Konkola Mine Dewatering Study

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ABSTRACT

The Konkola underground copper mine, located in the northern section of the Zambian Copperbelt, is one of the wettest underground mines in the world. Ground water inflow into Shaft No. 1 initiated in 1955 and since that time mine dewatering, water handling, pumping, and discharge have been an important and expensive part of mine operations. Reliable estimates of future mine water inflow and drawdown in various sections of the mine are essential for future mine planning.

The Zambia Consolidated Copper Mines, LTD is considering to substantially expand the underground mine and increase the ore production. The design and implementation of a new mechanized mining method with backfill is being considered for the flat part of the orebody. The proposed changes in mining methods and the deepening of the mine required reevaluation of the future mine drainage strategy.

The hydrogeologic study of the Konkola Mine included an analysis of the dewatering history, performance of in-mine permeability testing, and developing predictions for future dewatering needs. The predictions for future dewatering and assessment of drawdown in the major aquifers were based on the mining plans and were developed by adapting and applying a finite-difference mathematical model, called MODFLOW. This model was developed by the United States Geological Survey and adapted for the Konkola Mine conditions by Principia Mathematica, Inc. This adaptation, model calibrations, and applications are described in a separate technical paper presented by the same authors.

The complex geologic and hydrogeologic conditions of the Konkola Mine and the advanced stage of the mining operation made the task of computer dewatering simulation difficult and to a certain degree unique.

This paper presents the description of the hydrogeologic, mining, and mine dewatering conditions at the Konkola Mine, and discussions of the mathematical model application for practical solutions of the complex mine dewatering problems.

INTRODUCTION

The Zambian Copperbelt is situated approximately 13 degrees south of the equator and 28 degrees east of the Greenwich meridian. The copper deposits follow a strip of country about 50 km wide adjacent to the border of Zambia and Zaire, which extends for about 150 km from Chililabombwe in the northwest to Luanshya and Bwaba Mkubwa in the southeast (Figure 1). The ores of the Copperbelt occur in a metasedimentary sequence of late Proteozoic rocks belonging to the Katanga System, which overlie granites and other rocks of the Basement Complex. The Basement Complex on the Copperbelt forms the core of the Kafue Anticline, which is the dominant structural feature of the Copperbelt.

The Katanga System comprises rocks of the Mine and Kundelungu series and is separated from the Basement by a marked unconformity. The Mine Series consists of the Lower Roan, Upper Roan, and Mwashia Groups with the Copperbelt ore deposits being chiefly confined to the Lower Roan Group. The Mine Series varies from about 650 to 2300 m in thickness, largely as a result of the variation in thickness of the Lower Roan Group from zero to 1200 m. The stratigraphy of the Mine Series has been well-defined throughout the Copperbelt with lithostratigraphic sub-divisions. The Lower Roan is arenaceous at the base and ranges upwards through a mixed clastic sequence of shales, arenites and carbonates into the predominantly dolomitic Upper Roan which is succeeded by the carbonaceous shales and dolomites of the Mwashia Groups. The stratigraphic column at the Konkola Mine is shown on Figure 2.

The Konkola copper-cobalt deposit is composed of two orebodies separated by a barren gap. The North Orebody is opened by Shaft No. 3, and the South Orebody is mined from Shaft No. 1. Economic mineralization is present within the Ore Shale mostly in the form of chalkopyrite, bornite, chalcocite, and carrollite. The average copper grade is 3.8%, and the average cobalt grade is 0.07%. The orebody averages 7.6 metres in true thickness, but may range up to 24 metres.

The Konkola Mine, located in the northern section of the Zambian Copperbelt, is one of the wettest underground mines in the world. Ground water inflow into Shaft No. 1 initiated in 1955 and since that time mine dewatering, water handling, pumping, and discharge have been an important and expensive part of mine operations. Reliable estimates of future mine water inflow and drawdown in various sections of the mine are essential for future mine planning.

The scope of hydrologic studies for the Konkola Mine was to develop inflow and drawdown predictions for future mine operations. Predictions of future ground water inflow and drawdown are prepared by the Konkola Geology Department. In 1988, Hydro-Geo Consultants, Inc., a firm based in Denver, Colorado, specializing in mining hydrology, was retained by the Zambia Consolidated Copper Mines, LTD (ZCCM) and Mineral Resources Development, LTD (MRDL) to assist with the hydrologic studies, and future inflow and drawdown predictions for the Konkola Mine.

In December, 1989, the hydrologic study, including hydrologic computer modelling for the Konkola Mine, was completed. The modelling consisted of simulating ground water inflow into the Konkola Mine from year 1955 through 2020, with the use of a finite-difference ground water flow model called MODFLOW. Description of the modelling effort is the subject of a separate technical paper presented at this Congress.

