DEWATERING CONCEPTS AT ZCCM'S COPPERBELT MINES

E J NAISH - CONSULTING GEOLOGIST

ABSTRACT

During the financial year 1992/93, ZCCM Ltd pumped a total of 263 million tonnes of water from its various mining operations. During the same period the Company produced 23 million tonnes of ore, giving a water to ore ratio of 11.4 tonnes of water per tonne of ore produced. Hydrostatic pressures interesected in underground boreholes ranged upto about 50 bars. Against this background the dewatering techniques that have been practised on the Copperbelt at ZCCM's mines are reviewed. The methods include the surface exclusion of water, interception of water, simple drainage, breakthrough methods, dewatering drilling, grouting isotope analysis and computer modelling.

The surface exclusion of water includes the use of canals and pipelines to carry water over hydrological hazard zones, herringbone ditches to speed up run-off, stream gauging to locate hydrological hazard zones and weirs to quantify flow rates, and the judicious geological siting of dams and other surface water structures.

Interception methods basically revolve around the concept of interception of the potential mine drainage at the extremities of the mines in order to ensure that the cone of dewatering is lowered before it intercepts the main mining areas.

Simple drainage is the mining of drives into aquifers at reduced hydrostatic pressures in order to drain specific aquifers.

Breakthrough methods also involve the mining of drives into aquifers but in a more controlled manner than in simple drainage. In this instance drives are mined directly into aquifers utilising watertight doors or puddle pipes to protect the main mine workings.

Dewatering drilling is the most widely used method of dewatering used on the Copperbelt. It may be conveniently divided into surface and underground dewatering boreholes. Surface dewatering boreholes may be either pumped, utilising borehole pumps, used for piezometric measurements, or used in open pit situations to drain aquifers under hydrostatic pressure. Underground dewatering boreholes are the most widely practised method of dewatering on the Copperbelt and involve the drilling of boreholes into aquifers, in order to lower the hydrostatic head in a particular aquifer. A number of different techniques are discussed.

Grouting to exclude the inflow of water into mines has long been known as a method of groundwater exclusion. The uses of cementious grouts and resin grouts are discussed.

Isotope analysis has been used at Konkola Division to give indications of both the age and possible origins of the Konkola groundwaters.

Computer modelling utilising modflow software has been used at Konkola Division to predict drawdown of the hydrostatic head in a number of different mining scenarios.

A changeover from caving mining methods to mining methods involving the use of backfill should permit certain mines to effect major cost savings with regard to dewatering costs. The implications of this change in mining methods is discussed.

Environmental aspects of mine drainage from ZCCM's mines is addressed and the lack of an acid mine drainage problem briefly discussed.

INTRODUCTION

During the financial year 1992/93, ZCCM Ltd pumped a total of 263 million tonnes of water from its various mining operations. Over the same period the company produced 23 million tonnes of ore, giving a water : ore ratio of 11.4 tonnes of water to each tonne of ore produced. Dewatering, therefore, is a significant cost element in ZCCM's mining costs. This review will examine some of the techniques that have been utilised over the years in the dewatering of ZCCM's Copperbelt mines.

SURFACE CONTROL OF WATER

It is self-evident that any artificial means of excluding percolation or increasing the runoff rate in any hydrological basin should have the long-term effect of decreasing the recharge rate in the aquifers. To this end, the surface control of water, in the hydrological basins associated with ZCCM mining activity, has been practised for many years. The methods used to control surface water include the use of dams, canals and pipelines to carry water over hydrological hazard zones, herringbone ditches to speed up run-off, stream-gauging to locate hydrological hazard zones and quantity flow rates and the judicious siting of dams and other surficial water structures.

