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DEWATERING OF THE OPEN PITS AT LETLHAKANE AND ORAPA DIAMOND MINES, BOTSWANA

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ABSTRACT

Kimberlite pipes are mined open cast for diamonds at Orapa and Letlhakane in Botswana. The kimberlites are very low permeability even when weathered but are saturated due to high ground water levels. The country rocks of basalts overlying sandstones contain significant quantities of water at various piezometric pressures.

A very large kimberlite pipe is mined at Orapa and 2 small ones at Letlhakane. Investigations showed that dewatering was necessary at the latter and a perimeter deep well system was installed in 1982. The piezometric pressures in the country rocks have been successfully maintained below the pit floor, though some modifications will be required in future as mining goes deeper.

The Orapa kimberlite was shown to be too large and too low permeability to be successfully dewatered with wells or a gallery. Recommendations were given to reduce the problems created by wet kimberlite, in terms of day to day mining operations.

I INTRODUCTION

Orapa is situated 250km west of Francistown in Botswana, on the edge of the Kalahari Desert. Diamonds were discovered in the area in 1976 and the mine was established at Orapa (AKI) in 1970. The Letlhakane mines, DK1 and DK2, were established in 1974 about 45 km to the south east of Orapa. See Fig 1.

The main kimberlite pipe at Orapa is 1 700 metres long and 900 metres across and represents the second largest kimberlite pipe in the world after Williamson's mine in Tanzania. DK1 and DK2 pipes are much smaller being 400 and 200 metres diameter respectively.

The climate is semi-arid with summer rainfall. Mean annual precipitation is 389 mm. There are no perennial streams in the Orapa area but the natural water table is 10 to 20 metres below surface, therefore water problems would have been encountered early in the life of the open pits.

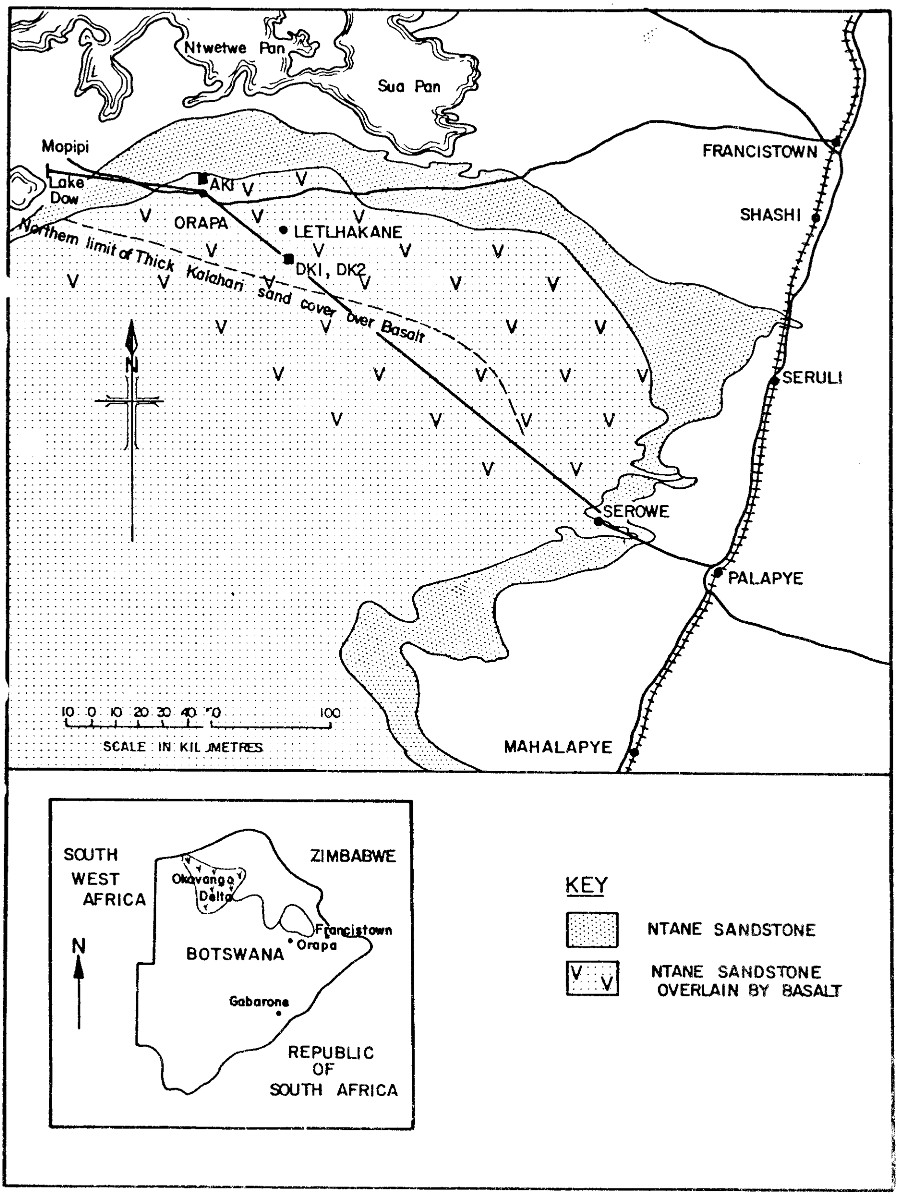


FIGURE 1. LOCALITY PLAN AND GENERAL GEOLOGY

To ensure rational forward planning of mining operations, slope stability and dewatering studies were undertaken before the water was reached. Feasibility studies were followed by design and implementation and this paper gives a brief overview of the investigations and describes the existing dewatering systems.

