International Journal of Mine Water, Vol. 6, No. 2, (1987) 37-48
Printed in Hungary

MINE WATER CONTROL IN CHINA'S KARST AQUIFERS

by
Xu Dakuan
The People's Republic of China

ABSTRACT

The relatively complex hydrogeology of Karst aquifers is often detrimental to mine production. Through experience, China has developed several different methods to control such mine water inflows. Selection of a method should be directed towards controlling the effects of prominent hydrogeological characteristics in different Karst types. For Karst, surface water flows, water cutoff ditches and subsequent diversion trenches are used. For ground water flows in semi-confined aquifers, drainage by deep wells and combinations of special water cutoff drifts and pre-drainage by galleries are used. In addition, in confined aquifers such techniques as combined of methods surface and underground water control, including multiple depressurising wells and water sealing wall operations are used.

INTRODUCTION

The key to mine water control in Karst water aquifers is a selection of correct drainage method. The optimization is based on a comprehensive study of the hydrogeology and the engineering geology of the whole mining area. In addition, a comprehensive study should be made of the hydrogeology of Karstic aquifers. Different control methods are then adopted to suit the main hydrogeological characteristics of different aquifers. This paper presents a survey of effective groundwater control methods used in three types of aquifers (unconfined, semi-confined and confined), on the basis of current mine production practice in China.

1. WATER CONTROL IN UNCONFINED KARSTIC AQUIFERS.

Unconfined karstic aquifers are hydrogeologically characterised by the occurence of the majority of water in the water divides of medium-height mountains or in their slope where soluble rocks mostly

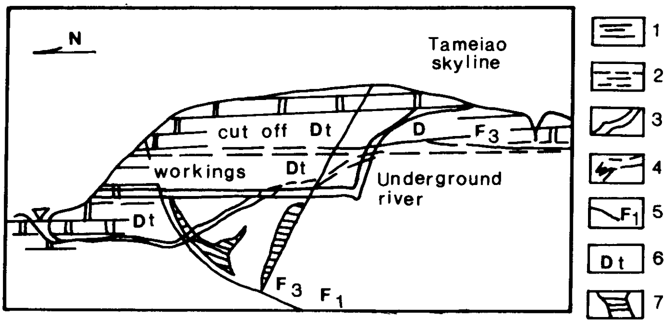

Figure 1. Longitudinal section of cut-off drift for underground river in Xianghualing mining district. (1) Cut-off drift with flow direction. (2) Cut-off adits (3) Underground river with flow direction. (4) Cross-section of underground river (5) Faults (6) Devonian Dolomitic Limestone and (7) Orebody.

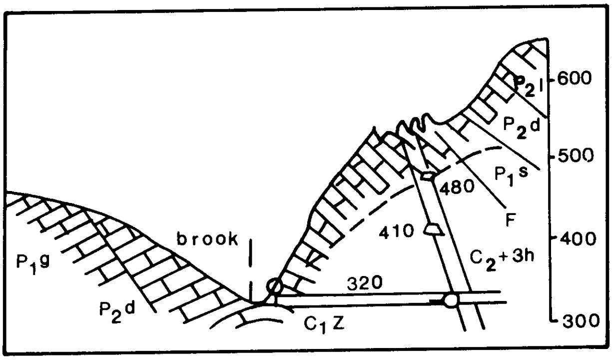

Figure 2. Natural drainage by adit at Anyuan mining district

outcrop on the surface. Surface Karst features often appear as dykes, cleats, solution channels, karst depression and doline, whilst underground karst appears mainly as underground rivers. Lithology, geological structures and bedding planes are controlling factors for karst development. No unified aquifers and groundwater table exist in mining districts. Pumping tests do not form complete depression cones, showing extremely unsteady water transmissivity. Underground rivers, i.e. karst caverns, are the main groundwater source which are recharged through vertical percolation by atmospheric precipitation. The underground rivers have the flow characteristics of sudden occurence, quick disappearance and wide variations of the dynamic flow varying between tens of m^3/h. Karst caverns containing large static reserves frequently causes disastrous water inrushes and accidents. Most of the caverns at shallow depths are not infilled, whilst those deep caverns are partially filled, hence forming a relatively stable ground surface.