Surface drainage modifications fall into two categories: modifications to the drainage system to avoid surface water loss over dewatered or caved ground; and attempts to decrease the amount of water available in the basin for recharge. Figure 1 shows the natural drainage system in the Lubengele Basin at ZCCM'S Konkola Division and the modifications made to it (Whyte and Lyall 1969). The largest project in this instance was the diversion of the Lubengele Stream from the vicinity of the Kirila Bomwe North Orebody. As sub-level open stoping would induce subsidence under the bed of the stream, it was considered essential that seasonal floodwater, resulting from the Rains, was diverted away from potentially caving ground. The Lubengele Dam, built of slimes on a rock toe, was constructed to act both as a tailings impoundment and as a surge barrier to control flood water in the Lubengele Stream and its upper tributaries. The dam was constructed to retain over 73873 million litres of water, which would flood approximately 855 hectares behind the dam. Equipped with two decant channels at different levels, the dam would retain 7956 million litres of water below the level of the upper decant channel; whilst use of the lower decant permits the complete emptying of the dam.

Originally, since the Lubengele Stream below the dam passed over dolomitic rocks, affected by dewatering at the mine, a channel over 9km in length was excavated from the dam to the Kafue River, in order to increase the flow rate and minimise losses, due to the sluggish flow and incised meandering course of the old stream bed. The original channel itself was rock-lined over the dolomite rocks. This channel has now been affected by subsidence. As a result, a new concrete-lined channel was constructed to the north. However, even this channel has now been badly cracked as a result of subsidence. Thus the discharge from the dam now needs to be effected by means of flexible pipelines, or channels over stabilised ground, approximately along the original stream bed, to the Kafue River. This remedial work is planned for the near future. Similar stream diversion schemes have been carried out at both Mufulira and Luanshya Divisions.

In addition to these measures, the natural run-off has been enhanced in many mining areas by the construction of both lined and unlined channels, and at Konkola Division by the excavation of a herringbone system of major and minor drains.

An experiment was also conducted at Konkola Division to try and increase the rate of evapotranspiration from dambo areas by planting groves of Eucalyptus grandis. This tree is known for its prodigious rate of transpiration. However, this experiment failed because although the trees undoubtedly grew well and transpired as planned, they also acted as a focus for rainfall and as a result there was no net dewatering benefit!

This subject, the surface control of groundwater and its specific application to Konkola Division, will be dealt with in some detail by Dr Mulenga at this Conference. (Mulenga 1993).

INTERCEPTION METHODS

These methods simply involve the siting of major underground dewatering centres at the extremities of the mining areas. The centres are so sited as to intercept the inflow of aquifer water, down the cone of dewatering towards the mine, in such a way as to prevent the recharge of the aquifers in the mining area. This method has been utilised, at Mufulira in particular, in order to control the inflow of dolomite water.

The method involved here is simply to site dewatering crosscuts at each extremity of the orebody on the lowest available mining level. Drilling from such crosscuts will intercept water flowing down the cone of dewatering into the mining area. When initially mined and drilled, such crosscuts cause the development of deep steep-sided cones of dewatering. Such cones obviously result in the highest flows from the dewatering boreholes.

Ultimately such distal crosscuts cause a much wider and flatter cone of dewatering around the mining area as time progresses.

SIMPLE DRAINAGE METHODS

This method is widely used throughout the Copperbelt, in mines where the pumping capacity is sufficient to cope with uncontrollable flows of groundwater. It is probably the simplest and most widely used drainage method throughout the world. It involves the mining of development drives into aquifer zones, where hydrostatic pressures have been previously reduced by dewatering drilling. The theoretically uncontrollable flows of water, induced by the mining, are catered for by substantial pumping capacity and arrangements of watertight doors, to protect shaft and other major underground installations.