2 DEFINITION OF THE PROBLEM

Ground water affects mining in many ways. The main influences can be summarised :

- large inflows to a pit can result in flooding and interruption of production

- the presence of water increases the cost of drilling and necessitates the use of more expensive, water resistant explosives

- water pressures and flows in pit side slopes, promote instability

- wet pit conditions increase wear and tear on equipment and provide uncomfortable working conditions

- in weathered kimberlites, the presence of water aids in deterioration of running surfaces which become very slippery, and make handling of ore difficult

The problem is to compare a wet and dry pit in terms of costs. A decision can then be made as to whether a dewatering system may be warranted. If so, what type of system is suitable.

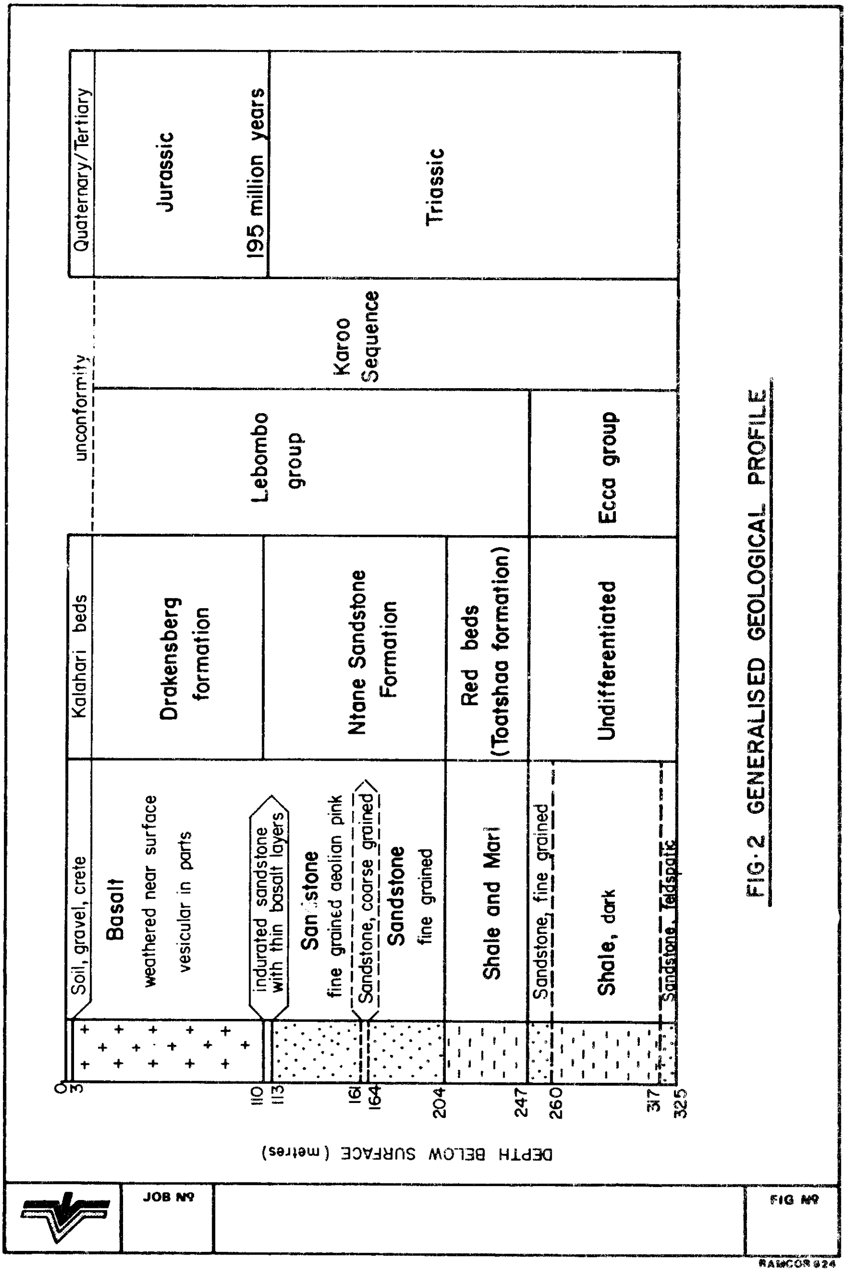
A further important consideration is that extraction of water from a dewatering system could become an important water supply, as surface water resources are scarce.

