MINE DRAINAGE IN KARST

Daniel B. Kleiman
Griffin International, Inc.
Irvington, New York 10533, U.S.A.

ABSTRACT

The problem of protecting surface and underground workings against water inflows in karst regions is of the highest magnitude in the field of mine drainage and, at the same time, perhaps the most misunderstood because of its complexity. Numerous instances of catastrophic water inrushes from karst zones have caused inundations of large mine working areas and, in some cases, the deaths of miners. Karst-water inflows into mines have reached 10000-20000 m^3/h and in some deposits up to 36000 m^3/h. The regime of karst-water inflows into mine workings is distinguished by an extreme irregularity "in location and time". The origin and development of karst openings in most regions are associated with tectonics and chemical processes, such as dissolution of limestone by percolating water. The dissolution process is controlled by the chemical kinetics of reaction between water-bearing carbonate rock and unsaturated water. The study of the mechanics of karst development is necessary in the understanding of the process of watering mine workings and in the prediction of the regime of karst-water inflows into mines. Three typical situations of mine watering by karst waters are discussed. Methods of hydrogeological investigations in karst regions are composed of special techniques and tests. The protection of mine workings against inundations in such conditions has distinctive characteristics. In general terms, the purpose of drainage works is to intercept ground-water inflows in the hazard zones outside of or within the boundaries of mine workings and to build an integrated mine-water discharge system in close coordination with the mine operation plan.

INTRODUCTION

The problem of protecting surface and underground workings against water inflows in karst regions is universal and of the highest magnitude in the field of mine drainage. At the same time, this problem is perhaps the most misunderstood because of its complexity. Mine operations and, accordingly, mine drainage in karst regions are very dangerous and, in many cases, unpredictable due to irregularity of the mine watering regime. Maximum karst-water inflows into mines have reached in some deposits 5000 m^3/h (the Virginia Lime Company's and the Friedensville underground mines in the U.S.A.), 10000-20000 m^3/h (underground mines on the Mirgalimsai copper deposit and North Ural Bauxite Region in the U.S.S.R.) and even, sometimes, exceed 35000 m^3/h (the Tin Tuk open pit mine in Southeastern Asia, where measured inflows in the monsoon periods reach 36000 m^3/h).

The list of mines, operating in extreme conditions of karst ground-water inflows, contains surface and underground mines from all around the world. Some of them have not been operated for a few months every year, during the rainy seasons. Output losses and labor time wastes on those mines are enormous. But we know from practice that, in most cases, the protection of mines against watering is feasible in any natural conditions, including karst.

Valuable field hydrogeological investigations, thorough analysis of the data and proper design and execution of the selected drainage methods are the keys to successful and economical mine operations in all deposits but particularly those in the karst regions.

TYPES OF LIMESTONE AQUIFERS

Character and regime of watering of mines, are controlled by the peculiarities of the natural and mine-operation conditions.

Generally, there are two types of limestone aquifers and, accordingly, two types of regime of ground-water flows into mines in these areas.

Aquifer in Evenly Fractured Limestone

In limestone, which is characterized by evenly distributed open fissures and fractures which are interlaced in a uniform net or system ("continuous" or "unbroken" fractureness), the ground waters are spread more or less evenly within the limestone body and are associated with continuous aquifers.

Fractured limestone is usually an exceptional water-bearing formation. Many large water-supply systems are based on using ground water from limestone aquifers. Mine operations in deposits where there are limestone aquifers, quite often are confronted with the necessity of the application of special dewatering measures for the protection of mine workings against ground-water inflows. Watering (or inundation) of mine workings in such aquifers occurs evenly during the mine operation (in many cases, the intensity of ground-water inflows changes with depth as the fractureness increases or decreases). Practically, sudden ground-water inrushes into mine workings do not occur under this condition.

The intensity of ground-water inflows into mines from unconfined aquifers depends usually directly on the intensity of the precipitation and the regime of surface waters. In contrast to unconfined conditions, the regime of ground-water inflows from confined aquifers is practically independent of the regime of surface water and precipitation.

The necessity of carrying out special water-control works in mines, which are developing in evenly fractured limestones, is dictated by reason of the mine openings stability and work conditions improvement. So, in the cases, when mine openings are sufficiently stable and ground-water inflows are not great, there is no necessity for special mine-drainage measures. In such cases, water-control works are limited usually to simple settling water-discharge systems.

