The mining of low-grade areas at Stilfontein Gold Mine*

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SYNOPSIS

As the price of gold increased, so did the viability of mining previously abandoned unpay areas of Stilfontein Mine. After an assessment to confirm the profitability of mining these areas, it was necessary to re-establish access-ways such as haulages, cross-cuts, and travelling ways. Opening-up is a labour-intensive, relatively slow operation, and attempts were made to mechanize and speed it up. Some of the techniques applied and the results achieved, whether successful or not, are discussed.

SAMEVATTING

As gevolg van die styging van die goudprys, het dit moontlik geword om ou areas van Stilfontein Myn, wat voorheen onbetaalbaar was, weer te heropen en met mynbou aktiwiteite te begin. Nadat daar 'n ontleding onderneem was om vas te stel of dit wel winsgewend was om na hierdie areas terug te keer, was dit nodig om toegangsroetes soos vervoerweë, dwarsgange en loopweë oop te maak, en weer in gebruik te neem. Die proses van heropening is aarbeidsintensief en relatief stadig; pogings was dus aangewend om meganisasie toe te pas om die werk te bespoedig. Sommige van die tegnieke wat aangewend was, en resultate wat behaal was, suksesvol of nie, word hier bespreek.

Introduction

Over the life of Stilfontein Mine, relatively substantial portions of the reserves had been abandoned for various reasons and are situated in areas where normal access routes are caved in places and will have to be re-established. The majority of reserves left behind were pillar and remnant blocks, and some of the reasons for the decision to abandon were as follows.

(1) It was uneconomical to mine low-grade blocks at the ruling gold price.

(2) Because of ventilation problems, it was necessary to concentrate mining operations in payable areas and to abandon scattered blocks where workings would have aggravated environmental conditions. Stope development for the purpose of negotiating faults had not been carried out in time for such areas to be mined concurrently with the rest of the stope.

(3) The high rate of closure of access routes and working places made it uneconomical to carry on mining some of the smaller blocks of ground available.

This paper gives an account of the rationale behind the decisions to return to these areas as the price of gold increased, together with some of the technical difficulties encountered and the steps taken in an attempt to speed up the process of opening-up.

The Gold Price and Production Costs

Opening-up operations were commenced during 1976 to augment the tonnage milled per month and extend the life of the mine, which continued operating on State aid until the end of 1976. As the gold price started increasing at a substantially greater rate than the cost of mining, the strategy of returning to previously abandoned blocks grew more attractive. Some of the basic premises considered when deciding to open up and re-establish mining operations were as follows.

(a) Mine production could be maintained for at least two to three years longer.

(b) The basic infrastructure would allow the mining of these areas on a marginal basis. The mining of these areas in isolation would not have been economical.

(c) Because of the greater tonnage mined per annum, the distribution of overhead costs and overall productivity could be optimized to achieve the lowest possible cost per ton milled for this mine.

Because of the sensitivity of these mining areas to variations in direct costs and the average price of gold, a computer model was developed to calculate the monthly profit contributions based on the rate of production, costs of labour and stores, efficiencies, current gold price, etc. An example of the type of analysis used is shown in Table I.

This model is updated monthly according to changes in the variables such as the rate of production, costs, and price of gold. From these results, planning decisions can be made as to the rate of mining and the effect of the net contribution to total profitability.

Geological Features

Both the hangingwall and the footwall in the Vaal Reef are very friable.

The hangingwall consists of a medium-grained argillaceous quartzite containing various conglomerate bands. Owing to the lack of cohesion between the conglomerate bands, the hangingwall is unstable and will collapse easily in certain circumstances.

The footwall varies from a very fine-grained, highly siliceous quartzite in the eastern section of the mine to a medium-grained pebbly argillaceous quartzite in the west. This quartzite is very weak and, because of a high concentration of faulting planes in most areas, has contributed to the rapid deterioration of the footwall haulages and cross-cuts in the areas that have to be opened up.