For example at Nkana, the crosscuts to the orebody, (crosscuts to lode) are mined to a position to the footwall side of the footwall aquifer, represented at Nkana by the Lower Conglomerate, Footwall Sandstone, and Footwall Conglomerate. The orebody is delineated by drilling from this position and the delineation holes, which intersect the footwall aquifer, prior to intersecting the orebody, are allowed to flow. When initial pressures have dropped, the heading is branched into extraction position in the footwall aquifer. This is allowed to bleed through the .....

surrounding rock into the extraction development where it is collected in a drain and allowed to run via gravity to the nearest pump chamber. Upto 10000m^3/d of uncontrollable water can be intersected in footwall aquifer development, although a figure of 500 - 1000m^3/d is more usual. If excessive volumes of water are intersected which hamper the charging of the development round, the heading is stopped until the yield diminishes.

As protection against excessive inrushes in development of this kind, the heading is carried under pilot hole cover. These pilot holes are drilled to give early warning of any such potential water hazard.

However, this is not a dewatering method to be entertained lightly, as many have found to their cost. The ill-fated mining venture at Mokambo by the Romanian company Geomin foundered because of inadequate pumping facilities and the lack of a suitable watertight door. Unfortunately circumstances also conspired against Geomin and a power failure during the breakthrough of footwall water plus the limited capacity of the backup generator, resulted in the flooding and closure of the mine.

BREAKTHROUGH METHODS

The breakthrough method of dewatering has been practised at Nkana, Konkola and Mufulira Divisions of ZCCM. It also involves the mining of drives or crosscuts into aquifers, but in a more controlled manner than in simple drainage. In this instance, drives or crosscuts are mined directly into specific aquifers, behind the protection of a watertight door or "puddle pipe" installed in the drive or crosscut being advanced. A watertight door is selfexplanatory, but is normally accompanied by the provision of two 12 inch pipes at drain-level, fitted with high pressure valves, to permit sealing or drainage with the door closed. The watertight doors are keyed into the surrounding drive and are usually capable of withstanding pressures of upto to 44 bars. A puddle pipe is a nominally 1 metre diameter (or 36 inch) pipe installed in the centre of a re-inforced concrete plug. Provision is made to mount a plate across the pipe flange to seal excessive amounts of water. Again two 12 inch pipes are installed at drainlevel. The main 1 metre diameter pipe permits access to the face for men and materials. All mining then takes place at the face beyond the watertight door or puddle pipe.

At Konkola, sustained flows in excess of 20 000m^3/d were achieved by this method from the Hangingwall Aquifer Zone, and at Mufulira a flow of 40 320 m^3/d was achieved from the Upper Dolomite, the stratigraphic equivalent of Konkola's Upper Roan Dolomite, on the eastern flank of the Kafue Anticline.

DEWATERING DRILLING

This is obviously the most widely used dewatering technique on the Copperbelt. It may conveniently be divided into surface and underground boreholes. Surface dewatering boreholes may be either pumped, utilising down-the-hole pumps, drilled into open pit walls to drain aquifers under hydrostatic pressure, or used for piezometric measurements. Whilst the pumping of surface holes, by means of down-the-hole pumps, was once widely considered as a method on the Copperbelt, this method has not been widely practised. However, at the Bwana Mkubwa Open Pit, now mined out, five large diameter boreholes were drilled into the dolomites of the Lower Kakontwe Limestone. Of these holes, three were used for monitoring the piezometric surface and two were pumped to evaluate the dewatering potential. The dewatering potential proved low, but pumping was maintained to provide clean water to the Bwana Mkubwa concentrator. Similarly in 1979 at Bwana Mkubwa, ten boreholes were drilled from surface on the northern perimeter of the pit, to delineate the extent of a perched water table, which had resulted into a number of hanging wall sloughs. However, drainage of the perched water table proved impractical, and as a result the hanging wall slope had to be flattened.

As Open Pits in Zambia are often associated with contiguous underground mines, the dewatering of open pits has to a large extent been carried out from the underground operation. However, in a number of instances, effective dewatering for open pit operations has been carried out using surface boreholes, by planned intersection of the surface borehole by a suitably protected underground drift. Currently all water from the Nchanga Open Pit reports to the 1500 level of the underground mine, via a series of surface boreholes drilled for this purpose.