KONKOLA MINE HYDROLOGY

The Konkola Mine is located at an elevation of 1330 metres above sea level. Most of the precipitation occurs during the wet season (November through March). Precipitation in the Zambian Copperbelt ranges from 1100 to 1600 mm annually. Evaporation measured at the Luano Catchments Research Project indicates an average of 1762 mm per year from a class A pan, which corresponds to about 1240 mm per year evaporation from a free water surface. Total evapotranspiration in the general area was estimated by various authors as 50 percent [(1)], 76 percent [(2)], and 80 percent [(3)] of total precipitation.

Most of the Konkola Mine area is drained by the Lubengele River, and a small southern portion of the area is drained by the Kakosa Stream. The surface streams generally flow toward the south, along the general strike of the area's strata. The two major perennial streams in the area are the Lubengele and its tributary, the Mingombe. Other local streams have small drainage basins and are ephemeral. Both the Lubengele and Kakosa streams discharge into the Kafue River approximately three kilometres south of Shaft No. 1. The elevation of the Lubengele drainage basin ranges from 1420 metres near Konkola village at the Zambia - Zaire border to 1265 metres at the confluence of Lubengele and Kafue rivers. In 1964 a dam was built at the Lubengele Stream upstream of Shaft No. 3. This dam has been used for tailings disposal since 1964. The Konkola Mine area drainage basin was calculated as 186.9 km^2.

Several studies addressing the potential stream losses into the ground water system, and finally into the mine were conducted between 1960 and 1973. The general conclusion of these studies of surface stream flow characteristics was that losses from Mingombe and Lubengele streams and the Kafue River in the general project area occur. However, these losses are not significant and will not impact to a great extent the Konkola Mine dewatering in the future.

The hydrogeologic characteristics of the Konkola Mine are very complex. There are three main aquifers adjacent to the orebody:

- Hangingwall Aquifer (dolomite, sandstone, siltstone);
- Footwall Aquifer (sandstone and conglomerate);
- Footwall Quartzite and the Lower Porous Conglomerate (quartzite and conglomerate).

The geologic formations of the Upper Roan Dolomite and the Lower Kundelungu (Kakontwe Limestone) located on the hangingwall of the orebody are also considered significant aquifers. Although the aquifers are lithologically separated by less permeable units (aquicludes), a potential hydraulic interconnection between aquifers is possible.

The aquifers have a combination of primary (i.e. inter-granular) and secondary (i.e. fracture) permeability. In the Hangingwall and Footwall aquifers and Lower Porous Conglomerate, primary permeability seems to prevail. In the Footwall Quartzite Aquifer, secondary permeability tends to predominate.

Ground water flow direction during pre-mining periods followed the local topography, toward the south and the water table was near the surface in most of the Lubengele drainage. In an area northwest of Shaft No. 3, artesian flow conditions were documented in several boreholes and springs. An artesian spring was reported by Irish [(4)] near the confluence of the Lubengele and Mingombe streams at an elevation of 1286 metres.

Recharge into the ground water system is evidently provided from infiltration of precipitation and downward percolation from losing sections of surface streams. The rate of infiltration was estimated by various authors between 7 and 40 percent of total annual precipitation. In our opinion, based on calibration of a computer model from the Kolwezi area in Zaire and comparison of hydrogeologic characteristics between the Kolwezi and

Konkola areas, the recharge in the Konkola area was originally about 12 percent of annual precipitation. However, the rate of infiltration of about 160 mm per year was applicable in the initial phase of mining. An extensive zone of influence was developed by many years of mine dewatering. To a certain degree the mine induced subsidence altered the infiltration patterns, by increasing permeability of the near surface strata due to the fracturing.

AQUIFER CHARACTERISTICS

During the past thirty years very few attempts to calculate basic hydrologic parametres of the area's aquifers have been made. Since July 1988 a total of 44 mine drainage boreholes were tested for permeability. Two types of tests, discharge and pressure build-up, were performed on the drainage boreholes. A total of 23 tests were performed at Shaft No. 1 and 21 tests at Shaft No. 3. The tests were distributed to various aquifers at different mine levels.

The following table shows the ranges and average values of hydraulic conductivity of the tested aquifers:

		HYDRAULIC CONDUCTIVITY m/day	
Aquifer	No. of tests	Range	Average Value
Shale with Grit	9	7.1 - 109.5	43.6
Hangingwall Aquifer	8	17.8 - 259.9	108.3
Hangingwall Quartzite	5	4.4 - 207.7	76.7
Footwall Aquifer	7	8.8 - 160.9	58.3
Footwall Quartzite	14	7.3 - 184.0	70.6
Lower Porous Conglomerate	1	8.4	8.4

The ranges of permeability values indicate the variability of hydraulic conductivity in both horizontal and vertical directions. Although the number of tests performed can not be considered sufficient for the great extension of the mine opening or the depth, ranges, and variability of aquifers, the results of 44 tests can be used to draw a significant conclusion.