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TABLE I

PLANNED DIRECT COSTS AND CONTRIBUTIONS PER STOPING CONTRACT

Working place	19–22A	17–25	20–23A	21–9	18–21	M/O	Sect mgr
Contribution R	91 412	183 343	128 534	99 900	238 762	741 951	1 504 000
Contract no.	159	113	126	162	160		
Plan m²	800	1 130	1 170	1 340	900	5 340	9 300
Stope kg	13,095	23,473	18,609	17,032	27,214	99,423	192,171
Average stope value	5,45	6,92	5,30	4,23	10,07	7,46	7,62
Amount recovered, kg	11,136	19,961	15,825	14,484	23,142	84,547	163,418
Unskilled labour							
Stoping	44	63	61	72	52	292	517
Per stope, m²	18,2	17.9	19,2	18,6	17,3	18,3	18,0
Total, m²							18,0
Stoping costs, (R)							
Unskilled	10 192	14 594	14 130	16 679	12 046	67 641	119 761
Skilled	1 201	1 697	1 757	2 013	1 352	8 020	14 559
Stores	9 529	13 460	13 936	15 961	10 720	63 606	104 369
Sub-total	20 923	29 750	29 824	34 652	24 117	139 267	238 689
Redist costs	30 870	43 604	45 147	51 707	34 728	206 056	358 861
Overheads	99 387	140 385	145 354	166 474	111 811	633 410	1 155 378
Total costs	151 180	213 739	220 325	252 833	170 657	1 008 733	1 752 928
Cost per m²	188,97	189,15	188,31	188,68	189,62	188,90	188,49
Gold price, R/kg	12 860	12 860	12 860	12 860	12 860	12 860	12 860
Revenue	143 205	256 697	203 505	186 259	297 608	1 087 273	2 101 550
Profit per contract	–7 975	42 958	–16 820	–66 574	126 951	78 541	348 622
Per m²	–10	38	–14	–50	141	15	37
Per stope unskilled	–181	682	–276	–925	2 441	269	674
Rel. profit per contract	123 374	174 069	181 210	207 045	138 217	515 041	1 129 888
Breakeven							
Average per contract	25 037	25 037	25 037	25 037	25 037	25 037	25 037
Per m²	19	19	19	19	19	19	19
Per stope unskilled	354	354	354	354	354	354	354
Breakeven this contract	14 657	20 722	21 360	24 512	16 545	97 795	169 943
Unit of achievement	–0,5	2,1	–0,8	–2,7	7,7	0,8	2,1

Areas to be Opened Up

The areas to be opened-up extend across the strike of the mine (about 7 km) and from 10 level at 1100 m below surface to 27 level at 2000 m below surface. Fig. 1 shows the spread and relative magnitude of the areas concerned, together with the major access routes that must be re-established. The value distribution ranges from 2 to 5 g/t and, as the gold price has increased, so has the viability of mining these blocks. Over the past four years, the areas included in the life-of-mine reserves have been as shown in Table II.

In order to achieve the planned rate of mining, an opening-up rate of approximately 1500 m per month will have to be maintained. Most of the reef blocks are situated in the upcast ventilation system and tend to present environmental problems, although to a large extent this has been improved by the use of chilled water in the drilling-water reticulation circuit.

TABLE II

AREAS INCLUDED IN LIFE-OF-MINE RESERVES

Year	Price of gold $/oz	Included in reserves, m²
1978	179	280 000
1979	309	787 000
1980	520	856 000*

* 100 000 m² were mined during 1980.

The areas that sag and collapse include the haulages, cross-cuts, travelling ways, and the gullies in the stope itself. It is not uncommon to find that a relatively new cross-cut from within 30 m of the reef intersection is no larger than 1,5 m by 2,0 m, compared with the original dimensions of 3 m by 3 m. Falls of ground must be cleared, and in most cases large rocks have to be drilled and blasted. Loading of broken rock is a major problem because, before any rolling stock can be brought into use, the excavation has to be opened and supported to the correct dimensions.

From the above it can be seen that opening-up is a task of considerable magnitude and is slow, requiring a large labour force.

Decision to Open Up

It may be suggested that, because of all the problems and costs associated with opening up, completely new access ways could be developed at a lower cost and at a

