The Basic Hydrogeological Characteristics of Solid Mineral Deposits in China

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ABSTRACT

In China the hydrogeological type of solid mineral deposits can be divided into A. Mineral deposits with fissure water; B. Mineral deposits with pore water; and C. Mineral deposits with karst water. The hydrogeological conditions of mineral deposits with fissure water are relatively simple with the exception of a few cases. Mineral deposits with pore water are few but great amounts of ground water can be encountered in the mine accompanied by floating sand or slope failure during the exploitation. Mineral deposits with karst water are complex in their hydrogeological conditions. Enormous inrushes occur frequently in the mines of north China; Karst collapses are a serious matter in the mines of the south; Subterranean river and conduit systems are often encountered in the southwest. This paper will give full discussion on these features and put forward a way of combating and controlling the groundwater problem in accordance with type and feature.

PREFACE

China is one of the countries rich in mineral resources and its hydrogeological conditions are diverse and complicated. The occurrences of water inrush, inundation and karst collapse in the mines have caused heavy financial losses and unnecessary work has often been undertaken in mines with simple hydrogeological conditions. It is, therefore, a key objective to study and research the basic hydrogeological characteristics of solid mineral deposits as well as the prevention and control of groundwater in a wide range of mineral deposits.

I. GENERAL

The solid mineral deposits of China can in accordance to climate, can be divided into two principle parts -- the arid region mineral deposits and the non-arid region mineral deposits.

In the arid region of northern and north-western China, precipitation is less than 250mm and the coefficient of moisture ranges from 0.0001 to 0.18. This region comprising 23.9 percent of the total area of China, includes Xinjiang, Qinghai, Gansu, most of Ningxia and part of Inner Mongolia. Owing to the lack of precipitation and surface runoff, there is little recharge to the groundwater. It means that the hydrogeological conditions are simple but for two cases: The exploitation of mineral deposits in the vicinity of surface runoff and mineral deposits buried in the alluvial or elluvial fan zones where the mine workings may be subjected to inflow of stored water during exploitation. In either case, mining should be undertaken with full awareness of the prevention and control of groundwater inflow. The main problem in the arid region is not one of mine dewatering but one of water supply because of the scarcety of groundwater. In contrast mining in non-arid regions may encounter inflow of water occasionally at enormous rates. This paper will emphasise the hydrogeological conditions of mineral deposits in the non-arid region.

Depending on the type of aquifer, solid deposits can be classified as

1. Mineral deposits with fissure water;
2. Mineral deposits with pore water;
3. Mineral deposits with karst water.

The first group is widely found in the hilly and mountainous zones with relatively simple hydrogeological conditions. The second is mainly encountered in the piedmont plains, river valleys and coastal zones and is comparatively the smallest of the three groups. However, mine inflow can be enormous, sometimes with floating sand or slope failure occurring. The third group, less common than the first group, can be divided into three subgroups;

1. mineral deposits with karst fissure water;
2. mineral deposits with karst cavernous water;
3. mineral deposits with subterranean rivers and/or conduit systems.

This paper will focus on mineral deposits with karst water and the effects on mining in China.

II. MINERAL DEPOSITS WITH FISSURE WATER

These deposits, including the Jurassic coal field, the Shihezi group of Permian coal fields, the Shanxi group of coal fields, the Tertiary coal fields, the Leping coal series of the Permian system in Yunnan and Guizhou provinces and most metallic ores and non-metallic deposits etc, are invaded by groundwater that occurs in the weathered fissures, tectonic fissures (joint, schistosity, fault fissures) and the original fissures of bedrock. The water abundance in these deposits is limited by the size, density and continuity of the fissures so that the mine inflow is generally less than 5000 cubic meters per day. There is no need to install a special pre-dewatering system, but exploitation is normally carried out with dewatering. However, the hydrogeological conditions are complex in the following cases:

1. Where the gigantic tectonic fissures are filled with water; eg the Neishan iron ore mine of Nanjing where the deposit occurs in the contact zone of the intrusive body of the augite-diorite porphyrite and the overlying augite-andesite of the upper Jurassic with groups of tension and compression shear faults. At the level of -200m, 15 gigantic faults occur in the range of 0.64 km. The fault width is from 0.5-3m, the maximum of which is up to 10m. From 1967 to 1976, 10 big inrushes took place and the biggest flow rate was 200 cubic meters per minute, but the discharge was from the static reserve and the inflow was exhausted after two days.

