Primary fracture from an array of shotholes

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SYNOPSIS

The effects of stress on the directions of cracks that are propagating in a brittle medium are described. It is shown that the superimposition of stress fields from the holes of an array always adversely affects fragmentation. Consequently, the best fragmentation will result when holes are fired far enough apart in space or time for each to develop its whole crack pattern without disturbance from the others. This concept leads to a philosophy for the design of more effective blasting patterns, which has been verified on model scale and which explains many published, empirical results.

SAMEVATTING

Die uitwerking van spanning op die rigting waarin barste in 'n bros middel versprei word beskryf. Daar word getoon dat die oplegging van spanningsvelde vanaf die gate in 'n reeks, altyd die fragmentasie ongunstig beïnvloed. Gevolglik word die beste fragmentasie verkry wanneer die gate vergenoeg uitmekaar in spasie of tyd geskiet word vir elkeen om sy eie growwe patroon te ontwikkel sonder steuning van die ander. Hierdie begrip voorsien 'n uitgangspunt vir die ontwerp van meer doeltreffende skietpatrone wat bevestig is op modelskaal en wat baie van die gepubliseerde, empiriese resultate verduidelik.

INTRODUCTION

It is well known that a cylindrical explosive charge fired in a brittle material produces predominantly radial cracks. This is a consequence of the symmetry of the stresses round the borehole. In practice, where multihole blasting is the rule, stress fields from adjacent holes may interact. Moreover, cracks from most shotholes propagate into previously cracked material. It is necessary to take both these effects into account in a prediction of the primary cracking from an array of shotholes. Primary cracking is important because, as is logical to assume, the density and distribution of these fractures have a major effect on fragmentation.

In this paper the principles governing the formation of crack patterns in multihole blasting are established experimentally on a model scale, and are supported by theoretical argument. These principles are used to show how more efficient blasting can be achieved.

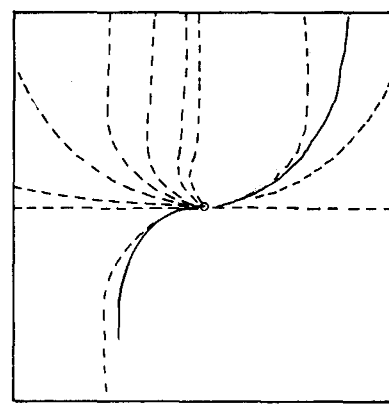
EXPERIMENTAL TECHNIQUES

Most of the model-scale shots described in this paper were done in polymethylmethacrylate (PMMA) sheet 25 mm thick. To avoid spurious effects from those edges of the sheet not associated with the burden, it was necessary to drill all the holes at least 300 mm from such edges. Cratering at each end of a hole was eliminated by 25 mm thick PMMA blocks stuck onto the test sheet to reinforce the material round the 'collar' and 'toe' of the hole. Holes of 1,5 mm diameter were drilled through the top block and the test sheet only, and the holes were filled with fine PETN at a loaded density of *ca* 0,8 g/cm³. Low-energy detonating cord was used to initiate the explosive column from the top. Any desired timing of shots in an array could be achieved.

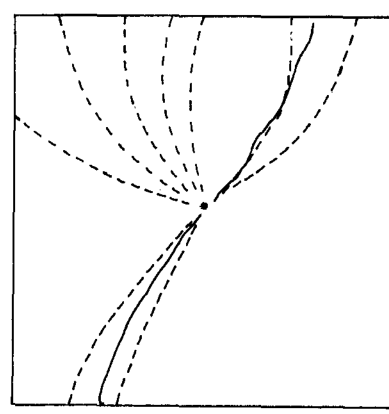
Two of the experiments reported here were done in 80 mm PMMA cubes, the holes being drilled to a depth of 60 mm from the centre of one face of the cube. In both these shots, the holes were notched with longitudinal diametrically opposed scratches on the wall of each hole. Such notched holes usually produce two major cracks starting in the direction of the radius vectors drawn through the notches. These cubes were uniaxially loaded normal to the axis of the hole when the shots were fired. The details of applied load, explosive, and hole diameter for each of these two shots are given later.

DIRECTIONS OF CRACK PROPAGATION IN STRESSED MATERIAL

Porter and Fairhurst[1] state that, in a two-dimensional situation, the instantaneous direction of crack propagation is always perpendicular to the vector of the greatest tensile strain. In an isotropic elastic material, this strain vector is normal to the axis of major principal stress. Accordingly, cracks follow the major isostatic — the curve to which the axis of major principal stress is everywhere tangential.