3 GEOLOGICAL SETTING

The geology of the area is fairly uniform consisting of recent Kalahari sediments of sand, silcrete or calcrete, overlying Drakensberg basalt which in turn overlies the Ntane sandstones and shales of the Ecca Group. The Karoo sediments form a sedimentary basin and Orapa lies on the northern edge as shown in Fig 1. The overlying basalts are about 140 metres thick at Letlhakane, 100 m at Orapa and thin out to expose the Ntane sandstone to the north and west of Orapa. The generalised geological profile is shown in Fig 2.

The Kalahari sand cover is about 1,0 metre at Orapa and 5 to 10 metres at Letlhakane. Although the cover is very thin, the very flat country does mean that exposure of the basalts is very poor.

The five main geological units are described in more detail, as they all have an influence on dewatering.



FIG·2 GENERALISED GEOLOGICAL PROFILE

3.1 The Kalahari Beds

The Kalahari beds consist of fine silty sands which are calcretized or silcretized in places. The sediments do contain water, which the local inhabitants tap with shallow hand dug wells. The water quality however, if often poor due to the proximity of the water table to the ground surface and the influence of evaporites.

3.2 Drakensberg Basalts

The basalt thickness at AK1 is about 100 metres and up to 140 metres at DK1 AND DK2. The basalt is very hard, massive and amygdaloidal in places. The rock is very weathered to depths of 10 to 20 metres below surface, but occasional, very weathered zones are recorded at depth in borehole core. Sellschop et al (1973) report that the base of the basalt, at the contact with the Ntane sandstone, is also highly weathered, possibly due to water flowing along it.

The basalt is well jointed and the major joints show clearly on aerial photographs. The primary permeability and porosity of the basalts is very low. Secondary permeability has developed along zones of weathering and joint zones. Various pump tests reported in the available literature indicate that although yields from the basalts are not usually great, wells passing through the basalts to the underlying sandstone do draw water from storage in the basalts. The contact zones between the major lava flows form important groundwater horizons.

3.3 The Ntane Sandstone

The sandstone is generally fine grained and occasionally medium and coarse grained, orange to white in colour. Sellschop et al (1973) report that the quartz grains are partially sorted and quite well rounded and apparently of aeolian origin. The sandstones are reasonably porous and permeable, though calcareous and siliceous cemented zones do occur which may result in less permeable zones.

The Ntane sandstone is well known as an aquifer over large areas of Botswana. At the top of the sandstone section, is an indurated zone about 3,0 metres thick, with thin layers of basalt. Below this layer, groundwater is usually good quality, fairly plentiful and under artesian pressure. The indurated zone appears to confine the water, but does permit the vertical downflow of water from the basalt into the Ntane sandstone; Sellschop et al (1973), Sir Alexander Gibb and Partners (1969). It was later shown that the upper zone of the Ntane sandstone was not the only water bearing horizon, and that better yields could be obtained from other zones, deeper in the sandstone. The aquifer yields water from primary and secondary features.

3.4 Red Beds

Below the Ntane sandstone are shales referred to as the "red beds", underlain by Ecca shales. These are locally termed the Toatshaa formation (Geological Survey Department 1979). It has been found (Sellschop et al 1973) that water from these beds is very highly saline. Very little information has been obtained but the shales probably respond as an aquiclude.

3.5 Dolerite

Post Karoo dolerite dykes occur in many parts of the Kalahari, particularly to the North East of the Orapa area. These would presumably have an influence on the flow of groundwater but none have been positively identified at AK1 or DK1/DK2. There are a number of large linear features visible on the air photographs but whether they are dykes or major joints has not be proved.

3.6 Kimberlite

Kimberlites were intruded in the Cretaceous period about 90 million years ago. The kimberlite in all three pipes, shows a general progression from highly weathered, buff coloured kimberlite to a depth of up to 100 metres. This is underlain by red, green and finally blue kimberlite in the fresh, unweathered state. AK1 shows a sequence of sedimentary or reworked kimberlite in the centre of the pit. The clayey nature of the weathered kimberlite and massive nature of the unweathered rock mean that hydraulic conductivities are very low.

3.7 General Geological Structure

On a regional scale, the Karoo strata are gently warped in basin structure and a few minor fold structures have been observed. However, deformation has been of an essentially brittle nature producing a rather complex fracture pattern. (Geological Survey Department 1979).

4 APPROACH TO INVESTIGATION

From 1969 a number of workers have investigated aspects of the ground water at Orapa for the mine. These included:

Gibb (1969), Sellschop et al (1973), Australian Groundwater Consultants 1974, Steffen, Robertson and Kirsten 1980, 1981 and Geological Survey Department (1979).

A considerable amount of hydrogeological information was therefore available. A review of this information provided sufficient information for first phase assessments of dewatering requirements, and limited amount of subsequent drilling and testing for full feasibility assessments.

The first phase of investigation concluded that dewatering systems for all three pits should be considered and a second phase investigation was done. This included geophysics to locate structures defined on air photographs, drilling exploratory wells and boreholes for piezometer installation, packer permeability testing of specific horizons and test pumping.

From this information hydrogeologic 'models' of each area were prepared.

