The improved rate of stope-face advance at Buffelsfontein Gold Mining Company Limited

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SYNOPSIS

To achieve a higher rate of stope-face advance, it was necessary to examine all aspects of the stoping operation, to identify bottlenecks, and to eliminate them or reduce their effect. The cleaning cycle was found to be the most significant bottleneck, and this problem was aggravated by long panel lengths, under-capacity winches in strike gullies, and excessively long strike scraping distances.

SAMEVATTING

Ten einde 'n beter frontvordering te bewerkstellig is dit nodig om alle faktore met betrekking tot afboubedrywighede te ondersoek, knelpunte te identifiseer en die invloed van laasgenoemde te elimineer of tot 'n minimum te beperk. Daar is gevind dat opruiming die grootste knelpunt is en hierdie probleem word vererger deur faktore soos lang panele, die gebruik van te swak wenasse in die strekgang en buitengewoon lang strekgange.

INTRODUCTION

Concentrated stoping operations have long been recognized in the gold-mining industry as a means of improving efficiencies and thereby profitability. This is particularly true in deep-level mining, which, if the environmental conditions are to be good, requires vast amounts of capital for large-diameter shafts and extensive refrigeration-plant installations. Concentrated operations not only allow for the optimum use of available ventilation and refrigeration, but provide facilities that increase the volume of output (and hence efficiency) and make the introduction of sophisticated equipment for mechanization economically viable.

Concentrated mining depends directly on the rate of face advance, and it was this consideration that influenced Buffelsfontein Gold Mining Company Limited to examine its face advance in detail and embark on a programme aimed at reducing the number of working stopes on the mine so that 'factory' conditions could be provided, which would allow for optimum use of human and material resources.

Up to then, the stoping method had been one that was designed for the blasting of faces in a cycle of 2, 3, or 4 days, depending on the prevailing conditions. This allowed for long cleaning cycles but not for rapid face advance. Because of widespread operations, the ventilation was not satisfactory, average face velocities being 0,5 m/s.

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To a certain extent, the goal that was set has been reached, but much work has yet to be done before the full potential of mining systems using blasting techniques can be realized.

The approach taken has been one of systematic analysis of operations, identification of bottle necks, their elimination wherever possible, and development of a stoping method that will allow for full cyclic operations. At this time, although certain conclusions have been reached, we recognize that many improvements are yet to come as labour costs increase and more research is done into mechanization.

INITIAL LAYOUTS

Prior to the new programme, stopes were laid out as follows:

(a) panel lengths: generally 30 to 35, depending on faulting
(b) boxhole layout: approximately one borehole per two panels
(c) distance between raises: 120 m
(d) distance mined on strike: wherever possible, east and west mining was done to mid-way between raises, but, owing to faulting, it was usually necessary to mine east for the full distance between raises
(e) ventilation: one vynide strike curtain (installed by stoper) per panel, 3 m above the gully
(f) winches: 22,5 kW gully and face winches
(g) scraper scoops: 2-ton hinge-back scoops for face and gully
(h) 1,1 m by 1,1 m 16 pointer packs installed at 3 m centres strike and dip
(i) barricade: 3 m slab lagging built up against packs and held in place by means of old drill steel and rope slings
(j) pack transport: hand transport, with the odd slide, sled, or mono-rail
(k) services: 100 mm of compressed air and 50 mm of water in the centre gully with 50 mm of air and water on strike for each panel
(l) sweepings: hand-held brooms and metal scrapers
(m) shifts worked: normal 8-hour day shift for drilling, sweeping, and support, and 8-hour night shift for cleaning (effective time probably not much more than 14 hours out of 24).

With the above layouts and equipment, panels were seldom planned to show more than 8 m of advance per month.

The average monthly results were as follows:

Face advance	7,0 m
Centares per Contractor	560 centares
Centares per Black (stoping)	17 centares

CLEANING

Winch Capacities and Panel Length

At an early stage, cleaning was identified as the major bottleneck in improved face advance, most of the other problems having an inter-relationship with the cleaning function. A detailed analysis of the cleaning cycle indicated that strike scraping presented the major bottleneck and that this was aggravated by long strike-scraping distances and long panels.