The main factors detrimental to production in such types of deposits are static reserves of groundwater, stored silts in karst caverns and dynamic flows of short duration following a torrential rainfall. For example, the Nanqin underground river in the Xianghualing mine district, South China, has a flow rate of 36,000 m^3/hr after a heavy rainfall. the Static reserves of underground water in siding lead-zinc mine are calculated to be up to 2,000,000 m^3. It is considered as a result of production practice that water cutoff drifts and diversion adits are the most effective methods of groundwater control in this type of aquifers. Specific measures are as follows:

(i) Drifting was accompanied by advanced horizontal drilling which aimed at exploring the extent of the karst, enabling the prediction and drainage of static water reserves in karst caverns. This would lower the water pressure (especially silt pressure) and was thus an important means of underground protection;

(ii) In combination with the lowest elevation of the local erosion surface, lower portions of intensified karst or the main channels of underground rivers were selected for driving natural drainage adits. This was the main method used to control the underground flood peak discharge. The application of water cutoff drifts and diversion adits in the Xianghualing lead-zinc mine (Fig.1.) and the Anyuan tin mine (Fig.2.) achieved good results. Water discharge of these underground rivers away from mine districts not only eliminated the water hazard but also greatly improved water supply to neighbouring agricultural areas.

(iii) Grouting of discontinuities in the natural drainage adits was performed to prevent water from percolating to the next level. At the Shiding lead-zinc mine, use was made of the favourable topography to drive a 1880 m. long horizontal drift in the karst aquifers (Fig. 3. and 4.). Karst caverns below the drift were treated by grouting, producing favourable drainage results.

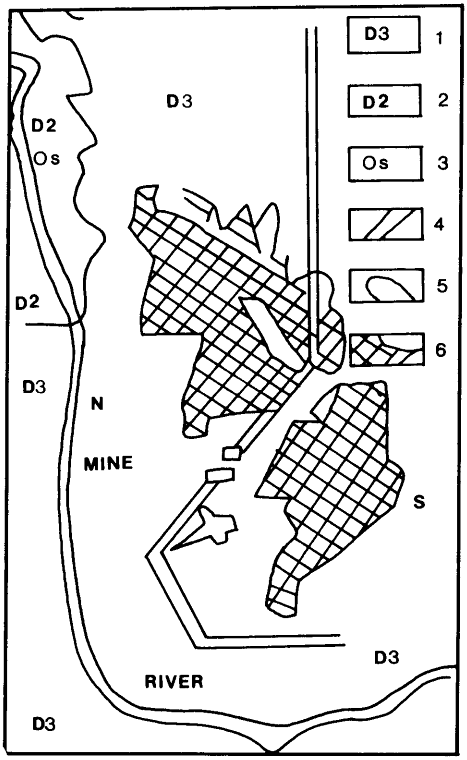

Figure 3. Layout of the drainage adit in Shiding lead and zinc mine
(1) Upper Devonian Limestone (Gualing system). (2) Middle Devonian quatzitic gravels (3) Silurian Ordivician sandy shale (4) Drainage adit (5) Large karst cavern (6) Orebody