5 HYDROGEOLOGIC SETTING

5.1 Piezometric Surface

A large number of wells have been drilled in the Orapa - Letlhakane area by the geological survey and the mine, in the development of rural wells and wellfields for mine supply. Details of these boreholes have been reported previously (Sellschop et al 1973; Geological Survey Department, 1979) and will not be presented here. For these observation observation points a piezometric contour plan of the area was compiled by the Botswana Geological Survey and published on a 1:50 000 preliminary hydrogeological map. The contours were presented as depth of piezometric surface below ground surface. These values were reduced to a piezometric surface elevation plan by the authors, and reproduced on Fig 3.

Although generalised, the plan does show the direction of ground water flow towards the north-east at a gradient of about 1 in 400.

In the Orapa and Letlhakane region, the piezometric surface is generally between 10 and 15 metres below surface.

Any piezometric surface plan must be viewed with caution. Table 1 presents results of multi-level piezometer installations. The key points to note are that a perched water table exists in the superficial deposits and a confined piezometric level exists in the Ntane sandstone which is usually 20 metres below the perched water table. Regionally there are some holes penetrating the sandstone which are flowing artesian. Piezometric elevations within the basalt are erratic. There can be considerable variation in water levels recorded in open boreholes depending on the relative hydraulic conductivity and thickness of the various horizons penetrated.

TABLE 1 : PIEZOMETER INSTALLATION DETAILS AND WATER LEVEL MEASUREMENTS

Bore-hole No	BH Total depth (m)	Casing depth (m)	Piezo-meter No	Geologic formation	Piezo-meter depth (m)	Depth to water level (m)*	Piezometric surface elevation (mamsl)
PZ1	164,0	20,0	3	Calcrete	28,00	5,724	1 007,27
			2	Basalt	72,50	7,466	1 005,52
			1	Cave sandstone	149,00	11,974	1 001,02
PZ2	200,0	18,8	3	Calcrete	24,00	5,090	1 008,12
			2	Basalt	68,42	5,241	1 007,95
			1	Cave sandstone	144,00	24,501	988,66
PZ3	200,0	12,0	3	Calcrete	28,00	5,597	1 007,60
			2	Basalt	74,45	17,943	995,24
			1	Cave sandstone	157,00	30,206	982,26