In general, mine-drainage systems in evenly fractured limestones are not complex. Protection of mines against ground water is commonly carried out by using conventional methods (surface, underground or combined), standard drainage systems (linear, perimeter, multicontour, etc.) and equipment (usually wells). Dewatering equipment in such mine-drainage systems is installed generally beyond the boundaries of the protected mine area. The purpose of such systems is a preliminary lowering of ground-water level and its maintenance below the mine working elevation during the period of developing the selected area of the deposit.

Aquifers in Karst Limestone

Limestone of the second type is predominantly dense, hard and low-permeable rock which is characterized by discontinuous fractureness, i.e., by lack of a uniform system of fractures net. Besides, conditions of limestone beddings in such areas are usually aggravated by the tectonic dislocations (thrusts, faults, warping, wedging out, disruptions, displacements, anticlinal and synklinal folds, etc.). In addition, limestone contains the regional integrated systems of the karst openings (see Photo No. 1).

Ground waters are spread in limestones of the second type unevenly. The greater part of their storage is mainly concentrated in the karst openings which can be considered as the major ground-water conduits. Some storage of ground water can be contained also within zones of heightened opened fractureness or within zones of tectonic dislocations (in many cases such zones are the same).

The regime of ground-water inflows into mine workings from limestone aquifers of the second type is distinguished by an extreme irregularity "in location and time". The explanation of this phenomena follows.

Water inflows are irregular "in location" - because zones of tectonic dislocations and karst openings are usually the main water conduits and, in some cases, the only water-carrying canals in the massive limestone.

Water inflows are irregular "in time" - because intensity of watering in these conditions is undulatory. Water-carrying canals in many cases are filled up with a low permeable silty or clayey material and, as a result of their intersecting with mine workings, the hydraulic balance in zones is disturbed, ground water begins to filtrate through such zones toward the mine workings, washing out on the way low permeable aggregate. As aggregate is washed out, the intensity of water flow is increased and reaches a critical magnitude. In the final analysis, a sudden water inrush into the working may happen, after which the inflow into the mine from such a zone is decreased and stabilized. In mine drainage practice, it is known that numerous cases of catastrophic water inrushes from such zones have caused, in some cases, death of miners and inundation of large mine working areas. Therefore, the necessity of drainage works in limestone of the second type is dictated primarily by reasons of safety and improvement of mine working conditions.

Exploitation of many underground and surface mines have been carried out in special mixed conditions which are characterized by the distinctive features of both above described types.

Mine drainage in karst limestone is very complicated. Due to irregularity in the location of ground water conduits, the use of regular drainage methods in such deposits would be hampered. Protection of mine workings against watering always reflects peculiarities of the local conditions, so drainage methods in karst areas often include grouting, plugging, clogging, etc. besides the conventional dewatering technique. Water level lowering equipment has been installed in these areas within zones of highest fractureness or even immediately into the water-carrying conduits.

ORIGIN AND DEVELOPMENT OF KARST OPENINGS

The origin and development of karst openings in most regions are associated with the tectonics of the area and the chemical processes, such as dissolution of limestone by percolating water. The process of dissolution is controlled by the chemical kinetics of reaction between the water-bearing carbonate rock and the undersaturated water. Development of karst openings proceeds when the time of direct contact between the undersaturated water and the carbonate rocks is shorter than the time of reaching the full (or critical) saturation; karst development ceases after attaining the dissolution equilibrium.

This process is aggravated by the mechanism of sedimentation of such materials as clay, silt, sand and even gravel and small boulders which are dragged by water flowing through karst openings.

Deposition of sediments in the karst openings usually begins in the lowest elevations of the systems and develops in the direction opposite to the water flow, up to the entrance of the system.

Karst openings are differentiated in sizes - from relatively small crevices to very large caves. It is reasonable to assume that deposition of the dragging material proceeds intensively in the narrow crevices and the lowest locations in the large caves (see Photo No. 2).

