The Control of Mine Drainage Water at Konkola Underground Copper Mine - Zambia

By S C Mulenga[1] and B C Chileshe[2]

[1]Zambia Consolidated Copper Mines Limited, Konkola Division, Chief Geologist
[2]Zambia Consolidated Copper Mines Limited, Konkola Division, General Manager

ABSTRACT

Konkola Mine currently pumps an average of 300 000 m^3/d, making it one of the wettest mines in the world. The ore hoisted to surface ratio currently stand at 1:49. Mine drainage is thus a major cost in mine planning and development, accounting for about 10-15% of the mine operating unit cost.

Against this background, an elaborate mine drainage and water control system has been developed over the years to facilitate safe mining and constantly reduce mine drainage costs.

The main features of the system are described focusing mainly on key aspects of; hydrogeological setting, mining method, dewatering approach, mine development through high-water-bearing rocks, drain drives development and location with respect to the mine aquifers and orebody, and mine water control and pumping systems.

The system has provided the mine with 85 - 90% controllability of the total mine water inflow.

INTRODUCTION

Konkola Underground Mine is the most northerly of the Zambian Copperbelt mines, and is 450 Kilometres northwest of Lusaka the capital city.

It is ZCCM's fourth largest copper mine, currently producing an annual average of 2.23 million tonnes of ore at 2.7% Total Copper. There are three main orebodies; the Kirila, Bomwe South and North and Konkola served by the Numbers 1, 3 and 2 Shafts respectively as shown in Figure 1. The South Orebody is on the Southwestern flank of the Kirila Bomwe Anticline, while the North Orebody is on the nose of the fold. Production is from the Nos 1 and 3 Shafts. The third shaft, No. 2 located on the Konkola Orebody, has remained closed since 1958.

The reserves as at end of March 1994 stand at 40 million tonnes at an average grade of 3.87% Total Copper. Ore resources are estimated at 1 billion tonnes at 3.5% Total Copper.

An average of 300 000 m^3/d of water is pumped from the mine, making Konkola one of the wettest if not the wettest mine in the world. The ore hoisted to water pumped to surface ratio is 1:49.

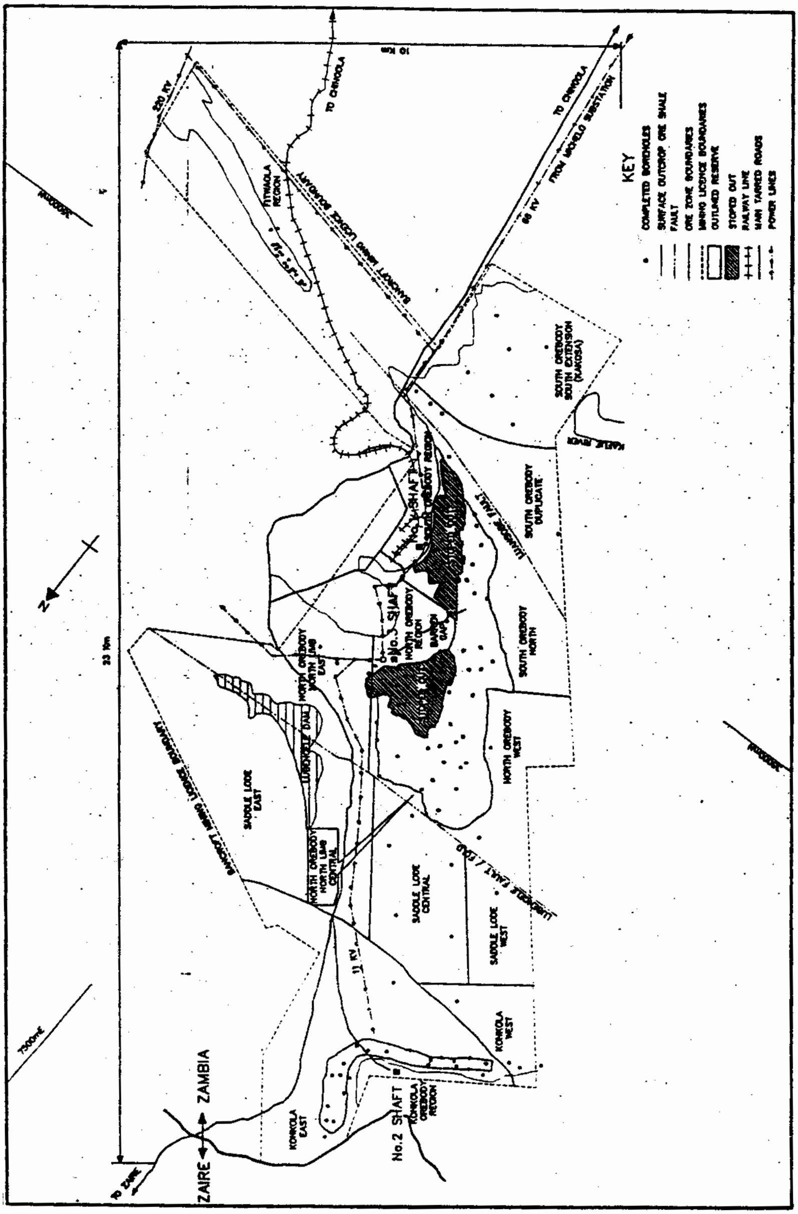

Figure 1. Map of Greater Konkola Area

Pumping increased from 15 000 m^3/d in July 1955 at the start of mining to a peak of 420 500 m^3/d in June 1978. Since then there has been a gradual decline in mine inflows to the current average.