The changes of permeability with depth are quite obvious from testing conducted in all three principal aquifers in Shaft No. 1. Values presented on the graph (Figure 3) for the Footwall Aquifer and Footwall Quartzite indicate a pronounced decrease of permeability with depth.

The trend of decreasing permeability with depth has been observed in many underground mining projects, and is due to the increasing weight of the overburden rock mass. Decreasing permeability with depth is a significant factor in predicting future inflow and drawdown values in any underground mine that is expanding downward.

KONKOLA MINE INFLOW

The Konkola Mine is known as one of the wettest underground mines in the world. The high inflow rates are caused by the following factors:

- Presence of several aquifers stratigraphically above and under the ore bearing strata;
- Potential for recharge from precipitation and local surface streams, swamps, etc.;
- Tension cracks associated with the Kirilabombwe Anticline which substantially increased permeability and storativity of the water bearing strata and caused interconnection between various aquifers.

The Konkola Mine drainage was initiated in 1955. Approximately 3,000 million cubic metres of water have been pumped from the Konkola Mine by the end of 1987. The total pumping rates ranged from less than 200,000 m^3/day in early 1960's to a peak inflow of over 400,000 m^3/day in 1980 and 1981. The inflow decreased to 359,452 m^3/day in December, 1988. The ratio of ore mined to water pumped ranged from 31 (tons of water pumped for one ton of ore mined) according to Howkins (1) to 74 (5). Recently, according to Tomkins (6), the ratio of tons of water pumped to the ore mined is 115. The history of measured and predicted inflows is graphically shown on Figure 2 of the modelling paper.

The distribution of water inflow into the Konkola Mine, Shaft Nos. 1 and 3 from the three principal aquifers has been changing with time. Percentages of inflow from the three main aquifers through the history of mine dewatering are shown on the following Table.

DISTRIBUTION OF WATER INFLOW INTO THE KONKOLA MINE

Year	References	Percent of Total Inflow		
		Hangingwall Aquifer	Footwall Aquifer	Footwall Quartzite
1962	Howkins	18.2	54.8	27.0
1972	Leeds, Hill, and Jewett	37.7	36.9	25.4
1985	(Konkola Geol. Dept.)	35.0	19.0	46.0
1988	(Konkola Geol. Dept.)	25.7	38.0	36.3

The interpretation of the distribution of water inflow into the Konkola Mine from the three major aquifers between 1971 and 1988 indicates that inflow from the Hangingwall Aquifer is decreasing, and inflow from the Footwall Quartzite is increasing. The inflow from the Footwall Aquifer has remained about the same. However, these conclusions are influenced by the location of development work and drainage drilling at the times listed in the table above. The percentage of inflow from the aquifers is related to the mining and dewatering activities.

The spatial distribution of inflow as presented on Figure 3 suggests that most of the ground water inflow into the Konkola Mine is from south and north, along the strata strike, and from northwest along the axis of the Kirilabombwe Anticline. Although most of the water is pumped from Shaft No. 1, a considerable volume of ground water enters the Shaft No. 3 area.

Development of the zone of influence and the drawdowns in water bearing strata due to mine drainage have been monitored by pressure and flow measurements in underground drainage boreholes, measurements of water levels in surface boreholes and Shaft No. 2, and by observations of discharge from several springs. Long term monitoring indicate that a considerable zone of influence has developed over the 32 years of mine drainage. Our estimate, based on water levels, springs monitoring and on an interpretation of the regional geology, indicates that the shape of the zone of influence is basically elliptic, with the elongated axis in north-south direction. The radius of the zone of influence is about 15 km along the north-south axis and 3 to 8 km along the east-west axis. The area of the zone of influence is estimated between 170 and 236 km^2.

The drawdown from the pre-mining water levels is substantial. A pre-mining potentiometric surface map for the general area was developed from the available water level and pressure measurements, and by the Konkola Hydrologic Model Calibration - steady state. Assuming a pre-mining water table in the Shaft No.1 area at an elevation of approximately 1260 metres, a maximum drawdown of over 860 metres was reached at certain sections at the 950 m level, by the end of 1988. The average drawdown in the general area of Shaft No. 1 and 3 is at least 250 metres.

DEWATERING METHODS

Dewatering in the Konkola Mine is accomplished by driving drainage drifts, and by drilling drainage boreholes from drainage crosscuts. Drainage drives and crosscuts are mined slightly below the levels of haulage drifts to improve drainage. The Footwall Quartzite was not originally dewatered, however after reaching the 660 m level (1984), high pressure caused the need for continuous dewatering.

Most of the drainage drives in Shaft No. 1 are mined in the Footwall Quartzite, and in the Argillaceous Sandstone in Shaft No. 3. However, a considerable amount of mining has been completed in the other formations as well. Two major water inrushes from the Footwall Quartzite occurred in the past with initial flows of 45,000 and 60,000 m^3/day. The later flow occurred on the 410 m level of Shaft No. 3 and flowed for seven years. Most of the footwall haulages, stope box raises, grizzly drives, and crosscuts are mined in the Footwall Aquifer.