The process of sedimentation occurs up to a certain point when it reaches an equilibrium between the forces of flowing water (hydraulic pressure) and resistance of dragging material. As this takes place, some crevices can become clogged up and the karst system becomes partially obstructed. In exceptional cases, the amount of the compact sedimented material can be sufficient to block the karst system completely. But even in the case of complete blockage, the process of the development of the karst openings does not cease completely; its intensity may be declined temporarily, until new channels have been dissolved by the fresh unsaturated water. This phenomenon results from the fact, that both processes - deposition of the dragging material and dissolution of limestone - proceed simultaneously.

TYPICAL SITUATIONS OF MINE WATERING BY KARST WATERS

The described mechanism of karst development is very important in understanding the process of watering the mines and the prediction of the regime of karst-water inflow into the mine workings. Let us consider the following three common situations in mine watering which most often arise during the mine operations in karst regions.

Case No. 1

A mine working intercepts a fully watered karst system which is partially filled with sedimented material. The interception occurs above the level of the filler sedimentation. In this case, water from the karst opening will rush into the mine at the instant of intercepting with maximum inflow rate. If the karst system is hydraulicly connected with a surface-water body, the mine may be inundated immediately and completely. If the karst system does not connect directly with a surface-water body, inflow of water into the mine will be very intensive during some relatively short period of time until the karst system is drained down by the mine. After that, intensity of water inflow will be abruptly reduced and, in some cases, may even be stopped. Water inflow can rise again after rain or snow melting and its regime and duration will depend on the intensity of the precipitation.

Case No. 2

A mine working intercepts a karst system which is filled up completely with a water-bearing, highly permeable material (for example, sand and gravel). In this case, conditions of mine watering would be much like those discussed in Case No. 1 but with two differences: 1) the alternation of the dry and watering periods and the intensity of the water inflows into the mine would not be as sharp; 2) water, flowing into the mine, would carry sand and gravel in a large amount, especially during the first period of watering. With time, this process would be slowed down.

Case No. 3

A mine working intercepts a karst system completely filled with a compact, dense and low-permeable but wet material such as silt and clay. As a result of blasting in the course of mine operation and especially at the instant of intercepting, the filler might be shaken up enough to start moving into the mine. After this occurence, the process would proceed with acceleration and be culminated in a dramatic inflow of wet clay and silt into a mine working, followed by only water ingress from the karst system taking place.

Now we can see, that even Case No. 3 may constitute a serious threat to the mine. Any occurrences of the intercepting of a karst system must be considered very seriously as a potential source of hazardous conditions for the mine operation.

RECHARGE OF KARST GROUND WATER

To find a solution to the mine-water problem in karst regions, it is extremely important to comprehend the mechanism of a karst ground-water regime and, first of all, the conditions of their recharge.

It is our belief that in most karst regions there are two major sources of recharge of ground water being contained in karst openings: precipitation and surface water. Probably, in some locations, additional recharge of karst water can be provided by ground water from local aquifers, if any. As we discussed earlier, ground waters are usually not widespread in limestone of the second type, their occurence is limited by fracture zones and, accordingly, their role in recharging karst water is negligible, especially in comparison with precipitation and surface water.

Generally, a direct hydraulic connection between the regime of precipitation and surface water on the one hand, and the regime of ground water, passing through the system of karst openings, on the other hand, is a typical event in most karst areas.

Due to this phenomenon, the rate of karst-water ingresses into the mine workings on most deposits increases dramatically after precipitations in very short periods of time. For example, the water-ingress rate increases after rains in a 24-hour period from 500 to 5000 m^3/h in the VLC mine, and from zero to 36000 m^3/h in the Tin Tuk open pit. Reduction of water inflows on these deposits during the dry periods, obviously indicates that precipitation is the predominant source of recharge of the karst water systems on both deposits.

Categories of Karst-Water Recharge

In reference to the periods and intensity of action of the two major sources of karst-water recharge, it may be classified in two categories: permanent and temporary.

Permanent recharge of karst water is effected at the expense of surface water with almost constant intensity throughout the year. As a result of the permanent recharge of the karst water, the watering of mines occurs usually with fairly constant ingressing rate during an extended period of time, being measured by years.

This steady increase is caused by the following two main reasons:

1. Long duration of karst-water inflow. During that period, the filler material, deposited in karst openings, has been washed out by water flowing into the mine, which has increased the size of the openings and thus permits more water to flow into the mine.