A labour force of 5 970 is employed, of which only 0.32% is expatriate.

Copper was first discovered in the Chililabombwe (Bancroft) Area in 1924. Sinking of No. 1 Shaft started in 1953 and production of ore commenced in 1957 at both numbers 1 and 2 shafts. Production at No. 3 Shaft started in 1963. However, in 1958 the mine was closed due to the fall in world copper prices. Production resumed in 1959 but only at Number 1 Shaft. Number 3 Shaft came into production in 1962 [1] [2] [3].

The Kirila Bomwe deposits are mainly copper sulphides (chalcopyrite, bornite and chalcocite) in shale with local oxidised patches (malachite, cuprite and chrysocolla). Near the surface the ore is predominantly oxides [4].

Mine expansion program, the Konkola Deep Mining Project, aimed at exploiting fully this massive ore resource, is scheduled to take off in April 1995. Production is to be raised to 6 million tonnes per annum by year 2000, through sinking of large diameter shafts to 1500m depth and introduction of mechanised mining methods. This will make Konkola the largest copper producing mine in Zambia and one of the largest underground mines in the world [5].

The mine has historically experienced difficulties in mining as a result of presence of large quantities of water. Against this background, expertise in mine groundwater drainage and control management has evolved such that the mine has now one of the best mine groundwater drainage and control system in the world. This comprise a network of pump chambers, emergency water storage facilities (in the form of sumps and settlers), drain drives, boreholes with valves, surge barriers and watertight doors.

Research carried out from 1987 to 1993 has established the origin of mine water recharge as being mainly from surface water bodies and regional hydrogeological catchment. The surface water bodies in form of streams, rivers and canals leak as they flow along and across geological discontinuity zones and thereby recharging the mine aquifers. Regional groundwater catchment brings in water from adjacent catchments.

This understanding has now made the problem of mine water inflow amenable to a permanent solution. The first step being implemented is to remove water at source through surface water-exclusion methods of groundwater control. These solution methods are currently being executed and are projected to reduce mine water inflow by about 54% [6] [7] [8].

HYDROGEOLOGICAL SETTING

Konkola mine is wedged between two major faults; the Lubengele in the north and the Luansobe in the south. In between these faults are the Kirila Bomwe Anticline Axis Fault which runs subparallel to the Lubengele Fault and the Cross-Anticline Axis Fault which link up the Lubengele and Luansobe Faults. These faults form the main hydrogeological boundaries and major channels of water flow into the mine (Figure 2).

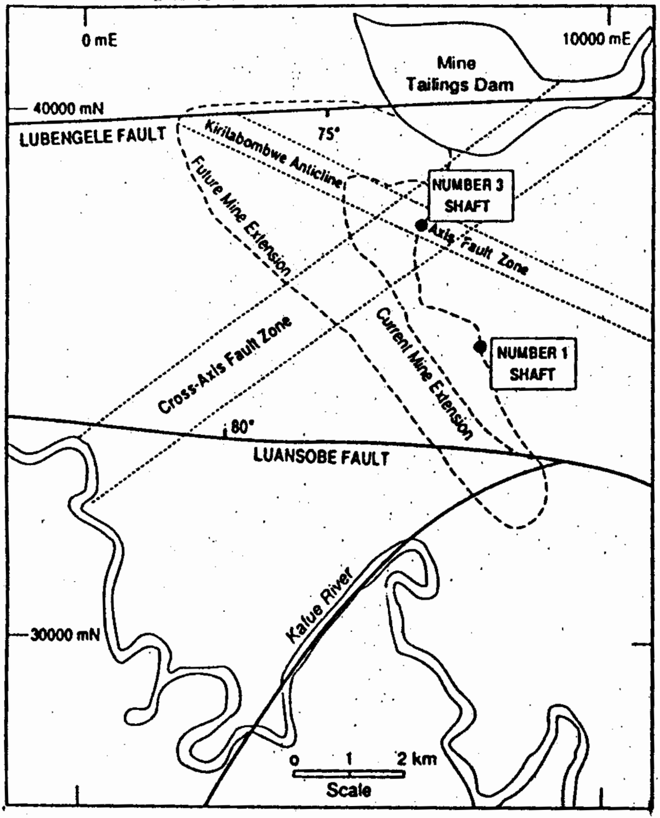

Figure 2. Konkola Mine Showing the Major Aspects of Structural Geology and the Limits of Mining

The orebody in Ore Shale Formation is sandwiched between major aquifers; hangingwall and footwall aquifers respectively as illustrated in Figures 3 and 4. The Hangingwall aquifers are mainly of carbonate rocks, limestones, dolomites and calcareous sandstones and siltstones. The Footwall aquifers are composed of siliceous rocks; quartzites, sandstones and conglomerates.