2. Where the water abundant zone of sandstone fissures are found on top of coal beds as in the Huang-huai region; the location ranging from the Huaihe River to the northern latitude of 35 degrees. The inrush or inundation of the workings originates from the sandstone at the top of coal beds containing great amounts of water in the fissures. For example, more than 100 water inflows from the sandstone have taken place since the 1960's in the mines of Xuzhou, Jiangsu Province. The maximum inflow is 660 cubic meters per hour, coming from the static reserve as the main source.

3. Where there are mineral deposits in the vicinity of a surface water body; the intrusion resulting from fissures caused by mining or natural fractures leading the surface water to the mine.

4. Where the fissures/caverns in the basalt are conduits. The only example of this is the Zhangbei coal mine where the main and the auxiliary shafts go through basalt with a thickness of 110m. These shafts, above the coal seams, encountered five layers of caverns with dimensions of 0.5-0.8m through which the water inflow approached 884 cubic meters per hour. And this is the static reserve only.

As for gigantic tectonic fissure water zones, the water abundant zone of sandstone fissures and the basalt fissure-cavernous water zone, a survey of the hydrogeological environment should be undertaken early and use of predewatering can get good results, as the inflow of water to the mine is mainly from the static reserve. Deposits in the vicinity of surface water bodies should be investigated thoroughly to make sure that passages through which connection may exist can be blocked through the available measures such as grouting or the reservation of pillars.

III. MINERAL DEPOSITS WITH PORE WATER

These fall into three types:-

1. The deposit lying directly in the loose uncemented Quaternary rock such as in the alluvial gold deposits of the northeast, northwest and southwest of China, the alluvial tin deposits, the alluvial tungsten deposits of the southern provinces and the quartze, zircon and ilmenite etc. of the coastal zones in the southeast;

2. Deposits in the semicemented Tertiary rock such as some coal mines and kerogen shale mines in Jilin and Guangdong Provinces;

3. The deposit located in the Quaternary aquifer bedrock such as the Yuanbaoshan coal mine in Inner Mongolia, and the southern section of the Sijiaying iron ore mine in Luanxian, Hebei Province and Gushan iron ore mine in the Anhui Province etc. The placer deposits, due to their shallow geology, have relatively simple hydrogeological conditions but the latter two have hydrogeological conditions that range from simple to complex.

The common hydrogeological problems encountered during mining in this type of deposit are:

1. In mineral deposits where the pore water occurs in the alluvial or elluvial fans, the river valleys are usually effected by the surface runoff and the inflow of water can be enormous, eg the southern section of the Sijiaying iron ore bed located in the alluvial fan of the Luanhe river. The ore body occurs in the Presinian metamorphic rock on which three gravel beds overlie to a thickness of 57-93m with the respective infiltration coefficients of 315m/d, 224.7m/d, and 47.7m/d. The first gravel bed has close hydraulic connection with the Luanhe river 2.5 km. away, with a peak flow up to 34000 cubic meters per second. The prediction of mine inflow is over a million cubic meters per day. The water inflow is also enormous to the Yianbaoshan coal mine located in the Yingjinhe river valley so that river realignment or a grouting screen to control the water intrusion is considered. Providing that a deposit is rich in exploitable water resources, dewatering and water supply should be considered under one in the general design;

2. Burst of floating sand: in the Shulan coal field of Jilin Province, the coal beds occur in the Miocene formation with 7-14 exploitable seams. There are occasional layers of semicemented fine sand, silt, and medium sand rocks in the top and the bottom of seams. Ingress of floating sand has taken place in the mines on many occasions such as at the No. 3 shaft of Fengguang. A burst of floating sand (water flow rate, maximum Q=1500 cubic meters per hour) occurred at level +170m in the 13th seam from the underlying fine sand rocks (thickness of 15-17m with a water head of 55m). The sand content was 50% and the floating sand rate was up to 8000 cubic meters. Surface subsidence took place 8 hours later and mining had to cease. One month later the steady-state rate of the water in-flow as 30 cubic meters per hour. The phenomena also occurred in the Gushan iron ore mine of Anhui Province. Ingress of floating sand is caused by the high water pressure. The confining layer is broken by the water pressure if it is too thin, allowing the sand/water mix to pour in. Use of predewatering to decrease the water pressure may solve this problem;

3. Slope instability: In the north and west quarries of the Gushan iron ore mine of Anhui Province, a 0.5-2m thick layer of sludgey sandy clay with rich organic mass occurs in the interbeded fine sand clay and the sandy clay. In April, 1979, the slip took place with a total mass downward along the sludgy sandy clay of about 20000-30000 tons, which caused a 7 days cease of operations.