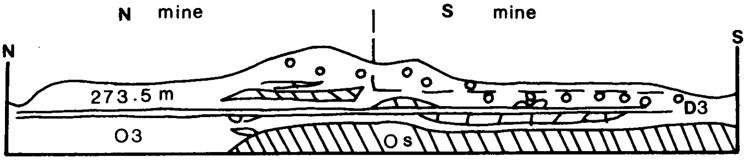

Figure 4. Cross-section of Drainage adit in Shiding lead/zinc mine

2. WATER CONTROL IN A SEMI-CONFINED KARSTIC AQUIFERS.

Such deposits are hydrogeologically characterised by soluble rocks covered by alluvial and dilurium gravel beds of Quaternary system, the majority in low hills and synclinal basins. At the surface Karst morphology is rarely seen, as it manifest itself mainly as underground caverns. Karst is controlled by lithology, structure and erosion. It is intensified near the surface on contact zones with the orebody. There is a unified groundwater table and water-bearing horizon. The Karst caverns drains in the form of spring groups and those discharge varying greatly with the season, principally in the horizontal direction. The Karst indirectly replenishes through the overburden by atmospheric precipitation and it is possible for pumping tests to cause the formation of convex-type cones of depression. Dynamic reserves are often stabilized at 10,000 m^3/day to 50,000 m^3/day. Karst caverns at shallow shallow depths have a high silt filling rate but deep-lying caverns fill at a low rate. Mine dewatering operations lead to a considerable drop in the groundwater table and also to a surface subsidence in the centre of the depression cone and drainage areas. Large amount of silt flow subsequently into underground workings. The threat to the production in this type of deposits in mainly from groundwater together with silt inflowing into underground workings and surface subsidence.

Case History 1

The water control experience at some mines in Guangdong province is concerned with the use of "pre-drainage". At the Fankou Lead-zinc Mine preliminary underground drainage occurs and at the Shilu Copper Mine as a preliminary surface drainage.

The underground drainage programme at Fankou Lead-zinc Mine is essentially a combination of special water cutoff drifts and pre-drainage by levels. Special water cutoff drifts are driven perpendicular to the groundwater recharge outside the orebody. The purpose is to drain and cutoff the groundwater in heavy-water bearing zones above the drift elevation. Horizontal dewatering boreholes are laid out at different levels inside the orebody, while taking into consideration the relative position of mine drifts. This drains the residual water in heavy water-bearing zones as well as the groundwater in lesser water-bearing zones.(Fig.5)

The drainage programme started in June 1965. An increased water-make resulted as the water table was lowered. Inflow averaged 33,700 m^3/day to 59,200 m^3/day from April 1968 to October 1969, with a maximum 69,000 m^3/day in June (rainy season) 1969. In October 1969, the deepest and largest depression cone had formed. The water table in the cone centre had lowered 121 m. producing a radius of influence of 2400 m. The mine, thus freed from water hazards was commissioned smoothly. Of note is that the silt contained in the water (less than 1%) wore the pumps severely and also clogged the dewatering boreholes, blocked sumps

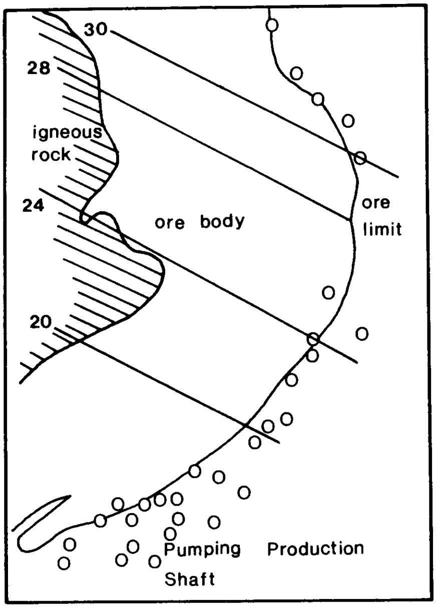

Figure 5. Drainage Layout at Fankou lead/zinc mine (1) Orebody (2) Dewatering boreholes (3) water cut-off drifts (4) Straight dewatering boreholes (5) Groundwater recharge Direction (6) Water table