In an effort to overcome this problem, 37,5 kW winches were introduced for gully scraping, and the scoop combination was altered to a 2-ton hinge-back scoop with a 1-ton boxhoe scoop. Improved face advances were achieved, the average results being better than those with the 22,5 kW strike winches, but, beyond 30m from the centre gully, regular daily blasts were not achieved.

A table was drawn up showing the theoretical cleaning times for different combinations of winches and scoops, but the results of the cleaning studies were so variable that no logical correlation could be made between these and the theoretical figures. It was concluded that most of the incidents (e.g., breakages of rigging equipment, falls of ground, etc.) that resulted in down time were unpredictable and, short of replacing all the equipment daily and resorting to extensive additional support, were to a large extent unavoidable. It was therefore concluded that the capacity of the strike-cleaning equipment must be such as to permit the panel to be completely cleaned in an 8-hour shift minus the average standing time.

A table was drawn up by our Technical Services Division from which maximum panel lengths under differing circumstances could be read off (Table I). From this and other information, it was decided to limit panel lengths to a maximum of 20 m, except where conditions were such, owing to faulting, as to make this unpractical.

Objections to the reduction of panel lengths, thereby increasing the number of strike gullies, centre mainly round the additional waste that has to be mined and the greater hazard offered by gullies than by stope faces.

The following were factors favouring the reduced panel length:

(a) improved face advance,

(b) smaller effect if blast is lost,

(c) ease of access into panels and improved supervision, and

(d) improved blasting

Boxholes

It is generally accepted that, to improve cleaning operations, boxholes should be provided for each gully if possible, and centre gully scraping should be done only where it is not possible to provide a boxhole. Owing to the shortage of labour, this concept must be reconsidered on the basis of the number of Black shifts involved in the development of boxholes, as against the number of Black shifts required to operate a centre gully winch.

Example

Consideration: Whether to develop a 48 m boxhole.

Assume rate of development of 6 m per Black per month.

Assume team of 5 Blacks take 3 days for the boxfront installation and 2 days for the grizzley.

Assume that average stope-face advance is 20 m per month and total distance stoped between raises is 100 m (5 months of mining).

Shifts to develop boxhole	208	
Shifts to strip boxhole, say,	10	
Installation of boxfront and grizzley	25	
Total	243	shifts

If, instead of a boxhole, a winch is used that serves one panel east and west only:

Installation of winch, say,	10	
Winch manned on 2 shifts for 5 months	260	
Total	270	shifts

According to the above example, it is more economical to develop the boxhole (based on loss of opportunity). If the centre gully winch is provided for two panels, i.e., in place of two boxholes, it is certainly more economical to install the centre gully winch. If the boxhole were 60 m long, it would also be more economical to provide a winch.

Naturally, the above exercise applies only where there is sufficient boxhole capacity in a raise.

As a substitute for the centre gully winch, a conveyor belt can be successfully used, particularly for the lower portion of a raise, where, instead of tipping into small-capacity boxholes, all the ore is transferred upwards along the centre gully to a large-capacity box. The installation of a conveyor belt is economically justified, provided only the short boxholes necessary for development of the raise are developed, and provided also that the conveyor is installed so that maintenance labour is kept to the minimum.

Distance Between Raises

In order to reduce the amount of development necessary to open a block of reef, the cross-cut spacing was increased from 120 to 150 m. This resulted in a saving of approximately 120 m of development per block, but increased the length of strike scraping. The 120 m of development represents approximately 750 shifts. On the basis of loss of opportunity, a substantial capital investment can be made for the purchase of the additional equipment that would be required to maintain the average face advance over the longer strike distance.

Extensive experiments were conducted in the use of conveyor belts to remove ore along gullies. The objective was to limit the strike scrape and thereby ensure that the strike cleaning capacity is maintained or increased over strike distances of up to 300 m. A wide variety of belts, drives, loading chutes, and support systems were tested, both in centre gullies and strike gullies. Unfortunately, because of the nature of the ground at Buffelsfontein and the excessive sag, the use of strike gully conveyors was abandoned. The solution to the problem encountered along the strike gully installation was to excavate the gully to such dimensions as would allow for total closure in the panels, but the amount of additional labour involved in this made it prohibitive.