* Water levels on 09.05.81

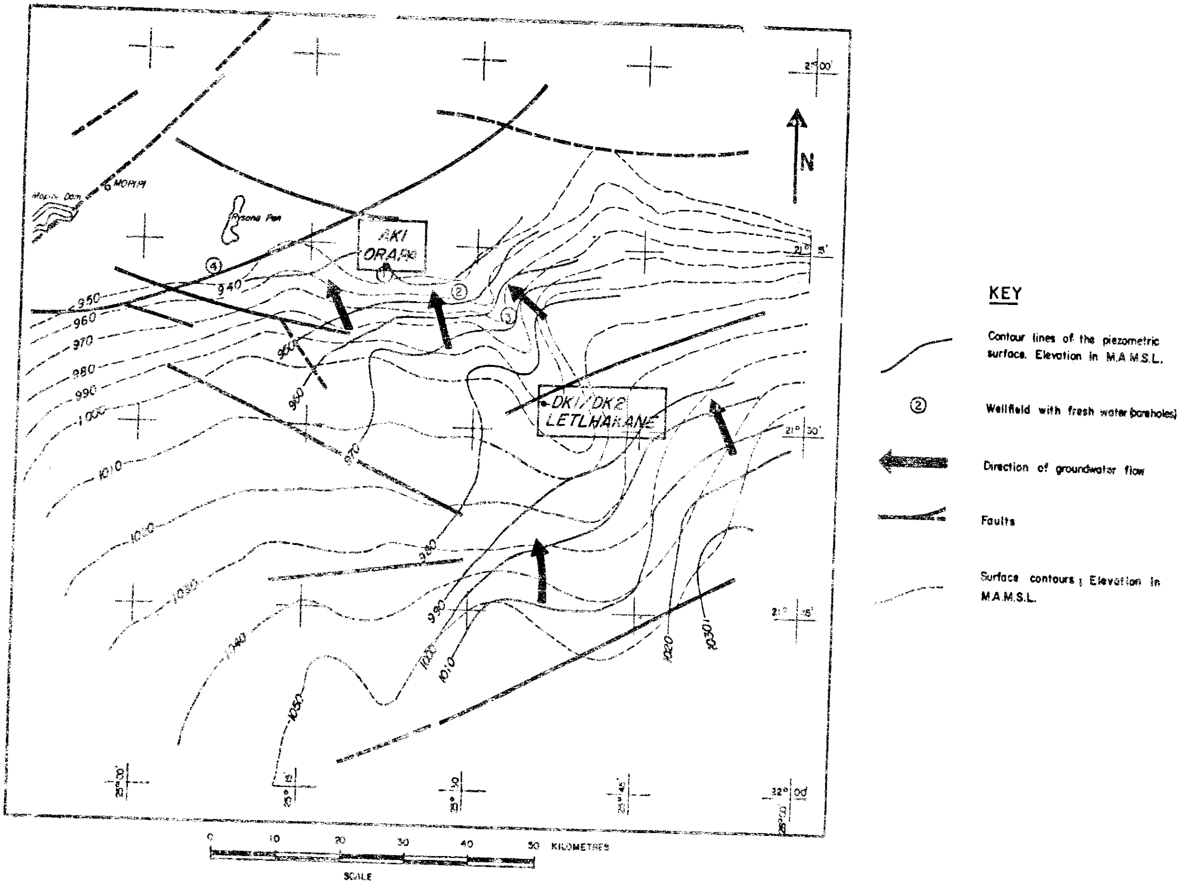


FIGURE 3 PLAN SHOWING REGIONAL GROUND SURFACE AND PIEZOMETRIC SURFACE CONTOURS

5.2 Transmissivity and Hydraulic Conductivity

For the purposes of this paper detailed results are not discussed. A summary is presented in Fig 4.

The diagrammatic model given represents the AK1 pit. The DK1 and DK2 pits are similar but with two important differences:

1 There is no sedimentary (reworked) kimberlite at DK1, DK2 and the hydraulic conductivity is about $1x10^{-5}$ cm/sec.

2 The kimberlite - country rock contact appears to be more open at DK1 and DK2 and possibly acts as a water conduit.

6 THE DEWATERING SYSTEMS

The hydrogeologic model for each of the pits is fairly well understood and a number of options for dewatering were available.

1 Deep wells

Placed around the perimeter of the pit, sited according to mine planning requirements, and to minimise interference with the mining operation.

The objective of these wells would be to fully penetrate the sandstone aquifer and reduce piezometric levels, and to dewater the upper calcrete and basalt aquifers. This would reduce flows towards the kimberlite and assist in stabilizing the pit side slopes.

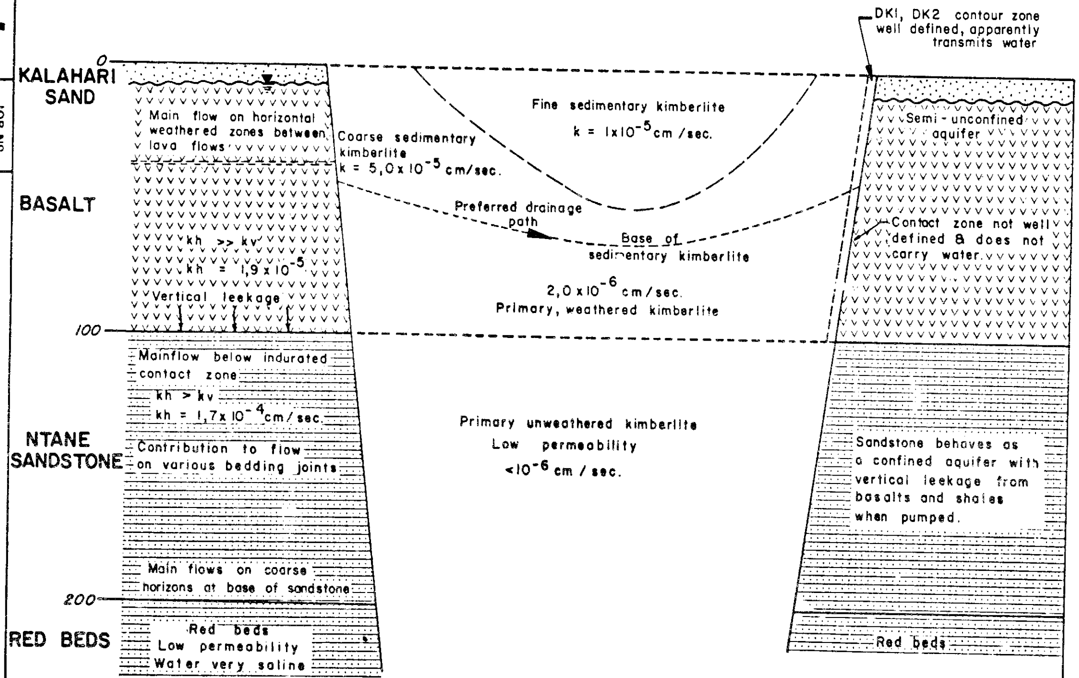
Test pumping of wells outside the pipe contacts showed minimal drawdown on wells in the kimberlite. The hydraulic conductivity of the kimberlite is too low to achieve effective gravity drainage but prevention of lateral recharge to the kimberlites would reduce the long-term flows from the kimberlites, and permit mining to a steeper side slope angle.

Allowing for interference effects and maintenance shut downs it was calculated that 7 wells should be sufficient for DK1 and 5 for DK2 assuming a well separation of about 400 m and sited 200 m from the pit centre. At AK1 an initial 16 wells would be required. After detailed field tests on the permeability of the kimberlite it was recognised that the kimberlites could not be cost effectively pre-drained but that significant benefit would be obtained from depressurising the sandstones, and draining the country rocks.

An important consideration was the vertical jointing in the basalts and sandstones which is difficult to intersect with vertical boreholes. There are however, adequate horizontal features which provide hydraulic continuity.