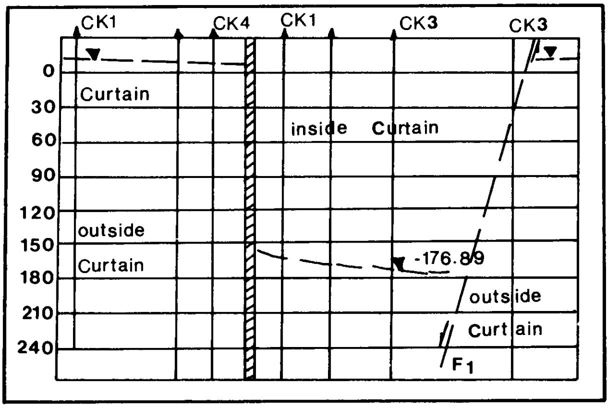

Figure 6. Typical section of Shilu Copper mine (1) First aquifer (2) First water barrier (3) Second water barrier (4) Second aquifer (5) Third aquifer (6) Igneous rock water barrier (7) Orebody (8) Ground Water Table

tens of thousands of m^3/day to hundreds of thousands of m^3/day. Karstic caverns at a shallow depth are often filled. After a substantial lowering in mine groundwater table, aquifers will outcrop, resulting in frequent surface subsidences in skyline areas of the Quaternary system and base rock.

The principal factor threatening the production of this type of deposit is the presence of large quantities of high-pressure water. Surface subsidence is of secondary concern. According to the information available, such methods as combined surface-underground water control techniques, advanced dewatering wells and sealing wall techniques are used.

Combined Surface and Underground Technique

At the Xianghuatai shaft in the Doulishan Mine, complex hydrogeological conditions exist. Mine water inflows amounted up to 3600 m^3/hr in June 1971, seriously threatening the mine safety. An analysis shows that atmospheric precipitation was the cause of partial recharge of the groundwater system. It also indicated that the Maokou limestone Karst water was the main source of water to the mine. The surface in outcrop region of aquifers has a strong natural connection to the groundwater system, thus a surface-underground water control method was used as follows:-

i) Surface Control: Used mainly to block surface water entring into underground strata. For example, the filling of sinkholes, building of flood retention dams and diversion of river channels, thus decreasing surface water running underground.

ii) Underground Control: It is to tap water by settting orifices and valves at selected underground water-make locations, so as to directly control water at these points. This method is based on the fact that Karst water has an extremely non-steady water bearing property through in a uniform aquifer. Sealing the main inflow locations will cause a corresponding decrease in water make. Between the workable coal seams to the Maokou limestone, there is a sandstone layer about 8 m. thick which acts as a water barrier. From experience, the water inrush coefficient per metre of water barrier ranges from 0.6 to 1.5 (table 1). The Doulishan mine selected 0.6 Kg/cm^2.m as a limit derived from pumping tests. In this case when water table rose by 30 m to 50 m, water inrush would not take place in mining areas. Desired tests results were obtained. Groundwater inflows reduced from 3600 m^3/hr to 1645 m^3/hr, ensuring a normal mine operation, together with saving of approximately RMB 60,000 in pumping costs per month.

and buried drains, thus , complicating the mine drainage system.

Case History 2

Shilu copper mine is an open-pit operation, at which drainage by deep pumping wells is used for lowering the groundwater level in the artesian Karst below the orebody footwall. Open-pit development began in 1966 and excavated below groundwater table in 1970. This was followed by heavy pumping. Now 18-22 sets of 254 mm deep well pumps are in operation, pumping rate of 60,000 m^3/day to 80,000 m^3/day. Drainage operations was up to -6 m to -8 m. The water table had to be lowered 8 m. in advance. Eleven years of subsequent production has proved this method practical. (Fig. 6-7)

To summarise, drainage by deep well pumps has three advantages:

(i) Easy construction and maintenance. Great savings in management costs are achieved by remote control from a central control station.

ii) Efficient utilization of groundwater resources as a water supply. The ore mining, processing and smelting facilities consume up to 30,000 m^3/day, supplied by deep well pumps.

iii) Reduced surface subsidence. The gradual increase in the number of pumps in the case of deep well drainage results in only a small increase in the rate of pumped and slow decrease in the rate of water table. In addition to this, underground filter tubes prevent the lowering passage of much of the silt contained in the drained water. This contributes to lowering the flushing force in the course of groundwater depression and to lessening the severity of the hydrodynamic conditions for subsidence. Compared with Fankou lead-zinc mine where underground drainage is used, Shilu copper mine has a much reduced subsidence problem.