(a)



(b)

Fig. 1—Some isostatics (dotted lines) for a shothole fired in a block subjected to vertical compressive stress. Traces of the observed cracks are shown by full lines.
(a) Horizontal notch, lead azide, 1,2 mm hole, $9,4 \times 10^6$ Nm^{-2} stress
(b) Diagonal notch, low-energy detonating cord, 2,6 mm hole, $4,7 \times 10^6$ Nm^{-2} stress

*AE & CI Limited.

Isostatics round an internally pressurized hole in a uniaxially stressed semi-infinite plate were calculated from the equations given by Jaegar[2], and the effective pressure in the boreholes was calculated from the known explosion pressure and thermodynamic behaviour of the explosion product gases[3]. It was assumed that, in the quasi-static state, the borehole (and therefore the contained gases) had expanded elastically until the internal pressure due to the gases was in equilibrium with the elastic forces, tending to restore the hole to its original diameter. The calculated isostatics are shown in Fig. 1, together with the cracks obtained from single, notched holes fired in PMMA cubes subjected to different uniaxial loads. In each case, the applied stress was in the vertical direction, giving rise to the isostatic patterns shown.

The shapes of the cracks were well predicted by the theory. The general effect is for the cracks to align themselves with the applied compressive stress as they move outwards from the hole. This effect is commonly observed in deep-level stoping, where cracks propagate disproportionately far in the vertical direction and may seriously weaken the hanging wall.

STRESS FIELDS IN MULTI-HOLE BLASTING

In multihole blasting, rows of holes are often fired on a detonating trunkline. Such almost simultaneous firing of nearby holes leads to a situation in which adjacent holes in a row possess nearly equal internal pressures during crack formation. In order to confirm that crack paths are predicted by the major isostatics, the situation of two simultaneously pressurized holes was investigated.

Models were prepared in which two suitably spaced holes were fired simultaneously, and the stresses resulting from the interaction of the two radial stress fields were calculated using the principle of superposition. The direction of the major principal stress at any point, and thus the isostatics, was obtained by the method described by Jaeger[2].

In Fig. 2, the cracks obtained in several of the models are shown superimposed on the calculated isostatics. As before, the observed crack paths are well represented by the major isostatics.

A feature of the two-hole case is the envelope of cracks (predicted and observed) between the holes. Some of these cracks would have contributed to long-range radial fracture had they not followed the isostatics. When a row of holes is fired simultaneously, a necklace of crack-envelopes will be formed, to the detriment of cracking away from the line joining the holes.

Since this situation is caused by the interaction of the quasi-static stress fields, it can be obviated either by a delay in the firing of each hole from its neighbours, or by an increase in the spacing between adjacent holes.

This fundamental argument is well illustrated by the PMMA models depicted in Figs. 3 to 5. It will be seen that the area cracked per hole is significantly smaller for simultaneously fired, closely spaced holes than it is for either widely spaced or independently fired holes.

PRACTICAL IMPLICATIONS

Various workers have attempted to improve fragmentation by empirical methods. It is interesting to analyse their results in the light of the above explanation of crack development.

Langefors[4], in model-scale blasting with staggered rows of holes in PMMA, found that the fragmentation improved with increasing spacing-to-burden ratio (S:B) and when there was a delay between shots. The same conclusion was reached by Bergman *et al.*[5] after a series of experiments in granite cubes, and Bhandari[6] reported more economical mining in several cases when S:B ratios were increased. More recently, the Ensign-Bickford Company[7] has made the categorical statement 'There is so much evidence that delaying every hole results in better fragmentation that there is just no room for argument'.

It is probable that these findings all mean the same thing: each hole must be allowed to develop its entire crack system without interference from the others. As shown in Fig. 3, this can be achieved in two ways. Simultaneously fired holes can be separated widely enough to ensure that the effect of the radial stress fields from one hole on another is negligible, or the firing of closely spaced holes can be delayed so that the quasi-static stress round each hole is relieved by gas escape