The area lies on the nose of the Kafue Anticline, dominant regional geological structure on the Zambian Copperbelt. Adjacent to this structure, lies the Lubengele syncline and the Konkola Dome as shown in the geological map in Figure 5.

The rocks present in the area range stratigraphically from the Archean Basement Complex to the Late Precambrian Katanga System. The Basement complex rocks are mainly granites, and the Katanga system comprises sedimentary rocks, ranging from quartzites, conglomerates sandstones, siltstones, dolomites and limestones.

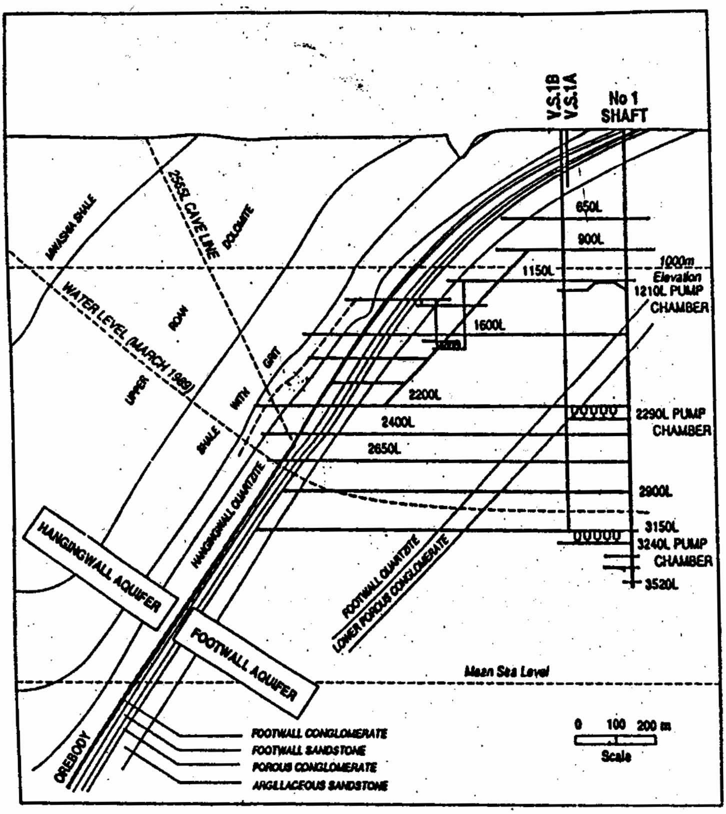

Figure 3. Konkola Mine: Generalized Geological Section at Number 1 Shaft Showing Orebody, Aquifers and Water Level

