THE CONTROL OF WATER AT WESTERN DEEP LEVELS, LIMITED

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SUMMARY

In mining circles water spells trouble and often, danger. There are many instances in mining history of mines closing down due to flooding or prohibitive cost of dewatering. Elaborate precautions are therefore taken to prevent flooding and everything possible is done to minimise the inflow of water into mines.

Shaft sinking and development at Western Deep Levels was done under cover of pre-grouting or cementation and pilot holes were drilled in advance of all headings to probe for water. Pumping installations were designed to handle the anticipated inflow and a generous margin was allowed for abnormally large influxes of short duration. To safeguard against possible flooding plugs and watertight doors were installed so that old workings could be used for temporary storage until the inrush was stemmed and additional pumps were installed.

INTRODUCTION

LARGE quantities of water are used for mining and treating the auriferous ores of the Republic and as the goldfields are, by and large, located in regions poorly endowed with surface water resources, it is fortunate that most mines find considerable quantities underground. Unfortunately, mine water is often highly contaminated with dissolved and suspended solids and has to be clarified and treated before use. This is the subject of a paper being presented at the Congress by a colleague.

Whilst reasonable quantities of mine water can be an asset, too much can be an embarrassment and a hazard to mining operations.

This paper outlines the way in which the flow of water into Western Deep Levels – one of the deepest mines in South Africa – is controlled and how it is pumped to surface. It also describes emergency steps taken to safeguard the mine when in danger of flooding.

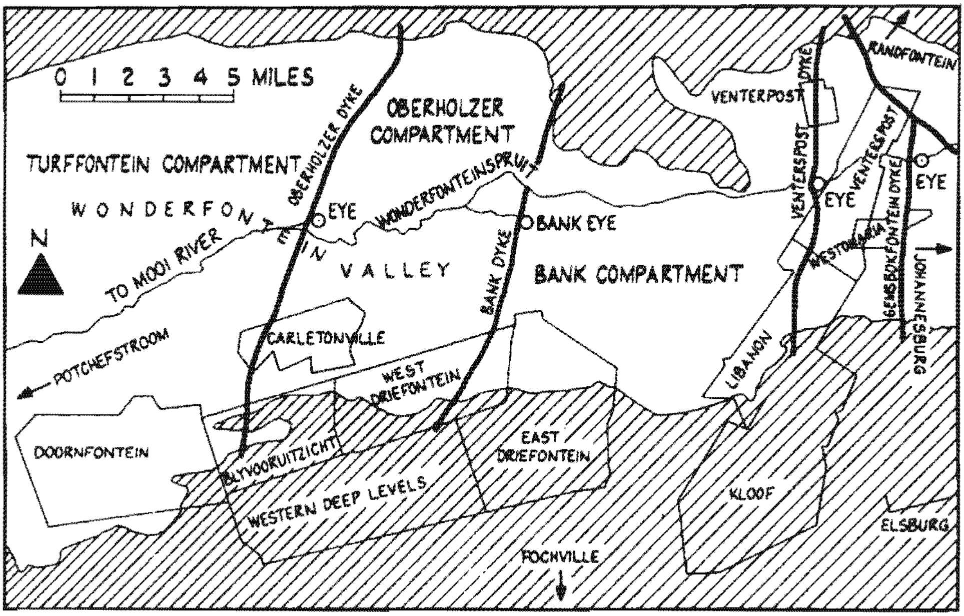
GEOGRAPHY OF THE OBERHOLTZER DISTRICT

The Western Deep Levels mining lease area straddles the boundary between the Oberholtzer and Potchefstroom magisterial districts of the Transvaal close to the town of Carletonville that lies some 64 kilometres (40 miles) to the west of Johannesburg. The boundary runs along the crest of a range of hills on the northern slopes of which the shafts are situated.

The terrain is typical highveld grassland with occasional hills breaking the monotony of the rolling plains. It enjoys an average rainfall of about 762 mm(30 in.)per annum and supports a thriving agricultural community engaged in maize and cattle farming on the dry lands and mixed farming on irrigated land along the water courses.

There are numerous streams fed by everflowing springs for which the district is renowned. The springs owe their origin to a massive dolomitic formation some 600 to 1 800 metres (2 000 to 6 000 feet) thick and hundreds of square kilometres in area that underlies this region of the Western Transvaal and acts as a vast reservoir for storing rain water. Centuries of leaching has created crevices and cavities, some very large, in the naturally porous dolomite and these are filled with water during the rains and discharge through the springs all the year round.

The dolomite formation is divided into several water-tight compartments by impervious dyke intrusions that were forced up from the molten core of the earth millions of years ago (Fig. 1). This is fortunate as it



