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STUDYING AND CONTROLLING MINE WATER IN XISHMEN IRON MINE

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INTRODUCTION

In North China, the development of mineral deposits is concerned with fissure-karst water in Ordovician limestone. The Xishmen Iron Mine is an underground mine of the Han-Xing Ore Mining District which is located in North China. Middle Ordovician limestone aquifer overlies the ore body. Because of its extensive area, large thickness, karstic nature and abundant recharge in rainy seasons, water danger is threatening the security of the mine. On the other hand, the mine is a semi-closed hydrogeologic unit and the yield of the aquifer is low in dry seasons. So, the shortage of water supply is also a serious problem. In the mine, hydrogeological investigation has been completed and the results have been verified by mine dewatering. In order to protect from water inrushes, and to guarantee the water supply, some effective works have been accomplished and some more will continue. The paper presents a case history of controlling mine water in North China, together with a brief description about the mine hydrogeologic conditions, the techniques of hydrogeologic investigations and aspects of mine water control.

REGIONAL HYDROLOGY AND HYDROGEOLOGY

The Xishimen Iron Mine is located in the south of Hebei Province in Northern China. The mine has the largest iron ore reserves and most complicated hydrogeological conditions in the Han-Xing Iron Ore Mining District.

The Han-Xing Iron Ore Mining District borders to the east of the Tiahon Shan Mountain and on the west of the North China Plain. It is situated in hilly country with relief decreasing eastwards.

The Han-Xing Iron Ore Mining District has a semi-arid continental climate. Mean annual rainfall is 560 millimetres with a minimum of less than 300 and a maximum as much as 1400 millimetres (1963). About 70-80 per cent of the annual rainfall is concentrated within the period from July to September, and only little is recorded in the other months. So, every year there is a short rainy season followed by a prolonged dry season with very little rainfall. The annual rainfall varies periodically, in every 7 - 10 years there exists a waterflood year when rainfall is more than 800 millimetres. Every 2 - 3 years there exists a dry year with rainfall less than 500 millimetres. There is also a prolonged drought every 7 - 10 years when the dry period extends to several years.

Four seasonal streams (Shahe River, Mahe River, Beiminghe River and Nanminghe River) run eastwards through or by the district (Figure 1). During the dry season they have little running water and even dry up. In the rainy season they are full of running water, which leaks down in its course over the limestone terrain. Ithas been measured that Shahe River lost water by as much as 20 cubic metres per second at the section next to the northwestern part of the district. According to estimations the Beiminghe River and Nanminghe River lose more than 5 million cubic metres of water per year.

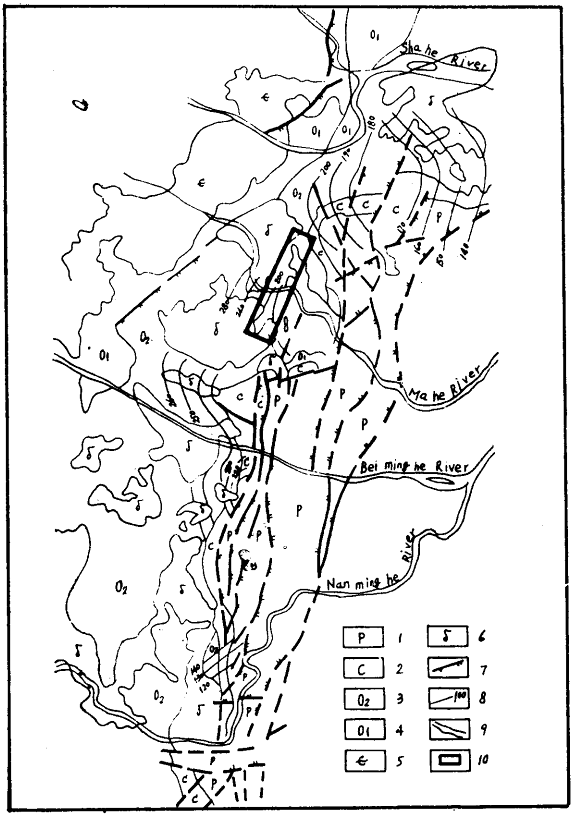
Inside and outside the district, limestones of Cambrian and Ordovician age cover near 3000 square kilometres of the ground surface. Inside the district the rocks are mainly limestone of Middle Ordovician age, sandstone and shale of the Carboniferous and Permian as well as diorite. The strata strike northeastwards and dips southeastwards with inclination of 15 degrees or so. Iron ore deposits of contact - metasomatic type occur along the contact zone of diorite with limestone in each mine. Fissures and karst are well developed within the Ordovician limestone and the limestone is rich in fissure-karst water. The water channels are corroded fissures. It is the principal aquifer in the district and also the direct roof above the mineral deposits, and consequently the main subject of exploiting and controlling ground water in the mines of the district. Generally, diorite acts as a relatively impermeable floor of the mineral deposits and impermeable boundary to the mines. The eastern and southern parts are covered with sandstone and shale, which resist the limestone aquifer's feeding from river water leakage and rainfall infiltration.