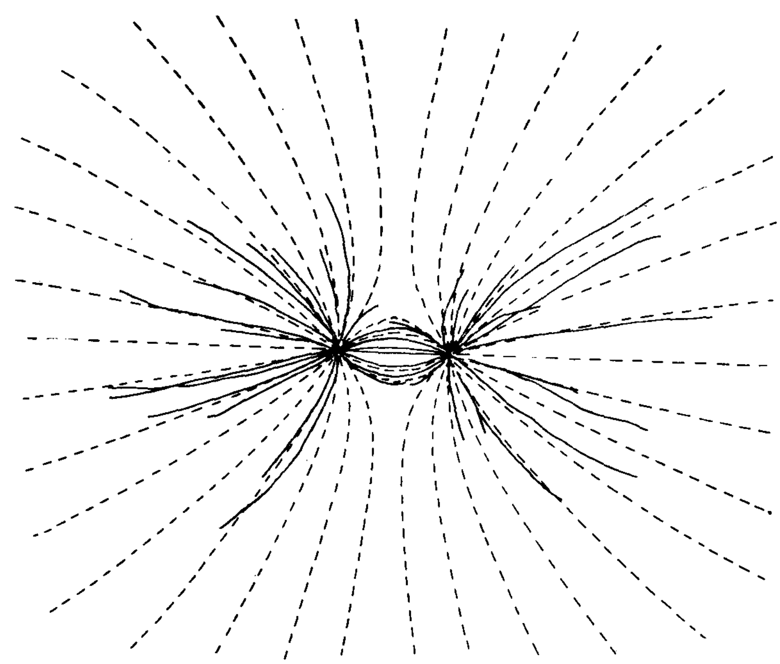


Fig. 2—Isostatics (dotted lines) and traces of actual cracks (full lines) for two holes fired simultaneously in a large sheet. Hole spacing=25 mm

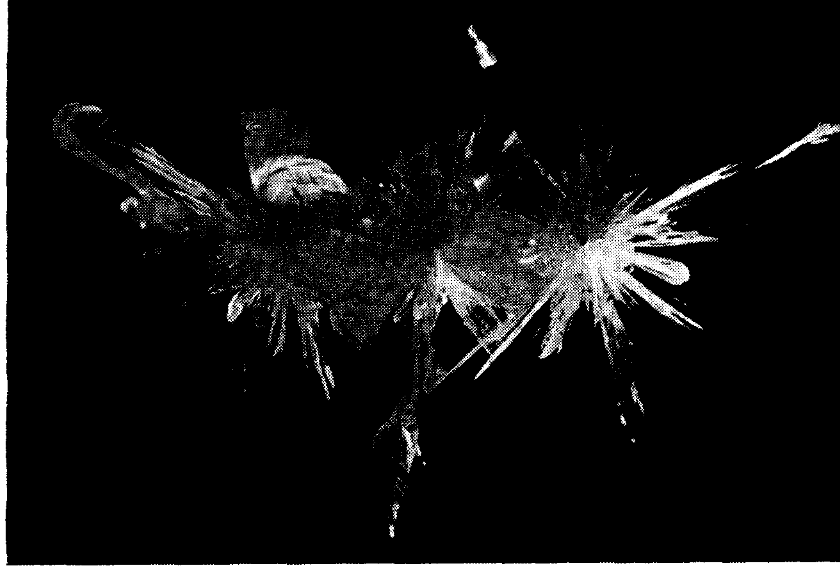


Fig. 4—Cracking round shotholes in PMMA models: 25 mm hole spacing, independent firing

Fig. 3—Cracking round shotholes in PMMA models: 25 mm hole spacing, simultaneous firing

from the borehole/crack system before the next hole is fired.

Since inter-shot delays do not improve fragmentation at an S:B of 8:1[4], it can be assumed that this spacing is sufficient to prevent significant interference of the stress fields from simultaneous shots.

In the tests done by Bergman *et al.*[5], closely spaced holes delayed by 6 ms per metre of spacing did not produce fragmentation as good as that produced by widely spaced delayed shots. A delay of more than 6 ms per metre appears to be necessary in this case to ensure the kind of crack development shown in Fig. 4. The minimum inter-hole delay will increase with quality of stemming and hole depth, since both will tend to maintain the pressure in the hole, and therefore the stress in the surrounding rock, for a longer time.

Fig. 5—Cracking round shotholes in PMMA models: 70 mm hole spacing, simultaneous firing

In any array of holes, the firing sequence and delays between shots can be arranged to allow each hole to develop its cracks fully. This is equivalent to firing holes 'independently'. If the resulting practical difficulties (specifically damage to the initiating system of unfired holes) can be avoided, firing patterns can be designed to give the best fragmentation for the given hole pattern. These firing patterns need not have the same geometry as the hole pattern; for example, a pattern of holes on a square grid can be fired at S:B of 1:1, 2:1, 2,58:1, etc. With this in mind, how should the holes be placed to give the most effective combination of primary crack patterns?