There is no doubt, however, that where closure is not excessive, strike conveyors can be economically justified, provided delays in blasting the faces, whilst extending the belts, winches, and funkey slides forward,

TABLE I

PANEL LENGTHS RELATED TO FACE ADVANCE, CLEANING EQUIPMENT, SLOPE WIDTH, AND MAXIMUM LENGTH OF STRIKE SCRAPE

Length of panel that can be cleaned in $7\frac{1}{2}$ h for corresponding length of hole

SSG unit: scraper winch 22 kW, rope speed 0,9 m/s   Scoops: two 1-ton boxhoe   Face unit: scraper winch, 15 or 22 kW, rope speed 0,9 m/s

Zone		Stope face						SSG at 40 m						SSG at 60 m						SSG at 80 m					
Stope width, cm		90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215
Length of hole	Face adv./blast	Maximum face length						Maximum face length						Maximum face length						Maximum face length					
0,76 (30″)	0,60	32	28	25	23	21	20	31	27	24	22	20	19	25	22	20	18	16	15	21	18	17	15	14	12
0,91 (36″)	0,73	28	25	22	20	19	17	27	23	20	18	17	16	22	18	17	15	14	13	18	15	14	13	11	10
1,07 (42″)	0,86	25	22	20	18	17	16	23	20	17	16	14	13	18	15	14	12	11	10	15	12	11	10	—	—
1,22 (48″)	0,98	22	20	18	17	16	15	20	17	15	14	12	11	16	13	12	11	10	—	13	11	10	—	—	—
1,37 (54″)	1,10	21	18	17	15	14	13	17	15	13	12	11	10	14	11	—	—	—	—	11	—	—	—	—	—

Scraping units as above, but cleaning shift 9 h

Zone		Stope face						SSG at 40 m						SSG at 60 m						SSG at 80 m					
Stope width, cm		90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215
Length of hole	Face adv./blast	Maximum face length						Maximum face length						Maximum face length						Maximum face length					
0,76 (30″)	0,60	40	34	31	29	26	24	40	34	31	29	26	23	33	28	26	23	21	19	28	23	21	19	17	16
0,91 (36″)	0,73	35	31	27	25	23	21	34	30	27	24	21	20	28	24	22	20	18	16	24	20	18	16	15	13
1,07 (42″)	0,86	31	27	24	22	20	19	30	25	23	20	18	17	24	20	18	16	15	14	20	17	15	13	12	11
1,22 (48″)	0,98	28	24	22	20	18	17	26	22	20	18	16	15	21	18	16	14	13	12	17	15	13	12	11	10
1,37 (54″)	1,10	26	22	20	18	17	16	24	20	18	16	14	13	19	16	14	12	11	10	15	13	11	10	—	—

Length of panel that can be cleaned in $7\frac{1}{2}$ h for corresponding length of hole

SSG unit: scraper winch 37 kW, rope speed 1,2 m/s   Scoops: one 1-ton boxhoe, one $\frac{1}{2}$-ton boxhoe   Face unit: scraper winch 22 kW, rope speed 0,9 m/s

Zone		Stope face						SSG at 40 m						SSG at 60 m						SSG at 80 m					
Stope width, cm		90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215
Length of hole	Face adv./blast	Maximum face length						Maximum face length						Maximum face length						Maximum face length					
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0,91 (36″)	0,73	29	24	23	21	19	18	30	26	24	22	20	18	25	21	19	18	16	15	22	18	16	15	13	12
1,07 (42″)	0,86	25	22	20	18	17	16	26	22	20	18	16	15	21	18	16	15	14	13	18	15	14	12	11	10
1,22 (48″)	0,98	23	20	18	17	16	15	23	19	17	16	15	14	19	16	14	14	12	11	16	13	12	11	10	—
1,37 (54″)	1,10	21	18	17	16	15	14	20	17	16	14	13	12	16	14	12	11	10	—	14	11	10	—	—	—