3. WATER CONTROL IN CONFINED KARSTIC AQUIFERS

These aquifers occur mostly in the inter-mountain synclinal basins or in plains surrounding the mountains. The Karst water-bearing beds are confined extensively by insoluble rocks. Soluble rocks, outcropped to a great extent in the mountain regions, dip towards the mining district, becoming buried in underground mainly as karst caverns. Controlling factors for Karst development are mainly lithology, structure and erosion (in some areas). A unified water-bearing horizon as well as a groundwater table exists in the mining district. Pumping tests can cause the formation of elliptic depression cones along the line of strike. Karst water in the mining water district isrecharged through regional aquifers mainly by atmospheric precipitation, draining in the form of structural springs. The groundwatertravels horizontally with little seasonal variation. The deposits contain large static reserves with their dynamic reserve between

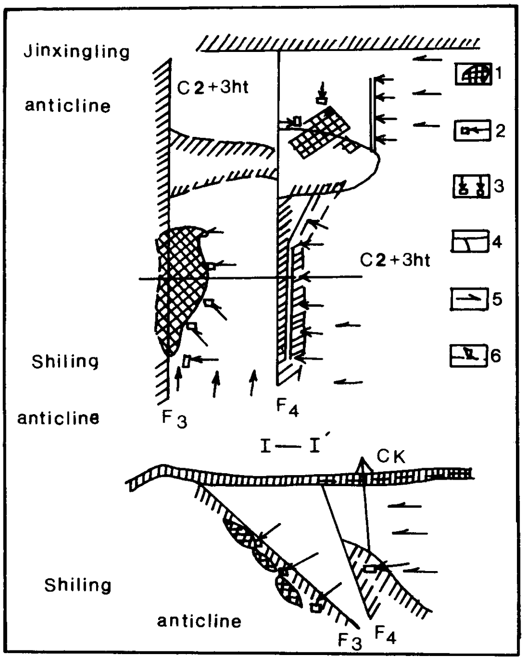

Figure 7. Location of pumping wells at shilu copper mine

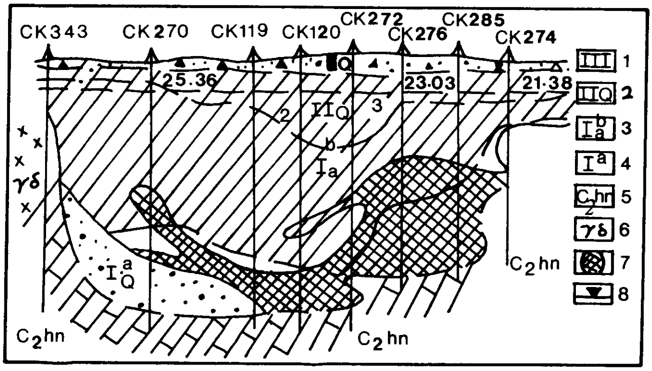

Figure 8. Cone of depression around a sealing wall

Table 1.
Mine Water-Inrush Coefficient
(Experienced Values)

Mine	Water-Inrush Coefficient (Kg/cm2.m)
Fengfeng	0.66 - 0.76
Jiaozuo	0.60 - 1.00
Zibu	0.60 - 1.40
Jingjing	0.60 - 1.50

Contact with main Karst aquifers (Maokou limestone) was avoided in the layout of underground workings at the Meitanba mine before 1961. Only coal drifts were driven and driving in Maokou limestone footwall were forbidden. However, Maokou limestone Karst water could still not be prevented from inflowing into coal drifts, resulting in a serious accident. Later on, measures were taken to drive haulage drifts directly into the Maokou limestone aquifers. As a first step to insure safety, shafts were sunk in a weakly-developed Karst areas of the Maokou limestone at a vertical distance of 30 m to 50 m from coal seams. After temporary drainage installations were finished, the excavation of the pump rooms and sumps started. With their completion and provision of sufficient drainage capacity, with the installed bulkheads, main drifts drivage followed. At the same time drifts near coal seams were excavated in the Maokou limestone in strongly developed Karst. On one occasion, a large water rush from faults (or from Karst cavern) was encountered during the course of the excavation. Temporary water gates with a grouting pipe were built immediately, followed by grouting to seal the inflow point. When this had been finished, the water gates were opened and driving operations continued.