THE WATER COMPARTMENTS IN THE DOLOMITE AREA OF THE WEST WITS LINE

FIG. I

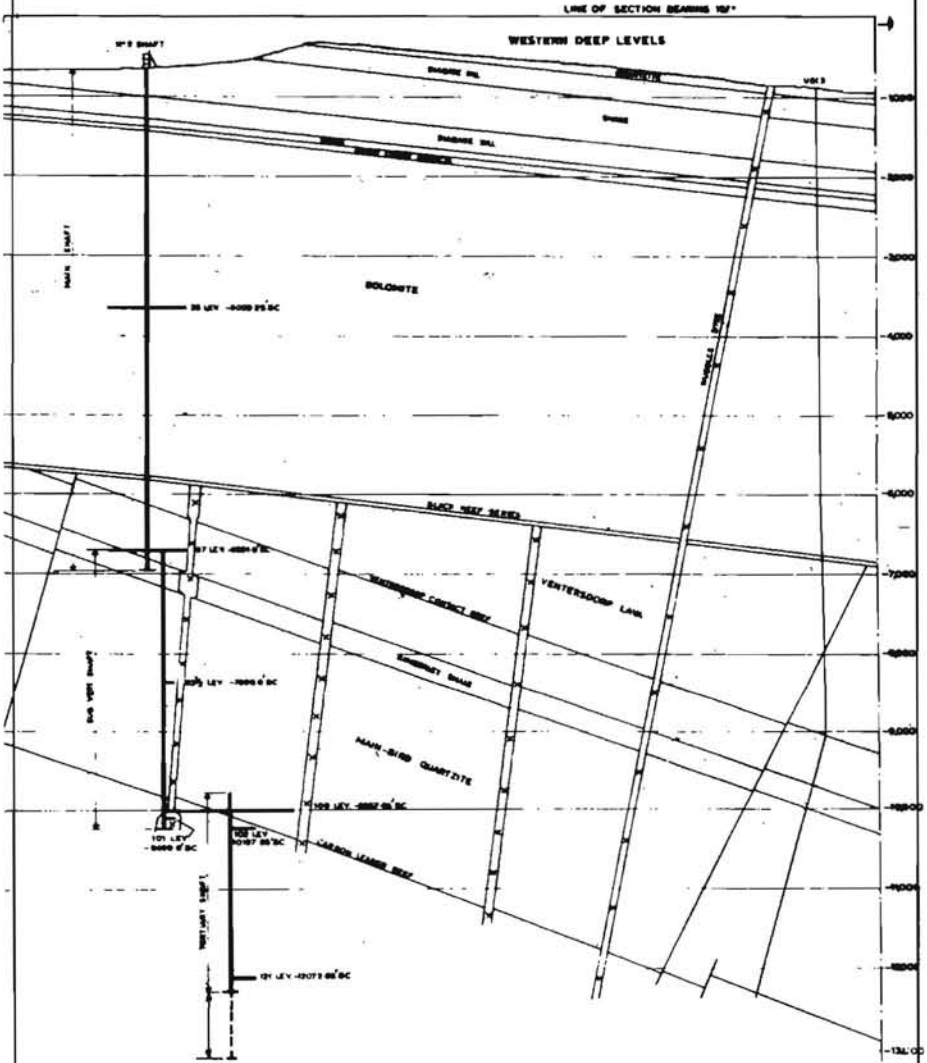
limits the effects of lowering the water table, due to mining operations, to those compartments overlying the mines. The most serious of these are drying up of springs and ground subsidence which, in severe cases, causes sink holes that can damage property and endanger lives.

CONTROL OF WATER DURING THE DEVELOPMENT PERIOD

Mines are particularly vulnerable during the shaft sinking period as the small capacity sinking pumps and temporary pumping installations in the shaft are not able to cope with large inflows of water.

By the time that shaft sinking commenced at Western Deep Levels, the Oberholtzer compartment had been partly dewatered by other mines in the district. Nevertheless, as the shafts had to be sunk through some 1 370 metres (4 500 feet) of possibly water-bearing dolomite before entering the relatively dry Ventersdorp lavas, stringent precautions were adopted to avoid flooding and the consequent loss of time in bringing the mine into production.

There are two shaft systems, each having twin shafts in close proximity, one for hoisting men, rock and material and the other for exhausting foul air from the mine. The hoisting shafts also admit fresh air to the mine and carry all the services such as compressed air and pumping columns and electric cables. The shafts go down to a depth of 2 890 metres (9 480 feet) below surface in two lifts; the upper or main shafts are approximately 1 940 metres (6 350 feet) and the lower or sub-vertical shafts 1 035 metres (3 400 feet) in depth. A start has been made on tertiary shaft systems that will go down to the -3 600 metre (-12 000 feet) horizon and may ultimately go down to the -3 965 metre (-13 000 feet) horizon (Fig. 2).



WESTERN DEEP LEVELS
DOLOMITE
VENTERSDORP LAVA
MAIN-BIRD QUARTZITE

FIG. 2.

Before shaft sinking commenced a number of holes ranging in depth from 90 to 1 200 metres (300 to 4 000 feet) were drilled vertically downwards into the dolomite just clear of the shaft periphery and cement slurry was pumped into them under high pressure to seal fissures or faults they had intersected. Shorter holes, 6 to 122 metres (20 to 400 feet) in depth were drilled into the overlying Pretoria Series for the same purpose. As the shafts advanced rings of holes were drilled at regular intervals fanning outwards and downwards from the shaft bottom and these too were pressure grouted to seal fissures missed during pre-grouting. As a final precaution probe holes were drilled in advance of the shaft bottom to give early warning of water-bearing ground. To give some idea of the scope of this work some 381 000 metres (1 250 000 feet) of pre-grout and cover drilling had been done and one million pockets of cement had been injected into the shaft areas by the time the shafts reached the Carbon Leader reef 2 990 metres (9 800 feet) below surface. In spite of these precautions inflows of up to 0.23 megalitres (50 000 gallons) per hour of water were experienced on several occasions and there can be little doubt that shaft sinking would have been delayed due to excessive water if pre-grouting had not been done.