When holes are fired independently, there will effectively be a cylinder of broken ground round each hole after firing. Seen in plan on the surface of the bench, each cylinder can be represented as a circle. If it is postulated that every point in the plan must be within at least one of these circles, the conventional square drilling pattern gives the arrangement of Fig. 6. The same analysis of equilateral-triangular and 8:1 staggered hole placing is shown in Figs. 7 and 8.

The equilateral-triangular hole placing (Fig. 7) produces the most uniform distribution of primary fractures and the largest amount of broken rock per borehole. Theo-

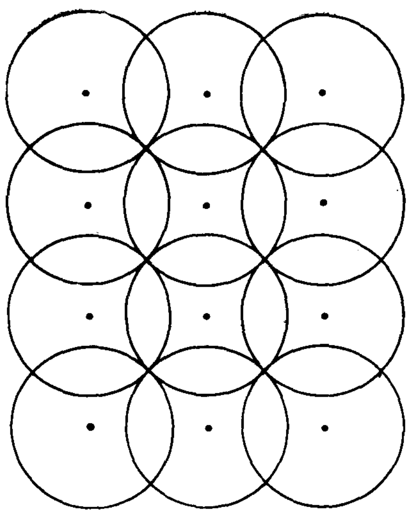


Fig. 6—A square drilling pattern, showing effective circles

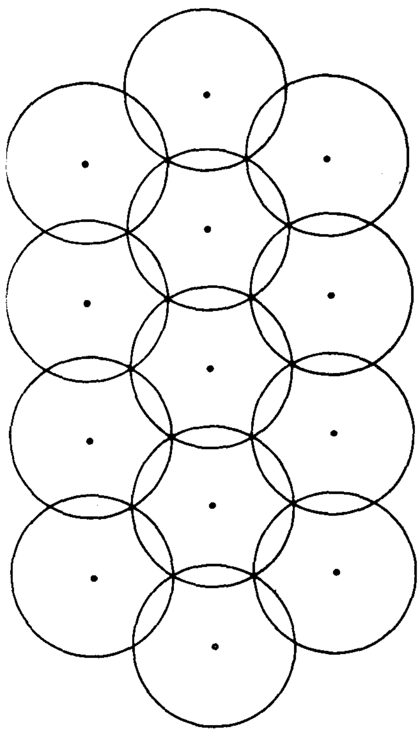


Fig. 7—An equilateral-triangular drilling pattern, showing effective circles

retically, the relative area broken per hole is as follows:

square	100
equilateral triangular	130
8:1 staggered	88

Results from PMMA models verify the general conclusion. Arrays of holes were drilled in 25 mm sheet on a triangular pattern giving an area of 900 mm^2 per hole, and on an 8:1 staggered pattern of 625 mm^2 per hole. Both patterns were fired row-by-row at an S:B of 8:1. The mean mass of the twenty largest fragments was 0,295 g for the triangular pattern, and 0,408 g for the staggered pattern, i.e., the triangular pattern broke more material to smaller size than the rectangular. A similar deduction can be drawn from Il'in[8] and from Bhandari[6] on empirical optimization of drilling and firing patterns in cut-and-fill and shrinkage stopes.

CONCLUSION

The arguments advanced in this paper appear to provide a coherent explanation for many of the results obtained in practical experiments on improved fragmentation by alteration of drilling and firing patterns. A saving of 30 per cent in drilling and in the consumption of explosives is theoretically possible by a change from square to equilateral-triangular hole placing and the choice of an appropriate firing pattern. It is intended to extend the experiments described here to larger-scale trials in rock, and thence to establish a rational system for the design of open-pit blasts.

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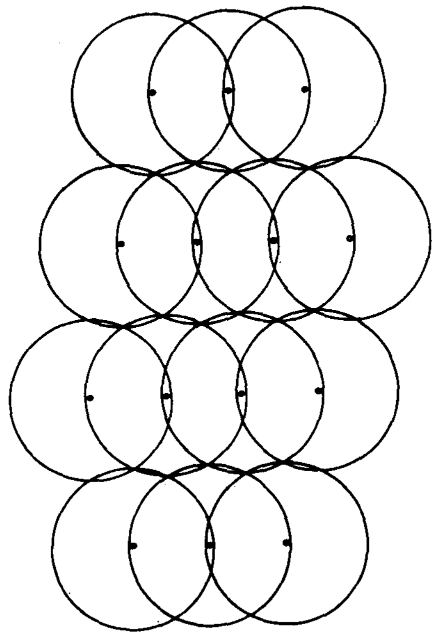

Fig. 8—An 8:1 staggered hole placing, showing effective circles

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NIM reports

The following reports are available free of charge from the National Institute for Metallurgy, Private Bag 7, Auckland Park 2006.