Scraping units as above—but cleaning shift 9 h

Zone		Stope face						SSG at 40 m						SSG at 60 m						SSG at 80 m					
Stope width, cm		90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215	90	115	140	165	190	215
Length of hole	Face adv./blast	Maximum face length						Maximum face length						Maximum face length						Maximum face length					
0,76 (30″)	0,60	40	34	31	29	26	24	+40	29	35	32	29	27	38	32	29	27	24	22	33	28	25	23	21	19
0,91 (36″)	0,73	35	30	27	25	23	21	40	34	30	27	25	23	33	28	25	22	20	19	28	24	22	19	18	16
1,07 (42″)	0,86	31	26	24	22	20	19	34	29	26	23	21	19	28	24	21	19	17	16	24	20	18	16	15	14
1,22 (48″)	0,98	28	24	22	20	19	17	30	15	23	20	19	17	24	21	19	17	15	14	21	17	16	14	13	12
1,37 (54″)	1,10	26	22	20	18	17	16	27	23	20	18	17	15	22	18	16	15	14	12	19	15	14	12	11	10

are limited to about once in every 50 m of stope-face advance. The normal delay involved in a 30 m extension was 3 days, which reduced the potential face advance.

In particularly good areas, crosscuts could be developed 300 m apart, and the use of strike conveyors should make it possible to maintain the average face advance over the full distance. It is in this application that conveyor belts have their greatest potential. Other advantages are their use as a means of transporting timber and as a means of access into areas that would normally require extensive off-reef development.

To overcome the problem of limited strike-scraping capacity over the increased strike distance where conveyors cannot be used, 55,9 kW winches have been installed. Good results have been achieved, although the effectiveness beyond 120 m has still to be assessed.

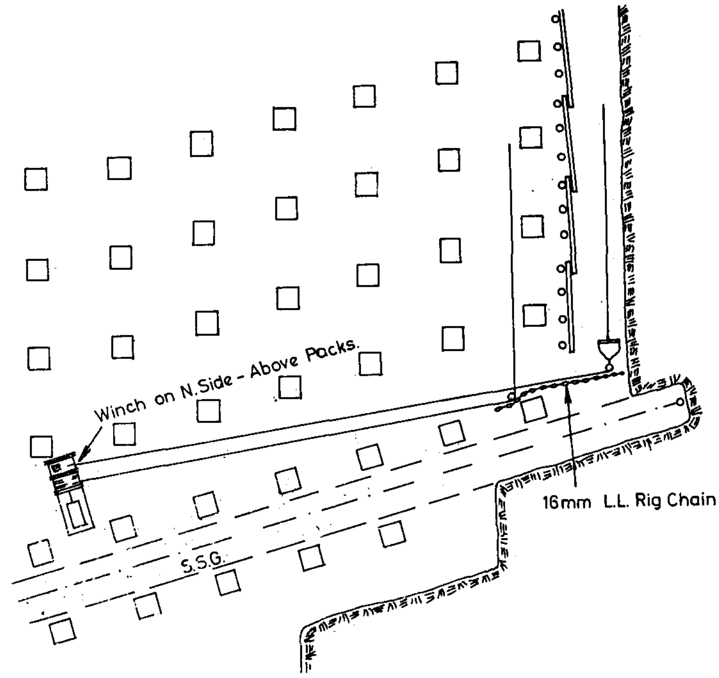

Fig. 1—The arrangement of a face winch where the dip of the reef exceeds 15° (Buffelsfontein)

Scraper Scoops

It is not within the scope of this paper to prove the effectiveness of different scoops, as their suitability usually depends upon the size and type of broken ore to be handled. At Buffelsfontein, the use of 2-ton hinge-back scoops was discontinued in favour of a re-designed $1\frac{1}{2}$-ton boxhoe scoop.

Rigging

Any reduction in the time taken to rig gully and face scrapers means additional time available for cleaning. Although extensive experimentation has been done in this field, little of significance has been developed, particularly in respect of bottom face rigs installed along gullies, where bad hanging conditions are normally encountered.

In an attempt to overcome this problem in areas where the reef dips at more than 15°, face winches are installed so that the ropes run between the first and second row of packs above the gully (Fig. 1). The advantages of this system are as follows:

(1) the strike and face winch ropes, rigs, and scoops are completely separate from one another, and either can be stopped and started as required without affecting the other;
(2) the rig is installed away from the gully, where hanging conditions are normally poor; and
(3) the gully scraper does not foul the face rig.

Attempts have been made to improve hanging-wall conditions along gullies by the installation of grouted roofbolts, but this has not met with much success.

Length of Cleaning Shift

An increase in the length of the cleaning shift, if required on a long-term basis, can be accomplished only by a reduction in travelling time or by the introduction of two cleaning shifts. Working overtime is a most unsatisfactory means of overcoming this problem.