Underground dewatering boreholes are the mostly widely practised method of dewatering on the Copperbelt. This involves the drilling of boreholes into aquifers, to lower the hydrostatic head. Boreholes are drilled through a flanged standpipe and on completion are equipped with gate valves to control the water intersected. Where water at a pressure of upto 10 bars is intersected a gate valve is used, but where a pressure in excess of this is anticipated, a more costly high pressure barrel action valve is installed. Special crews have been trained at all Divisions to ensure that all the valves on the dewatering boreholes are in working order and to make repairs where necessary.

This is essential since in the event of a power failure, it may be necessary to reduce the volume of water pumped to a level which can be safely handled by emergency generators. Power failures often occur during thunderstorms in Zambia's Rainy Season, and emergency water control procedures have been developed for each of ZCCM's mines, to cater for this eventuality. These procedures entail the orderly closure of dewatering borehole valves, the erection of surge barricades and in extreme emergencies, the closure of watertight doors.

At Nkana Division, the high temperature of the water in the Near Water Aquifer at Central Shaft, (43°C) necessitates the use of stainless steel valves and stand-pipes in order to avoid corrosion. The valves are reclaimed, after dewatering has been effected from a particular site or replaced by boreholes on a lower level.

A number of specialised techniques have been evolved in order to cater for the difficult drilling conditions on the Copperbelt. One of these, the "Ogram Method", was named after an Irish diamond drill Mine Captain at Konkola Division. This method was developed in order to prevent caving of the incompetent Hangingwall Aquifer Zone at Konkola blocking-off water flows from this aquifer. The borehole is drilled by conventional diamond drilling at NXC size until it just intersects the incompetent "sandy fissure" zone at the base of the Hangingwall Aquifer. Slotted casing with a casing shoe is then inserted into the hole, to the base of the fissure zone, and kept free by constant turning. The diamond drilling machine is then swung off the hole and a bar mounted drifter equipped with a cruciform 3½" rock bit put in its place. Using the rock bit the hole is advanced, with the slotted casing being spun in behind the rock bit. The casing shoe effectively reams out the hole, to accommodate the casing. Once the rock bit intersects the competent base of the Shale-with-Grit, it is drilled approximately 1 metre into the competent rock, to give a firm foundation for the following casing. The casing is then pushed to the end of the hole. The casing prevents caving from blocking the hole and the slotting allows the passage of water. If required the borehole can then be progressed into the Shale-with-Grit, where further water intersections are frequently made.

As mentioned in the preceding section on surface dewatering, the intersection of surface exploration holes has also provided an excellent method of underground dewatering in the past. By using a down-the-hole survey instrument, it is possible to pinpoint the position of surface boreholes along their length. On a number of occasions dewatering crosscuts have been mined to intersect surface holes, with the crosscut protected by a watertight door or puddle pipe. Successful intersections, often with dramatic resulting drawdowns, have been made at Chibuluma Mine, Nkana's Central Shaft and at Nchanga's underground mine.

On the negative side, until we learned better, a number of unplanned intersections of surface boreholes were made, again at Chibuluma and Nkana, and these caused both concern and mining problems. However, we did learn by our mistakes and currently ALL surface exploration boreholes are cemented to a position 50 metres above the top of the orebody. This protects the underground workings from unexpected inrushes but still allows free transfer of water in the hanging wall aquifers, so as not to impede drawdown by conventional dewatering drilling.

The use of rotary and DTH rigs for dewatering has been investigated on the Copperbelt, chiefly because of the speed of drilling and cheap operating costs. However, no machines of suitable size have yet been marketed, although a number of firms have expressed interest in modifying a production machine, by equipping it with a large electrohydraulic motor. The initial capital cost of such a machine, however, tends to militate against a move in this direction, despite the low operating costs when compared to diamond drilling.