Reduction of water inflow during development driving in the Footwall Quartzite is achieved by cover drilling and grouting. In the more fractured lower section of the Footwall Quartzite a five borehole cover is typically used. In the low fractured sections a one borehole cover is typically used. Prior to blasting, five additional jack hammer holes are usually drilled. The cover drilling is increased in sections with large water inflow. Cover boreholes are grouted until the discharge is reduced to about 50 m^3/day.

The open stoping mining method used at the Konkola Mine requires dewatering of the Hangingwall Aquifer. The theoretical subsidence cracks above the stopes propagate at an angle of 65° to surface. Ground water within the zone which is theoretically impacted by subsidence has to be drained prior to stoping. Dewatering of the Hangingwall Aquifer is accomplished by the mining of dewatering crosscuts into the base of the aquifer, and drilling of dewatering boreholes. The crosscuts are driven under a cover of pilot boreholes.

The dewatering crosscuts are developed at approximately 1000 metre centres along the main drainage drifts. The future dewatering activities will concentrate on levels 950 m and 1180 m. Dewatering boreholes are drilled from the drilling bays into the Hangingwall Aquifer, most of the time. However, the Shale with Grit, and Upper Roan Dolomite are also dewatered through boreholes. The locations of the main dewatering centres are shown on Figure 1 of the modelling paper.

Dewatering of the Footwall Aquifer will be enhanced by drilling of drainage boreholes from the Drainage Drifts at levels 950 m and 1180 m at approximately 100 metre centres. Dewatering of the Lower Porous Conglomerate (LPC) is currently underway at the 660 m level, at 2000 m N by drainage boreholes.

Ground water discharge into the mine is divided into two categories, controllable and uncontrollable. Controllable discharge can be shut off in case of power or pumping equipment failures. If the ratio between uncontrollable and controllable water reaches a certain value, measures to reduce inflow are implemented.

The present sustained pumping capacity to the surface is 502,507 m^3/day. However, most of this capacity (about 400,000 m^3/day) is on the 370 m level and cannot be used, as it is not supplied with enough water from the lower levels due to the current pumping scheme [7]. Most of the pumping capacity is provided by low and high lift centrifugal pumps. The use of submersible pumps is limited. Plans for the future include installation of a pumping station at the 1430 m level. This pumping station will deliver water directly to the pump chamber at the 985 m level. Shafts Nos. 1 and 3 are interconnected by drainage drives at levels 345 m and 660 m.

FUTURE MINING AND DEWATERING PLANS

Most of the mine development in the future 25 years will concentrate on the 500 to 1100 metre levels in Shaft No. 1 and on the 500 to 870 metre levels in Shaft No. 3.

In order to accomplish the proposed mining plans it is essential that the dewatering continues ahead of the ore extraction. Typically, in the history of mining in both Shaft Nos. 1 and 3, mine development and dewatering drilling preceded the ore extraction by 1.5 to 2 years.

The general method of ore production is sub-level open stoping. In Shaft No. 1 (South Orebody) most of the current production is by gravity stoping, while in Shaft No. 3 (North Orebody) scraping was necessary in sections of the orebody with low dips.

In the future, the mining methods in the steeply dipping South Orebody and in the low dipping sections of the North Orebody, could change to mechanized cut and fill methods with cemented backfill. The use of backfilling will have an impact on the required degree of dewatering. Depending on the type of the backfill and its placement, sections of the mine to be backfilled and the time of mining, a reduction in the need of dewatering should be considered.

The results of the Konkola Hydrology Modelling indicate that with the application of the proposed dewatering, and the drainage drifts at the 950 m and the 1180 m levels, there should not be any significant problems with the proposed mining schedule.

The mine inflow will be decreasing with time when deeper sections of the Konkola

Mine ore are reached. The inflow will be relatively steady, with a range of 244,000 to 296,000 m^3/day through 1994. After 1994 the inflow will substantially decrease. By the year 2007 the inflow will drop below 200,000 m^3/day, and between years 2004 and 2017 the inflow will be in a range of 154,000 m^3/day to 192,000 m^3/day. Water inflow into the Konkola Mine will very probably never drop below 140,000 m^3/day. The presented predictions after year 2017 are not considered as final because detailed development and mining plans were not available at the time of the completion of this study.

The drawdown corresponding to the dewatering rates will be quite satisfactory for the proposed mining plans. Water level elevations from 1988 through 2020 in various sections of the Hangingwall Aquifer at the Konkola Mine (both Shaft Nos. 1 and 3) were summarized. The comparison of mining plans in Shaft Nos. 1 and 3 through year 2010, with the predicted drawdown indicate that in Shaft No. 1 in year 1990/1991 at 1500m N of the 950 m level, the water level elevation will be about 68 metres below the 950 m level cave line. In the other sections of Shaft No. 1 the water level in the HWA will be at least 100 metres below the HWA cave line. A marginal dewatering could be experienced in years 2005 through 2007 at 800 m S where a dewatering crosscut at level 950 m is at the same level as the planned stoping.