After the shafts had been completed and equipped many excavations had to be mined in the shaft pillar to house plant and equipment and to provide facilities for handling rock, material and personnel. Simultaneously development was being advanced towards the ore bodies on several levels. Much of this work was done before the main shaft pumps had been commissioned and great care was taken to avoid drilling or blasting into water-bearing ground. Once the main pumps had been commissioned the mine was in a much better position to cope with an inrush of water but the precautionary measures were not relaxed.

PUMPING CAPACITY

Once stoping commenced it was no longer possible to exercise the same strict control over drilling operations that had characterised the initial development period and the main pumping plant had to be capable of handling any quantity of water encountered.

One of the more difficult decisions to make when opening up a new mine is the pumping capacity to provide. Empiric formulae have been evolved to give the probable amount of seepage into a mine but this depends on so many variables such as rainfall and the geology and topography of the region that they cannot be relied upon and the final decision is usually based on the judgment and experience of geologists and mining engineers. The experience of neighbouring mines, too, can be a useful, but sometimes misleading guide as proved to be the case at Western Deep Levels.

Less water was expected at Western Deep Levels than at the neighbouring mines because the dolomite series is overlain by impervious measures of the Pretoria Series that act as an umbrella over the mine and protect the dolomite from leaching and minimises seepage into the mine. Further, dolerite sills cover large areas of the dolomites and lower down the Ventersdorp lavas cover about 85 per cent of the claim area (Fig. 2). Taking all these factors into account it was estimated that the inflow would increase over the years as follows:

48 megalitres (10.5 million gallons) per day after 6 years
64 megalitres (14.0 million gallons) per day after 8 years
96 megalitres (21.0 million gallons) per day after 10 years

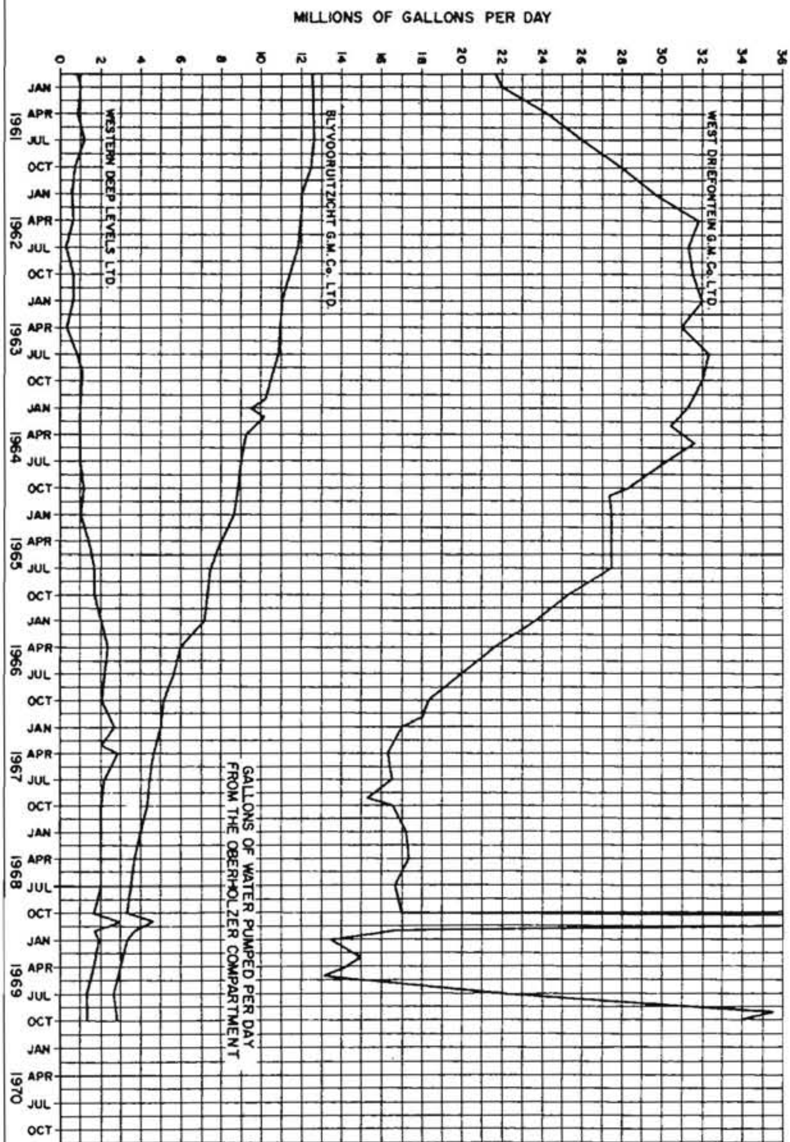

MILLIONS OF GALLONS PER DAY
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
1961 1962 1963 1964 1965 1966 1967 1968 1969 1970
JAN APR JUL OCT
WESTERN DEEP LEVELS LTD.
BLYVOORUITZICHT G.M. Co. LTD.
WEST DRIEFONTEIN G.M. Co. LTD.
GALLONS OF WATER PUMPED PER DAY FROM THE OBERHOLZER COMPARTMENT

FIG. 3

In the event, the inflow has never exceeded 14 megalitres (3 million gallons) per day and this can be attributed, in the main, to the dewatering of the Oberholtzer compartment.