Double-shift cleaning has been very successfully introduced in stopes where strike scraping distances have become excessive. The cleaning shift is increased from the normal $6\frac{1}{2}$ hours to an effective 12 hours, and the drilling shift from $6\frac{1}{2}$ to 8 hours, thereby utilizing all the available time, 4 hours being allowed for re-entry. Travelling time is taken care of by the working of three 8-hour shifts within 20 hours. Normally, the first shift after the blast cleans only the gullies, and then rigs in the face scrapers for the second shift to complete the cleaning. This system requires more-specialized labour, but this is offset by the improved face advance.

LABOUR UTILIZATION

Allocation

The concept of labour allocation for stoping was usually based on the achievements of the preceding quarter. Labour was allocated on a stope basis, regardless of the number of panels and equipment in the stope, although it was normally dependent on what had previously been achieved.

The above philosophy had been entrenched over a period of many years, and it was subsequently most difficult to initiate a system that allocated labour on the basis of an effective team to ensure a full daily cycle on each panel.

Example

For a 25 m panel, the following labour is required for a daily blast:

	Day Shift	*Night Shift*
Team Leader	1	1
Winch Driver	2	2

Machine	4		—
Spanner	4		—
Team	9		1
Total	20	+	4=24

Labour was previously allocated at 16 centares per Black. If the panel was planned for 20 m of advance (500 centares), the allocation for the panel would have been 31 Blacks (500/16).

With the new allocation, 20,8 centares per Black (500/24) is achieved, although the labour allocation has the potential of blasting the face daily and achieving 26 m of advance for the month (650 centares) at a rate of 27 centares per Black (650/24).

If the advance per blast is increased to, say, 1,2 m an afternoon shift introduced so as to be assured of a clean face, and an additional team member brought in for timber transport etc. (i.e., an additional 4 Blacks), then for 26 blasts an advance of 31,2 m (785 centares) would be achieved at a rate of 28 centares per Black (785/28).

The above figures, although theoretical, have regularly been achieved in 'factory' stopes where all the necessary equipment has been provided and good environmental conditions prevail.

Ventilation

To achieve good conditions along working faces, it is necessary, firstly, that a sufficient quantity of air is available and, secondly, that this air is coursed so that it flows where required. The first requirement is attained by the concentrating of operations. It has been found, however, that stopers are generally not particularly concerned with the coursing of air into stope faces and often neglect to install brattices and curtains.

After many attempts at enforcing the standard, it was decided to make this task the responsibility of the Ventilation Department. The labour allocated to stopers was reduced and this labour given to the Ventilation Department. Initially, the results were disappointing but, after a few months, face velocities increased remarkably (Fig. 2).

The installation of the vynide curtain was improved by the use of chicken mesh spanned between packs as a backing. This system not only results in less leakage but it also prevents entry into back areas and discourages damage to curtains.

MECHANIZATION

Unfortunately, owing to the nature of the reef and the rapid closure in back areas where accessways are situated, equipment introduced for the mechanization of operations must be such that it can be dismantled into reasonably small components for transport. This places a limitation on the type of equipment that can be introduced but does not exclude the mechanization of stoping systems.

After numerous experiments, a system of stoping with hydraulic props was developed, and the use of pneumatic winches has substantially reduced the physical effort normally associated with prop and barricade movement.

The aim was to introduce a system that would achieve cyclic operations, resulting in more consistent blasting and a much better control of ore. Although there has been no significant improvement in face advance to date, labour efficiencies should improve from the reduced complement per panel. It is expected that face advance will improve once the practice of stoping with props has been extended to all the mechanized panels, and the efficiencies have improved as teams become more competent in their use.

PLANNING

Mechanized panels are planned at a minimum face advance of 20 m per month, and this had led to a marked reduction in working faces. It is now essential that operations are carefully planned because delays in these units could result in substantial losses in production. Similarly, it is essential that all the back-up services are planned; the larger volumes of ore being produced from concentrated workings mean that any hold-up or breakdown in these services could be serious.

Provision must, for the same reasons, be made for a possible major breakdown in a 'factory' stope by the preparation of standby units. As a result of the reduced working panels, additional winches become available that can be used to equip the standby 'factory' stopes.