Macroscopically speaking, Han-Xing Iron Ore Mining District is a gigantic underground water reservoir of Middle Ordovician limestone. This reservoir possesses the following main characteristics:

1. With corroded fissures being the main water reservoir and having better interconnection, the limestone aquifer has a united ground water surface or piezometric surface. By the action of extracting water from the aquifer, it is surely possible to form a united depression cone. As a result of discharging by two groups of springs, of which one is northeast and the other is south of the district, there occurs an extensive seepage flow field all over the district with water levels being higher in the west and lower in the east, higher in the middle and lower both in the north and in the south of the district.

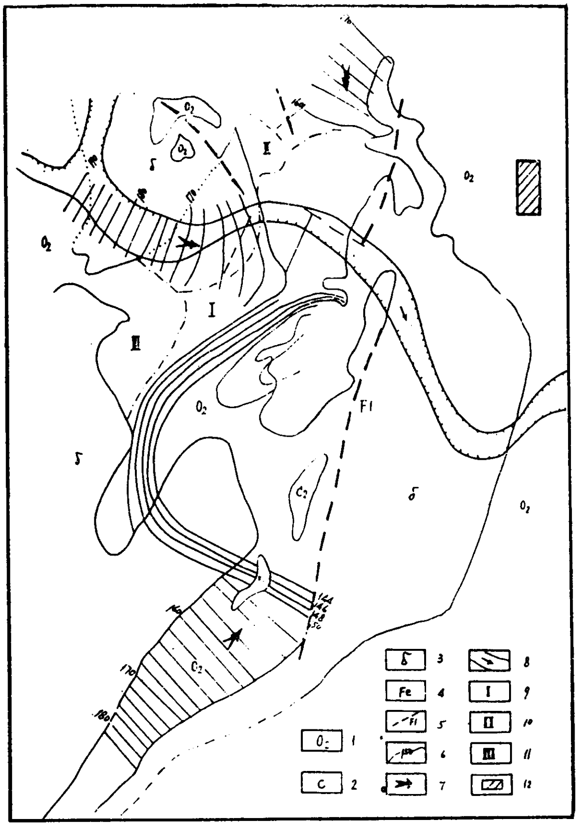
2. Because of the wide extent, large thickness and being rich in corroded fissures, the aquifer is of high capacity to store and convey water.

3. During the wet season the aquifer gets a large recharge caused by river water leakage and rainfall percolation. The ground water level rises rapidly, the amount of stored water increases, and the ground water runoff increases consequently. During the dry season, the recharge in question ceases. In addition, two groups of springs discharge continuously, using up water storage in the aquifer. As a consequence the ground water level lowers and the ground water runoff reduces.



1 - Permian;
2 - Carboniferous;
3 - Middle Ordovician;
4 - Lower Ordovician;
5 - Cambrian;
6 - diorite;
7 - fault;
8 - isoline of ground water level;
9 - stream;
10 - Xishimen Iron Mine.

Figure 1 Hydrogeologic sketch map of Han-Xing Iron Mine District



1 - Middle Ordovician limestone;
2 - Carboniferous shale;
3 - diorite;
4 - outcrop of iron ore body;
5 - fault;
6 - isoline of ground water level (Sept 15, 1978);
7 - ground water flow direction;
8 - Mahe River;
9, 10, 11 - portions with different permeability;
12 - supplementary water source spot.