Results of modelling for Shaft No. 3 indicate that commencing in year 1991 there will always be about 100 metres difference between the cave line and water level elevation through the year 2010. After year 2010 the water level elevation approaches the cave line elevation in sections at the Nose. However, a minimal difference between the cave line and the predicted water level of 20 metres should be sufficient for the proposed mining.

The dewatering concept for the Konkola Mine is based on driving main dewatering drives about one year ahead of the sub-level development. The sub-level development starts one to two years ahead of stoping. Dewatering drilling sites are located on dewatering crosscuts mined from the dewatering drives at regular, typically 1000 metre, intervals.

At this time the main dewatering drives are mined at the 800 m, 875 m, and 950 m levels in Shaft No. 1 and on the 590 m level in Shaft No. 3. The drain drive at the 950 m level is the major dewatering feature for the entire mine. According to the existing plans, this drainage drive will be mined at a speed of 100 metres per month. In March 1989 the drainage drive reached 1850m N, and will continue in the northwestern direction through station 3550m N. At this point the drainage drive will split in two sections. The first will continue in the same direction (northwest) and should reach the "Nose" area at 5500m N dewatering crosscut by 1997. The second section heading northeast and aimed at dewatering the North Limb, should reach the Nose area and connect with the Northwest Nose section by 2018. For location of the drainage drive please look at Figure 1 of the modelling paper.

Results of the computer modelling indicated that with the increasing depth of the mine, the ground water inflow will be decreasing. The estimated decreasing permeability with the increasing depth did not substantially change the computer modelling results. The decreasing permeability of the water bearing strata will cause the dewatering of the strata to be slower.

CONCLUSIONS

The Konkola Mine is considered one of the wettest underground mines in the world. Mine dewatering, composed of dewatering drifts and cross-cut mining, drainage borehole drilling, and water pumping and treatment are important and expensive parts of the mining operation.

The plans for future increase of the ore production and a substantial deepening of the mine require accurate future water inflow and drawdown predictions. The predictions of ground water inflow into the mine and development of drawdowns in various parts and levels of the mine were based on computer simulations with a finite-difference numerical model called MODFLOW. The computer modelling was preceded by a detailed study of the hydrologic and hydrogeologic characteristics of the Konkola Mine, including extensive permeability testing.

Knowledge of the hydrologic characteristics of the mine was necessary for the successful application of a numerical model and simulation of ground water flow and drawdown development in such complex geologic and hydrogeologic conditions. The applied computer model proved to be a useful tool for mine planning, and for the prediction of future inflow and drawdowns in particular.