GROUTING

Grouting to exclude the inflow of water to the mines of the Copperbelt has long been a tried and trusted method of groundwater exclusion. Both cementitious and resin grouts have been utilised on the Copperbelt. Resin grouts have found little use to date on the Copperbelt although a test programme has been approved for one of our mines in the near future. The high cost of importing resin grouts has tended to cloud their high efficiency in sealing specific fissure type inflows. I am convinced that these compounds offer a cost effective solution to certain fissure inflow occurrences.

Cementitious grouts have found wide usage through the Copperbelt for sealing casual water inflows and sealing fissures. Their usage is well-known and widely reported and so will not be dwelt upon here. However, ZCCM has investigated the use of a patented Ukrainian system, which involves the addition of clay materials and other additives to cementitious grouts and a trial programme has been scheduled at Konkola. In addition "Geoseal Z" a proprietory product from Eastern Europe was used to seal the traverse of the Lower Porous Conglomerate on the 1850ft level (590m level) at No 3 Shaft at Konkola. However, conventional cementitious grout was used for the parallel Drain Crosscut to Lode with similar mediocre results.

CHEMICAL AND ISOTOPE ANALYSIS

Chemical analysis has been used throughout the Copperbelt in an attempt to fingerprint the various aquifer waters. This approach has met with limited success. Similarly, in attempts to quantify the relative proportions of modern water and old meteoric water flowing into our mines, at Konkola in particular, isotope analysis has been undertaken on a number of occasions. The most recent isotope analysis was carried out at Konkola (FernandezRubio 1993) and will be discussed in detail by a later presenter to this conference. However, the recent isotope work (Mulenga 1991, Fernandez-Rubio 1993) conflicts dramatically with the earlier work (Sweeney and Schmidt 1988 and Leeds, Hill and Jewett 1972). See Figure 2.

Faced with these conflicting isotope results further study is required to resolve the paradox.

COMPUTER MODELLING

Computer modelling has been used at ZCCM's Konkola Division to predict the drawdown of the hydrostatic heads for a number of different mining scenarios. The modelling was based on an adaptation of a finite-difference mathematical model called MODFLOW, which was developed by the United States Geological Survey and adapted for the Konkola conditions by our external consultants, (Sharma, Cole and Straskraba 1991 and Straskraba, Sharma and Naish 1991).

The modelling was based upon an analysis of the dewatering history, pumping rates and drawdown rate in the mine, and the results of in-mine permeability testwork. The modelling has produced predictions for future dewatering requirements, based upon a number of different mining scenarios. Whilst conservatively based, the modelling has indicated that dewatering will not be a constraint, to the future increased production from the Konkola Deep Mining Project. Follow-up studies have indicated that the opportunity exists to significantly reduce dewatering drilling and development costs and pumping costs, as the result of the introduction of modern backfill technology (qv).

Computer modelling has undoubtedly considerably advanced our knowledge of the extremely complex hydrological and geological conditions at Konkola Division. It has also permitted a more rapid response to changing mining scenarios.

CHANGES IN MINING METHODS

The proposed changes in mining methods at a number of Copperbelt mines, with the introduction of modern backfill technology allied to cut-and-fill mining methods, offers ZCCM a significant opportunity to reduce dewatering costs.

Current dewatering practices are based upon the premise that hydrostatic heads in the hanging wall aquifers must be lowered to a position, below the intersection of the theoretical caveline (from a particular mining level) with the base of the aquifer, before production from that particular level is initiated. (Figure 3).

For a cemented hydraulic fill situation, where the ore removed is replaced by cemented backfill, we can geotechnically model the hanging wall subsidence. The computer output, using UDEC software, illustrates that hanging wall subsidence is reduced by over 90% to the base of the hanging wall aquifers. Under these circumstances, complete drainage of the hanging wall aquifers is not required. In the future, therefore, we shall pursue a course of hydrostatic pressure reduction in the hanging wall aquifers. This policy, recommended by our external consultants Hydro-Geo, with regard to the mining of the Nkana Division Zero Fold (HydroGeo 1991) has been endorsed by the Zambia Mines Safety Department, which has given its permission to reduce the hanging wall dewatering at Nkana. ZCCM will be looking to extend this policy to its other mines where cut-and-fill mining will be practised.