Figure 2 Hydrogeologic sketch map of Xishimen Iron Mine

TABLE 1

PORTIONS WITH DIFFERENT PERMEABILITY

Portion	Related Structure	Rocks	Space filled with water	Hydraulic Gradient (%)	Unit yield of borehole (1/sec-m)*
I (high permeability)	Fault F_2 Anticline$_2$	limestone pure; graniphyric; bracciated	corroded fissures; palernoster karst pores	0.01	>10
II (medium permeability)	Fault F_1 Syncline$_2$			0.20	1 - 10
III (low permeability)	Intrusion of diorite	limestone graniphyric; dolomitic; brecciated	fissures; karst pores	1.50	<1

* litre per second and per metre of drawdown

4. Cut by faults and intruded by magmatic mass, the whole gigantic ground water reservoir has been divided into several hydrogeological blocks of different sizes and different forms, connected to each other and distinguished from each other. In general, inside a block the corroded fissures have developed to a greater degree, the permeability is higher, and result in a great amount of static reserve of ground water. On the other hand, the block may be surrounded by diorite or bounded by impermeable (or water-obstructing) faults, or bordered with a zone of low permeability. And in some cases, there exists one or more "gates", ie permeable limestone passages with relatively low conveyable capacity, linking up the block to another one. Depending upon its close degree, every block has a corresponding hydraulic relation with the regional limestone aquifer or to another block next to it.

HYDROGEOLOGICAL CONDITION OF THE MINE

The Xishmen Iron Mine is located in the western fringe of central Han-Xing Ore Mining District. It is a low and bare hilly land of diorite and Middle Ordovician limestone, with elevation undulating from +268 to +300 metres. The iron ore body occurrs along the contact zone of diorite (floor) and limestone (roof), being 5100 metres long in longitude and 120 to 500 metres wide in latitude, lying from ground surface to the depth of 550 metres and from +270 to -280 metres in elevation. The average thickness varies from 10 to 30 metres and the maximum is 93 metres. Middle Ordovician limestone in the mine appears as a trough in longitude which is surrounded and supported by diorite. Only in the southern, western and northeastern parts respectively there is a "gate" through which the limestone aquifer within the mine is connected with the regional one. So, from the point of view of hydrogeology, the mine is a relatively independent unit, being a semi-closed hydrogeological block in Han-Xing Iron Ore Mining District. (Figure 2)

The main aquifer, the Middle Ordovician limestone in the mine covers an area about 4 square kilometers. It is 5200 metres long in longitude and 300 - 1160 metres wide in latitude. It is 150 - 250 metres thick and dips to the southeast. It contains three groups of water-bearing corroded fissure taking orientations of NE, NNE and NNW respectively. Because of the difference in lithologic character, fracture degree and filling degree of corroded fissures, the aquifer can be divided in accordance to permeability into 3 portions in area (Figure 2, Table 1) and 2 intervals in depth. The upper interval is above the elevation of +140 metres and is of relatively high permeability, the lower one is below this elevation and of low permeability. But on the whole, the permeability is quite high inside the mine and rather low at the "gates". The average coefficient of permeability of the limestone aquifer inside the mine is as much as 29.6 metres per day. The northeastern "gate" permeabilities are higher (the coefficient of permeability is 23.8 metres per day), but the width, and consequently the transmissivity is limited. (Figure 3, Figure 4 and Figure 5)

The Mahe River runs through the northern part of the mine, with a length of 2100 metres lying above limestone. According to flood investigations in the area of the mine the historical flood peak discharge of Mahe River is 3160 cubic metres per second (1936). The river deposits are proluvial and alluvial sands, gravels and clayey gravels, which are 3 to 20 metres thick. During the dry seasons, there is no runoff in the river bed. In the wet season, the river is full of water and loses a large quantity. It was determined that about 71000 cubic metres of river water leaked down per

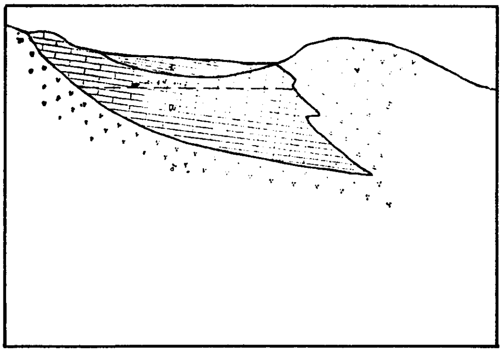


Figure 3 Transverse section of the southern "gate"