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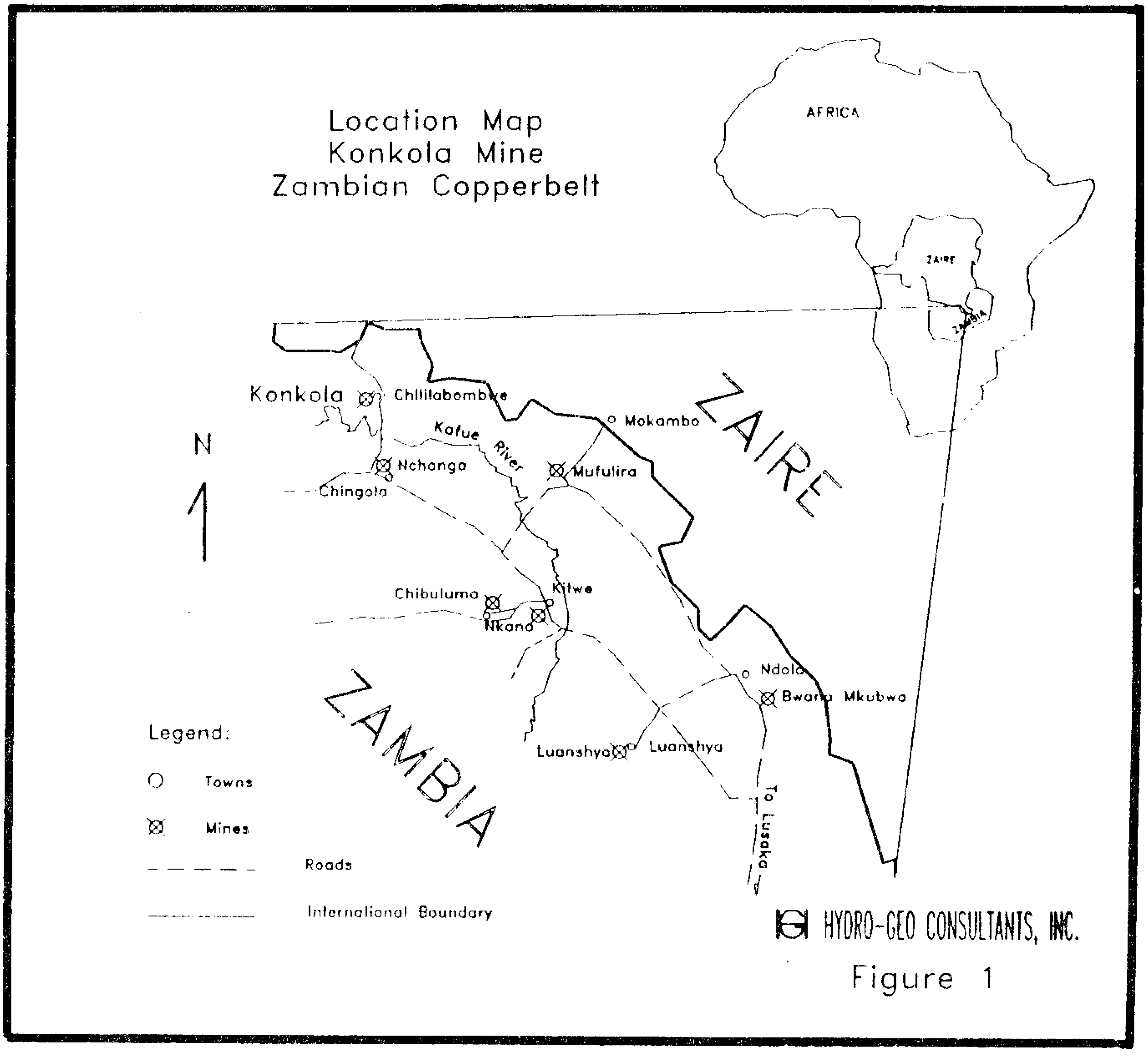
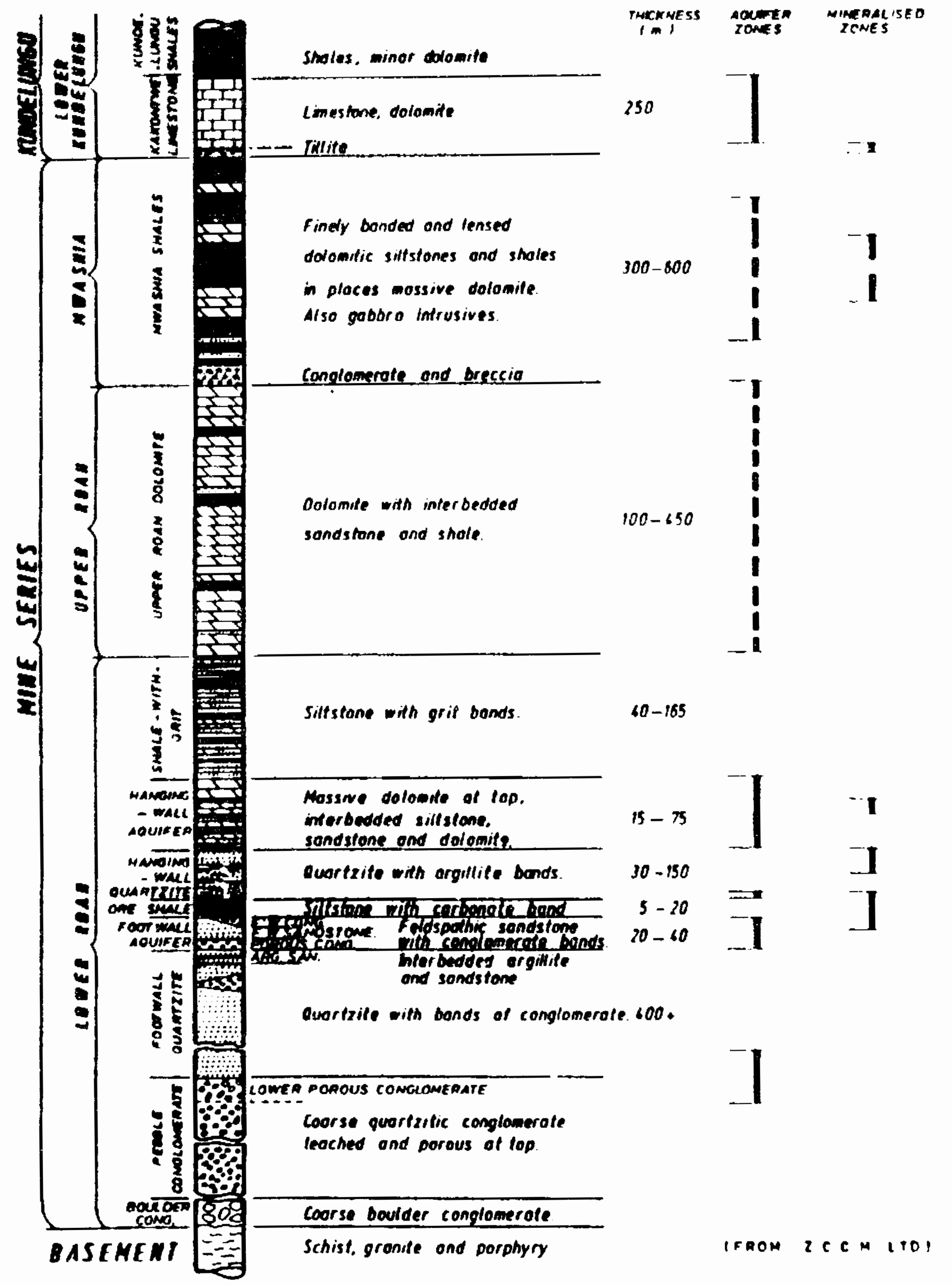