A far more serious risk, however, particularly when mining in dolomitic formations, is the possibility of striking fissures or faults connected to large water bodies overhead. An allowance for such a contingency must be made when determining the capacity of a pumping installation.

Taking all factors into consideration it was decided to install pumping plant capable of handling 90 megalitres (20 million gallons) per day initially but capable of expansion in later years.

The rates of pumping from Western Deep Levels, Blyvooruitzicht and West Driefontein from 1960 to 1970 are shown in Fig. 3 and the dramatic reduction in recent years due to dewatering the Oberholtzer compartment is apparent. Permission to do so was granted by the Government in 1963 in the interests of safety and economy in return for compensation to those who suffered damage or loss as a result. After the disastrous flooding of West Driefontein in 1968, about which more will be said later, permission was granted in December 1969 to dewater the Bank compartment as well. This will be a long and costly operation as it is about 156 square kilometres (60 square miles) in area and is estimated to hold some 455 gigalitres (100 000 million gallons) of water. Fig. 3 shows the increase in pumping rates at the three mines at the time of the flooding and the continued high rate of pumping at West Driefontein since then.

PUMPING ARRANGEMENTS

Water gravitates from the working faces and other sources in drains along the drives to settlers and sumps adjacent to the main pumping plants. There, the bulk of the grit and fine suspended solids is removed by cycloning or settling and the clear water is then pumped to surface up the service shafts. Some of the water is tapped from the rising main and stored in dams at suitable elevations in the shaft for re-use as service water for drilling, cooling and dust suppression. The remainder is used for industrial purposes in surface plants and if there is a surplus, it is conveyed by pipe line and concrete lined canal over the dolomitic area to the Mooi River which is a tributary of the Vaal.

Each of the service shafts has pumping plant capable of handling 45.5 megalitres (10 million gallons) per day and water can be transferred underground from one to the other to take advantage of spare capacity in either system.

Water is pumped to surface in four stages to limit the pressure to acceptable values and the physical size of individual units to manageable proportions.

The stage lifts in the main shafts are approximately 915 metres (3 000 feet) and in the sub-vertical shafts, 458 metres (1 500 feet). Initially, each of the main shaft pump stations had three pumping units and the sub-vertical shafts two units as less water was expected at depth. A single 356 mm (14 in.) bore pumping column designed to take the output of two pumps was provided in each shaft but a third pump could be run, with marked fall-off in output as shown below:

Number of Pumps	*VELOCITY* *m/s*	*ft/s*	*QUANTITY PER DAY* *mega-litres*	*million gallons*
One	2.2	7.2	18.7	4.1
Two in parallel	4.0	13.2	34.6	7.6
Three in parallel	5.5	18.0	47.3	10.4