2 Drainage Gallery

Drainage galleries are tunnels which are excavated at depth, usually behind the final pit face and can be a very effective means of dewatering because of the high surface area exposed for drainage. They are however, initially expensive and careful consideration of costs and benefits



DIAGRAMMATIC REPRESENTATION OF THE HYDROGEOLOGIC MODEL.

JOB Nº		FIG Nº
2523	ORAPA DIAMOND MINE	4

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is required. Reliability is improved and running costs are lower than a conventional well system. A gallery would not interfere with any mining operations and could be used to assist evaluation of the orebody at depth. The position and size of the gallery is important as shown by Sharp (1970).

The optimum position for a gallery at AK1 would be at a depth of 200 metres, equivalent to the base of the Ntane sandstone. The lateral position would depend on mine planning, but it should be within the kimberlite and away from the contact with the sandstone. This would provide ore grade information and diamond recovery could offset some of the development costs. A vertical shaft would be required, which would have to be sited outside the perimeter of the final open pit. Tunnelling conditions can be expected to be fairly good, as the ground is not highly weathered and jointing is not well developed. A gradient would have to be built into the gallery to enable seepage water to flow back to the shaft. A series of radiating holes would have to be drilled upwards and sideways towards the Ntane sandstone from the tunnel to intercept the horizontal features.

The ratio of the radius of the tunnel to depth below piezometric surface, also influences the affect on drawdown. In this case, the effective radius of the tunnel will be considerably augmented by the radial drilling, therefore tunnel size will not matter, provided there is sufficient access for drilling machines.

3 Toe drains and sumps

Sub-horizontal boreholes drilled into the slopes from the benches, are used mainly for slope stability purposes. They have a disadvantage in that they cannot be drilled until a face is developed. In the Orapa and Letlhakane environment, the horizontal features carrying the groundwater would have to be intersected to be effective, therefore the benefit of such holes would probably be limited.

Toe drains are usually used in conjunction with a sump from which the water is pumped out of the pit. Sumps are required in any pit, to cater for storm water. In a pit the size of AK1, two sumps would be required with one each in DK1 and DK2. The storm water requirement would be larger than the side slope seepage requirement, therefore the sumps should be sized according to the former.

4 Control of surface water

The ground surface around all three pits is very flat and no water courses apparently pass through the pits. A perimeter road with a small earth berm would probably be adequate to control surface storm water.

5 Costs and timing

Drainage galleries, deep wells and toe drains each have timing and cost implications. Drainage galleries are a high capital expense, with low running costs but take time to install. Deep wells can be installed progressively giving lower capital costs, higher running costs, but can be installed quickly. The above considerations must therefore be built into the mine planning and dewatering method selection process.

Final selection for each of the pits is described below.

Letlhakane Mine (DK1, DK2)

Test pumping and permeability packer tests were used to evaluate the hydraulic characteristics of the aquifers. Methods of test pumping analysis included Jacob, Hantush and Walton. The aquifers generally responded to semi confined or leaky artesian type curves.

Early time transmissivity values for the sandstones gave about $10 m^2$/day and late time was $16 m^2$/day. Storage coefficient was 5×10^{-5}. Hydraulic conductivity values for the kimberlite were found to be at least an order of magnitude lower although storage coefficients were about 1×10^{-4}. The basalts gave transmissivity and storage coefficients which were about half those for the sandstone.

Results from the multiple piezometers showed significant variations in piezometric surface.

Average values were as follows:

FORMATION	DEPTH BELOW SURFACE (m)
SURFACE CALCRETE	5,5
BASALT	10,0
NTANE SANDSTONE	24

The effects of the above variations are seen in the resulting drawdown after 2 days of pumping a well 50 m outside the pipe perimeter. These are shown in Table 2.

Table 2 : Observed drawdowns during test pumping

BOREHOLE	OBSERVED DRAWDOWNS m
1 Pumping well (PW)	
50 m outside pipe perimeter	65,0
2 Multiple piezometers	
(± 60 m from PW)	
Kalahari beds	5,0
Drakensberg lava	10,0
Ntane sandstone	45,0
3 610 m Exploration boreholes	
Used as observation wells in	
kimberlite pipe (60-115, from PW)	0,3 m - 1,5 m

Calculations of drawdown for various configurations of 4, 5, 6 or 7 wells of DK1 were done.

A seven well system was considered suitable, assuming an average long-term pumping rate of 12,5 m^3/h each. At this stage, a gallery was not considered, as dewatering was required immediately and a gallery would have taken a couple of years to develop. The small size of the pit did not warrant a gallery and deep wells have greater flexibility in that the amount of water extracted can be kept to a minimum depending on the required drawdown.

A plan of DK1, DK2 and the boreholes is shown in Fig 5.

The seven wells were drilled, equipped and commissioned by April 1982. The wells were drilled to about 200 m. After several months borehole yields ranged from 7 to 24 m^3/h with an average of about 13 m^3/h.

A system of 5 wells was selected for initial dewatering of DK2 pit. These systems should have been adequate for 10 years when additional wells would be considered.