In order to control slope instability and burst of floating sand, Gushan iron ore mine used deep well or gallery dewatering but the results were not remarkable. Current methods used are comprehensive water control engineering ---along the edge of the mining boundaries, using a combination of gallery and conventional wells to keep the 90000cubic meters per day of water recharge from the Quaternary formation out of the workings. Clay walls against infiltration are also built up concurrent with the higher residual head.

IV. MINERAL DEPOSITS WITH KARST WATER

Mineral deposits with karst water can be classified into three groups: A. Mineral deposits with karst fissure water; B. Mineral deposits with karst cavernous water; and C. Mineral deposits with subterranean river and conduit systems.

A. Mineral Deposits with karst fissure water

This type of deposit is located to the north of the Qinling-Huaihe region with aquifers formed mainly by karst fissure system networks. The ore bodies include Carboniferous coal fields, bauxite, skarn-iron deposits and limestone deposits etc. A number of these deposits occur in the karst water systems which cover an area of several hundreds to thousands of square kilmeters. The area has been cut by the fractures and igneous activities into separate zones with various water abundance and boundary conditions, but there are still hydraulic connections between the zones. That is the reason why, in this system, the mine inflow varies greatly from mine to mine. Providing that the mineral deposits with open or semi confined boundaries could get recharge from regional karst water, the mine inflow would be enormous, even so enormous that mining could be impossible. For example, a pump test indicated that the water level at the pumping center dropped only 1.76m at a discharge rate of 135216 cubic meters/day in mid-Ordovician limestone at the Fengfeng mine in the Fengfeng coal field/Heilongdong karst water system. It is estimated that the pumping rate will reach millions of cubic meters/day in order to obtain the zero inflow level.

Yang-er-zhuang iron ore mine located in the north of Fengfeng with semi-confined boundaries pumps out groundwater at the rate of 10000-25000 cubic meters/day and the water level has dropped around 84m in ten years of pumping. Inrush from the pit bottom is the main problem of the mines of northern China. In broad brush terms more than 200 inrushes at the rate over 10 cubic meters/min has taken place and caused serious losses. There are two types of inrush from the bottom:

1. Most inrushes are caused by the confining bed being too thin or the strength of the bottom weakened by fault zones;

2. Inrush caused by collapsed karst columns: the collapsed karst column developed in the Midordovician limestone resulted in upper layer collapse and water was led to the underground workings through fissures caused by the collapse. For example, the inrush was up to 2050 cubic meters/min at the 2171 working face of the Fangezhuang mine in Kailuan, and the mine was flooded in 20 hours and 55 minutes. This is an exceptional case even on a world basis.

B. Mineral deposits with karst cavern water.

This type of deposit with aquifers formed mainly by a network connected with fissures is distributed through southern China to the south of the Qinling-Huaihe such as the Permian coal fields and the Tertiary lignite fields and some multimetal ore zones.

A karst cavern water system, can be divided into the shallow karst cavern zone and the deep karst fissure zone. The karst caverns are so well filled and the water-bearing strata so limited by the regional structure that only small water bodies (less than 50 square kilometers) form resulting in mine inflow of less than 40000 cubic meters per day. Hence only a few mines encounter great amounts of water inflow. A common and serious problem to this type of mineral deposit is karst collapse which may cause heavy damage to construction, farmland, and transporation, etc. and by which mining development can be badly affected. The occurrence of karst collapse is usually in the well developed karst section, the central part of the depression cone, both sides of the fault, the river valley, the alluvial flat and the catchpit etc. The formation condition for karst collapse are:

1. A shallow-buried well developed karst section;
2. A loose upper layer with a thickness less than 30m;
3. A water table in a friable layer.

When intensified drainage proceeds for a long time, stability of the layer will be ruined, causing the materials filling the cavern to lose buoyancy, and result in suction erosion, potential erosion and removal leading to possible surface collapse.

C. Mineral deposits with the karst subterranean river and conduit system.

This type, mainly distributed through the southwest of China, contains the coal fields and the sulfide-iron deposits in the southeast of Sichuan, some coal fields in the Guizhou Province and some metal ore deposits in the Guangxi and Hunan Provinces. The form of subterranean river and conduit system is complex. The distribution of karst water is inconsistent with the inhomogenity of karst development. Inflow may be enormous as a tunnel is excavated through the subterranean river, while being small beyond it.

For example, in a sulfide-iron mine of southern Sichuan, the inflow from the Tian Tang subterranean is up to 24.5 cubic meter/s but pumping test of the aquifer show only q=0.00006 - 0.09 l/s.m. The pumping test cannot form an adequate depression cone in the subterranean river and fissure water system without the close hydraulic connection contained in the deposit, although the latter may recharge the former. Groundwater in the subterranean river and conduit system have the hydraulics characteristics of pipes and ship canals.