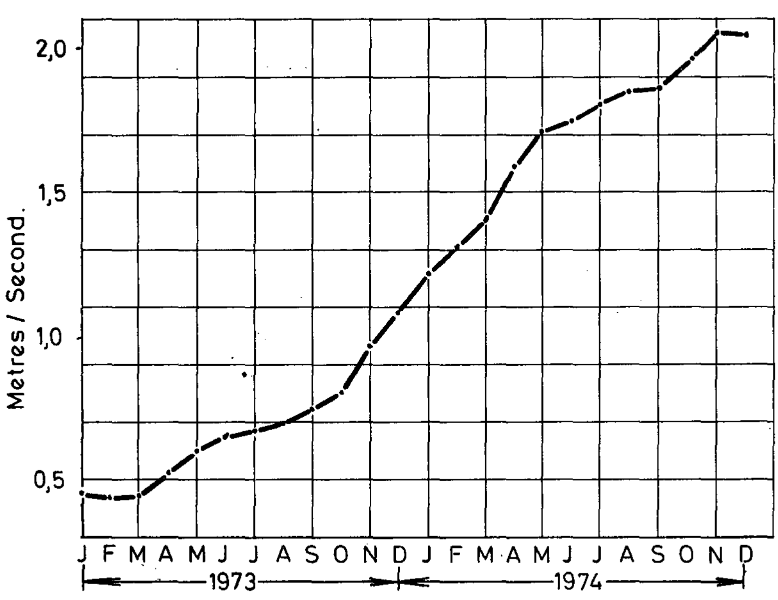

Fig. 2—Average stope-face velocities (Buffelsfontein)

RESULTS

Face Advance (Fig. 3)

The average face advance in 'factory' stopes, from which approximately 60 per cent of the total production is obtained, is between 20 and 25 m per month. Ledging, and mining out of blocks and remnants, reduce the overall aver-

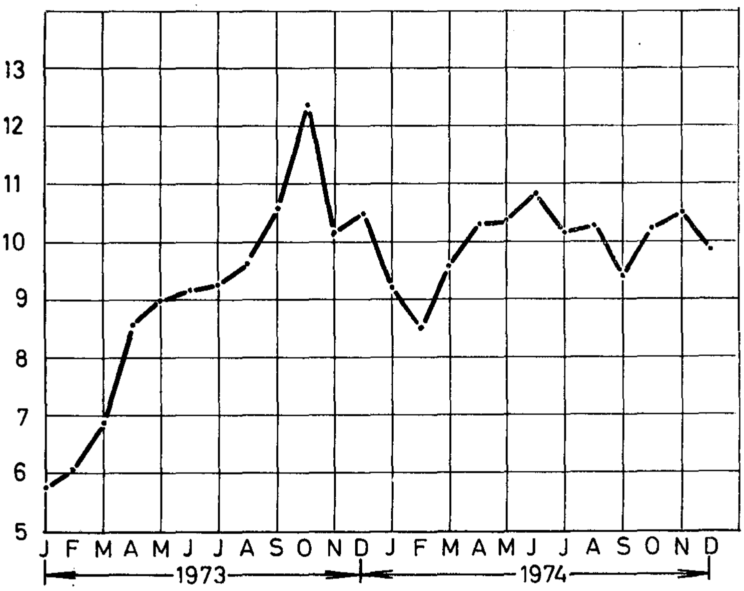

Fig. 3—Stope-face advance in metres (Buffelsfontein)