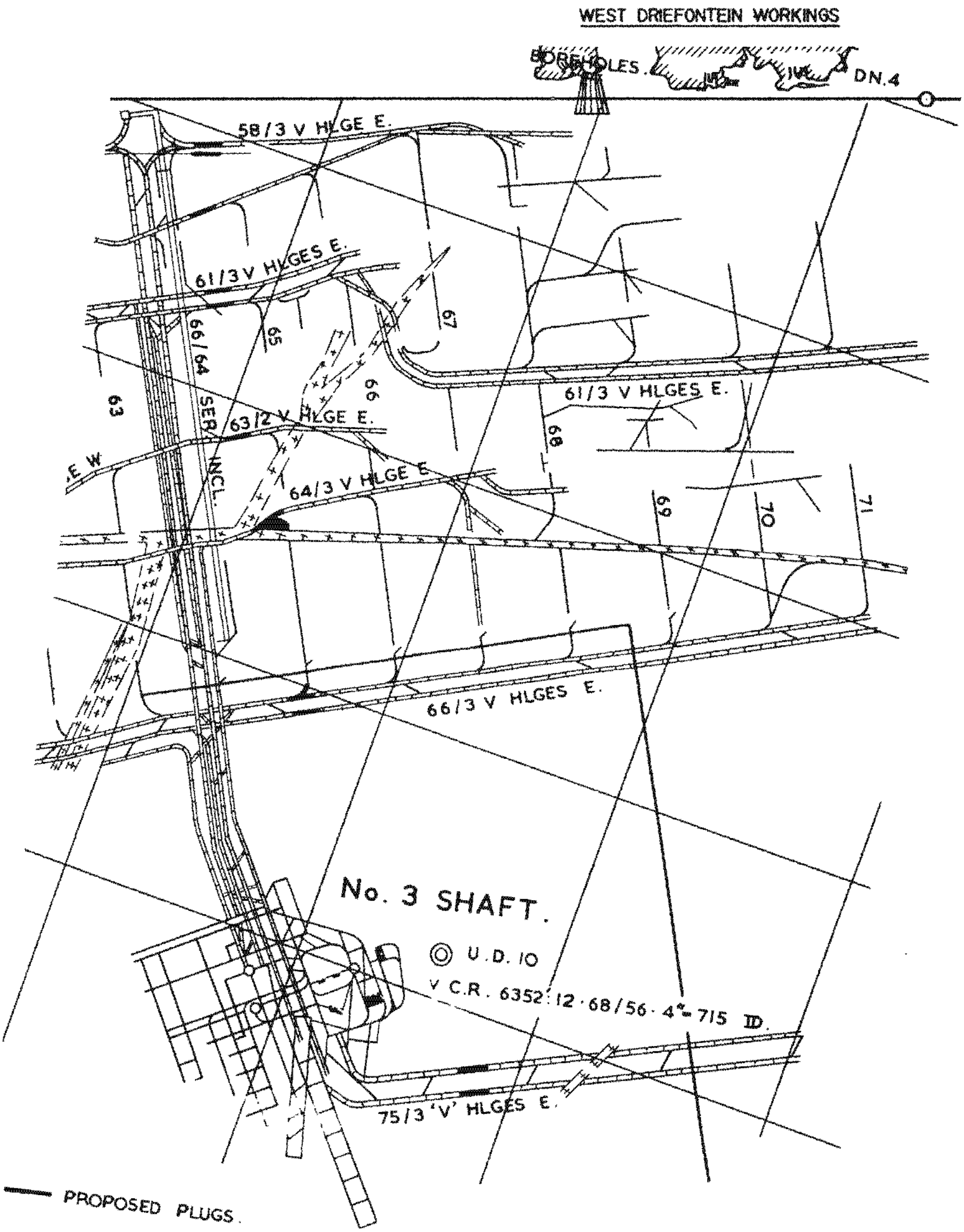

WEST DRIEFONTEIN WORKINGS
BOREHOLES.
DN.4
58/3 V HLGE E.
61/3 V HLGES E.
65
67
66/64
66
SER. INCL.
63
63/2 V HLGE E.
E W
64/3 V HLGE E.
61/3 V HLGES E.
68
69
70
71
66/3 V HLGES E.
No. 3 SHAFT.
U.D. 10
V C.R. 6352: 12·68/56·4"= 715 ID.
75/3 'V' HLGES E.
PROPOSED PLUGS.

FIG. 4

To give some idea how costly pumping from a deep mine can be, an average of 9.6 megalitres (2.1 million gallons) of water per day was pumped from Western Deep Levels during 1968 at a cost of R0.2 per kilo litre (0.89 per 1 000 gallons).

A gradual reduction in the amount of water pumped from the mine over the past few years seemed to indicate that the extensions to the pumping plant planned for later years might not be necessary or could, at least, be delayed for a long time. However, in October 1968 the flooding of West Driefontein necessitated a change of plan and initiated a period of intense activity to safeguard the mine against possible flooding.

FLOOD CONTROL

On the 26th October 1968 water started pouring into West Driefontein through a fissure in the flooded Bank compartment. The massive influx was estimated to be of the order of 387 megalitres (85 million gallons) per day which, with the normal inflow of 68 megalitres (15 million gallons) per day was far in excess of the installed pumping capacity of 287 megalitres (63 million gallons) per day and the mine was in danger of flooding. Had this happened both Blyvooruitzicht and Western Deep Levels could have been in great danger. In the event, this did not happen and the story of how the mine was saved has been told dramatically by A.P. Cartwright in "West Driefontein – Ordeal by Water". But at the time this could not be foreseen and steps were taken immediately to protect the mine in the event of West Driefontein being completely inundated.

Western Deep Levels is mining at a greater depth than either of its neighbours, West Driefontein and Blyvooruitzicht, so if either of them were to flood, only the boundary pillars between them would save Western Deep Levels from suffering a similar fate. The boundary pillars are only 27 metres (90 feet) thick and probably not water-tight as they are traversed by numerous faults and have been subjected to extreme ground pressure and movement that has weakened their structure.

The greatest threat was from West Driefontein on the Ventersdorp Contact reef horizon where there were old workings on either side of the boundary pillar (Fig. 4). The Blyvooruitzicht boundary was much safer except in one place on the Carbon Leader reef horizon where an exploratory heading approached the boundary pillar.

It seemed highly likely that if West Driefontein were lost, Blyvooruitzicht would flood too as they shared a very long common boundary pillar that was suspect. Western Deep Levels would then be threatened on two fronts and could be in grave danger of flooding.

First consideration was therefore given to ways and means of assisting West Driefontein to combat the flood waters and the quickest way of doing so was to make use of the surplus pumping capacity at Blyvooruitzicht and Western Deep Levels. But a tremendous amount of work had to be done before this was possible and it was estimated that it would be a forthnight before the first water was tapped from West Driefontein. Then the two mines would be able to take 114 megalitres (25 million gallons) per day between them and the combined pumping capacity of the three mines would very nearly match the inflow. During this period West Driefontein would have to store, in abandoned sections of the mine, water surplus to its pumping capacity which increased daily as more and more pumps were installed, unless it was successful in stopping the inrush in the meanwhile.

BOREHOLES

It was decided to drill eight 152 mm (6 in.) diamond drill holes through the boundary pillar and line them with thick-walled casing to the outlet end of which would be fitted high pressure valves capable of withstanding the maximum pressure that could build up if West Driefontein was abandoned and the water level rose to near the surface. This could be as high as 155 bars (2 257 lbs./sq. inch) but if all went well it was hoped to limit the pressure on the boundary pillar to about 3.5 bars (50 lbs./sq. inch), the pressure required to force the desired quantity of water through the boreholes, in order to minimise leakage through the pillar.