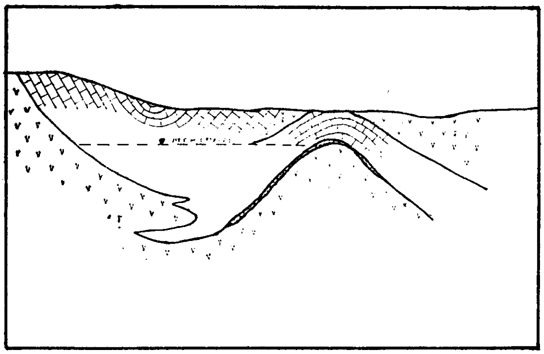


Figure 4 Transverse section of the northeastern "gate"

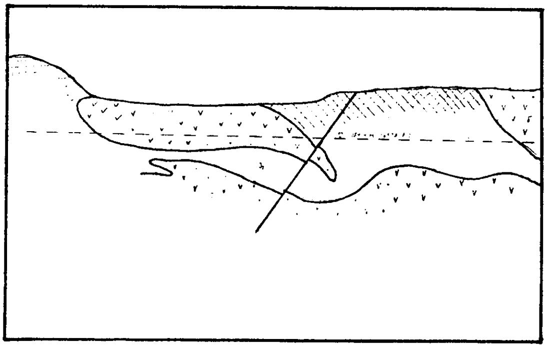


Figure 5 Longitudinal section of the western "gate"

day during the rainy season of 1973. The river water leaks into the limestone in two ways: percolating through Quaternary deposits in the river bed and by penetrating into river side fissures.

Rainfall is the recharge source of the limestone aquifer in the mine. Recharge occurs in four ways:

i) leaking of the Mahe River,

ii) percolating of rainfall on bare limestone,

iii) lateral recharging through "gates" from the regional limestone aquifer, and

iv) the infiltration of fissure water in the weathered zone of diorite surrounding the mine.

The first two, especially the first, play an important role. It is the Mahe River that will be the main factor threatening the safety of the mine. The last one can offer only a little water. In reality, regional ground water goes through the southern "gate" and the western "gate" into the mine and mine ground water goes through the northeastern "gate" out of the mine. When the mine is subject to dewatering the regional ground water comes into the mine through all three "gates". Limited by low conveyable capacity of these "gates", the lateral discharge quantity if not so great. But, it is this water that can be utilized for water supply both in the rainy season and in the dry season.

As a result of the rainfall periodicity, the recharge quantity of all forms varies periodically, as does the ground water level (Figure 6). One year matches a short variational period with general amplitude; 7 to 10 years matches a longer period with a high ground water level and a rather low one within it. Thus, ground water level is constantly changing. Before mine dewatering commenced, the peak level and the lowest one were +250 and +160 metres respectively, peak amplitude was 90 metres and the general annual amplitude varied from 14 to 23 metres (the maximum being 66 metres). The largest monthly rising value was 30 metres and the largest daily lift was 3.6 metres.

HYDROGEOLOGICAL PROSPECTING WITH THE MINE

Hydrogeological prospecting was completed in 1973. Before that, since the late fifties, only odd scraps of hydrogeological work had been done.

Information from about 200 geological prospect holes was turned to full use. Some of the prospect holes were utilized for hydrogeological observations and tests. In addition, there were bored 4 large-diameter holes (two of them for water supply) and pumping tests were run respectively. As a result, a preliminary finding was that diorite surrounding the mine and lying under the ore body was whole and, that the mine is a semi-closed ground water reservoir in which 3 portions in area and 2 intervals in vertical section of different permeabilities were recognized.

Based on this, a combined pumping test was operated. It included 4 large-diameter holes for pumping and 21 small-diameter holes as observation wells. The discharge was 10210-16957 cubic metres per day, and the test lasted 31 days. As a consequence, drawdown was not large - the average in all