Report no. 911

The recovery of gold from sulphidic and arsenical ores mainly from the Barberton area. (10th Aug., 1970. Re-issued Nov., 1975.)

The results of cyanidation experiments on a number of gold ores and calcined gold concentrates that contained sulphidic and arsenical minerals or their oxidation products were analysed. It was found that the results were not entirely compatible with previously postulated theories on the refractoriness of such ores. It has been assumed in the past that gold should be recoverable by the cyanidation process unless the surface of the gold particles is not exposed to attack or unless the nature of the ore minerals is such that they react with the cyanide or oxygen in the solution, leaving insufficient quantities of reagents for the dissolution of the gold.

Experimental work carried out on pure gold discs has shown conclusively that the dissolution of gold in cyanide solution can be inhibited by the presence of iron sulphide and arsenide minerals and their oxidation products in a manner that can be accounted for only by the formation of strongly adherent films of some as yet unkown species on the surface of the gold.

The effects of alkalinity, cyanide concentration, oxygen concentration, rate of agitation, and temperature of solution on the rate of the dissolution of gold in the presence of various minerals were investigated.

Report no. 1438

A mineralogical examination of fluorspar ores from the Ottoshoop area. (11th Jul., 1972. Re-issued Nov., 1975.)

Several types of fluorspar ore from the Marico district were examined mineralogically, and fluorspar concentrates were prepared from selected specimens. Major mineralogical impurities present in these ores are dolomite, talc, tremolite, quartz, pyrite, calcite, siderite, phyllosilicates, and occasionally iron hydroxides. High-grade fluorspar concentrates were prepared from four samples of the dolomitic fluorspar ore known as 'breccia-spar', and from a mineralized talc–tremolite horizon. Siliceous ores (termed 'klipspar') proved more difficult to upgrade by the gravity and magnetic methods used, owing to the presence of minute inclusions of pyrite in quartz grains, which effectively increased the density of the quartz without increasing its magnetic susceptibility. However, these ores should be amenable to upgrading by flotation.

Weathered breccia-spar ores (called 'kokerman'), which consist largely of talc with iron and manganese oxides and hydroxides, are abundant on the surface and, in addition, have been encountered in many boreholes. This ore, therefore, may be expected to form part of the production of any mine established in the area, and will also require an upgrading technique.

Report no. 1636

Trace elements in diamonds from the Premier, Finsch, and Jagersfontein Mines, and their petrogenetic significance.

Neutron-activation studies of the impurity chemistry of more than 1500 natural diamonds from three South African kimberlite sources, Premier, Finsch, and Jagersfontein, provide evidence for the presence of submicroscopic inclusions of a quenched (or temperature re-equilibrated) melt from which these diamonds crystallized.

These microscopic inclusions of parental magma contain variable amounts of fluids rich in water and carbon dioxide, as well as iron–nickel–copper–cobalt sulphides, and a major silicate phase, which is remarkably constant in composition irrespective of the source of the diamonds and the age of emplacement of their host kimberlite. These microscopic inclusions are present in varying amounts in all the diamonds that were analysed, and may even dominate the impurity chemistry of diamonds having observable mineral inclusions.

An estimate of the composition of the major elements in the silicate melt indicates that the diamonds that were investigated crystallized from pictritic magma rich in water and carbon dioxide in the presence of immiscible iron–nickel–copper–cobalt sulphides.

Report no. 1726

Mertieite and an unnamed compound of palladium with arsenic and tin in a mineral intergrowth from the Atok Mine.

The mertieite is similar in X-ray pattern, chemical composition, and optical and physical properties to mertieites found at Goodnews Bay, Alaska, and those from the Inagli and Oktiabr deposits, U.S.S.R., and to the isomertieite from Itabira, Brazil.

The unnamed $(Pd, Pt)_{2,2}(As, Sn)$, has a similar X-ray pattern to the Russian palladium arsenostannide from the Oktiabr deposit, from which it differs in its high arsenic and low tin contents. It appears to belong to the same solid solution as the Russian mineral, being the other end member. A compound of palladium with tin and arsenic of such composition has not been reported before.