Subsequently, a change in mine planning meant that DK2 was no longer going to require dewatering as there was adequate dewatering from the DK1 system for the revised shallow depth of mining. Furthermore, the deepening of DK1 has increased considerably faster than originally planned.

The current drawdown in the sandstone is very much as predicted but there are considerable fluctuations in total yield from the system, depending on breakdowns. This in turn has a very significant effect on piezometric surface. This is summarised in Fig 6.

A reduction from 15 000 to 7000 m^3/week can cause a rise of 20 m in piezometric head. It can be seen that the base of mining in 1985 onwards, is such that certain minimum levels of pumping need to be maintained to avoid inflows to the pit and possible instability of the sidewalls. There are three ways this can be done:

- improved priority on pump maintenance
- increase well yields by lowering pumps
- increase number of wells

The discussion above has related to the main aquifer, the Ntane sandstone. The wells were designed to permit flow from the basalts as well as promoting vertical flow down to the sandstones once the piezometric head was lowered sufficiently. There are some local wet faces in the basalts due to 'perched' water. Although not a major problem it is hoped to promote drainage by using gravity drainage wells down into the sandstones. The piezometric level in the basalts is currently about 45 m below surface and about 90 m in the sandstone.

In the long term, as the pit develops and the basalt and sandstone become exposed in the sidewalls, the use of local wells on benches or toe drains will be considered. The present system should satisfy requirements to 1990.

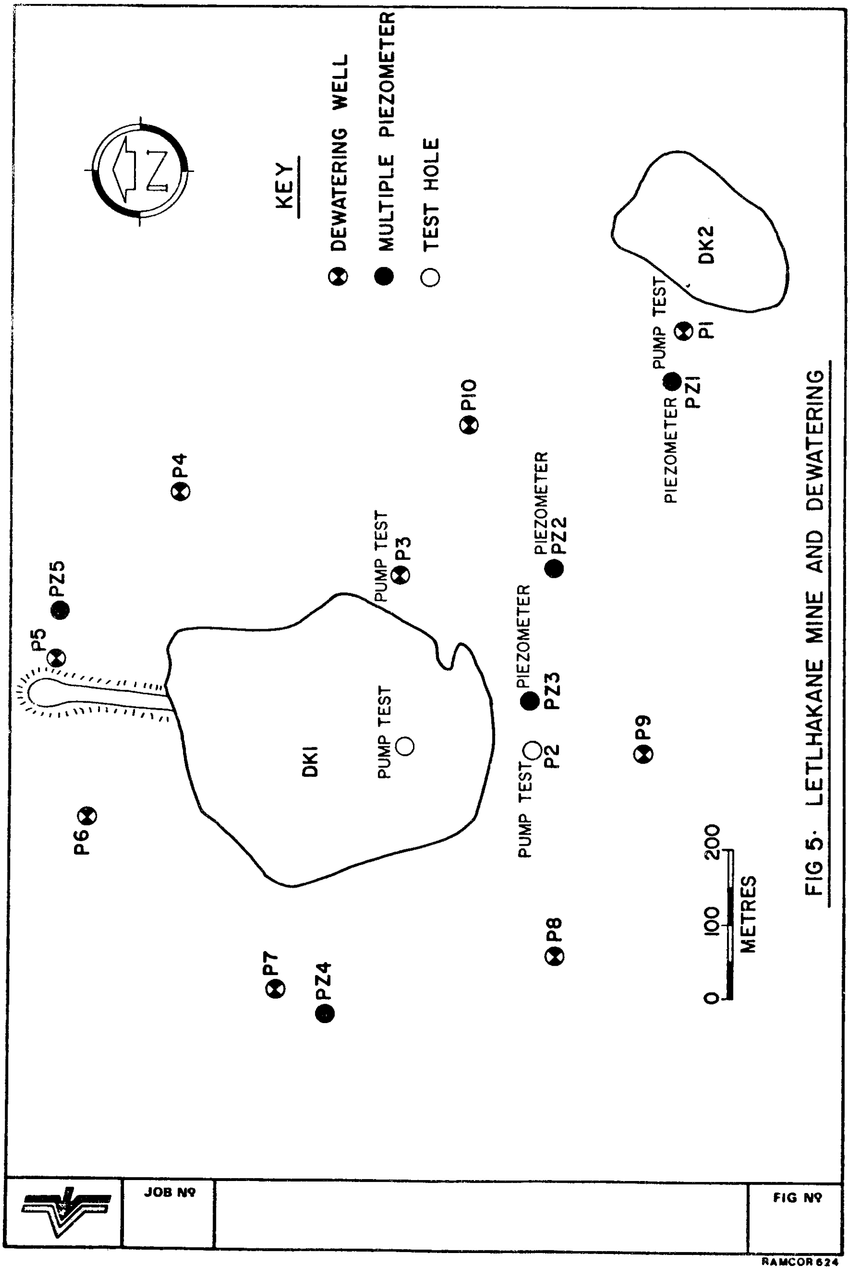


FIG 5· LETLHAKANE MINE AND DEWATERING

Orapa Mine

A similar approach to investigation for a dewatering system, was made for Orapa as for DK1, but the end result was different.