2. Gradual increasing of mine depth and, accordingly, lowering of water-ingress points elevation.

Temporary recharge of karst water is caused by intense precipitation. In this connection, the regime of watering of the mine workings by the karst water, temporarily recharged, is characterized by fast and sharp changes in intensity as a result of the precipitation. Generally, durations of periods of water flow into the mine and its intensity depend not only on length and intensity of the precipitation periods, but also on conditions of water-passing conduits within the karst system. The fairly sharp increases of water inflow rates shortly after heavy rains indicates that the karst-conduit system has been washed out properly and water passing through it from the surface meets no serious obstacles on its way.

In many areas, the recharge of the karst water, flowing into the mine, is a combination of both, permanent and temporary sources. As a result of the permanent recharge, the rate of water inflow runs, for instance, between 800-1000 m^3/h in the Virginia Lime Company's mine. The temporary recharge affects the rate of water inflow here up to an additional 4000-4500 m^3/h and more.

HYDROGEOLOGICAL FIELD INVESTIGATIONS IN KARST REGIONS

In most deposits in karst regions, there are numerous locations of sinking surface water bodies, sometimes even completely disappearing creeks, streams, ponds, etc. Another phenomenon in these locations is the existence of areas on the surface which are obviously the local water-catchment or discharge spots for surface runoffs. Obviously all of these areas and locations can be considered as possible intake areas for penetrating surface waters into the systems of karst openings.

One of the principle objectives of hydrogeological investigations in karst regions is to establish a possible hydraulic connection between water ingressing into a mine from the karst and the surface water; also, to check out the possibility of reverse filtration of mine water from discharge systems back into a mine.

Methods of hydrogeological investigations in karst regions are specific and include some special techniques and tests, such as tracer tests (see Photo No. 3).

The tracer test, with the use of fluorescein as a dye, is the most widespread method of field investigations. This method has been described in many publications, so we will limit ourselves by giving some practical recommendations for the use of this method.

1. Fluorescein has to be applied into the surface water body near its disappearing point during the few-hour period.

2. Three techniques can be recommended for the application of the dye:

   a) instant introduction of large amounts of fluorescein (0.5-1 kg) into surface water;

   b) continuous input of large amounts of fluorescein into surface water (more than 0.5 kg) by small portions during 2-3 hours;

   c) use of cloth roll with 1 kg of fluorescein placed and anchored in the surface stream.

3. Water samples must be tested in the mine at the points of water ingress. For testing water samples, an optical brightener has to be used, usually it is the UV (black) lamp which allows recognition of less than one part of fluorescein in 10 billion parts of water.

4. Testings of water in the mine must be conducted around-the-clock. During this period, the flow rates of the surface water stream and the karst-water inflow in the mine must be measured. If the rate of the surface stream is much greater than the rate of the karst-water flow in the mine, the concentration of fluorescein must be extremely high and the use of the UV (black) lamp is indispensable.

DRAINAGE METHODS IN KARST REGIONS

Modern mine-drainage methods are based on three fundamental principles:

. water is allowed to enter the mine openings and is pumped out from the mine by open pumping as it proceeds with the operation;

. water is controlled in advance of the mine operation by grouting water conduits or by various mine-drainage systems;

. water flow is intercepted in hazard zones outside of or within mine boundaries before entering the working area, brought to the central mine pumping station and diverted from the mine.

Open pumping, which is the oldest and, generally, the simplest and most economical method in the field of mine drainage, has been employed in many undergound mines and quarries all around the world. Although open pumping can be practical, it is the least desirable method of dewatering since it allows the water to enter the mine openings with the corresponding risk of mine inundation or, in the worst case, destruction of mine workings. In the areas where this can arise, open pumping is conducted in combination with special measures, protecting the slopes and bottom of the mine openings against slides, collapsing, and other such occurences.

These measures are costly and, in some instances, can lead to drastic increases in the overall cost of the open-pumping program. In such circumstances, the cost of an open-pumping system may become comparable to, or exceed, the cost of regular mine-drainage methods.