Mertieite and $(Pd, Pt)_{2,2}(As, Sn)$ are very similar in colour, being light greyish-yellow and distinctly anistropic under crossed nicols, with slight bireflectance. The reflectance measured at wavelengths between 436 and 656 nm varies from 47,46 to 58,67 per cent for mertieite, and from 47,67 to 58,05 per cent for $(Pd, Pt)_{2,2}(As, Sn)$. The Vickers microhardness is 536 kg/mm^2 for mertieite and 585 kg/mm^2 for $(Pd, Pt)_{2,2}(As, Sn)$ when a 25 g load is used.

On the assumption that the symmetry of the cell is pseudohexagonal, the cell dimensions for mertieite were calculated to $a=15,038$ and $c=22,481$ and, for $(Pd, Pt)_{2,2}(As, Sn)$, to $a=8,677$ and $c=17,106$.

The chemical composition in mass per cent is as follows: for mertieite, Pd=74,7, Pt=3,2, As=8,5, Sb=14,8, and Sn=0,1; for (Pd, Pt)$_{2,2}$(As, Sn), Pd=71,8, Pt=2,5, As=19,9, Sb=0,4, and Sn=5,0. The respective recalculated formulae are as follows:

$(Pd_{2,974}Pt_{0,072})_{3,046}(Sb_{0,517}As_{0,479}Sn_{0,004})_{1,00}$, $(Pd_{2,174}Pt_{0,042})_{2,216}(As_{0,855}Sn_{0,135}Sb_{0,010})_{1,0}$.

Comparison of the chemical and physical properties, and the X-ray patterns, of the mertieite and (Pd, Pt)$_{2,2}$(As, Sn) from the Atok Mine with those of mertieites and other compounds of palladium with arsenic, antimony, and tin that are available in the literature shows that their structures and other properties are close but never identical. The similarity can be explained if it is assumed that the minerals form solid solutions, the end members being Pd_5As_2, Pd_5Sb_2, and Pd_3Sn_2.

Report no. 1749

Epithermal-neutron-activation analysis for uranium in Barberton and Bushveld granites.

A simple method is described for the determination of uranium in granitic rocks. The powdered samples were enclosed in a cadmium shield during their irradiation in SAFARI I. The cadmium effectively filtered out the thermal neutrons and allowed only the epithermal neutrons to interact with the samples. This method provides greater sensitivity than conventional thermal-neutron-activation and delayed-neutron-activation analyses. Although it is a more time-consuming method than the latter, it has the potential of providing concentrations below the parts-per-million level for uranium, as well as for thorium and gold. This non-destructive procedure yields a detection limit of 0,1 p.p.m. for uranium in granite samples of 200 to 400 mg. For reasonably large batches of samples (25 to 50), the man-hours spent per sample could be as low as 0,5.

Report No. 1753

Full-scale flotation-plant data for modelling purposes.

Full-scale flotation data were obtained on a phosphate flotation plant by sampling of the concentrate from each individual cell and the combined streams from each bank of cells. Simultaneously, timed batch tests were conducted on several streams. Each sample was analysed for total apatite content as well as for the apatite content in several size fractions. This information was valuable in obtaining a good mass balance on the plant. The unexpected increase in both apatite and gangue production towards the end of the rougher, scavenger, and cleaner stages was attributed to the combined effects of short-circuiting of pulp in the open hog trough and incomplete conditioning of the pulp. It would be possible to model these effects by determination of the mixing characteristics of the pulp and the incorporation of a rate constant that is a function of time. The complications that would result from such changes in the modelling of the flotation process would have been of limited value. Modelling was therefore terminated, especially in view of the possible improvements that could result from elimination of the above-mentioned effects.

Timed batch tests on the same samples showed significant differences between plant-scale and batch-scale equipment.

Froth-height adjustments over a wide range had no benefit, provided there was no spillage of pulp into the concentrate.

Recommendations for the attainment of better metallurgical results are made.

Hoisting

The Proceedings of the International Conference on Hoisting held in October 1973 and organized by the S.A. Institution of Mechanical Engineers are now available. The Conference attracted world-wide attention from engineers involved in the hoisting of men, materials, and minerals, and the problems involved are dealt with in a most comprehensive and authoritative manner. Besides those by leading South African engineers, papers were delivered by authorities from Canada, Australia, the United Kingdom, West Germany, and Sweden. They cover modern developments in all aspects of hoisting: shaft systems, hoists, hoist components, conveyances, ropes, and maintenance. Several papers deal with hydraulic hoisting.