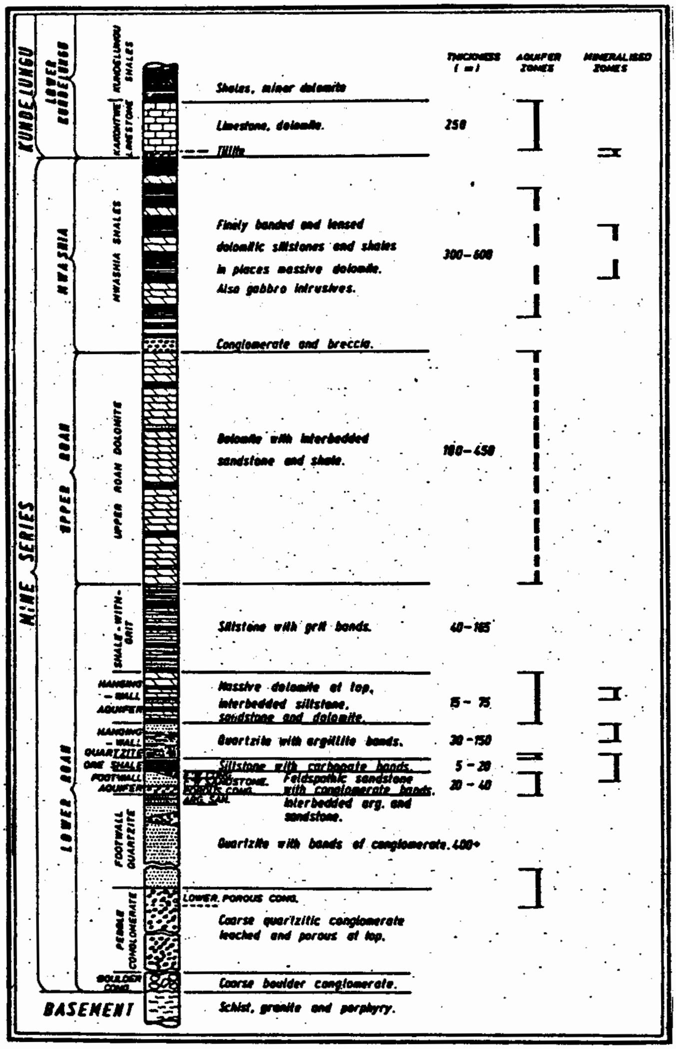

Figure 4. Stratigraphic Succession

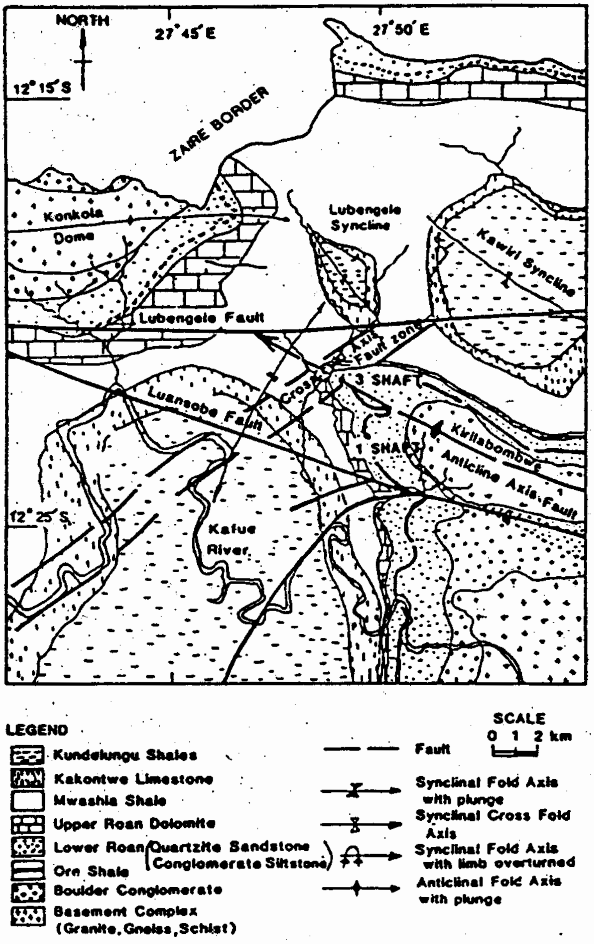

Figure 5. Geological Map of the Konkola Mine Area

There are four main aquifers; two above and two below the orebody.

Footwall Quartzite Aquifer. This is the lower most aquifer. It consists of the Lower Porous Conglomerate and the lower part of the Footwall Quartzite. It is about 150m thick. Large volumes of water are intersected in this aquifer. Water in the quartzite is mainly joint/fissure controlled.

Footwall Aquifer. The Footwall Aquifer is composed of three formations; the Porous Conglomerate, Footwall Sandstone and Footwall Conglomerate. This aquifer directly underlies the orebody. It has a thickness of about 20m to 40m. Water intersection in this aquifer is stratigraphically controlled and generally easily drained.

Hangingwall Aquifer. This aquifer lies above the orebody. Because it is situated close to and above the orebody, this aquifer creates the greatest water inflow problems at the mine. It is about 700m thick and outcrops in the immediate vicinity of the mine. Comprises Hangingwall Aquifer , Shale-with-Grit, and Upper Roan Dolomite formations.

Kakontwe Limestone Aquifer. The Kakontwe Limestone outcrops very near to the mine. It has an average thickness of 250m.

The surface drainage system in the mine area is controlled by the Kafue River and its tributaries. The two important tributaries are the Lubengele and Kakosa Streams. These streams flow over the mine hangingwall aquifers and in some areas they flow along and cross the main fault system of the area, which is in hydraulic continuity with mine aquifers.

The main mode of groundwater movement in mine aquifers is fissure-flow. Stratigraphic control of flow through pores and vugs plays a significant part especially in the unfaulted regions of the mine.

The source of recharge to the mine aquifers is two fold. There are two dinstinct bodies of water recharging the mine; recent and ancient. The young (recent) waters of the Hangingwall Aquifer (cold) ingresses the mine from surface water system and flows mainly downwards. The old (ancient) waters of the Footwall (hot) originates at depth from the regional aquifers and moves upwards mainly through fissure and fault zones. These waters mix in the fault zones.

MINING METHOD

The crux of the problem lies in the stratigraphic position of the orebody between the Footwall and Hangingwall Aquifers and regional geological structures. The effects and constraints which these large volumes of water impose cannot be fully appreciated without first understanding the mining method used at Konkola Division.