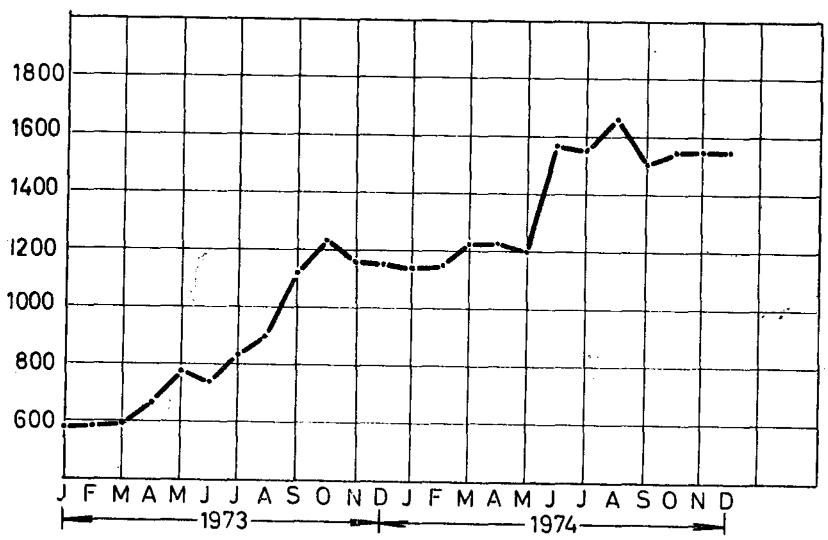

Fig. 4—Centares per stoper (Buffelsfontein)

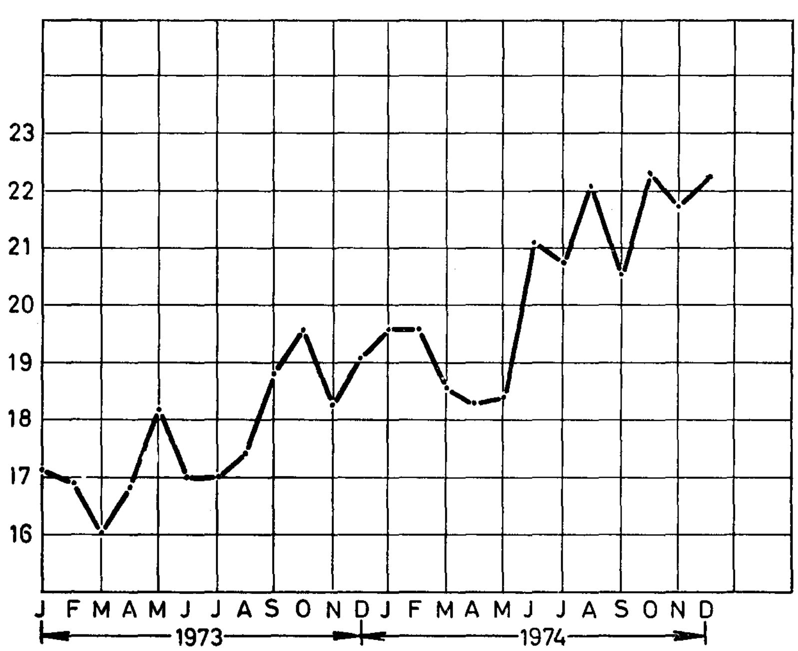

Fig. 5—Centares per Black (Buffelsfontein)

age advance for the mine to between 10 and 11 m per month. To improve on this advance would require either an increase in the face advance in mechanized stopes to more than 1 m per day, or a change in the method of mining to a longwall system, which reduces pillars and the amount of ledging required. Unfortunately, because of faulting, the application of longwall systems to Buffelsfontein is limited.

The overall results were good in the first year of the programme, increasing from 6 m to more than 10 m, but since then have steadied out and will probably not increase until mining has progressed into the 150 m blocks, and then only by a nominal amount.

Centares per Contractor (Fig. 4)

Probably the best improvement has been made in this field. Within twelve months, the output per contractor has increased from about 550 centares to about 1600 centares per month. The concept of 'factory' stopes producing between 1500 and 3000 centares has become common practice.

Centares per Black (Fig. 5)

Although efficiencies have improved substantially, it is expected that, in the not-too-distant future, the introduction of mechanized methods will improve the output to 25 centares per Black, and eventually to over 30 centares per Black.

CONCLUSION

To achieve an improved rate of face advance, it is necessary for all stoping activities to be analysed in some detail so that bottlenecks can be identified. If positive steps based on sound economic principles are taken to eliminate these bottlenecks or reduce their effect, the ultimate objective of concentrating operations will be achieved.

To a large extent, the rate of progress in this direction will depend upon whether efforts made by research organizations in both the mining and private sectors will be given support and incentive by mine managements and supervisory staff.

Technical training, communications, and motivation of staff have become factors that, if not attended to, could prevent many projects from getting off the ground.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the dynamic approach taken by the Consulting Engineers of General Mining & Finance Corporation Limited, Mr J. C. Fritz (General Manager), and Mr D. J. Theron (Senior Manager, Gold and Uranium Division). This approach has led to developments in stoping techniques that would otherwise not have been attempted.