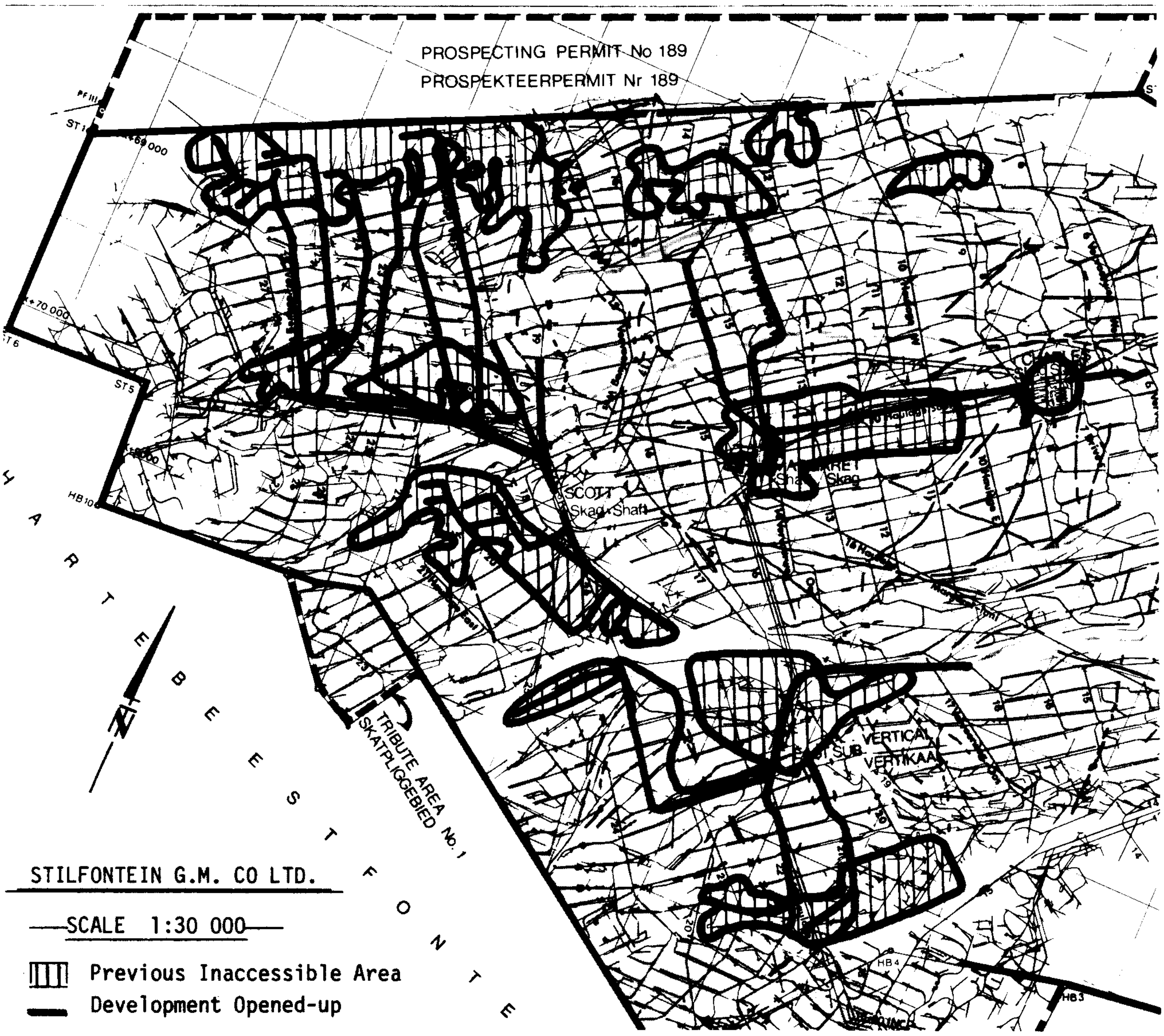

Fig. 1—The distribution of recently opened development areas (these areas are not 'solid' blocks of ground but are made up of many isolated small pillars and blocks that had been abandoned)

higher rate of advance. However, a number of factors must be considered before a decision can be taken to re-develop completely, and these are discussed below.

As can be seen in Fig. 1, the distances involved are considerable, and in many cases long sections of haulages or cross-cuts that have passed through stable areas are still intact and require the minimum of work for their re-establishment. When considering the economics of an operation, the total cost for the section of haulage should be assessed for both methods. In most cases, opening-up remains the more economical.

Rock mechanics considerations with regard to the stability of excavations in the vicinity of the reef horizon could preclude re-development, and with the additional support that may be required would increase the cost beyond that of opening-up.

Where possible, as much use is made of existing stope-orepasses and any other facilities that may still be intact.

Methods Used

From the inception of this programme in 1977, a number of systems and methods have been tried with varying degrees of success. In many cases, recourse has been made to the basic use of manual labour because of the inefficiency, impracticability, or poor economic viability of the equipment employed. However, because of the increased activity in this field on other mines, a brief account is given of all the equipment that has been tried, whether successful or not, in the hope that this will stimulate ideas and applications among other interested persons.

The basic elements of the opening-up operation can be divided into six elements:

(1) supporting areas that are highly fractured and have a tendency to continue scaling and falling once disturbed;

(2) breaking large rocks by non-explosive methods or with explosives,
(3) removing old timber and pipes from the rockfalls,
(4) loading broken rock once the support is advanced and the large rocks broken up,
(5) breaking up the sidewall without drilling and blasting if possible,
(6) picking and trenching the footwall for the removal and re-installation of tracks.

Support

When they were originally developed, the haulages, cross-cuts, travelling ways, and centre gullies were supported with roofbolts and timber sets. These have proved to be inadequate over an extended period of time; the timber set caps are broken by sidewall pressure, and the hangingwall in turn breaks away and damages the cribbing. Once there has been a high degree of fracturing and scaling, it becomes almost impossible to install an active support system such as bolting with wire meshing and steel-wire rope lacing, which is the system now used in current high-stress development ends. As a result, it was decided to install yielding steel arches to create a 'steel tunnel' through the collapsed areas to the working stopes. The steel arches are cribbed up to the hangingwall, and adequately restrain fractured hangingwall and sidewall, although they cannot stop closure on a regional basis.

Initially, a commercially available arch was used, but price increases prompted the development and design of a 'Stilfontein' yielding steel set, as well as a fully equipped manufacturing facility on the mine. The peak consumption of sets at one stage reached 1500 per month.

Subsequent extensive tests and evaluation led to the use of a commercially available arch that is comparable both in price and efficiency.