The method of extraction is sub-level open stoping with longhole drilling. At No. 1 Shaft where the orebody is mainly steep dipping (45^0-80^0), ore gravitates down into grizzleys where secondary blasting takes place. At No. 3 Shaft the orebody is generally shallow dipping (8° - 30°) and most ore is extracted by scraping down dip into drawpoints (Figure 6).

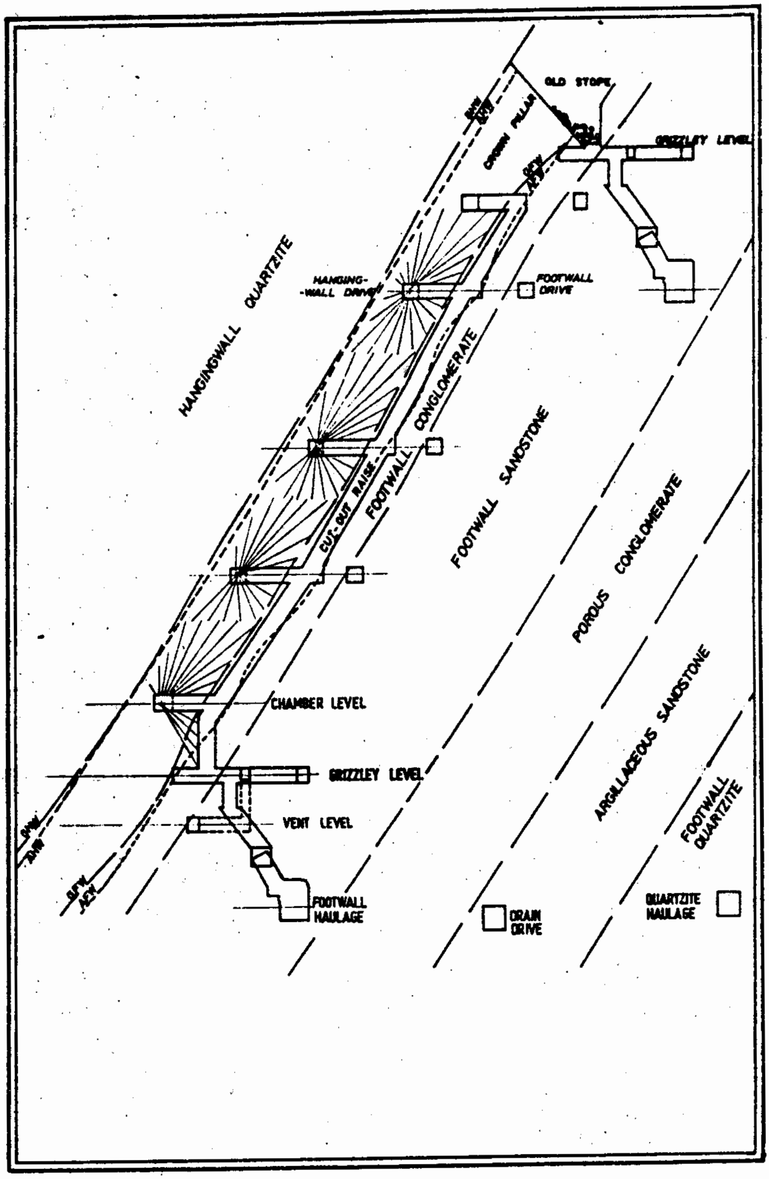

Figure 6. Mining Layout for Gravity Stoping at No. 1 Shaft
Scale 1 : 1000

When the stope rings have been blasted and the ore extracted, first the rib pillar and then the crown pillar are blasted and the stope is filled either by hangingwall collapse or by waste gravitating from old stopes above. Most sub-level development takes place in the orebody.

Main level development - Shafts, Pump Chambers, Quartzite Haulages and other ancillary development are mined in the Footwall Formations. Footwall Haulages are mined parallel to and below the orebody in such a position that ore from the stopes gravitates into stope boxes in these haulages. Mined ahead of and parallel to each Footwall Haulage is a Drain Drive at a slightly lower elevation. A watertight door is installed on each main tramming level just below the Lower Porous Conglomerate.

MINING THROUGH HIGH-WATER BEARING ROCKS

Mining of crosscuts to lode from the shaft and main ore and waste rock tramming haulages inevitably pass through high-water bearing strata, the Lower Porous Conglomerate and Footwall Quartzite respectively. Flows of as much as 5 000 m^3/d and more are frequently intersected during mining development in this aquifer.

Thus in order to cope with these wet conditions development is achieved through use of cementitious grouting system.