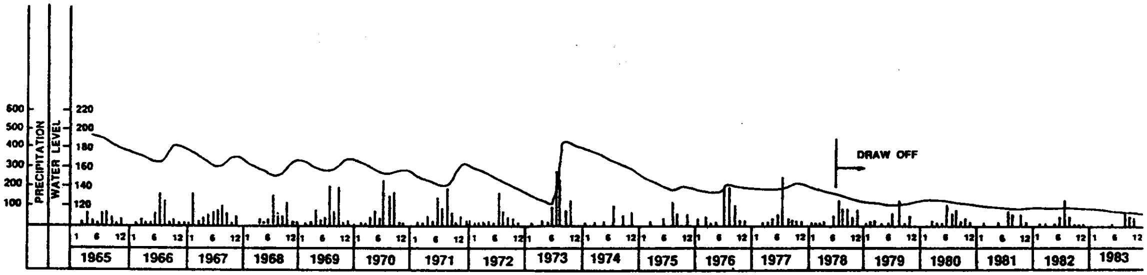


Figure 6. Correlative Diagram of the Ground Water Level and Precipitation

observation holes being 3.56 metres and drawdown rate was quite low. The depression cone inside the mine was extremely gentle and seemed to drop synchronistically. The hydraulic gradient at the southern "gate" and western one increased but at the northeastern one it decreased. The tests showed that the transmissibility of the aquifer inside the mine was high but the conveyable capacity of the "gates" was low and that the mine is rich in static groundwater reserve but lateral flow quantities are limited. The pumping test provided the necessary and essential data for determining the hydrogeological parameters of the limestone aquifer inside the mine and at the "gates".

The "gates" are the factors controlling ground water flow from the region into the mine. In order to examine them and roughly determine their outlines and sizes, a few boreholes were drilled through them.

With a view to studying the leakage of the Mahe River, besides a surface survey, hydrological measurements and river deposit investigations, a ground water micro regime observation was carried out conscientiously during the rainy season. The observation was operated in frequency of several times a day or once an hour. It was found that no sooner had water flow appeared in the river bed than the ground water levels began to rise under the bed, forming a ridge of water and leading to an increase in ground water levels all over the mine (Figure 7). According to this, the significance of the Mahe River leakage was observed.

There had been accumulated a huge amount of data over nearly 20 years' time concerning the ground water regime of the region and the mine, which included the year 1963, (the historic flood peak year in the century). This is a golden key in the realisation of the basic hydrogeological characterisitics of the mine as well as the region. The data described the seepage flow field and its variation, which provided a basis for realizing conditions of recharge, flow and discharge of ground water. The data showed some high-level yields for high flow years, warning that the mine could be faced with the water hazard of large inflow or inrush during waterflood years, especially in a flood peak year. The data also displayed some low-level yields for low flow years, reminding that the mine would have to encounter a special difficulty in water supply during dry years, especially in the dry year period every 7 - 10 years. It is these two problems that must be evaluated before the Xishimen Iron Mine is to be developed.

After the hydrogeological conditions had been ascertained, ground water inflow was predicted for the future ground gallery system of the +120 metres level. In accordance with specific conditions about water sources, boundaries and conduits the mine was approximately modeled as a hydrogeological object with lateral flow through three "gates" and in-situ feeding resulting from the Mahe River leakage, rainfall percolation and peripheral diorite's discharge. The lateral flow quantity was evaluated using the Section Method. The Mahe River leakage quantity was estimated according to the ridge-form ground water table and its recovery rate in which the coefficient of permeability and the storage capacity of the aquifer had been known. Rainfall infiltration quantities and peripheral diorite's discharge were evaluated using the Equilibrium Method. The predicted inflow are as follows:

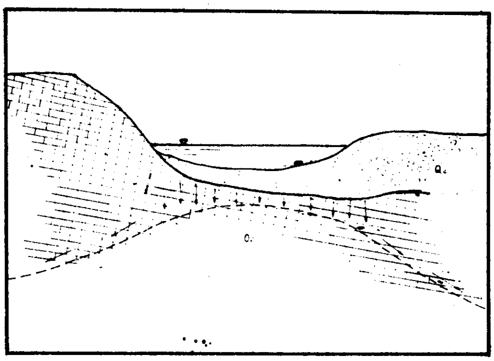


Figure 7 Schematic diagram of Mahe River leakage

Total for flood term appearing once every 7 - 10 years

	161000 cubic metres per day
Lateral flow	72000 cubic metres per day
In-situ flow	(mainly Mahe River leakage 89000 cubic metres per day)

Total for dry term appearing once every 7 - 10 years

	23000 cubic metres per day
Lateral flow	20000 cubic metres per day
In-situ flow	(all peripheral diorite's discharge 3000 cubic metres per day)

In addition the mine dewatering procedure was predicted using the New Unit Static Reserve Method.

MINE DEWATERING

The Xishimen Iron Mine is an underground mine. It was originally dewatered by means of draining water in boreholes drilled from chambers and concentratively pumping water from an underground sump up to ground surface.