The important thing to note is the considerably larger size of the Orapa pipe, being 1 700 m long by 900 m wide.

Test boreholes were drilled around the pipe perimeters. Where possible, observation wells were drilled in the kimberlite. Test results showed very similar aquifer characteristics to DK1 but although large cones of drawdown could be induced against the pipe contact, no drawdown could be induced even a few metres inside the pipe.

Tests were attempted in the kimberlites but yields were so low that results were not meaningful. The hydraulic conductivity of the kimberlite in the floor of the pit is about 2×10^{-6} cm/sec and decreases with depth.

The pit will deepen very slowly due to the large size and relatively slow rate of mining. Mining for many years will be confined to the kimberlite therefore inflows will be low. The kimberlites do contain water in storage which creates a nuisance.

Calculations show that perimeter wells in the country rock could dewater the sandstones but gravity drainage of the kimberlites could not be achieved.

Slope stability is not a problem as very shallow side slope angles can be used for many years.

It was also shown that a gallery within the kimberlite and using drainage holes in the roof of the gallery would also not achieve an adequate rate of drawdown.

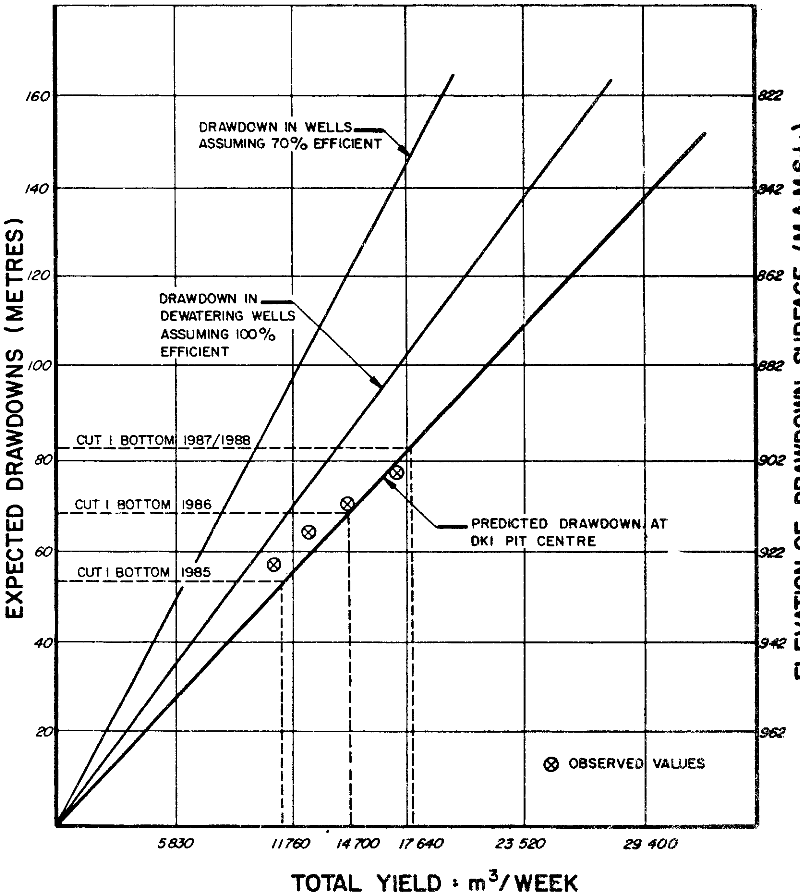
It was therefore decided that no special pre-dewatering techniques would be cost effective. Recommendations were given to improve mining conditions by changing aspects of mining practice. These recommendations included:

- mining mini-pits or deep sumps at both ends of the pit as rapidly as possible, to promote drainage of upper benches

- the use of pre-split blasting to promote drainage of each pre-split block

- once a face is blasted, to leave the rock to drain for several days, before moving

The above has to be considered in the light of mine planning and scheduling requirements.



GRAPH OF DRAWDOWNS FOR VARIOUS YIELDS

	JOB Nº		FIG Nº
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7 CONCLUSIONS AND FUTURE REQUIREMENTS

. The hydrogeologic model showed that although the kimberlites are of low permeability, high water pressures could induce slope stability problems and fairly high inflows could occur, particularly at DK1 and DK2.

. The main problem was the Ntane sandstone acting as a confined aquifer.

. DK1 and DK2 required immediate attention due to their small size, rapid deepening and exposure of country rock early in the mining life.

. A perimeter deep well system was established for DK1 to drain water from the Kalahari beds, the basalts and de-pressurise the sandstone.

. Dewatering has been successful although improved well maintenance is currently required to maintain total well discharge and maintain piezometric levels below mining levels. Some additional wells will be required in future years.

. At AK1, the rate of pit deepening, large size of pit and low permeability, means that pre-dewatering would not be cost effective. Management of mining in the wet kimberlites to permit drainage and drying was recommended.

Acknowledgment

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