The method of advance starts with drilling two 20m to 30m long pilot holes ahead of the mining face. If the flow from each hole is less than 100 m^3/d, the holes are sealed with grout and the face handed over for mining. With flows of over 100 m^3/d in each hole, additional three holes as shown in Figure 7 are drilled, to make it a standard five-hole cover pattern. Holes with intersections of over 100 m^3/d are re-drilled after grouting and repeatedly grouted and redrilled until the flow is reduced to less than 100 m^3/d.

If the holes intersect substantial volumes of water, 200 m^3/d or more from each hole, additional four holes are drilled to make it a 9-hole cover. Grouting and redrilling is carried out as above until each hole makes less than 100 m^3/d.

The water volumes and pressures are measured for each hole when drilling in rock or redrilling cement. When drilling and grouting have been completed, a mining advance equivalent, to the length of holes less 6 metres is issued. The last six metres provides safety buffer.

DEWATERING METHODS

Hangingwall Aquifers

The mining method of sub-level open stoping practised at Konkola dictates that the hangingwall aquifer be dewatered prior to stoping, to facilitate safe ore exploitation. This is achieved through underground dewatering **diamond core** drilling.

Most of the active dewatering drilling is concentrated on the hangingwall aquifer and is all done underground in the mine workings. This is because it is necessary to lower the water level in the aquifer to below the stoping caveline, measured from the coning level at an average angle of 65° as illustrated in Figure 8.