Figs. 2 and 3 show the typical dimensions and instal-

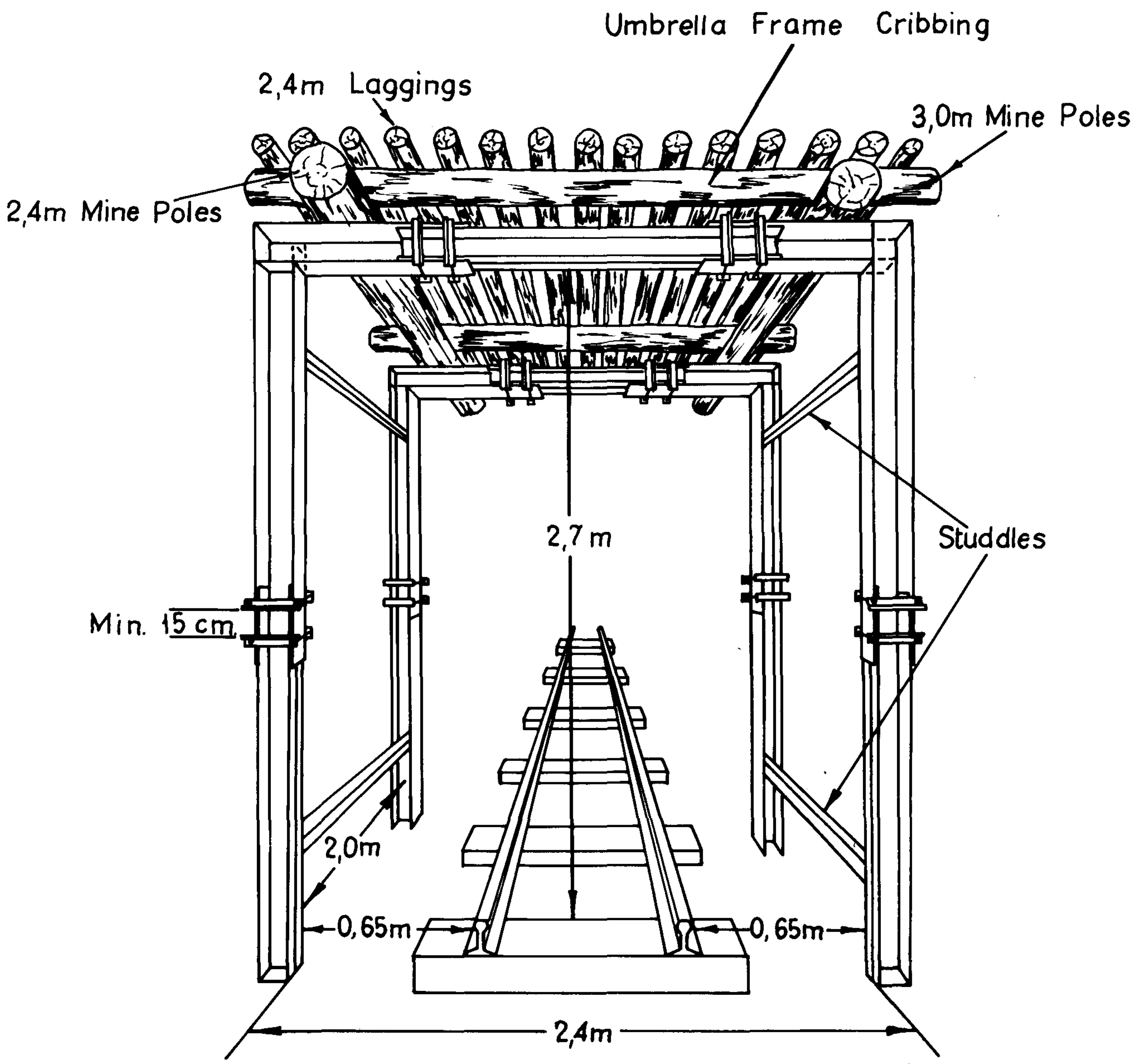

Fig. 2—The 'Stilfontein' square steel set

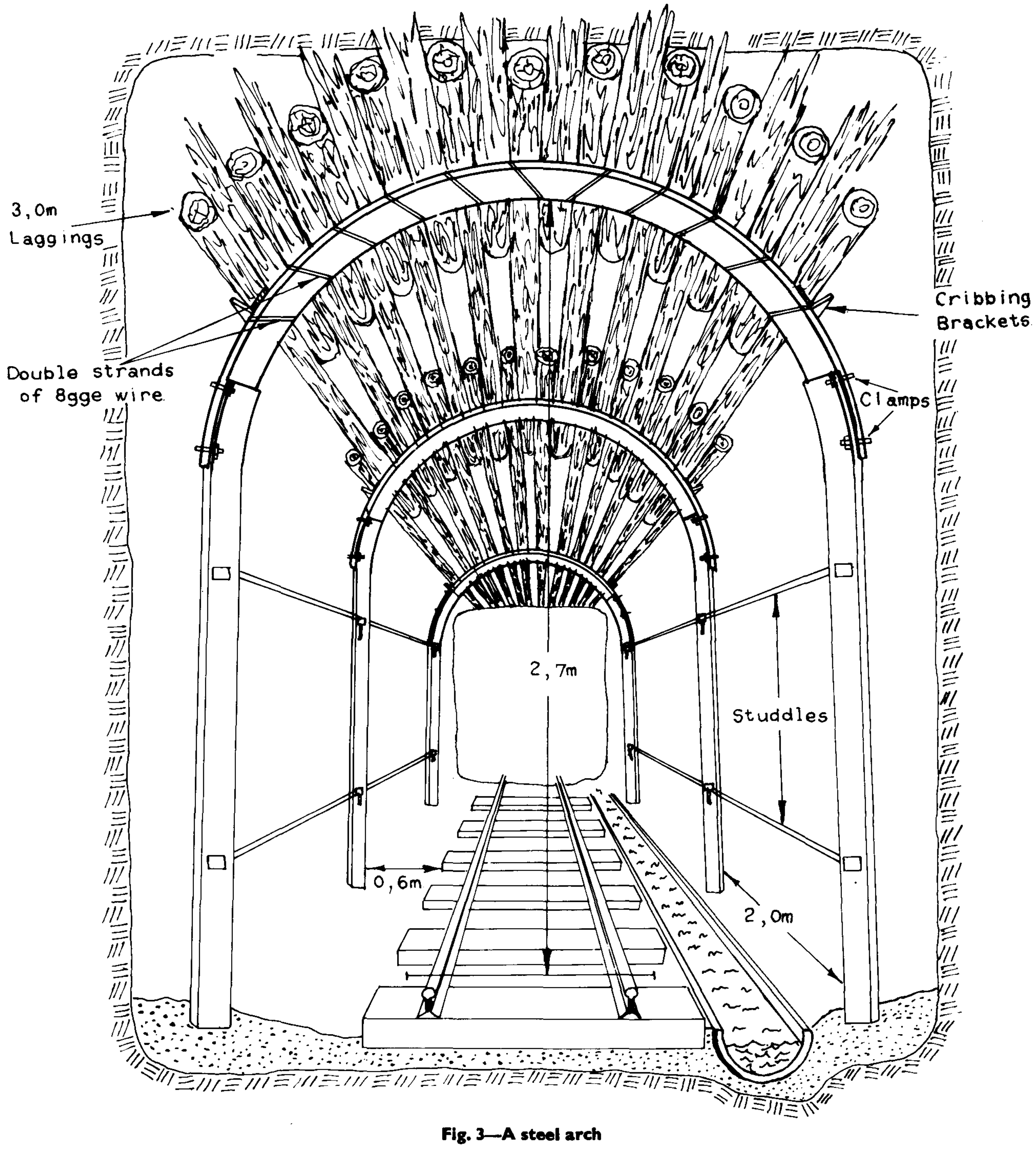

Fig. 3—A steel arch

lations of the square Stilfontein steel set and the curved type of arch now being used.

The following are some of the advantages of the steel arches:

(a) yielding action of the arch
(b) safety during installation
(c) ease of maintenance
(d) safe bleeding of hangingwall and sidewall if required.

The use of steel arches was one of the most important decisions with regard to the opening-up of old areas at Stilfontein, and it is considered that it will remain an integral element as long as these operations continue.

A hydraulic steel set pusher, Fig. 4, was designed and built for the purpose of installing steel sets in a partially closed form below broken timber sets. It consists of hydraulically operated rams mounted on a carriage, the power pack and controls being mounted separately. The top segments of the steel sets are placed in the cradles, and the machine then pushes out the segments to their full demensions, squeezing any broken timber until the required tunnel size has been achieved. The leg segments are clamped in position and the studdles are attached. The method employed avoids the blasting down of the broken timber sets, which normally causes total collapse. The machine is connected to an electrical-power supply unit by means of a trailing cable and exerts a force of 250 kN per ram, i.e. 750 kN per steel set. It is operated by three unskilled men who are positioned in complete safety behind the machine; up to eight yielding steel sets can be installed per 8-hour shift.

The technical details of the pusher are as follows:

Length 2,1 m	
Width 1,7 m	
Height in closed position	1,63 m
Height in open position	2,36 m
Power pack	One 11 kW electric motor driving a Vickers hydraulic pump.

The pusher is no longer used. Because of its size and difficulty in manoeuvring the machinery in and out, and because hoppers had to be brought in to load the broken rock, its use was actually increasing the cycle time instead of decreasing it.

Breaking Large Rocks

Heavy demolition breakers were tried for breaking up large rocks. A number of short holes were drilled in the conventional manner and then the breaker was used to push an 'easy break' tapered steel rod into the hole, thereby breaking the rock. The machine was equally effective in breaking up the sidewall behind steel sets.

However, this system was found not to be as efficient as explosives. An alternative was the use of a small mobile hydraulic breaker, (i.e. the Joy Hefti hammer), but the capital outlay could not be justified by the potential increase in the rate of advance.