Valves capable of withstanding such pressures and able to handle gritty water were not available in the Republic and even overseas could only be procured from manufacturers of oil well equipment. After much searching two suppliers were located, one in the United Kingdom and the other in the U.S.A., and soon the valves were on their way to Johannesburg by air. As some valves were required urgently, those from the United Kingdom were sent by charter flight and arrived on the 10th November. Those from the U.S.A. arrived a few days later by normal air service. Smaller valves that would be required for drain pipes in plugs that were to be built as a second line of defence were ordered at the same time and they, too, were flown to South Africa. In all, sixteen 152 mm (6 in.) and twenty-six 102 mm (4 in.) high pressure valves were bought at a cost of R78 000 of which R26 700 was for air freight and handling charges.

Whilst the valves were being procured a start was made on drilling the holes through the boundary pillar. First, a suitable site had to be found and prepared (Figs. 4 & 7). A prospect raise from the 59 level, 1 760 metres (5 800 feet) below surface was selected and enlarged and extended for this purpose. As there was a distinct possibility that the boreholes would break into a

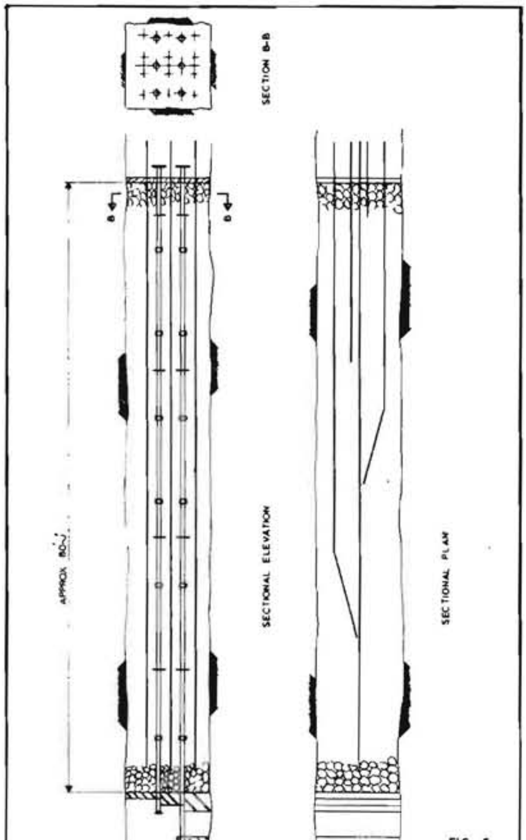


FIG. 5

flooded section of West Driefontein the holes were only drilled partway through the pillar in the first instance and then cased with high pressure piping that was grouted in position. When the valves arrived they were bolted to the outlet end of the casing and the drilling was completed through the pillar in the first instance and then cased with high pressure piping that was grouted in position. If high pressure water had been encountered, the drill rods would have been withdrawn and the valves closed to seal off the water.

As the normal drainage system would not have been able to cope with the anticipated flow it was decided to pipe the water under pressure to the sumps at Nos. 2 and 3 shafts and some 6 100 metres (20 000 feet) of large bore piping was installed in drives and haulages for this purpose.

All the preparatory work sounds very simple and straightforward when reviewed in retrospect but at the time when the mine could have been in danger of flooding and men were working round the clock in confined spaces and hot and humid conditions, it did not seem so. In spite of the difficulties and unpleasant conditions the men worked with a will and on the 13th November 1968 the first water flowed through the boreholes.

PLUGS

Whilst the boreholes were being drilled other steps were being taken to safeguard the mine if the boundary pillar developed major leakages.

The most competent ground on the Ventersdorp Contact reef horizon in the No. 3 shaft area was in the service incline pillar running northwards from the main shaft to the common boundary with West Driefontein. It was therefore decided to seal off all drives running eastwards from the shaft and service incline by constructing a row of plugs in the pillar and to use the worked out slopes east of the pillar as an emergency storage reservoir. This necessitated the construction of 10 plugs on the Ventersdorp Contact reef horizon (Fig. 4) and one on the Carbon Leader reef horizon to secure the Blyvooruitzicht boundary.

The mining industry has had a lot of experience in designing and constructing plugs as flooding is by no means an uncommon occurrence, but rarely for pressures of the magnitude envisaged in this instance namely 260 bars (3 775 lbs./sq. inch) for the plug on the lowest level.