ENVIRONMENTAL ASPECTS

Zambia, unlike Zaire, holds the bulk of its ore reserves and resources in the form of sulphide mineralisation. Sulphide mineralisation throughout the world is normally synonymous with acid mine drainage. However, Zambia is extremely fortunate in that the host rocks for its mineralisation, and indeed the vast proportion of the Katangan cover rocks of the Copperbelt, are dolomitic in composition. The dolomites have the effect of buffering and neutralising the effects of acid mine drainage. The result is a significant environmental advantage, for which we are extremely thankful!

In addition, the large volumes of neutral water pumped from ZCCM mines acts to dilute the effects of any less environmentally friendly constituents to mine drainage. This allow ZCCM to operate as an environmentally friendly company, in the context of mine drainage.

ACKNOWLEDGEMENT

This paper is published with the kind permission of the Technical Director of Zambia Consolidated Copper Mines Limited.

REFERENCES

Fernandez-Rubio R	1991	Quantification of Konkola Mine Water Inflow by Source. FRASA Report No. 01 Konkola Hydrogeological Project Unpublished Co Report April 1993.
Geology Department ZCCM Ltd - Konkola Division	1985	The Konkola Water Problem Unpublished Co Report April 1985.
Hydro-Geo Inc	1991	Hydrogeological Study Nkana Zero Fold. Unpublished Co Report for ZCCM Ltd HydroGeo Inc. Lakewood Colorado Nov. 1991
Leeds, Hill, and Jewett	1972	Hydrologic Report on Konkola Un-watering Problem. Unpublished Co Report for NCCM Ltd. Leeds Hill and Jewett Inc. San Francisco California. June 1972.
Mulenga S C	1993	"Konkola Mine Groundwater Inflow" Unpublished Co Report, ZCCM Ltd - Konkola Division, Hydrogeology Dept 1993.
Mulenga S C	1991	Groundwater Flow through Konkola (Bancroft) Copper Mine - Zambia. Unpublished PhD Thesis Royal School of Mines, Imperial College, University of London - 259 pages.
Sharma D, Cole S E, and Straskraba V	1991	Mathematical Modelling of the Konkola Mine Dewatering. Proc 4th Int. Mine Water Congress Sept 1991 pp149-162.
Straskraba V, Sharma D and Naish E J H	1991	Konkola Mine Dewatering Study. Proc. 4th Int. Mine Water Congress Sept 1991 pp163-174.
Sweeney M A and Schmidt R M	1988	A Geochronological and Geochemical Study of Zambia Minewaters.
Whyte W J and Lyall R A	1969	Control of Groundwater at Bancroft Mines Ltd Zambia. 9th Comm Min and Metall Congress 1969 Paper 16. Inst Min and Metall London.