Removing Broken Timber and Pipes

The presence of old timber from sets and cribbing, and of old pipe columns trapped in the rockfalls, is one of the major factors militating against the use of mechanized loading equipment. Because they are so firmly lodged in the rockpile, the sticks and pipes obstruct the digging and crowding actions of the mechanical loaders. Various methods have been used to pull the timber out, ranging from chains pulled by a locomotive to pneumatic chain hoists, and to a hydraulically operated rail-mounted grapple machine. The pulling force required to remove the timber is generally estimated to be in the region of 10 t. Safety is a major factor: the sticks or pipes have to be pulled from areas that have not been permanently re-supported, which is a potentially hazardous operation.

The present method involves manual clearing of as much rock around the timber as possible, followed by the sawing off and removal of the loosened timber. Pneumatically driven chainsaws have been successfully used to assist this operation.

Loading of Broken Rock

This operation remains the most physically arduous and difficult of all. Because of the confined space, coupled with the need to shunt hoppers in and out of the end as loading takes place, it is not practical to use much of the mechanical equipment available. Conventional rocker shovels could be used but in most cases are restricted by the height available and by the presence of timber and

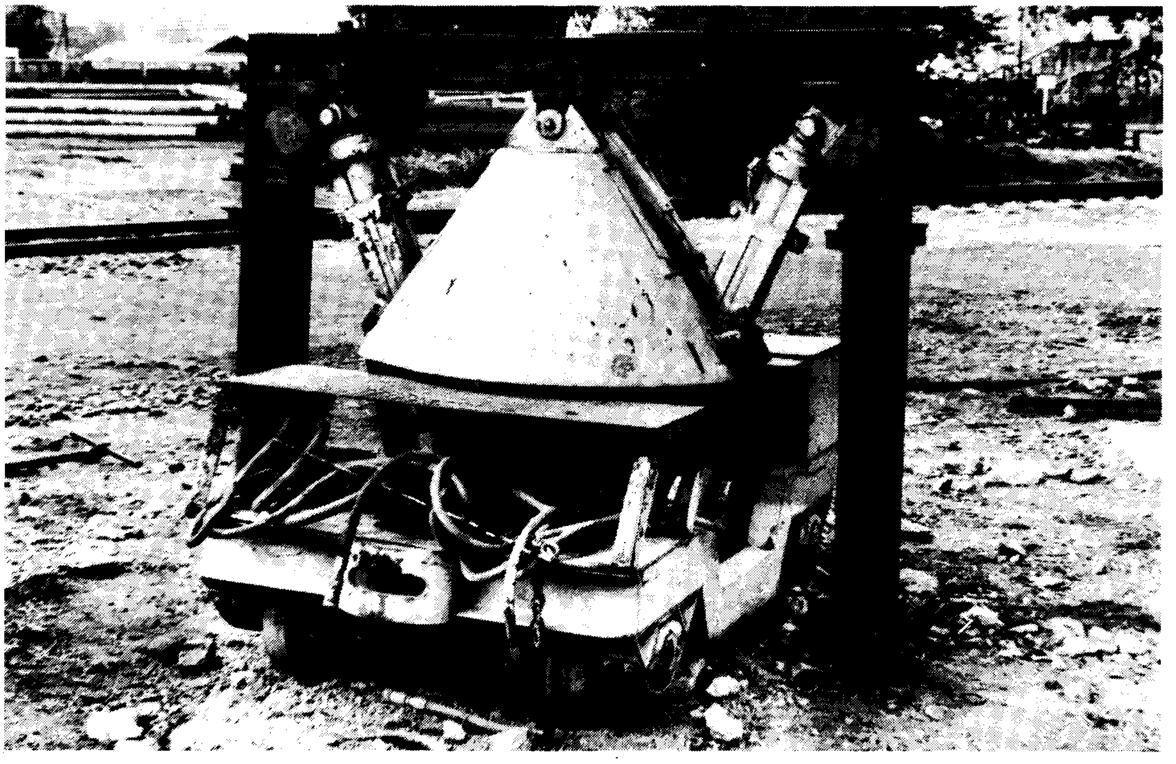

Fig. 4—A hydraulic steel-set pusher

piping in the rockpile to be loaded, which prevents efficient operation.

Use was made of a Wagner Scoop Tram ST 2B, which is a trackless diesel-driven front-end loader powered by a 78 h.p. Deutz engine. The tram can discharge into a hopper either from the side or end on, and is a powerful unit with a shovel capacity of 2,5 t. It pulls out sticks and pipes from underneath falls of ground and can dig into the footwall as well as be used as a platform for barring. The unit requires a certain amount of tipping room, and arrangements have to be made for this purpose. Owing to its width, the machine tends to slip into the drain when driven along a haulage. It generates a fair amount of heat and can operate only under good ventilation conditions.

Because it was operating in a very hot, hostile environment, the number of breakdowns and maintenance costs became excessive. The unit was therefore withdrawn to a surface-loading operation.