The length of a plug is given by a simple formula:—

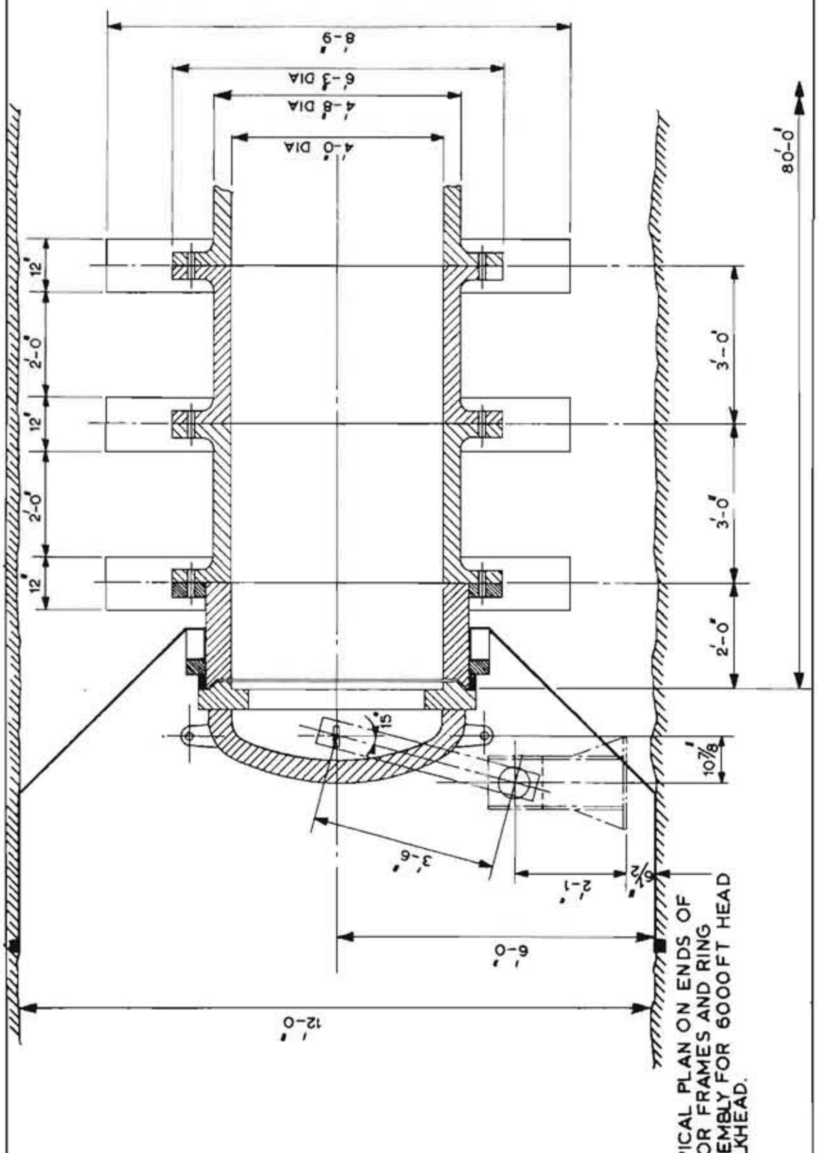
Length of plug

$$= \frac{\text{Area of Drive x Static Water Pressure}}{\text{Perimeter of Drive x Shear Factor}}$$

The shear factor has been determined experimentally for various conditions and for those at Western Deep Levels was taken as 827 kilo Newtons per square metre (120 lbs./sq. inch) using a safety factor of 3.

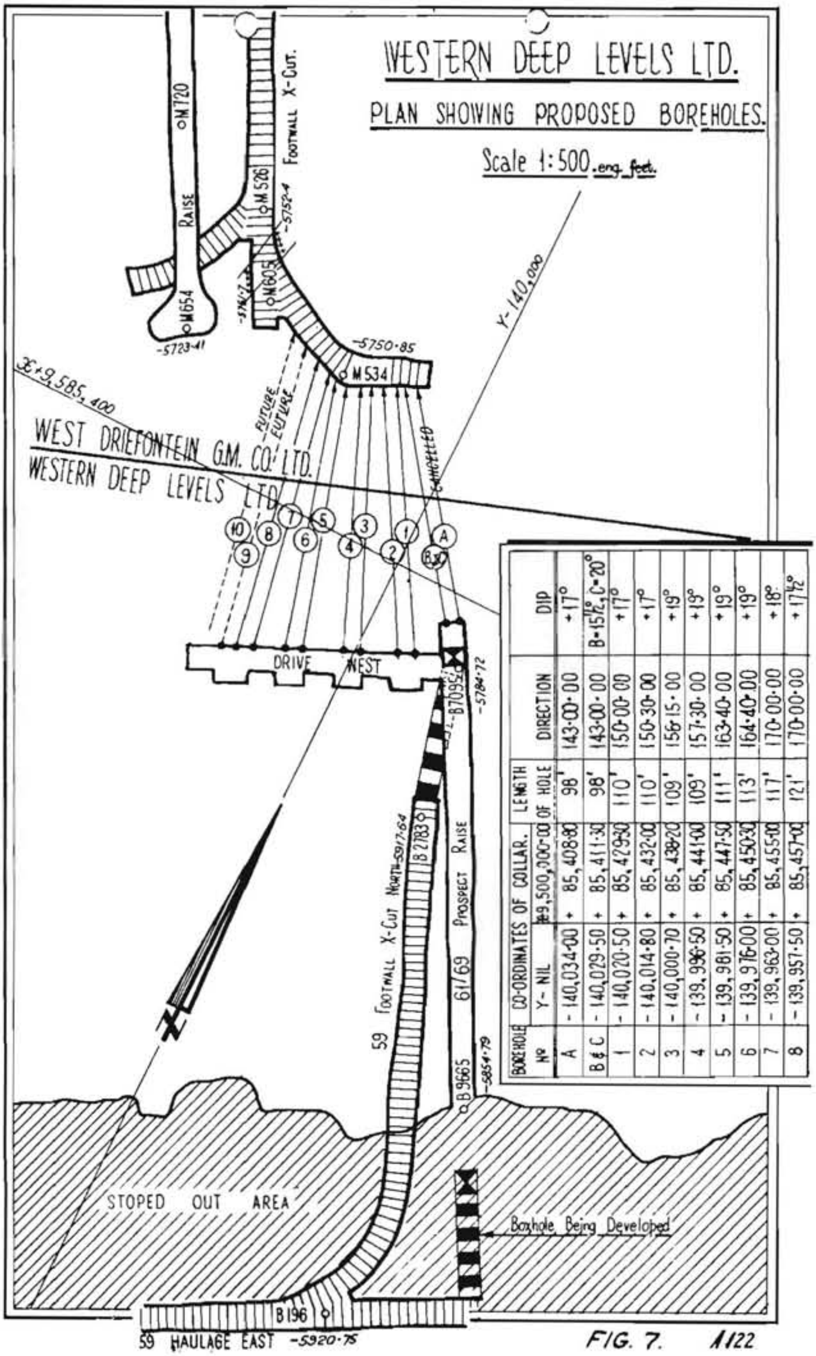
The area of the drives ranged from 12 to 15 square metres (128 to 162 square feet) and were at different elevations, consequently the plug lengths varied from 24 to 30 metres (80 to 100 feet).