Mine dewatering began with dewatering tests of the +120 metre level and +40 metre level respectively, utilizing some drainage works already completed. Dewatering measures included 46 drainage boreholes from 12 chambers, a ventilation shaft and 2 water supply boreholes. There were 22 observation boreholes in the mine and 19 outside the mine, which covered an area of 120 square kilometres. The dewatering test of +120 metre level lasted 84 days, from June to September 1978, including a length of dry season and the whole rainy season of that year. The discharge was 60000 - 75000 cubic metres per day. As a result, in the middle part of the mine, ground water levels dropped from +180 metres to + 140 metres, a drawdown of 40 metres. The dewatering test of the +40 metre level was performed during July and August 1980 and lasted 48 days in the rainy season of the year. The discharge was 35000 - 52000 cubic metres per day. As a result, in the middle part of the mine, ground water levels dropped to near +100 metres with drawdown of 35 metres or so. Between the two tests and after the second one, drainage was continued with the discharge maintained at about 20000 cubic metres per day. In such a case the ground water level seemed to be going down extremely slowly. In the rainy seasons pumping was increased to restrain the large recovery of ground water levels.

The drainage in question has dewatered both the +120 metre level and the upper ones, the earlier mining levels. It paved the way for mine development. It is also a check on results of hydrogeological exploration of the mine.

The form of the depression cone coincided quite well with permeability distributions determined from hydrogeological prospecting. In portion I, (high permeability) drawdown was larger and the hydraulic gradient was lower than the others. Except for the quantity of Mahe River leakage, all over the portion (being over 4000 metres long) ground water levels dropped in nearly the same degree. In Portion II, (less permeability), and Portion III (low permeability), things were apparently different from Portion I and different from each other. Of course, the seepage flow field under dewatering conditions was more complicated. For example, after ground water level had dropped it was found in the north part of Portion I a relatively low permeability zone, which made the field more complicated.

Though dewatering brought about a great variation and adjustment in the seepage flow field of the mine, it did not evidently affect the ground water levels out of "gates". There, the ground water levels varied naturally, keeping step with the regional ground water regime. So, loss of head occurred as much as a few tens of metres at each "gate". It has been proved that the "gates" are really low transmissivity. (Table 2)

During the dewatering period, whenever the Mahe River bed was filled with water in rainy season, the ground water level under the bed rose rapidly, the ground water level all over the mine rose to some degree and inflows were enlarged consequently. For example, during a period of the rainy season of 1982, rainfall lasted for 6 days, total rainfall was 315 millimetres, and the Mahe River bed was filled with water for 10 days, causing ground water levels in the northern part of the mine to recover from +116 metres to +144 metres caused inflows to increase by 43000 cubic metres per day. This showed that the Mahe River leakage considerably affected the mine inflow. Since 1978, dry years with lower annual rainfalls appeared one by one. So, the degree of influence of the Mahe River leakage in the waterflood year has not been exposed during the dewatering period.

TABLE 2

SOME DATA ABOUT THE FIRST DEWATERING TEST (IN 1978)

date		ground water level inside the mine (m)			ground water level out of the "gates" (m)			withdrawal (m^3/day)
		northern part	central part	southen part	southern	north-eastern	western	
dry season	22 June (initial)	177.30	181.67	182.28	193.75	175.10	194.70	
	22 July	162.88	161.16	164.16	188.46	174.12	193.91	65,000
wet season	31 July	168.20	161.45	163.66	189.00	188.99	196.74	65,000
	9 August	166,36	157.65	160.41	190.54		207.05	65,000
	20 August	162.77	146.93	151.84	186.64		200.16	75,000 - 85,000
	15 September	158.95	139.81	143.62	187.26		163.02	60,000 - 70,000

During the dry seasons after dewatering tests, pumping was kept at nearly 20000 cubic metres per day, ground water level outside the mine. Thus, it can be seen that the predicted inflow for the dry season (23000 cubic metres per day) is very close to that as in practice. As to the predicted inflow for rainy season, it has not been verified due to the absence of a waterflood year in recent years.

As a result of dewatering, a quite extensive and considerably deep depression cone has existed for a long time, but it has not brought about ground surface collapse in the mine and ground water level drawdown outside the mine. The reason for this is that the spaces filled with water in the aquifer are mainly corroded fissures, not caverns, and in addition that the mine is hydrogeologically semi-closed.