The volume of almost 500 pages is well printed and illustrated and is a must for all engineers interested in hoisting on mines. It is available from the S.A. Institution of Mechanical Engineers, P.O. Box 61019, Marshalltown, 2107, at a cost of R20,00.

New techniques in the foundry industry

The South African Institute of Mining and Metallurgy, The South African Institute of Foundrymen, and the Institution of Metallurgists (Local Region) collaborated closely in arranging a colloquium on 'New Techniques in the Foundry Industry'. This was held in the Dorothy Susskind Auditorium at the University of the Witwatersrand on October 29th, 1975. It is hoped that this will prove the first in a series of joint colloquia of major interest to metallurgists engaged in metal-processing operations.

Physical metallurgy is playing an increasingly important part in the South African metallurgical field, and for this reason a Trust Fund has been established by the three above-mentioned Institutes in order to ensure that world-wide advances in the technology associated with physical metallurgy are brought to the attention of those involved in this field. It is the intention to invite overseas specialists in physical metallurgy to visit South Africa from time to time. The first of these was Dr P. R. Beeley, from the University of Leeds, who addressed the colloquium on the topic of metal founding.

The colloquium was attended by 148 delegates, and was opened at 09h00 by the President of the South African Institute of Mining and Metallurgy, Dr R. E. Robinson. The morning and afternoon sessions were chaired by Mr E. Attenborough, President of the South African Institute of Foundrymen, and Mr W. M. Wedderburn, Honorary Secretary to the local region of the Institution of Metallurgists. The colloquium closed with a cocktail party.

The following papers were presented:

Metal Founding — A Modern Perspective, by Dr P. R. Beeley, University of Leeds.

The Foundry Industry in South Africa, by Mr J. Steele, *F.W.P. Journal.*

Core & Mould Making Processes, by Dr K. Campbell, Foseco S.A. (Pty) Ltd.

Scabbing Tests in Foundry Practice, by Dr H. Fidos, CSIR.

Costing in the Foundry Industry, by Mr M. Postma, T.M.F. (Pty) Ltd.

Different Melting Techniques in the Iron Foundry, by Mr J. Davies, Ferrovorm Ltd.

Outstanding Liner Life in Crushing and Milling Operations with Reinforced Ni Hard — a Combination of Hardness and Toughness, by P. Ageland, Brown-Boveri Ltd.

Centrifugal Casting of Heat Resisting Tubes, by Dr K. Armitage, Metallurgical Processes Ltd.

Gratitude is expressed to the undernoted organizations, who contributed to the Trust Fund:

Arlabs (Pty) Ltd
Cullinan Holdings Ltd
Eclipse Engineering Ltd
Foseco South Africa (Pty) Ltd
James Brown & Hamer Ltd
Industrial Iron & Steel Works (Pty) Ltd
Light Castings (Pty) Ltd
Scaw Metals Ltd
Standard Brass, Iron & Steel Foundries Ltd
The Union Steel Corp. of S.A. Ltd
Vecor Heavy Engineering Ltd
Vereeniging Refractories Ltd

Bursaries for 1976

Two bursaries for a study tour of Swedish mines will be awarded to young mining graduates with at least three years' post-graduate experience. The awards, established by the Atlas Copco organization in collaboration with the Swedish Mining Association, are restricted to members of the Institution of Mining and Metallurgy. The bursaries will cover travel and accommodation for a six-week tour of Swedish mining operations in September 1976. Travelling expenses to and from Sweden will be paid for one bursar from any country and for one bursar from a European country. Candidates based outside Europe but who can be in Europe at the time will be considered for the second bursary.

The successful candidates will be expected to write a short paper on any aspect of the operations seen during their visit.

Application forms can be obtained from the Secretary of the Institution, 44 Portland Place, London W1N 4BR. The closing date for applications is 15th March, 1976.

Remote control and monitoring in mining

In collaboration with an International Mining Exhibition organized by the Council of Underground Machinery Manufacturers, the National Coal Board is sponsoring an international conference on remote control and monitoring in mining. The aim of the conference is to review the current position and highlight the developments and future trends associated with remote control, monitoring and automation of mining machinery, and systems and the environment, with special emphasis on safety and reliability.

It is proposed that the various techniques employed in metalliferous, coal, and other non-metalliferous mining methods should be covered under the following headings:

Surface
Mineral getting
Other mining activities
Communication
Environment.