Location Map
Konkola Mine
Zambian Copperbelt
AFRICA
ZAIRE
ZAMBIA
N
Konkola
Chililabombwe
Kafue
River
Nchanga
Chingola
Mokambo
Mufulira
ZAIRE
Chibuluma
Kitwe
Nkana
Ndola
Bwana Mkubwa
ZAMBIA
Luanshya
Luanshya
To Lusaka
Legend:
Towns
Mines
Roads
International Boundary
HYDRO-GEO CONSULTANTS, INC.

Figure 1



KONKOLA STRATIGRAPHIC COLUMN HYDRO-GEO CONSULTANTS, INC.
FIGURE 2

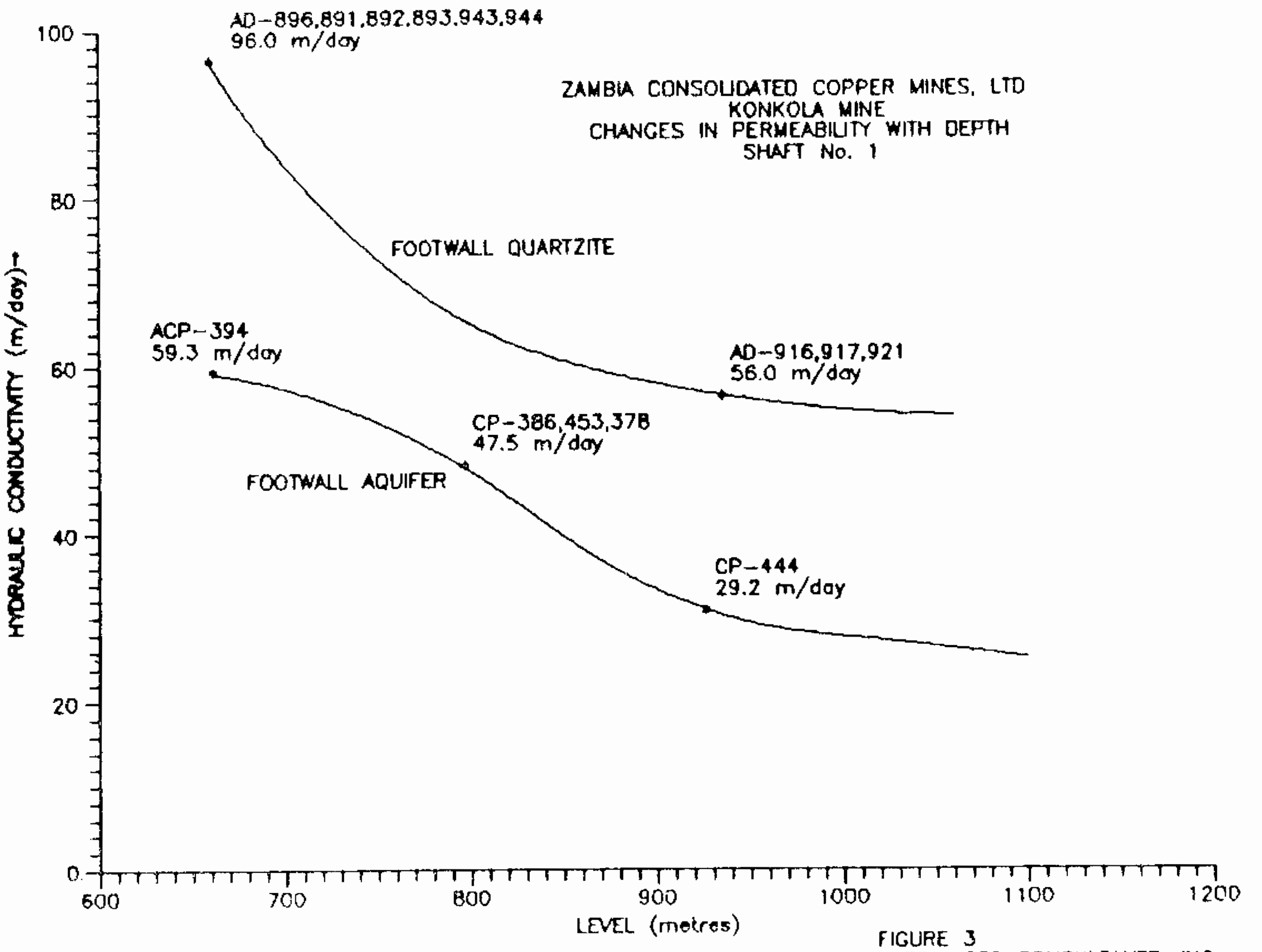
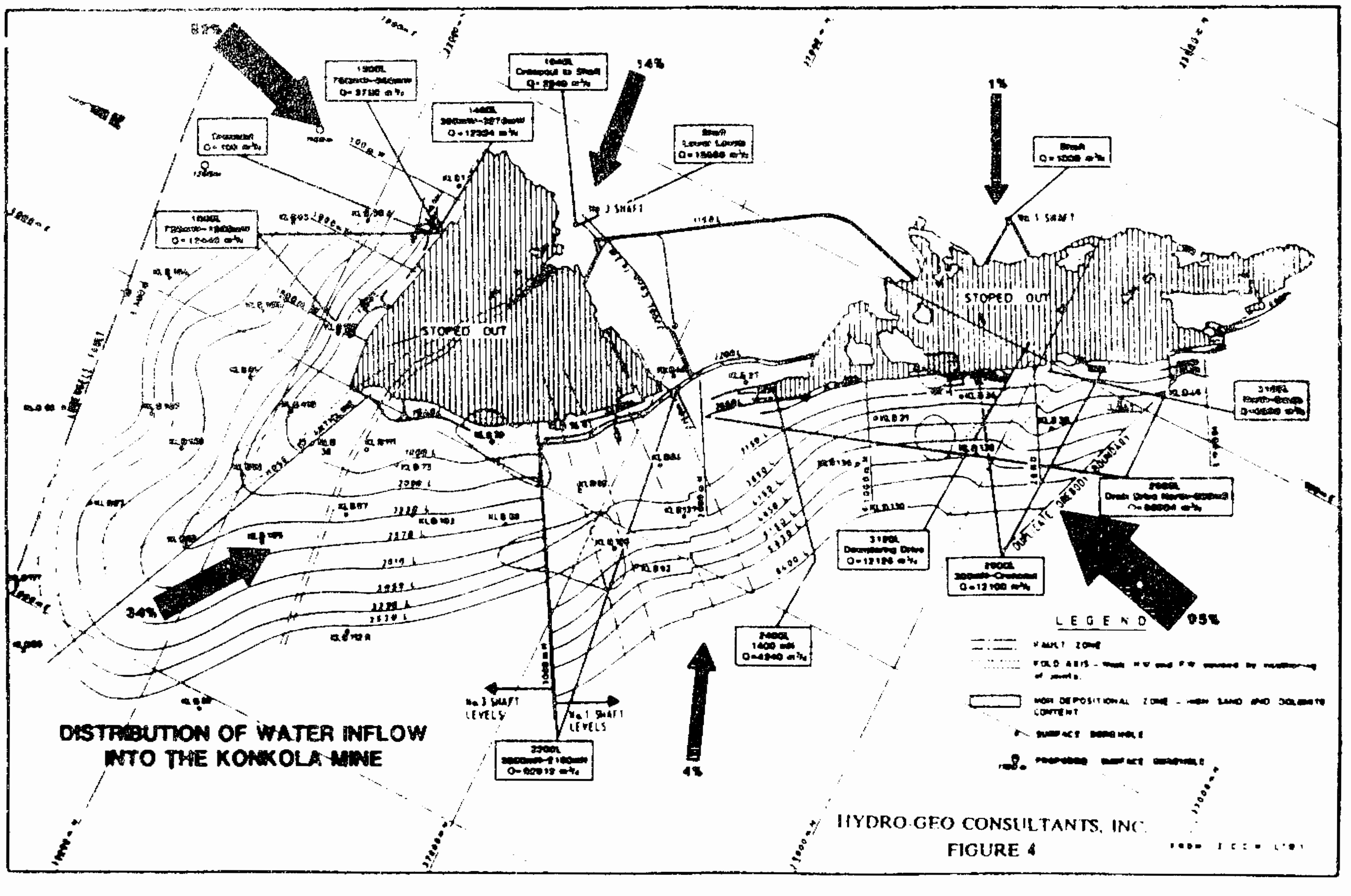


FIGURE 3
HYDRO-GEO CONSULTANTS, INC.



HYDRO-GEO CONSULTANTS, INC
FIGURE 4