The Hägglund Loader (Fig. 5) was also tried. This is a gathering-arm loader, electrically and hydraulically driven, with a flight chain conveyor that discharges directly into a hopper. The unit is connected to an electrical supply by a single trailing cable. It has an efficient loading capacity and can be operated by one person.

Several disadvantages caused the withdrawal of the unit from service: the chassis was too low, causing it to stick on the tracks if they were only slightly uneven; its overall size was too large to go into the forward areas of badly closed tunnels; the maintenance costs were high; it was difficult to manoeuvre in confined spaces; and the initial capital cost was very high. The unit has been recommissioned with a modified chassis height and will be tried again in actual working conditions.

Manual lashing of rock remains the most effective, although labour-intensive, means of clearing broken rock in this situation because of the wide variation in conditions and the difficulty of operating large, heavy equipment in confined, potentially hazardous areas. Attention is being given to the construction of a portable lightweight conveyor approximately 4 to 6 m long that can be used to take rock from the point of loading into the hopper without having to throw the rock. Initial surveys have indicated that this could double the present rate of loading.

Breaking and Clearing Sidewalls

The Hydraulic Sidewall Breaker (Fig. 6) was designed to break the generally slabbed sidewall prior to the installation of the yielding steel arches. It can also be used to assist the bleeding of sidewall behind installed steel arches. The unit consists of two back-to-back hydraulic rams with chisel bits of high-grade tensile steel fabricated into a boom that is fitted to a 4,5 t diesel locomotive. A force of 250 kN is exerted by the chisel bits and is sufficient to break the sidewall rock.

Some of the technical details of the breaker are as follows:

Length of boom Closed 2,0 m, open 2,7 m,
Length of ram Closed 1,7 m, open 3,3 m.

Power is generated by a hydraulic pump driven by the engine of the locomotive.

The breaker was not put into general use because a separate locomotive would have had to be available for mounting the unit. The mounting boom had to be reasonably long to protect the operator, and this made the