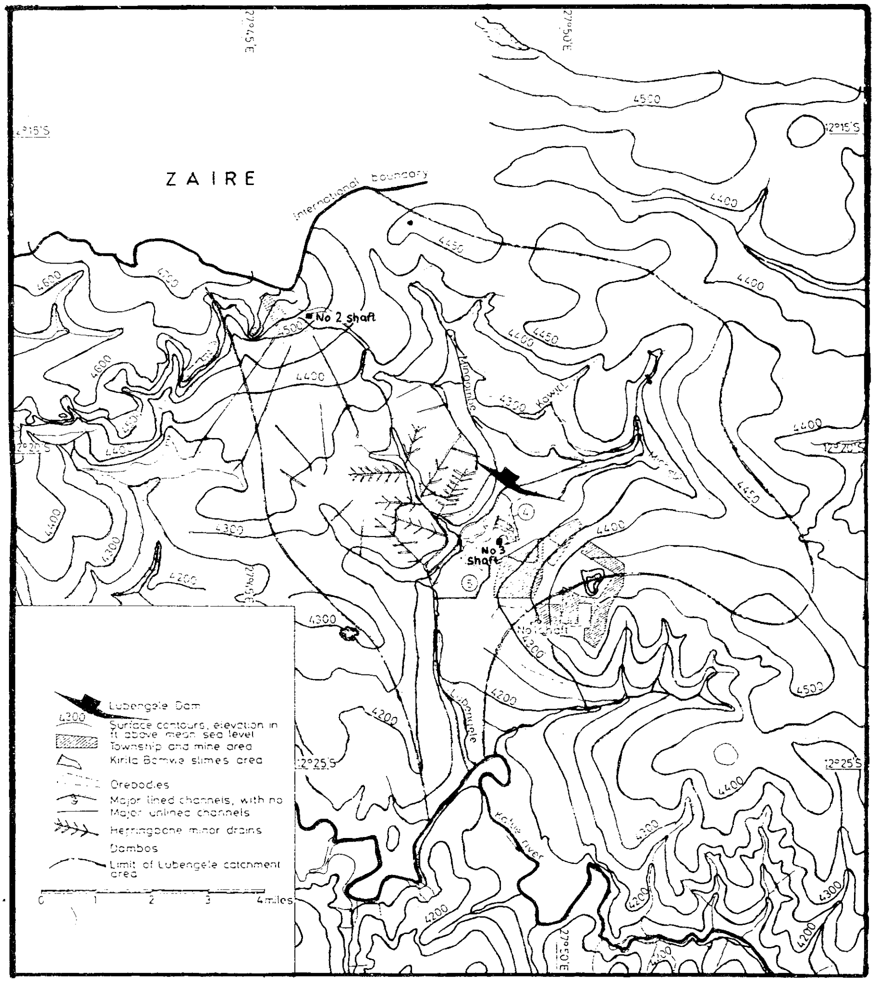

FIGURE 1 (after Whyte and Lyall 1969)