WATER SUPPLY

The Xishimen Iron Mine requires about 60000 cubic metres of water per day to supply for mining, dressing, irrigating and drinking. It has been planned that the mine water would be utilized as much as possible. Inflows predicted for the dry season however are only a little more than 20000 cubic metres per day. Even if all inflow is used effectively, there is a water imbalance of 40000 cubic metres per day during the dry seasons. As the mine is a semi-closed one, it is not possible to supply the shortage within the mine and it is necessary to get supplies from outside.

According to the regional hydrogeological conditions, a supplementary water source spot has been constructed in a section which is 2.5 kilometres east of the mine, separated from the mine by diorite.

The supplementary water source spot is situated in the middle of a ground water passage in Middle Ordovician limestone in the Han-Xing Iron Mine District. The limestone in the section in question is bounded on the west by diorite, limited on the east by a large sized water-obstructing fault and covered with Quaternary sediments and Carboniferous-Permian strata. It is 420 - 470 metres thick. The mean coefficient of permeability is 40 metres per day, the interval from 50 to 400 metres in depth being a high permeable one. Most of the ground water flow in the middle part of the district passes through the section in the direction from south to north. The ordinary natural flow rate equals 40000 - 60000 cubic metres per day and the hydraulic gradient ranges from 0.03% to 0.07%. The elevation of ground surface is about +230 metres. The ground water level varies from +165 metres (dry season) to +195 metres (rainy season), with the recorded minimum and maximum being +126 metres and +214 metres respectively.

The water supply scheme is exploiting ground water with concentrated boreholes, pumping with submersible borehole pumps and conveying water by pipe lines.

By now, all of 20 planned boreholes have been constructed, each being 380 metres deep or so. They are 500 millimetres in diameter at the top and 219 millimetres at the bottom. Single borehole pumping tests show that while the discharge keeps 3000 - 4000 cubic metres and flow capacity of 125 - 200 cubic metres per hour. It is estimated that in an ordinary dry season, if 15 pumps are under operation, a total discharge of

45000 cubic metres per day can be obtained with total drawdown being less than 15 to 20 metres.

HARNESSING THE MAHE RIVER

As indicated above, the Mahe River leakage in the rainy season is the important source of mine inflow at the Xishimen Iron Mine. What is more, if there exists cracks and collapse of ground surface caused by mining, the Mahe River could lead a large inrush and flooding of the mine. In this view, a primary programme to restrict the Mahe River has been worked out.

The principle of harnessing the river is to prevent water inrushes and to pay close attention to elimination of leakage. It has been preliminarily planned to construct an artificial channel with concrete to carry the river water over the mine area. Main works are concerned with building a narrow trough along the course inside the mine, and making an underground dike at the upstream end to collect incoming water to the river bed into the trough and constructing another one at the downstream end to prevent leaving water from percolating back into the mine.

Because of the long service period of the mine, the flood carrying capacity is designed according to the peak flood with a return period of 100 years and is checked by the peak flood with a return period of 200 years. Hydraulic model experiments show that the planned artificial channel will be effective in restricting the Mahe River.

CONCLUSIONS

1. In hydrogeology, the Xishimen Iron Mine is characterized mainly by the heterogeneous permeability of the aquifer, the periodic feeding and the semi-closed boundary conditions. Development of the mine is faced with both water hazards and water shortages.

2. The hydrogeological prospecting in the mine was aimed at investigating the water feeding source, boundaries and passages - the three basic factors controlling inflow, and studying their variations. The stress of hydrogeological prospecting was placed on analysing the data from a large amount of prospect holes, studying the long term regime and micro-regime of the ground water, investigating the three "gates" of the mine, and operating pumping tests lasting a longer time with a larger discharge. Mine water inflows were predicted for the water flood term and dry term respectively with pertinent hydrogeological models. It has been basically verified by mine dewatering that the hydrogeological exploration of the mine was successful.

3. Mine water control was based on concrete conditions concerned with flow sources, boundaries and passages. Now the mine has been advance dewatered, in order to supply the water shortage during the dry terms, a supplementary water source spot has been constructed in the highly permeable passage of the regional fissure-karst water. With the view of restricting the Mahe River, it has been preliminarily intended to construct an aritificial channel along the river course in the

mine. The mine is partly operated at present and will be put into fullscale operation in the near future. It can be reasonably expected that the mine will be in such an excellent condition that no water hazard during waterflood terms will occur and full water supply during dry seasons will be guaranteed.