A novel method of constructing plugs by a cementation process, called Colgrout, had been evolved by a South African firm and this was employed at Western Deep Levels (Fig. 5). First the site is prepared by barring down all loose rock and then it is thoroughly cleaned and washed. A timber shutter or brick wall is erected at the high pressure end of the plug and all pipes that have to pass through the plug are accurately positioned and held in place by temporary supports. Specially selected clean lumps of rock ranging in size from 76 to 230 mm (3 in. to 9 in.) are packed in layers about 350 mm (12 in.) deep over the whole length and breadth of the



TYPICAL PLAN ON ENDS OF DOOR FRAMES AND RING ASSEMBLY FOR 6000 FT HEAD BULKHEAD.

FIG. 6.



BOREHOLE Nº	CO-ORDINATES OF COLLAR. Y- NIL	X9,500,000·00	LENGTH OF HOLE	DIRECTION	DIP
A	- 140,034·00	+ 85,408·80	98'	143·00·00	+17°
B & C	- 140,029·50	+ 85,411·30	98'	143·00·00	B-15½°, C-20°
1	- 140,020·50	+ 85,429·30	110'	150·00·00	+17°
2	- 140,014·80	+ 85,432·00	110'	150·30·00	+17°
3	- 140,000·70	+ 85,438·20	109'	156·15·00	+19°
4	- 139,996·50	+ 85,441·00	109'	157·30·00	+19°
5	- 139,981·50	+ 85,447·50	111'	163·40·00	+19°
6	- 139,976·00	+ 85,450·30	113'	164·40·00	+19°
7	- 139,963·00	+ 85,455·00	117'	170·00·00	+18°
8	- 139,957·50	+ 85,457·00	121'	170·00·00	+17½°

FIG. 7. 1122

plug, starting at the high pressure end and retreating towards the low pressure end, until the drive is completely filled. As the stone packing proceeds, high pressure pipes for grouting are embedded in the rock to a set pattern. The pipes vary in length and are at different elevations so that cement slurry can be injected uniformly along the length, breadth and depth of the plug. Great care must be taken to pack stone closely around pipes and in awkward corners so as to reduce the voids to a minimum. When stone packing has been completed timber shuttering is erected at the low pressure end of the plug with all pipes projecting through it. High pressure valves are fitted to the grouting pipes and cement slurry is then pumped through them into the plug. There is an art in doing this to ensure that all voids are filled before the cement sets and there must be no interruptions once cementation has started. In the final stages of grouting the pressure is increased to about 69 bars (1 000 lbs./sq. inch) to ensure that all voids are filled with cement. The plug is allowed to set and then regrouted to compensate for shrinkage If the surrounding rock is suspect it must also be pressure grouted to avoid leakage past the plug.

It was estimated that some 3 000 cubic metres (4 000 cubic yards) of concrete would be required to construct the eleven plugs and as most of the material had to be brought from surface it presented a major problem and determined the rate at which the plugs could be constructed.

One of the plugs had a man travelling way through it to allow access to the boreholes and this had a water-tight door made from 11.4 mm (2½ in.) thick steel plate capable of withstanding a pressure of 180 bars (2 600 lbs./sq. inch) (Fig. 6.)

The upstream face of the plugs would be subject to pressures in excess of the crushing strength of concrete so a special semi-plastic epoxy cement was imported from the U.S.A. to protect the concrete.

ADDITIONAL PRECAUTIONS AGAINST FLOODING

Although the installed pumping capacity at Western Deep Levels was five times the pumping rate at the time of the emergency it has been decided to increase the capacity from 90 to 136 megalitres (20 to 30 million gallons) per day as soon as possible by installing an additional pumping unit in each station and a second 356 mm (14 in.) pumping column in each service shaft at an estimated cost of R2.5 million. A number of low pressure water-tight doors are also to be installed at a cost of R50 000. This seemed cheap insurance for a mine that made a working profit of R31.8 million in 1969. The pumping systems have been designed for an ultimate capacity of 180 megalitres (40 million gallons) per day but it is extremely unlikely that this output will ever be required.

CONCLUSION

The mining engineer has to be constantly on guard against many dangers, not the least of which is water. Water out of control, be it on surface or underground, is frightening and can do tremendous damage. In mining history there are many instances of mines closing down and lives being lost due to flooding. The deeper the mine the greater the danger and ways and means of controlling water and of keeping it in check in the event of flooding are exercising the ingenuity of engineers responsible for the planning of the ultra deep mines of the future.

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