Multiple Well System

The second method used was advanced dewatering by multiple wells in the faulted zones. There is a close hydraulical connection and obvious interference between mine shafts, (e.g. after a water rush of 2700 m^3/hr in No.5 shaft, the pumping rate in No.1 shaft dropped from 2400 m^3/hr to 1700 m^3/hr. again, after a pumping rate rise from 400 m^3/hr to 3177 m^3/hr in No.6 shaft, water inrush went down from 2400 m^3/hr to 1490 m^3/hr) The adoption of drainage by multiple wells in faulted zones accelerated dewatering and lowered the water head and thus ensuring a safe operation.

By the above mentioned drainage measures the pumping rate in the main shaft reached 8323 m^3/hr in May 1977. The groundwater table in the Markou limestone was thus considerably lowered, draining the groundwater in old workings above the current production levels and in upper aquifers. For eighteen years, no shaft flooding occured and mine production capacity increased six fold, timber consumption decreased from 550 m^3 to 230 m^3 / per ten thousand tons of coal mined. The forced drainage of groundwater, on the other hand, induced subsidence of large areas and pumping costs rose to 20% of the total cost of raw coal. To change this situation, a programme for using a water cutoff drifts as the chief solution is being evaluated in a combination with water prevention, drainage and sealing of operations.

Sealing Wall Operations

Zhangmadum iron mine is located in a runoff discharge area of the Jilan monoclinal artesian structure. The limestones of Ordovician series are the main aquifers and have great thickness, depth and well developed Karst features with a relatively high hydraulic head. A maximum water-make is estimated at 450,000 m^3/day for horizontal mining. This is a typical large mine with the power plant, iron and steel plant, fertilizer plant, etc., requiring underground water. Process water amounts to 300,000 m^3/hr. This severely affects water sources interfering with water supplies to the industrial and agricultural facilities and may even induce surface subsidence when the mine drainage programme starts in the future. In order to prevent a great drop in the regional groundwater table, tests have ben conducted on water control by sealing wall operations achieving good results. The water table difference inside and outside the sealing is more than 180 m (Fig.8). Several years of mine pumping practice has confirmed that underground mining exerts no destructive influence on water supply to the plants in the mine district. This is an important contribution to the protection of underground water resources. Through pumping tests it is found that there is less water-make in the drifts behind the curtain and that water control efficiency has risen to 80%. Annual savings in pumping costs amount to RMB 2,190,000 and savings in electrical energy are more than 19,000,000 Kw.

CONCLUSIONS

The above information from different mine districts indicates the great difficulties in process, domestic water supply will occur due to the lowering of the regional groundwater table using advanced dewatering scheme. Practice, however, demonstrates that different methods should be applied for controlling mine water in different types of Karst water aquifers. For unconfined aquifers featuring large water quantities with quick fluctuations, drainage (flood control) by adit should be used. If underground pre-drainage is used for well type deposits, the surface subsidence will be reduced, although it would not be as effective as the surface dewatering schemes. For confined aquifers with artesian water pressure, pre-drainage must be carried out before mine production is started. Such pre-drainage is a combination of underground drainage by levels and that by borehole pumps. It is expected that with the development of new technology like high-lift, large flow-rate submersible pumps, the use of vertical de-pressurising boreholes for mine drainage will obtain better results. Advanced dewatering (Combined drainage), intensified mining, water drainage combined with water supply for variety of purposes will gradually become the general practice for groundwater control in major confined aquifers.