Grouting of karst openings that deliver water into the workings is successful on many mines especially underground ones. Usually this method is supplemented by conventional drainage. Among mines employing grouting, we can mention mines in South Africa, U.S.A., and other regions. But, in some mines, this method is inapplicable. For example, in the Virginia Lime Company's mine, one of the major breakthroughs occurred in the south adit in 1978. Shortly after the breakthrough, various precautions were taken to block the water inflow. Among these were attempts to plug this area with rocks, to inject cement into the karst openings through specially drilled holes and to build a thick concrete plate on the floor of the adit; however, the hydraulic pressure and flow rate of the ground-water inrush were so high that all of these attempts turned out to be unsuccessful and the south adit became the major area of ground-water ingress. Water has flowed into the south adit from the holes drilled for cement injection, from the openings under the concrete plate and from the openings in the south wall of the adit. After entering the south adit water has flowed down along the adit and has flooded a large section of the workings which has served as a sump. The sump covers about 25% of the entire mine area (see Photo 4).

In many cases, the protection of mine workings against karst water is possible only by enforced (compulsory) lowering of the ground-water level in the karst system to below the floor of an opening at the area of water ingress. This lowering of the ground-water level can be executed through pumping the ground water directly from its pathway near its ingress point, usually by vertical dewatering devices. For the lowering of the level of the karst ground water below the elevation of its ingressing point, the total pumping rate of the drainage system (or group of dewatering devices) must be higher than the inflow rate of the ground-water ingress into the mine. An accurate magnitude of the required pumping capacity can be determined on the basis of a pumping test which must be conducted at the site before designing in detail the recommended drainage system.

Final selection of a given mine-drainage method must be based on the rational comparison of the technical and economic factors, its feasibility and practicability in the mine.

Generally, planning a mine-drainage system in karst conditions is carried out in the following order:

1. Sites and zones, which can be hazardous for mine works, are revealed on the basis of thorough study of the regional and local geology, tectonics, hydrogeology, etc.

2. Conditions and sources of recharge, occurence and discharge of ground water under natural conditions, undisturbed by mine operation, are also investigated.

3. On the basis of an analysis of the full complex of natural conditions of the area and plans for mine operation for the period of, say 3-5 years, a prognosis is made of possible water inflows into projected mine workings (ground water for underground mines; ground water, precipitation and run-off for open pit mines).

4. In close coordination with the plan of mine works, a plan is developed for their protection against inundation, including the installation of special drainage devices, such as vertical or horizontal wells and anti-seepage curtains, and water-discharge systems.

5. For existing inundated mine sites, local urgent drainage measures are formulated as a part of the general plan, with emphasis on intercepting the inflowing mine water and its diversion to a central collection reservoir. Improvement (if necessary) of the existing water-discharge systems (ditches, pipelines, sumps, pumps and pumping stations) should also be made on this stage of mine-drainage system planning.

MINE DRAINAGE IN KARST

CASE HISTORIES

Table No. 1

Country	Location	Type of Operation	Mine Product	Rate of Water Inflow, m^3/h		Mine Drainage Method	Pumping Rate m^3/h	
				Reg.	Max.		Reg.	Max.
1	2	3	4	5	6	7	8	9
U.S.A.	Virginia	Underground	Lime	1000	5000	Underground: dewatering wells drilled from the pump room near the water ingress (designed system)	1100 (estimated)	5700
	Friedensville Mine, Pennsylvania	Underground	Zinc	6000	13650	Open pumping, plugging	6000	9100
	Watson Mine Cent.Florida	Open pit	Phosphate			Gravity connector dewatering wells	475	
Hungary	Transdanubian Mountain Region	Underground & open pits	Coal & bauxite	45000		Combined	36100	
Greece	Domokos	Underground	Chromite	320-500		Open pumping	400	
	Aliveri	Underground	Lignite		1200	Open pit and cement grouting	60	500
	Megalopolis	Open pit	Lignite			Dewatering wells	7200 (estimated)	9200

Table No. 1 (continued)

1	2	3	4	5	6	7	8	9
China	Handan and Xingtei Districts	Underground	Coal, iron ore			Dewatering wells. Dams and reservoirs in the upper and and lower reaches of the rivers; grouting, cementing, straightening and diverting water courses in the middle reaches.		
U.S.S.R.	North Urals	Underground	Bauxite		33000	Dewatering wells cementation of river beds. Open pumping.	11000	20000 (estimated)
	Mirgalimsai, Kazakhstan	Underground	Polimetallic ore	10000-12000		Dewatering wells. Open pumping		

LIST OF PHOTOS