. Fisenko, G.L., Muronenko, V.A., 1972. Drenahk kar'ernik polei (Drainage of open cast mine fields) Nedra, Moscow.
37. Shestakov, V.M., 1979. Dinamika podzemnik vod. (Dynamics of underground waters) Izd-vo MGU, Moscow.