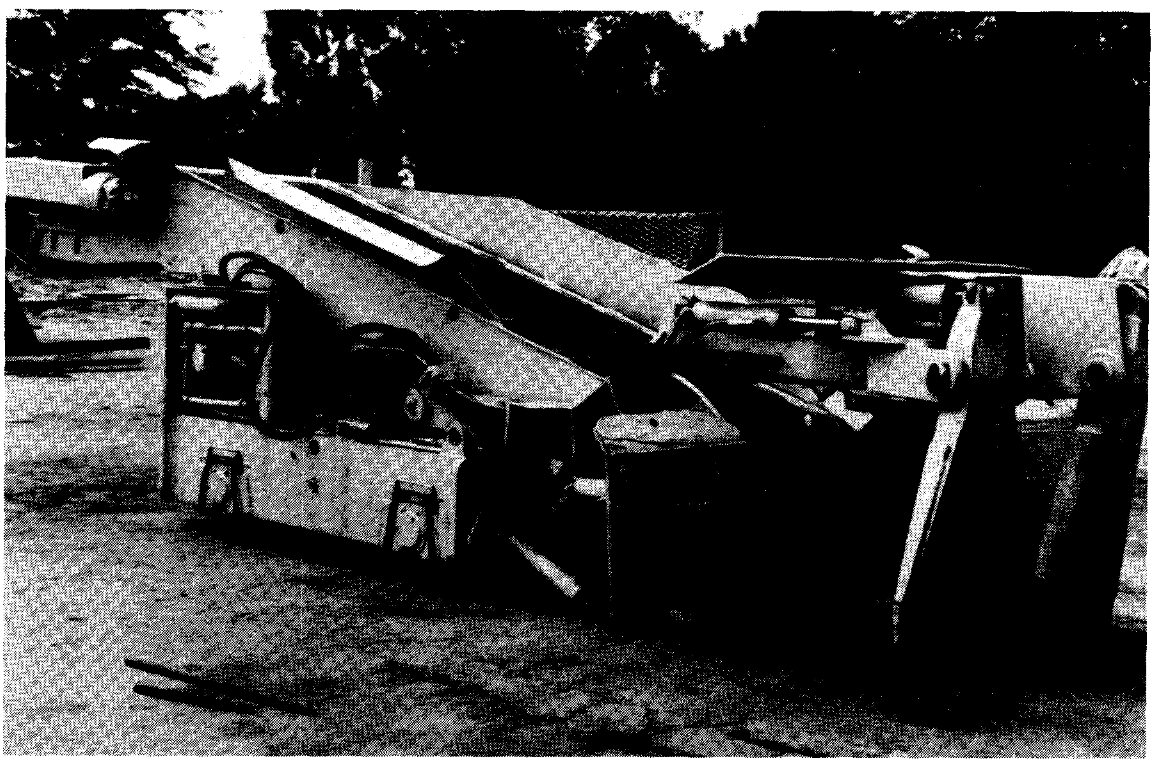

Fig. 5—A Hägglund gathering-arm loader

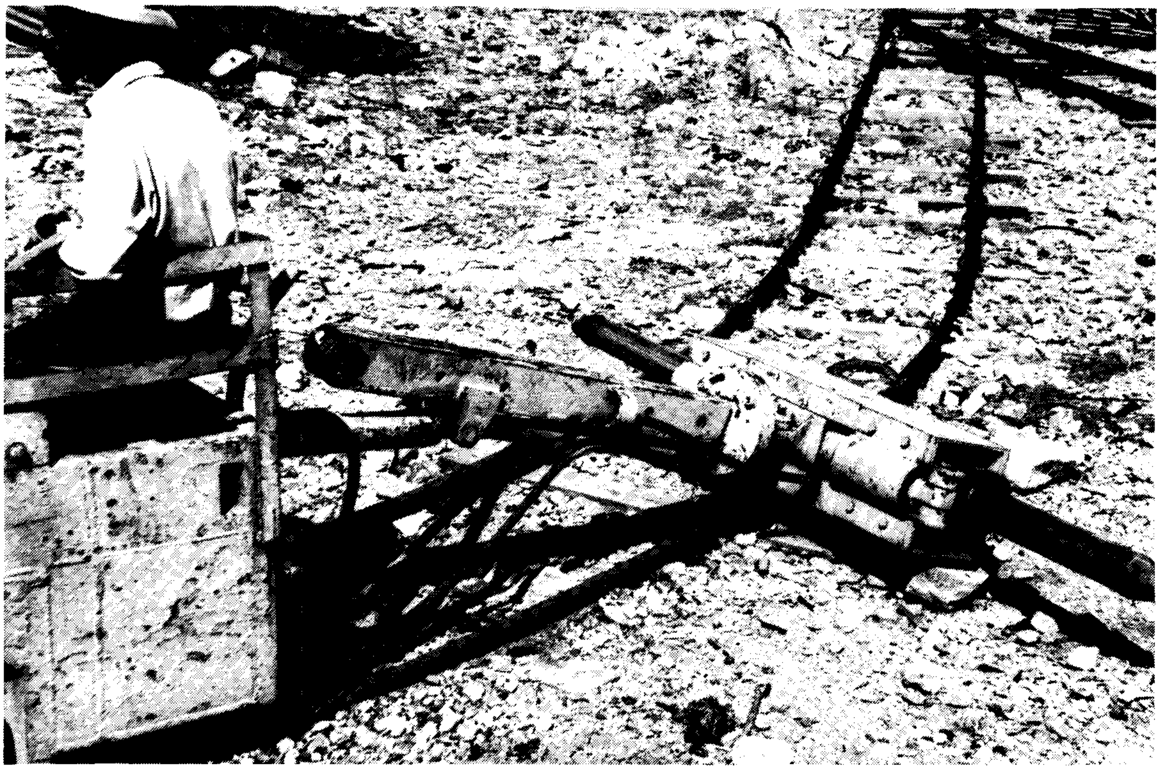

Fig. 6—A hydraulic side-wall breaker (rams extended)

locomotive unstable and unsuitable for shunting hoppers for the loading of broken rock.

Picking the Footwall to Clear and Re-install Tracks

Lightweight pneumatic picks with interchangeable picks and spades have been used successfully. They are relatively light and are very effective for loosening and re-consolidating the ballast during the regrading of tracks.

Rock Mechanics Considerations

Owing to the nature of the ground and the position of the areas to be opened up relative to one another and to the footwall excavations, due consideration has to be paid to the method of extraction with a view to facilitating mining and minimizing stress loadings. For this purpose, the mine is divided into sections that can be regarded as being independent of one another. A section is placed on the analogue computer and the safest mining sequence is determined and each block of ground is then considered individually. Use is again made of the analogue computer to pre-determine the stresses and stress loadings that would be produced by different mining methods. Once the optimum method has been determined, the rock mechanics department makes a full report to the relevant mining section.

Should it be necessary to re-develop a cross-cut to stope an isolated block of ground, care must be taken to situate it in an overstoped area where the stope faces will advance away from the cross-cut. Unless this is done, the stress loads generated will again cause the cross-cut to deteriorate and close up.

All opening-up plans, sequences, and proposed methods are taken into consideration at monthly planning sessions. Any deviation from the standard has to be accounted for and rectified.

Conclusion

One of the major advances in Stilfontein Mine has been the application of steel arches in the support function. Mechanization is not easily achieved because of the scattered nature of the operation and the very high capital cost of sophisticated equipment, making economic justification difficult.

The higher price of gold and the potential increase in profit justified the decision to return to these areas and to mine the lower-grade areas that had been abandoned. Even though there is a high degree of manual labour involved, the efficiency per labourer is comparable with that of normal development, and should improve if some of the suggestions made here can be pursued and developed further. However, it should be noted that, if the potential rate of advance and efficiency per labourer is less than for normal development, a completely new haulage or cross-cut should be considered.

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