The author also wishes to express his sincere thanks to Mr L. V. Grobler, General Manager, Buffelsfontein Gold Mining Company Limited, for his assistance, and to Mr P. Loubser and Mr H. Kruger, Assistant Managers, for their invaluable support in developing and introducing the new systems.

REFERENCE

Christos, B. P. Mechanisation at Buffelsfontein Gold Mining Company Limited 1973-1974. Circular 1/75 Association of Mine Managers, 1975.

Discussion of the above paper

M. B. ALGEO*

The management and staff of Buffelsfontein Gold Mining Company Limited are to be congratulated on the excellent performances described in the paper presented by Mr Christos. In this day and age, with the current economic and labour situation, the mining industry is being constantly pressed to increase the productivity of ever-diminishing quanta of resources. The paper has outlined a very suitable blue print of action that could be implemented by most mine managements.

In the area of improved face advance, the Union Section of Rustenburg Platinum Mines Limited has failed to achieve results comparable with those of Buffelsfontein. Fig. 1 illustrates the 40 per cent improvement in the rate of face advance attained over the past sixteen months.

*Rustenburg Platinum Mines Limited, Union Section.

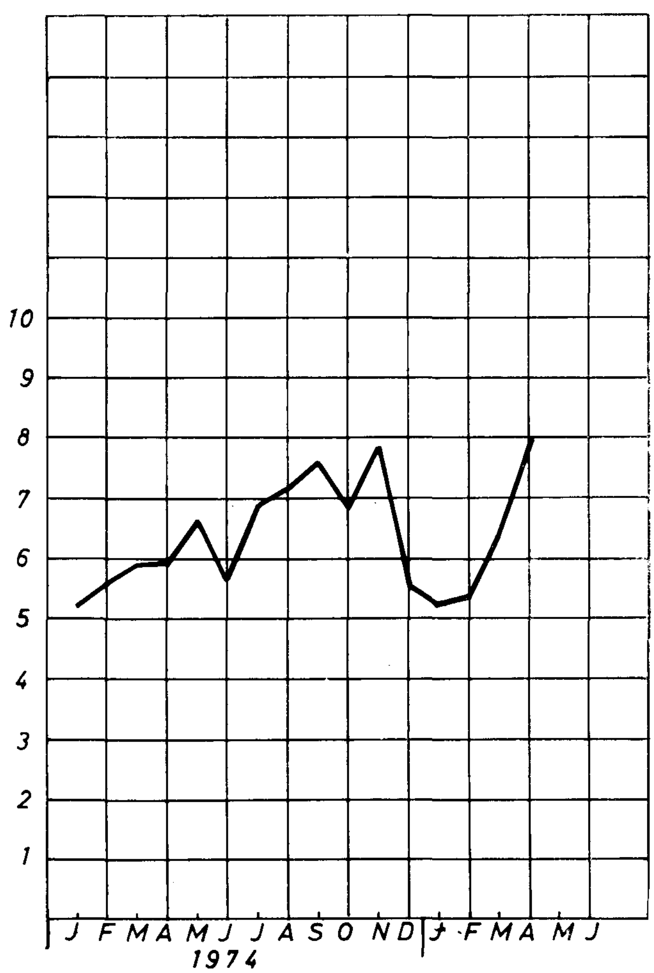

Fig. 1—Stope-face advance in metres (Rustenburg)

Over the same period, the major effort by management has been directed towards improving the labour productivity, and an indication of the results obtained in these areas may be of some interest.

The performance of the stopers is shown in Fig. 2. The indicated increase in output (82 per cent) is commensurate with that attained at Buffelsfontein. The performance of Black labour has been represented in terms of both the total tonnage broken per total underground Black and centares per stoping Black. It is felt that the former is more meaningful and representative of the cost of production. Fig. 3 represents this achievement, and Fig. 4 shows the achievements attained on the basis of centares broken per stoping Black.

Significantly, the results displayed in Fig. 4 are in excess of those given for Buffelsfontein. Contributing to these achievements are the following primary factors:

1. Complement setting in accordance with standards derived by universally accepted work-study methods.
2. A continuous process of work rationalization and evaluation in terms of an ordered set of priorities that reflect the emphasis of the Company's objectives and policies.
3. Training of Black and White