There is a close relationship between the subterranean river flow and precipitation. The flow rate changes with increasing precipitation. The peak flow rate can follow in a few hours after precipitation and drop to a certain level as the rain stops a few days after. The inflow is also seasonal. The normal flow rate is 10 to 100 times less than during the rainy period, so that large inrush is the serious problem associated with the rainy season, eg the normal flow rate is 799 cubic meters/h with a minimum of 166 cubic meters/h, but the maximum inflow is 92000 cubic meters/h and the total inflow in the workings is up to 28000 cubic meters/h after a storm in Hongyan coal mine of Sichuan Province. The inrush from the conduit system reaches 900000 cubic meters/h in the Jianbei coal mine of Sichuan Province.

The prevention and control of karst water flow should be carried out in accordance with its type,and regional characteristics. The principle is to ensure the safe exploitation, the economic extraction and the protection of the water resources as well as the close interaction of dewatering and water supply.

Passive prevention methods are mostly used in mineral deposits with karst fissure water in northern China. Since 1970s, the objective has been "mining with water pressure", which means that intensified exploitation proceeds in the low water pressure area while dewatering methods are fully prepared. This objective has been commonly adopted in the coal mining departments and about five million tons of coal have been extracted from the lower group of seams associated with karst water of the Midordovician in Fengfeng coal field in recent years. It is feasible and economical to mine the shallow seams with relatively low water pressure, but the matter has not been solved for deeper deposits under influence of karst water. The active prevention method of grouting screens is successfully used in some mines such as Zhangmatun iron ore mine, Heiwang iron ore mine, Zaozhuang, Xinwen coal mines in Shandong Province and No. 4 coal mine of Fengfeng in Hebei Province, Yanmazhuang mine of Jiaozuo in Henan Province and Xuzhou coal mine in Jiangsu Province. The results are remarkable not only in the way the grouting screen can reduce the mine inflow but also how water resources can be protected from drainage.

However, before grouting, hydrogeological conditions should be surveyed and the economic feasibility must be considered. In general, the grouting screen is best suited where semi-confined boundaries exist. A study of large drawdowns in mineral deposits with open or semi-open boundaries as a result of intensified drainage should be carried out since the whole karst water system most likely will be affected by extractions of water to depths of 200 - 300m. Regional and local karst springs and water supply sites might be exhausted. The inter-dependence of dewatering and water supply should be considered systematically and engineering must consider their relative balance. As for mineral deposits with karst cavern water this can be pumped out provided the withdrawal rate is small as mining proceeds. As for deposits requiring large withdrawal rates, advance dewatering should be adopted by means of a drainage gallery. For example, at Xiangzhong the gallery is driven into the underlying Maokou limestone and at the Lianshao coal fields the catchwater gallery and co-level advance drainage system are used in the Fankou lead-zinc mine, Guangdong Province.

There is a risk of dewatering by means of a gallery because it may be flooded by large amounts of water, and the water is easly polluted. Good results have been obtained by using a surface deep-well-pumping system in Shilu copper mine, Guangdong Province. The pumping rate is 100000 cubic meters/day at which mining can proceed and water supply can be maintained simultaneously with good quality. But the system has not solved the problem of karst collapse. The trend for solving this problem is to reduce the collapse to a minimum by way of controlling the rate of variation in the groundwater gradient. Thus advanced dewatering avoids sudden and extreme collapses. Mine exploration should be carried out thoroughly in order to find the distribtuion of the possible collapse area and to control it. Provided that the collapse has occurred packing should be carried out immeditely. Conditions permitting, grouting should be adopted as long as economic and technical feasibility is ensured. In this way the dewatering cost can be reduced, the collapse contolled and water resources are protected.

How to prevent and control the subterranean river and conduit system inflow to mineral deposits? Many practical experiences can be summarised as follows:

A thorough investigation should be carried out of the distribution of the subterranean river and conduit system, before mining, both regionally and locally. All necessary water-control measures should be employed in a mine such as predewatering, avoiding areas with large amounts of water, building of dams, etc., best of all, a catchwater adit should be used to trap ground water before the subterranean river and condit system runs into the mine. Catchwater adit engineering is now successfully used in the Hongyan coal mine, Shiping sulfide-iron mine, Tianfu coal mine in Sichuan and Xianghualing multimetal ore mine in Hunan Province and at Xuanghualing the discharge from the subterranean river is led to irrigating 3100 Chinese Mu of farmland and the problem of drinking water for the 4000 local farmers has been solved as well.

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