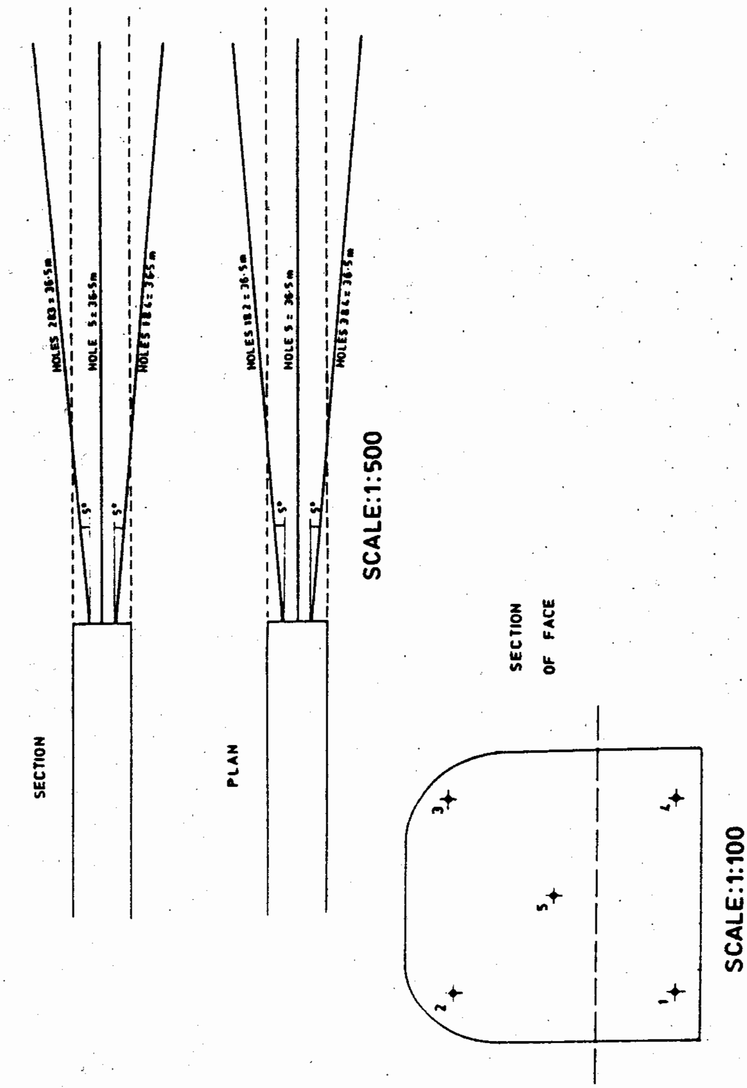

Figure 7. Standard Five Hole Cementation Cover Layout

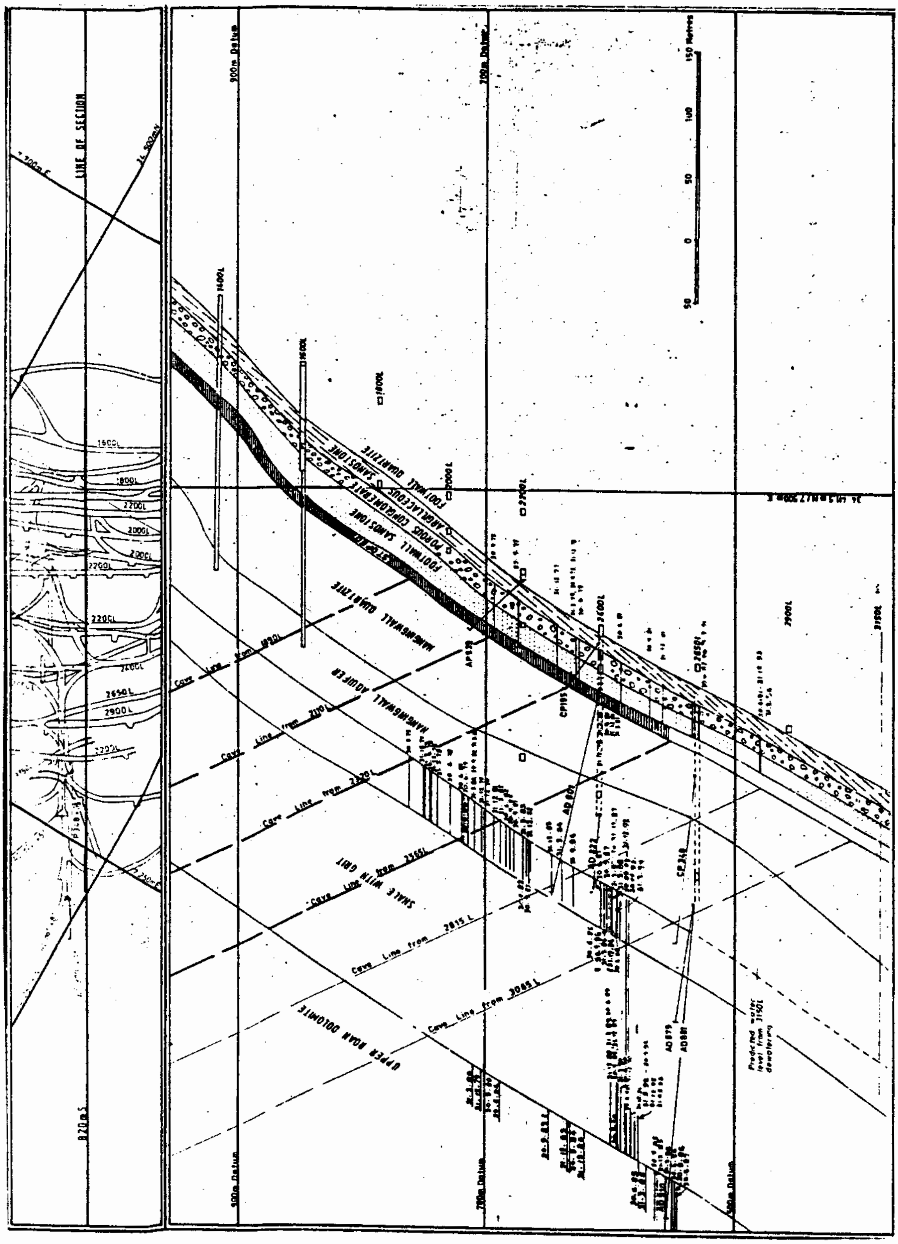

Figure 8. Dewatering Section Through 820 m South

Dewatering is achieved by mining a crosscut through the orebody into generally the base of the aquifer. From here a bay is established from which holes are drilled into the aquifer to tap the water.

Boreholes are drilled through a 3m long 114 mm diameter flanged standpipe and on completion are equipped with gate valves to control the water intersected. Gate valves are used in areas where the hydrostatic pressure head is 10 bars or less and high pressure barrel action valves in areas of pressures greater than 10 bars.

The dewatering crews have been trained to ensure that these valves are kept in good working order at all times. This is necessary for in case of power failure it is essential that the volume of water reporting to pump chambers is significantly reduced to a level which can be safely handled by emergency generators.

Up to 1992, the dewatering drilling centres were located at regular intervals along the strike of the orebody at an average of 500m. Now we locate these centres on the basis of hydrogeological conditions, in areas of high discharge yields, which are primarily fault/fracture zones. Higher yields of discharge are now being achieved than hitherto.

Discharge of as much as 30 000 m^3/d to 40 000 m^3/d per drilling bay is not uncommon. At end of December 1993, the hangingwall aquifer water accounted for about 34% of the total mine water flow.

Footwall Aquifer

The water in this aquifer is mainly stratigraphically controlled except in fault zones where flow is mainly through fissures.

Dewatering is generally achieved by **normal haulage development** and **diamond core drilling** of pilot holes from the drain drives. The porous nature of the conglomerates and jointing in the sandstone facilitate effective drawdown.

5 000 m^3/d is about the normal yield from an advancing wet face. If large volumes of water are intersected the haulage is stopped until the yield diminishes, generally one to two weeks being sufficient time for this to occur.

The water level in this aquifer generally drops fairly quickly as the rate of drawdown is very much dependent on development advance rate. The faster the development, the higher the rate of drawdown. The average fall in water level ranges between 11 to 18 metres/year.

At 1993 year end about 33% of the total mine water inflow was intersected in this aquifer.