The organizing committee invite offers of contributions of approximately five typescript A4 pages (294 by 210 mm), which allows for 2500 words of text, or less if illustrations are included, for consideration for inclusion in the Conference programme. Those intending to make an offer should submit a synopsis (approximately 200 words) by 31st March, 1976 to Papers Committee Secretary, Remote Control and Monitoring Conference, National Coal Board, The Lodge, South Parade, Doncaster, Yorkshire DN1 2DX, United Kingdom.

The Conference will be held at the National Exhibition and Conference Centre, Birmingham, U.K., on 11th to 13th October, 1977.

Further information is available from the NCB Conference Secretary at the above address.

Geostatistics

The University of Leeds is offering two courses on geostatistics in 1976, each covering ten working days.

Geostatistics began with the study of mine sampling data, and led to what has now become known as the theory of regionalized variables; that is, variables whose magnitudes are controlled to some extent by their positions. In mine sampling, for example, the phenomena of high-grade and low-grade areas and pay-shoots are commonplace, and obviously assay values are not scattered at random throughout a deposit. It requires a special kind of statistics to deal with such phenomena, and geostatistics has been developed for this purpose.

Geostatistics recognizes both features of mine sampling data: firstly, the structural aspect as revealed by high- and low-grade sections, and, secondly, the random aspect in that there is always the possibility of taking a low-grade assay in a high-grade area and *vice versa*. It also accounts for other structural features of the mineralization such as the anisotropies common to alluvial data, the range of influence of a sample value and trend.

A further important point concerns the volume of an individual sample as the characteristics of the regionalized variable alter with changes in this volume; geostatistics enables the effects of such changes to be calculated in advance. The basic tool of geostatistics is the semi-variogram, and from this a coherent theory has been evolved covering all aspects of practical mine valuation. The semi-variogram, for example, allows the effectiveness of future sampling programmes to be evaluated before the samples are taken, by calculating the confidence limits of estimates based on any chosen sampling arrangements. It also answers such questions as the optimum sampling interval, or whether there are any practical advantages to be gained in changing to a larger size of drill core.

The courses are intended to be a PRACTICAL introduction to the study of geostatistics. Practical exercises taken from real situations will be used to introduce or reinforce the theoretical background of the subject. The courses are designed for engineers and geologists concerned with the valuation of mineral deposits and stoping blocks, and a minimum mathematical background is assumed. As far as possible, the approach to the subject is via geology and familiar practical situations, and the mathematical content is introduced in that manner. However, it will be helpful both to course members and lecturers if members do some recommended reading beforehand. An excellent book is *Introduction to Statistical Method* by Brookes and Dick, publisher Heinemann.

On joining the course, members are issued with a set of bound course notes, practical exercises, and geostatistical tables. The notes and exercises are printed on one side only, leaving alternate pages free for members to add their own notes as they wish. Thus, extra note books need not be brought, and there are no loose papers to be lost later; graph papers are bound into the exercises at the appropriate places. The three books form a complete practical introduction to geostatistics. During the second week of the course further practical work and exercises will be done to reinforce the work of the first week. Members are encouraged to bring their own data for orebodies in which they are interested. In this case the data should either be on computer cards, or ready to be punched on to cards. Anyone contemplating using this facility is advised to write to Mr A. G. Royle, who will advise on the format required for the data cards, and whether the jobs are suitable for the time allowed. This preliminary check is essential as there is little time on the course for getting data into a suitable format for card punching, and the data set should be of adequate size for the task. Every member is recommended at least to have a try at producing a semi-variogram for an orebody with which he is concerned, as this should form the basis for much valuable practical work on returning to his company.

Course 1 will be held from 22nd March to 2nd April, 1976, and Course 2 from 12th to 23rd July, 1976.

Further information is obtainable from the Director of Special Courses, Department of Adult Education and Extramural Studies, The University, Leeds LS2 9JT, England.

Analytical chemistry

The Analytical Division of the Chemical Society is to hold the Fourth SAC Conference from 17th to 22nd July, 1977, at the University of Birmingham. Plenary lectures will be given by internationally known authorities, and contributed papers will be arranged in the following sections:

Instrumentation in analysis
Atomic and molecular spectroscopy
Analysis in the life sciences
Chromatography and other separation methods
Analysis in industry
Nuclear and radiochemical analysis
Thermal analysis
Microchemical techniques
Analytical microscopy
Electroanalysis, including ion-selective electrodes
Techniques for remote analysis
Pollution and environment control analysis
Forensic analysis
Newer techniques.

The Conference has been granted IUPAC sponsorship.

Further details are obtainable from The Secretary, Analytical Division, Chemical Society, Burlington House, London, WIVOBN.