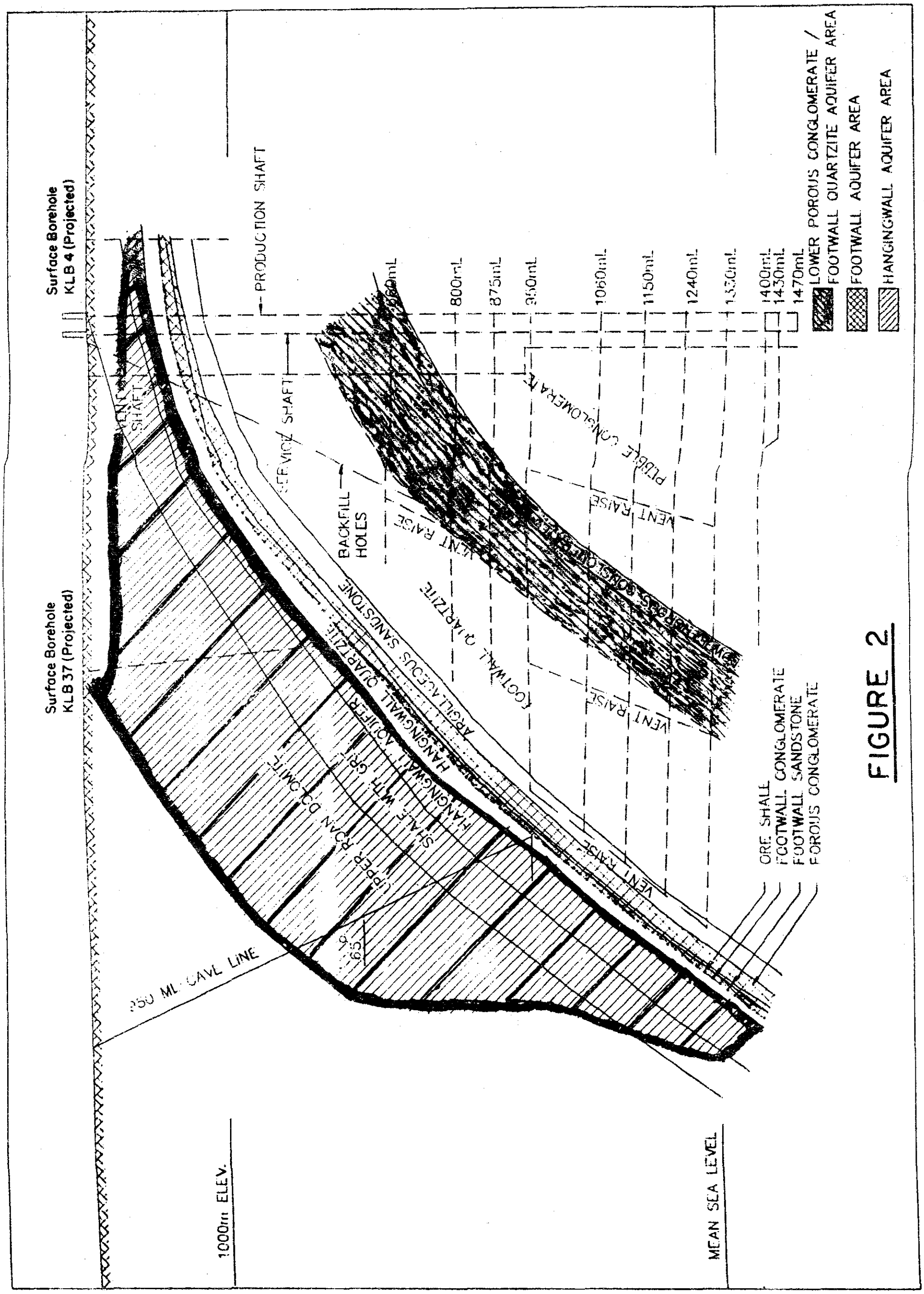
Surface Borehole
KLB 4 (Projected)
Surface Borehole
KLB 37 (Projected)
PRODUCTION SHAFT
SERVICE SHAFT
VENT SHAFT
BACKFILL HOLES
VENT RAISE
VENT RAISE
VENT RAISE
VENT RAISE
PEBBLE CONGLOMERATE
FOOTWALL QUARTZITE
ARGILLACEOUS SANDSTONE
HANGINGWALL QUARTZITE
HANGINGWALL AQUIFER
SHALE WITH GRIT
UPPER ROAN DOLOMITE
350 ML CAVE LINE
65°
800mL
875mL
950mL
1060mL
1150mL
1240mL
1330mL
1400mL
1430mL
1470mL
ORE SHALE
FOOTWALL CONGLOMERATE
FOOTWALL SANDSTONE
POROUS CONGLOMERATE
LOWER POROUS CONGLOMERATE / FOOTWALL QUARTZITE AQUIFER AREA
FOOTWALL AQUIFER AREA
HANGINGWALL AQUIFER AREA
1000m ELEV.
MEAN SEA LEVEL

FIGURE 2

AQUIFER	WATER AGE IN YEARS		RELATIVE AGES		
	1972	1988	1991	1992	
				1 #	3 #
Upper Roan Dolomite	3750	4660	—	—	—
Hangingwall Aquifer	2300	3975–4475	YOUNG	YOUNG	OLD
Footwall Aquifer	680	2655–4295	OLD	OLD	OLDE
Footwall Quartzite	N.A.	N.A.	—	—	YOUN
Lower Porous Conglomerate	N.A.	230–1115	OLDEST	OLDEST	—

FIGURE 3 COMPARISON OF TRITIUM RESULTS