Footwall Quartzite Aquifer

Water in the Footwall Quartzite is mostly joint and fracture controlled, whilst in the Lower Porous Conglomerate is mainly in vugs.

Until 1980 it had not been necessary to actively dewater this aquifer. Pilot cover drilling and subsequent sealing off of water by cementation sufficed.

Major breakthroughs into open fissures within the Footwall Quartzite have occurred, one of which is the 1240 ft (380m) Level at No 3 Shaft gave an initial surge of 60 000 m^3/d in 1974. It continued to flow at an average of 30 000 m^3/d for seven years before drying up.

As the mine has got deeper and high pressure heads and water intersections encountered in the order of 55 bars and 10 000 m^3/respectively, active dewatering has become essential in order to make mining conditions safe. Drainage is mainly by **Diamond Core Drilling.**

At the end of December 1993, about 33% of the total mine water inflow was intersected in this aquifer.

MINE WATER CONTROL

In the event of power failure the main objective is to ensure safety of all personnel working underground, equipment, the shafts, main haulages and travel ways. Every main level has a watertight door to protect the shaft and other major underground installations.

Against this background an elaborate system of water control and emergency water storage facility has been established. Emergency water storage facilities include sumps and settlers, drain drive penstock valves, surge barriers and water tight doors.

For the purpose of water control, mine inflow is termed either **controllable** or **uncontrollable. Controllable** water is that which is derived from boreholes with valves which can be turned off. At end of December 1993, this accounted for 55% of the total mine water inflow.

Uncontrollable is free-flowing water from open joints, fissures and seepage from rock strata. This is controlled through channelling in drain drives, which are mined at a lower elevation parallel to main haulages to facilitate gravity flow. The control of this water is mainly through emergency storage facilities as outlined earlier. At end of December 1993 about 45% of the mine water inflow fell under this category.

The water control system in place guarantees that the **uncontrollable** water is also **controlled** by use of surge barriers and penstock valves located on drain drives leading to pump chambers. All in all the controllability of mine water inflow is about 90%.

Pumping facilities

The mine has a total of 471 168 m^3/d pump-chamber sustainable installed capacity. At present total mine water pumping of 300 000 m^3/d, a spare capacity of 171 168 m^3/d is available to cope with any excess water inflow.

All the mine water is pumped to surface at No. 1 Shaft, the deeper of the two shafts. No. 3 Shaft water is channelled through drain drives by gravity flow to No. 1 Shaft. There are three pump chambers, located at No. 1 Shaft 985m, 690m and 370m levels respectively. The deepest production levels at both shafts form the main drainage centres, being 950m and 590m levels at No. 1 and 3 Shafts respectively.

At No. 3 Shaft all mine drainage water collects in the bottom production level, the 590m, from which it is channelled to No. 1 Shaft 690m level pump chamber via a 3km long drain drive.

At No. 1 Shaft the bottom level pump chamber, 985m level, collects the bulk of the Shaft drainage water. In the pump chamber, the water is channelled through a series of sumps for settling and sedimentation thus facilitating clear water to overflow in settlers, from where it is pumped to surface.

On discharge to surface the water is channelled through a concrete-lined canal to be disposed off in the nearby Kafue river.

A loss of electrical power for any period of time can endanger the safety of the mine due to large mine water inflows. In order to guarantee availability of power at all times, an independent power supply of 20 megawatts provided by the Gas Turbine Alternators has been installed at the mine.

Water Control Procedure

When power failure occurs, a water-control procedure is automatically initiated. This entails the immediate closure of all boreholes and if need be progressive storage of water in drain drives, sumps and settlers. Specially trained water control personnel execute the procedure as follows:

- all controllable borehole water in drain drives and dewatering crosscuts is turned off
- the sumps and settlers are filled leaving one pair of sump and settler empty to provide extra storage capacity
- valves in penstocks are closed to stop the water supply to sumps and settlers, and surge barriers are erected in the vicinity of the main shafts to stop water entering the shafts and tips.
- Surge barriers are erected on main water producing levels to provide storage capacity
- only in the event that the above mentioned stages, are not able to control the water and there is prolonged no-pumping period, would the need to close the watertight doors arise. This has never happened in the whole 39 life history of the mine.

CONCLUSION

The mine drainage and water control system in place at Konkola mine , has facilitated safe mining. Throughout its history apart from the early years of mine development, the mine has experienced no flooding and loss of life and property due to failure to control mine water inflow.

Through the installation of valves on boreholes in the hangingwall aquifers and other critical areas like the Footwall Quartzite Aquifer, mining under cementitious grouting system in high water bearing rocks, maximum control of mine drainage water is ensured. This is further complemented by presence of more than adequate emergency water storage facilities to handle free flowing water and stand by Gas Turbine Power Generator.

The system provides 85% - 90% controllability of the total mine drainage water.

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